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Department of Energy
Richland Operations Office
P.O. Box 550
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18-AMRP-0178

SEP 25 2018

Mr. David Einan, Manager
Office of Environmental Cleanup
Site Cleanup Unit 4
U.S. Environmental Protection Agency
825 Jadwin Avenue, Suite 210
Richland, Washington 99352

Dear Mr. Einan:

REMEDIAL DESIGN INVESTIGATION REPORT FOR THE 200-UP-1 OPERABLE UNIT SOUTHEAST CHROMIUM PLUME, DOE/RL-2017-60, DRAFT A

This letter transmits the Remedial Design Investigation Report for the 200-UP-1 Operable Unit Southeast Chromium Plume, DOE/RL-2017-60, Draft A to the U.S. Environmental Protection Agency for review.

This draft remedial design investigation report along with the U.S. Department of Energy Richland Operations Office letter 18-AMRP-0132, dated July 9, 2018, completed 22 wells, meets the Tri-Party Agreement Milestone M-016-193, "Investigate SE Chromium Plume, Install Wells, Eval. GW Monitoring Data & Install Monitoring Wells."

If there are any questions, please contact me or your staff may contact Mike Cline, of my staff, on (509) 376-6070.

Sincerely,

for

William F. Hamel, Assistant Manager
for the River and Plateau

AMRP:JPH

Attachment

cc: See page 2

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cc w/attach:
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DOE/RL-2017-60
Draft A

Remedial Design Investigation Report for the 200-UP-1 Operable Unit Southeast Chromium Plume

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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DOE/RL-2017-60
Draft A

Remedial Design Investigation Report for the 200-UP-1 Operable Unit Southeast Chromium Plume

Date Published
September 2018

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

U.S. DEPARTMENT OF ENERGY | Richland Operations Office
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APPROVED
By Janis D. Aardal at 10:08 am, Sep 17, 2018

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Executive Summary

This report summarizes the southeast chromium plume remedial design investigation for the 200-UP-1 Operable Unit (OU), updates the southeast chromium plume conceptual site model, and evaluates remedial options. This report supports *Hanford Federal Facility Agreement and Consent Order*[1] Milestone M-16-193 to complete the remedial design investigation of the southeast chromium plume.

During 2016 and 2017, 11 wells were drilled and sampled to characterize the nature and extent of the southeast chromium plume. Chromium, measured as total chromium (trivalent and hexavalent) and hexavalent chromium, was the target contaminant of concern for the investigation. Based on groundwater sample results from the new wells, the southeast chromium plume extends further to the east, south, and west than the extent based on data available in 2015. In each of these directions, the plume is bounded by wells with concentrations below the 48 µg/L cleanup level for hexavalent chromium. Based on new well data from 2017, the plume >48 µg/L is about twice as large as depicted by the 2015 data.

The southeast chromium plume is inferred to have originated from waste associated with the Reduction-Oxidation (REDOX) process in the 202S Building (S Plant), specifically past wastewater discharges from the 202S Building to the 216-S-10 Ditch and adjacent ponds and cribs, including the 216-S-10 Pond, 216-S-11 Pond, 216-S-17 Pond, 216-S-5 Crib, and 216-S-6 Crib, and the 216-S-20 Crib. Based on the 2017 data, the southeast chromium plume has migrated away from these sources and does not extend back to the 216-S-10 Ditch and the adjacent ponds and cribs or the 216-S-20 Crib source areas at concentrations >48 µg/L. Distinct, small chromium plumes remain at the 216-S-10 and 216-S-20 source areas.

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

The remedy selected for the southeast chromium plume in the 200-UP-1 OU Record of Decision[2] is groundwater extraction and treatment in combination with monitored natural attenuation (MNA). The 2017 southeast chromium plume interpretation was used in numerical fate and transport simulations to develop and evaluate remedial options for the plume. The model also evaluated a no action scenario for information only. The three remedial options for the southeast chromium plume are as follows:

- **Option 1:** Pump and treat (P&T) at the 216-S-10 and 216-S-20 source sites and MNA for the southeast chromium plume.
- **Option 2:** P&T at the 216-S-10 and 216-S-20 source sites and P&T and MNA for the southeast chromium plume. Option 2 has three treatment options: Option 2a uses onsite ion-exchange (IX) treatment for extracted groundwater, Option 2b uses IX treatment at the 200 West P&T for extracted groundwater, and Option 2c uses biological treatment at the 200 West P&T for extracted groundwater.
- **Option 3:** P&T at the 216-S-10 and 216-S-20 source sites and P&T for the southeast chromium plume.

The remedial options were compared based on their effectiveness, implementability, and cost (Table ES-1). The remedial design for the selected option will be provided in a revision to the remedial design/remedial action work plan (DOE/RL-2013-07[3]).

---

[2] EPA, Ecology, and DOE, 2012, *Record of Decision for Interim Remedial Action Hanford 200 Area Superfund Site 200-UP-1 Operable Unit*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/docDetail?accession=0091413.

[3] DOE/RL-2013-07, 2013, *200-UP-1 Groundwater Operable Unit Remedial Design/Remedial Action Work Plan*, Rev. 0, U.S. Department of Energy, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0087671.

Table ES-1. Comparative Analysis of Remedial Options for the 200-UP-1 OU Southeast Chromium Plume

CERCLA Criteria	Remedial Options				
	1	2a	2b	2c	3
Effectiveness	★★☆☆	★★★☆	★★★☆	★★★☆	★★★★
Implementability	★★★★	★★★☆	★★★☆	★★☆☆	★☆☆☆
Estimated time to achieve cleanup levels for chromium (years)[a]	275	120	120	120	25
Total cost[b]	$191,000,000	$263,000,000	$271,000,000	$617,000,000	$663,000,000

★☆☆☆ = Expected to perform less well against the CERCLA balancing criteria with more disadvantages or uncertainty.

★★☆☆ = Expected to perform moderately well against the CERCLA balancing criteria with some disadvantages or uncertainties.

★★★☆ = Expected to perform well against the CERCLA balancing criteria with minimal disadvantages or uncertainties.

★★★★ = Expected to perform very well against the CERCLA balancing criteria with no disadvantages or uncertainties.

a. The estimated time to achieve cleanup levels for chromium is based on the 95% upper confidence limit on the mean of the annual dissolved concentration.

b. These cost estimates represent the total nondiscounted costs, prepared to meet the -30% to +50% range of accuracy recommended in EPA/540/G-89/004, *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*.[4]

Remedial options:

Option 1: 25 years of P&T at the 216-S-10 and 216-S-20 source sites using IX treatment at ETB-3 and 275 years of MNA for the southeast chromium plume

Option 2a: 25 years of P&T at the 216-S-10 and 216-S-20 source sites and southeast chromium plume using onsite IX treatment and 120 years of MNA for the southeast chromium plume

Option 2b: 25 years of P&T at the 216-S-10 and 216-S-20 source sites and southeast chromium plume using IX treatment at 200 West P&T and 120 years of MNA for the southeast chromium plume

Option 2c: 25 years of P&T at the 216-S-10 and 216-S-20 source sites and southeast chromium plume using biological treatment at 200 West P&T and 120 years of MNA for the southeast chromium plume

Option 3: 25 years of P&T at the 216-S-10 and 216-S-20 source sites and southeast chromium plume using onsite IX treatment

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
ETB = exchange treatment building
IX = ion exchange
MNA = monitored natural attenuation
P&T = pump and treat

[4] EPA/540/G-89/004, 1988, *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*, Interim Final, OSWER Directive 9355.3-01, Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. Available at: https://rais.ornl.gov/documents/GUIDANCE.PDF.

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Terms

ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
CCU	Cold Creek unit
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
COC	contaminant of concern
CPGWM	Central Plateau Groundwater Model
CSM	conceptual site model
DO	dissolved oxygen
DOE	U.S. Department of Energy
DOE-RL	DOE Richland Operations Office
DQO	data quality objective
DWS	drinking water standard
EPA	U.S. Environmental Protection Agency
ERDF	Environmental Restoration Disposal Facility
ETB	extraction transfer building
F&T	fate and transport
FS	feasibility study
GFM	geologic framework model
IC	institutional control
IX	ion exchange
K_d	distribution coefficient
MCL	maximum contaminant level
MNA	monitored natural attenuation
MTCA	Model Toxic Control Act
NTU	nephelometric turbidity unit
O&M	operations and maintenance
OU	operable unit
P&T	pump and treat

PNNL	Pacific Northwest National Laboratory
PPE	personal protective equipment
QA	quality assurance
QC	quality control
RAO	remedial action objective
RD/RAWP	remedial design/remedial action work plan
REDOX	Reduction-Oxidation (Plant or process)
Rlm	Ringold Formation member of Wooded Island – lower mud unit
ROD	Record of Decision
Rtf	Ringold Formation member of Taylor Flat
Rwia	Ringold Formation member of Wooded Island – unit A
Rwie	Ringold Formation member of Wooded Island – unit E
SAP	sampling and analysis plan
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
UCL_{95}	95% upper confidence limit
WMA	waste management area

1 Introduction

The groundwater in the southeast portion of the 200-UP-1 Operable Unit (OU) on the Hanford Site is contaminated with chromium (hereinafter referred to as the southeast chromium plume). The source of the chromium was historical contaminated liquid discharges to waste sites overlying the 200-UP-1 OU.

The Record of Decision (ROD) for the 200-UP-1 OU was issued in 2012 (EPA et al., 2012, *Record of Decision for Interim Remedial Action, Hanford 200 Area Superfund Site 200-UP-1 Operable Unit* [hereinafter referred to as the 200-UP-1 OU ROD]). The remedy selected for the southeast chromium plume is groundwater restoration using pump and treat (P&T) and monitored natural attenuation (MNA). The 200-UP-1 OU ROD specifies that the remedy will be conducted in accordance with the remedial design/remedial action work plan (RD/RAWP), which was issued in 2013 (DOE/RL-2013-07, *200-UP-1 Groundwater Operable Unit Remedial Design/Remedial Action Work Plan*). The original conceptual design in the RD/RAWP estimated 25 years of P&T (two extraction wells, two injection wells, and a total extraction rate of 757 L/min [200 gal/min]), followed by 100 years of MNA for the southeast chromium plume, with an estimated total cost of $89.4 million. Prior to implementing the selected remedy, the RD/RAWP addressed the need for additional monitoring wells to further characterize the vertical and lateral extent of the southeast chromium plume to support remedial design (Section 3.1.1 of DOE/RL-2013-07).

To address the need for additional characterization identified in the RD/RAWP (DOE/RL-2013-07), 11 wells were drilled and sampled in 2016 and 2017 to characterize the lateral and vertical extent of the southeast chromium plume. Chromium, measured as total (trivalent and hexavalent) chromium and hexavalent chromium, was the target contaminant of concern (COC) for this remedial design investigation. Based on groundwater sample results from the new wells, the southeast chromium plume extends farther to the east, south, and west than the inferred plume from 2009 that was used in the 200-UP-1 OU ROD (EPA et al., 2012). In each of these directions, the plume is now bounded by wells with hexavalent chromium concentrations below the 48 µg/L cleanup level. The refined plume configuration was used to develop and evaluate options for plume remediation.

The U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), the lead regulatory agency for the 200-UP-1 OU, are expected to select the remedial option for the southeast chromium plume from among the remedial options evaluated in this report. The remedial design for the selected option will be provided in a revision to the RD/RAWP (DOE/RL-2013-07).

1.1 Purpose and Scope of Report

This report summarizes the southeast chromium plume remedial design investigation for the 200-UP-1 OU; updates the southeast chromium plume conceptual site model (CSM); and develops and evaluates remedial options based on numerical fate and transport (F&T) simulations and comparisons of effectiveness, implementability, and cost. Submittal of Draft A of this report to EPA by September 30, 2018, supports the remedial design investigation component of Ecology et al., 1989, *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) Milestone M-16-193 (see Section 2.2 of this report).

The remainder this chapter provides site background for the southeast chromium plume, source waste sites, previous investigations, regulatory history, and geohydrology. Chapter 2 describes the southeast chromium plume remedial design investigation approach, and Chapter 3 presents the results. Chapter 4 summarizes the F&T modeling used to develop the southeast chromium plume remedial options; describes the options; and evaluates the options based on implementability, effectiveness, and cost.

Chapter 5 presents conclusions from the investigation and recommendations. Chapter 6 includes the references cited in this report.

1.2 Site Background

The 200-UP-1 OU is located on the Central Plateau, a roughly 190 km^2 (75 mi^2) area near the center of the Hanford Site (Figure 1-1). The southeast chromium plume originated primarily from liquid effluent discharged to waste sites associated with the Reduction-Oxidation (REDOX) process in the 202S Building (S Plant). The two sites that received the largest documented chromium inventory were the combined 216-S-10 Pond, 216-S-10 Ditch, and 216-S-11 Pond; and the 216-S-20 Crib (Figure 1-2).

1.2.1 Southeast Chromium Plume History

The southeast chromium plume was first included in the annual Hanford Site groundwater monitoring report for 1995 (Section 5.13.3 of PNNL-11141, *Hanford Site Ground-Water Monitoring for 1995*). This initial plume was based on detections of chromium >50 µg/L in three widely spaced wells. The maximum chromium concentration detected in filtered samples from these three wells was 220 µg/L, the only concentration exceeding the EPA maximum contaminant level (MCL) of 100 µg/L for total chromium. The report states: "This chromium contamination has only recently been recognized and its source and extent are very uncertain. The extent to the south is particularly poorly defined." The 1997 annual groundwater report (Section 5.12.3.3 of PNNL-11793, *Hanford Site Groundwater Monitoring for Fiscal Year 1997*) identified early disposal near the 216-S-10 Pond and 216-S-10 Ditch as one possible source of the chromium contamination.

Chromium is a common element widely found in the environment, including groundwater, in one of two forms: trivalent chromium (Cr^{3+}) and hexavalent chromium (Cr^{6+}). Trivalent chromium typically forms low-solubility oxide and hydroxide compounds in the environment and, as such, is not readily mobile in water. Trivalent chromium also exhibits low toxicity to human and ecological receptors. Conversely, hexavalent chromium is found in a variety of highly water-soluble anionic forms, most commonly in Hanford Site groundwater as the water-soluble chromate ion (CrO_4^{2-}), and exhibits well-documented toxic effects on human and ecological receptors. Hexavalent chromium may also be found in the environment as the dichromate ion ($Cr_2O_7^{2-}$), depending on Eh and pH conditions.

Chromium in groundwater samples (such as those discussed in this report) may be present as suspended solid particles (commonly composed of low-solubility compounds of trivalent chromium), as dissolved ions (e.g., chromate ions), or most commonly as a combination of both. Chromium in groundwater can be measured by several methods. A total elemental analysis may be performed that measures the combined presence of both trivalent and hexavalent chromium; this is commonly referred to as total chromium. The term "total chromium" refers to a measurement technique, not a specific form of chromium. If the total elemental analysis is performed on a sample aliquot that has been filtered, the measurement result is commonly referred to as total filtered chromium or dissolved chromium. At the Hanford Site, dissolved chromium in groundwater most commonly consists of hexavalent chromium ions. Alternatively, groundwater samples may be analyzed specifically for the presence of hexavalent chromium using a different analytical method. Dissolved chromium (as determined by a total metal analysis of a filtered sample aliquot) typically exhibits the same, or similar, concentration as a measurement of the same sample specifically for hexavalent chromium. These two measurements should be considered interchangeable for the purpose of discussing the 200-UP-1 OU southeast chromium plume.

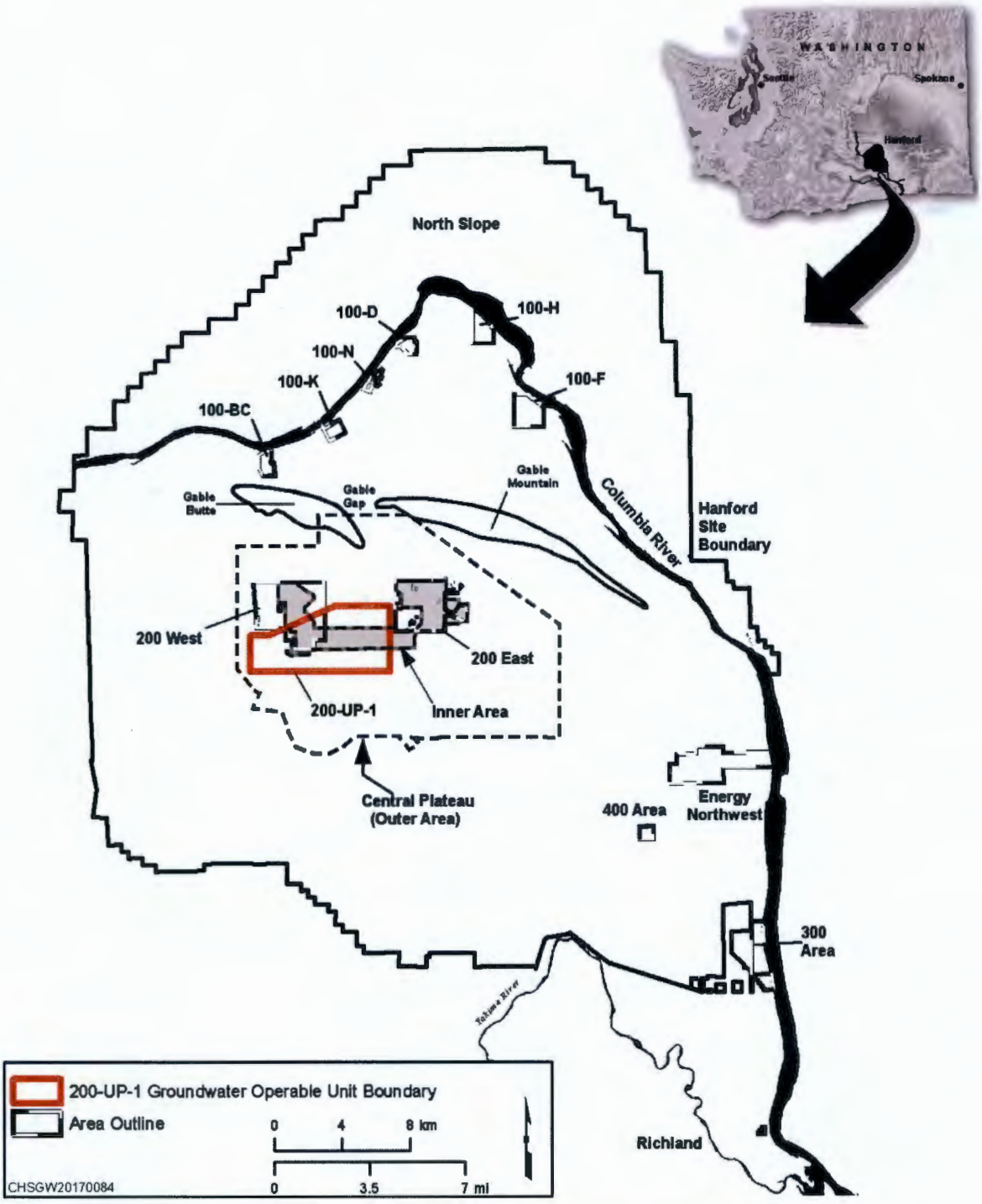
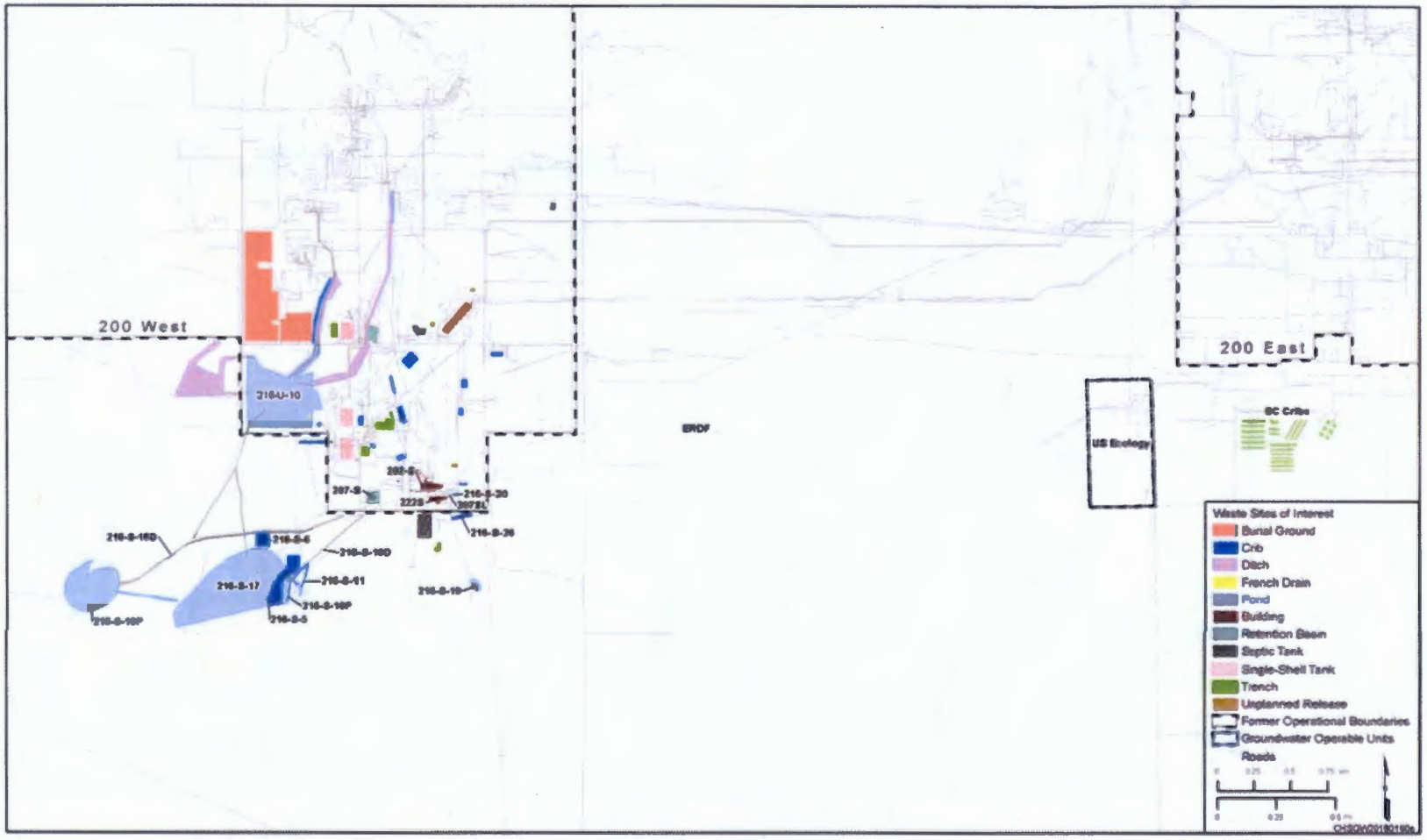


Figure 1-1. Location of the 200-UP-1 OU on the Hanford Site



Source: Modified from Figure 3-20 in DOE/RL-2009-122, *Remedial Investigation/Feasibility Study for the 200-UP-1 Groundwater Operable Unit.*

Figure 1-2. 200-UP-1 OU Waste Sites

The cleanup levels for the groundwater chromium remedial action in the 200-UP-1 OU ROD (EPA et al., 2012) are federal and state drinking water MCLs and state groundwater cleanup levels (where more stringent than the MCLs) that are applicable or relevant and appropriate requirements (ARARs) for the selected remedy (Section 12.4 in the 200-UP-1 OU ROD). The Washington State Department of Ecology groundwater cleanup level for hexavalent chromium is 48 µg/L based on WAC 173-340, "Model Toxics Control Act—Cleanup" (MTCA) Method B (Table 14 in the 200-UP-1 OU ROD). The federal (EPA) drinking water standard (DWS) for total chromium (trivalent and hexavalent) is 100 µg/L; there is no federal DWS for hexavalent chromium. Based on these differing ARAR cleanup levels, it is necessary to measure and evaluate both hexavalent chromium and total chromium concentrations in groundwater to assess this plume condition.

1.2.2 Source Waste Sites and Disposal History

The REDOX process was used from 1951 to 1967 in the 202S Building to extract plutonium and uranium from dissolved fuel rod solutions by an aqueous/nonaqueous separation process that used hexone as the nonaqueous solvent. The uranium fuel was dissolved in nitric acid, and the solution was treated with sodium dichromate ($Na_2Cr_2O_7*2H_2O$, a hexavalent chromium salt) to oxidize the plutonium (Table 1-8 in HW-18700, *REDOX Technical Manual*). Chromic nitrate ($Cr(NO_3)_3$, a trivalent chromium salt) was used during treatment to remove ruthenium (pp. 108–109 in HW-18700). The first solvent extraction cycle, which separated the fuel rod solution into different aqueous streams, reduced the plutonium to a lower valence state. Sodium dichromate was used to oxidize plutonium during the second and third plutonium solvent-extraction cycles (pp. 110–111 in HW-18700). The sodium dichromate was purchased as a dry chemical and made up into the desired solutions as part of the aqueous makeup system (p. 803 in HW-18700). In summary, the REDOX process used substantial quantities of hexavalent chromium in process solutions; hexavalent chromium was present at substantial concentrations in numerous liquid waste streams generated by the plant.

Aqueous waste sewers at the 202S Building were segregated into chemical sewers and process sewers. The chemical sewers drained all nonradiological portions of the plant (e.g., operating galleries, service areas, and aqueous makeup areas). Waste from the chemical sewers flowed directly to a pond where they percolated into the soil or evaporated. The process sewers drained water and steam condensate from process equipment (e.g., heat exchanger jackets and coils) that could become radiologically contaminated under upset conditions. The process sewer waste flowed into the 207S Retention Basin to be held up before discharge to a pond. The waste in the retention basin was monitored to ensure that radionuclide disposal limits were not exceeded (p. 1020 in HW-18700). The 207S Retention Basin was bypassed in 1954 after becoming grossly contaminated.

The chemical sewer waste was discharged to the 216-S-10 Ditch, 216-S-10 Pond, and 216-S-11 Ponds (Section 1.2.2.1). The process sewer waste was discharged to the 216-S-17 Pond, 216-S-5 Crib, 216-S-6 Crib, and 216-S-16 Ditch and Pond (Section 1.2.2.2).

The 222S Laboratory provided chemical and radiological analytical services. Sodium dichromate was used in the 222S Laboratory (Table 2-9 in DOE/RL-91-60, *S Plant Aggregate Area Management Study Report*). Aqueous 222S Laboratory process waste was directed to the 207SL Retention Basin for temporary storage while awaiting assay information on radionuclides concentrations. Waste containing radionuclides below the prescribed limits was discharged to open ponds or ditches. Waste containing radionuclides above these limits was discharged to a crib (p. 1031 in HW-18700). The 222S Laboratory waste was discharged to the 216-S-19 Pond, 216-S-20 Crib, and 216-S-26 Crib (Section 1.2.2.3).

The 216-S-10 Ditch, 216-S-10 Pond, 216-S-11 Pond, 216-S-17 Pond, 216-S-5 Crib, 216-S-6 Crib, and 216-S-16 Ditch and Pond are collocated southwest of the 202S Building, outside of the 200 West Area perimeter (Figure 1-2). The 216-S-20 Crib is southeast of the 202S Building, within the 200 West Area perimeter; the 216-S-26 Crib and 216-S-19 Pond are south of the 216-S-20 Crib and outside the 200 West Area perimeter (Figure 1-2). Table 1-1 lists the operational history for each waste site.

Table 1-1. Source Waste Sites History

Waste Site	Years of Operation[a]	Effluent Volume[a] (L)	Estimated Mean Chromium Inventory[b] (kg)
202S Building Chemical Sewer Waste			
216-S-10 Ditch	1951–1991[c]	6.73×10^{9}	2,981.1
216-S-10 Pond			
216-S-11 Pond			
202S Building Process Sewer Waste			
216-S-17 Pond	1951–1954	6.44×10^{9}	3.3
216-S-5 Crib	1954–1957	4.08×10^{9}	3.6
216-S-6 Crib	1954–1972	4.44×10^{9}	0.2
216-S-16 Ditch and Pond	1957–1972	4.07×10^{10}	1.5
222S Laboratory Waste			
216-S-19 Pond	1952–1984	1.30×10^{9}	655.9
216-S-20 Crib	1952–1973	1.35×10^{8}	5,878.6
216-S-26 Crib	1984–1995	2.19×10^{8}	110.6

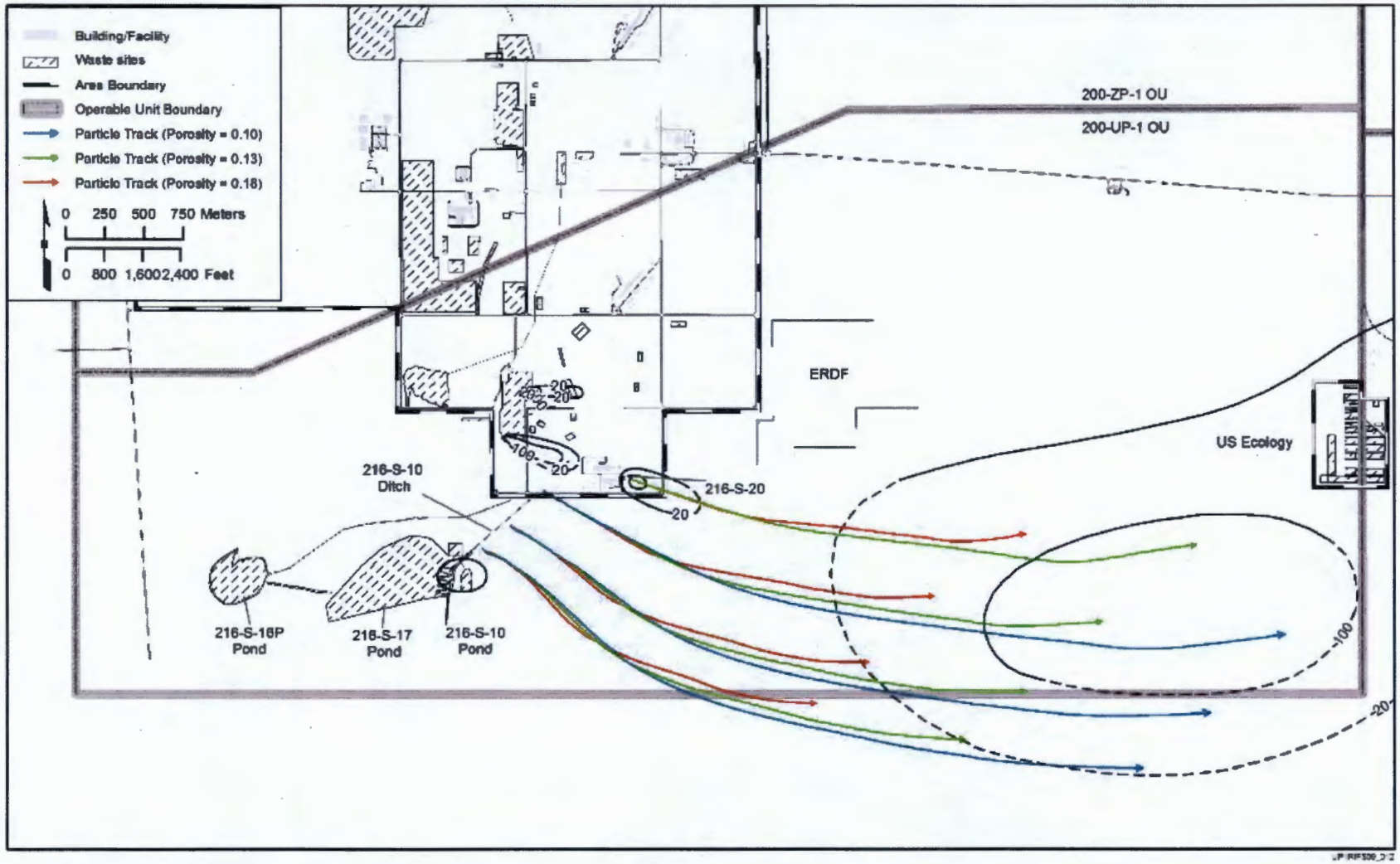
Reference: RPP-26744, *Hanford Soil Inventory Model, Rev. 1.*

a. From Table A5-21 in RPP-26744.

b. From Appendix C of RPP-26744. 216-S-20 is in the REDOX zone table. All the other sites are in the 200-W Ponds zone table.

c. Table A5-21 in RPP-26744 notes that the 216-S-10/216-S-11 site began receiving waste from the 202S Building in 1951 but the volume records did not begin reporting until 1954. RPP-26744 calculated and applied an average monthly volume to that prior timeframe.

As part of the 200-UP-1 OU remedial investigation, a chromium particle-tracking analysis was prepared using a transient groundwater flow model (Figure 1-3). Particle tracks originating from the 216-S-10 Pond and Ditch and the 216-S-20 Crib in 1951 ended in 2009 near the fiscal year 2008 position of the southeast chromium plume (Section 4.2.4 in DOE/RL-2009-122, *Remedial Investigation/ Feasibility Study for the 200-UP-1 Groundwater Operable Unit*).



Source: Figure 4-25 in DOE/RL-2009-122, *Remedial Investigation/Feasibility Study for the 200-UP-1 Groundwater Operable Unit.*

Figure 1-3. Simulated Total and Hexavalent Chromium Particle Movement Between 1951 and 2009 from the 216-S-20 Crib and the 216-S-10-Ditch

Based on the estimated chromium mass and effluent volume released to each potential source site, the estimated average source concentrations were much higher at the 216-S-20 Crib (~43,000 µg/L) than at the combined 216-S-10 Pond and Ditch and 216-S-11 Pond, 216-S-19 Pond, and 216-S-26 Crib (~500 µg/L each) (Table 1-1). The 200-UP-1 OU remedial investigation concluded that the most probable source for the southeast chromium plume was the 216-S-20 Crib because this crib had higher source concentrations and was consistent with the particle tracking, but acknowledged that effluent from the 216-S-10 Pond and Ditch and 216-S-19 Pond may also have contributed (Section 4.2.4 in DOE/RL-2009-122). However, based on the characterization in 2016 and 2017 to refine the southeast chromium plume geometry, it appears that the complex of waste sites southwest of the 202S Building contributed significantly to the chromium currently observed in the southeast chromium plume (Section 3.2.3 in this report).

1.2.2.1 Chemical Sewer Waste Discharge History

The 216-S-10 Ditch received chemical sewer wastewater from the 202S Building when the REDOX process began operations in August 1951 and overflow water from the high water tower (216-S-10 in Volume III.S-200W of RHO-CD-673, *Handbook 200 Areas Waste Sites*). In February 1954, the 216-S-10 Pond (four separate trenches) was excavated at the southwest end of the 216-S-10 Ditch to provide additional leaching surface (Figure 1-4). By May 1954, the 216-S-10 disposal system again was at capacity, so the two 216-S-11 leach ponds were dug on the southeast side of the 216-S-10 Ditch (216-S-10 in Volume III.S-200W of RHO-CD-673). The 216-S-11 Pond inlets were higher than the bottom of the 216-S-10 Ditch so the 216-S-11 Ponds would only fill when the ditch water level raised. The 216-S-11 Ponds were in use until August 1965, the last date that the 216-S-10 Ditch water level was high enough to overflow into the ponds (216-S-11 in Volume III.S-200W of RHO-CD-673). In 1984, the 216-S-10 Pond and the southwest end of the 216-S-10 Ditch were backfilled and stabilized (Sections 4.3 and 4.4 of BHI-00176, *S Plant Aggregate Area Management Study Technical Baseline Report*). The northern portion of the ditch was used through 1991 to receive nondangerous wastewater from the 202S Building chemical sewer and overflow water from the high water tower (Section 11.1.1 of DOE/RL-93-09, *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1992*).

The 216-S-10 Pond and Ditch was used as the disposal site for the 222S Chemical Engineering Laboratory, located next to the 202S Building, between 1980 and 1983 (DOE, 1987, *216-S-10 Ditch and Pond Preliminary Closure/Post-Closure Plan*). In September 1983, the 216-S-10 Pond and Ditch received one documented dangerous waste discharge from the Chemical Engineering Laboratory during a pilot-scale run to simulate recovery of double-shell tank slurry from a waste tank. The 216-S-10 Pond and Ditch received 420 L (110 gal) of simulated double-shell tank slurry consisting of sodium nitrate (46%); sodium hydroxide (41%); and small quantities of sodium phosphate, sodium fluoride, sodium chloride, and potassium dichromate (hexavalent chromium) (Section 3.0 of DOE, 1987).

1.2.2.2 Process Sewer Waste Discharge History

From October 1951 through March 1954, the 216-S-17 Pond received process sewer wastewater (i.e., process vessel heat exchange cooling water and steam condensate) from the 202S Building. Beginning in January 1953, it also received overflow from the 216-U-10 Pond via the 216-U-9 Ditch. Beginning in October 1952, a series of leaks in process vessel heat exchanger coils in the 202S Building released radioactive cooling water into the 207S Retention Basin and subsequently to the 216-S-17 Pond. The pond was taken out of service in March 1954 because the radionuclide inventory in the sediments exceeded prescribed limits (216-S-17 in Volume III.S-200W of RHO-CD-673). The 202S Building process sewer waste was rerouted to the newly constructed 216-S-5 Crib, and the overflow from the 216-U-10 Pond was discontinued (216-S-17 [pp. A-22 and A-23] in ARH-2155, *Radioactive Liquid Waste Disposal Facilities 200 West Area*).

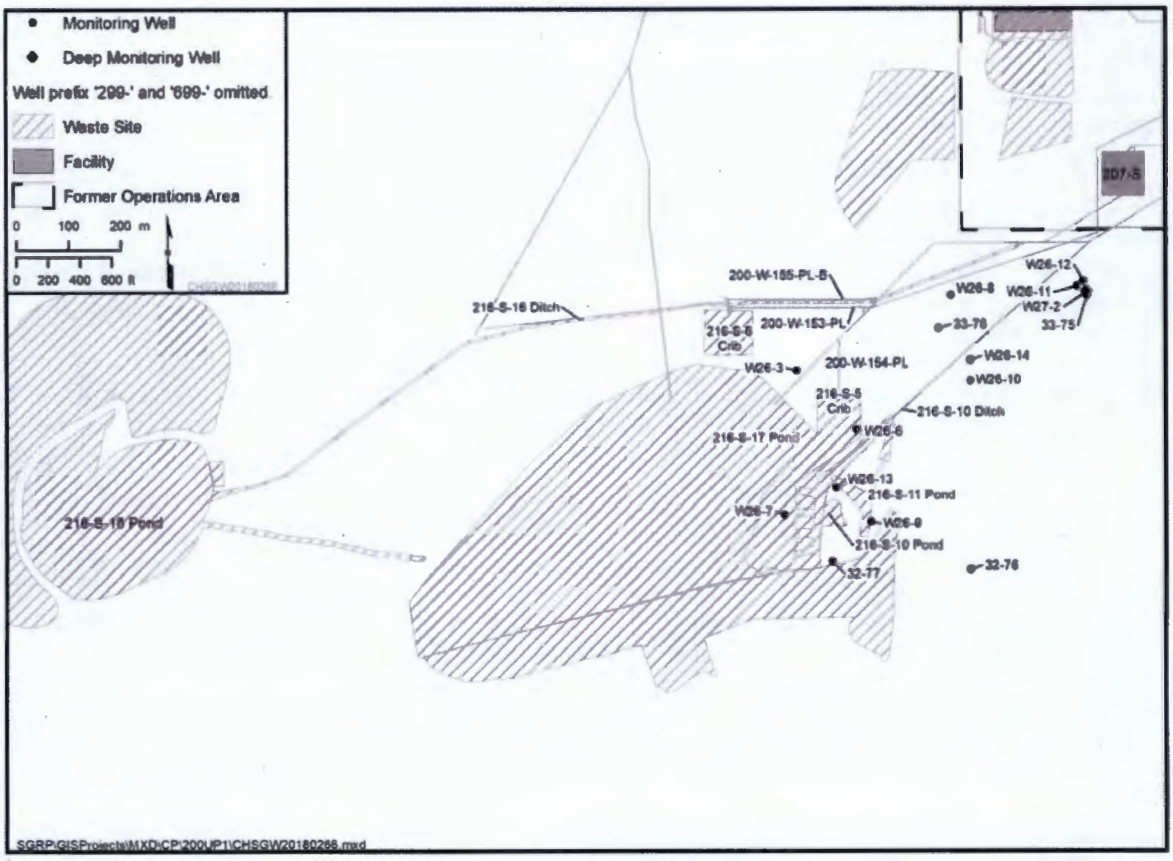


Figure 1-4. Waste Sites Southwest of the 202S Building that Received Chemical and Process Sewer Waste from the REDOX Process

The 216-S-5 Crib received process sewer wastewater from the 202S Building from March 1954 to March 1957. In November 1954, water from 202S Building process vessels with greater potential for radioactive leaks was rerouted from the 216-S-5 Crib to the new 216-S-6 Crib. In May 1956, a hole was cut in the 216-S-5 Crib to discharge overflow cooling water onto the ground immediately southwest of the 216-S-5 Crib. Use of the 216-S-5 Crib and overflow pond continued until construction of the first 216-S-16 Pond in 1957 (216-S-5 in Volume III.S-200W of RHO-CD-673).

The 216-S-6 Crib received process sewer wastewater with a high potential for radioactive contamination (e.g., as a result of leaks from process vessel coils) from the 202S Building from November 1954 to June 1967. In September 1955, a small corner of the crib was cut open to allow discharge of overflow water, but no water overflowed to the runoff ditch (216-S-6 in Volume III.S-200W of RHO-CD-673). From July 1967 to July 1972, the 216-S-6 Crib received steam condensate from waste concentrators in the 202S Building (216-S-6 [p. A-8] in ARH-2155).

The 216-S-16 Ditch and 216-S-16 Pond received process sewer wastewater from the 202S Building from 1957 to 1967. The first pond was completed in 1957 and received effluent rerouted from the 216-S-5 Crib via the 216-S-19 Ditch. The site was soon enlarged to include two overflow ponds that wrapped around the south and southwest bank of the original pond (216-S-16 in Volume III.S-200W of RHO-CD-673). From 1967 to 1975, the pond received process sewer wastewater (condenser and process vessel cooling water) from the concentrator boil-down operations in the 202S Building (216-S-16 [pp. A-20 and A-21] in ARH-2155).

1.2.2.3 222S Laboratory Waste Discharge History

The 216-S-19 Pond received effluent from the 222S Laboratory ventilation cooling water and miscellaneous waste from laboratory hoods and decontamination sinks via the 207SL Retention Basin from February 1952 through December 1954. From December 1954 to October 1955, the site was inactive because the radionuclide concentration in the 207SL Retention Basin liquid waste was above the prescribed disposal guidelines, and building effluents were rerouted to the 216-S-20 Crib. From October 1955 to October 1984, the site received ventilation cooling water and miscellaneous waste from laboratory hoods and decontamination sinks in the 222S Laboratory via the 207SL Retention Basin (Section 2.3.5.1.6 in DOE/RL-91-60).

Between October 1984 and December 1988, the 216-S-26 Crib replaced the 216-S-19 Pond and received steam condensate, equipment cooling water, and sink waste from the 222S Laboratory. The crib also received water from the 222SA Chemical Standards Laboratory and the 291S stack complex. In addition, the crib received three or more 4,200 L (1,100 gal) tanker discharges of Plutonium Finishing Plant caustic flushwater with pH of 12.5 that decreased the crib infiltration rate. The 216-S-26 Crib operated from 1984 to 1995 (Section 2.3.3.11 in DOE/RL-91-60).

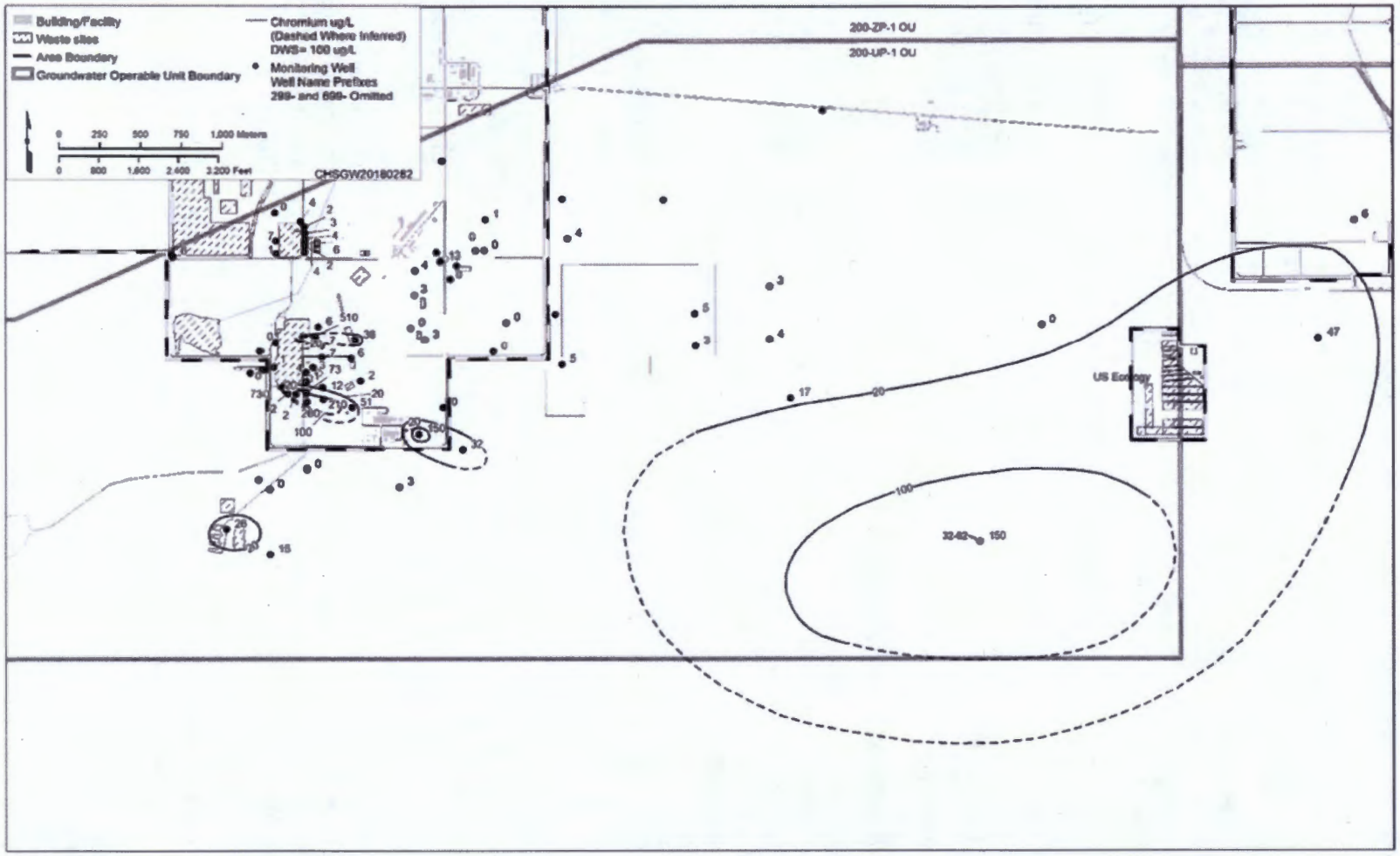
From January 1952 until September 1963, the 216-S-20 Crib received miscellaneous waste from laboratory hoods and decontamination sinks in the 202S Building. Beginning in July 1953, the site also received 300 Area laboratory waste via tanker truck. From September 1963 to January 1969, the crib received miscellaneous waste from laboratory hoods and decontamination sinks in the 222S Laboratory. After January 1969, the 300 Area laboratory waste was rerouted to the 216-T-28 Crib. From January 1969 to November 1972, the unit was inactive due to the ground caving in above the unit (Section 2.3.3.7 in DOE/RL-91-60).

1.2.3 Previous Investigations and Remediation

Groundwater monitoring for chromium in the area of the southeast chromium plume began in 1992, but the plume extent had not been sufficiently defined for purposes of remedy implementation. P&T technology is being used to remediate other groundwater plumes in the 200-UP-1 OU closer to their sources, demonstrating that P&T technology is a potential remedial technology for the southeast chromium plume.

1.2.3.1 Southeast Chromium Plume

Well 699-32-62 was drilled approximately 5 km (3 mi) east of the 216-U-10 Pond in 1960 and monitored for water levels and contaminants (page 3-41 in DOE/RL-2009-122). Sampling for chromium began in 1992. Through 2005, it was the only routinely monitored well in this area in which filtered total chromium exceeded the 100 µg/L MCL (Figure 1-5).



Source: Modified from Figure 4-20 in DOE/RL-2009-122, *Remedial Investigation/Feasibility Study for the 200-UP-1 Groundwater Operable Unit.*

Figure 1-5. Inferred Southeast Chromium Plume in 2008

Well 699-30-66 was drilled south of the Environmental Restoration Disposal Facility (ERDF) in 2004 to define the southern boundary of the tritium and iodine-129 plumes (Section 7.1.3.2 of CP-15329, *Data Quality Objectives Summary Report for Establishing a RCRA/CERCLA/AEA Integrated 200 West and 200 East Area Groundwater Monitoring Network*). The well, which is 1.1 km (0.7 mi) southwest of well 699-32-62, was drilled to the bottom of the unconfined aquifer at a total depth of 124 m (406 ft) (Section 2.4.2 of WMP-26333, *Borehole Summary Report for Six CERCLA Wells Drilled in the 200-UP-1 and 200-ZP-1 Operable Units, and Six RCRA Wells Drilled in the A-AX, B-BX-BY, and U WMA; CY 2004-2005*). Vertical profile groundwater samples were collected, but the chromium results had been affected by reducing conditions during drilling and were not representative of aquifer conditions (Section 3.3.6 of DOE/RL-2011-118, *Hanford Site Groundwater Monitoring for 2011*).

In 2006, filtered total chromium concentrations also exceeded the 100 µg/L MCL in well 699-30-66 (Section 2.1.9.7 in PNNL-16346, *Hanford Site Groundwater Monitoring for Fiscal Year 2006*). Well 699-30-66 is completed deep in the unconfined aquifer. The high chromium concentration at depth indicated that chromium might be distributed throughout the aquifer thickness in this region (Figure 4-24 and Section 4.2.4 of DOE/RL-2009-122).

No active remediation has been implemented to address the southeast chromium plume.

1.2.3.2 200-UP-1 Operable Unit Pump and Treat

P&T systems were operated as treatability tests in 1985 and from 1994 to 2011 near the 216-U-1 and 216-U-2 Cribs south and southeast of U Plant to remove uranium and technetium-99 from 200-UP-1 OU groundwater. The 1985 system was located near the contamination source, and the 1994–2011 system was downgradient from the source. The success of these systems in remediating 200-UP-1 OU groundwater demonstrated that P&T could be a viable remedial technology for the southeast chromium plume.

At the end of 2017, three active remedies were operating in accordance with the 200-UP-1 OU ROD (EPA et al., 2012): Waste Management Area (WMA) S-SX groundwater extraction system, U Plant area groundwater extraction system, and iodine-129 plume hydraulic containment system.

The WMA S-SX groundwater extraction system began operating in July 2012 using three extraction wells to remove technetium-99 from the aquifer east of the tank farms. The extracted groundwater is conveyed via aboveground pipelines and a transfer building to the 200 West P&T. Although this system removes commingled chromium associated with WMA S-SX, this chromium is not the source of the southeast chromium plume.

The current U Plant groundwater extraction system began operating in September 2015 using two extraction wells to remove uranium, technetium-99, and nitrate from the groundwater downgradient of the 216-U-1 and 216-U-2 Cribs. A third extraction well was added in September 2017. Extracted groundwater is conveyed via aboveground, dual-walled pipelines to the 200 West P&T.

The iodine-129 plume hydraulic containment system began operating in October 2015 using three hydraulic control injection wells to slow the eastward migration of the iodine-129 plume while treatment technologies for the plume are investigated. Of the 200 West P&T injection wells, these three are the closest to the southeast chromium plume but do not impact the water table in the plume area (Section 1.2.5.2).

Previous investigations and remediation for the 200-UP-1 OU are described in Section 1.5 and Section 2 of DOE/RL-2009-122. Additional details about P&T operations are available in Chapter 3 of DOE/RL-2017-68, *Calendar Year 2017 Annual Summary Report for the 200-ZP-1 and 200-UP-1 Operable Unit Pump-and-Treat Operations*.

1.2.4 Regulatory History and Framework

The 2008 interpretation of the southeast chromium plume used in the 200-UP-1 OU feasibility study (FS) (Figure 4-20 in DOE/RL-2009-122) was based on one well screened at the water table (699-32-62) with a concentration above the federal DWS for chromium (100 µg/L) and above the state MTCA B cleanup level for hexavalent chromium (48 µg/L) (Figure 1-5). The plume at the 20 µg/L contour was relatively well constrained to the north and northeast but was not constrained to the south, west, or east. (The 20 µg/L contour shown in Figure 4-20 in DOE/RL-2009-122 [Figure 1-5 in this report] does not have a regulatory basis but was added to further describe the chromium extent based on available data).

The remedial alternative selected for the southeast chromium plume in the 200-UP-1 OU ROD (EPA et al., 2012) is groundwater extraction and treatment in combination with MNA, remedy performance monitoring, and institutional controls (ICs). The timeframe to achieve the cleanup level for chromium is 25 years of P&T remediation followed by 125 years of MNA. The cleanup level is 100 µg/L (federal DWS) for total chromium and 48 µg/L (MTCA Method B) for hexavalent chromium (Table 14 in the 200-UP-1 OU ROD).

The RD/RAWP identified the need to further characterize the vertical and lateral extent of the southeast chromium plume as the initial step in implementing the remedy (Section 3.1.1 of DOE/RL-2013-07) The RD/RAWP also noted that the southeast chromium plume would require long pipeline and electrical runs to convey groundwater to the 200 West P&T and that alternate approaches (e.g., a smaller onsite treatment system) would be considered during the remedial design process (Section 3.4 of DOE/RL-2013-07).

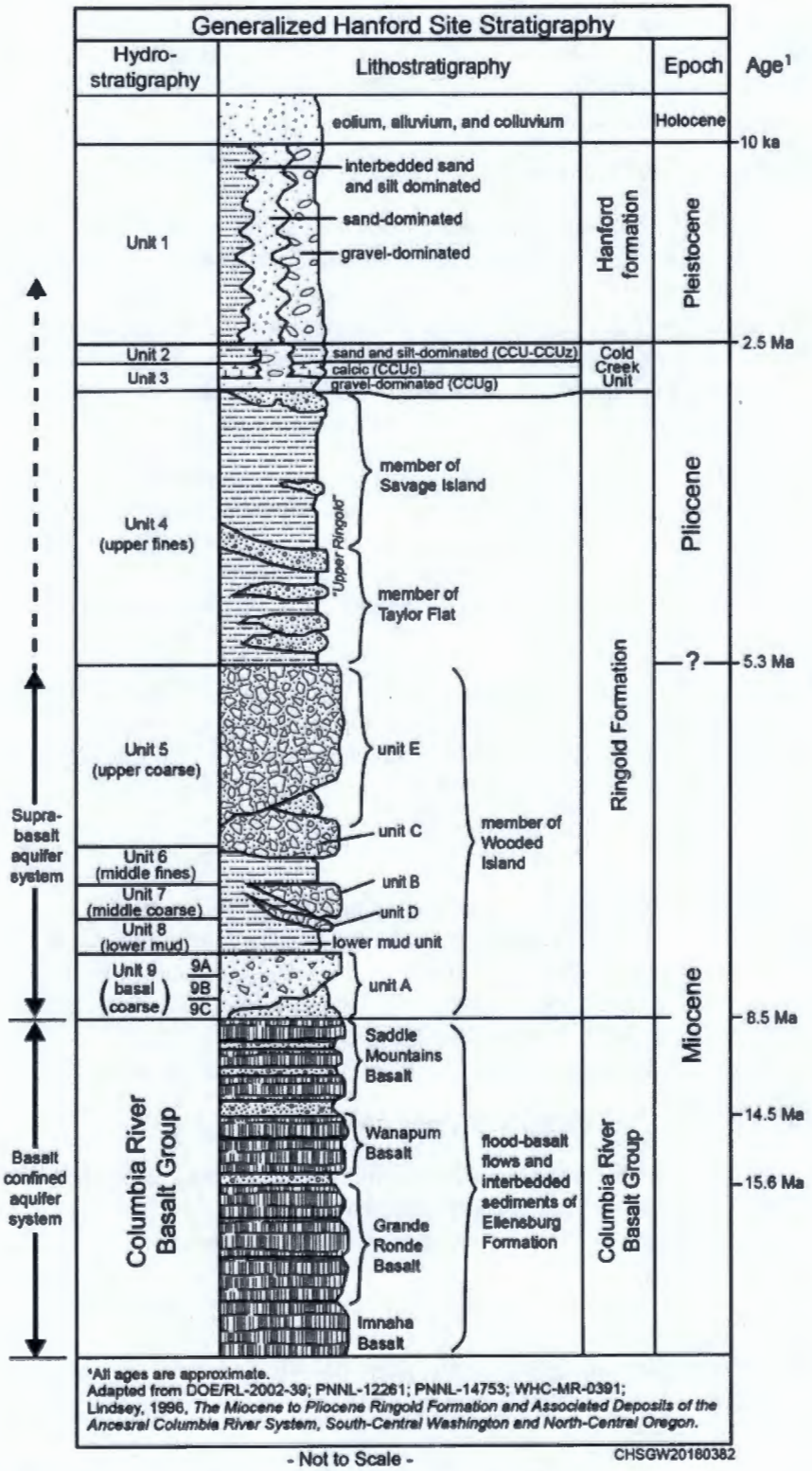
The alternate approaches for treating the groundwater extracted from the southeast chromium plume (using the 200 West P&T or an onsite treatment system) are evaluated in Section 4.3. Because the remedy selected in the 200-UP-1 OU ROD (EPA et al., 2012) for the southeast chromium plume was evaluated using the nine *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) evaluation criteria (Table 10 in the 200-UP-1 OU ROD), the alternate approaches are only evaluated relative to three CERCLA balancing criteria: implementability, effectiveness, and cost.

1.2.5 Geohydrologic Characteristics of the Study Area

Groundwater migration is the primary contaminant transport pathway in the 200-UP-1 OU. The groundwater flow direction and gradient have changed as a result of the 216-U-10 Pond mound development and dissipation, and more recently due to groundwater extraction and injection in the 200-UP-1 OU (Section 1.2.5.2).

1.2.5.1 Geology

The major geologic units on the Central Plateau are, from oldest to youngest, the Columbia River Basalt Group, the Ringold Formation, the Cold Creek unit (CCU), and the Hanford formation (Figure 1-6).



Note: Complete reference citations are provided in Chapter 6.

Figure 1-6. Generalized Stratigraphy of the Hanford Site

The volcanic basalt flows of the Columbia River Basalt Group were deposited during the Miocene and are the bedrock under the 200-UP-1 OU. The basalt surface slopes upward over a distance of ~6.8 km (4.2 mi) from an elevation of about 27 m (88.6 ft) near the 216-S-10 Pond to an elevation of about 58 m (190.3 ft) near the eastern end of the southeast chromium plume area (Figure 3-7 in DOE/RL-2009-122).

The fluvial and lacustrine sediments of the Ringold Formation were deposited on top of the basalt surface during the Miocene to Pliocene. In the area of the southeast chromium plume, the Ringold Formation consists of (from oldest to youngest) the following:

- Ringold Formation member of Wooded Island – unit A (Rwia), a fluvial gravel unit
- Ringold Formation member of Wooded Island – lower mud unit (Rlm), a lacustrine mud unit
- Ringold Formation member of Wooded Island – unit E (Rwie), a fluvial gravel unit
- Ringold Formation member of Taylor Flat (Rtf), a fluvial sands and silts unit

The Rlm, which is relatively thick and has low permeability, separates the confined aquifer in the Rwia from the unconfined aquifer in the Rwie. The surface of the lower mud is irregular but is regionally deeper to the west of the southeast chromium plume and shallower to the east of the plume. The southeast chromium plume is contained primarily within the Rwie. The upper Rtf is locally present beneath the 200-UP-1 OU waste sites and in the area overlying the southeast chromium plume.

The CCU overlying the Ringold Formation consists of a lower caliche unit and an upper silt unit. The caliche deposit is composed of precipitated calcium carbonate that accumulated in available pore spaces, binding the sediment grains together. These cemented deposits are extensive, relatively impermeable, deeply buried, and impede the downward migration of liquid and contaminants in the vadose zone beneath the waste sites overlying the 200-UP-1 OU. The CCU is present above the western end of the southeast chromium plume. The CCU is not present at the eastern area of the plume (Section 2.3.3.3 of DOE/RL-2010-49, *Remedial Investigation/Feasibility Study Work Plan for the 200-WA-1 and 200-BC-1 Operable Unit*).

The Hanford formation consists of Pleistocene cataclysmic flood deposits that are predominantly unconsolidated and range from boulder-sized gravel to silt. Hanford formation sediments have higher permeability and hydraulic conductivity than those of the CCU and Ringold Formation. The Hanford formation is important because contaminants must migrate through this thick vadose zone unit to reach the CCU and groundwater.

1.2.5.2 Hydrogeology

Groundwater contamination in the 200-UP-1 OU moves within the unconfined aquifer in the Rwie. Groundwater in the 200-UP-1 OU naturally flows from west to east toward the Columbia River.

During the nuclear materials production and processing period at the Hanford Site, flow directions and gradients in the 200-UP-1 OU were dominated by persistent, artificially elevated groundwater mounds that developed initially under the former 216-T-4 Pond in the northern 200 West Area and later under the former 216-U-10 Pond (Figure 1-2). The 216-U-10 Pond mound exerted the greatest effect in the southern part of the 200-UP-1 OU, deflecting unconfined groundwater in the area to the southeast. Discharges of liquid effluent to the ground overlying the 200-UP-1 OU were discontinued by the early 1990s, and the groundwater mound began to slowly dissipate. At well 699-32-62 in the southeast chromium plume, the artificially elevated water table began declining in about 1990 (Figure 1-7). As the mound declines, the groundwater flow direction is returning to a more natural eastward flow (Figure 1-8). The groundwater elevations within the 200-UP-1 OU remain elevated above background conditions (before artificial mounding) and are presently declining at a rate of ~0.3 m/yr (1 ft/yr).

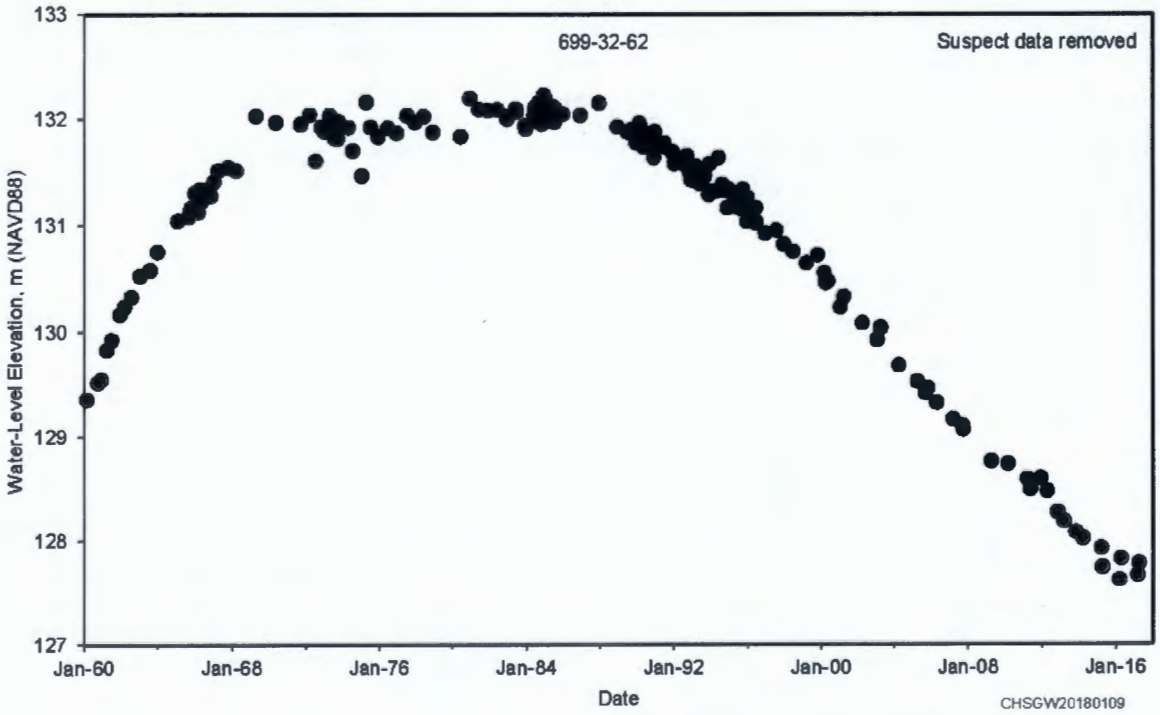
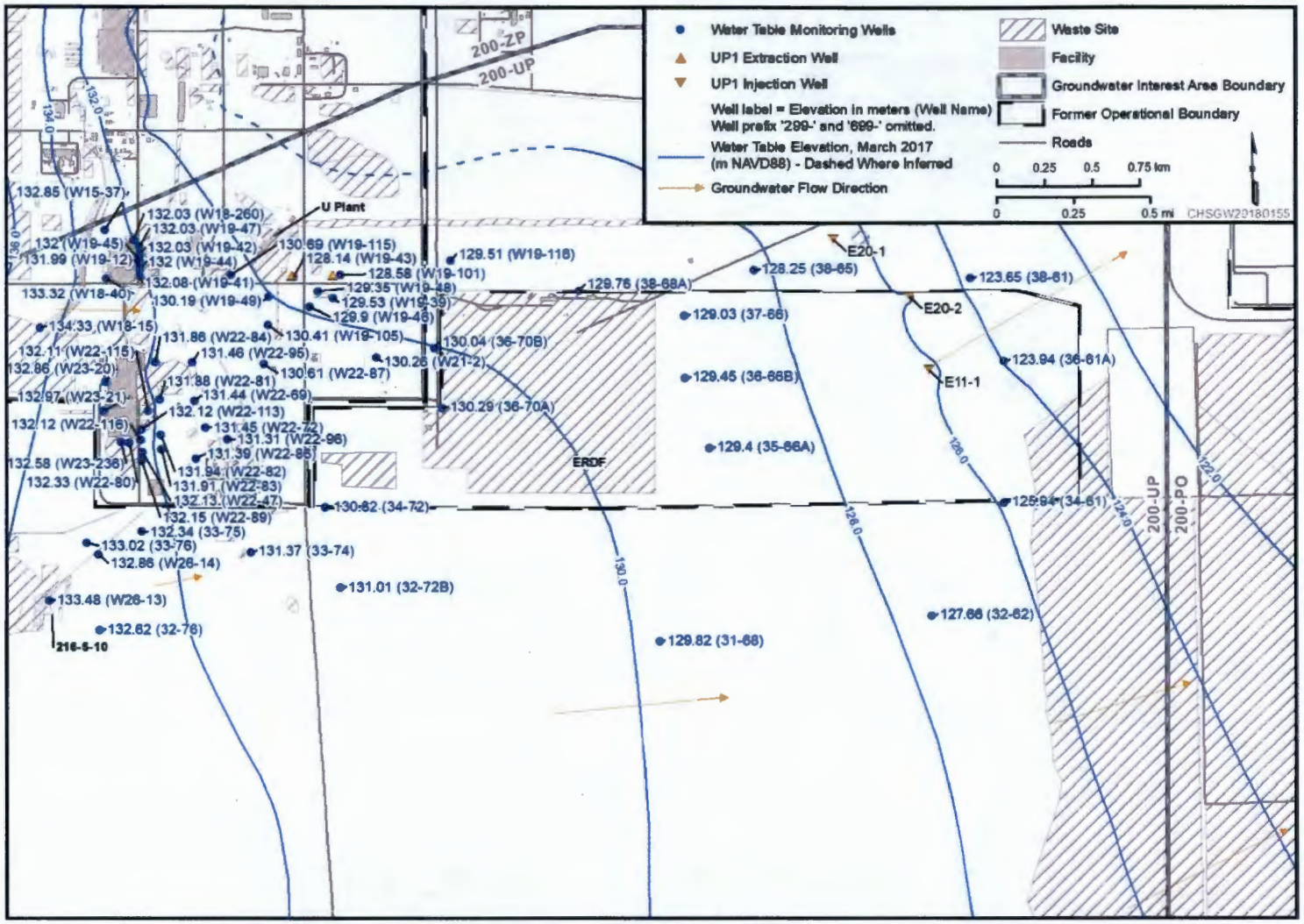


Figure 1-7. Changes in Groundwater Elevation over Time in Well 699-32-62 in the Southeast Chromium Plume

The hydraulic capture zones for the WMA S-SX and U Plant area groundwater extraction systems do not extend within the southeast chromium plume (Figures 3-11 and 3-35 in DOE/RL-2017-68). The injection wells closest to the southeast chromium plume are wells 299-E11-1, 299-E20-1, and 299-E20-2, used to hydraulically contain the iodine-129 plume (Figure 1-8). Injection of treated water through these wells locally perturbs the water table but not in the area of the southeast chromium plume (Figure 3-54 of DOE/RL-2017-68).

The depth to groundwater in the unconfined aquifer ranges from 70 m (230 ft) at the western end of the southeast chromium plume (based on well 699-30-73 in SGW-61319, *Borehole Summary Report for the Installation of Five Monitoring Wells in the 200-UP-1 Operable Unit, FY 2017*) to 104 m (340 ft) at the eastern end of the southeast chromium plume (Section 2.3.4.3 in DOE/RL-2010-49). The saturated thickness of the aquifer is ~51 m (166 ft) at the western end of the southeast chromium plume (based on well 699-30-73 in SGW-61319). The saturated thickness of the aquifer is 21 m (68 ft) at the eastern area of the southeast chromium plume (Section 2.3.4.3 of DOE/RL-2010-49).

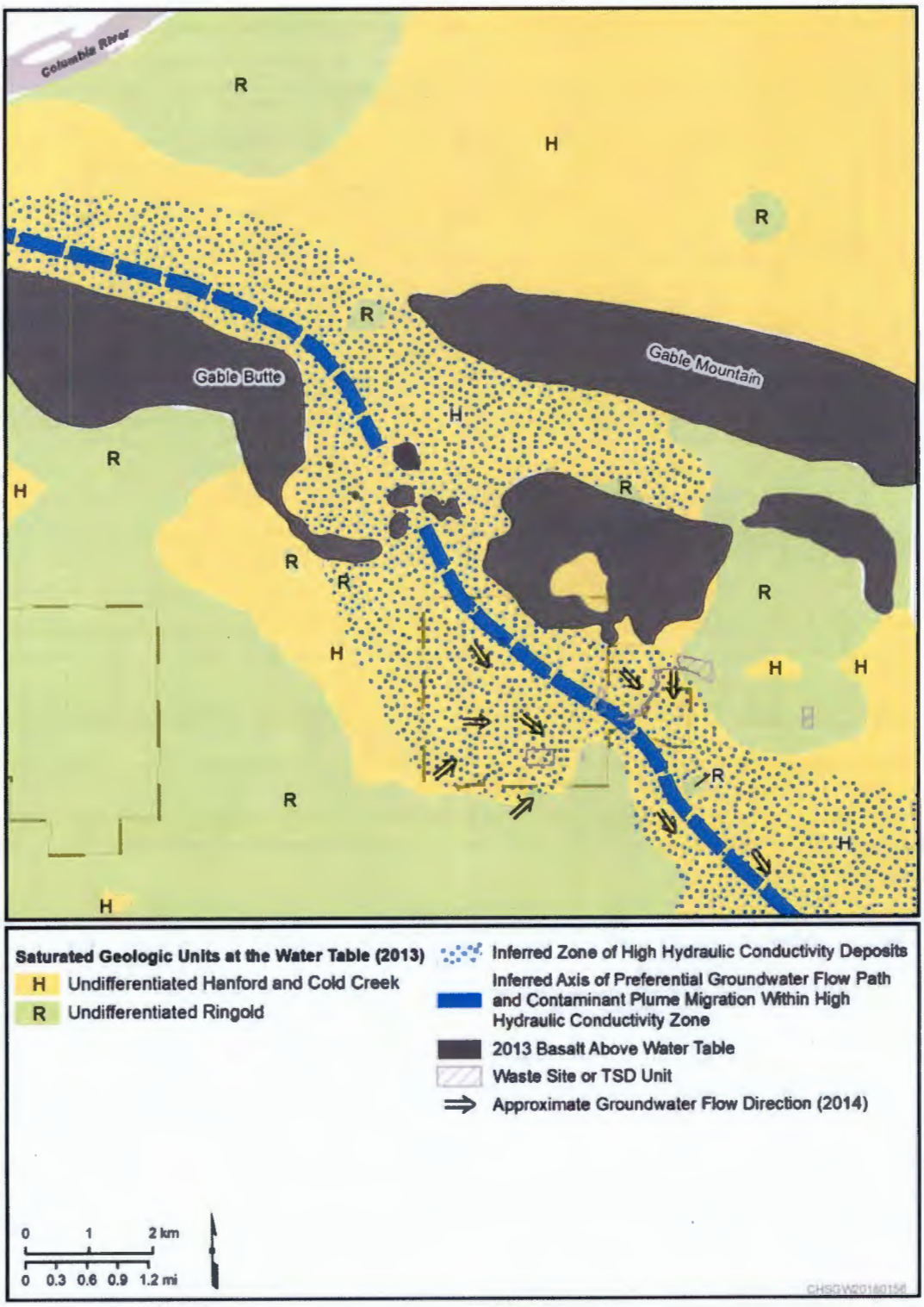
A paleochannel filled with high-conductivity Hanford formation sediments trends northwest-southeast between the 200 East Area and the Columbia River (Figure 1-9). The paleochannel creates a preferential pathway to the southeast for groundwater flowing from the west toward the Columbia River.



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

Note: Modified from Figure 11-2 in DOE/RL-2017-66, *Hanford Site Groundwater Monitoring Report for 2017.*

Figure 1-8. 200-UP-1 OU Water Table Map, March 2017



Note: Modified from Figure 2-13 in DOE/RL-2010-93, *Interim Status Groundwater Monitoring Plan for the 216-A-36B PUREX Plant Crib.*

Figure 1-9. Generalized Representation of High Hydraulic Conductivity Zone Associated with Hanford and Cold Creek Paleochannel Deposits

2 Investigation Approach

This chapter presents the approach for the southeast chromium plume remedial design investigation and the sampling and analysis plan (SAP) requirements.

2.1 Remedial Design/Remedial Action Work Plan and Sampling and Analysis Plan

Historically, the extent of the southeast chromium plume was not sufficiently defined to support remedy implementation, particularly on the southern side of the plume. Characterization activities to refine the vertical and horizontal extent of the plume to focus and optimize the remedial design were required by the 200-UP-1 OU RD/RAWP (Section 3.5.5 of DOE/RL-2013-07). In accordance with the RD/RAWP, the data quality objective (DQO) process was used to define the final number, location, and type of characterization wells, as well as the measurement frequency. Consideration was given to sampling groundwater over the entire thickness of the aquifer to understand the vertical distribution of chromium and to select the appropriate screen intervals. The flexibility of completing the wells for dual use (i.e., monitoring wells and extraction or injection wells) was also considered. The results of the DQO process were documented in the 200-UP-1 OU SAP (Section 1.1 of DOE/RL-2014-27, *Sampling and Analysis Plan for Remediation Wells in the 200-UP-1 Operable Unit*).

2.2 Sampling and Analysis Plan Requirements

The SAP for drilling the southeast chromium plume wells defined sampling and analytical requirements for the remedial design investigation (DOE/RL-2014-27, as amended by TPA-CN-0793, *Tri-Party Agreement Change Notice Form: DOE/RL-2014-27, Sampling and Analysis Plan for Remediation Wells in the 200-UP-1 Operable Unit, Rev. 2*). Characterization data needed for the investigation included the vertical profile and lateral extent of chromium contamination in groundwater, aquifer particle-size distribution over the well screen interval, and information to evaluate the F&T of contaminants. The number and location of samples, sampling procedures, and analyses were specified in the field sampling plan (Chapter 3 of DOE/RL-2014-27).

Initially, six characterization wells were planned to further define the nature and extent of the southeast chromium plume to support remedial design. These six wells were located based on the extent of the 2015 plume, which was the latest interpretation at the start of the drilling program (Figure 2-1). Chromium concentrations at the two northern wells (699-31-68 and 699-32-64) were consistent with the 2015 plume, but the relatively high concentrations in the three southern wells (699-29-66, 699-30-63, and 699-30-57) indicated that the plume above the 48 µg/L cleanup level extended further south. The DOE Richland Operations Office (DOE-RL) and EPA met on January 19, 2017, to review the findings from the first six wells and agreed to install and sample four additional characterization wells in 2017. These four wells were located to investigate the eastern (699-31-50), southeastern (699-29-55), southwestern (699-27-68), and western (699-30-70) extent of the plume. DOE-RL and EPA also agreed to collect four quarters of groundwater samples from each of the initial six wells to evaluate the groundwater monitoring data for temporary reducing conditions affecting chromium concentrations.

In well 699-30-70, chromium concentrations during drilling were relatively high (average filtered total chromium of 98 µg/L), indicating that the plume extended further to the west. DOE-RL and EPA met on July 20, 2017, and agreed to drill an eleventh well (699-30-73) to define the western extent of the plume closest to the 216-S-10 source area. Concurrence was reached that 11 wells would be sufficient to define the nature and extent of the southeast chromium plume, to support completion of the Draft A remedial design investigation report, and to satisfy the remedial design investigation requirement of Tri-Party Agreement Milestone M-16-193 (Ecology et al., 1989) for the southeast chromium plume.

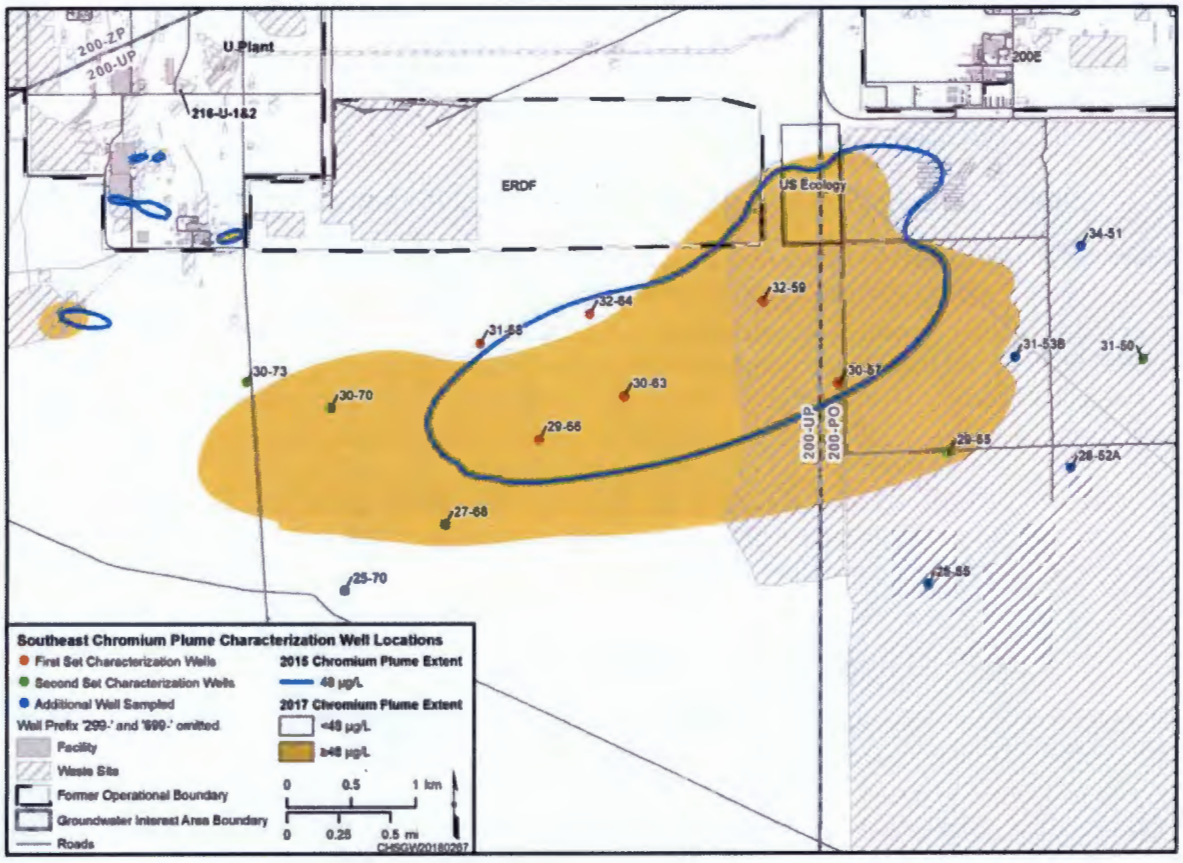


Figure 2-1. Locations of the 11 Southeast Chromium Plume Remedial Design Investigation Wells

Table 2-1 summarizes the samples collected during drilling of the 11 southeast chromium plume characterization wells and compares the planned depths (from Table 3-1 in the SAP [DOE/RL-2014-27]) to the actual depths. Sections 2.2.3. 2.2.4, and 2.2.5 discuss the specific types of samples collected from each well. In addition, TPA-CN-0802, *Tri-Party Agreement Change Notice Form: DOE/RL-2015-14, Performance Monitoring Plan for the 200-UP-1 Groundwater Operable Unit Remedial Action, Rev. 0,* added five older wells near the southern and eastern perimeter of the southeast chromium plume (wells 699-25-55, 699-25-70, 699-28-52A, 699-31-53B, 699-34-51) to the total and hexavalent chromium monitoring well network to support implementing the remedial action (Figure 2-1).

2.2.1 Contaminants of Concern

Chromium, measured as total chromium and hexavalent chromium, was the target COC for this remedial design investigation. Groundwater samples were also analyzed for tritium to determine whether the southeast chromium plume was commingled with the nearby tritium plume. Samples were analyzed for manganese, dissolved oxygen (DO), and reduction-oxidation potential as indicators of reducing conditions. Analytes for sampling are identified in Table 3-1 of the 200-UP-1 OU SAP (DOE/RL-2014-27).

Table 2-1. 200-UP-1 OU Southeast Chromium Plume Depth-Discrete Samples

Well Name (ID)/Type	Sample Matrix	Planned Sample Depth		Actual Sample Depth	
		Below Water Table (m [ft])	Below Ground Surface (m [ft])	Below Water Table (m [ft])	Below Ground Surface (m [ft])
699-27-68 (C9632)/ monitoring	Water (depth discrete)	3.0 (10)	70.4 (231)	5.6 (18.3)	71.7 (235.2)
		9.1 (30)	76.5 (251)	11.5 (37.6)	77.6 (254.6)
		15.2 (50)	82.6 (271)	17.4 (57.2)	83.5 (274.1)
		21.3 (70)	88.7 (291)	24.1 (79.0)	90.2 (296.0)
		27.4 (90)	94.8 (311)	29.9 (98.1)	96.0 (315.0)
		33.5 (110)	100.9 (331)	36.0 (118.1)	102.1 (335.1)
	Saturated soil (split spoon)	3.0(10)	70.4 (231)	5.5-6.2 (17.9-20.2)	71.6-72.3 (234.9-237.2)
		15.2 (50)	82.6 (271)	17.7-17.8 (58.0-58.5)	83.8-84.0 (275.0-275.5)
		27.4 (90)	94.8 (311)	30.0-30.3 (98.5-99.5)	96.2-96.5 (315.5-316.5)
699-29-55 (C9634)/ monitoring	Water (depth discrete)	3.0 (10)	91.1 (299)	4.4 (14.5)	91.7 (300.9)
		9.1 (30)	97.2 (319)	10.5 (34.5)	97.8 (320.9)
		15.2 (50)	103.3 (339)	19.6 (64.4)	106.9 (350.8)
		21.3 (70)	109.4 (359)	25.8 (84.5)	113.1 (370.9)
		27.4 (90)	115.5 (379)	31.9 (104.5)	119.2 (390.9)
		—	—	37.9 (124.5)[a]	125.2 (410.9)
	Saturated soil (split spoon)	3.0 (10)	91.1 (299)	2.9-3.0 |(9.5-10.0)	90.1-90.2 (295.5-296.0)
		15.2 (50)	103.3 (339)	16.7-17.5 (54.8-57.3)	103.9-104.6 (340.8-343.3)
		27.4 (90)	115.5 (379)	32.0-32.6 (104.9-106.)9	119.1-119.8 (390.9-392.9)
699-29-66 (C9413)/ monitoring	Water (depth discrete)	6.1 (20)	80.5 (264)	7.2 (23.7)	83.5 (274.0)
		27.4 (90)	101.8 (334)	25.4 (83.2)	101.9 (334.2)
		48.8 160)	123.1 (404)	46.3 (152.0)	122.8 (403.0)
		—	—	73.4 (240.9)[a]	149.7 (491.1)
	Saturated soil (split spoon)	6.1 (20)	80.5 (264)	7.5-8.3 (24.6-27.1)	83.5-84.3 (274.1-276.6)
		27.4 (90)	101.8 (334)	25.7-26.3 (84.4-86.4)	101.8-102.4 (333.9-335.9)
		48.8 (160)	123.1 (404)	74.9-75.5 (245.8-247.8)	151.0-151.6 (495.3-497.3)

Table 2-1. 200-UP-1 OU Southeast Chromium Plume Depth-Discrete Samples

Well Name (ID)/Type	Sample Matrix	Planned Sample Depth		Actual Sample Depth	
		Below Water Table (m [ft])	Below Ground Surface (m [ft])	Below Water Table (m [ft])	Below Ground Surface (m [ft])
699-30-57 (C9417)/ monitoring	Water (depth discrete)	6.1 (20)	93.6 (307)	9.7 (31.9)	96.7 (317.2)
		25.9 (85)	113.4 (372)	25.8 (84.7)	112.8 (370.0)
		45.7 (150)[b]	133.2 (437)	—	—
	Saturated soil (split spoon)	6.1 (20)	93.6 (307)	5.4-6.1 (17.6-20.1)	93.4-94.2 (306.5-309.0)
		25.9 (85)	113.4 (372)	25.5-26.2 (83.5-86.0)	113.5-114.3 (372.4-374.9)
		45.7 (150)[b]	133.2 (437)	—	—
699-30-63 (C9602)/ dual-use	Water (depth discrete)	6.1 (20)	87.5 (287)	7.1 (23.3)	90.1 (295.5)
		12.2 (40)	93.6 (307)	13.3 (43.6)	96.3 (315.9)
		19.8 (65)	101.2 (332)	19.3 (63.3)	102.3 (335.6)
		27.4 (90)	108.8 (357)	25.4 (83.4)	108.4 (355.7)
		33.5 (110)	114.9 (377)	31.5 (103.2)	114.5 (375.5)
		—	—	37.5 (123.1)[a]	120.5 (395.4)
	Saturated soil (split spoon)	6.1 (20)	87.5 (287)	5.4-6.1 (17.6-20.1)	89.3-90.1 (293.1-295.6)
		19.8 (65)	101.2 (332)	18.5-19.2 (60.6-62.9)	102.4-103.1 (336.1-338.4)
		33.5 (110)	114.9 (377)	30.1-31.0 (98.8-101.8)	114.1-115.0 (374.3-377.3)
699-30-70 (C9635)/ monitoring	Water (depth discrete)	3.0 (10)	68.9 (226)	4.6 (15.1)	71.8 (235.5)
		9.1 (30)	75.0 (246)	10.7 (35.0)	77.8 (255.4)
		15.2 (50)	81.1 (266)	16.8 (55.1)	83.9 (275.4)
		21.3 (70)	87.2 (286)	22.9 (75.1)	90.0 (295.4)
		27.4 (90)	93.3 (306)	28.9 (94.9)	96.1 (315.2)
		33.5 (110)	99.4 (326)	36.0 (114.9)	102.2 (335.2)
		39.6 (130)	105.5 (346)	40.9 (134.1)	108.0 (354.4)
		45.7 (150)	111.6 (366)	47.0 (154.1)	114.1 (374.4)
	Saturated soil (split spoon)	3.0 (10)	68.9 (226)	4.9-5.6 (16.1-18.5)	72.0-72.6 (236.1-238.1)
		21.3 (70)	87.2 (286)	23.1-23.8 (75.7-78.1)	120.6-121.3 (395.7-398.1)
		39.6 (130)	105.5 (346)	40.9-41.3 (134.1-135.5)	107.9-108.4 (354.1-355.5)

Table 2-1. 200-UP-1 OU Southeast Chromium Plume Depth-Discrete Samples

Well Name (ID)/Type	Sample Matrix	Planned Sample Depth		Actual Sample Depth	
		Below Water Table (m [ft])	Below Ground Surface (m [ft])	Below Water Table (m [ft])	Below Ground Surface (m [ft])
699-30-73 (C9636)/ monitoring	Water (depth discrete)	3.0 (10)	70.1 (230)	3.3 (10.7)	73.3 (240.4)
		9.1 (30)	76.2 (250)	9.3 (30.6)	79.3 (260.3)
		15.2 (50)	82.3 (270)	15.3 (50.3)	85.3 (280.0)
		21.3 (70)	88.4 (290)	21.5 (70.6)	91.5 (300.3)
		27.4 (90)	94.5 (310)	27.5 (90.3)	97.5 (320.0)
		33.5 (110)	100.6 (330)	33.7 (110.6)	103.7 (340.3)
		39.6 (130)	106.7 (350)	39.7 (130.4)	109.7 (360.1)
		45.7 (150)	112.8 (370)	45.9 (150.5)	115.9 (380.2)
		51.8 (170)[b]	118.9 (390)	—	—
	Saturated soil (split spoon)	3.0 (10)	70.1 (230)	3.3-3.5 (10.9-11.4)	73.4-73.6 (240.9-241.4)
		21.3 (70)	88.4 (290)	21.7-21.9 (71.3-71.8)	91.8-92.0 (301.3-301.8)
		39.6 (130)	106.7 (350)	39.7-39.8 (130.2-130.7)	109.8-109.9 (360.2-360.7)
699-31-50 (C9737)/ monitoring	Water (depth discrete)	3.0 (10)	96.6 (317)	5.1 (16.7)	99.1 (325.0)
		9.1 (30)	102.7 (337)	10.7 (35.2)	105.2 (345.0)
		15.2 (50)	108.8 (357)	17.2 (56.4)	111.6 (366.2)
		21.3 (70)	114.9 (377)	22.9 (75.2)	117.3 (385.0)
		27.4 (90)	121.0 (397)	29.3 (96.2)	123.7 (406.0)
		33.5 (110)	127.1 (417)	35.3 (115.7)	129.7 (425.5)
		—	—	41.2 (135.2)[a]	135.6 (445.0)
	Saturated soil (split spoon)	3.0 (10)	96.6 (317)	4.9-5.3 (16.0-17.5)	98.8-99.5 (325.0-326.5)
		15.2 (50)	108.8 (357)	16.7-17.4 (54.7-57.2)	110.9-111.6 (363.7-366.2)
		27.4 (90)	121.0 (397)	29.0-29.6 (95.0-97.0)	12.31-123.7 (404.0-406.0)
		—	—	35.1-35.5 (115.0-116.5)[a]	129.2-129.7 (424.0-425.5)

Table 2-1. 200-UP-1 OU Southeast Chromium Plume Depth-Discrete Samples

Well Name (ID)/Type	Sample Matrix	Planned Sample Depth		Actual Sample Depth	
		Below Water Table (m [ft])	Below Ground Surface (m [ft])	Below Water Table (m [ft])	Below Ground Surface (m [ft])
699-31-68 (C9416)/ monitoring	Water (depth discrete)	6.1 (20)	86.3 (283)	12.3 (40.3)	92.8 (304.5)
		24.4 (80)	104.5 (343)	24.4 (80.2)	104.9 (344.3)
		42.7 (140)	122.8 (403)	45.8 (150.4)	126.3 (414.5)
	Saturated soil (split spoon)	6.1 (20)	86.3 (283)	11.5-12.2 (37.8-39.8)	92.8-93.4 (304.5-306.5)
		24.4 (80)	104.5 (343)	23.7-24.3 (77.6-79.6)	104.9-105.6 (344.3-346.3)
		42.7 (140)	122.8 (403)	45.0-45.7 (147.8-149.8)	126.3-126.9 (414.5-416.5)
699-32-59 (C9603)/ dual-use	Water (depth discrete)	6.1 (20)	99.4 (326)	9.4 (31.0)	102.6 (336.5)
		10.7 (35)	103.9 (341)	15.3 (50.3)	108.5 (355.8)
		16.8 (55)	110.0 (361)	21.7 (71.2)	114.8 (376.8)
		22.9 (75)	116.1 (381)	24.7 (80.9)	117.8 (386.5)
		27.4 (90)[b]	120.7 (396)	—	—
	Saturated soil (split spoon)	6.1 (20)	99.4 (326)	8.1-8.9 (26.6-29.1)	102.3-103.0 (335.5-338.0)
		16.8 (55)	110.0 (361)	15.1-15.8 (49.7-51.7)	109.3-`09.9 (358.6-360.6)
		27.4 (90)	120.7 (396)	24.1-24.9 (79.2-81.7)	117.4-118.2 (385.2-387.7)
699-32-64 (C9601)/ dual-use	Water (depth discrete)	6.1 (20)	90.2 (296)	10.3 (33.9)	96.3 (316.0)
		12.2 (40)	96.3 (316)	13.4 (43.9)	99.4 (326.0)
		18.3 (60)	102.4 (336)	19.1 (62.7)	105.1 (344.7)
		24.4 (80)	108.5 (356)	25.6 (83.9)	111.6 (366.0)
		30.5 (100)	114.6 (376)	31.7 (104.1)	117.7 (386.1)
	Saturated soil (split spoon)	6.1 (20)	90.2 (296)	6.9-7.8 (22.8-25.7)	93.8-94.7 (307.7-310.6)
		18.3 (60)	102.4 (336)	18.6-19.4 (60.9-63.7)	105.4-106.3 (345.8-348.6)
		30.5 (100)	114.6 (376)	30.3-3.0 (99.5-101.7)	117.2-117.8 (384.4-386.6)

a. Depth to the Ringold Formation member of Wooded Island – lower mud unit greater than estimated; additional sample required.

b. Depth to the Ringold Formation member of Wooded Island – lower mud unit less than estimated: final estimated sample depth not reached.

ID = identification

2.2.2 Characterization Wells

The 11 southeast chromium plume wells were drilled between March 2016 and October 2017. The wells were drilled in accordance with descriptions of work for drilling:

- SGW-59416, *Description of Work for the Installation of Three Monitoring Wells in the 200-UP-1 Groundwater Operable Unit, FY16*
- SGW-60084, *Description of Work for the Installation of Three Multipurpose Wells in the 200-UP-1 Groundwater Operable Unit, FY 2017*
- SGW-60568, *Description of Work for the Installation of Four Monitoring Wells Near the Southeastern Portion of the 200-UP-1 Operable Unit, FY 2017*

Three of the original six wells were planned and constructed as dual-use wells (699-30-63, 699-32-59, and 699-32-64) and will initially be used for groundwater monitoring but could later be used for groundwater extraction or injection. The other eight wells were planned and constructed as groundwater monitoring wells.

Depth-discrete samples of saturated sediment and groundwater were collected in accordance with the SAP (DOE/RL-2014-27). The sampling is described in this chapter, and the results are summarized in Chapter 3.

2.2.3 Groundwater Samples

Depth-discrete groundwater samples were collected during drilling of the 11 southeast chromium plume characterization wells to determine the vertical profile of chromium contamination. Groundwater samples were also collected following well development and during subsequent quarterly monitoring. Nearby existing groundwater wells were sampled to supplement the data from the new wells.

Groundwater samples were analyzed for total chromium and hexavalent chromium. Filtered total chromium concentrations are considered equivalent to hexavalent chromium concentrations, although there can be differences caused by normal analytical variability or sample turbidity (Section 1.2.1). Filtered total and hexavalent chromium concentrations can be affected by temporary reducing conditions caused by the drilling process.

Temporary chemically reducing conditions have been documented when drilling at the Hanford Site. The conditions are generally caused by the drilling activity breaking pieces of basalt (or other iron-bearing rock types) and exposing reduced iron in the fractured surfaces. The exposed reduced iron in rock surfaces can be readily oxidized by dissolved oxygen in the groundwater; this can temporarily deplete the oxygen content in the water, resulting in reducing conditions. These reducing conditions can temporarily affect the oxidation state of other elements, including chromium and manganese. The reducing conditions can cause hexavalent chromium to reduce to trivalent chromium (which is less soluble) and can cause hexavalent chromium concentrations observed during drilling to be artificially low. It can take up to a year after a well is drilled before the aquifer fully recovers and representative samples can be collected (Section 3.3.6 of DOE/RL-2011-118), depending on the drilling method and the nature of the geological material encountered.

The southeast chromium wells were drilled using the air rotary method rather than the cable tool method to maintain oxygenated conditions and mitigate reducing conditions in the subsurface during drilling (Section 2 of ECF-200UP1-17-0238, *Development of the 3D Hexavalent Chromium Groundwater Plume using Leapfrog for Southeast 200-UP-1*) (provided as Appendix B of this report). Samples for manganese

analysis were collected because manganese is also sensitive to reduction-oxidation conditions. Manganese is insoluble under normal oxidizing conditions in the aquifer. Thus, the presence of elevated manganese in sample results indicates reducing conditions (Chapter 2 of ECF-200UP1-17-0238). Increasing chromium concentrations and decreasing manganese concentrations during recovery from the drilling process were used as indicators that samples are representative of the oxidizing conditions normal for the Hanford Site aquifer. Dissolved oxygen concentrations <7,000 µg/L also suggest some degree of chemical reduction.

2.2.3.1 Vertical Profile Sampling

Depth-discrete groundwater samples were generally collected from the upper, middle, and lower portions of the aquifer for the first three wells drilled (699-29-66, 699-30-57, and 699-31-68), and every 6.1 m (20 ft) below the water table for the remaining eight wells, to determine the vertical profile of chromium contamination in the unconfined aquifer. The first sample was typically collected 1.5 to 3.1 m (5 to 10 ft) below the targeted depth for the first water sample (Table 2-1) so the well would produce enough water for sampling. Section 3.1.2.1 discusses the depth-discrete sample results.

The samples were collected using a 3/4-horsepower, temporary submersible pump. When possible, the boreholes were purged until dissolved oxygen stabilized ≥7,000 µg/L and reduction-oxidation potential was at least 200 mV (Section 3.1.6 of the SAP [DOE/RL-2014-27]). This requirement resulted in longer purge times and the generation of larger volumes of purge water than normal in an effort to mitigate the reducing effects caused by the drilling process. During purging of the two deepest sample intervals in well 699-29-66, the dissolved oxygen level did not exceed 7,000 µg/L (Section 2.2.1 of SGW-60463, *Borehole Summary Report for the Installation of Three Monitoring Wells in the 200-UP-1 Groundwater Operable Unit, Fiscal Year 2016*).

Table 2-1 lists the sample depths for each well. An additional water sample was collected at wells 699-29-55, 699-29-66, 699-30-63, and 699-31-50 because the depth to the Rlm was greater than estimated (Table 2-1). One less water sample was collected at wells 699-30-57, 699-30-73, and 699-32-59 because the depth of the Rlm was less than estimated (Table 2-1).

Groundwater samples from the same sample depths were sent to Pacific Northwest National Laboratory (PNNL) to support the Deep Vadose Zone Applied Field Research Initiative scientific investigations of controlling processes for contaminant behavior (Section 3.2.3 of DOE/RL-2014-27). Three to eight depth-discrete groundwater samples were collected at 10 of the new wells; samples were not collected for PNNL from well 699-30-73 because it was the last well drilled and PNNL did not require additional samples.

2.2.3.2 Sampling After Well Development

Well development for each of the 11 new southeast chromium plume wells was conducted following well construction. Details regarding well development are provided in the three borehole summary reports (Table 2-2 in SGW-60463; Table 2 in SGW-60727, *Borehole Summary Report for Installation of Three Multipurpose Wells in the 200-UP-1 Groundwater Operable Unit, FY 2017*; and Table 2 in SGW-61319). Well development was performed at one or more intervals. Each interval was pumped until water turbidity was <5 nephelometric turbidity units (NTUs) and additional water quality parameters (conductivity, DO, pH, and temperature) had stabilized. Final drawdown measurements for each pumped interval are listed in the borehole summary reports. Groundwater samples were collected following completion of well development. Table 2-2 lists the pump intake depths for the post-development samples. Section 3.1.2.2 discusses the groundwater monitoring results.

Table 2-2. Southeast Chromium Plume Well Pump Intake Depths

Well Name (ID)	Post-Well Development Pump Intake (m [ft] bgs)	Routine Sampling Pump Intake (m [ft] bgs)
699-27-68 (C9632)	87.6 (287.5)	84.7 (278)
699-29-55 (C9634)	114.6 (376.1)	109.1 (358)
699-29-66 (C9413)	103.4 (339.4)	103.3 (339)*
699-30-57 (C9417)	96.6 (317)	96.6 (316.9)
699-30-63 (C9602)	116.2 (381.1)	98.0 (321.5)
699-30-70 (C9635)	107.6 (353)	98.0 (321.5)
699-30-73 (C9636)	77.8 (255.1)	78.6 (258)
699-31-50 (C9737)	99.3 (325.7)	116.4 (382)
699-31-68 (C9416)	91.1 (299)	90.4 (296.5)
699-32-59 (C9603)	117.1 (384.1)	103.9 (341)
699-32-64 (C9601)	96.7 (317.3)	119.5 (392)

*Based on the tube length of 103.6 m (340 ft), the 0.8 m (2.55 ft) between ground surface and top of casing, and a 0.9 m (3 ft) long pump with the intake near the middle.

bgs = below ground surface

ID = identification

2.2.3.3 Routine Groundwater Data from New Wells

Routine quarterly groundwater samples are being collected from each new southeast chromium plume well to evaluate temporal variability of filtered total chromium and hexavalent chromium concentrations. Table 2-2 lists the pump intake depths for the routine groundwater samples. Section 3.1.2.3 discusses the groundwater monitoring results

2.2.3.4 Groundwater Data from Existing Wells

Based on the higher-than-anticipated chromium concentrations observed at characterization well 699-30-57 in 2016, additional sampling of existing groundwater monitoring wells for total chromium and hexavalent chromium was conducted in 2017. The 28 wells selected for additional monitoring surround the southeast chromium plume (Figure 2-2). Section 3.1.2.4 discusses the groundwater monitoring results.

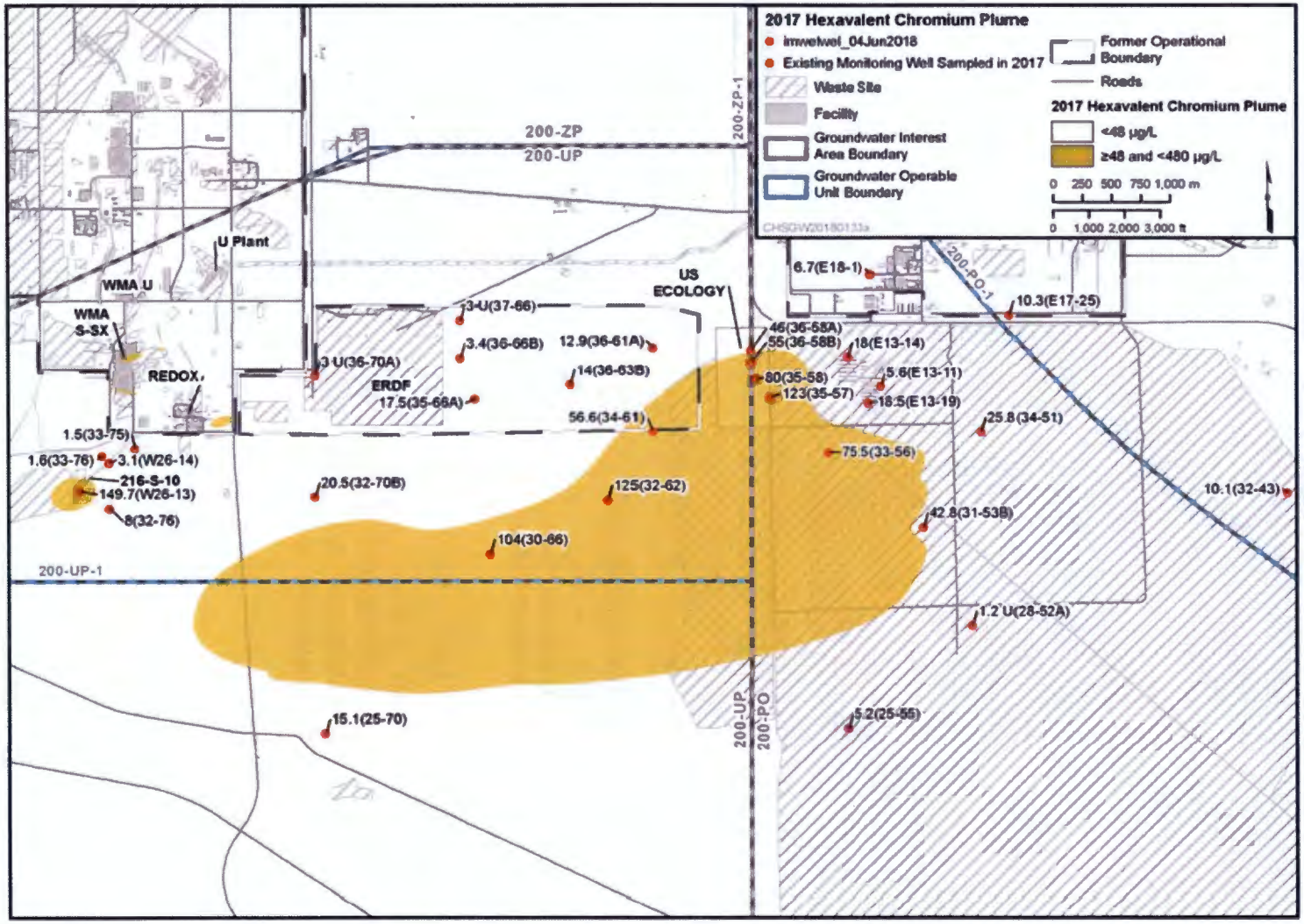


Figure 2-2. Location of Existing Groundwater Wells near the Southeast Chromium Plume Sampled in 2017 as Part of the Remedial Design Investigation

2.2.4 Soil Samples

Depth-discrete grab soil samples were collected from drill cuttings every 1.5 m (5 ft) throughout the borehole for archiving in accordance with the descriptions of work for drilling (SGW-59416, SGW-60084, and SGW-60568).

Construction of the new groundwater wells required analysis of particle-size distribution in soil samples collected during drilling to define well completion specifications. Depth-discrete grab samples were collected at 1.5 m (5 ft) intervals from drill cuttings within the unconfined aquifer and were composited into samples representing 6.1 to 12.2 m (20 to 40 ft) long intervals for sieve analysis. Sieve analyses of the borehole cuttings collected over the well screen interval were used to design the filter pack and select the screen slot size for the wells. Lithologic descriptions in the geologist's borehole log were also considered in designing the well completion.

Saturated zone soil samples were collected and sent to PNNL to support the Deep Vadose Zone Applied Field Research Initiative scientific investigations of controlling processes for contaminant behavior (Section 3.2.3 of DOE/RL-2014-27). Samples were collected at the upper, middle, and lower portions of the unconfined aquifer, starting between 3 to 6.1 m (10 to 20 ft) below the water table, to characterize the geochemistry of the sediment and associated pore water. Three split-spoon soil samples were collected within the unconfined aquifer at 10 of the new wells and two samples were collected at well 699-30-57 (Table 2-1).

The saturated zone soil samples were collected for PNNL using 10.2 cm (4 in.) diameter split-spoon samplers that contained four 15.2 cm (6 in.) long liners. These liners were wrapped in aluminum foil and plastic to preserve water content immediately after recovery.

Chromium transport may be impacted by physical or geochemical interaction with aquifer sediments. A single split-spoon sample from one well (699-30-63) downgradient of the chromium source sites was selected to assess processes controlling contaminant transport. Section 3.1.3 summarizes the results of the assessment.

2.2.5 Deviations from the Sampling and Analysis Plan

The SAP (DOE/RL-2014-27) requirements for well completion and for soil and groundwater sampling for the southeast chromium plume wells were met. Some depth-discrete groundwater sample depths varied from planned depths based on availability of sufficient groundwater volume for sampling. At some wells, the deepest soil sample depth varied from the planned depth based on Rlm elevation.

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3 Investigation Results

This chapter provides the results of the southeast chromium plume remedial design investigation and presents the updated CSM based on the new characterization data.

3.1 Southeast Chromium Plume Investigation Data

This section summarizes the well drilling and completion information and the sampling results for the 11 wells drilled to investigate the southeast chromium plume.

3.1.1 Well Completion

The 11 characterization wells were drilled between March 2016 and October 2017 (Table 3-1). Eight of the boreholes were completed as 10.2 cm (4 in.) diameter monitoring wells, and three of the boreholes were completed as 20.3 m (8 in.) diameter, dual-use monitoring and extraction wells. The final screened intervals for the 11 new wells were chosen based on the highest dissolved chromium (total filtered or hexavalent) concentrations in samples collected during drilling. Screens for seven of the eight monitoring wells begin at the water table; the screen in monitoring well 699-29-66 begins 21.3 m (70 ft) below the water table due to the high dissolved chromium (total filtered and hexavalent) concentration at that depth (56 and 55 µg/L, respectively, at 25.4 m [83.2 ft] below the water table).

Total screen lengths range from 6.1 to 30.5 m (20 to 100 ft) (Table 3-2). Dual-use wells 699-30-63, 699-32-59, and 699-32-64 were constructed with the longest screened intervals to allow possible groundwater extraction. Screens were installed using one to three segments varying from 6.1 to 19.8 m (20 to 65 ft) long. Sections of blank casing with annular seals were constructed between screen segments to allow for installation of packers to prevent vertical flow in the well between screen segments and to allow monitoring to target specific depth intervals to obtain representative samples. Dedicated sampling pumps were installed within the screened interval or, in the case of multi-screened intervals, at the depth with the highest dissolved chromium concentration. Table 2-2 provides the pump intake depths. Packers have not yet been installed in any of the wells with multiple screened intervals.

Sieve analyses of drill cuttings collected over the well screen interval were used to select the well screen slot size (Section 2.2.4). The monitoring wells have 20-slot screens (0.02 in.). The dual-use wells have 40-slot screens (0.04 in.) (for well 699-32-59) or 50-slot screens (0.05 in.) (for wells 699-30-63 and 699-32-64) (Table 3-2).

Additional details about drilling and construction of the 11 new characterization wells are provided in the borehole summary reports (SGW-60463, SGW-60727, and SGW-61319). The borehole summary reports contain the well summary sheets, borehole logs, drill cutting photographs, geophysical logging reports, and survey data reports.

Table 3-1. Well Construction Summary

Well Name (ID)	Well Type/ Diameter (cm [in.])	Drilling/Construction Dates		Northing	Easting	Elevation of Brass Survey Marker (NAVD88) (m)	Total Depth (m [ft] bgs)	Depth to Water (m [ft] bgs)
		Drilling Start and Finish	Construction Finish	NAD83(91) (m)				
699-27-68 (C9632)	Monitoring 10.2 (4)	05/25/2017 06/21/2017	8/21/2017	131676.4	569324.8	196.6	106.2 (348.4)	66.1 (217) (06/01/2017)
699-29-55 (C9634)	Monitoring 10.2 (4)	06/28/2017 07/26/2017	9/25/2017	132230.2	573241.9	210.6	138.1 (453.0)	88.1 (289) (07/11/2017)
699-29-66 (C9413)	Monitoring 10.2 (4)	05/03/2016 05/25/2016	10/5/2016	132336.9	570053.5	206.0	157.5 (516.7)	76.5 (251) (05/25/2016)
699-30-57 (C9417)	Monitoring 10.2 (4)	06/02/2016 06/16/2016	8/24/2016	132770.8	572394.4	211.4	132.9 (436.0)	86.9 (285) (06/15/2016)
699-30-63 (C9602)	Dual-use (monitoring/ extraction) 20.3 (8)	11/10/2016 12/13/2016	3/15/2017	132674.9	570716.9	211.7	124.3 (407.7)	82.9 (272) (11/28/2016)
699-30-70 (C9635)	Monitoring 10.2 (4)	05/16/2017 06/22/2017	8/24/2017	132581.7	568428.9	198.2	122.5 (401.9)	67.4 (221) (05/18/2017)
699-30-73 (C9636)	Monitoring 10.2 (4)	10/11/2017 10/26/2017	12/6/2017	132789.8	567781.9	201.3	122.6 (402.3)	70.1 (230) (10/12/2017)
699-31-50 (C9737)	Monitoring 10.2 (4)	08/30/2017 09/27/2017	11/14/2017	132959.2	574751.2	216.2	142.5 (467.5)	94.5 (310) (09/11/2017)
699-31-68 (C9416)	Monitoring 10.2 (4)	03/21/2016 04/06/2016	9/19/2016	133080.6	569598.0	210.4	135.4 (444.2)	80.5 (264) (03/29/2016)

Table 3-1. Well Construction Summary

Well Name (ID)	Well Type/ Diameter (cm [in.])	Drilling/Construction Dates		Northing	Easting	Elevation of Brass Survey Marker (NAVD88) (m)	Total Depth (m [ft] bgs)	Depth to Water (m [ft] bgs)
		Drilling Start and Finish	Construction Finish	NAD83(91) (m)				
699-32-59 (C9603)	Dual-use (monitoring/ extraction) 20.3 (8)	01/16/2017 02/14/2017	3/21/2017	133400.3	571800.1	217.6	126.7 (415.7)	93.0 (305) (01/31/2017)
699-32-64 (C9601)	Dual-use (monitoring/ extraction) 20.3 (8)	10/11/2016 11/07/2016	2/16/2017	133304.0	570451.0	214.7	123.6 (405.6)	85.6 (281) (10/31/2016)

References:

NAD83, *North American Datum of 1983.*

NAVD88, *North American Vertical Datum of 1988.*

bgs = below ground surface

ID = identification

Table 3-2. Well Screen Intervals

Well Name (ID)	Total Screen Length (m [ft])	Screen Segments								
		Upper Screen Top (m [ft] bgs)	Upper Screen Bottom (m [ft] bgs)	Upper Screen Length (m [ft])	Middle Screen Top (m [ft] bgs)	Middle Screen Bottom (m [ft] bgs)	Middle Screen Length (m [ft])	Lower Screen Top (m [ft] bgs)	Lower Screen Bottom (m [ft] bgs)	Lower Screen Length (m [ft])
699-27-68 (C9632)	18.3 (60)[a]	65.3 (214.39)	74.5 (244.39)	9.1 (30)	77.5 (254.39)	86.7 (284.4)	9.1 (30)	—	—	—
699-29-55 (C9634)	18.3 (60)[a]	86.8 (284.89)	96.0 (314.89)	9.1 (30)	106.6 (349.89)	115.8 (379.92)	9.1 (30)	—	—	—
699-29-66 (C9413)	6.1 (20)[a]	98.9 (324.61)	105.0 (344.61)	6.1 (20)	—	—	—	—	—	—
699-30-57 (C9417)	10.7 (35)[a]	86.9 (285.12)	97.6 (320.13)	10.7 (35)	—	—	—	—	—	—
699-30-63 (C9602)	30.5 (100)[b]	83.1 (272.59)	92.1 (302.14)	9.1 (30)	95.1 (312.15)	104.3 (342.16)	9.1 (30)	107.3 (352.15)	119.5 (392.15)	12.2 (40)
699-30-70 (C9635)	24.4 (80)[a]	67.1 (220)	73.2 (240.01)	6.1 (20)	82.3 (270)	94.5 (310)	9.1 (30)	97.5 (320.01)	106.7 (350.03)	9.1 (30)
699-30-73 (C9636)	10.7 (35)[a]	69.8 (229.09)	80.7 (264.83)	10.7 (35)	—	—	—	—	—	—
699-31-50 (C9737)	22.9(75)[a]	94.2 (309.15)	104.9 (344.14)	10.7 (35)	107.9 (354.12)	120.1 (394.13)	12.2 (40)	—	—	—
699-31-68 (C9416)	10.7 (35)[a]	80.5 (264)	91.1 (299.01)	10.7 (35)	—	—	—	—	—	—

Table 3-2. Well Screen Intervals

Well Name (ID)	Total Screen Length (m [ft])	Screen Segments								
		Upper Screen Top (m [ft] bgs)	Upper Screen Bottom (m [ft] bgs)	Upper Screen Length (m [ft])	Middle Screen Top (m [ft] bgs)	Middle Screen Bottom (m [ft] bgs)	Middle Screen Length (m [ft])	Lower Screen Top (m [ft] bgs)	Lower Screen Bottom (m [ft] bgs)	Lower Screen Length (m [ft])
699-32-59 (C9603)	27.4 (90)[c]	92.6 (303.83)	103.3 (338.85)	10.7 (35)	106.3 (348.86)	123.1 (403.87)	16.8 (55)	—	—	—
699-32-64 (C9601)	30.5 (100)[b]	86.1 (282.43)	96.8 (317.43)	10.7 (35)	99.8 (327.42)	119.6 (392.44)	19.8 (65)	—	—	—

Note: Cells containing "—" indicate that well does not have additional screen segment.

a. 20-slot vee-wire wrapped screen.

b. 50-slot vee-wire wrapped screen.

c. 40-slot vee-wire wrapped screen.

bgs = below ground surface

ID = identification

3.1.2 Groundwater Samples

Four types of groundwater samples were collected as part of the southeast chromium plume remedial design investigation. Depth-discrete samples were collected during drilling for vertical profiling of chromium concentrations (Section 2.2.3.1). Groundwater samples were collected from the new characterization wells following well development (Section 2.2.3.2). Routine quarterly groundwater samples were collected after well development to establish chromium concentration baselines and to evaluate whether depth-discrete concentrations had been impacted by drilling (Section 2.2.3.3). Groundwater samples were collected from existing monitoring wells near the southeast chromium plume to supplement the data from the new wells (Section 2.2.3.4). Appendix A discusses chromium concentrations in the groundwater samples.

3.1.2.1 Vertical Profile Sampling

Depth-discrete groundwater chromium concentrations for the 11 new characterization wells are listed in Table A-1 and are shown in Figures 3-1 and 3-2 as concentrations at increasing drilling depths. All of the groundwater sampling results are shown in Figures 3-3 and 3-4 as concentrations over time.

The depth-discrete data were evaluated by project scientists using chromium and manganese concentrations, as well as field parameters (conductivity, DO, pH, and temperature) to determine if concentrations were affected by reducing conditions during drilling. The drilling process can create temporary reducing conditions in the aquifer that can cause hexavalent chromium (soluble) to reduce to trivalent chromium (insoluble), which would under-represent dissolved chromium plume concentrations (Section 2.2.3). Selected depth-discrete samples from wells 699-27-68 and 699-30-70 were determined to have been affected by reducing conditions based on anomalously low hexavalent and total chromium concentrations, relatively high manganese concentrations, and low dissolved oxygen. The chromium results affected by reducing conditions are interpreted as suspect (Figure 3-2). Reducing conditions were interpreted for depth-discrete results from wells 699-29-55 and 699-29-66 based on the higher dissolved chromium concentration in the post-development samples compared to the lower chromium concentrations in the depth-discrete samples (Figures 3-3 and 3-4) and the relatively high manganese concentrations during drilling. Routine quarterly samples were collected for one year to allow the wells to recover from drilling to obtain representative sample results (Section 3.1.2.3). No other wells were determined to have been substantially affected by reducing conditions.

The suspect hexavalent chromium result shown for well 699-32-59 in Figures 3-1 and 3-3 is interpreted to be low because of excessive sample turbidity. The suspect total chromium result shown for well 699-30-63 in Figure 3-3 is based on the likelihood that the sample was inadvertently switched with another sample in the field. The suspect total chromium result shown for well 699-32-64 in Figure 3-3 is anomalously high.

3.1.2.2 Sampling After Well Development

A post-development groundwater sample was collected from each well after well development was completed. The well development sample chromium results are shown in Figures 3-3 and 3-4 as the isolated sample event following the depth-discrete sampling during drilling. The well development sample results are not included in the time series for the depth-discrete samples (Section 3.1.2.1) or the routine quarterly samples (Section 3.1.2.3) in Figures 3-3 and 3-4. Table A-2 provides the post-development groundwater results.

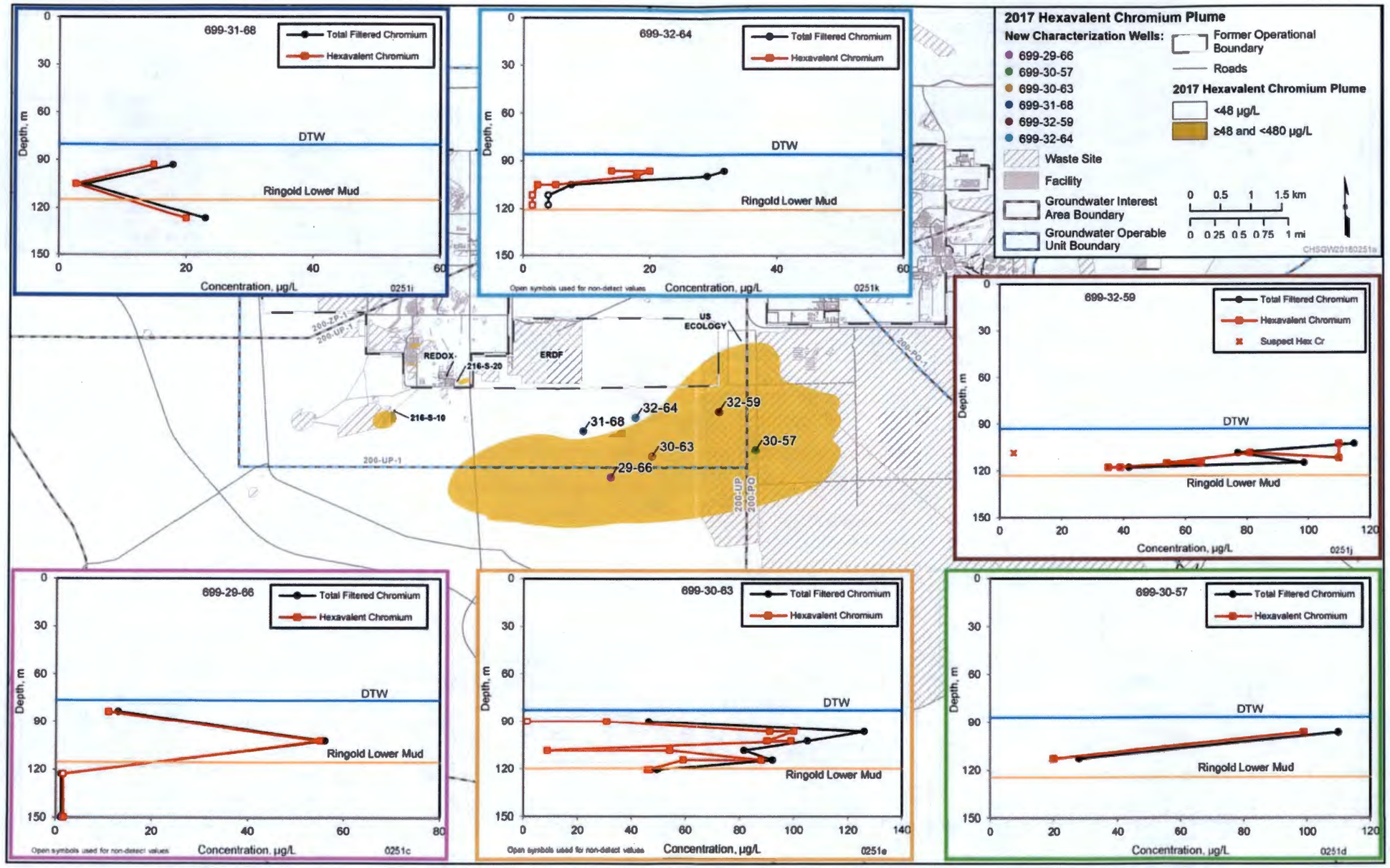


Figure 3-1. Depth-Discrete Chromium Concentrations in Groundwater Samples from the First 6 of the 11 New Characterization Wells

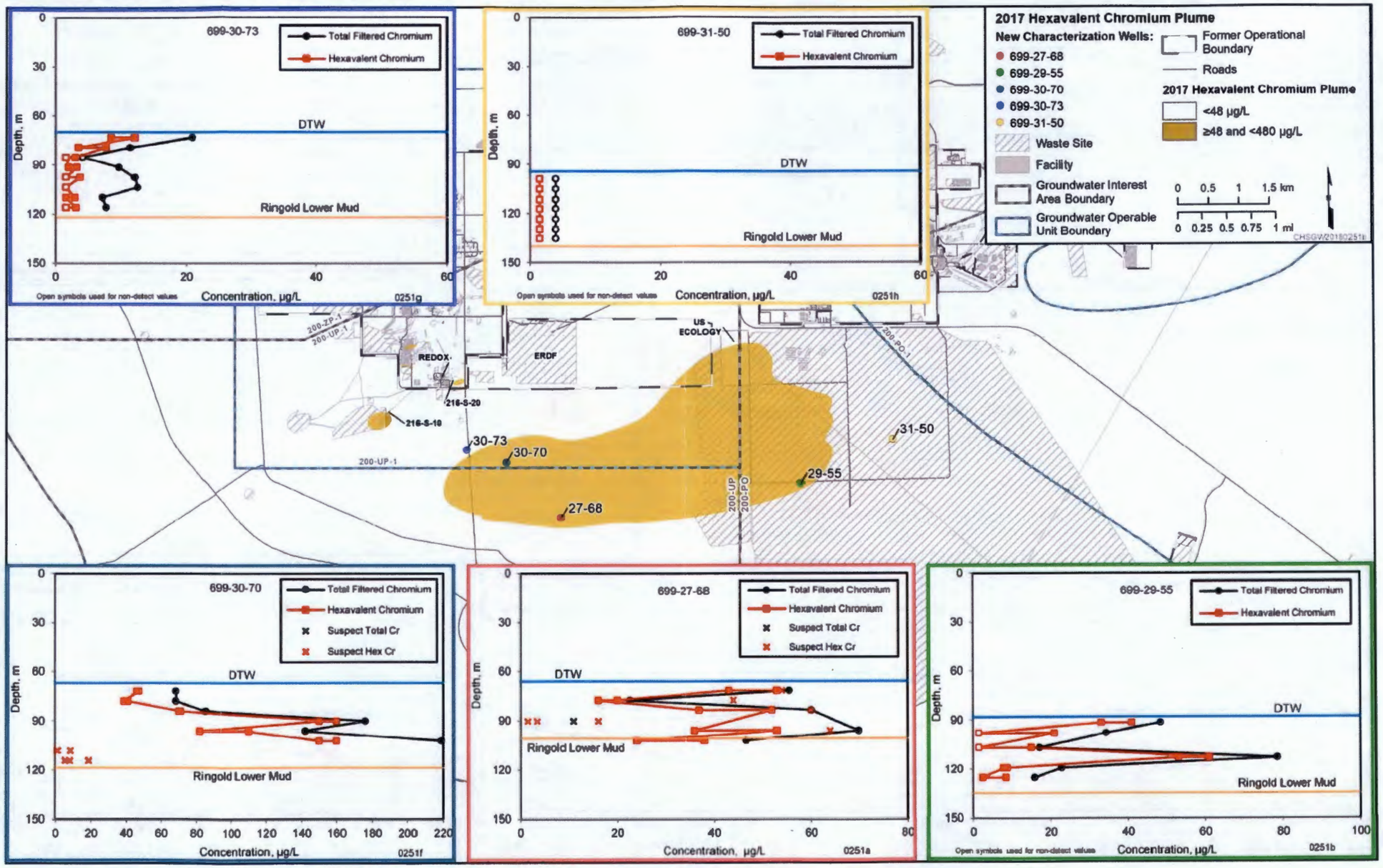


Figure 3-2. Depth-Discrete Chromium Concentrations in Groundwater Samples from the Last 5 of the 11 New Characterization Wells

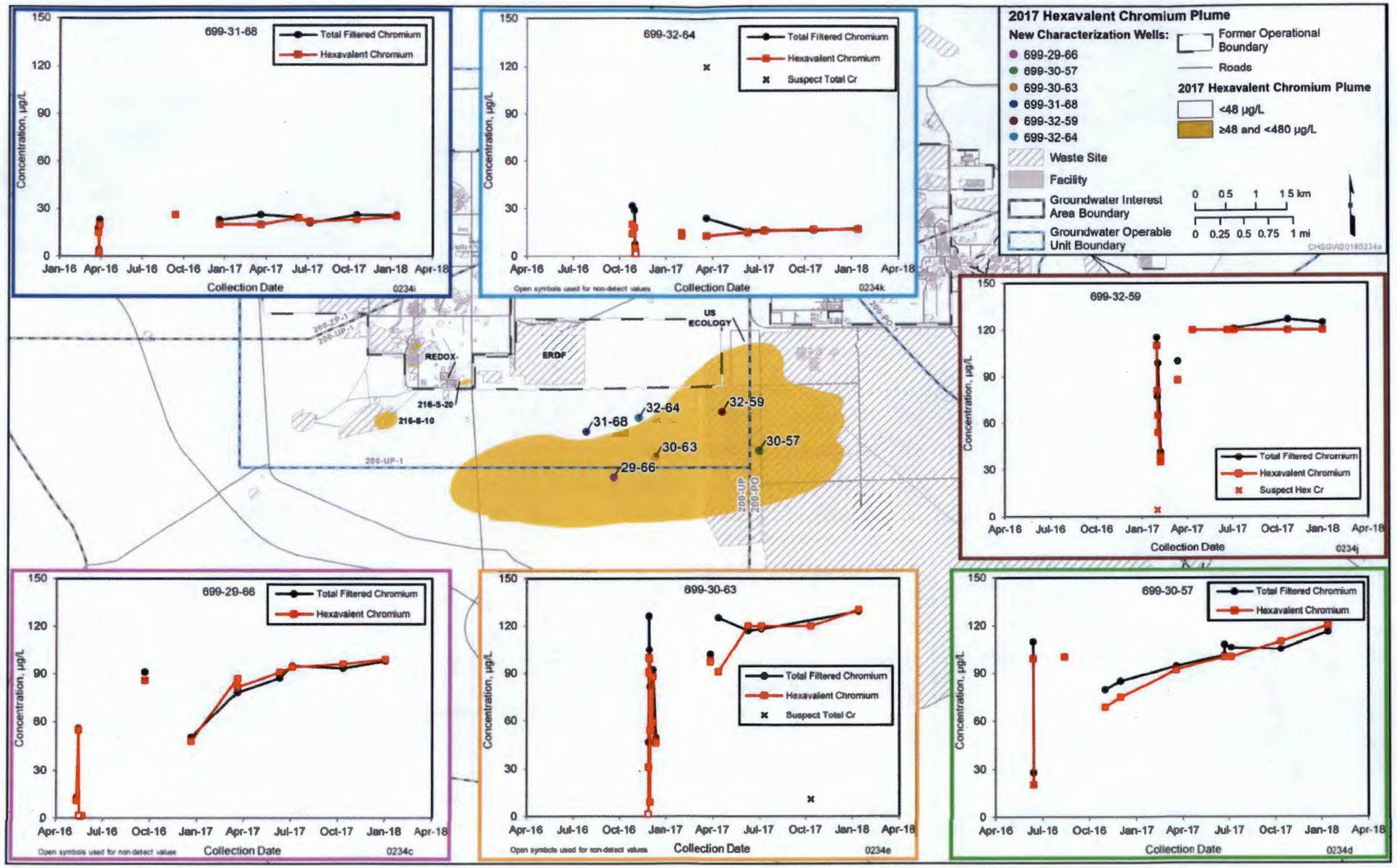


Figure 3-3. Chromium Concentrations in Groundwater Samples from the First 6 of the 11 New Characterization Wells

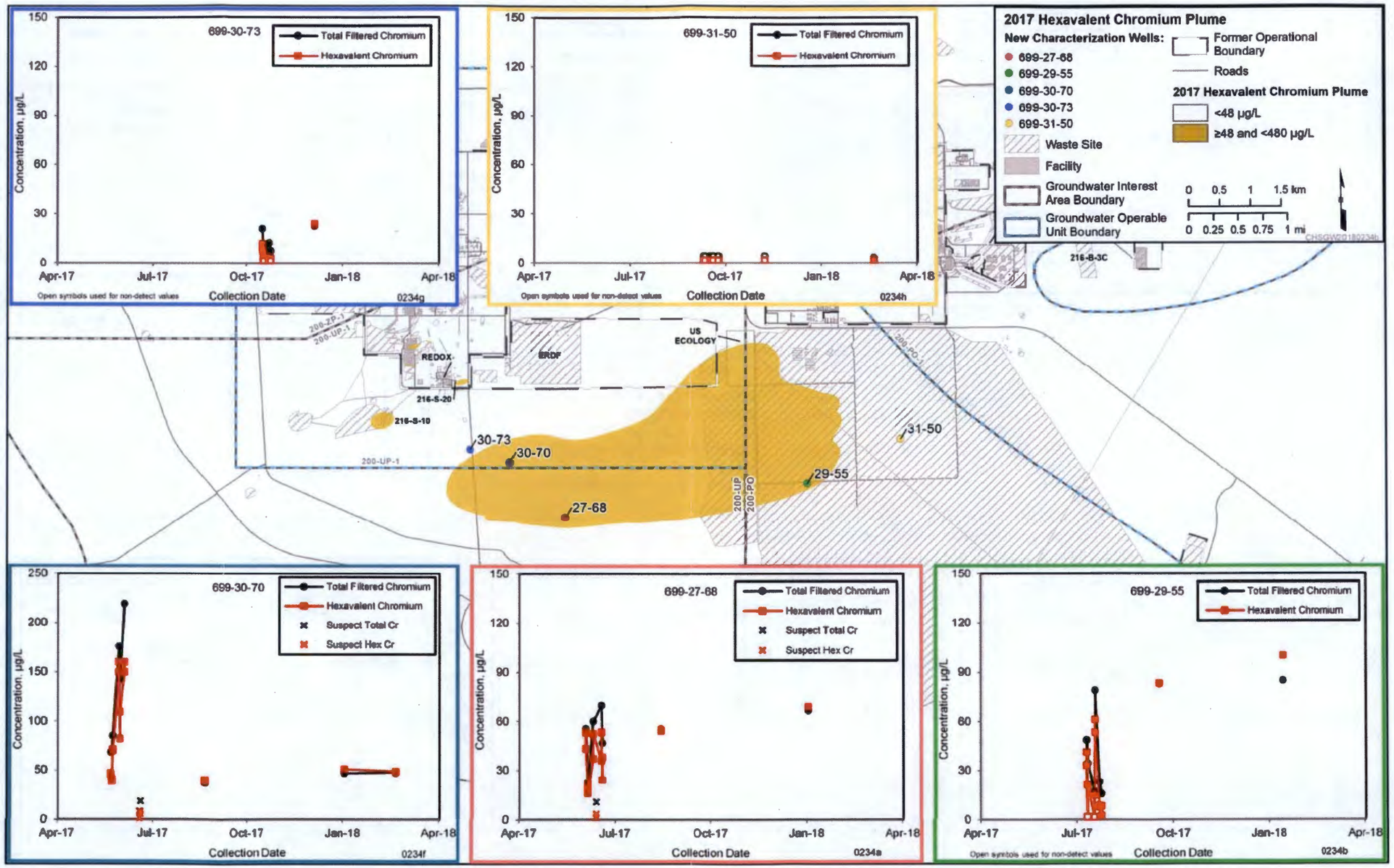


Figure 3-4. Chromium Concentrations in Groundwater Samples from the Last 5 of the 11 New Characterization Wells

Table 2-2 lists the pump intake depths for collecting post-development groundwater samples. Due to large purge volumes during well development, the post-development samples likely represent the flow-weighted average concentration along the entire well screen and not any specific depth. As a result, the chromium concentrations in the post-development samples tend to be similar to the concentrations in the routine quarterly samples (Figures 3-3 and 3-4).

3.1.2.3 Routine Groundwater Data from New Wells

Routine quarterly groundwater sample results for chromium in the 11 southeast chromium wells are listed in Table A-3 and are shown in Figures 3-3 and 3-4. Chromium results for the routine samples are shown in Figures 3-3 and 3-4 as the most recent time series for samples collected as of March 31, 2018. As of March 31, 2018, routine samples had not been collected from well 699-30-73; and one routine sample had been collected from wells 699-27-68, 699-29-55, and 699-31-50. None of the wells with multiple screened intervals have had packers installed in the blank casing sections between screen segments (Section 3.1.1).

Routine quarterly groundwater samples were collected from the first six characterization wells for one year to allow time for the aquifer to recover from any reducing conditions caused by drilling (Section 2.2.3). Chromium concentrations in well 699-29-66 have shown some rebound since routine sampling began in December 2016. Chromium concentrations appear to be stabilizing at ~100 µg/L. Chromium concentrations in well 699-30-57 have also shown rebound since routine sampling began in November 2016, but concentrations do not appear to have stabilized. Chromium concentrations in wells 699-31-68, 699-32-64, 699-32-59, and 699-30-63 appear to be relatively stable. Routine quarterly samples are being collected from the last five characterization wells, but insufficient data are available as of March 31, 2018, to evaluate trends.

3.1.2.4 Groundwater Data from Existing Wells

Routine groundwater samples were collected from 28 wells near the southeast chromium plume in 2017. Table A-4 lists the sample results, and Figure 2-2 shows the sampling locations. These results supported refinement of the southeast chromium plume lateral extent above the 48 µg/L cleanup level. For comparison to ARARs, the plume area exceeding the lowest ARAR (i.e., the 48 µg/L Washington State cleanup level) was developed.

3.1.3 Soil Samples

One soil sample from well 699-30-63 was characterized by PNNL for contaminant attenuation and transport parameters (e.g., changes in sorption, mobility, or degradation resulting from physical or chemical interaction of chromium with aquifer sediments, diffusion, and dissolution). The sample was from the deeper part of the unconfined aquifer (114.1 m [374.3 ft] below ground surface [bgs], 5.8 m [19 ft] above the Rlm) and was composed of 99.6% sand. The sample was selected for analysis based on the relatively high groundwater hexavalent chromium concentration (88 µg/L) at this depth and the finer grained texture of the sample. PNNL-26894, *Contaminant Attenuation and Transport Characterization of 200-UP-1 Operable Unit Sediment Samples*, provides the analysis results.

Hexavalent chromium was present in aqueous effluent during leaching of the core sediment with groundwater. The initial release was rapid but decreased with time, suggesting that the slow release of hexavalent chromium from the sediment is likely chemically controlled rather than diffusion controlled (Section 4.2 of PNNL-26894). No additional analyses were made to evaluate chromium transport parameters based on characterization of this one sample (Section 4.1.2.4).

3.1.4 Geophysical Logging

Geophysical logging was performed in each of the 11 characterization wells. Before each string of temporary casing was downsized and after total depth was reached, the borehole was logged using the spectral gamma logging system and neutron moisture logging system to identify natural and man-made gamma-emitting radionuclides and moisture levels. The log data reports are provided in the borehole summary reports (SGW-60463, SGW-60727, and SGW-61319). The geophysical logging results are used to evaluate the nature and depth of stratigraphic contacts. Geophysical logging was required by the descriptions of work for drilling the 11 southeast chromium plume wells (SGW-59416, SGW-60084, and SGW-60568).

3.2 Southeast Chromium Plume Conceptual Site Model Update

Geologic and hydrogeologic observations, measurements of chromium distribution in groundwater, and integration with existing information were used to update aspects of the CSM for the southeast chromium plume. These aspects include the CSM of the geohydrologic characteristics of the southeast chromium plume area, the inferred lateral and vertical distribution of chromium in groundwater, and inference of the apparent source of the southeast chromium plume. These elements of the CSM are discussed in the following sections.

3.2.1 Ringold Formation Member of Wooded Island – Lower Mud Unit

In 2011, the surface of the Rlm, which defines the base of the unconfined aquifer, was based on three wells (699-30-66, 699-32-62, and 699-33-56) in the southeast chromium plume area (Figures A-1 and A-11 in DOE/RL-2013-07). The configuration of the Rlm surface in the southeast chromium plume area has been refined using geologic data from the 11 new wells and revised interpretations of geologic contact data for existing wells (Figure 3-5).

The Central Plateau Groundwater Model (CPGWM) was used to evaluate the impact of the updated Rlm surface on the water table in the southeast chromium plume area (Section 4.1) (ECF-200UP1-17-0238, *Development of the 3D Hexavalent Chromium Groundwater Plume using Leapfrog for Southeast 200-UP-1* [provided in Appendix B of this report]). The model simulated the 2016 water table using the previous and the updated Rlm surfaces. The largest difference in hydraulic head was about 15 cm (5.9 in.). The magnitude of the hydraulic gradient changed by 5E-05 m/m, and the direction of the hydraulic gradient changed by less than two degrees. Based on this evaluation, the change to the Rlm surface interpretation is not an important factor controlling the water table and groundwater flow.

The Rlm surface slopes down to the west at the western end of the southeast chromium plume area and slopes down to the east-southeast at the southeastern end. The surface slopes down to the north on the southern side of the plume and slopes down to the south on the northern side of the plume. The Rlm surface is relatively flat under the central portion of the southeast chromium plume. From west to east, parallel to the long axis of the plume, the Rlm surface is deeper at the west end and shallower at the east end, consistent with the 2011 cross section.

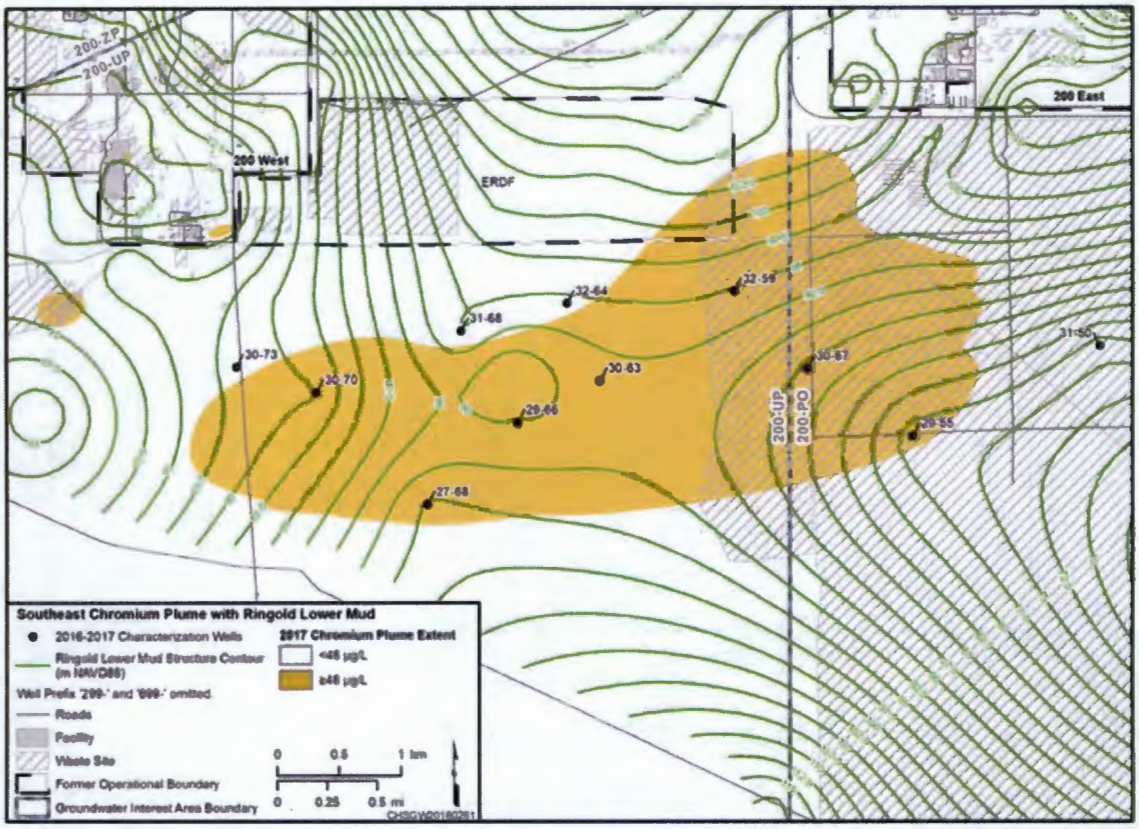


Figure 3-5. Contour Map of Rlm Surface in Area of Southeast Chromium Plume

3.2.2 Chromium Distribution

The lateral and vertical distribution of chromium in the southeast chromium plume, particularly to the west and south, was previously not sufficiently defined for remedy implementation due to a lack of monitoring wells (Figure 1-5). Historically, the highest chromium concentration was consistently observed at well 699-32-62. Filtered total chromium concentrations at well 699-32-62 have been declining since chromium was first analyzed at this well in 1992, indicating that the high-concentration portion of the plume has been migrating past this well to the east (Figure 3-6).

Characterization to better define the vertical and horizontal extent of the plume began in 2016. The 2017 plume is based on data from all 11 southeast chromium plume wells and routine groundwater monitoring data from nearby existing wells (Figure 3-7). The plume is bounded by wells with hexavalent chromium concentrations below the cleanup level (48 µg/L).

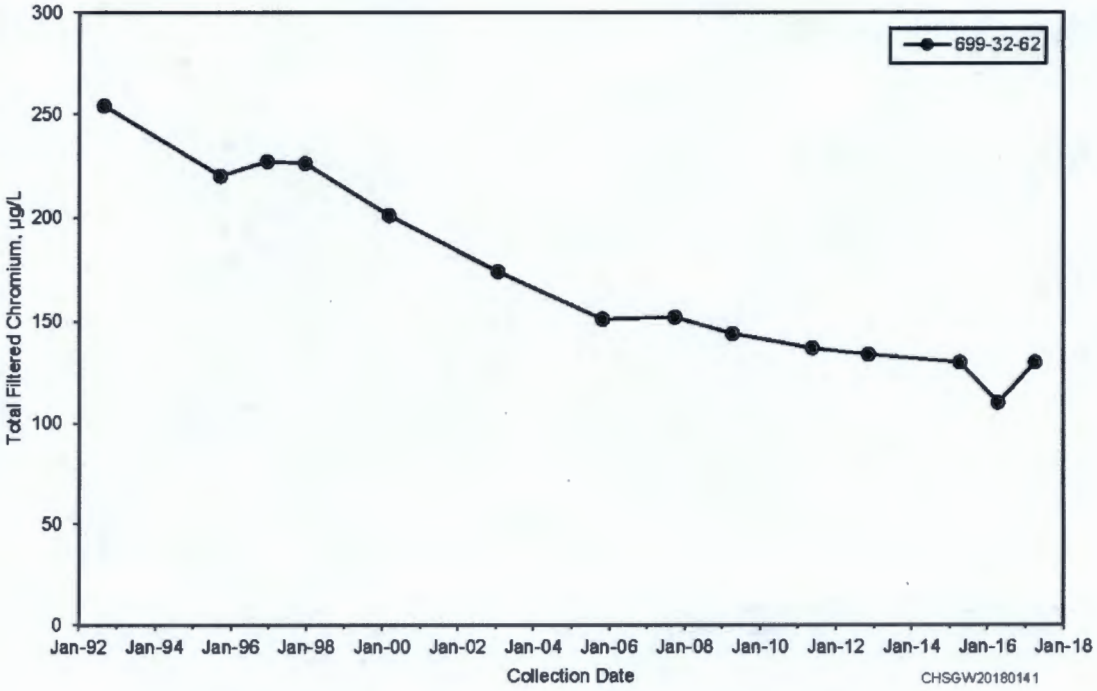
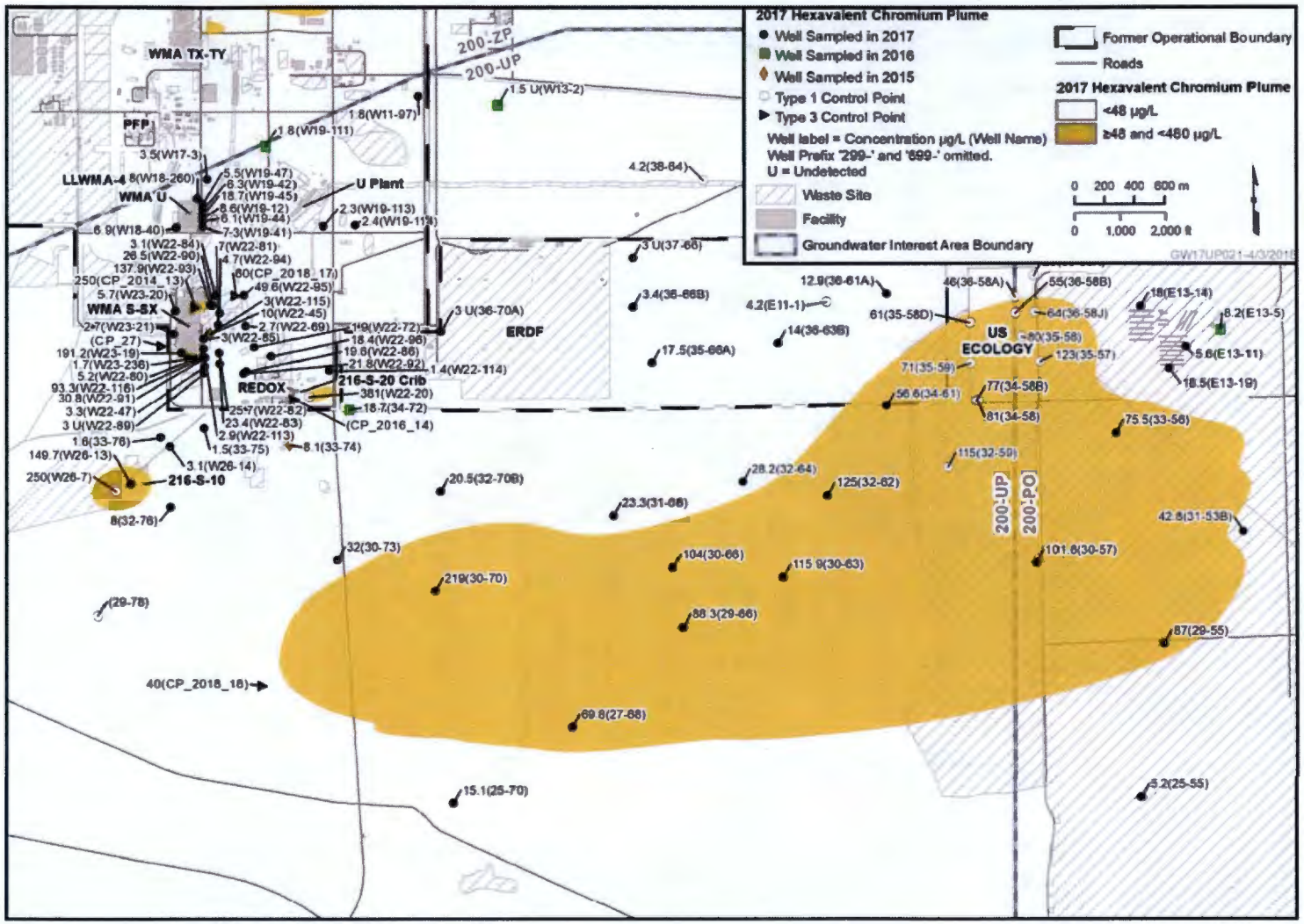


Figure 3-6. Trend of Filtered Total Chromium in Well 699-32-62

Figure 3-8 compares the lateral extent of the 2015 and 2017 chromium plume interpretations. The 2015 and 2017 plumes are based on the maximum chromium values representative of dissolved chromium (hexavalent chromium or filtered total chromium) at each well, regardless of the depth of the sample. The interpreted area of the 2017 southeast chromium plume above the 48 µg/L contour is about twice as large as the 2015 interpreted plume area and extends further to the east, west, and south. However, the maximum chromium concentrations in the two plumes are about the same. The maximum filtered total chromium concentration during drilling of the 11 new wells occurred at well 699-30-70 (219 µg/L).

The 2009 southeast chromium plume area above the 48 µg/L cleanup level shown in Figure 9 in the 200-UP-1 OU ROD is 573 ha (1,416 ac). The 2017 southeast chromium plume area above the 48 µg/L cleanup level shown in Figure 3-7 is 1,101 ha (2,720 ac). The 2017 plume is about twice the size of the 2009 plume.

Depth-discrete samples were collected during drilling to characterize the vertical distribution of dissolved chromium concentrations. The depth-discrete concentrations, supplemented by routine groundwater monitoring results from nearby wells, were used to generate a three-dimensional interpretation of the southeast chromium plume. The methodology used to develop the three-dimensional interpretation is discussed in ECF-200UP1-17-0238 (provided as Appendix B of this report). The three dimensional interpretation of the southeast chromium plume is shown in Figure 6-1 in ECF-200UP1-17-0238; five cross sections through the southeast chromium plume are presented in Figures 6-2 through 6-6 in ECF-200UP1-17-0238.



Source: Figure 11-22 in DOE/RL-2017-66, *Hanford Site Groundwater Monitoring Report for 2017*.

Figure 3-7. Southeast Chromium Plume in the 200-UP-1 OU, 2017

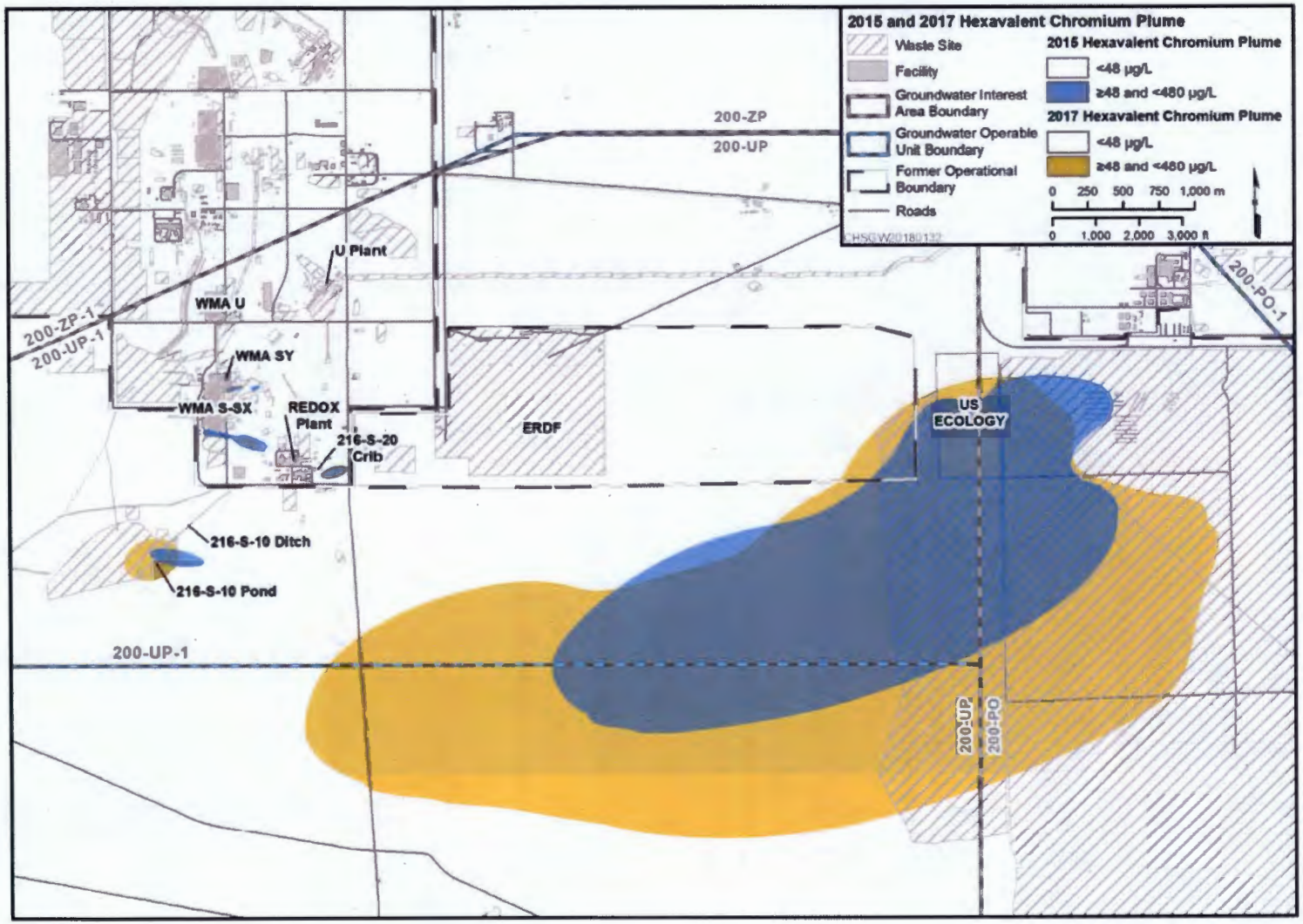


Figure 3-8. Comparison of Southeast Chromium Plume Interpreted Lateral Extent, 2015 and 2017

The three-dimensional interpretation shows that the southeast chromium plume is continuous (Chapter 6 of ECF-200UP1-17-0238 [provided as Appendix B of this report]). Relatively higher chromium concentrations (>100 μg/L) occur in the lower portion of the unconfined aquifer at the western end of the 2017 southeast chromium plume (Figures 6-2 through 6-6 in ECF-200UP1-17-0238). At the eastern end of the plume, higher chromium concentrations occur in the upper portion of the aquifer. The higher chromium concentrations are continuous from west to east across the central portion of the plume (Figure 6-5 in ECF-200UP1-17-0238). The chromium plume has a steeper concentration gradient on the north side (Figure 4-4).

3.2.3 Chromium Source

The southeast chromium plume is inferred to have originated from REDOX wastewater discharges to the 216-S-10 Ditch and adjacent ponds and cribs and the 216-S-20 Crib (Section 1.2.2). The 216-S-10 waste sites include the 216-S-10 Ditch, 216-S-10 Pond, 216-S-11 Pond, 216-S-17 Pond, 216-S-5 Crib, and 216-S-6 Crib.

Particle tracks originating from the 216-S-10 Pond and Ditch and the 216-S-20 Crib in 1951 end in 2009 near the 2008 position of the chromium plume (Figure 1-4). The same particle tracks are overlain on the 2017 extent of the southeast chromium plume in Figure 3-9. The 2017 plume extent to the south and west is consistent with the particle tracks originating at the 216-S-10 Pond and Ditch. Under the influence of the historical mounding at the 216-U-10 Pond and 216-S-10 Pond (and adjacent waste sites), the groundwater flow direction would have been to the southeast. With dissipation of the mounding, the flow direction has resumed a more eastward direction. The elevated hexavalent chromium currently observed in groundwater from well 299-W26-13 adjacent to 216-S-10 Pond and Ditch and 216-S-11 Pond is currently inferred to be migrating to the east-northeast (Figure 1-8) and not following a path to the southeast chromium plume. As a result, the current chromium contamination at the 216-S-10 Pond and Ditch source is separated from the older, larger plume to the southeast.

The 2017 plume map and cross sections show that the southeast chromium plume is not connected to the 216-S-10 Pond and Ditch source area at concentrations >48 μg/L (Figures 6-2 and 6-3 in ECF-200UP1-17-0238). Characterization well 699-30-73, which is located between the 216-S-10 source and the southeast chromium plume, was sampled throughout the aquifer (from 73.26 to 115.87 m bgs) during drilling in October 2017. The maximum filtered total chromium concentration was 20.9 μg/L.

Hexavalent chromium concentrations started increasing in 2008 at well 299-W26-13 at the 216-S-10 Pond (Figure 3-10). The 10-year-long increasing chromium trend was not observed in nearby well 699-32-76, located to the southeast between well 299-W26-13 and the southeast chromium plume or in well 299-W26-14 to the northeast (Figure 3-7). The 216-S-10 Pond and Ditch are no longer active sources that provide a relatively continuous supply of chromium to the large, southeast chromium plume, although they may be a source of chromium to the aquifer.

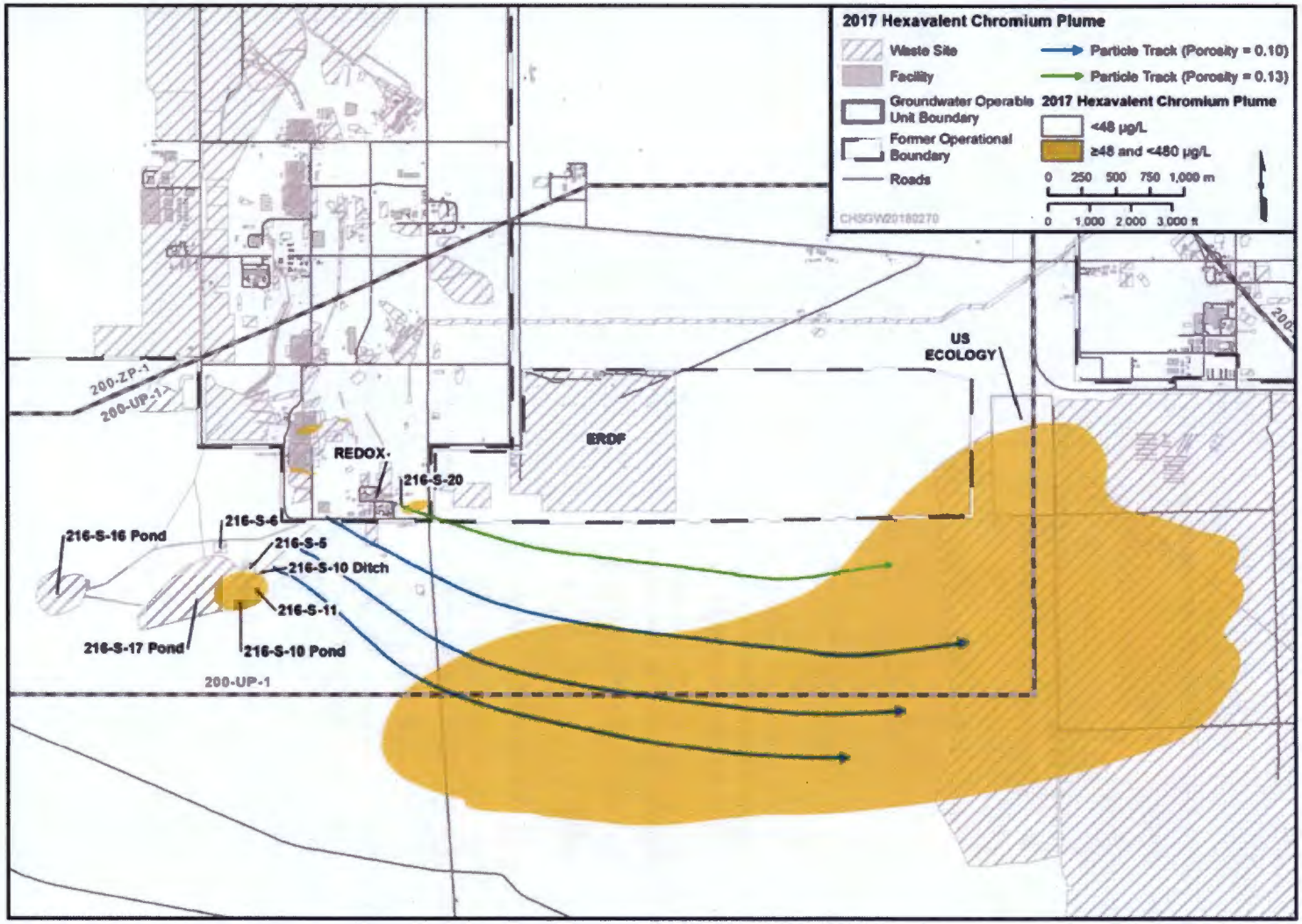


Figure 3-9. Simulated Total and Hexavalent Chromium Particle Movement Between 1951 and 2009 from the 216-S-20 Crib and the 216-S-10-Ditch Compared to the Extent of the 2017 Plume

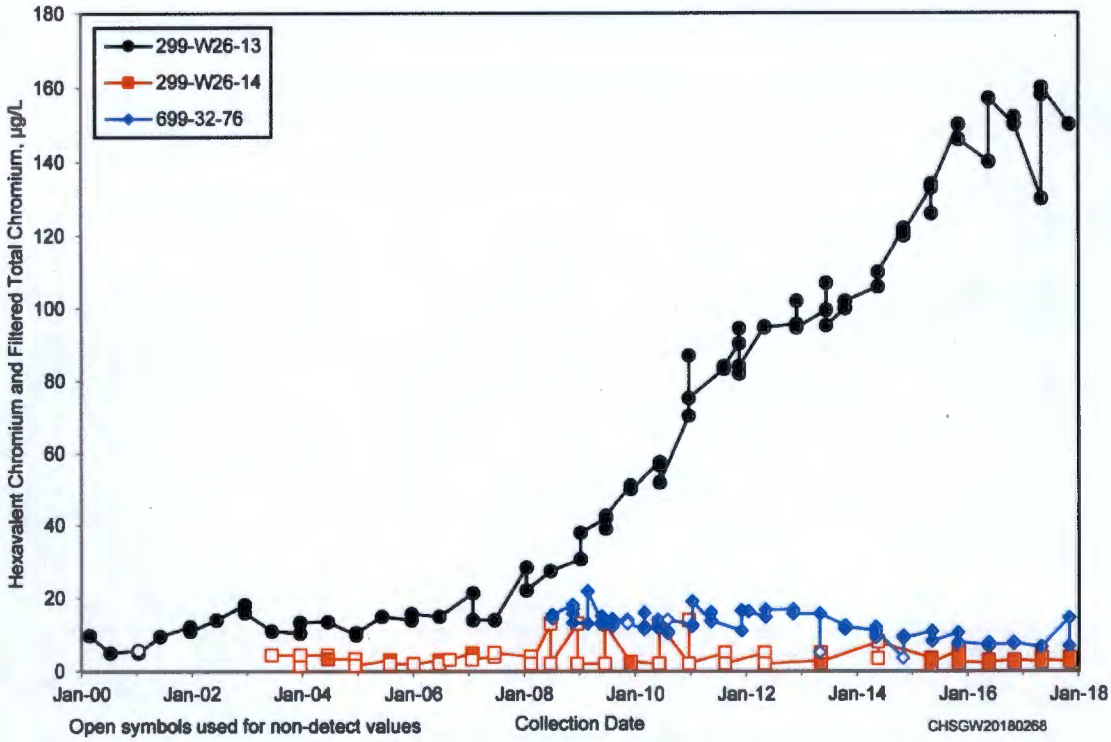


Figure 3-10. Filtered Chromium Trends at Well 299-W26-13 at the 216-S-10 Pond, Well 699-32-76 to the Southeast, and Well 299-W26-14 to the Northeast

The elevated chromium formerly detected in well 299-W22-20 at the 216-S-20 Crib (Figure 3-11) does not appear to lead to an elevated chromium plume downgradient of the 216-S-20 waste site (Figure 3-7). The 216-S-20 Crib received laboratory waste from the 222S Laboratory and the 300 Area, and those discharges did affect groundwater. One component of laboratory waste is 1,4-dioxane, which is used in liquid scintillation analyses for beta emitters. The constituent 1,4-dioxane has been detected in groundwater from well 299-W22-20 in 2002, 2003, 2006, and 2009. It also has been detected in low concentrations in well 699-34-72 (east of well 299-W22-20; Figure 3-7) in 2010, 2012, 2013, and 2014. Assuming that the 216-S-20 Crib is the source, the detection of 1,4-dioxane in well 699-34-72 indicates that the groundwater flow direction from 216-S-20 is to the east. Chromium is detected at low concentrations in well 699-34-72 and well 699-32-70B (southeast of the 216-S-20 Crib) (Figure 3-7). (Note: Well 299-W22-20 is no longer sampled because the well is dry. The last four filtered chromium results for this well shown in Figure 3-11 are considered suspect and not representative of groundwater because trends of reduction-oxidation-sensitive analytes indicated reducing conditions in the wellbore as the well was going dry.)

3.3 Tritium in Groundwater

The groundwater samples from the 11 new southeast chromium plume wells were analyzed for tritium. Tritium concentrations in routine groundwater samples exceed the MCL of 20,000 pCi/L in only well 699-31-68, just north of the southeast chromium plume (well location shown in Figure 3-7). Between December 2016 and April 2018, tritium concentrations have ranged from 18,600 to 22,000 pCi/L. Well 699-31-68 is the southernmost extent of the 2017 tritium plume in the 200-UP-1 OU (Figure 11-13 in DOE/RL-2017-66, *Hanford Site Groundwater Monitoring Report for 2017*). The southeast chromium plume is not commingled with the 200-UP-1 OU tritium plume to the northwest.

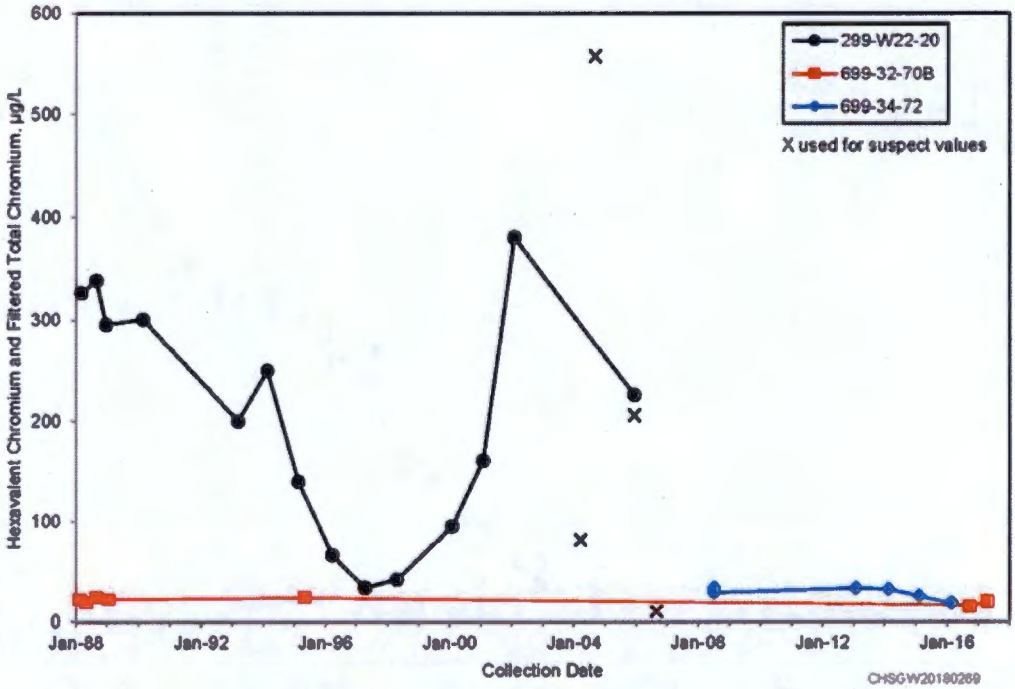


Figure 3-11. Filtered Chromium Trends at Well 299-W22-20 at the 216-S-20 Crib, Well 699-34-72 East of the 216-S-20 Crib, and Well 699-32-70B Southeast of the 216-S-20 Crib

3.4 Quality Assurance/Quality Control

The SAP specified field and laboratory quality control requirements (Section 2.2.3 of DOE/RL-2014-27). No field quality control (QC) samples were required to support the southeast chromium plume remedial design investigation. Table 2-4 in the SAP lists the laboratory QC sample requirements. The results of routine groundwater monitoring are reported annually in Hanford Sitewide groundwater monitoring reports (e.g., DOE/RL-2017-66). The quality assurance (QA)/QC data are evaluated annually in an appendix to the annual reports (e.g., Appendix E in DOE/RL-2017-66).

The primary data generated through the SAP (DOE/RL-2014-27) were only intended to support well design and plume characterization and were not intended to be used for regulatory purposes. Independent third-party validation or data quality assessment activities are not required or planned (Section 2.4.1 of DOE/RL-2014-27).

4 Remedy Evaluation

The remedy selected for the southeast chromium plume in the 200-UP-1 OU ROD (EPA et al., 2012) is groundwater extraction and treatment in combination with MNA. The selected remedy for the southeast chromium plume was expected to achieve cleanup levels for total chromium and hexavalent chromium with 25 years of P&T and 125 years of MNA. ICs will prevent exposure and groundwater use until cleanup levels are achieved.

This chapter provides a summary of the F&T modeling used to develop remedial options for the southeast chromium plume, describes three P&T remedial options, identifies criteria that were used for the comparative analysis of the options, and summarizes the evaluation results. A no action scenario simulation is provided for informational purposes only.

4.1 Hydraulic Capture and Fate and Transport Modeling Methodology

Evaluation of remedial options for the southeast chromium plume used model simulations of groundwater flow and contaminant F&T. The simulations were performed using the CPGWM (CP-47631, Rev. 4, *Model Package Report: Central Plateau Model, Version 8.4.5*). This model was originally developed in 2008 to support design of the 200 West P&T for remediation of carbon tetrachloride in the 200-ZP-1 OU. The model was later modified to support decision making for all Central Plateau groundwater OUs (200-ZP-1, 200-UP-1, 200-BP-5, and 200-PO-1 OUs). The most recent update and calibration of the model was performed in 2017 (CP-47631).

The CPGWM is a transient, three-dimensional, seven-layer model simulating groundwater conditions on the Central Plateau for the period from 1944 through September 2016. The model consists of two parts: (1) a hydraulic model to simulate groundwater flow, and (2) a transport model for contaminant migration and fate. The hydraulic model is implemented using MODFLOW, a finite difference groundwater flow model code developed by the U.S. Geological Survey (Harbaugh et al., 2000, *MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-Water Flow Process*). The transport model is implemented using MT3DMS, a three-dimensional transport model code simulating advection, dispersion, and chemical reactions (Zheng and Wang, 1999, *MT3DMS: A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide*).

P&T systems were simulated as part of the evaluation, and hydraulic capture for these systems was determined by particle tracking. With this method, particles representing a parcel of water were released surrounding extraction and injection wells and their movement through the aquifer was calculated for a specified period. The migration pathways denote the region of the aquifer affected by the remedy well. The particle tracking code used was MODPATH Version 6, developed by the U.S. Geological Survey (Pollock, 2012, *User Guide for MODPATH Version 6 – A Particle-Tracking Model for MODFLOW*).

In the following sections, a three-dimensional spatial model of the chromium plume used to specify the initial conditions for the transport modeling is described (Section 4.1.1), the groundwater model design is described (Section 4.1.2), and the process of applying the CPGWM to F&T simulations of the southeast chromium plume is explained (Section 4.1.3). The results of the modeling scenarios are presented in Section 4.2. Additional details can be found in calculation briefs ECF-200UP1-17-0238 (provided as Appendix B of this report) and ECF-200UP1-18-0008, *Simulations of Remedial Options for the 200-UP-1 Southeast Chromium Plume using the Central Plateau Groundwater Model* (provided as Appendix C of this report).

4.1.1 Southeast Chromium Plume Three-Dimensional Spatial Model

Data collected during the drilling investigation (Section 3.1) were used to develop a three-dimensional spatial extent of the southeast chromium plume. This extent was used to specify the initial plume concentrations for F&T modeling. The spatial extent was based on vertical profile sample results from the characterization wells and routine sample results from existing wells in the plume area. This section summarizes the development of the spatial model, and additional information is provided in ECF-200UP1-17-0238 (included as Appendix B of this report).

4.1.1.1 Geologic Framework Model

The chromium plume extends to the bottom of the aquifer, which is the Rlm; thus, the surface of the Rlm is needed to properly model the extent of the chromium plume. The Rlm surface was obtained from the updated Hanford South Geologic Framework Model (GFM) (ECF-HANFORD-13-0029, Rev. 5, *Development of the Hanford South Geologic Framework Model, Hanford Site, Washington*), which incorporated information from the 11 southeast chromium plume characterization wells. A GFM is a virtual representation of geologic units, where the top of each unit is represented using computer software as a three-dimensional surface. The Hanford South GFM represents the hydrostratigraphic units of the southern portion of the Hanford Site encompassing the Central Plateau groundwater OUs and is maintained to support groundwater modeling activities.

The Hanford South GFM is composed of six hydrostratigraphic units, which are geologic units with distinct groundwater flow properties. The six hydrostratigraphic units are as follows:

- Hanford formation
- CCU
- Rtf
- Rwie
- Rlm
- Rwia

The Hanford South GFM was updated based on revised interpretations from existing wells and data from newly drilled wells, including the southeast chromium plume characterization wells (ECF-HANFORD-13-0029, Rev. 5). The updated Rlm surface was used as the lower boundary of the chromium plume spatial model.

4.1.1.2 Development of the Chromium Plume Three-Dimensional Spatial Model

Two types of chromium sample data were used to develop the three-dimensional spatial chromium plume: (1) results of depth-discrete samples collected during drilling of the characterization wells, and (2) results of routine samples collected from existing wells in the area. The depth-discrete data were evaluated to determine if data were affected by reducing conditions during drilling (Section 3.1.2.1). Selected samples from wells 699-29-55 and 699-27-68 were determined to have been affected by reducing conditions and were not used (ECF-200UP1-17-0238 [provided as Appendix B of this report]). The depth-discrete samples from well 699-29-66 were also determined to have been affected by reducing conditions, and the concentrations were scaled higher based on the post-development sample.

The model was constrained using boundary surfaces (i.e., the water table for the upper boundary and the Rlm for the lower boundary) (as revised using information from the 11 new characterization wells). The water table grid was interpolated from the sitewide water table map for 2016 (ECF-HANFORD-16-0080, *Preparation of the March 2016 Hanford Site Water Table and*

Potentiometric Surface Maps). The Rlm surface was obtained from the Hanford South GFM (ECF-HANFORD-13-0029, Rev. 5), described in Section 4.1.2.1. Because every mathematical interpolation method has limitations, control points were used to guide interpolation of the three-dimensional plume. In particular, control points from a two-dimensional plume map constructed using maximum chromium concentrations from the characterization wells were used to constrain the plume at the 24 µg/L concentration boundary in the three-dimensional model (ECF-200UP1-17-0238 [provided as Appendix B of this report]). The plume was mapped to the 24 µg/L concentration level so dispersion of the plume at the 48 µg/L cleanup level would be more realistically simulated.

4.1.1.3 Chromium Plume Three-Dimensional Spatial Model

The chromium plume, as interpolated in the three-dimensional spatial model, is about twice as large as the interpretation prior to drilling the characterization wells (Figure 4-1). The plume is now interpreted to extend farther to the east, south, and west. In each of these directions, the plume is bounded by wells with concentrations below the cleanup level.

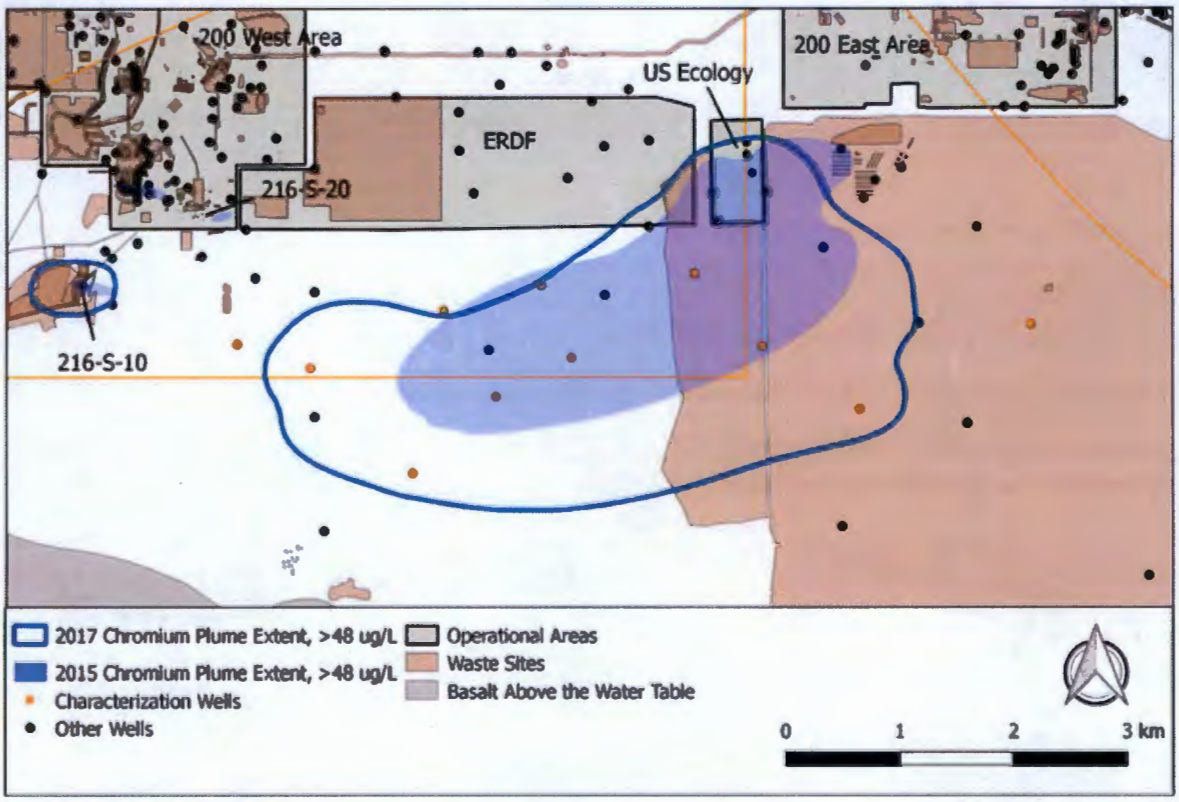


Figure 4-1. Extent of the 2017 Southeast Chromium Plume Compared to the 2015 Interpretation

Concentrations within the plume vary laterally and vertically. Figure 4-2 shows an overview of the three-dimensional plume and includes the location of the cross section shown in Figure 4-3. A continuous core of relatively higher chromium concentrations (>100 µg/L) runs through the plume west to east, as seen in Figure 4-3. This high-concentration area tends to occur deeper in the western part of the plume and shallower in the eastern part. Figure 4-4 shows a two-dimensional contour map of the plume developed from maximum concentrations in the three-dimensional model. It shows that the high-concentration core is primarily in the northern part of the plume.

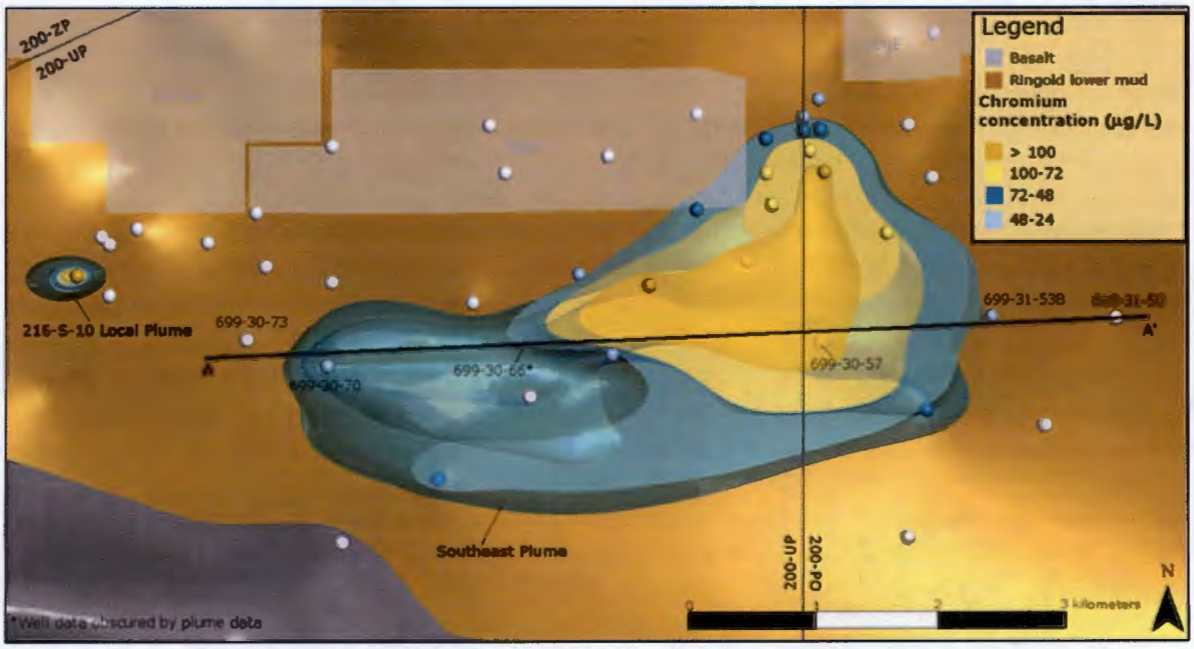


Figure 4-2. Overview of the Three-Dimensional Chromium Plume Spatial Model with Cross-Section Location

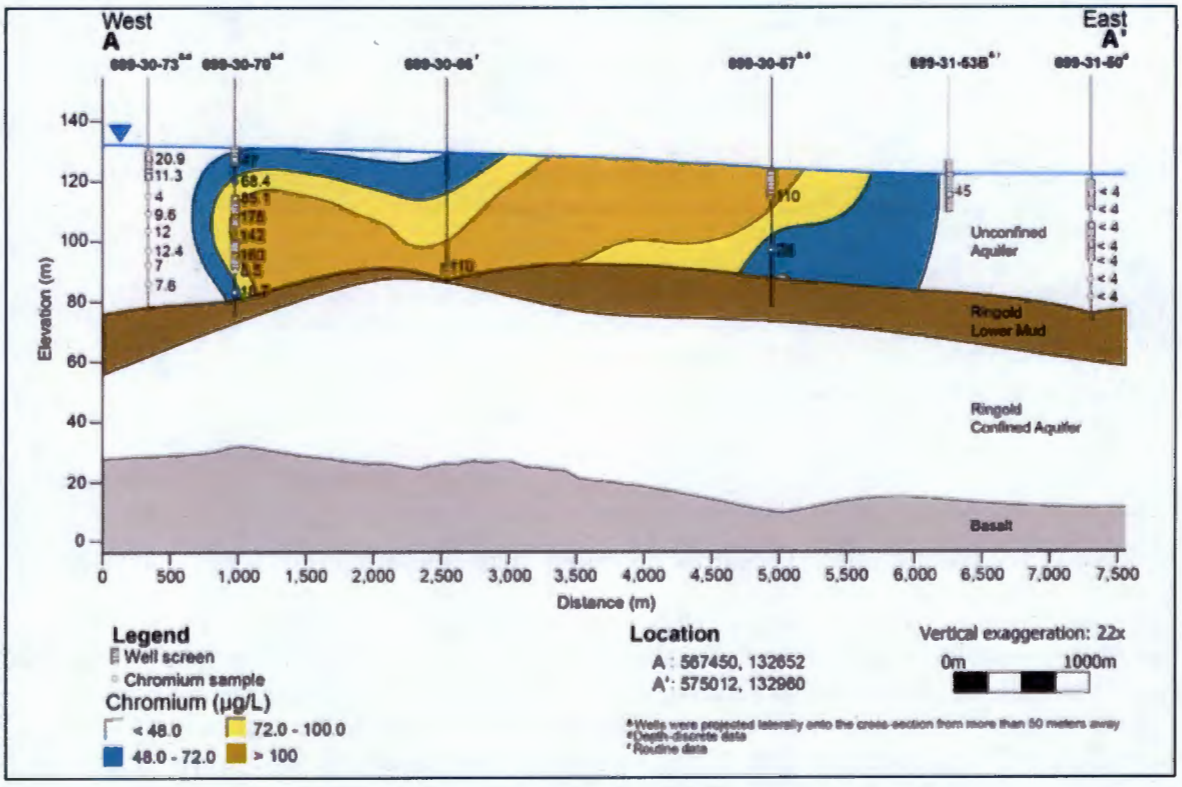


Figure 4-3. Cross Section Through the Southeast Chromium Plume

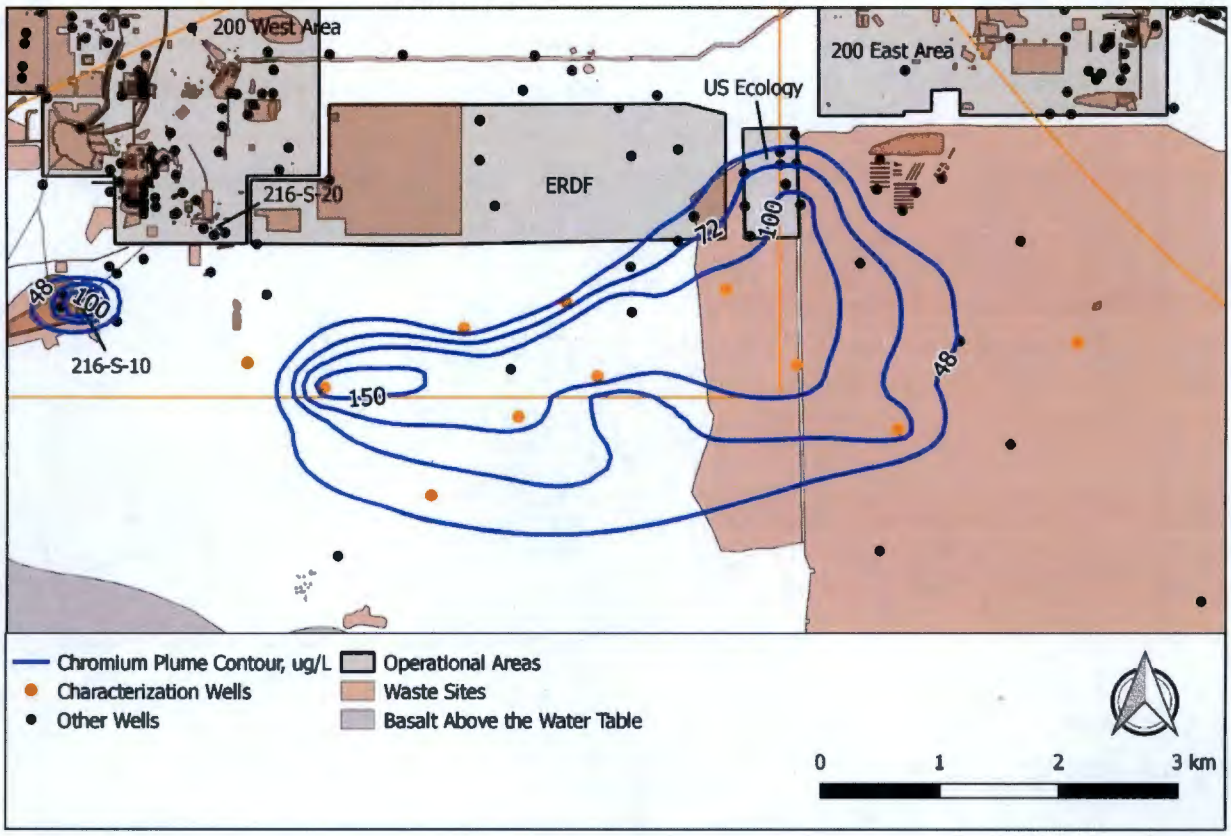


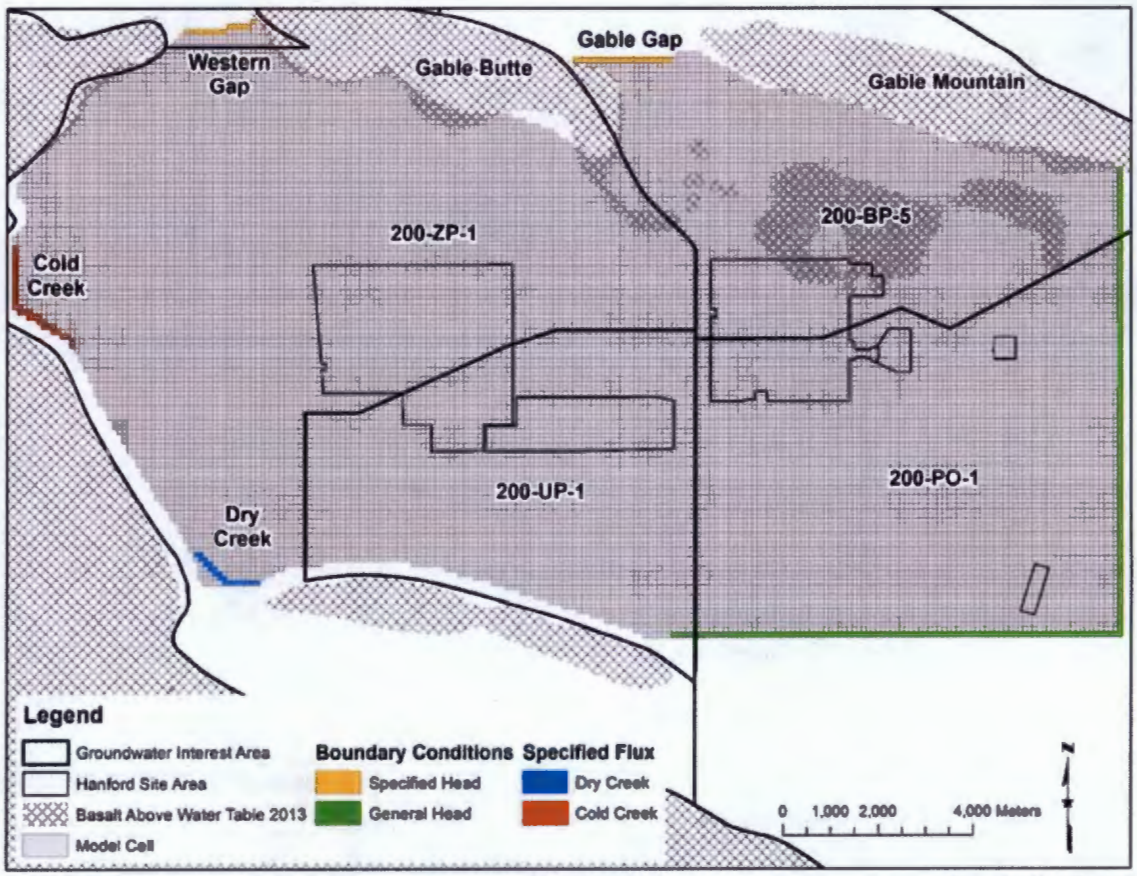
Figure 4-4. Two-Dimensional Map of Maximum Concentrations in the Southeast Chromium Plume

4.1.2 Central Plateau Groundwater Model Design

This section presents a brief overview of the design of the CPGWM, including the domain, boundary conditions, and hydraulic and transport properties. CP-47631 provides additional information.

4.1.2.1 Model Domain

The CPGWM encompasses the 200 West and 200 East Areas and covers a region 13.4 km (8.3 mi) north-south and 25.6 km (15.9 mi) east-west (Figure 4-5). The domain is discretized into grid cells with a uniform horizontal spacing of 100 m by 100 m (328.1 ft by 328.1 ft). Vertically, the model is discretized into seven layers and the geology is based on ECF-HANFORD-13-0029, Rev. 4, *Development of the Hanford South Geologic Framework Model, Hanford Site, Washington Fiscal Year 2016 Update.* The unconfined aquifer at the location of the southeast chromium plume is mostly within the Rwie. The aquifer is bounded below by the Rlm, which separates the unconfined aquifer from the confined aquifer in the Rwia. The base of the model is basalt bedrock.



Source: Figure 4-1 in CP-47631, *Model Package Report: Central Plateau Model, Version 8.4.5*, Rev. 4.

Figure 4-5. CPGWM Extent and Boundary Conditions

4.1.2.2 Boundary Conditions

Figure 4-5 shows the locations and types of boundary conditions in the CPGWM. Aquifer recharge occurs from the Cold Creek and Dry Creek Valleys, infiltration of precipitation (i.e., natural recharge), and infiltration from wastewater disposal sites (i.e., artificial recharge). The Dry Creek and Cold Creek Valleys are represented as specified flux boundaries (i.e., the rate of recharge is directly specified as input to the model). On the north side of the model domain, gaps between the basalt ridges are represented as specified head boundaries (i.e. the model calculates the amount of water to add or remove from the domain to maintain the specified hydraulic head at the boundary). The southern and eastern edges of the model are represented as general head boundaries, in which the model calculates the amount of water to add or remove from the domain based on the difference between the simulated hydraulic head at the boundary and the hydraulic head at an external reference boundary (in this case, the Columbia River). Natural and artificial recharge are applied on a cell-by-cell basis to the uppermost saturated layer as described in CP-47631.

4.1.2.3 Hydraulic Properties

Hydraulic properties of the geologic units were determined using model calibration. As an example, horizontal hydraulic conductivities in layer 2 of the model (near the southeast chromium plume) are shown in Figure 4-6. Where much of the plume is located, horizontal hydraulic conductivities range between 1.0 and 6.5 m/d (3.3 and 21.3 ft/d). The horizontal hydraulic conductivity at the eastern edge of the plume is higher, ranging from 35.5 to 53.3 m/d (116.5 to 174.9 ft/d). At the western part of the plume, the upper part of the aquifer (layer 2 of the model) is conceptualized as the CCU, which is more permeable. The horizontal hydraulic conductivity in this area is 2,000 m/d (6,561.7 ft/d).

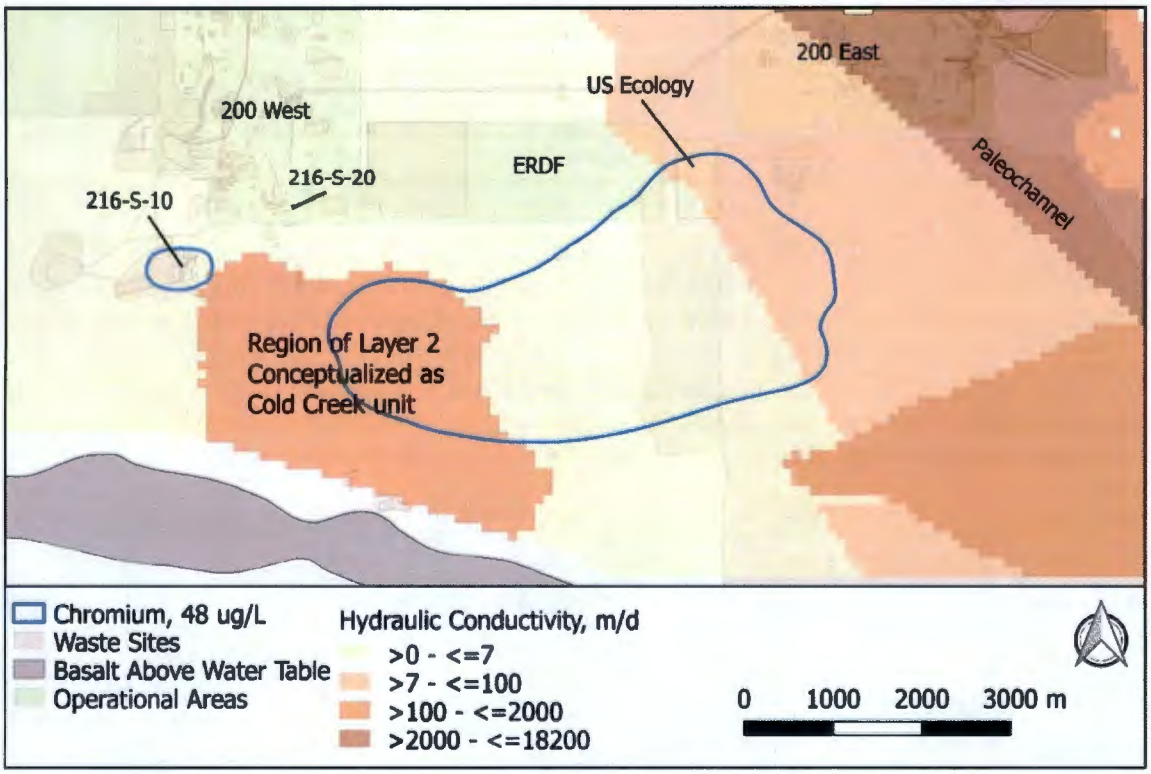


Figure 4-6. Horizontal Hydraulic Conductivity in Layer 2 of the CPGWM

Horizontal hydraulic conductivity is substantially higher approximately 2 km (1 mi) east of the plume area where a buried paleochannel occurs (Figure 4-6). The channel trends northwest to southeast and has a horizontal hydraulic conductivity of 15,400 m/d (50,524.9 ft/d), changing to 2,000 m/d (6,561.7 ft/d) to the southeast. This feature affects the fate of the chromium plume, as described in Section 4.2.1.

Vertical hydraulic conductivities in the CPGWM are mostly equal to one-tenth of the horizontal values, with some exceptions (CP-47631). Specific yield in the plume area is 0.08 for all the Rwie model layers and 0.25 where the CCU is conceptualized in layer 2.

4.1.2.4 Transport Parameters

Parameters are needed for transport modeling to describe the processes of contaminant mobility, advective migration, mixing during transport, and degradation/decay. Some contaminants sorb to aquifer sediments by various processes such as surface adsorption and/or chemical precipitation. When this occurs, contaminant mobility is reduced. Contaminant mobility is described by a distribution coefficient (K_d), which is the ratio of the sorbed concentration to the dissolved concentration assuming equilibrium

between the dissolved and sorbed phases. Chromium occurs in groundwater in the 6+ valence state (i.e., hexavalent) as polyatomic anions (either chromate or dichromate, both of which are negatively charged) and is, therefore, nonsorbing (because sediment surfaces are negatively charged). Furthermore, no substantial chemical processes were identified that would limit chromium mobility for the southeast chromium plume (Section 3.1.3). Thus, the K_d for chromium was set to zero for the transport modeling. Chromium in groundwater is not radioactive and no degradation processes have been identified, so chromium was simulated as a conservative constituent (i.e., no degradation/decay). Table 4-1 summarizes the chromium transport parameters.

Table 4-1. Chromium Transport Parameters

Constituent	Half-Life (yr)	Distribution Coefficient (mL/g)
Chromium	Not applicable	0.0

Table 4-2 shows the transport parameters for the aquifer, which are the same as those identified in CP-47631. Effective porosity is used to convert output from the hydraulic model into groundwater flow velocities for contaminant migration. Mixing processes consist of dispersion and diffusion. Dispersion occurs in three dimensions and is specified by dispersivity values, with longitudinal dispersion (along the flow direction) being the most dominant. Vertical dispersion and diffusion were assumed to be negligible and are not simulated in the transport model.

Table 4-2. Transport Parameters for the Aquifer

Property[a]	Value
Effective porosity	0.15, 0.20[b]
Longitudinal dispersivity	3.5 m
Transverse horizontal dispersivity	0.7 m
Transverse vertical dispersivity	0.0 m
Molecular diffusion	0.0 m^2/d

a. Because sorption was not simulated (i.e., distribution coefficient = 0.0 mL/g), bulk density was not used.

b. In the Central Plateau Groundwater Model, values for effective porosity are assigned by soil type based on data presented in Table D-2 (Appendix D) of DOE/RL-2007-28, *Feasibility Study Report for the 200-ZP-1 Groundwater Operable Unit*. A value of 0.15 is used for the Ringold Formation Member of Wooded Island – unit E sediments. A value of 0.20 is used for the portion of layer 2 conceptualized as Cold Creek unit and in the more permeable sediments of the Hanford formation (paleochannel).

4.1.3 Model Application

Modifications were made to the CPGWM to support F&T simulations of the southeast chromium plume. Modeling was only performed on the southeast chromium plume and not for the small localized source plumes. The elevation of the top of the Rlm near the plume was updated in the CPGWM based on the updated Hanford South GFM (ECF-HANFORD-13-0029, Rev. 5), which incorporated new geologic information obtained from drilling the characterization wells (see Section 4.1.1.1). This update was evaluated by performing simulations of groundwater flow for the entire calibration period (1944 through

September 2016) and comparing the results before and after the update (for the period of 2008 through September 2016). The Rlm elevation update had very little effect on simulated water levels and groundwater flow (ECF-200UP1-18-0008 [provided as Appendix C of this report]). The model was also evaluated by comparing simulated water levels to measured water levels at monitoring wells near the chromium plume. The agreement was good, indicating that the simulated groundwater flow field provided a good foundation for simulations of plume transport. ECF-200UP1-18-0008 provides details on the evaluations.

Predictive simulations were performed for a 300-year time period from January 1, 2018, to January 1, 2318, so the model simulation period was extended beyond September 2016. This necessitated changes to the boundary condition in Gable Gap and the natural and artificial recharge rates. The specified head in Gable Gap was extended to January 1, 2318, using an exponential function to estimate the future decline of the water table from the current elevation to an estimate of the baseline water table in that area (120.5 m [395 ft]). Natural and artificial recharge had been extended to year 2137 for a previous model study using the data and process described in CP-47631 (ECF-200W-17-0043, *Capture-Zone and Particle-Tracking Analysis for the 200-UP-1/200-Z--1 Area Using the 2017 Updated Central Plateau Model*). That extension was used for the current modeling, and the recharge rates from 2137 were assumed to be constant until January 1, 2318.

4.2 Remedial Options

To address the P&T remedy selected in the 200-UP-1 OU ROD (EPA et al., 2012), three P&T remedial options were modeled and evaluated, as well as a no action scenario simulation for information only:

- No action scenario (for information only)
- P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib; MNA for the southeast chromium plume
- P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib; MNA and P&T for the southeast chromium plume
- P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib; P&T for the southeast chromium plume

Source control refers to local P&T for containment of potential chromium sources to the aquifer using extraction wells. In these options, two source-control extraction wells were assumed operating at 189 L/min (50 gal/min) each for 25 years. However, these were not included in the F&T simulations because experience with existing extraction wells indicates that 189 L/min (50 gal/min) would be sufficient to contain the potential sources. Thus, the continuing sources themselves (presumed to be the 216-S-10 Pond/Ditch and 216-S-20 Crib) are not included in the F&T simulations for these options. The potential effect of the 216-S-10 Pond/Ditch chromium source on future aquifer conditions was evaluated as a sensitivity case (Section 6.6.3 in ECF-200UP1-18-0008 [provided as Appendix C of this report]). A source term was not developed for the 216-S-20 Crib because of the lack of recent groundwater sample results at this crib (Section 6.6.3 in ECF-200UP1-18-0008).

Predictive F&T simulations were performed to support the following remedial options:

1. **No action:** F&T of the southeast chromium plume was simulated with no active remedy until concentrations declined to below the cleanup level by natural processes. This scenario provides a baseline for comparison to the active remedy options.

2. **Option 1 – Source Control:** F&T of the southeast chromium plume is identical to that identified in the no action scenario. Source control wells were included in this option for evaluation purposes; however, no additional F&T simulations were performed.

3. **Option 2 – P&T with MNA:** A P&T system was designed to operate for 25 years in combination with MNA for the southeast chromium plume. Although not included in the F&T simulation, source control wells were included in this option for evaluation purposes.

4. **Option 3 – P&T without MNA:** A P&T system was designed to operate for 25 years and achieve cleanup levels within 25 years (i.e., no MNA component). Although not included in the F&T simulation, source control wells were included in this option.

For the southeast chromium plume, Option 2 is consistent with the remedy selected in the 200-UP-1 OU ROD (EPA et al., 2012) using P&T and MNA. However, it is larger in scope due to the results of the post-remedial investigation characterization activities. Option 3 provides a bounding case to address the cleanup of the entire plume.

Sections 4.2.1 through 4.2.4 describe the results of these simulations. Section 4.3.2 describes and evaluates the treatment methods.

4.2.1 No Action

In this scenario, no active remedy was applied, and the southeast chromium plume was allowed to attenuate solely by natural processes. This option provided a baseline for comparison to the active remedy scenarios. There are several biological, physical, and chemical processes that can reduce contaminant concentrations in an aquifer, such as microbial degradation, volatilization, dispersion, sorption, hydrolysis, reduction-oxidation reactions, and radiological decay. The only substantial process identified for the chromium plume is dispersion, so no other processes were considered in the no action simulation.

Results of the no action modeling scenario are shown as plume maps in Figures 4-7 through 4-10 for year 0 (January 1, 2018), year 120 (January 1, 2138), year 200 (January 1, 2218), and year 275 (January 1, 2293) of the simulation, respectively (for maps at 25-year intervals through year 300, see ECF-200UP1-18-0008 [provided as Appendix C of this report]). The maps represent maximum concentrations integrated vertically (i.e., the concentration for each model cell used to prepare the maps is the maximum extracted from all the model layers). Thus, the maps show the full lateral extent and maximum concentrations of the simulated plume.

Figure 4-7 shows the chromium plume for year 0 (January 1, 2018), the start of the simulation (i.e., the initial conditions). In subsequent years, the plume migrates toward the east-northeast with groundwater flow and disperses during transport. At the cleanup level concentration (48 μg/L), the plume reaches the paleochannel between year 50 (January 1, 2068) and year 75 (January 1, 2093) and disperses quickly. Figure 4-8 shows the simulated plume for year 120 (January 1, 2138), the end of the Central Plateau cleanup timeframe, and dispersion at the paleochannel is evident by the sharp eastern plume boundary and tailing of the 24 μg/L contour to the southeast along the channel. This occurs because of the much higher hydraulic conductivity in the channel compared to outside the channel where the plume is located. In the model simulation for year 75 (January 1, 2093), discharge in the paleochannel is 5.5 times higher than discharge entering the channel where the plume is located. This higher flow in the paleochannel "shears off" the eastern end of the plume and it quickly disperses to below the cleanup level. At no time during the simulation were concentrations in the paleochannel greater than the cleanup level.

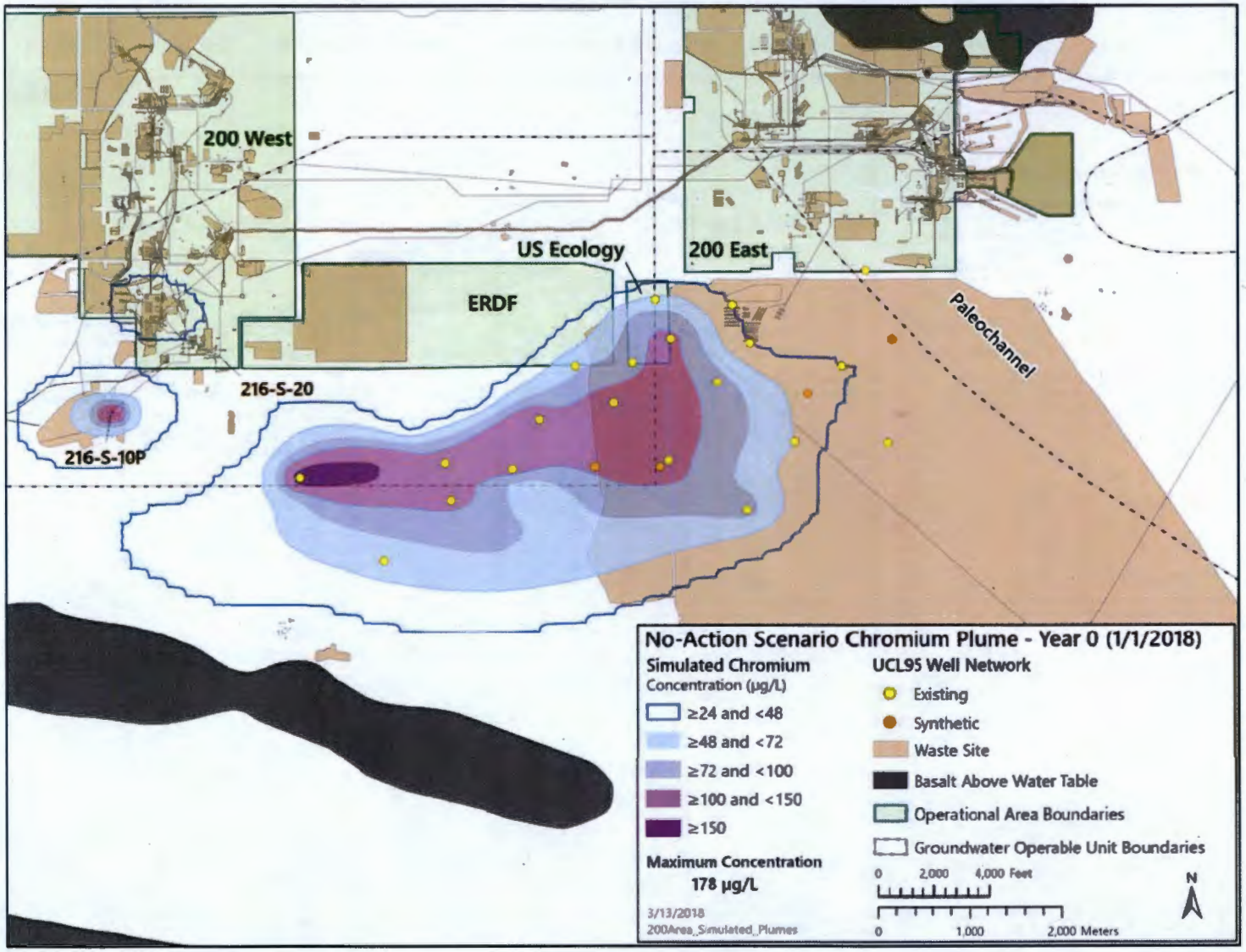


Figure 4-7. Chromium Concentrations for the No Action Scenario, Year 0 (January 1, 2018)

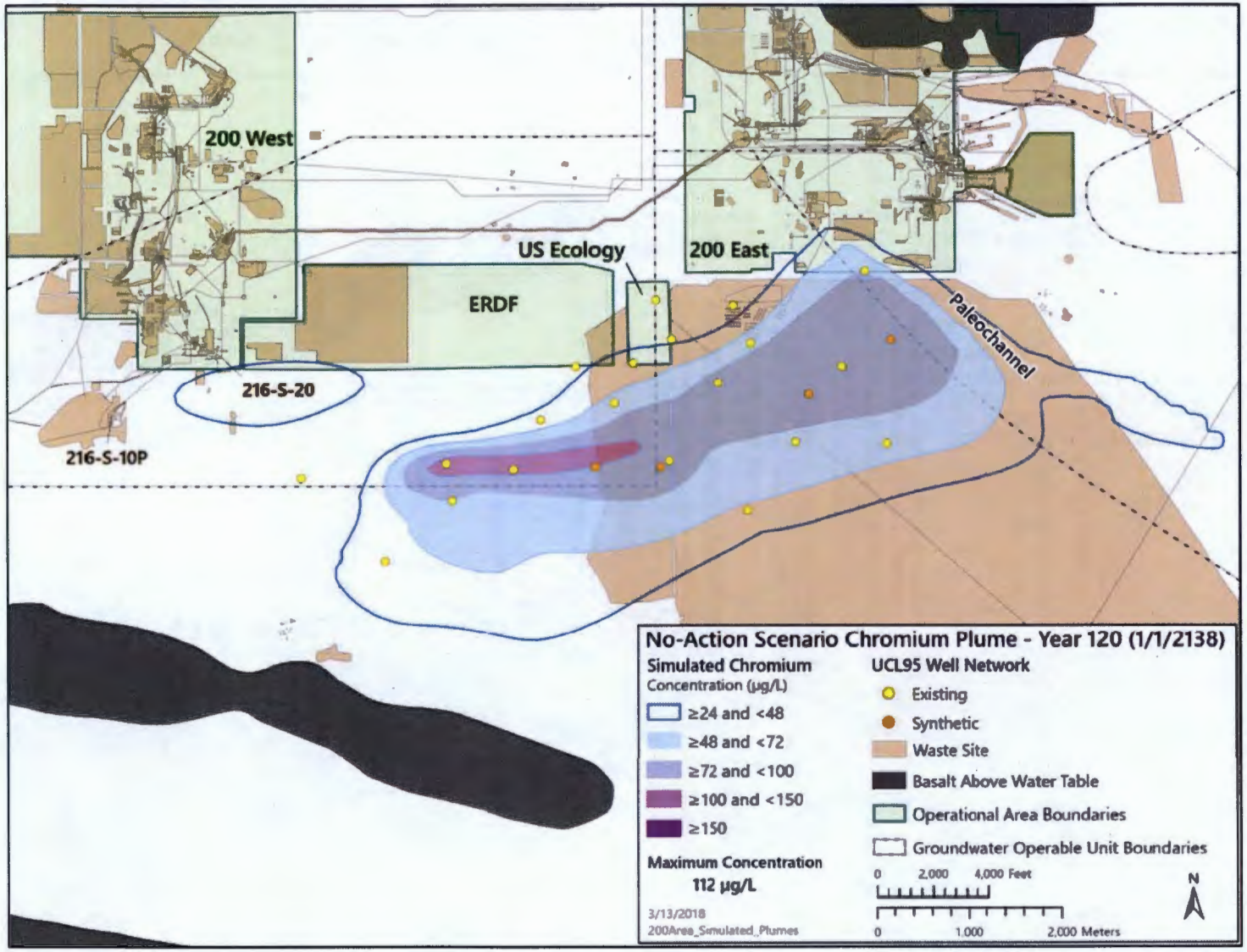


Figure 4-8. Simulated Chromium Concentrations for the No Action Scenario, Year 120 (January 1, 2138)

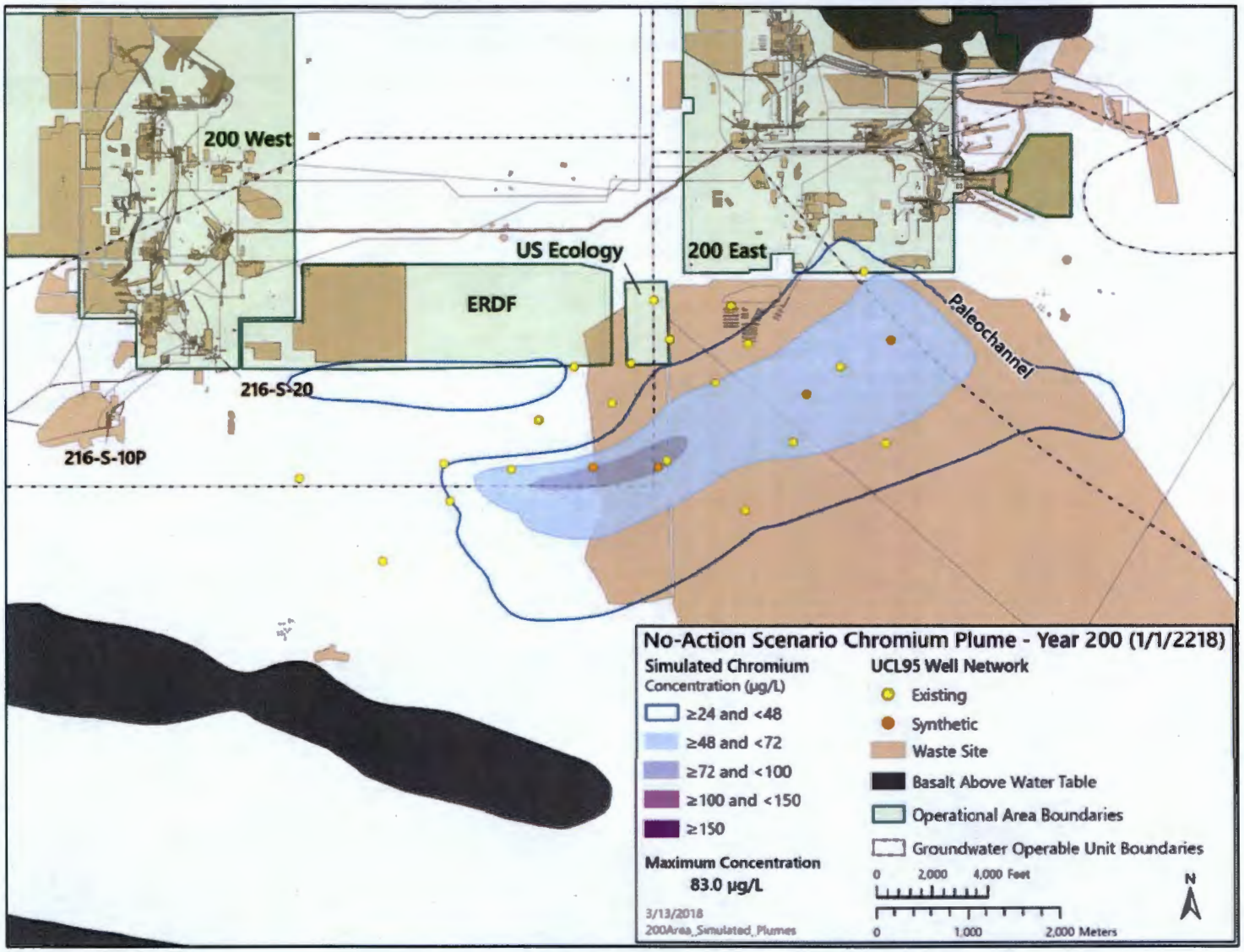


Figure 4-9. Simulated Chromium Concentrations for the No Action Scenario, Year 200 (January 1, 2218)

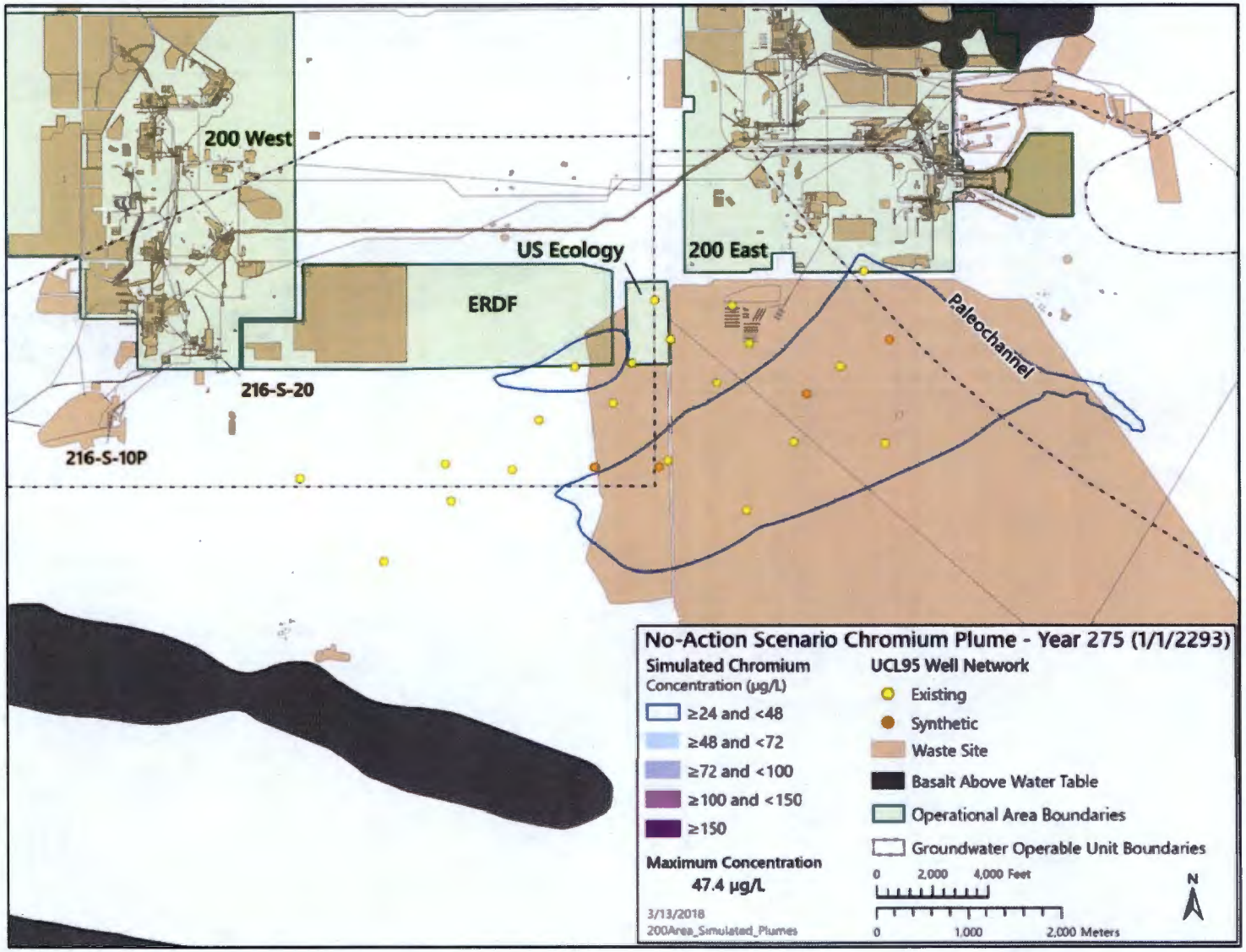


Figure 4-10. Simulated Chromium Concentrations for the No Action Scenario, Year 275 (January 1, 2293)

At year 120 (the end of the cleanup timeframe), a substantial portion of the plume remains with concentrations above the cleanup level (Figure 4-8). This indicates that dispersion alone would not be sufficient to achieve the cleanup level within 120 years. Throughout the remainder of the simulation, the plume continues to migrate northeast and disperse quickly at the paleochannel (Figure 4-9). Concentrations throughout the plume decline to below the cleanup level by year 275 (January 1, 2293), as shown in Figure 4-10.

Figure 4-11 shows the results of the no action scenario as a chart of concentrations over time in. The chart shows the maximum concentration and the 95th percentile upper confidence limit (UCL_{95}) on the mean plume concentration. The UCL_{95} is the same metric recommended for calculating groundwater plume exposure point concentrations in superfund risk assessment guidance (OSWER 9285.6-10, *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*). The UCL_{95} provides a comprehensive evaluation of plume concentrations in a single metric. It is calculated using Student's *t*-distribution and simulated concentrations at monitoring wells. The locations of these wells are shown on the plume maps (Figures 4-7 through 4-10). Additional locations added to augment the monitoring well data set are shown as "synthetic wells" on the maps.

The UCL_{95} declines to below the 48 µg/L cleanup level in year 160 (2178), and this is also when the maximum concentration declines to below the 100 µg/L DWS for total chromium (Figure 4-11). The maximum concentration declines to below the 48 µg/L cleanup level in year 275 (2293).

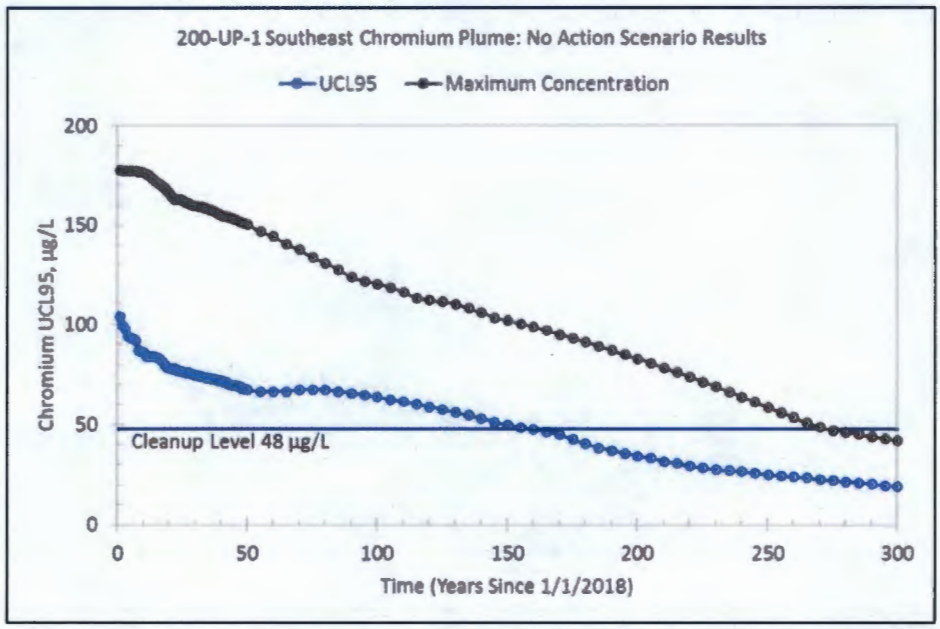


Figure 4-11. Simulated UCL_{95} and Maximum Concentration Results for the No Action Scenario

4.2.2 Option 1 – Source Control with Monitored Natural Attenuation

In this scenario, no active remedy was applied for the southeast chromium plume, which was allowed to attenuate solely by natural processes identical to that of the no action scenario (the plume is predicted to take 275 years to disperse to below cleanup levels [Section 4.2.1]). However, this option includes extraction wells (operating at 189 L/min [50 gal/min] each for 25 years) placed downgradient of two potential chromium sources: the 216-S-10 Pond/Ditch, and the 216-S-20 Crib. As described in Section 4.2, these wells were not specifically simulated, so additional modeling was not performed for this option.

4.2.3 Option 2 – Source Control and Pump and Treat with Monitored Natural Attenuation

In the 200-UP-1 OU ROD (EPA et al., 2012), the selected remedy for the southeast chromium plume was P&T for 25 years followed by MNA. This section presents the model simulation results of a preliminary P&T system designed to meet these requirements. This option also includes source control extraction wells described in Section 4.2.2; however, additional modeling was not performed for these source control extraction wells.

Results of the no action scenario (Section 4.2.1) indicated that chromium plume dispersion at the paleochannel is an important mechanism for plume attenuation. Therefore, the portion of the plume not expected to reach the paleochannel within the cleanup timeframe was the focus of the active remedy. To identify this region, a particle-tracking analysis was performed to determine the advective travel time to the paleochannel for different parts of the plume. Within the plume, particles were released from each grid cell in layer 4 of the model, and their movements were simulated using the groundwater flow results of the no action scenario (extended to run 600 years for this analysis). The particles were tracked until they reached the paleochannel, and their travel times were recorded. The travel times were assigned to each particle's starting location, allowing for a travel time map for the plume to be generated (Figure 4-12).

Advective travel times for portions of the plume to reach the paleochannel ranged from <60 years to >420 years. The portion of the plume that would reach the paleochannel within 120 years (the end of the cleanup timeframe) is shown in green in Figure 4-12, and the portion that would take longer than 120 years is shown in blue. Thus, the blue area delineates the region of the plume on which the active remedy for the P&T with MNA scenario was focused, while the portion in green was allowed to migrate to the paleochannel and disperse.

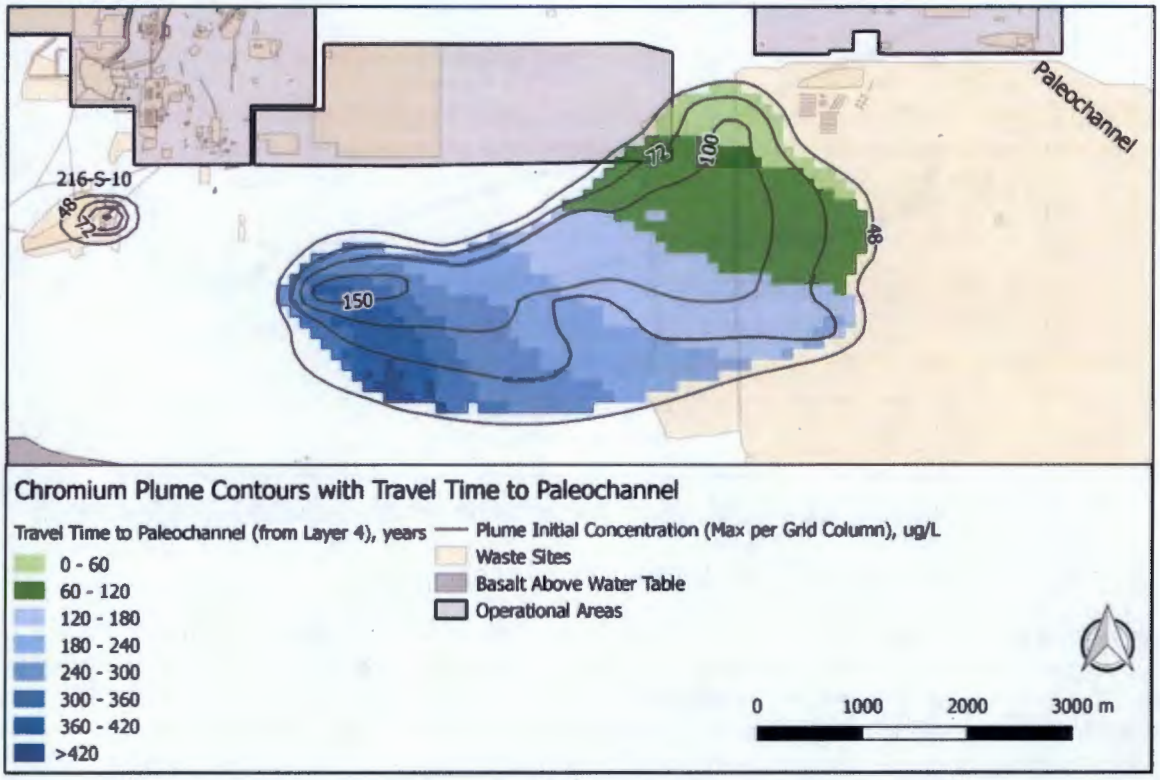


Figure 4-12. Advective Travel Time to the Paleochannel for the Southeast Chromium Plume

Figure 4-13 shows the remedy wells simulated for the P&T system. The design uses the concept of a treatment cell formed by a downgradient extraction well and an upgradient injection well. For example, extraction well E14 and injection well I14 in Figure 4-13 form a treatment cell. Wells comprising a treatment cell were spaced so approximately one pore volume[1] was flushed during their operational period. This concept was used to generate relatively clean regions within the plume that mix with the remaining contaminated regions by dispersion following the active remedy. Because longitudinal dispersion dominates over transverse dispersion (compare the dispersivity values in Table 4-2), the treatment cells were used to divide the plume into sections perpendicular to the flow direction, increasing the effectiveness of longitudinal dispersion. Not all of the remedy wells simulated formed treatment cells. For instance, the easternmost injection wells shown in Figure 4-13 have no corresponding downgradient extraction wells. These wells are used to separate the portion of the plume allowed to migrate to the paleochannel from the remainder of the plume.

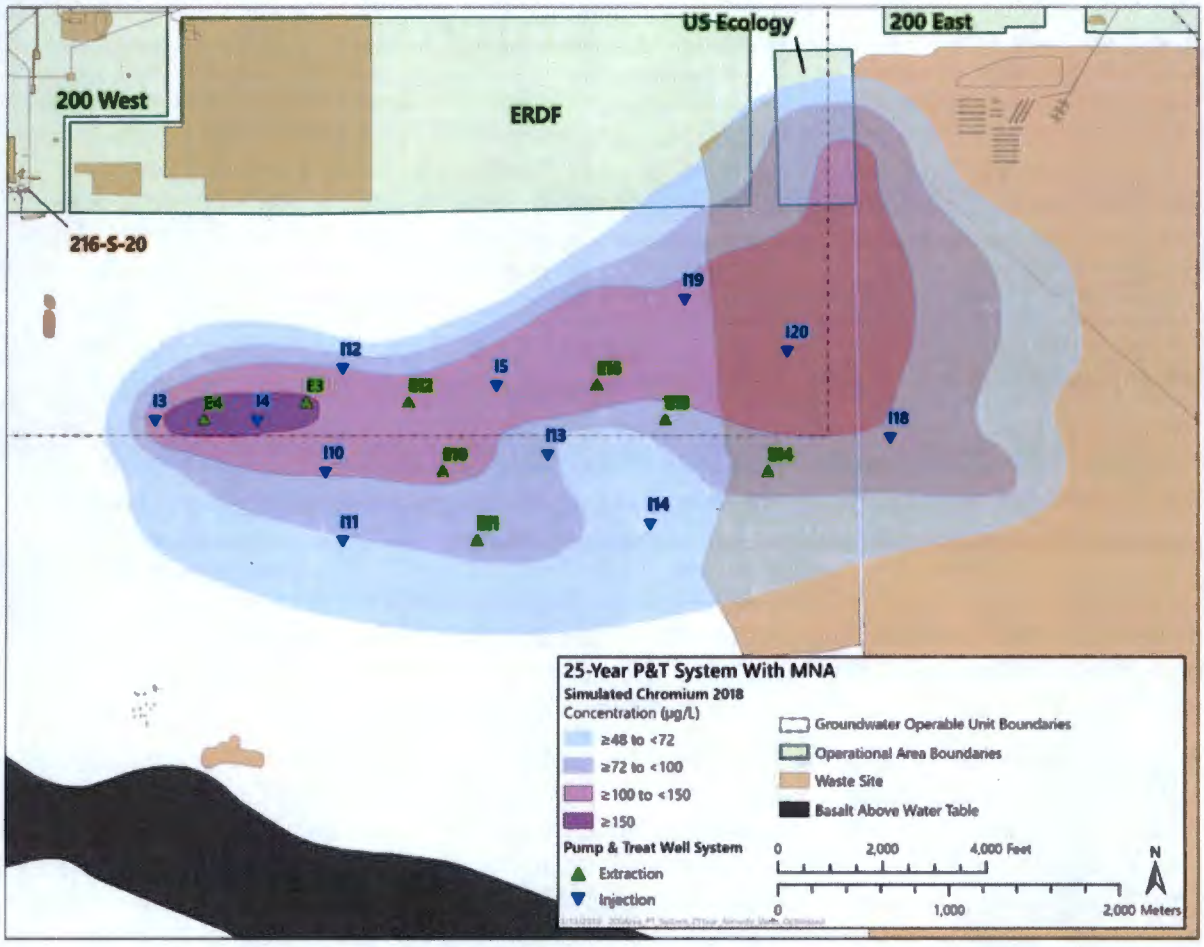


Figure 4-13. Remedy Well Locations for the 25-Year P&T (with MNA) – Option 2

[1] A pore volume is the volume of water within the pore space of an aquifer within a defined region (i.e., in this case, a treatment cell).

The P&T system is operated in two phases at a total flow of 1,893 L/min (500 gal/min) for each phase. Phase 1 lasts 15 years and consists of operating the three downgradient injection wells (I18, I19, and I20), the two treatment cells in the high-concentration region of the plume (>150 μg/L) (E3, E4, I3, and I4), the treatment cell to the west (E16 and I5), and two additional extraction wells (E10 and E14). In Phase 2, operation of all wells from Phase 1 (except extraction wells E10 and E14) is stopped and the remaining wells shown in Figure 4-13 become active. Pumping was assumed to begin on January 1, 2020 (start of year 3 of the simulation), with Phase 1 ending on January 1, 2035 (end of year 17 of the simulation), and Phase 2 ending on January 1, 2045 (end of year 27 of the simulation). Flow rates for all wells were 379 L/min (100 gal/min), except for injection wells I3, I4, and I5, which operate at 254 L/min (67 gal/min) each.

Simulated hydraulic capture zones formed by operating the P&T system are shown in Figure 4-14 for Phase 1 and in Figure 4-15 for Phase 2. Although the figures show two-dimensional maps of the particle tracks, the particles move in three dimensions within the model. The longer tracks for some of the wells in the western part of the plume are due to particles that enter the high hydraulic conductivity portion of layer 2 (conceptualized as the CCU) and migrate further. Both figures show the treatment cells formed that divide the plume into sections.

Figures 4-16 through 4-19 show the results of the model simulation for the P&T with MNA scenario. The figures display the predicted lateral extent of chromium in the aquifer at the end of Phase 1 of the active remedy (January 1, 2035), the end of Phase 2 (January 1, 2045), year 75 (January 1, 2093), and through the end of the cleanup timeframe at year 120 (January 1, 2138). The maps represent maximum concentrations integrated vertically (i.e., the concentration for each model cell used to prepare the maps is the maximum extracted from all the model layers). Thus, the maps show the full lateral extent and maximum concentrations of the simulated plume.

At the end of Phase 1, the three downgradient injection wells have effectively divided the plume into two sections: an eastern part allowed to migrate to the paleochannel, and a western part requiring further active remediation (Figure 4-16). The two treatment cells operating at the western end of the plume have effectively reduced the high concentrations in this area. At the end of Phase 2, the P&T system has effectively divided the plume into four sections (Figure 4-17). At year 75, the western portion of the plume shows substantial reductions in concentration due to dispersion, while the eastern portion continues to migrate toward the paleochannel (Figure 4-18). At the end of the cleanup timeframe, only three small portions of the plume remain at concentrations barely above the cleanup level (the maximum concentration at this time is 48.5 μg/L) (Figure 4-19).

Figure 4-20 shows the simulated UCL_{95} and maximum concentration over time, both of which decline rapidly during the active remedy phase. Concentrations in the western part of the plume are higher than the eastern part until about year 20. At that time, the active remedy has reduced the maximum concentration in the western part of the plume to below the maximum in the eastern part where no active remedy is operating. This causes the inflection in the maximum concentration trend in Figure 4-20 prior to the end of pumping. The UCL_{95} declines to below the cleanup level in year 42, and the maximum concentration essentially reaches the cleanup level at the end of the cleanup timeframe. Thus, the model simulations indicate that the P&T system would be effective in achieving cleanup objectives within the 120-year cleanup timeframe.

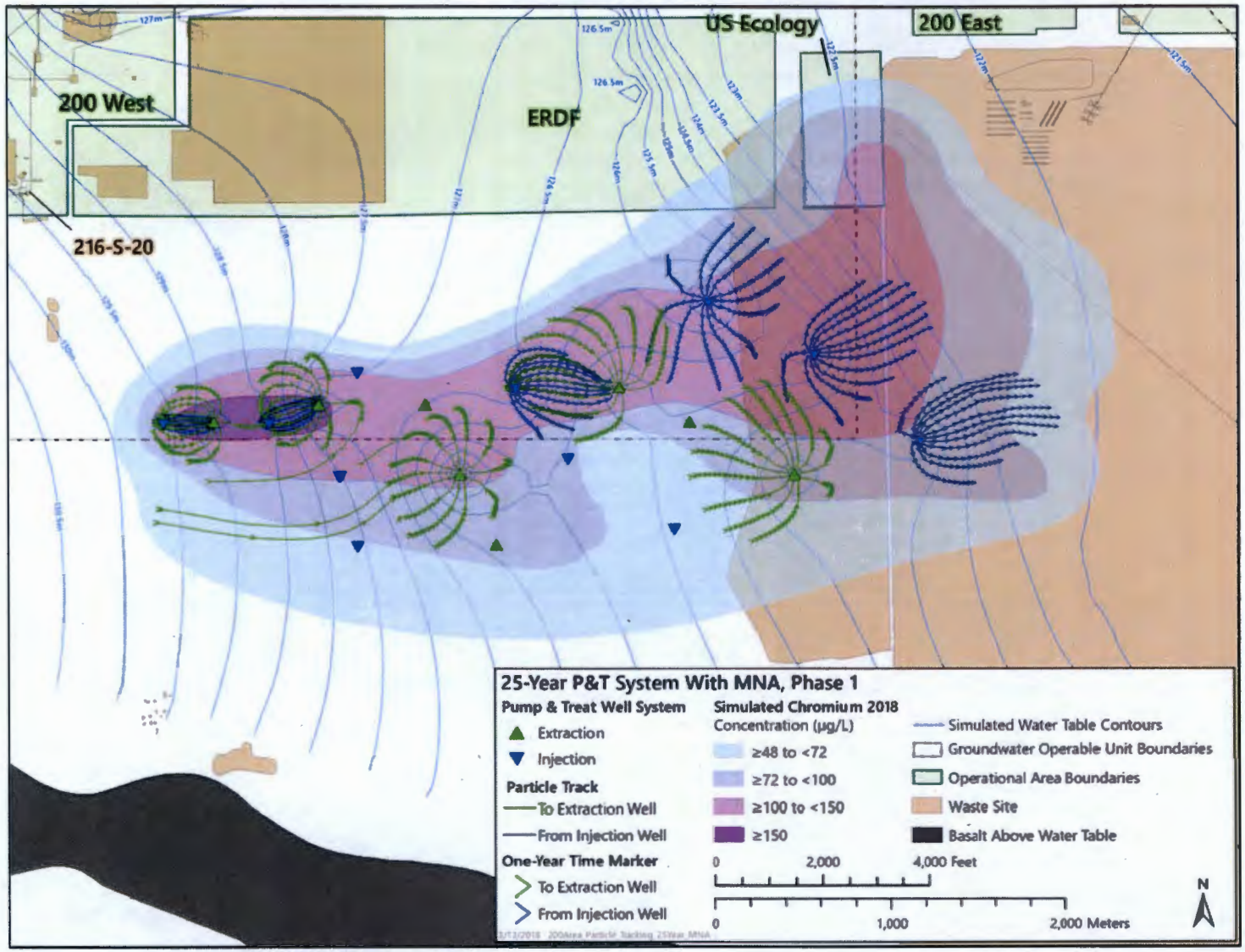


Figure 4-14. Capture Zones for the 25-Year P&T (with MNA) – Phase 1

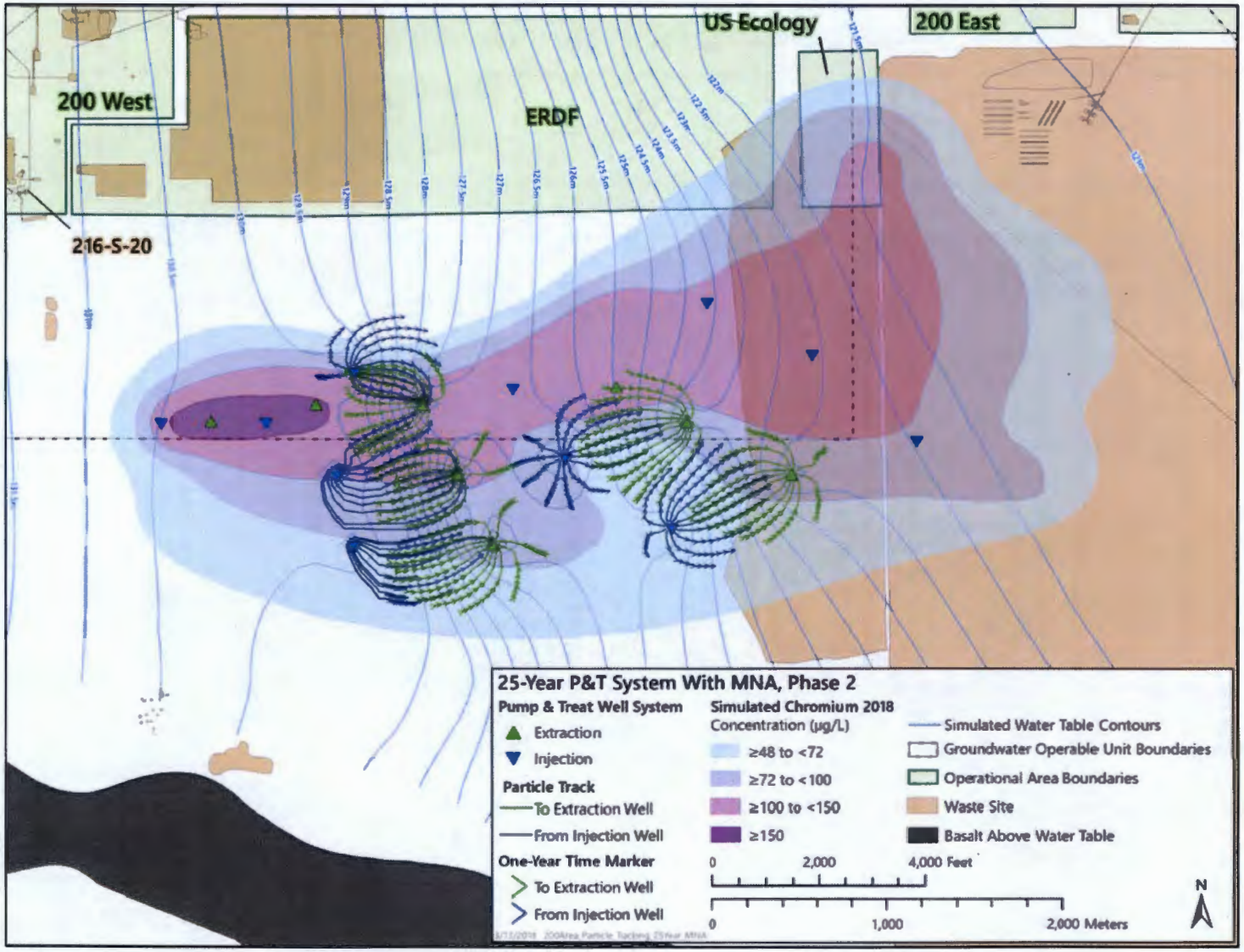


Figure 4-15. Capture Zones for the 25-Year P&T (with MNA) – Phase 2

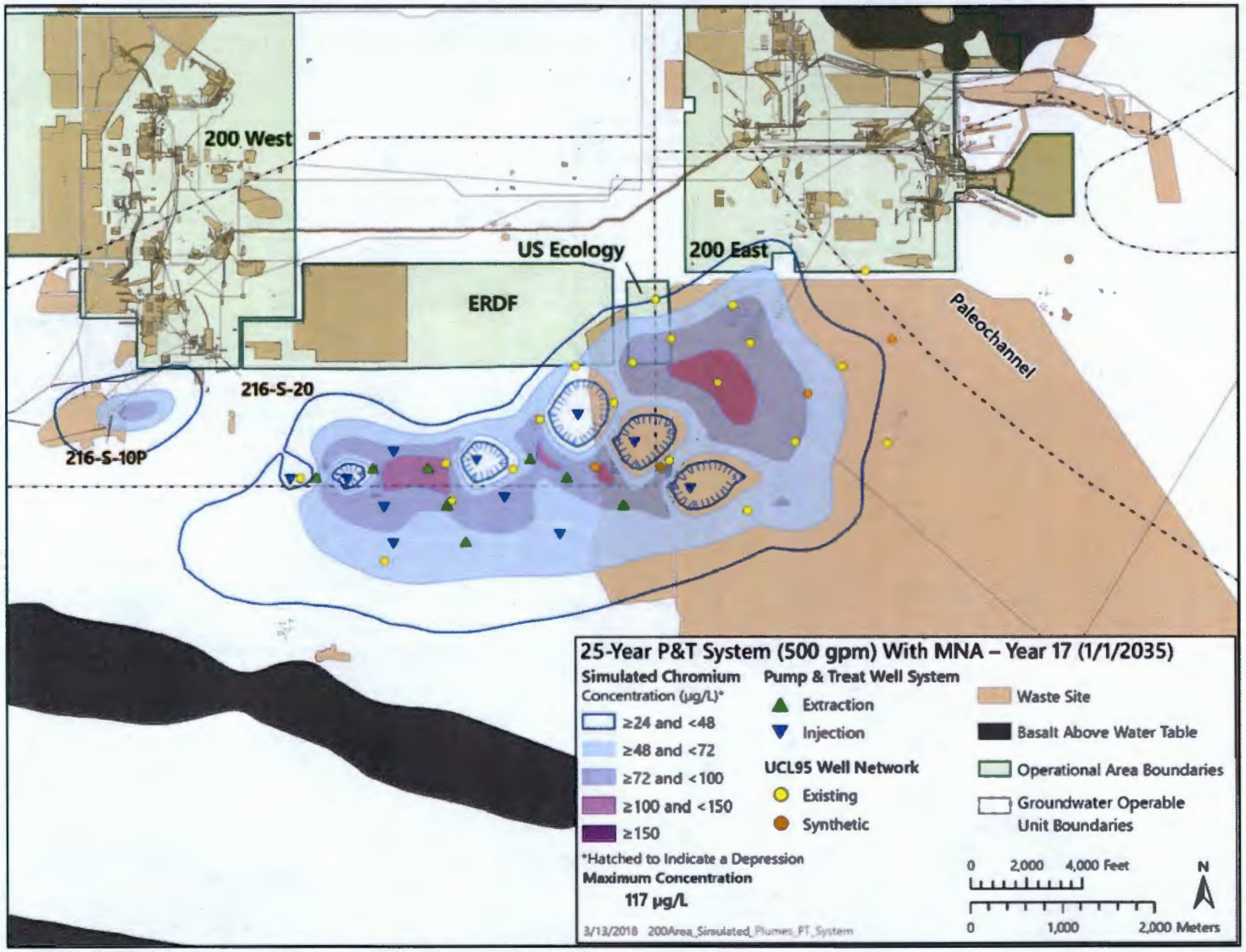


Figure 4-16. Simulated Chromium Concentrations for the 25-Year P&T (with MNA), at the End of Phase 1 (Year 17, January 1, 2035)

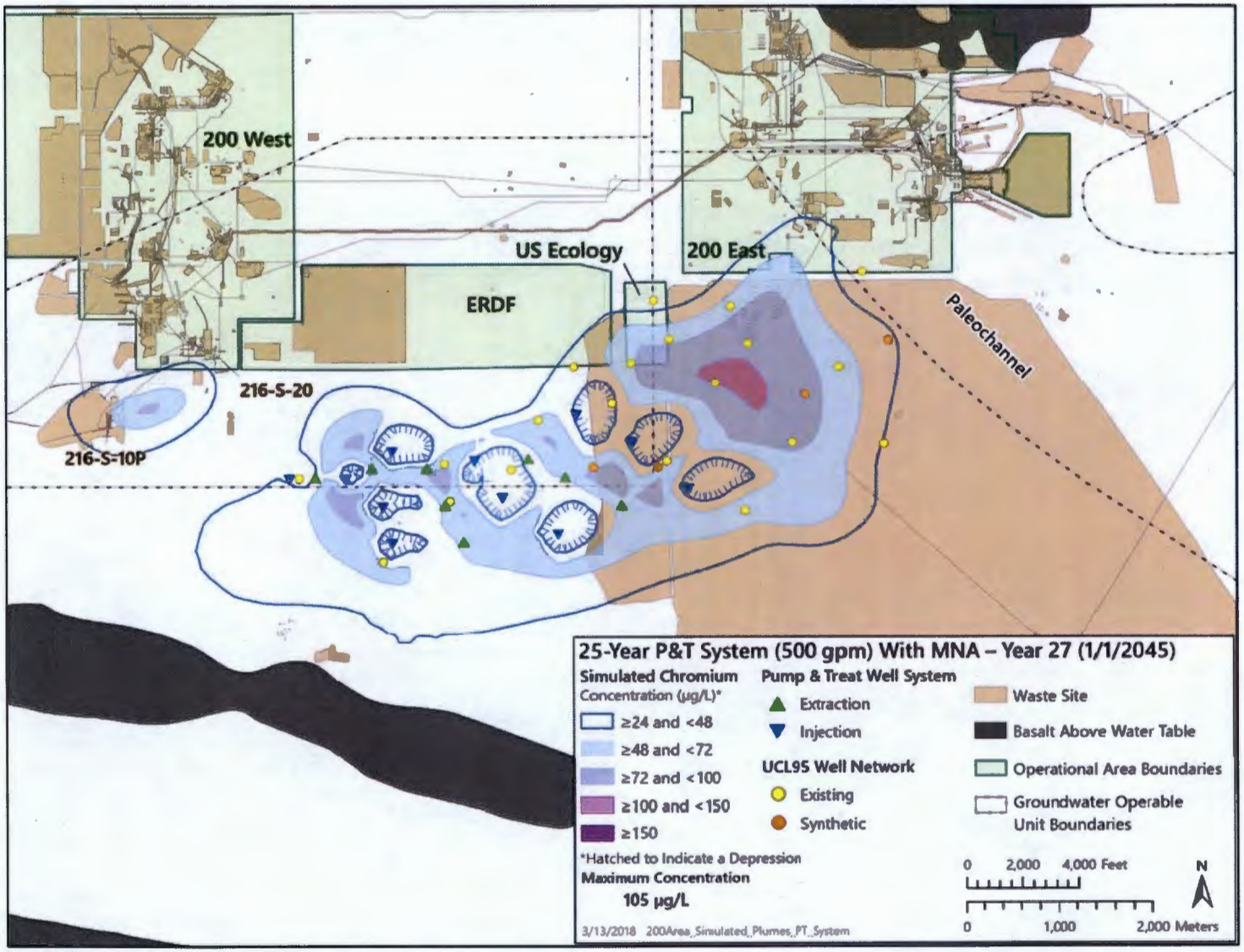


Figure 4-17. Simulated Chromium Concentrations for the 25-Year P&T (with MNA) at the End of Phase 2 (Year 27, January 1, 2045)

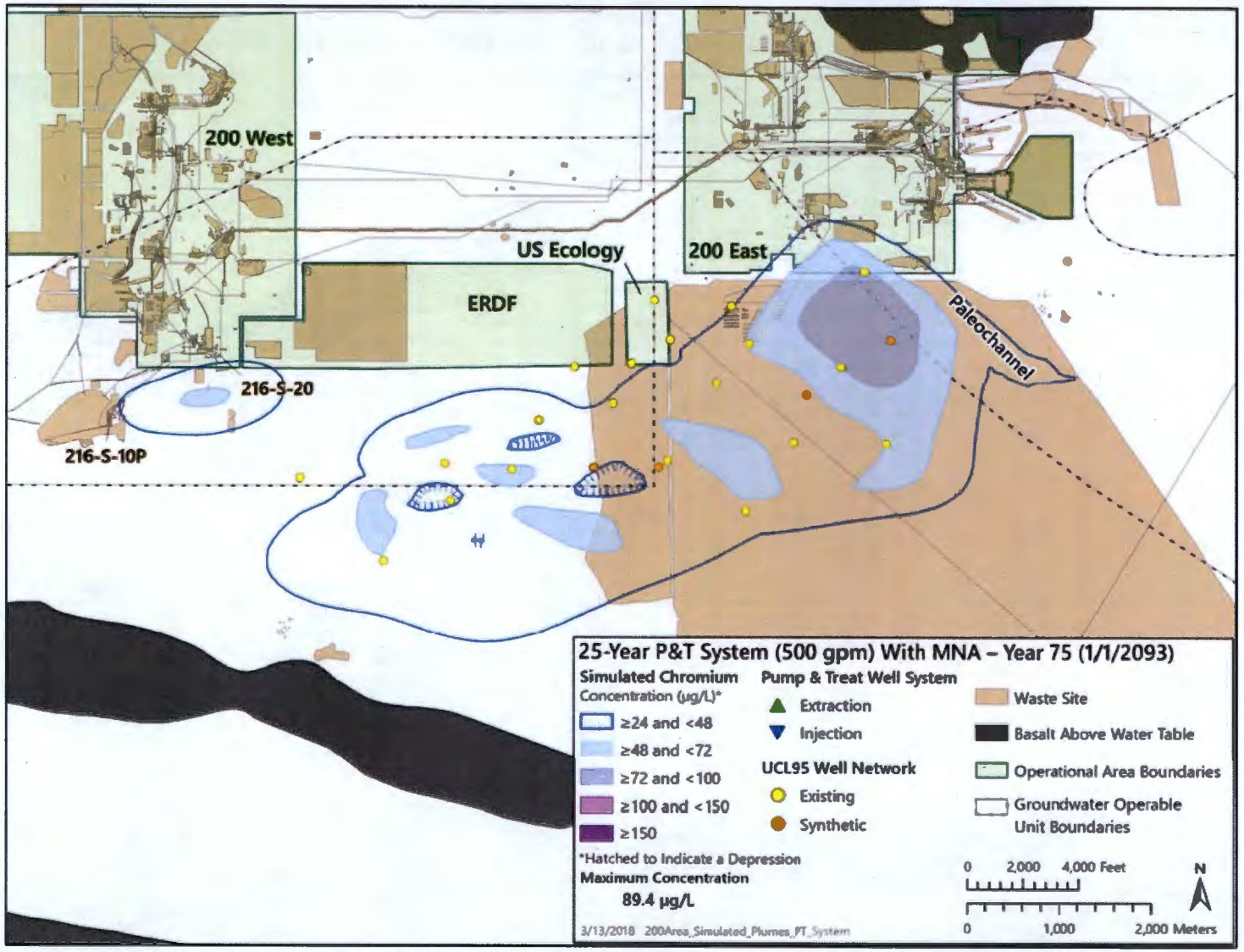


Figure 4-18. Simulated Chromium Concentrations for the 25-Year P&T (with MNA), Year 75 (January 1, 2093)

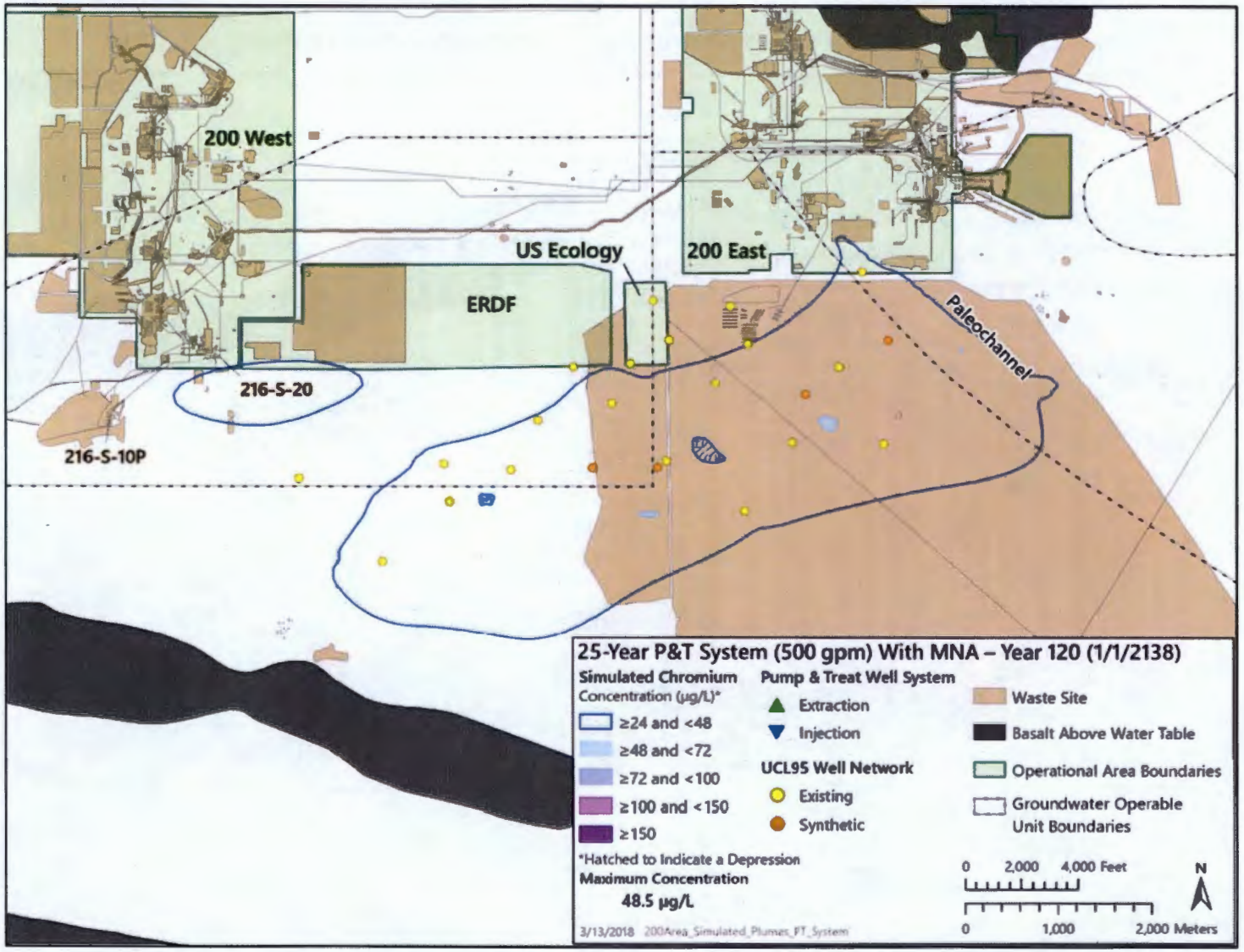


Figure 4-19. Simulated Chromium Concentrations for the 25-Year P&T (with MNA), Year 120 (January 1, 2138)

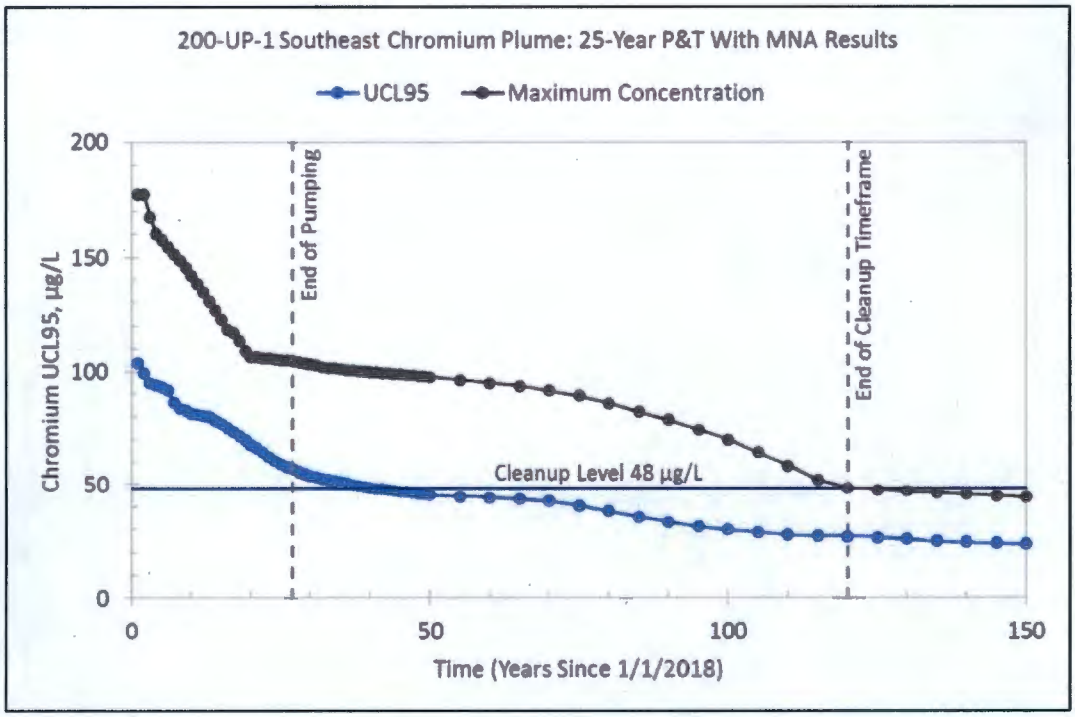


Figure 4-20. UCL_{95} and Maximum Concentration Results for the 25-Year P&T (with MNA)

4.2.4 Option 3 – Source Control and Pump and Treat without Monitored Natural Attenuation

As a bounding remedial option, a P&T system that would achieve cleanup levels within 25 years was designed and simulated. This option also includes source control extraction wells described in Section 4.2.2. However, additional modeling was not performed for these source control extraction wells.

In this option, the P&T system addressed the entire plume since MNA was not a component (i.e., the eastern portion of the plume was not allowed to migrate to the paleochannel and disperse because that would take longer than 25 years). Treatment cells were implemented as rows of remedy wells oriented perpendicular to the flow direction and covering the entire plume (Figure 4-21). The wells are more closely spaced in the western part of the plume to mitigate the effect of the higher hydraulic conductivity in layer 2 (i.e., the region conceptualized as the CCU). The system consists of 54 remedy wells and was simulated to operate in two phases. In Phase 1 (shown in Figure 4-21), 27 treatment cells were operated for 13 years, removing approximately one pore volume of water from the cells. This left contamination remaining in the regions between downgradient injection wells and upgradient extraction wells. Thus, in Phase 2 (lasting 12 years), the roles of the wells were reversed in that many of the extraction wells in Phase 1 became injection wells in Phase 2, and vice versa. A total of 44 wells were operated in Phase 2. The wells operated at 379 L/min (100 gal/min) each for a total flow of 10,221 L/min (2,700 gal/min) in Phase 1 and 8,328 L/min (2,200 gal/min) in Phase 2.

The capture zones are shown in Figure 4-22 for Phase 1 and in Figure 4-23 for Phase 2. The results show mostly well-formed treatment cells between upgradient injection wells and downgradient extraction wells. The regions of the plume not remediated in Phase 1 are effectively covered during Phase 2.

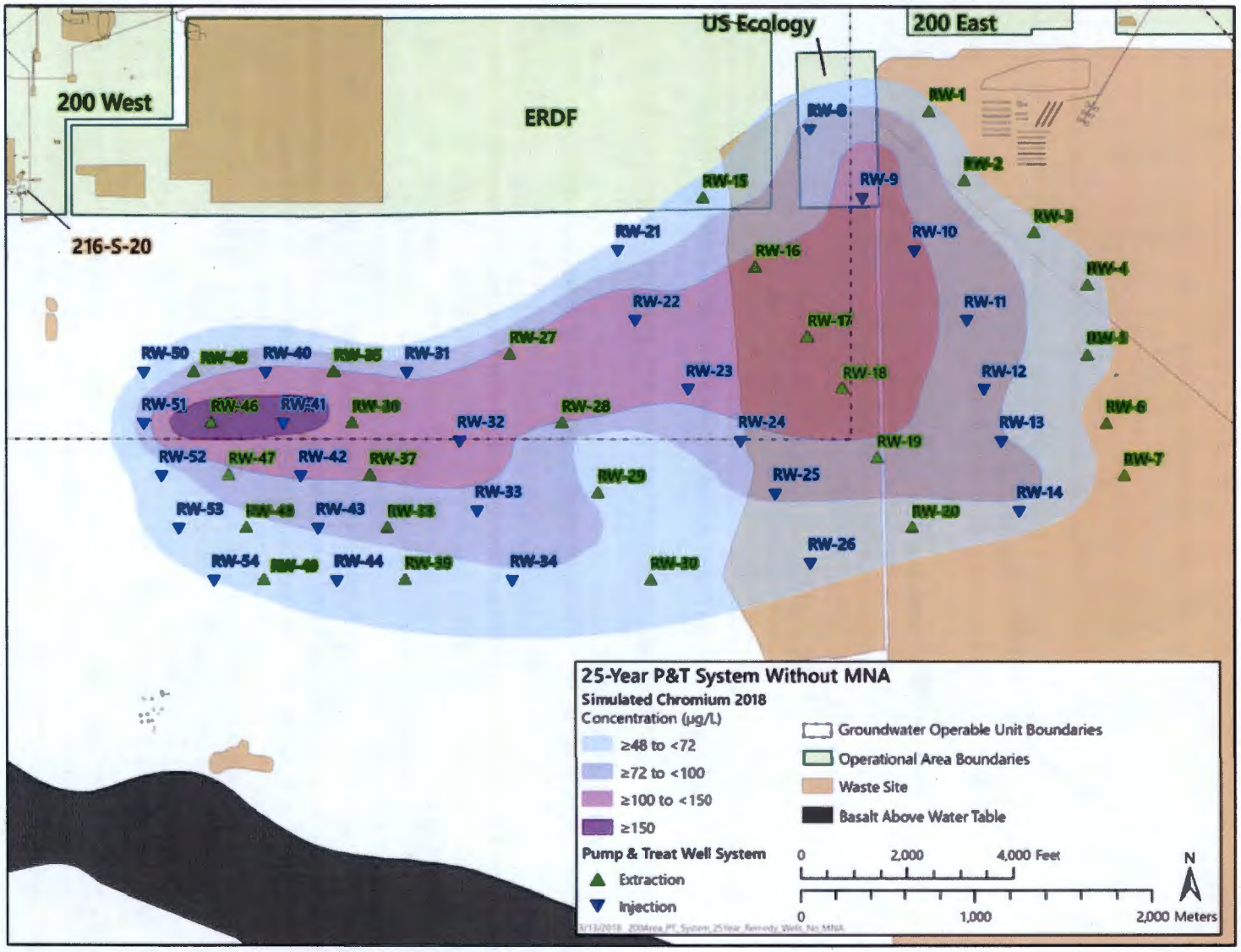


Figure 4-21. Remedy Well Locations for the 25-Year P&T (Without MNA)

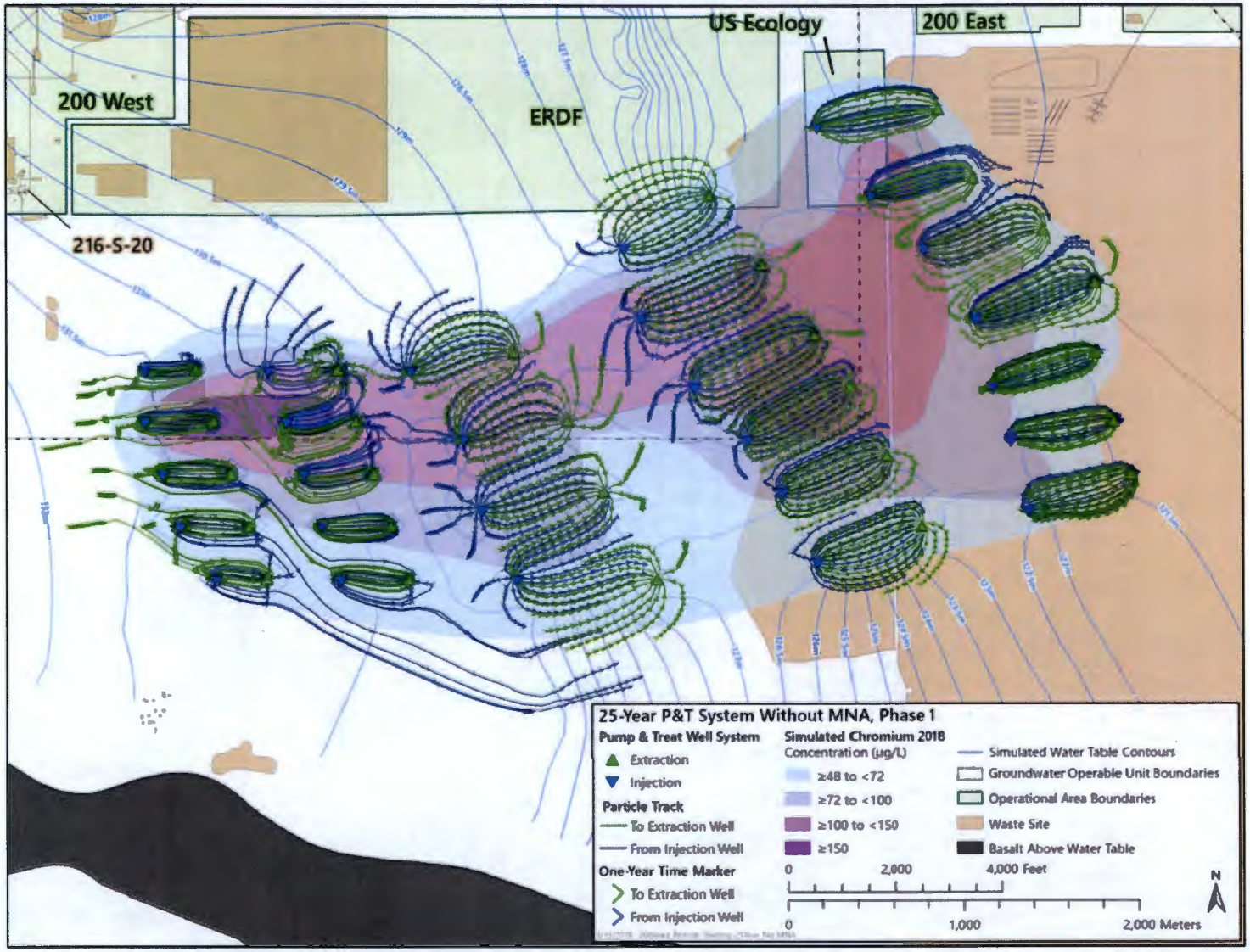


Figure 4-22. Capture Zones for the 25-Year P&T (Without MNA) – Phase 1

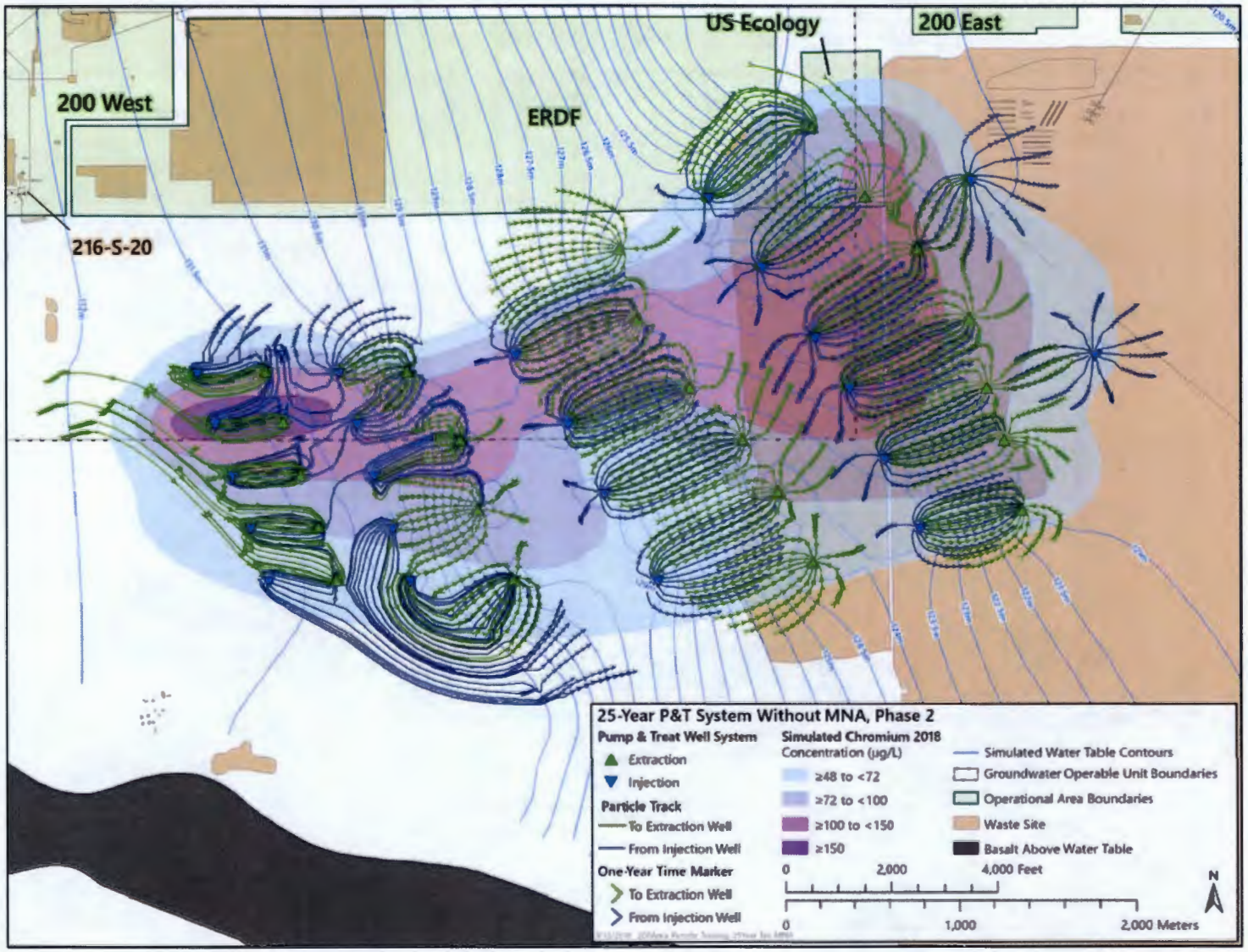


Figure 4-23. Capture Zones for the 25-Year P&T (Without MNA) – Phase 2

Results of the simulation are shown in Figures 4-24 and 4-25 for the end of Phase 1 (year 15; January 1, 2033) and the end of Phase 2 (year 27; January 1, 2045), respectively. The maps represent maximum concentrations integrated vertically (i.e., the concentration for each model cell used to prepare the maps is the maximum extracted from all the model layers). Thus, the maps show the full lateral extent and maximum concentrations of the simulated plume.

At the end of Phase 1, remediation of the aquifer has been very effective within the five bands of operating treatment cells (Figure 4-24). Only a small portion of the plume has migrated past the eastern extraction wells. Nearly the entire plume was effectively remediated at the end of Phase 2 (Figure 4-25). Only a few portions of the plume (located between some of the extraction wells) remain at concentrations above the cleanup level, but these disperse to below the cleanup level within 2 years. The small portions of the plume that had migrated beyond the eastern extraction wells disperse to below the cleanup level by the end of Phase 2.

Figure 4-26 shows the simulated UCL_{95} and maximum concentration over time. Both the UCL_{95} and maximum concentration decline rapidly during the active remedy. The UCL_{95} declines to below the cleanup level in year 16. The maximum concentration is above the cleanup level at 62.4 µg/L at the end of pumping, but it declines to below the cleanup level 2 years later due to mixing with the low-concentration areas created by the treatment cells.

4.2.5 Summary of Remedial Options

Table 4-3 provides a summary of the P&T remedial options modeled and evaluated in Sections 4.2.1 through 4.2.4. The treatment methods and locations for extracted groundwater are described in Section 4.3.2 and included in the remedial options summarized in Table 4-3.

4.3 Evaluation of Remedial Options

This section describes the criteria that were used to evaluate the remedial options discussed in Section 4.2 to support final design. As described in Section 1.2.4, the remedial options were evaluated against three CERCLA balancing criteria:

- Effectiveness
- Implementability
- Cost

The "balancing criteria" represent technical considerations upon which the detailed analysis is primarily based. These criteria provide the framework for conducting an analysis of options to support a future remedial action design. Section 4.3.1 describes the three balancing criteria. Section 4.3.2 evaluates each of the remedial options based on the CERCLA balancing criteria, and Section 4.3.3 compares the performance of the options relative to the three balancing CERCLA criteria.

4.3.1 Evaluation Criteria

The three balancing criteria that were used to evaluate the individual options are described in the following sections. Table 4-4 provides the more detailed considerations that CERCLA guidance (EPA/540/G-89/004, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*) be used to address the three balancing criteria.

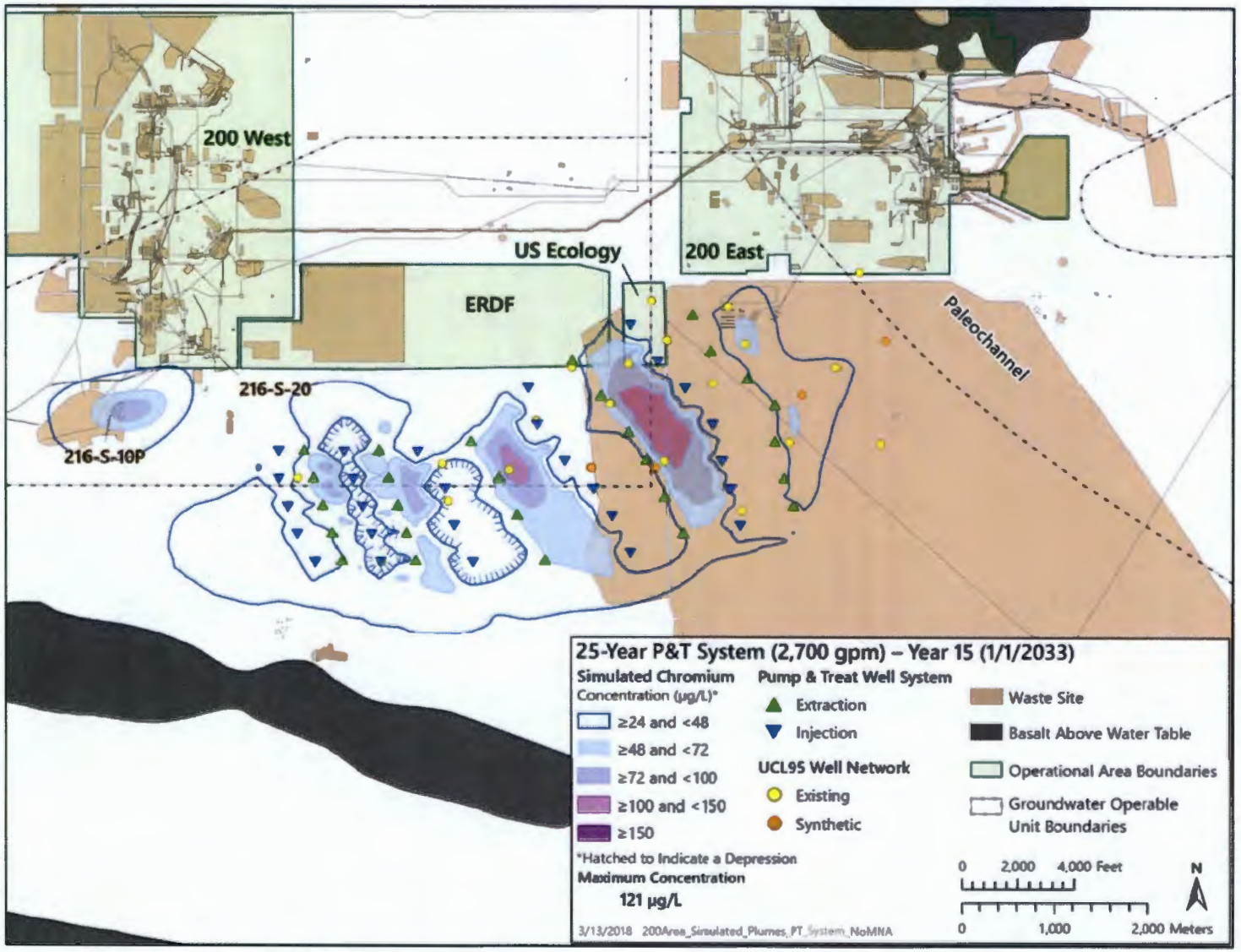


Figure 4-24. Simulated Chromium Concentrations for the 25-Year P&T (Without MNA) – End of Phase 1

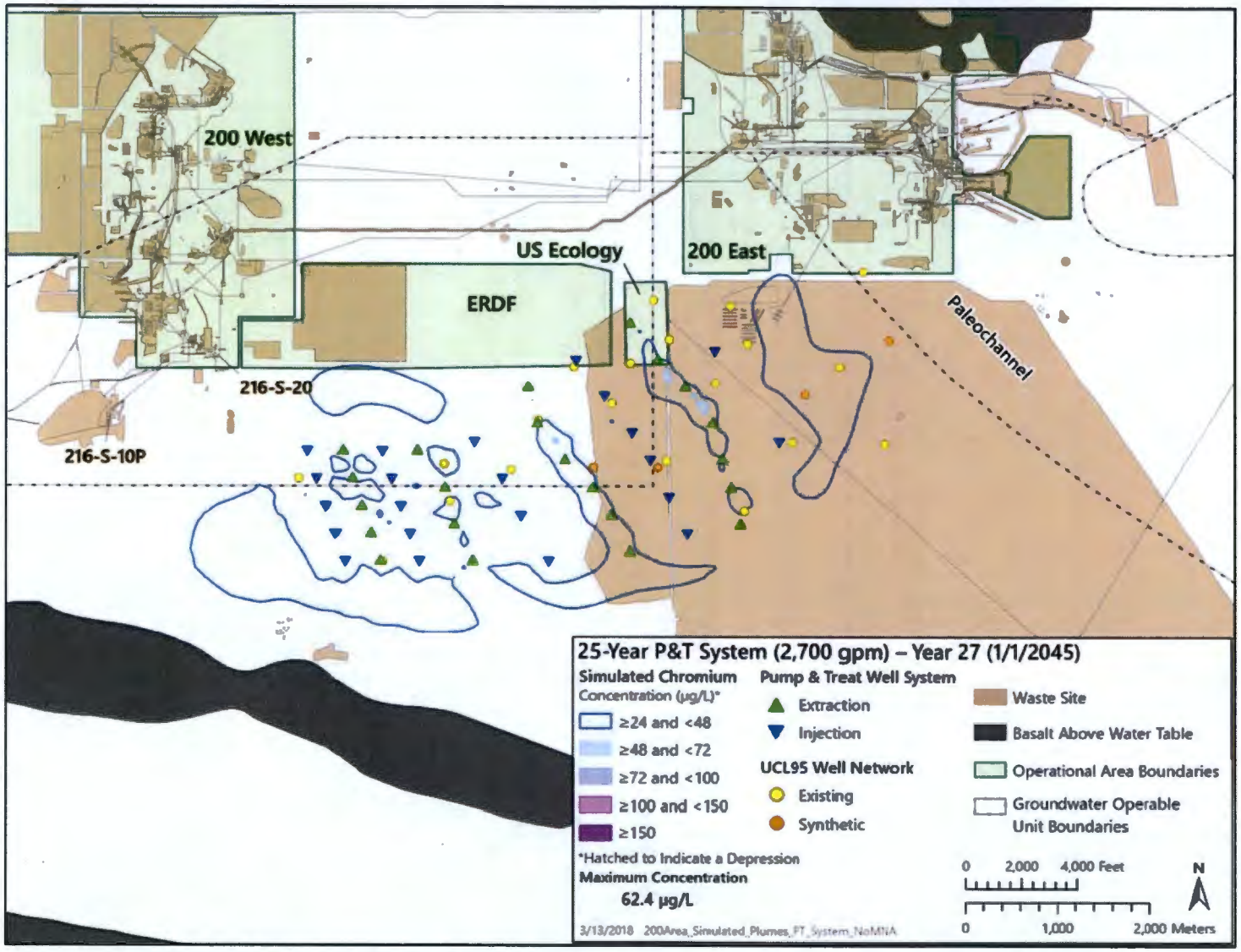


Figure 4-25. Simulated Chromium Concentrations for the 25-Year P&T (Without MNA) – End of Phase 2

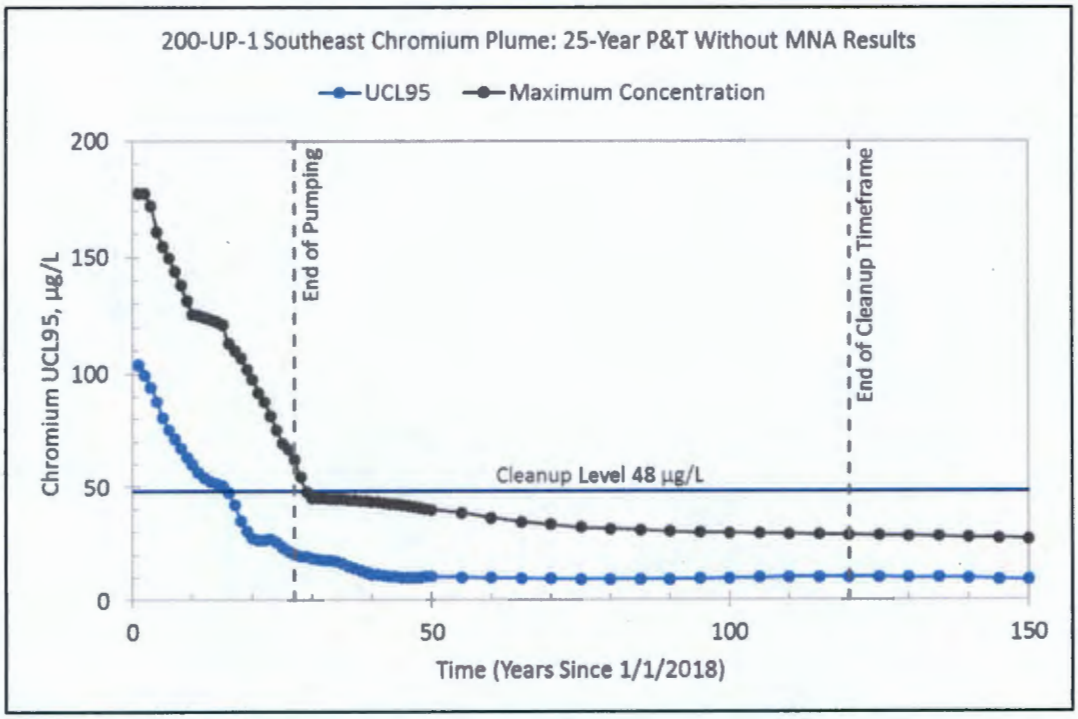


Figure 4-26. UCL_{95} and Maximum Concentration Results for the 25-Year P&T (Without MNA)

4.3.1.1 Effectiveness

The effectiveness criterion evaluates the anticipated ability of the options to maintain reliable protection of human health and the environment for the duration of time that risk is above allowable levels. Options are assessed for the long-term effectiveness and permanence they afford, along with the degree of certainty that the option will prove successful in meeting the remedial action objectives (RAOs). Options are assessed for their short-term effectiveness in protecting human health and the environment during the construction and implementation phase until RAOs are met.

4.3.1.2 Implementability

The implementability criterion assesses the technical and administrative feasibility of implementing an option and the availability of various services and materials required during its implementation.

4.3.1.3 Cost

The cost estimates are based on a variety of information, including costs provided from current Hanford Site vendors and service providers, generic unit costs, conventional cost-estimating guides, and prior Hanford Site experience for similar work tasks. The cost estimates were prepared based on the information available at the time the estimate was prepared and are designed to assist in evaluating remedial options. Details of the cost estimates are provided in ECE-200UP118-00002, *Environmental Cost Estimate for the 200-UP-1 Southeast Chromium Plume Remedial Options* (provided as Appendix D of this report). Costs will be updated during the remedial design.

Table 4-3. Summary of Remedial Options

Remedial Method	No Action	Option 1 P&T for Source Control and MNA for Southeast Chromium Plume	Option 2 P&T for Source Control and Southeast Chromium Plume and MNA for Southeast Chromium Plume	Option 3 P&T for Source Control and Southeast Chromium Plume
MNA	N/A	275 years	120 years	N/A
Source control – extraction	N/A	25 years Two extraction wells operating at 379 L/min (100 gal/min)	25 years Two extraction wells operating at 379 L/min (100 gal/min)	25 years Two extraction wells operating at 379 L/min (100 gal/min)
Source control – treatment sub options	N/A	IX using ETB-3	2a) IX at new onsite treatment facility 2b) IX at 200 West P&T 2c) Biological at 200 West P&T	IX at new onsite treatment facility
Southeast chromium plume – extraction	N/A	N/A	25 years Eight extraction and 11 injection wells operating at 1,893 L/min (500 gal/min)	25 years A total of 27 extraction and 27 injection wells operating at 10,221 L/min (2,700 gal/min) (Phase 1) A total of 22 extraction and 22 injection wells operating at 8,328 L/min (2,200 gal/min) (Phase 2)
Southeast chromium plume – treatment sub-options	N/A	N/A	2a) IX at new onsite treatment facility 2b) IX at 200 West P&T 2c) Biological at 200 West P&T	IX at new onsite treatment facility
Total extraction flow rate	N/A	379 L/min (100 gal/min)	2,272 L/min (600 gal/min)	10,600 L/min (2,800 gal/min) (Phase 1) 8,707 L/min (2,300 gal/min) (Phase 2)

ETB = extraction transfer building
IX = ion exchange
MNA = monitored natural attenuation
N/A = not applicable
P&T = pump and treat

Table 4-4. CERCLA Balancing Criteria for the 200-UP-1 OU Southeast Chromium Plume Remedial Option Evaluation

Balancing Criteria	Evaluation Summary
Effectiveness	Options are assessed for effectiveness factors, as appropriate, that include the following: 1. Magnitude of residual risk from untreated waste or treatment residuals remaining at the conclusion of the remedial activities. The cerharacteristics of the residuals should be considered to the degree that they remain hazardous, considering their toxicity, mobility, and volume, and the propensity to bioaccumulate. 2. Adequacy and reliability of controls such as containment systems and institutional controls that are necessary to manage treatment residuals and untreated waste. This factor addresses in particular the uncertainties associated with land disposal for providing long-term protection from residuals; the assessment of the potential need to replace technical components of the option such as a cap, a slurry wall, or a treatment system; and the potential exposure pathways and risks posed should the remedial action need replacement. 3. Short-term risks that might be posed to the community during implementation of an option. 4. Potential impacts on workers during remedial action and the effectiveness and reliability of protective measures. 5. Potential environmental impacts of the remedial action and the effectiveness and reliability of mitigative measures during implementation. 6. Time until protection is achieved.
Implementability	Options are evaluated to assess the ease or difficulty of implementation considering the following as appropriate: 1. Technical feasibility, including technical difficulties and unknowns associated with the construction and operation of a technology, the reliability of the technology, ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy. 2. Administrative feasibility, including activities needed to coordinate with other offices and agencies and the ability and time required to obtain any necessary approvals and permits from other agencies (for offsite actions). 3. Availability of services and materials, including the availability of adequate offsite treatment, storage capacity, and disposal capacity and services; the availability of necessary equipment and specialists, and provisions to ensure any necessary additional resources; the availability of services and materials; and availability of prospective technologies.
Cost	Options are evaluated with respect to the capital cost, annual operation and maintenance cost, periodic cost, and total lifecycle cost (present-worth cost). The cost estimates are for comparison purposes and are prepared to meet the -30% to +50% range of accuracy recommended in EPA/540/G-89/004, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*. The cost estimates are based on specific response action scenarios and assumptions. Detailed sensitivity analyses were not performed to quantify the potential effect of changing key parametric assumptions.

The cost estimates were developed in accordance with EPA 540-R-00-002, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*. Microsoft Excel software was used to calculate the cost estimate for each of the remedial options. The cost estimates are for comparison purposes and were prepared to meet the -30% to +50% range of accuracy recommended in CERCLA remedial investigation/feasibility study guidance (EPA/540/G-89/004).

The cost estimates for each remedial option include allowances for capital costs, operations and maintenance (O&M), and periodic costs, which are defined as follows:

- **Capital costs:** Consist primarily of expenditures incurred to construct the remedy (e.g., construction of a groundwater extraction/injection system and related site work). It also includes all labor, equipment, and material costs for mobilization/demobilization; site work; installation of extraction, containment, or treatment systems; and disposal of waste products.
- **O&M costs:** Include those post-construction costs necessary to support the remedy until RAOs are achieved. These costs are estimated on an annual basis. Annual O&M costs include all labor, equipment, and material costs for monitoring; and operating and maintaining extraction, injection, and treatment systems.
- **Periodic O&M costs:** Occur only once every few years (e.g., 5-year reviews, nonannual equipment replacement, and well rehabilitation/replacement), or expenditures that occur only once during the entire remedial timeframe (e.g., decommissioning costs of facilities).

A total nondiscounted cost estimate was developed for each option based on year 2018 dollars.

4.3.2 Individual Analysis of Options

This section evaluates the no action scenario and each of the remedial action options against the CERCLA balancing criteria described in Section 4.3.1. The following ratings scale indicates the expected performance of each option relative to the CERCLA criteria:

★★★★ = Expected to perform very well against the CERCLA balancing criterion with no disadvantages or uncertainties.

★★★☆ = Expected to perform well against the CERCLA balancing criterion with minimal disadvantages or uncertainties.

★★☆☆ = Expected to perform moderately well against the CERCLA balancing criterion with some disadvantages or uncertainties.

★☆☆☆ = Expected to perform less well against the CERCLA balancing criterion with more disadvantages or uncertainty.

4.3.2.1 No Action

A no action scenario was provided for information only and comparison to the three remedial options. No action assumes that no further (i.e., no additional) remedial action would be taken. Any current ICs would be terminated. Contaminant attenuation, along with other natural processes, would be relied upon to reduce COC concentrations in groundwater over time. However, there would be no monitoring to track concentration changes or plume migration patterns. Table 4-5 summarizes the individual analysis of the no action scenario.

Table 4-5. Individual Analysis for No Action

Balancing Criterion	Rating	Detailed Analysis
Effectiveness	Not evaluated	An evaluation against the balancing criteria was not performed because no action is being taken.
Implementability		
Cost (Base Year 2018)		
Estimated capital costs	$0	N/A
Estimated nondiscounted operations and maintenance and periodic cost	$0	N/A
Total nondiscounted cost	$0	N/A

N/A = not applicable

4.3.2.2 Option 1 – Source Control with 275 Years of MNA

Option 1 includes the following components:

- Active groundwater remediation using P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib (one extraction well at each of the two sites) for 25 years at a total flow rate of 379 L/min (100 gal/min).
- Groundwater treatment for chromium from source control wells using a smaller scale ion-exchange (IX) resin treatment train installed in extraction transfer building (ETB) ETB-3, which is currently part of 200 West P&T operations.
- Two injection wells at a total flow rate of 379 L/min (100 gal/min) for treatment plant water balance.
- MNA and groundwater monitoring for chromium for 275 years.
- Maintenance of ICs for 275 years.

Figure 4-27 provides a diagram depicting the groundwater extraction, treatment, and injection flows for this option using a smaller scale IX resin treatment train installed in ETB-3. The treated water would be injected into the aquifer using 200 West P&T injection wells.

The individual analysis of the balancing criteria for Option 1 is summarized below and shown in Table 4-6.

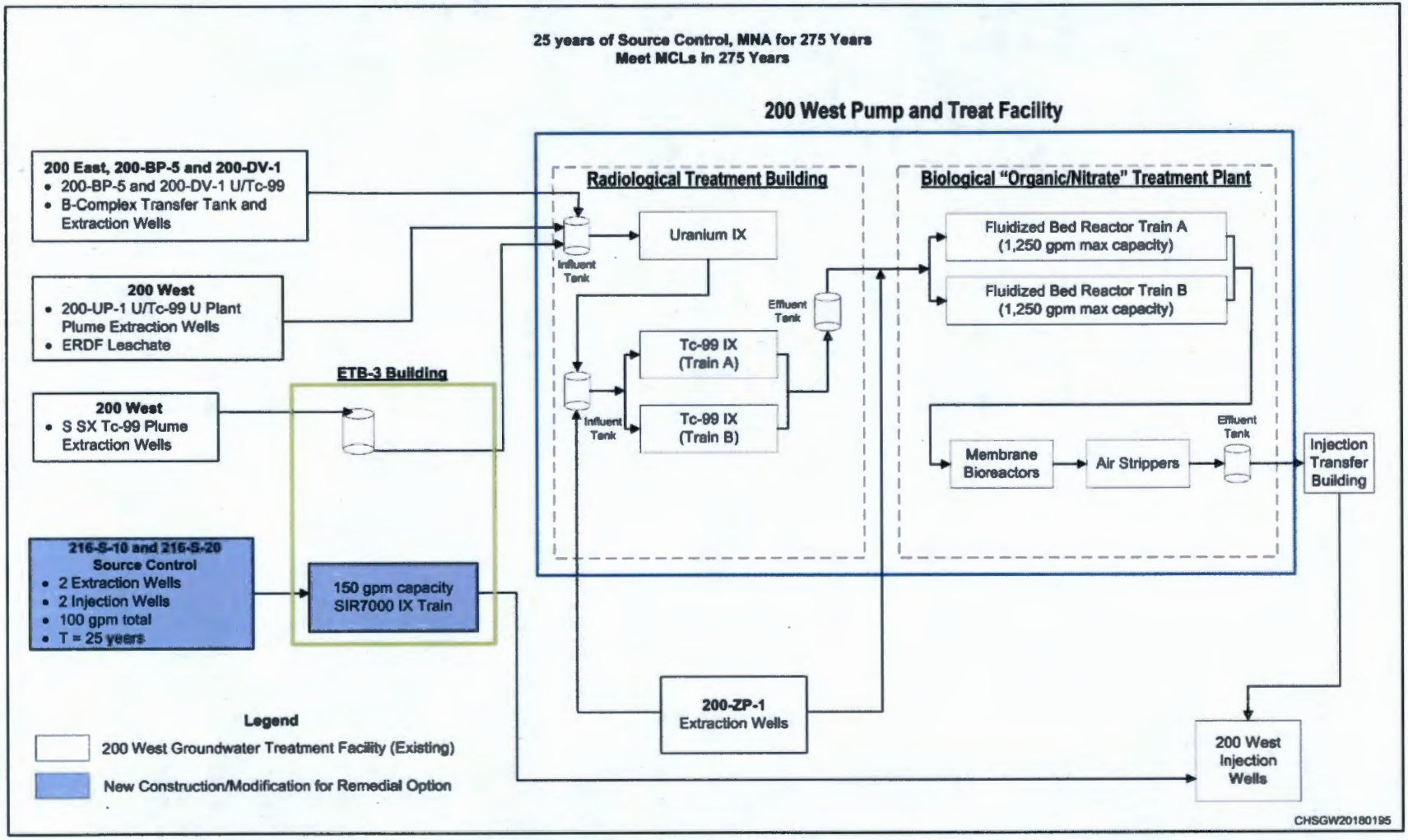


Figure 4-27. Conceptual Block Flow Diagram for Option 1 – Source Control Using ETB-3 at 379 L/min (100 gal/min)

Table 4-6. Individual Analysis for Option 1– Source Control and MNA

Balancing Criterion	Rating	Detailed Analysis
Effectiveness	★★☆☆	
Magnitude of residual risk		No significant residual risk after 275 years because plume is below RAOs.
Degree of expected reduction in toxicity, mobility, and volume through treatment		Toxicity and volume reductions for chromium occur through MNA (dispersion). Southeast chromium plume attenuate below RAOs after the 275-year remedial action period.
Adequacy and reliability of controls		ICs maintained for land and groundwater use during the entire 275-year remedial action period.
Short-term risks to community during remedial actions		Due to remote site location, no increased risk to the community during construction, P&T operations, and passive treatment (MNA) remedy phase.
Protection of workers during remedial actions		Onsite workers will adhere to health and safety plan and personal protective equipment requirements during construction and operation to ensure protection.
Environmental impacts		Groundwater monitoring during remedy implementation will provide information on plume migration and chromium concentration trends.
Time until cleanup levels achieved		275 years
Implementability	★★★★	
Ability to construct and operate the technology		Additional monitoring wells can readily be installed and incorporated into existing monitoring programs. ICs are widely used at the Hanford Site.
Reliability of the technology		Monitoring and IC technologies are reliable.
Ease of undertaking additional remedial actions, if necessary		Additional monitoring can readily be incorporated into existing monitoring programs. ICs are widely used at the Hanford Site.
Ability to monitor effectiveness of remedy		Monitoring of chromium and adequacy of ICs are important components of MNA.
Ability to obtain approvals from other agencies		No issues expected.
Coordination with other agencies		No issues expected.
Availability of offsite treatment, storage, and disposal services and capacity		Readily available onsite at the Environmental Restoration Disposal Facility.
Availability of necessary equipment and specialists		Readily available.
Availability of prospective technologies		Technologies readily available.

Table 4-6. Individual Analysis for Option 1– Source Control and MNA

Balancing Criterion	Rating	Detailed Analysis
Cost (Base Year 2018)		
Estimated capital costs	$20,000,000	
Estimated nondiscounted operations and maintenance and periodic cost	$170,400,000	
Total nondiscounted cost	$191,000,000	

IC = institutional control
MNA = monitored natural attenuation
P&T = pump and treat
RAO = remedial action objective

Effectiveness

Under Option 1, the footprint of the chromium plume associated with sources is controlled by P&T for 25 years, and the southeast chromium plume attenuates to below cleanup levels in 275 years. ICs are used to protect against inadvertent exposure until RAOs are achieved. ICs perform well at the Hanford Site because the measures are comprehensive, with enough redundancy to ensure that protectiveness is maintained even if one measure fails.

There is no risk to the community due to the remote location of the plumes. Some short-term risk to construction workers may arise during well installation and monitoring well network O&M activities. However, this work would be performed by experienced workers using well-established Hanford Site safe work processes and personal protective equipment (PPE).

Periodic groundwater sampling performed to track MNA effectiveness will ensure that the environment is protected during remedy implementation.

Implementability

Option 1 is readily implementable. The activities contained within this option, including extraction/injection well installation, treatment of chromium-contaminated groundwater using IX resin, groundwater monitoring, data evaluation, and maintenance of ICs, are already performed on a routine basis at the Hanford Site.

Cost

The estimated total nondiscounted cost for Option 1 is $191 million. This cost includes a capital cost of $20 million, and nondiscounted O&M and periodic costs of $170.4 million. The capital costs are associated with the construction of the source control system, while the majority of the O&M and periodic costs are associated with monitoring for 275 years.

4.3.2.3 Option 2a – Source Control, 25 Years Active Remediation for Southeast Chromium Plume Using Onsite IX Treatment, and 120 Years of MNA

Option 2a includes the following components:

- Active groundwater remediation using P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib (one extraction well at each of the two sites) for 25 years at a total flow rate of 379 L/min (100 gal/min).

- Active groundwater remediation using P&T for the southeast chromium plume using 8 extraction wells and 11 injection wells for 25 years at a total flow rate of 1,893 L/min (500 gal/min).
- Groundwater treatment for chromium at a new onsite treatment facility using IX resin with a design capacity of 2,839 L/min (750 gal/min). Injection of treated water would occur in the southeast chromium plume area.
- MNA and groundwater ICs controls for 120 years.

Figure 4-28 provides a diagram depicting the groundwater extraction, treatment, and injection flows for this option using a new standalone onsite treatment building and IX resin treatment trains. Figure 4-13 shows groundwater extraction and injection well locations for Option 2a.

The individual analysis of the balancing criteria for Option 2a is summarized below and shown in Table 4-7.

Effectiveness

Under Option 2a, the footprint of the chromium plume associated with sources is controlled by P&T for 25 years. Active remediation on the southeast chromium plume reduces the mass by 65% after 25 years of P&T, while ICs controls are used to protect against inadvertent exposure until RAOs are achieved. ICs perform well at the Hanford Site because the measures are comprehensive, with enough redundancy to ensure that protectiveness is maintained even if one measure fails.

There is no risk to the community due to the remote location of the plumes. Some short-term risk to construction workers may arise during well installation, treatment system construction, and treatment system O&M activities. However, this work would be performed by experienced workers using well-established Hanford Site safe work processes and PPE.

Periodic groundwater sampling performed to track MNA effectiveness will ensure that the environment is protected during remedy implementation.

Implementability

Option 2a is readily implementable. The activities contained within this option, including extraction/injection well installation, treatment of chromium-contaminated groundwater using IX resin, groundwater monitoring, data evaluation, and maintenance of ICs, are already performed on a routine basis at the Hanford Site.

Cost

The estimated total nondiscounted cost for Option 2a is $263 million. This cost includes a capital cost of $80.1 million, and nondiscounted O&M and periodic costs of $182.8 million.

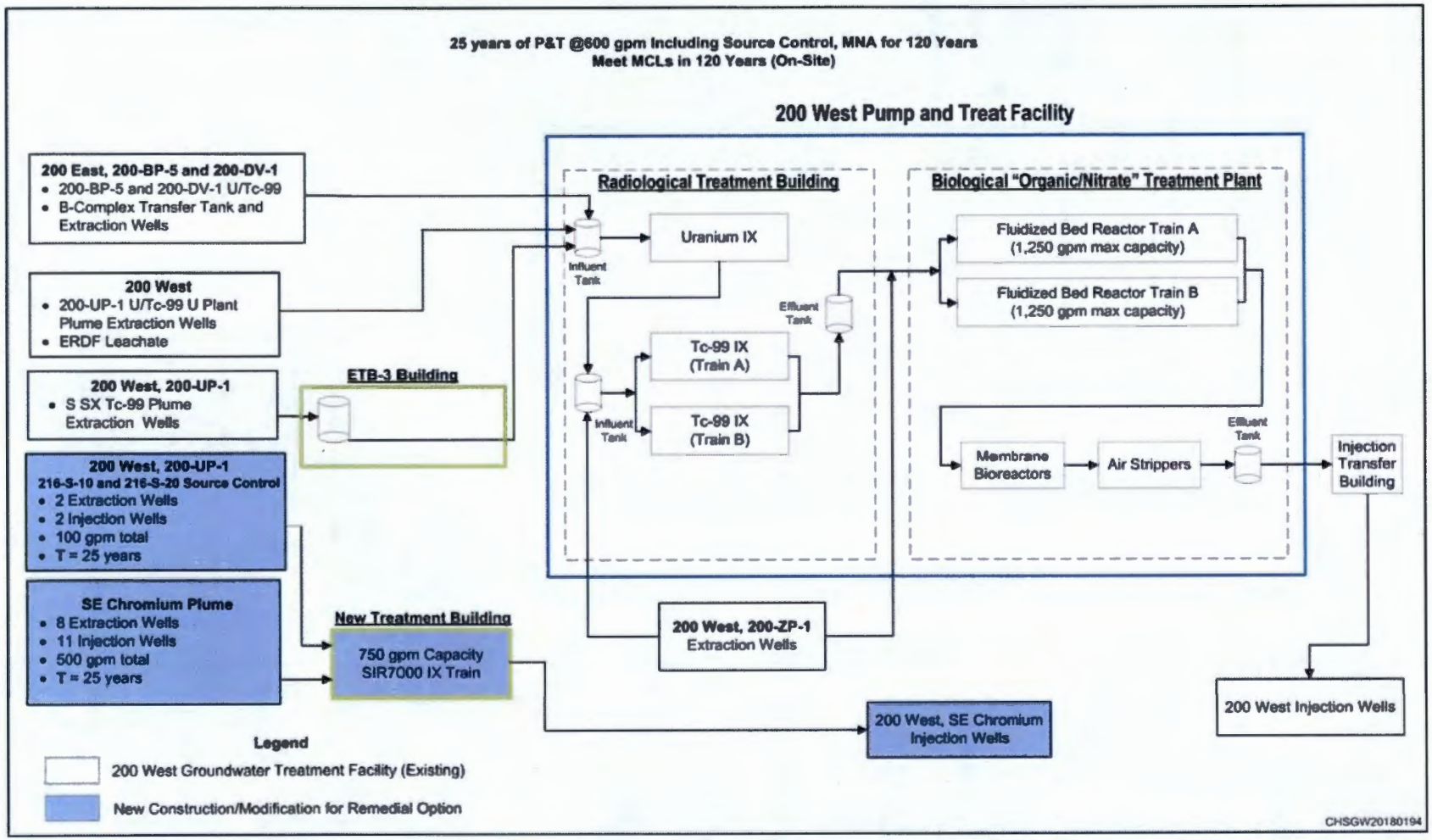


Figure 4-28. Conceptual Block Flow Diagram for Option 2a – Source Control and 25 Years Active Remediation (New Onsite Facility) at 2,272 L/min (600 gal/min)

Table 4-7. Individual Analysis for Option 2a – Source Control, 25 Years Active Remediation Using Onsite IX Treatment for Southeast Chromium Plume, and MNA

Balancing Criterion	Rating	Detailed Analysis
Effectiveness	★★★☆	
Magnitude of residual risk		No significant residual risk after 120 years because plume is below RAOs.
Degree of expected reduction in toxicity, mobility, and volume through treatment		Toxicity and volume reductions for chromium is 65% through P&T over first 25 years. Southeast chromium plume attenuates below RAOs after the 120-year remedial action period.
Adequacy and reliability of controls		ICs maintained for land and groundwater use during the entire 120-year remedial action period.
Short-term risks to community during remedial actions		Due to remote site location, no increased risk to the community during construction, P&T operation, and passive treatment (MNA) remedy phase.
Protection of workers during remedial actions		Onsite workers will adhere to health and safety plan and personal protective equipment requirements during construction, and operation to ensure protection.
Environmental impacts		Groundwater monitoring during remedy implementation will provide information on plume migration and chromium concentration trends. Potential impacts to ecological environment due to remote site location.
Time until cleanup levels achieved		120 years
Implementability	★★★☆	
Ability to construct and operate the technology		P&T technology is widely used at the Hanford Site. There is plentiful construction, operation, and optimization experience available for chromium. Additional monitoring can readily be incorporated into existing monitoring programs. ICs are widely used at the Hanford Site. Construction of onsite treatment system and facility will be required.
Reliability of the technology		P&T treatment technologies that will be used to address chromium has proven reliability in the 100 Areas.
Ease of undertaking additional remedial actions, if necessary		Additional extraction and injection wells can be readily installed if treatment capacity available.
Ability to monitor effectiveness of remedy		Groundwater monitoring is the primary technology used for assessing P&T effectiveness, natural attenuation process, adequacy of ICs, and tracking chromium.
Ability to obtain approvals from other agencies		No issues expected.
Coordination with other agencies		No issues expected.

Table 4-7. Individual Analysis for Option 2a – Source Control, 25 Years Active Remediation Using Onsite IX Treatment for Southeast Chromium Plume, and MNA

Balancing Criterion	Rating	Detailed Analysis
Availability of offsite treatment, storage, and disposal services and capacity		Readily available onsite at the Environmental Restoration Disposal Facility.
Availability of necessary equipment and specialists		Readily available.
Availability of prospective technologies		Technologies readily available.
Cost (Base Year 2018)		
Estimated capital costs	$80,100,000	
Estimated nondiscounted operations and maintenance and periodic cost	$182,800,000	
Total nondiscounted cost	$263,000,000	

IC = institutional control
MNA = monitored natural attenuation
P&T = pump and treat
RAO = remedial action objective

4.3.2.4 Option 2b – Source Control, 25 Years Active Remediation for Southeast Chromium Plume Using IX Treatment at 200 West P&T, and 120 Years of MNA

Option 2b includes the following components:

- Active groundwater remediation using P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib (one extraction well at each of the two sites) for 25 years at a total flow rate of 379 L/min (100 gal/min).
- Active groundwater remediation using P&T for southeast chromium plume using 8 extraction wells and 11 injection wells for 25 years at a total flow rate of 1,893 L/min (500 gal/min).
- Groundwater treatment for southeast chromium plume at the 200 West P&T with the addition of one IX vessel in the radiological treatment building. Minimum design capacity of 2,839 L/min (750 gal/min) is required. A new transfer station would be required to convey water from the southeast chromium plume to the 200 West P&T. Injection of treated water would occur in the southeast chromium plume area.
- MNA and groundwater monitoring for chromium for 120 years.
- Maintenance of ICs for 120 years.

Figure 4-29 provides a diagram depicting the groundwater extraction, treatment, and injection flows for this option using the existing 200 West P&T. Figure 4-13 shows groundwater extraction and injection well locations for Option 2b.

The individual analysis of the balancing criteria for Option 2b is summarized below and shown in Table 4-8.

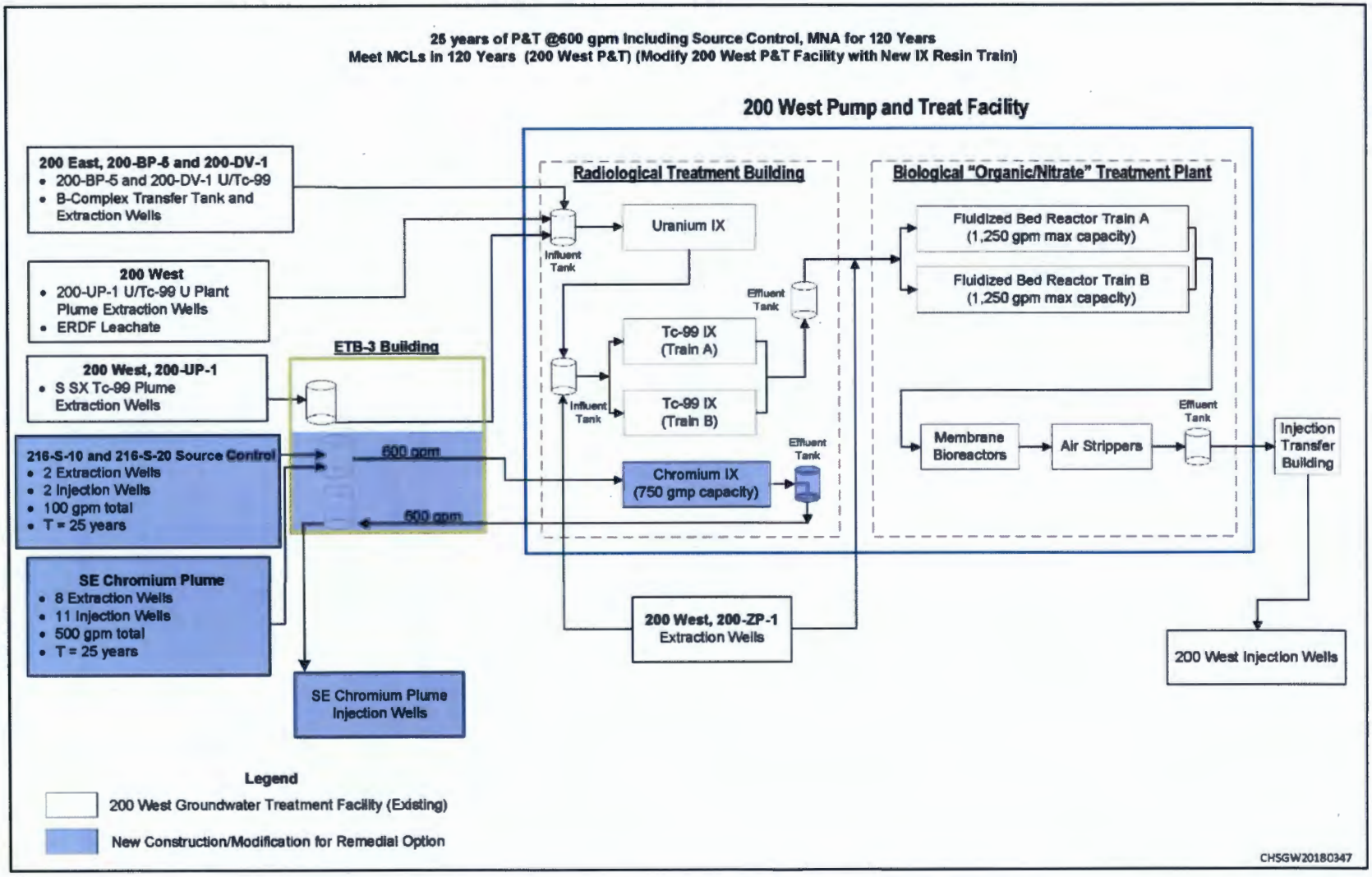


Figure 4-29. Conceptual Block Flow Diagram for Option 2b – Source Control and 25 Years Active Remediation (200 West P&T) at 2,272 L/min (600 gal/min) Using IX Treatment

Table 4-8. Individual Analysis for Option 2b – Source Control, 25 Years Active Remediation Using IX Treatment at the 200 West P&T for Southeast Chromium Plume, and MNA

Balancing Criterion	Rating	Detailed Analysis
Effectiveness	★★★☆	
Magnitude of residual risk		No significant residual risk after 120 years because plume is below RAOs.
Degree of expected reduction in toxicity, mobility, and volume through treatment		Toxicity and volume reductions for chromium is 65% through P&T over first 25 years. Southeast chromium plume attenuates below RAOs after the 120-year remedial action period.
Adequacy and reliability of controls		ICs maintained for land and groundwater use during the entire 120-year remedial action period.
Short-term risks to community during remedial actions		Due to remote site location, no increased risk to the community during construction, P&T operation, and passive treatment (MNA) remedy phase.
Protection of workers during remedial actions		Onsite workers will adhere to health and safety plan and personal protective equipment requirements during construction and operation to ensure protection.
Environmental impacts		Groundwater monitoring during remedy implementation will provide information on plume migration and chromium concentration trends. Potential impacts to ecological environment due to remote site location.
Time until cleanup levels achieved		120 years
Implementability	★★★☆	
Ability to construct and operate the technology		P&T technology is widely used at the Hanford Site. There is plentiful construction, operation, and optimization experience available for chromium. Additional monitoring can readily be incorporated into existing monitoring programs. ICs are widely used at the Hanford Site. Modifications to the 200 West P&T to add ion-exchange vessel are straightforward.
Reliability of the technology		P&T treatment technologies that will be used to address chromium has proven reliability in the 100 Areas.
Ease of undertaking additional remedial actions, if necessary		Additional extraction and injection wells can be readily installed if treatment capacity available.
Ability to monitor effectiveness of remedy		Groundwater monitoring is the primary technology used for assessing P&T effectiveness, natural attenuation process, adequacy of ICs, and for tracking chromium.
Ability to obtain approvals from other agencies		No issues expected.
Coordination with other agencies		No issues expected.
Availability of offsite treatment, storage, and disposal services and capacity		Readily available onsite at the Environmental Restoration Disposal Facility.

Table 4-8. Individual Analysis for Option 2b – Source Control, 25 Years Active Remediation Using IX Treatment at the 200 West P&T for Southeast Chromium Plume, and MNA

Balancing Criterion	Rating	Detailed Analysis
Availability of necessary equipment and specialists		Readily available.
Availability of prospective technologies		Technologies readily available.
Cost (Base Year 2018)		
Estimated capital costs	$89,900,000	
Estimated nondiscounted operations and maintenance and periodic cost	$181,200,000	
Total nondiscounted cost	$271,000,000	

IC = institutional control
MNA = monitored natural attenuation
P&T = pump and treat
RAO = remedial action objective

Effectiveness

Under Option 2b, the footprint of the chromium plume associated with sources is controlled by P&T for 25 years. Active remediation on the southeast chromium plume reduces the mass by 65% after 25 years of P&T, while the remaining portion of the plume attenuates to below cleanup levels in 120 years. ICs are used to protect against inadvertent exposure until RAOs are achieved. ICs perform well at the Hanford Site because the measures are comprehensive, with enough redundancy to ensure that protectiveness is maintained even if one measure fails.

There is no risk to the community due to the remote location of the plumes. Some short-term risk to construction workers may arise during well installation, treatment system modifications, and treatment system O&M activities. However, this work would be performed by experienced workers using well-established Hanford Site safe work processes and PPE.

Periodic groundwater sampling performed to track MNA effectiveness will ensure that the environment is protected during remedy implementation.

Implementability

Option 2b is readily implementable. The activities contained within this option, including extraction/injection well installation, treatment of chromium-contaminated groundwater using IX at the 200 West P&T, groundwater monitoring, data evaluation, and maintenance of ICs, are already performed on a routine basis at the Hanford Site. However, the treatment facility modifications associated with this option would require the IX vessel for chromium treatment to be placed in the radiological treatment building.

Cost

The estimated total nondiscounted cost for Option 2b is $271 million. This cost includes a capital cost of $89.9 million, and nondiscounted O&M and periodic costs of $181.2 million.

4.3.2.5 Option 2c – Source Control, 25 Years Active Remediation for Southeast Chromium Plume Using Biological Treatment at 200 West P&T, and 120 Years of MNA

Option 2c includes the following components:

- Active groundwater remediation using P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib (one extraction well at each of the two sites) for 25 years at a total flow rate of 379 L/min (100 gal/min).
- Active groundwater remediation using P&T for southeast chromium plume using 8 extraction wells and 11 injection wells for 25 years at a total flow rate of 1,893 L/min (500 gal/min).
- Groundwater treatment for southeast chromium plume at the 200 West P&T with the addition of one additional fluidized bed reactor, two membrane biological reactors, an air stripper, and two additional granular activated carbon containers. Minimum design capacity of 2,839 L/min (750 gal/min) is required. A new transfer station would be required to convey water from the southeast chromium plume to the 200 West P&T. Injection of treated water would occur in the southeast chromium plume area.
- MNA and groundwater monitoring for chromium for 120 years.
- Maintenance of ICs for 120 years.

Figure 4-30 provides a diagram depicting the groundwater extraction, treatment, and injection flows for this option using the existing 200 West P&T. Figure 4-13 shows groundwater extraction and injection well locations for Option 2c.

The individual analysis of the balancing criteria for Option 2c is summarized below and shown in Table 4-9.

Effectiveness

Under Option 2c, the footprint of the chromium plume associated with sources is controlled by P&T for 25 years. Active remediation on the southeast chromium plume reduces the mass by 65% after 25 years of P&T, while the remaining portion of the plume attenuates to below cleanup levels in 120 years. ICs are used to protect against inadvertent exposure until RAOs are achieved. ICs perform well at the Hanford Site because the measures are comprehensive, with enough redundancy to ensure that protectiveness is maintained even if one measure fails.

There is no risk to the community due to the remote location of the plumes. Some short-term risk to construction workers may arise during well installation, treatment system modifications, and treatment system O&M activities. However, this work would be performed by experienced workers using well-established Hanford Site safe work processes and PPE.

Periodic groundwater sampling performed to track MNA effectiveness will ensure that the environment is protected during remedy implementation.

Implementability

Option 2c is implementable. The activities contained within this option, including extraction/injection well installation, treatment of chromium-contaminated groundwater using the 200 West P&T, groundwater monitoring, data evaluation, and maintenance of ICs, are already performed on a routine basis at the Hanford Site. However, as described above, significant treatment facility modification would be required for the 200 West P&T under this option.

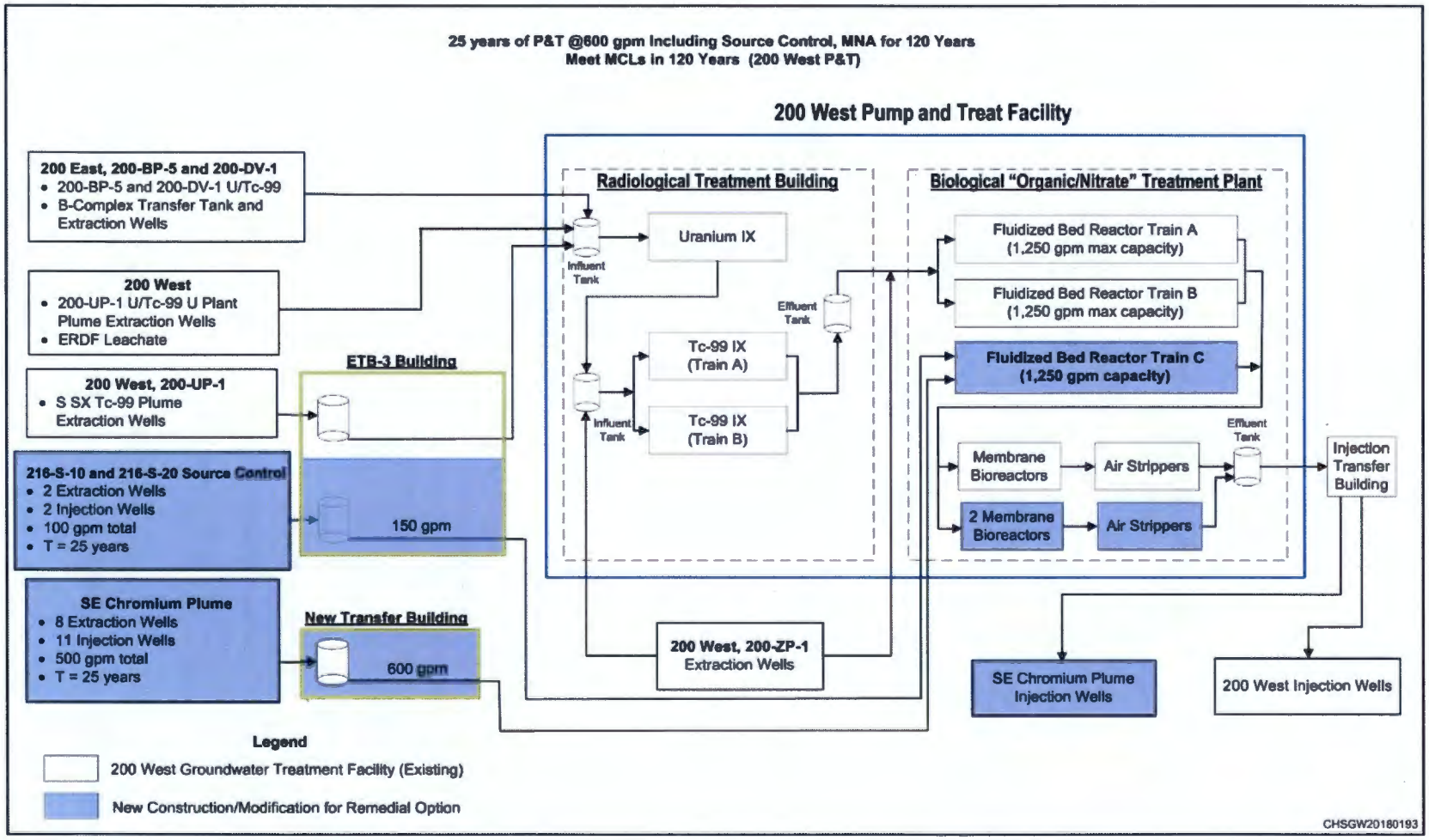


Figure 4-30. Conceptual Block Flow Diagram for Option 2c – Source Control and 25 Years Active Remediation (200 West P&T) at 2,272 L/min (600 gal/min) Using Biological Treatment

Table 4-9. Individual Analysis for Option 2c – Source Control, 25 Years Active Remediation Using 200 West P&T for Southeast Chromium Plume, and MNA

Balancing Criterion	Rating	Detailed Analysis
Effectiveness	★★★☆	
Magnitude of residual risk		No significant residual risk after 120 years because plume is below RAOs.
Degree of expected reduction in toxicity, mobility, and volume through treatment		Toxicity and volume reductions for chromium is 65% through P&T over first 25 years. Southeast chromium plume attenuates below RAOs after the 120-year remedial action period.
Adequacy and reliability of controls		ICs maintained for land and groundwater use during the entire 120-year remedial action period.
Short-term risks to community during remedial actions		Due to remote site location, no increased risk to the community during construction, P&T operation, and passive treatment (MNA) remedy phase.
Protection of workers during remedial actions		Onsite workers will adhere to health and safety plan and personal protective equipment requirements during construction and operation to ensure protection.
Environmental impacts		Groundwater monitoring during remedy implementation will provide information on plume migration and chromium concentration trends. Potential impacts to ecological environment due to remote site location.
Time until cleanup levels achieved		120 years
Implementability	★★☆☆	
Ability to construct and operate the technology		P&T technology is widely used at the Hanford Site. There is plentiful construction, operation, and optimization experience available for chromium. Additional monitoring can readily be incorporated into existing monitoring programs. ICs are widely used at the Hanford Site. Additional treatment capacity at the 200 West P&T will require significant modifications.
Reliability of the technology		200 West P&T treatment technologies that will be used to address chromium has proven reliability.
Ease of undertaking additional remedial actions, if necessary		Additional extraction and injection wells can be readily installed if treatment capacity available.
Ability to monitor effectiveness of remedy		Groundwater monitoring is the primary technology used for assessing P&T effectiveness, natural attenuation process, adequacy of ICs, and for tracking chromium.
Ability to obtain approvals from other agencies		No issues expected.
Coordination with other agencies		No issues expected.
Availability of offsite treatment, storage, and disposal services and capacity		Readily available onsite at the Environmental Restoration Disposal Facility.

Table 4-9. Individual Analysis for Option 2c – Source Control, 25 Years Active Remediation Using 200 West P&T for Southeast Chromium Plume, and MNA

Balancing Criterion	Rating	Detailed Analysis
Availability of necessary equipment and specialists		Readily available.
Availability of prospective technologies		Technologies readily available.
Cost (Base Year 2018)		
Estimated capital costs	$156,000,000	
Estimated nondiscounted operations and maintenance and periodic cost	$461,600,000	
Total nondiscounted cost	$617,000,000	

IC = institutional control
MNA = monitored natural attenuation
P&T = pump and treat
RAO = remedial action objective

Cost

The estimated total nondiscounted cost for Option 2c is $617 million. This cost includes a capital cost of $156 million, and nondiscounted O&M and periodic costs of $461.6 million.

4.3.2.6 Option 3 - Source Control and 25 Years Active Remediation to Below Cleanup Levels for Southeast Chromium Plume Using Onsite IX Treatment

Option 3 includes the following components:

- Active groundwater remediation using P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib (one extraction well at each of the two sites) for 25 years at a total flow rate of 379 L/min (100 gal/min).
- Active groundwater remediation using P&T for southeast chromium plume using 54 remedy wells for 13 years at a total flow rate of 10,221 L/min (2,700 gal/min), followed by using 44 remedy wells for 12 years at a total flow rate of 8,328 L/min (2,200 gal/min).
- Groundwater treatment for chromium at a new onsite treatment facility using IX resin with a design capacity of 11,356 L/min (3,000 gal/min). Injection of treated water would occur in the southeast chromium plume area.
- Maintenance of ICs for 25 years.

Figure 4-31 provides a diagram depicting the groundwater extraction, treatment, and injection flows for this option using a new, large, standalone onsite treatment building and IX resin treatment trains. Figure 4-21 shows groundwater extraction and injection well locations for Option 3.

The individual analysis of the balancing criteria for Option 3 is summarized below and shown in Table 4-10.

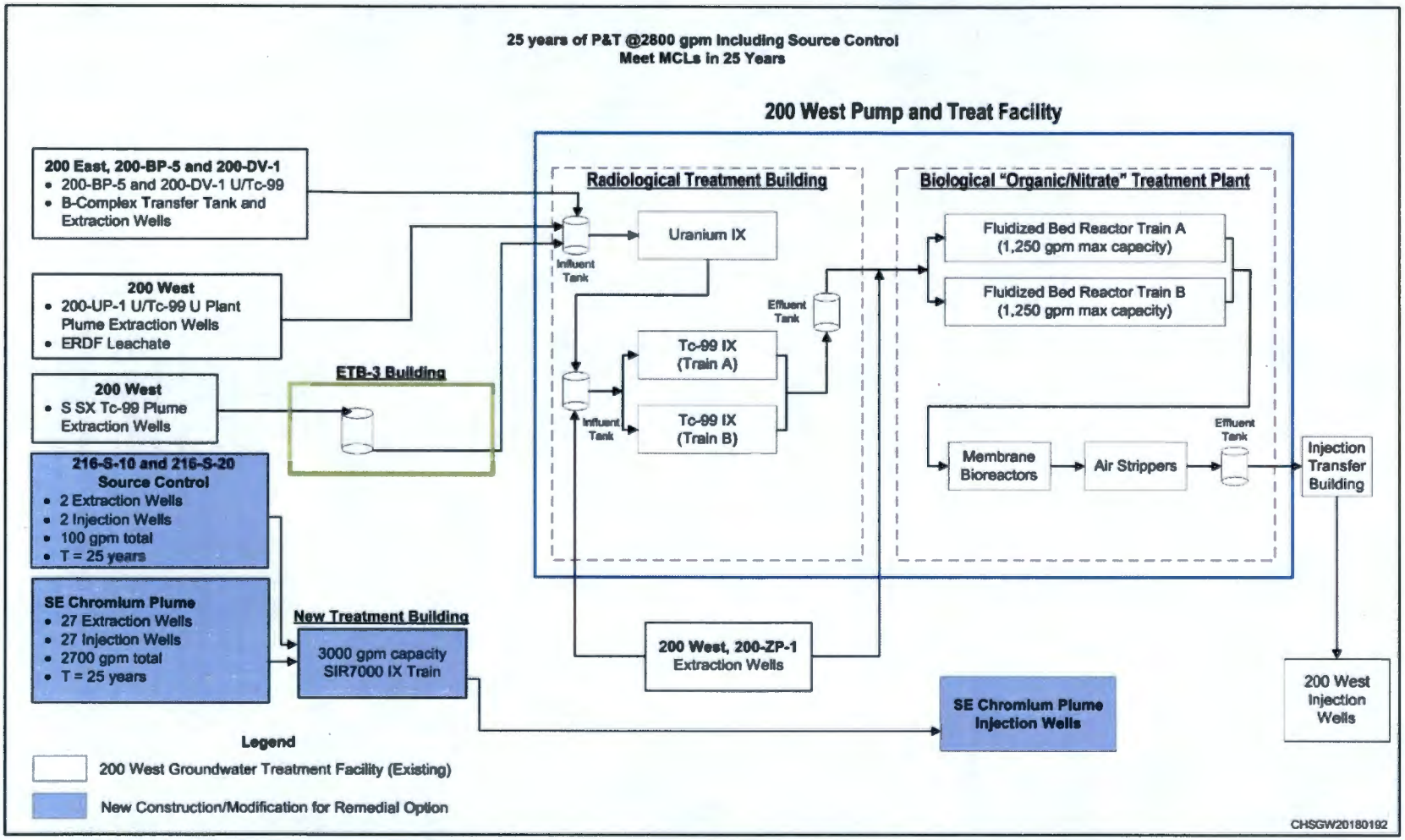


Figure 4-31. Conceptual Block Flow Diagram for Option 3 – Source Control and 25 Years Active Remediation (New Onsite Facility) at 10,600 L/min (2,800 gal/min) for 13 Years and 8,707 L/min (2,300 gal/min) for 12 Years

Table 4-10. Individual Analysis for Option 3 – Source Control and 25 Years Active Remediation to Below Cleanup Levels for Southeast Chromium Plume Using Onsite IX Treatment

Balancing Criterion	Rating	Detailed Analysis
Effectiveness	★★★★	
Magnitude of residual risk		No significant residual risk after 25 years because plume is below RAOs.
Degree of expected reduction in toxicity, mobility, and volume through treatment		Toxicity and volume reductions for chromium to below cleanup levels through P&T over first 25 years. No MNA required.
Adequacy and reliability of controls		ICs maintained for land and groundwater use during the entire 25-year remedial action period.
Short-term risks to community during remedial actions		Due to remote site location, no increased risk to the community during construction and P&T operation remedy phase.
Protection of workers during remedial actions		Onsite workers will adhere to health and safety plan and personal protective equipment requirements during construction, and operation to ensure protection.
Environmental impacts		Groundwater monitoring during remedy implementation will provide information on plume migration and chromium concentration trends. Potential significant impacts to ecological environment due to remote site location and required infrastructure.
Time until cleanup levels achieved		25 years
Implementability	★☆☆☆	
Ability to construct and operate the technology		P&T technology is widely used at the Hanford Site. There is plentiful construction, operation, and optimization experience available for chromium. Additional monitoring can readily be incorporated into existing monitoring programs. ICs are widely used at the Hanford Site. However due to the number of wells required, remedy implementation will not be timely. Construction of large onsite treatment system and facility will be required.
Reliability of the technology		P&T treatment technologies that will be used to address chromium have proven reliability in the 100 Areas.
Ease of undertaking additional remedial actions, if necessary		Additional extraction and injection wells can be installed, if treatment capacity available.
Ability to monitor effectiveness of remedy		Groundwater monitoring is the primary technology used for assessing P&T effectiveness, adequacy of ICs, and tracking chromium.
Ability to obtain approvals from other agencies		No issues expected.
Coordination with other agencies		No issues expected.
Availability of offsite treatment, storage, and disposal services and capacity		Readily available onsite at the Environmental Restoration Disposal Facility.

Table 4-10. Individual Analysis for Option 3 – Source Control and 25 Years Active Remediation to Below Cleanup Levels for Southeast Chromium Plume Using Onsite IX Treatment

Balancing Criterion	Rating	Detailed Analysis
Availability of necessary equipment and specialists		Readily available.
Availability of prospective technologies		Technologies readily available.
Cost (Base Year 2018)		
Estimated capital costs	$220,000,000	
Estimated nondiscounted operations and maintenance and periodic cost	$443,000,000	
Total nondiscounted cost	$663,000,000	

IC = institutional control
MNA = monitored natural attenuation
P&T = pump and treat
RAO = remedial action objective

Effectiveness

Under Option 3, the footprint of the chromium plume associated with sources is controlled by P&T for 25 years. Active remediation on the southeast chromium plume reduces the plume size to below cleanup levels after 25 years of P&T. ICs are used to protect against inadvertent exposure until RAOs are achieved.

There is no risk to the community due to the remote location of the plumes. Some short-term risk to construction workers may arise during well installation, treatment system construction, and treatment system O&M activities. However, this work would be performed by experienced workers using well-established Hanford Site safe work processes and PPE.

Periodic groundwater sampling performed to track P&T effectiveness to ensure that the environment is protected during remedy implementation.

Implementability

The activities contained within Option 3, including extraction/injection well installation, treatment of chromium-contaminated groundwater using IX resin, groundwater monitoring, data evaluation, and maintenance of ICs, are already performed on a routine basis at the Hanford Site. Option 3 is implementable; however, due to the large number of extraction and injection wells, road construction, treatment system construction, and associated electrical and piping, the remedy implementation will not be timely.

Cost

The estimated total nondiscounted cost for Option 3 is $663 million. This cost includes a capital cost of $220 million, and nondiscounted O&M and periodic costs of $443 million.

4.3.3 Comparative Analysis of Remedial Options

The comparative analysis of the remedial options identifies the relative advantages and disadvantages of each option in the context of the CERCLA evaluation criteria so the key trade-offs can be identified and balanced. The comparative analysis provides a measure of the relative performance of the options against each evaluation criterion. Table 4-11 provides a comparative analysis and summary for each of the options.

4.3.3.1 Effectiveness

All of the options provide comparable levels of effectiveness if ICs are reliable in the long term. Otherwise, Option 3 is the most effective with a remedy duration of 25 years, followed by Options 2a, 2b, and 2c because the remedy duration is considerably shorter (120 years) than Option 1 (275 years).

Options 2a, 2b, 2c, and 3 provide the highest degree of TMV reduction for chromium because a significant portion of the mass is removed from the aquifer using P&T, with treatment residuals immobilized and disposed at a secure long-term management facility (ERDF). Under Option 3, P&T is used to reduce the concentrations of the southeast chromium plume to below cleanup levels using a large number of extraction and injection wells. For Options 2a 2b, and 2c, P&T is used to capture 65% of the southeast chromium mass using lower pumping rates and include fewer extraction and injection wells, with MNA accounting for the remaining portion of the plume. Option 1 provides source control and uses MNA over 275 years for reduction of the southeast chromium plume concentrations.

All of the options provide similar levels of effectiveness relative to protection of the community because the location is in a remote portion of the Hanford Site where community exposure would not occur.

With respect to protection of workers, work associated with these options can be performed safely with minimal risk to workers and the environment by conducting the work in accordance with existing Hanford Site safe work processes. As the scope of a remedial option grows, the potential for worker risk increases. Therefore, Option 1 would pose the least short-term risk to workers, followed by Options 2a, 2b, 2c, and 3, which involve significant use of P&T. However, Option 3 was rated higher on effectiveness because the larger P&T flow volume significantly decreases the overall duration of the remedy to 25 years (compared to 120 to 275 years for Options 1 and 2).

4.3.3.2 Implementability

All of the options are readily implemented using existing Hanford Site safe work procedures. However, as the scope of an option grows, the degree of difficulty associated with its implementation increases. Option 1 is the easiest to implement because extraction/injection wells, pipelines, and treatment capacity would be used only for source control, and MNA would be used for the southeast chromium plume. Options 2a, 2b, and 2c are expected to pose implementation challenges because of either the modifications required to the 200 West P&T to increase capacity or the construction of a new onsite treatment facility. Option 3 is expected to pose the greatest implementation challenge because of the large number of extraction and injection wells required, pipelines, construction of a new treatment facility, and operation of the treatment process associated with the larger flow volume.

Table 4-11. Summary of Comparative Analysis of Remedial Options for the 200-UP-1 OU Southeast Chromium Plume

Criteria	No Action	Option 1 – 25 Years of P&T for Source Control Using Onsite Treatment and 275 Years of MNA for Southeast Chromium Plume	Option 2a – 25 Years of P&T for Source Control and Southeast Chromium Plume Using Onsite IX Treatment and 120 Years of MNA for Southeast Chromium Plume	Option 2b – 25 Years of P&T for Source Control and Southeast Chromium Plume Using IX Treatment at 200 West P&T and 120 Years of MNA for Southeast Chromium Plume	Option 2c – 25 Years of P&T for Source Control and Southeast Chromium Plume Using Biological Treatment at 200 West P&T and 120 Years of MNA for Southeast Chromium Plume	Option 3 – 25 Years of P&T for Source Control and Southeast Chromium Plume Using Onsite IX Treatment
Effectiveness						
Magnitude of residual risk	Not evaluated.	Active source control for chromium (total and hexavalent) plume using smaller scale IX P&T reduces risk; ICs prevent exposure until MNA achieves cleanup levels for southeast chromium plume.	Active source control and aggressive treatment for chromium (total and hexavalent) plume using onsite IX P&T reduces risk; ICs prevent exposure until active remediation and MNA achieve cleanup levels for southeast chromium plume.	Active source control and aggressive treatment for chromium (total and hexavalent) plume using 200 West P&T reduces risk; ICs prevent exposure until active remediation and MNA achieve cleanup levels for southeast chromium plume.	Active source control and aggressive treatment for chromium (total and hexavalent) plume using 200 West P&T reduces risk; ICs prevent exposure until active remediation and MNA achieve cleanup levels for southeast chromium plume.	Active source control and most aggressive treatment for chromium (total and hexavalent) plume using onsite IX P&T reduces risk; ICs prevent exposure until active remediation achieves cleanup levels for southeast chromium plume.
Degree of expected reduction in toxicity, mobility, and volume through treatment	Not evaluated.	Volume of groundwater treated and mass of contaminants removed is expected to be minimal from source control compared to the larger P&T systems for the southeast chromium plume under Options 2 and 3.	Volume of groundwater treated and mass of contaminants removed for the southeast chromium plume is expected to be good (plume area reduced by 65%). Under this option the remaining portion of the southeast chromium plume attenuates in 120 years.	Volume of groundwater treated and mass of contaminants removed for the southeast chromium plume is expected to be good (plume area reduced by 65%). Under this option the remaining portion of the southeast chromium plume attenuates in 120 years.	Volume of groundwater treated and mass of contaminants removed for the southeast chromium plume is expected to be good (plume area reduced by 65%). Under this option the remaining portion of the southeast chromium plume attenuates in 120 years.	Because this option includes an aggressive P&T component, the volume of groundwater treatment and mass of contaminants removed is greatest under this option. Under this option, the treatment occurs within a shorter timeframe.
Adequacy and reliability of controls	Not evaluated.	Active treatment using P&T technology is a reliable means for removing and controlling contaminant mass at source waste sites. ICs are reliable tool for preventing exposure until cleanup levels achieved.	Active treatment using P&T technology is a reliable means for controlling and removing contaminant mass. ICs are reliable tool for preventing exposure until cleanup levels achieved.	Active treatment using P&T technology is a reliable means for controlling and removing contaminant mass. ICs are reliable tool for preventing exposure until cleanup levels achieved.	Active treatment using P&T technology is a reliable means for controlling and removing contaminant mass. ICs are reliable tool for preventing exposure until cleanup levels achieved.	Active treatment using P&T technology is a reliable means for controlling and removing contaminant mass. ICs are reliable tool for preventing exposure until cleanup levels achieved.
Short-term risks to community during remedial actions	Not evaluated.	Due to remote site location no increased risk to community during construction and system operation.	Due to remote site location no increased risk to community during construction and system operation.	Due to remote site location no increased risk to community during construction and system operation.	Due to remote site location no increased risk to community during construction and system operation.	Due to remote site location no increased risk to community during construction and system operation.
Protection of workers during remedial actions	Not evaluated.	Onsite workers will adhere to health and safety plan and personal protective equipment requirements during construction and operation to ensure protection.	Onsite workers will adhere to health and safety plan and personal protective equipment requirements during construction and operation to ensure protection.	Onsite workers will adhere to health and safety plan and personal protective equipment requirements during construction and operation to ensure protection.	Onsite workers will adhere to health and safety plan and personal protective equipment requirements during construction and operation to ensure protection.	Onsite workers will adhere to health and safety plan and personal protective equipment requirements during construction and operation to ensure protection.
Environmental impacts	Not evaluated.	Groundwater monitoring during remedy implementation will provide information on plume migration and concentration trends.	Effluent from groundwater treatment operations will be monitored to ensure that standards are met. Groundwater monitoring during remedy implementation will provide information on plume migration and concentration trends.	Effluent from groundwater treatment operations will be monitored to ensure that standards are met. Groundwater monitoring during remedy implementation will provide information on plume migration and concentration trends.	Effluent and emissions from groundwater treatment operations will be monitored to ensure that standards are met. Groundwater monitoring during remedy implementation will provide information on plume migration and concentration trends.	Effluent and emissions from groundwater treatment operations will be monitored to ensure that standards are met. Groundwater monitoring during remedy implementation will provide information on plume migration and concentration trends.
Time until cleanup levels achieved	Not evaluated.	25 years for active treatment for source control, 275 years for MNA of southeast chromium plume.	25 years for active treatment for source control and southeast chromium plume, 120 years for MNA for southeast chromium plume.	25 years for active treatment for source control and southeast chromium plume, 120 years for MNA for southeast chromium plume.	25 years for active treatment for source control and southeast chromium plume, 120 years for MNA for southeast chromium plume.	25 years for active treatment for source control and southeast chromium plume, no MNA for southeast chromium plume.

Table 4-11. Summary of Comparative Analysis of Remedial Options for the 200-UP-1 OU Southeast Chromium Plume

Criteria	No Action	Option 1 – 25 Years of P&T for Source Control Using Onsite Treatment and 275 Years of MNA for Southeast Chromium Plume	Option 2a – 25 Years of P&T for Source Control and Southeast Chromium Plume Using Onsite IX Treatment and 120 Years of MNA for Southeast Chromium Plume	Option 2b – 25 Years of P&T for Source Control and Southeast Chromium Plume Using IX Treatment at 200 West P&T and 120 Years of MNA for Southeast Chromium Plume	Option 2c – 25 Years of P&T for Source Control and Southeast Chromium Plume Using Biological Treatment at 200 West P&T and 120 Years of MNA for Southeast Chromium Plume	Option 3 – 25 Years of P&T for Source Control and Southeast Chromium Plume Using Onsite IX Treatment
Implementability						
Ability to construct and operate the technology	Not evaluated.	P&T technology is widely used at the Hanford Site. Plentiful construction, operation, and optimization experience available for chromium. Additional monitoring can readily be incorporated into existing monitoring programs. ICs used widely at the Hanford Site.	P&T technology is widely used at the Hanford Site. Plentiful construction, operation, and optimization experience available for chromium. Additional monitoring can readily be incorporated into existing monitoring programs. ICs used widely at the Hanford Site. Construction of onsite treatment system and facility will be required.	P&T technology is widely used at the Hanford Site. Plentiful construction, operation, and optimization experience available for chromium. Additional monitoring can readily be incorporated into existing monitoring programs. ICs used widely at the Hanford Site. Addition of IX vessel in radiological treatment building and associated facility modifications will be required.	P&T technology is widely used at the Hanford Site. Plentiful construction, operation, and optimization experience available for chromium. Additional monitoring can readily be incorporated into existing monitoring programs. ICs used widely at the Hanford Site. Additional treatment capacity will require significant modifications to 200 West P&T.	P&T technology is widely used at the Hanford Site. Plentiful construction, operation, and optimization experience available for chromium. Additional monitoring can readily be incorporated into existing monitoring programs. ICs used widely at the Hanford Site. Due to the number of wells required, construction will not be timely. Construction of large onsite treatment system and facility will be required.
Reliability of the technology	Not evaluated.	Monitoring and IC technologies are reliable.	P&T technologies for chromium have proven reliable in the 100 Areas.	P&T technologies for chromium have proven reliable in the 100 Areas.	200 West P&T technologies for chromium have proven reliable.	P&T technologies for chromium have proven reliable in the 100 Areas.
Ease of undertaking additional remedial actions, if necessary	Not evaluated.	Additional monitoring can readily be installed and incorporated into existing monitoring programs. ICs used widely at the Hanford Site.	Additional extraction and injection wells can be readily installed if treatment capacity is available.	Additional extraction and injection wells can be readily installed if treatment capacity is available.	Additional extraction and injection wells can be readily installed if treatment capacity is available.	Additional extraction and injection wells can be readily installed if treatment capacity is available.
Ability to monitor effectiveness of remedy	Not evaluated.	Monitoring of chromium and adequacy of ICs are important components of MNA.	Groundwater monitoring is the primary technology used for assessing P&T effectiveness, natural attenuation process, adequacy of ICs, and tracking chromium.	Groundwater monitoring is the primary technology used for assessing P&T effectiveness, natural attenuation process, adequacy of ICs, and tracking chromium.	Groundwater monitoring is the primary technology used for assessing P&T effectiveness, natural attenuation process, adequacy of ICs, and tracking chromium.	Groundwater monitoring is the primary technology used for assessing P&T effectiveness, adequacy of ICs, and tracking chromium.
Ability to obtain approvals from other agencies	Not evaluated.	No issues expected.	No issues expected.	No issues expected.	No issues expected.	No issues expected.
Coordination with other agencies	Not evaluated.	No issues expected.	No issues expected.	No issues expected.	No issues expected.	No issues expected.
Availability of offsite treatment, storage, and disposal services and capacity	Not evaluated.	Readily available onsite at ERDF.	Readily available onsite at ERDF.	Readily available onsite at ERDF.	Readily available onsite at ERDF.	Readily available onsite at ERDF.
Availability of necessary equipment and specialists	Not evaluated.	Readily available.	Readily available.	Readily available.	Readily available.	Readily available.
Availability of prospective technologies	Not evaluated.	Technologies readily available.	Technologies readily available.	Technologies readily available.	Technologies readily available.	Technologies readily available.

Table 4-11. Summary of Comparative Analysis of Remedial Options for the 200-UP-1 OU Southeast Chromium Plume

Criteria	No Action	Option 1 – 25 Years of P&T for Source Control Using Onsite Treatment and 275 Years of MNA for Southeast Chromium Plume	Option 2a – 25 Years of P&T for Source Control and Southeast Chromium Plume Using Onsite IX Treatment and 120 Years of MNA for Southeast Chromium Plume	Option 2b – 25 Years of P&T for Source Control and Southeast Chromium Plume Using IX Treatment at 200 West P&T and 120 Years of MNA for Southeast Chromium Plume	Option 2c – 25 Years of P&T for Source Control and Southeast Chromium Plume Using Biological Treatment at 200 West P&T and 120 Years of MNA for Southeast Chromium Plume	Option 3 – 25 Years of P&T for Source Control and Southeast Chromium Plume Using Onsite IX Treatment
Cost						
Estimated capital cost	$0	$20,000,000	$80,100,000	$89,900,000	$156,000,000	$220,000,000
Estimated nondiscounted operations and maintenance and periodic cost	$0	$170,400,000	$182,800,000	$181,200,000	$461,600,000	$443,000,000
Total nondiscounted cost	$0	$191,000,000	$263,000,000	$271,000,000	$617,000,000	$663,000,000

ERDF = Environmental Restoration Disposal Facility
IC = institutional control
IX = ion exchange
MNA = monitored natural attenuation
P&T = pump and treat

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4.3.3.3 Cost

Option 1 at a total nondiscounted cost of $191 million has the lowest cost, followed by Option 2a at $263 million, Option 2b at $271 million, Option 2c at $617 million, and Option 3 at $663 million.

The estimated costs developed for this report are significantly higher than those provided in the 200-UP-1 OU FS (DOE/RL-2009-122). The original cost estimate for remediating the southeast chromium plume was $89.4 million, which included two extraction wells and two injection wells with an extraction rate of 757 L/min (200 gal/min) based on the 2009 plume area of 573 ha (1,416 ac). As discussed in Chapter 3, the current plume size based on 2017 data shows that the plume size has almost doubled in size to 1,101 ha (2,720 ac).

Because of the increased size of the southeast chromium plume, significantly more infrastructure and capacity will be needed to remediate the plume, depending on which option is selected. Comparing the preliminary numbers provided in DOE/RL-2009-122 to those included in this report shows the following differences:

- Increased the number of extraction wells from 2 to a maximum of 27
- Increased the number of injection wells from 2 to a maximum of 27
- Increased treatment capacities from 757 L/min (200 gal/min) to a maximum of 10,211 L/min (2,700 gal/min)
- Additional treatment system components may be needed

In addition, the costs associated with source control were introduced and included in the cost estimates provided in this report.

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5 Conclusions and Recommendations

This report summarizes the southeast chromium plume remedial design investigation for the 200-UP-1 OU; updates the southeast chromium plume conceptual site model; and evaluates remedial options. The need for additional monitoring wells will be evaluated based on the remedial option selected. This report supports Tri-Party Agreement Milestone M-16-193 (Ecology et al., 1989) to complete the remedial design investigation of the southeast chromium plume.

5.1 Conclusions

During 2016 and 2017, 11 wells were drilled and sampled in the 200-UP-1 OU to refine the southeast chromium plume geometry. The refined plume geometry was used in numerical F&T models to develop and evaluate remedial options for the plume. The remedial options were compared based on their effectiveness, implementability, and cost.

5.1.1 Sampling and Analysis Plan Requirements

All of the 200-UP-1 OU SAP (DOE/RL-2014-27) requirements were met during the southeast chromium plume investigation.

Depth-discrete groundwater samples were collected during drilling of all 11 wells for vertical profiling of chromium concentrations. Samples were also collected after well development. Routine quarterly sampling began after well development; four quarters of routine sampling were completed for the first six wells drilled. Groundwater samples were collected from 28 nearby existing wells to support characterization of the southeast chromium plume area.

At each well, three split-spoon aquifer soil samples (only two from well 699-30-57) and three vertical profile groundwater samples (none from well 699-30-73) were collected and transferred to PNNL for research as part of the Deep Vadose Zone Applied Field Research Initiative. Depth-discrete soil samples were collected from drill cuttings within the unconfined aquifer for sieve analyses to design the well completion.

No vadose zone samples were collected for laboratory analysis.

5.1.2 Nature and Extent of Southeast Chromium Plume

The southeast chromium plume, as interpolated in the three-dimensional spatial model, is about twice as large as the interpretation prior to drilling the 11 characterization wells (Figure 3-8). The interpreted 2017 plume extends further to the east, south, and west than the interpreted 2015 plume. In each of these directions, the plume is bounded by wells with concentrations below the 48 µg/L cleanup level.

Concentrations within the plume vary laterally and vertically. A continuous region of relatively higher chromium concentrations (>100 µg/L) runs through the plume from west to east (Figure 4-3). This high-concentration area tends to occur deeper in the western part of the plume and shallower in the eastern part. The high-concentration region is primarily in the northern part of the plume.

Depth-discrete samples collected during drilling of the 11 characterization wells were evaluated to determine if the wells were affected by reducing conditions during drilling. The drilling process can create temporary reducing conditions in the aquifer that can cause hexavalent chromium (soluble) to reduce to trivalent chromium (insoluble), which would under-represent dissolved chromium plume concentrations. Selected depth-discrete samples from wells 699-27-68 and 699-30-70 were determined to have been affected by reducing conditions based on anomalously low hexavalent and total chromium

concentrations, relatively high manganese concentrations, and low DO. Reducing conditions were interpreted for depth-discrete results from wells 699-29-55 and 699-29-66 based on the higher dissolved chromium concentration in the post-development samples compared to the lower chromium concentrations in the depth-discrete samples and the relatively high manganese concentrations during drilling. No other wells were determined to have been substantially affected by reducing conditions.

The southeast chromium plume is inferred to have originated from REDOX wastewater discharges to the 216-S-10 Pond and Ditch and the 216-S-20 Crib (Section 1.2.2). The 216-S-10 Pond and Ditch are collocated with the 216-S-11 Pond, 216-S-17 Pond, 216-S-5 Crib, and 216-S-6 Crib.

The 2017 plume map and cross sections extending east from the 216-S-10 Pond and Ditch and 216-S-20 Crib source sites show that the southeast chromium plume is no longer connected to the 216-S-10 Pond and Ditch and 216-S-20 Crib source areas at concentrations >48 µg/L (Figure 3-7; Figures 6-2 and 6-3 in ECF-200UP1-17-0238 [provided as Appendix B of this report]). Well 699-30-73, which is located between the 216-S-10 Pond and Ditch and the southeast chromium plume, was sampled throughout the aquifer (from 73.26 to 115.87 m bgs) during drilling in October 2017. The maximum filtered total chromium concentration was 20.9 µg/L.

5.1.3 Remedial Option Evaluation

The three remedial options for the southeast chromium plume are as follows:

- **Option 1:** P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib; MNA for the southeast chromium plume.
- **Option 2:** P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib; P&T and MNA for the southeast chromium plume.
  - **Option 2a:** Uses onsite IX for treatment of extracted groundwater.
  - **Option 2b:** Uses IX treatment at the 200 West P&T for treatment of extracted groundwater.
  - **Option 2c:** Uses the biological treatment at the 200 West P&T for treatment of extracted groundwater.
- **Option 3:** P&T for source control at the 216-S-10 Pond/Ditch and 216-S-20 Crib; P&T for the southeast chromium plume.

The remedial options were evaluated based on the CERCLA balancing criteria of effectiveness, implementability, and cost (Section 4.3.1). These criteria were used to evaluate the options individually (Section 4.3.2) and then compared to the other options (Section 4.3.3). Table 5-1 summarizes the comparative analysis of the three remedial options.

5.2 Recommendations

The need for additional monitoring wells and changes to the groundwater sampling design for the southeast chromium plume will be evaluated based on the remedial option selected. The remedial design for the selected remedy option will be provided in a revision to the RD/RAWP (DOE/RL-2013-07).

5.2.1 Additional Monitoring Wells

Additional characterization wells are not needed to refine the current nature and extent of the southeast chromium plume to support remedial option selection. The need for additional groundwater monitoring wells will be evaluated based on the remedial option selected.

Table 5-1. Comparative Analysis of Remedial Options for the 200-UP-1 OU Southeast Chromium Plume

CERCLA Criteria	Remedial Options				
	1	2a	2b	2c	3
Effectiveness	★★☆☆	★★★☆	★★★☆	★★★☆	★★★★
Implementability	★★★★	★★★☆	★★★☆	★★☆☆	★☆☆☆
Estimated time to achieve cleanup levels for chromium (years)[a]	275	120	120	120	25
Total cost[b]	$191,000,000	$263,000,000	$271,000,000	$617,000,000	$663,000,000

★☆☆☆ = Expected to perform less well against the CERCLA balancing criteria with more disadvantages or uncertainties.

★★☆☆ = Expected to perform moderately well against the CERCLA balancing criteria with some disadvantages or uncertainties.

★★★☆ = Expected to perform well against the CERCLA balancing criteria with minimal disadvantages or uncertainties.

★★★★ = Expected to perform very well against the CERCLA balancing criteria with no disadvantages or uncertainties.

a. The estimated time to achieve cleanup levels for chromium is based on the 95% upper confidence limit on the mean of the annual dissolved concentration.

b. These cost estimates represent the total nondiscounted costs, prepared to meet the -30% to +50% range of accuracy recommended in EPA/540/G-89/004, *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*.

Remedial options:

Option 1 – 25 years of P&T at the 216-S-10 and 216-S-20 source sites using IX treatment at ETB-3 and 275 years of MNA for the southeast chromium plume

Option 2a – 25 years of P&T at the 216-S-10 and 216-S-20 source sites and southeast chromium plume using onsite IX treatment and 120 years of MNA for the southeast chromium plume

Option 2b – 25 years of P&T at the 216-S-10 and 216-S-20 source sites and southeast chromium plume using IX treatment at 200 West P&T and 120 years of MNA for the southeast chromium plume

Option 2c – 25 years of P&T at the 216-S-10 and 216-S-20 source sites and southeast chromium plume using biological treatment at 200 West P&T and 120 years of MNA for the southeast chromium plume

Option 3 – 25 years of P&T at the 216-S-10 and 216-S-20 source sites and southeast chromium plume using onsite IX treatment

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
ETB = exchange treatment building
IX = ion exchange
MNA = monitored natural attenuation
P&T = pump and treat

5.2.2 Changes to Sampling Design

The 11 new southeast chromium plume wells are sampled quarterly. Existing nearby wells are sampled annually for the 200-UP-1 OU. The need for changes in monitoring wells and sampling frequencies will be evaluated based on the remedial option selected. DOE/RL-2015-14, *Performance Monitoring Plan for the 200-UP-1 Groundwater Operable Unit Remedial Action*, will be revised as needed to reflect any changes.

5.2.3 Remedy

DOE and EPA are expected to select the remedial option for the southeast chromium plume from among the three remedial options listed in Section 5.1.3. The remedial alternative in the 200-UP-1 OU ROD (EPA et al., 2012) was based on an inferred southeast chromium plume that was about half the size of the 2017 plume. It is anticipated that the remedy option selected for the 2017 plume will be documented in an explanation of significant differences for the 200-UP-1 OU ROD or as a ROD amendment.

5.2.3.1 Remedial Design

The remedial design for the selected remedy option will be provided in a revision to the RD/RAWP (DOE/RL-2013-07). The RD/RAWP will include details regarding the basis for the remedial action, the remedial design and implementation, the remedial process optimization, cost, and schedule.

5.2.3.2 Remedy Implementation Schedule

The remedy implementation schedule will vary depending on which option is selected for the southeast chromium plume. Figure 5-1 provides a project schedule with estimated durations for each option. If an explanation of significant differences is required for the 200-UP-1 OU ROD (EPA et al., 2012), it can be completed within 8 months. However, if a ROD amendment is necessary, an additional 4 to 6 months will be needed.

The actual durations for installing extraction and injection wells and conducting construction activities will vary due to the significant differences in the infrastructure (e.g., numbers of wells, lengths of piping, or locations of treatment facilities) required to implement the different remedial options. Allocation of funding could also impact the schedule for the selected option.

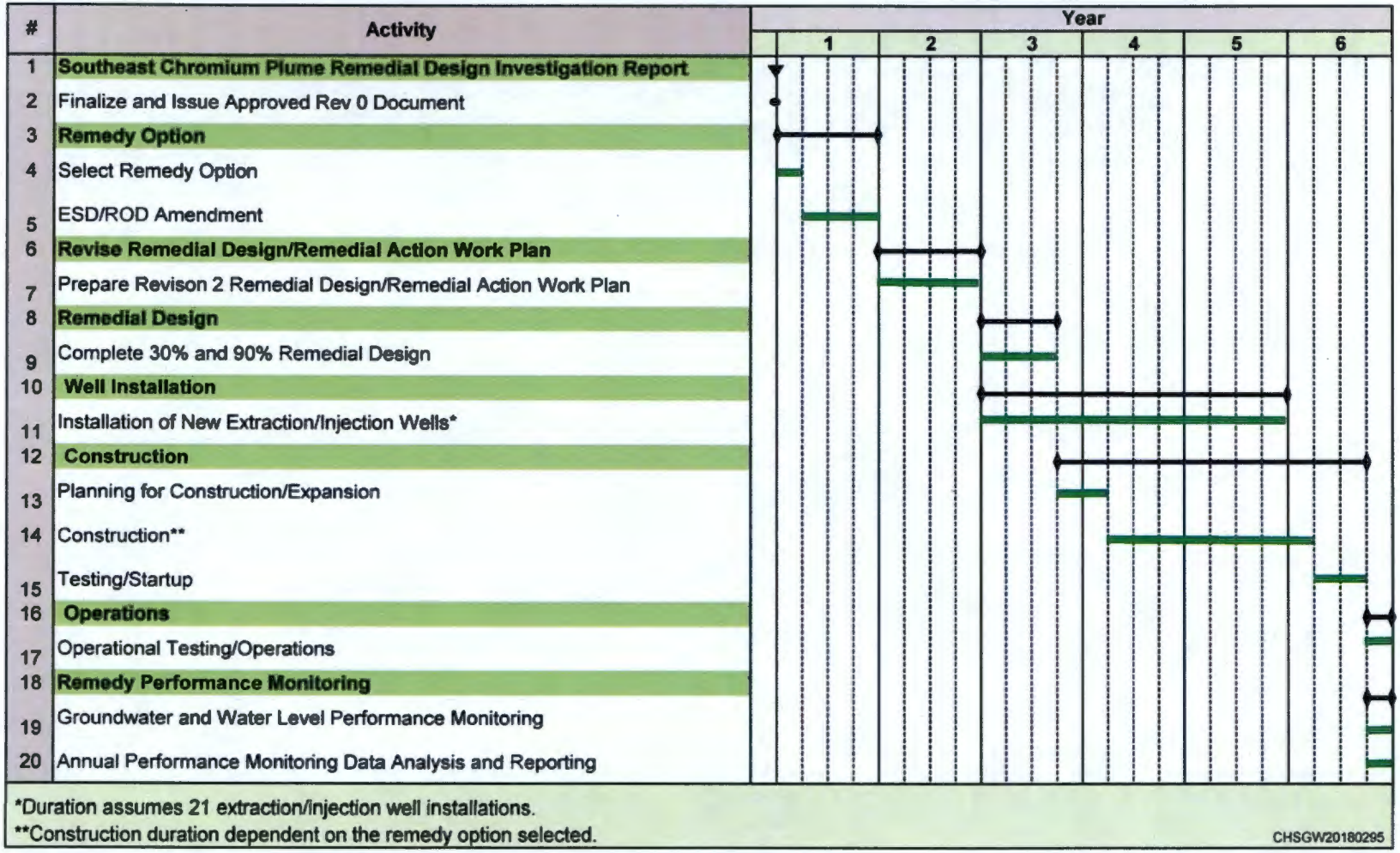

Figure 5-1. 200-UP-1 OU Southeast Chromium Plume Remedy Implementation Schedule

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6 References

ARH-2155, 1971, *Radioactive Liquid Waste Disposal Facilities 200 West Area*, Atlantic Richfield Hanford Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0080807H.

BHI-00176, 1995, *S Plant Aggregate Area Management Study Technical Baseline Report*, Rev. 00, Bechtel Hanford, Inc., Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D198038143.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC 9601, et seq., Pub. L. 107-377, December 31, 2002. Available at: https://www.csu.edu/cerc/researchreports/documents/CERCLASummary1980.pdf.

CP-47631, 2018, *Model Package Report: Central Plateau Groundwater Model, Version 8.4.5*, Rev. 4, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0066449H.

CP-15329, 2003, *Data Quality Objectives Summary Report for Establishing a RCRA/CERCLA/AEA Integrated 200 West and 200 East Area Groundwater Monitoring Network*, Rev. 0, Fluor Hanford, Inc., Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0081104H.

DOE-RL, 1987, *216-S-10 Ditch and Pond Preliminary Closure/Post-Closure Plan*, Rev. 0, U.S. Department of Energy, Richland Operations Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196003121.

DOE/RL-91-60, 1992, *S Plant Aggregate Area Management Study Report*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D195065601.

DOE/RL-93-09, 1993, *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1992*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196136826.

DOE/RL-2002-39, 2002, *Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/pdf.cfm?accession=0081471H.

DOE/RL-2007-28, 2008, *Feasibility Study Report for the 200-ZP-1 Groundwater Operable Unit*, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0808050315. https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=00098828.

DOE/RL-2009-122, 2012, *Remedial Investigation/Feasibility Study for the 200-UP-1 Groundwater Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0092344. http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0092342. http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0092341.

DOE/RL-2010-49, 2017, *Remedial Investigation/Feasibility Study Work Plan for the 200-WA-1 and 200-BC-1 Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0072177H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0072173H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0072172H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0072171H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0072170H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0072169H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0072168H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0072167H.

DOE/RL-2010-93, 2016, *Interim Status Groundwater Monitoring Plan for the 216-A-36B PUREX Plant Crib*, Rev. 2, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0073381H.

DOE/RL-2011-118, 2012, *Hanford Site Groundwater Monitoring for 2011*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0091795.

DOE/RL-2013-07, 2013, *200-UP-1 Groundwater Operable Unit Remedial Design/Remedial Action Work Plan*, Rev. 0, U.S. Department of Energy, Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0087671.

DOE/RL-2015-14, 2015, *Performance Monitoring Plan for the 200-UP-1 Groundwater Operable Unit Remedial Action*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at:
https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0080202H.

Amended by:

TPA-CN-0802, 2017, *Tri-Party Agreement Change Notice Form: DOE/RL-2015-14, Performance Monitoring Plan for the 200-UP-1 Groundwater Operable Unit Remedial Action, Rev. 0*, dated November 7, U.S. Department of Energy, Richland Operations Office, and U.S. Environmental Protection Agency, Richland, Washington. Available at:
https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0066963H.

DOE/RL-2014-27, 2016, *Sampling and Analysis Plan for Remediation Wells in the 200-UP-1 Operable Unit*, Rev. 2, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0071352H.

Amended by:

TPA-CN-0793, 2017, *Tri-Party Agreement Change Notice Form: DOE/RL-2014-27, Sampling and Analysis Plan for Remediation Wells in the 200-UP-1 Operable Unit, Rev. 2*, dated August 22, U.S. Department of Energy, Richland Operations Office, and U.S. Environmental Protection Agency, Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0068662H.

DOE/RL-2017-66, 2018, *Hanford Site Groundwater Monitoring Report for 2017*, in publication, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2017-68, 2018, *Calendar Year 2017 Annual Summary Report for the 200-ZP-1 and 200-UP-1 Operable Unit Pump and Treat Operations*, in publication, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

ECF-200W-17-0043, 2017, *Capture-Zone and Particle-Tracking Analysis for the 200-UP-1/200-ZP-1 Areas Using the 2017 Updated Central Plateau Model*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0064962H.

ECF-HANFORD-13-0029, 2017, *Development of the Hanford South Geologic Framework Model, Hanford Site, Washington Fiscal Year 2016 Update*, Rev. 4, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0072357H.

ECF-HANFORD-13-0029, 2018, *Development of the Hanford South Geologic Framework Model, Hanford Site, Washington*, Rev. 5 (in publication), CH2M HILL Plateau Remediation Company, Richland, Washington.

ECF-HANFORD-16-0080, 2017, *Preparation of the March 2016 Hanford Site Water Table and Potentiometric Surface Maps*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0071365H.

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

EPA/540/G-89/004, 1988, *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*, Interim Final, OSWER Directive 9355.3-01, Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. Available at: https://rais.ornl.gov/documents/GUIDANCE.PDF.

EPA 540-R-00-002, 2000, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, OSWER 9355.0-75, U.S. Army Corps of Engineers and U.S. Environmental Protection Agency, Washington, D.C. Available at: https://semspub.epa.gov/work/HQ/174890.pdf.

EPA, Ecology, and DOE, 2012, *Record of Decision for Interim Remedial Action, Hanford 200 Area Superfund Site 200-UP-1 Operable Unit*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/docDetail?accession=0091413.

Harbaugh, A.W., E.R. Banta, M.C. Hill, and M.G. McDonald, 2000, *MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-Water Flow Process*, Open-File Report 2000-92, U.S. Geological Survey, Reston, Virginia. Available at: http://pubs.er.usgs.gov/usgspubs/ofr/ofr200092.

HW-18700, 1951 (declassified 1974), *REDOX Technical Manual*, General Electric Company, Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0076412H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0076411H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0076410H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0076409H.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0076408H.

Lindsey, K.A., 1996, *The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon*, Open File Report 96-8, Washington Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia, Washington. Available at:
http://www.dnr.wa.gov/Publications/ger_ofr96-8_ringold_formation.pdf.

NAD83, 1991, *North American Datum of 1983*, as revised, National Geodetic Survey, Federal Geodetic Control Committee, Silver Spring, Maryland. Available at: http://www.ngs.noaa.gov/.

NAVD88, 1988, *North American Vertical Datum of 1988*, as revised, National Geodetic Survey, Federal Geodetic Control Committee, Silver Spring, Maryland. Available at:
https://www.ngs.noaa.gov/PUBS_LIB/NAVD88/navd88report.htm.

OSWER Directive 9285.6-10, 2002, *Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites*, Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. Available at:
http://itrcweb.org/FileCabinet/GetFile?fileID=6873.

PNNL-11141, 1996, *Hanford Site Ground-Water Monitoring for 1995*, Pacific Northwest National Laboratory, Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1102090345.

PNNL-11793, 1998, *Hanford Site Groundwater Monitoring for Fiscal Year 1997*, Pacific Northwest National Laboratory, Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D199132962.

PNNL-12261, 2000, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington*, Pacific Northwest National Laboratory, Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0906180659.

PNNL-14753, 2006, *Groundwater Data Package for Hanford Assessments*, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington. Available at:
http://www.pnl.gov/main/publications/external/technical_reports/PNNL-14753Rev1.pdf.

PNNL-16346, 2007, *Hanford Site Groundwater Monitoring for Fiscal Year 2006*, Pacific Northwest National Laboratory, Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0911240803.

PNNL-26894, 2017, *Contaminant Attenuation and Transport Characterization of 200-UP-1 Operable Unit Sediment Samples*, Pacific Northwest National Laboratory, Richland, Washington. Available at:
https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-26894.pdf.

Pollock, D.W., 2012, *User Guide for MODPATH Version 6 - A Particle-Tracking Model for MODFLOW*, U.S. Geological Survey Techniques and Methods 6-A41, Reston, Virginia. Available at: https://pubs.usgs.gov/tm/6a41/pdf/TM_6A_41.pdf.

RHO-CD-673, 1979, *Handbook 200 Areas Waste Sites*, 3 vols., Rockwell Hanford Operations, Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196039027.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196039028.
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196039029.

RPP-26744, 2005, *Hanford Soil Inventory Model, Rev. 1*, Rev. 0, Washington. CH2M HILL Hanford Group, Inc., Richland, Washington. Available at:
http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0081114H.

SGW-59416, 2015, *Description of Work for the Installation of Three Monitoring Wells in the 200-UP-1 Groundwater Operable Unit, FY16*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at:
https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0065667H.

SGW-60084, 2016, *Description of Work for the Installation of Three Multipurpose Wells in the 200-UP-1 Groundwater Operable Unit, FY 2017*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at:
https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0065666H.

SGW-60463, 2017, *Borehole Summary Report for the Installation of Three Monitoring Wells in the 200-UP-1 Groundwater Operable Unit, Fiscal Year 2016*, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at:
https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0065665H.

SGW-60568, 2017, *Description of Work for the Installation of Four Monitoring Wells Near the Southeastern Portion of the 200-UP-1 Operable Unit, FY 2017*, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at:
https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0065664H.

SGW-60727, 2017, *Borehole Summary Report for Installation of Three Multipurpose Wells in the 200-UP-1 Groundwater Operable Unit, FY 2017*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at:
https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0065663H.

SGW-61319, 2018, *Borehole Summary Report for the Installation of Five Monitoring Wells in the 200-UP-1 Operable Unit, FY 2017*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at:
https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0065668H.

WAC 173-340, "Model Toxics Control Act—Cleanup," *Washington Administrative Code*, Olympia, Washington. Available at: http://apps.leg.wa.gov/WAC/default.aspx?cite=173-340.

WHC-MR-0391, 1992, *Field Trip Guide to the Hanford Site*, Westinghouse Hanford Company, Richland, Washington. Available at:
https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196136627.

WMP-26333, 2005, *Borehole Summary Report for Six CERCLA Wells Drilled in the 200-UP-1 and 200-ZP-1 Operable Units, and Six RCRA Wells Drilled in the A-AX, B-BX-BY, and U WMA; CY 2004-2005*, Rev. 0, Fluor Hanford, Inc., Richland, Washington. Available at: https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=DA01562491.

Zheng, C., and P.P. Wang, 1999, *MT3DMS: A Modular Three-Dimensional Multi-Species Transport Model for Simulation of Advection, Dispersion and Chemical Reactions of Contaminants in Groundwater Systems; Documentation and User's Guide*, Contract Report SERDP-99-1, U.S. Army Engineer Research and Development Center, U.S. Army Corps of Engineers, Vicksburg, Mississippi. Available at: http://hydro.geo.ua.edu/mt3d/mt3dmanual.pdf.

Appendix A

Groundwater Analytical Data

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A Groundwater Analytical Data

Eleven wells were drilled in 2016 and 2017 to characterize the southeast chromium plume in the 200-UP-1 Operable Unit. Depth-discrete groundwater samples were collected during drilling of all 11 wells for vertical profiling of chromium concentrations (Table A-1). Groundwater samples also were collected after well development (Table A-2). Routine quarterly sampling is being conducted at each well (Table A-3). Groundwater samples were collected from 28 nearby existing wells in 2017 to supplement the new characterization data for the southeast chromium plume (Table A-4). Unfiltered and filtered groundwater samples were analyzed for total chromium and hexavalent chromium. Analytical results for samples collected in 2016 and 2017 are included in Tables A-1 through A-4.

Table A-1. Chromium Results for Depth-Discrete Samples Collected from 11 Wells Drilled in 2016 and 2017 to Characterize the 200-UP-1 Operable Unit Southeast Chromium Plume

Well Name (Well ID)	Sample Date	Sample Depth (m [ft] bgs)	Total Chromium, Unfiltered Concentration (µg/L)	Total Chromium, Filtered Concentration (µg/L)	Hexavalent Chromium, Unfiltered Concentration (µg/L)	Hexavalent Chromium, Filtered Concentration (µg/L)
699-27-68 (C9632)	06/05/2017	71.7 (235.2)	82.5 D	55.5 D	43.0 G	53.0 G
	06/07/2017	77.6 (254.6)	30.8 D	22.6 D	16.0	20.0
	06/12/2017	83.5 (274.1)	63.6 D	60.1 D	37.0	52.0
	06/15/2017	90.2 (296.0)	19.8 DY	10.9 DY	1.5 UY	3.5 BY
	06/20/2017	96.0 (315.0)	97.9 D	69.8 D	36.0	53.0
	06/21/2017	102.1 (335.1)	63.6 DA	46.6 DA	24.0 A	38.0 A
699-29-55 (C9634)	07/12/2017	91.7 (300.9)	100.0 D	48.4 D	33.0	41.0
	07/13/2017	97.8 (320.9)	50.4 DA	34.3 DA	1.5 U	21.0
	07/19/2017	106.9 (350.8)	156.0 D	17.2 D	1.5 U	15.0
	07/20/2017	113.1 (370.9)	93.2 D	78.6 D	53.0	61.0
	07/24/2017	119.2 (390.9)	57.4 D	22.9 D	7.8	8.7
	07/26/2017	125.2 (410.9)	23.8 DA	15.9 D	2.5 B	8.4
699-29-66 (C9413)	05/12/2016	83.5 (274.0)	NA	13.0	NA	11.0
	05/16/2016	101.9 (334.2)	NA	56.0	NA	55.0

Table A-1. Chromium Results for Depth-Discrete Samples Collected from 11 Wells Drilled in 2016 and 2017 to Characterize the 200-UP-1 Operable Unit Southeast Chromium Plume

Well Name (Well ID)	Sample Date	Sample Depth (m [ft] bgs)	Total Chromium, Unfiltered Concentration (µg/L)	Total Chromium, Filtered Concentration (µg/L)	Hexavalent Chromium, Unfiltered Concentration (µg/L)	Hexavalent Chromium, Filtered Concentration (µg/L)
	05/17/2016	122.8 (403.0)	NA	1.1 U	NA	1.5 U
	05/23/2016	149.7 (491.1)	NA	1.1 U	NA	1.6 B
699-30-57 (C9417)	06/14/2016	96.7 (317.2)	NA	110.0	NA	99.0 A
	06/15/2016	112.8 (370.0)	NA	28.0	NA	20.0 H
699-30-63 (C9602)	11/28/2016	90.1 (295.5)	57.1 D	46.5 D	1.5 U	31.0
	11/29/2016	96.3 (315.9)	151.0 D	126.0 D	91.0	100.0
	11/30/2016	102.3 (335.6)	147.0 D	105.0 D	90.0 ZH	99.0 ZH
	12/01/2016	108.4 (355.7)	151.0 D	81.5 D	9.0	54.0
	12/07/2016	114.4 (375.5)	126.0 D	92.1 D	59.0	88.0
	12/13/2016	120.5 (395.4)	83.4 D	49.5 D	46.0	47.0
699-30-70 (C9635)	05/23/2017	71.8 (235.5)	52.3 D	68.4 D	46.0	47.0
	05/24/2017	77.8 (255.4)	75.0 D	68.4 D	39.0	41.0
	05/25/2017	83.9 (275.4)	109.0 D	85.1 D	70.0	71.0
	05/31/2017	90.0 (295.4)	185.0 DG	176.0 DG	150.0	160.0
	06/1/2017	96.1 (315.2)	147.0 DG	142.0 DG	82.0	110.0
	06/5/2017	102.2 (335.2)	254.0 D	219.0 D	150.0	160.0 G
	06/20/2017	108.0 (354.4)	77.2 DY	8.5 BDY	1.5 UY	1.5 UY
	06/21/2017	114.1 (374.4)	42.4 DY	18.7 DY	5.5 Y	8.1 AY
699-30-73 (C9636)	10/17/2017	73.3 (240.4)	21.8 D	20.9 DA	8.4	12.0

Table A-1. Chromium Results for Depth-Discrete Samples Collected from 11 Wells Drilled in 2016 and 2017 to Characterize the 200-UP-1 Operable Unit Southeast Chromium Plume

Well Name (Well ID)	Sample Date	Sample Depth (m [ft] bgs)	Total Chromium, Unfiltered Concentration (µg/L)	Total Chromium, Filtered Concentration (µg/L)	Hexavalent Chromium, Unfiltered Concentration (µg/L)	Hexavalent Chromium, Filtered Concentration (µg/L)
	10/18/2017	79.3 (260.3)	13.4 D	11.3 D	3.4 B	7.6
	10/18/2017	85.3 (280.0)	20.3 D	4.0 UD	1.5 U	2.9 B
	10/19/2017	91.5 (300.3)	23.6 D	9.6 BD	1.9 B	3.1 B
	10/23/2017	97.5 (320.0)	24.3 D	12.0 D	1.5 U	3.6 B
	10/24/2017	103.7 (340.3)	18.8 D	12.4 D	1.5 U	1.5 B
	10/25/2017	109.7 (360.1)	34.8 D	7.0 BD	1.5 UA	2.8 BA
	10/25/2017	115.9 (380.2)	32.1 D	7.6 BD	1.5 U	3.0 B
699-31-50 (C9737)	09/12/2017	99.1 (325.0)	4.0 UD	4.0 UD	1.5 U	1.5 U
	09/13/2017	105.2 (345.0)	4.0 UD	4.0 UD	1.5 U	1.5 U
	09/18/2017	111.6 (366.2)	4.0 UD	4.0 UD	1.5 U	1.5 U
	09/19/2017	117.3 (385.0)	4.0 UD	4.0 UD	1.5 U	1.5 U
	09/20/2017	123.7 (406.0)	10.4 D	4.0 UD	1.5 U	1.5 U
	09/21/2017	129.7 (425.5)	4.0 UD	4.0 UD	1.5 U	1.5 U
	09/26/2017	135.6 (445.0)	4.0 UD	4.0 UD	1.5 U	1.5 U
699-31-68 (C9416)	03/28/2016	92.8 (304.5)	NA	18.0	NA	15.0
	03/29/2016	104.9 (344.3)	NA	4.2 B	NA	2.7 B
	03/31/2016	126.3 (414.5)	NA	23.0	NA	20.0
699-32-59 (C9603)	01/31/2017	102.6 (336.5)	127.0 D	115.0 D	110.0 A	110.0
	02/01/2017	108.5 (355.8)	144.0 D	77.1 D	4.5 Y	81.0

Table A-1. Chromium Results for Depth-Discrete Samples Collected from 11 Wells Drilled in 2016 and 2017 to Characterize the 200-UP-1 Operable Unit Southeast Chromium Plume

Well Name (Well ID)	Sample Date	Sample Depth (m [ft] bgs)	Total Chromium, Unfiltered Concentration (µg/L)	Total Chromium, Filtered Concentration (µg/L)	Hexavalent Chromium, Unfiltered Concentration (µg/L)	Hexavalent Chromium, Filtered Concentration (µg/L)
	02/02/2017	114.8 (376.8)	132.0 D	98.7 D	54.0	65.0
	02/07/2017	117.8 (386.5)	106.0 D	41.8 D	35.0	39.0
699-32-64 (C9601)	10/27/2016	96.3 (316.0)	29.5 D	31.7 D	20.0	14.0 Y
	10/31/2016	99.4 (326.0)	25.6 D	29.0 D	18.0	18.0
	11/01/2016	105.1 (344.7)	23.8 D	7.6 BD	2.3 B	5.2
	11/02/2016	111.6 (366.0)	12.5 D	4.0 UD	1.5 U	1.5 U
	11/03/2016	117.7 (386.1)	4.9 BD	4.0 UD	1.5 UA	1.5 UA

bgs = below ground surface

ID = identification

Data qualifiers:

A = indicates an issue with the chain of custody that could affect data integrity

B = analyte was detected at a value greater than or equal to the method detection limit but less than the practical quantitation limit

D = analyte was determined using a secondary dilution factor greater than one

G = result has been reviewed and determined to be correct, or the laboratory has supplied a corrected result

H = laboratory holding time was exceeded before the sample was analyzed

U = constituent was analyzed for but was not detected

Y = result is suspect

Z = indicates a result-specific comment is provided in the data report and/or case narrative

Table A-2. Chromium Results for Post-Development Samples Collected from 11 Wells Drilled in 2016 and 2017 to Characterize the 200-UP-1 Operable Unit Southeast Chromium Plume

Well Name (Well ID)	Sample Date	Pump Intake Depth (m [ft] bgs)	Total Chromium, Unfiltered Concentration (µg/L)	Total Chromium, Filtered Concentration (µg/L)	Hexavalent Chromium, Unfiltered Concentration (µg/L)	Hexavalent Chromium, Filtered Concentration (µg/L)
699-27-68 (C9632)	08/16/2017	87.6 (287.5)	54.8 D	55.7 D	55.0	54.0
699-29-55 (C9634)	09/19/2017	114.6 (376.1)	82.6 D	82.4 D	83.0	83.0
699-29-66 (C9413)	09/22/2016	103.4 (339.4)	NA	91.0 G	NA	86.0
699-30-57 (C9417)	08/15/2016	96.6 (317.0)	NA	100.0	NA	100.0
699-30-63 (C9602)	03/29/2017	116.2 (381.1)	101.0 D	102.0 D	97.0	98.0
699-30-70 (C9635)	08/22/2017	107.6 (353.0)	36.8 D	36.9 D	39.0	40.0
699-30-73 (C9636)	12/06/2017	77.8 (255.1)	23.1 DA	22.6 D	24.0	24.0
699-31-50 (C9737)	11/09/2017	99.3 (325.7)	4.0 UD	4.0 UD	1.5 U	1.5 U
699-31-68 (C9416)	09/13/2016	91.1 (299.0)	NA	26.0	NA	26.0
699-32-59 (C9603)	03/15/2017	117.1 (384.1)	98.2 D	100.0 D	88.0	88.0
699-32-64 (C9601)	02/02/2017	96.7 (317.3)	14.7 D	15.1 D	13.0	15.0

bgs = below ground surface
ID = identification
NA = not analyzed

Data qualifiers:

A = indicates an issue with the chain of custody that could affect data integrity
D = analyte was determined using a secondary dilution factor greater than one
G = result has been reviewed and determined to be correct, or the laboratory has supplied a corrected result
U = constituent was analyzed for but was not detected

Table A-3. Chromium Results for Routine Quarterly Samples Collected as of March 31, 2018, from 11 New Wells Drilled in 2016 and 2017 to Characterize the 200-UP-1 Operable Unit Southeast Chromium Plume

Well Name (Well ID)	Sample Date	Pump Intake Depth (m [ft] bgs)	Total Chromium, Unfiltered Concentration (µg/L)	Total Chromium, Filtered Concentration (µg/L)	Hexavalent Chromium, Unfiltered Concentration (µg/L)	Hexavalent Chromium, Filtered Concentration (µg/L)
699-27-68 (C9632)	01/03/2018	84.7 (278)	69.1	66.8	69.0	NA
699-29-55 (C9634)	01/15/2018	109.1 (358)	104.0	84.6	100.0	NA
699-29-66 (C9413)	12/21/2016	103.3 (339)	46.9	50.3	48 ZH	NA
	03/21/2017		80.5, 79.5	78.6, 78.5	87.0, 82.0	NA
	06/12/2017		88.8	87.6	91.0	NA
	07/07/2017		95.8	94.9	94.0	NA
	10/13/2017		92.4 Q	93.3 Q	96 A	NA
	01/03/2018		99.5 D	97.8 D	99.0	NA
699-30-57 (C9417)	11/02/2016	96.6 (316.9)	77.3	79.7	69.0	NA
	12/02/2016		83.4	85.0	75.0	NA
	03/21/2017		95.3	94.1	92.0	NA
	06/23/2017		104.0, 104.0	108.0, 101.0	100.0, 100.0	NA
	07/07/2017		103.0	106.0	100.0	NA
	10/13/2017		106.0	105.0	110.0	NA
	01/15/2018		116.0	116.0	120.0	NA
699-30-63 (C9602)	04/14/2017	98.0 (321.5)	132.0 D	125.0 D	91.0	NA
	06/12/2017		115.0 D	117.0 D	120.0	NA
	07/07/2017		117.0	118.0	120.0	NA
	10/13/2017		4.5 BYQ	11.0 YQ	120.0	NA
	01/15/2018		136.0	129.0	130.0	NA
699-30-70 (C9635)	01/03/2018	98.0 (321.5)	51.3 D, 48.1 D	47.8 D, 46.8 D	51.0, 51.0	NA
	02/21/2018		50.6, 50.2	48.0, 47.1	49.0, 48.0	NA
699-31-50 (C9737)	02/21/2018	116.4 (382)	3.0 U	3.0 U	1.5 U	NA

Table A-3. Chromium Results for Routine Quarterly Samples Collected as of March 31, 2018, from 11 New Wells Drilled in 2016 and 2017 to Characterize the 200-UP-1 Operable Unit Southeast Chromium Plume

Well Name (Well ID)	Sample Date	Pump Intake Depth (m [ft] bgs)	Total Chromium, Unfiltered Concentration (µg/L)	Total Chromium, Filtered Concentration (µg/L)	Hexavalent Chromium, Unfiltered Concentration (µg/L)	Hexavalent Chromium, Filtered Concentration (µg/L)
699-31-68 (C9416)	12/21/2016	90.4 (296.5)	22.0	22.8	20.0 ZH	NA
	03/21/2017		24.8	26.1	20.0	NA
	06/12/2017		24.7	24.5	24.0	NA
	07/07/2017		22.0	21.0	22.0	NA
	10/19/2017		28.0	26.0 C	23.0 A	NA
	01/15/2018		28.5	25.8	25.0	NA
699-32-59 (C9603)	04/14/2017	103.9 (341)	126.0	120.0	120.0	NA
	06/23/2017		117.0 D	120.0 D	120.0	NA
	07/07/2017		127.0	121.0	120.0	NA
	10/24/2017		116.0	127.0 N	120.0	NA
	01/03/2018		126.0 D	125.0 D	120.0	NA
699-32-64 (C9601)	03/22/2017	119.5 (392)	25.0 C	24.0 C, 120.0 F	13.0	NA
	06/12/2017		16.0	16.0	15.0	NA
	07/14/2017		16.4	16.4	16.0	NA
	10/20/2017		17.3 Q	16.5 Q	17.0	NA
	01/15/2018		18.1	17.5	17.0	NA

bgs = below ground surface
ID = identification
NA = not analyzed

Data qualifiers:

A = indicates an issue with the chain of custody that could affect data integrity
B = analyte was detected at a value greater than or equal to the method detection limit but less than the practical quantitation limit
C = analyte was detected in both the sample and the associated method blank, and the sample concentration was less than or equal to five times the blank concentration
D = analyte was determined using a secondary dilution factor greater than one
F = result is undergoing further review
H = laboratory holding time was exceeded before the sample was analyzed
N = matrix spike recovery is outside control limits. The associated sample data may be biased
Q = associated field QC sample is out-of-limits
U = constituent was analyzed for but was not detected
Y = result is suspect
Z = indicates a result-specific comment is provided in the data report and/or case narrative

Table A-4. Chromium Results for Routine Samples Collected in 2017 from Groundwater Wells near the 200-UP-1 Operable Unit Southeast Chromium Plume

Well Name (Well ID)	Sample Date	Total Chromium, Unfiltered Concentration (µg/L)	Total Chromium, Filtered Concentration (µg/L)	Hexavalent Chromium, Unfiltered Concentration (µg/L)	Hexavalent Chromium, Filtered Concentration (µg/L)
299-E13-11 (A5858)	07/24/2017	5.74 B	5.58 B	NA	NA
299-E13-14 (A4726)	04/06/2017	29.0 C	13.0 CG	23.0 G	NA
299-E13-19 (A5864)	07/24/2017	17.6	18.0	19.0	NA
299-E17-25 (C3926)	01/17/2017	10.1 D	10.3 D	NA	NA
299-E18-1 (A4743)	01/17/2017	16.3 D	6.7 BD	NA	NA
299-W26-13 (B8817)	05/02/2017	165.0	158.0	160.0	130.0
	11/01/2017	154.0	150.0	150.0	150.0
299-W26-14 (B8828)	05/02/2017	4.3 B	3.8 B	2.6 B	3.0 B
	11/01/2017	4.1 B	3.7 B	2.6 B	3.0 B
699-25-55 (A5098)	09/15/2017	6.0 B	6.1 B	4.4	NA
699-25-70 (A5099)	02/24/2017	16.3	15.2	13.0	NA
	09/15/2017	17.3	16.0	16.0	NA
699-28-52A (A5111)	09/15/2017	1.0 U	1.0 U	1.5 U	NA
699-30-66 (C4298)	10/27/2017	94.0	98.0	110.0	NA
699-31-53B (A8507)	03/21/2017	44.7	46.9	17.0	NA
	06/23/2017	43.0	43.8	40.0	NA
	09/15/2017	47.8	44.8	45.0	NA
	12/05/2017	54.2 A	54.2 A	51.0	NA
699-32-43 (A5127)	02/24/2017	10.2	10.1	NA	NA
699-32-62 (A5128)	04/05/2017	140.0 A	130.0 A	120.0	NA
699-32-70B (A5129)	04/10/2017	29.0 C	21.0 C	20.0	NA

Table A-4. Chromium Results for Routine Samples Collected in 2017 from Groundwater Wells near the 200-UP-1 Operable Unit Southeast Chromium Plume

Well Name (Well ID)	Sample Date	Total Chromium, Unfiltered Concentration (µg/L)	Total Chromium, Filtered Concentration (µg/L)	Hexavalent Chromium, Unfiltered Concentration (µg/L)	Hexavalent Chromium, Filtered Concentration (µg/L)
699-32-76 (C4975)	05/02/2017	7.0 B	6.6 B	6.6	6.4
	11/01/2017	7.7 B	14.5	6.8	6.8
699-33-56 (A5133)	02/26/2017	77.8 D	76.9 D	74.0	NA
699-33-75 (C4974)	05/02/2017	1.37 B	1.45 B	1.5 U	1.5 U
	11/01/2017	1.3 U	1.3 U	1.5 U	1.5 U
699-33-76 (C4976)	05/02/2017	2.1 B	2.3 B	1.5 U	1.5 U
	11/01/2017	2.6 B	1.3 U	1.5 U	1.5 U
699-34-51 (A5137)	03/21/2017	25.4	24.7	25.0	NA
	06/23/2017	26.2	26.2	25.0	NA
	10/02/2017	26.4	26.0	26.0	NA
	12/05/2017	28.2 DA	26.5 DA	27.0	NA
699-34-61 (A5463)	03/17/2017	149.0	63.2	50.0	NA
699-35-66A (A5139)	03/09/2017	21.6, 22.0	20.2. 20.2	15.0, 14.0	NA
	09/27/2017	19.2	17.9	NA	NA
699-36-61A (A5144)	06/19/2017	16.3 D	12.9 D	NA	NA
699-36-63B (C9593)	01/24/2017	NA	13.0 A	NA	13.0
	04/14/2017	14.3	14.1	14.0	NA
	06/19/2017	16.2	14.6	14.0	NA
	09/18/2017	16.1	14.5	13.0	NA
	12/05/2017	18.0	14.0	14.0	NA
699-36-66B (C6219)	03/09/2017	3.37 B	3.17 B	NA	NA
	09/27/2017	3.2	3.6	NA	NA
699-36-70A (A9901)	03/09/2017	3.0 U	3.0 U	NA	NA
	09/27/2017	3.0 U	3.0 U	NA	NA

Table A-4. Chromium Results for Routine Samples Collected in 2017 from Groundwater Wells near the 200-UP-1 Operable Unit Southeast Chromium Plume

Well Name (Well ID)	Sample Date	Total Chromium, Unfiltered Concentration (µg/L)	Total Chromium, Filtered Concentration (µg/L)	Hexavalent Chromium, Unfiltered Concentration (µg/L)	Hexavalent Chromium, Filtered Concentration (µg/L)
699-37-66 (C5704)	03/08/2017	3.16 B	3.0 U	NA	NA
	09/27/2017	3.0 U, 3.0 U	3.0 U, 3.0 U	NA	NA

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D = analyte was determined using a secondary dilution factor greater than one

G = result has been reviewed and determined to be correct, or the laboratory has supplied a corrected result

U = constituent was analyzed for but was not detected

Appendix B

ECF-200UP1-17-0238, *Development of the 3D Hexavalent Chromium Groundwater Plume using Leapfrog for Southeast 200-UP-1*

https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0064965H

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Appendix C

ECF-200UP1-18-0008, *Simulations of Remedial Options for the 200-UP-1 Southeast Chromium Plume using the Central Plateau Groundwater Model*

https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0064964H

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Appendix D

ECE-200UP118-00002, *Environmental Cost Estimate for the 200-UP-1 Southeast Chromium Plume Remedial Options*
https://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0064818H

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