DOE/RL-2009-122
Draft A

Remedial Investigation/ Feasibility Study for the 200-UP-1 Groundwater Operable Unit

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

U.S. DEPARTMENT OF ENERGY

Richland Operations Office

P.O. Box 550
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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Executive Summary

The U.S. Department of Energy (DOE) has completed a *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) remedial investigation (RI) and feasibility study (FS) of the 200-UP-1 Groundwater Operable Unit (OU) within the 200 Area National Priorities List Site located in Washington State at DOE's Hanford Site. The RI was conducted to collect additional data to refine the nature and extent (N&E), assess the fate and transport (F&T), and evaluate potential risks to human health and the environment (HHE) from 200-UP-1 Groundwater OU contaminants. The information collected during the RI, per the 200-UP-1 RI/FS Work Plan (DOE/RL-92-76, Rev. 1), was used to support the completion of the FS and develop a clearly defined technical basis for remedial action decisions in this OU.

The 200-UP-1 Groundwater OU, shown in Figure ES-1, is the southernmost of two groundwater OUs that underlie the 200 West Area located on the Central Plateau of the Site. The 200-UP-1 Groundwater OU extends to the south-southeast of the 200 West Area across the Site, east to the 200-PO-1 Groundwater OU interface and north to the 200-ZP-1 Groundwater OU.

The observed groundwater contamination in the 200-UP-1 Groundwater OU has resulted largely from operations and process liquid waste disposal practices associated with U Plant, S Plant (Reduction-Oxidation [REDOX] Plant), and the 241-S-SX Single-Shell Tank (SST) Farm and 241-U Tank Farm Waste Management Areas (WMAs). Liquid wastes generated by the U Plant and S Plant operations were routinely discharged to the ground through engineered discharge structures and surface impoundments including cribs, French drains, reverse wells, ditches, and ponds. A number of the SSTs in the 241-S, SX Tank Farm (WMA S-SX), and 241-U Tank Farm (WMA U) have leaked and are suspected or known contributors to vadose zone soil contamination, which in turn represents a 200-UP-1 Groundwater OU contaminant source.

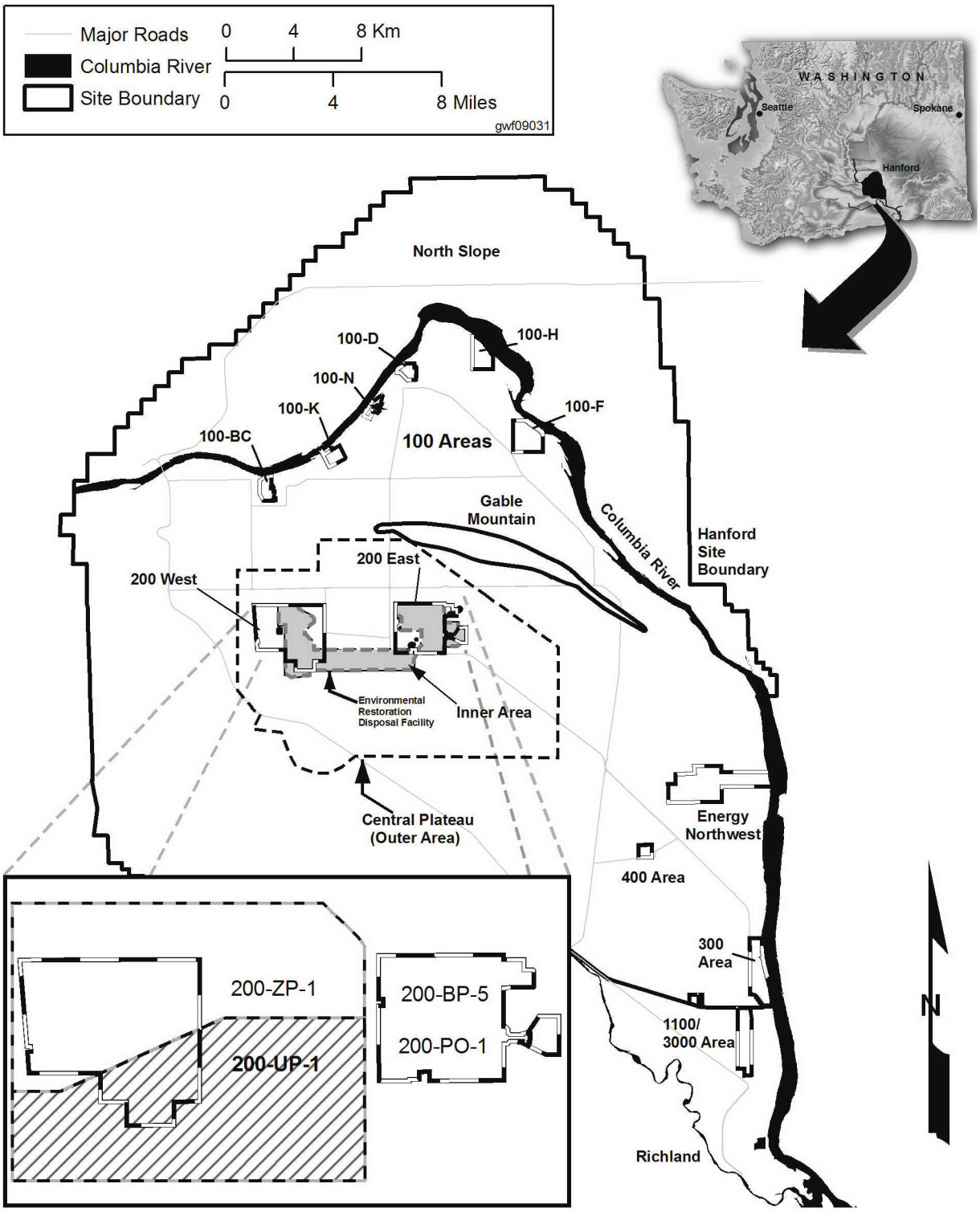

Figure ES-1. Location of the 200-UP-1 Groundwater OU

Consistent with the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement [TPA]; Ecology et al., 1989a), DOE/RL-2007-20, and DOE/RL-2009-81, the evaluation and remediation of waste sites and impacted vadose zone soils overlying the 200-UP-1 Groundwater OU will be addressed as discrete CERCLA OUs with their own accompanying Record of Decision (ROD). The 200-UP-1 Groundwater OU RI/FS addresses the contamination already present in the aquifer, within the geographic boundary of the OU. The source OU RODs will include provisions to define and incorporate future groundwater protection requirements into remedial actions intended to prevent further degradation of the groundwater beneath the Site and to restore Central Plateau groundwater to beneficial use.

The primary objectives of the 200-UP-1 Groundwater OU **RI activities** were to:

- Evaluate groundwater samples from existing and newly installed CERCLA and Resource Conservation and Recovery Act (RCRA) monitoring wells located within the OU, and use the last 5 years of available data to further refine the conceptual site model of contaminant releases and related impacts, refine the F&T models physical inputs, and complete a baseline risk assessment (BRA).
- Define the N&E of 200-UP-1 groundwater contaminants that pose major risks to HHE from the 37 identified contaminants of potential concern (COPCs).
- Provide the information and data needed to support the use of the cleanup levels listed in the 200-ZP-1 OU ROD for evaluating 200-UP-1 OU remedial alternatives.

The primary objectives of the 200-UP-1 Groundwater OU **FS activities** were to:

- Ensure that appropriate remedial alternatives are developed and evaluated such that relevant information concerning the remedial action options can be presented to the public and an appropriate remedy selected.
- Evaluate the 200-ZP-1 OU remedial action objectives (RAOs) to ensure they address the specific threats posed by the contaminants present in 200-UP-1 OU groundwater.
- Identify and screen remedial technologies and associated process options capable of achieving the RAOs.
- Develop and evaluate a range of viable remedial action alternatives that eliminate, reduce, or control risks to HHE.

- Evaluate the use of the facilities being constructed in the 200 West/200-ZP-1 OU as a means for treatment of 200-UP-1 OU extracted groundwater, if P&T is selected as a remedial technology.

The data and information collected during the RI confirmed that several groundwater contaminants occur at concentrations above drinking water standards (DWS) within the 200-UP-1 Groundwater OU. Table ES-1 summarizes the sampling results for the 200-UP-1 contaminants. The contaminants shown in bold were retained as contaminants of concern (COCs) for remedial technology screening and alternative development. Chapter 4 presents the complete sampling results and a full discussion on the N&E of the groundwater contaminant plumes.

Table ES-1. Summary of Sample Results for the 200-UP-1 Groundwater OU Contaminants[a]

Contaminants, units	Number of Analyses	Number of Detections	Natural Background[a]		Drinking Water Standard[a]	
Carbon tetrachloride, µg/L	693	639	0	(614)	5	(529)
Chloroform, µg/L	696	581	0	(562)	80	(0)
Chromium (filtered), µg/L	922	567	3.17	(511)	100	(90)
Chromium (unfiltered), µg/L	376	237	--	--	100	(39)
Iodine-129, pCi/L	540	193[b]	0.000131	(191)	1	(180)
Nitrate, mg/L	1,248	1,248	41.7	(565)	45	(538)
Strontium-90, pCi/L	157	13	0.02	(11)	8	(2)
Technetium-99, pCi/L	1,245	1,122	0.988	(1,098)	900	(351)
Trichloroethene, µg/L	696	295	0	(291)	5	(52)
Tritium, pCi/L	540	401	142	(398)	20,000	(143)
Uranium (total), µg/L	940	891	14.4	(304)	30	(260)
1,4-Dioxane µg/L	390	1	0	(1)	--	--
Chromium (VI) µg/L	144	89	--	--	100	(5)
Tetrachloroethene µg/L	695	54	0	(49)	5	(0)

a. The number of sampling results above Natural Background and DWS concentrations is presented in parenthesis. Excludes results flagged as “suspect,” “reject,” or otherwise flagged to indicate a laboratory quality control problem.

b. All results greater than or equal to 1 pCi/L counted as detections.

DWS = drinking water standard

OU = operable unit

Concentrations of technetium-99 (Tc-99) above the DWS of 900 pCi/L were found within four distinct contaminant plumes in the 200-UP-1 Groundwater OU. One plume originates from the 216-U-1 and 216-U-2 Cribs and a portion of this plume has migrated to the east of the 200 West Area. At the WMA S-SX, a second plume originates from the 241-SX Tank Farm in the southwestern corner of the WMA, while a third plume originates from the 241-S Tank Farm in the north part of the WMA. The fourth plume originates from WMA U where Tc-99 concentrations in the downgradient wells are elevated compared to concentrations in the upgradient wells, indicating that the 241-U Tank Farm is the source of the contamination.

Concentrations of uranium above the DWS of 30 μg/L were detected in only two areas within the OU. The first is an area downgradient from the 216-U-1 and 216-U-2 Cribs. Similar to Tc-99, the uranium contamination originated from the cribs when they were active from 1951 to 1961. Uranium has also been detected at concentrations slightly above the DWS in the vicinity of the 216-U-10 Pond. Concentrations of iodine-129 (I-129) above the DWS of 1 pCi/L were detected in two contaminant plumes. One plume appears to originate from the 216-U-1 and 216-U-2 Cribs. The second plume originates from the southern part of the 200 West Area, the source of which is believed to be the 216-S-1, 216-S-2, 216-S-7, and 216-S-9 Cribs. It is likely that these sources also account for the highest concentrations within the I-129 plume east of the 200 West Area.

Concentrations of chromium above the DWS of 100 μg/L were detected in three regions of the OU. Two distinct plumes originate from WMA S-SX; the first occurs in the south part of the WMA downgradient from the 241-SX Tank Farm, the second occurs in the north part of the WMA downgradient from the 241-S Tank Farm. In general, chromium concentrations are increasing at WMA S-SX and the areal extents of both the northern and southern plumes are growing. A third chromium plume occurs in the 600 Area east-southeast of the 200 West Area. The 216-S-20 Crib is the most probable source for the 600 Area chromium plume, although effluent from the 216-S-10 Pond and Ditch and 216-S-19 Pond may also have contributed.

Concentrations of tritium above the DWS of 20,000 pCi/L were detected in the vicinity of the REDOX Plant cribs (216-S-1, 216-S-2, 216-S-7, 216-S-21, and 216-S-25) in the southern part of the 200 West Area. Two high-concentration plumes occur within this region; a large plume extends to the east and northeast from the 200 West Area and a smaller plume extends to the east-southeast from the 216-S-25 Crib.

Concentrations of nitrate above the DWS of 45 mg/L were detected throughout the OU. During the RI, nitrate concentrations were found above the DWS at WMA S-SX, WMA U, near and/or downgradient from the 216-S-20, 216-S-25, 216-U-1, 216-U-2, 216-U-8, and 216-U-12 Cribs. A large nitrate plume originates near the U Plant disposal sites and extends from the 200 West Area east-northeast into the 600 Area. Two smaller nitrate plumes originate near the REDOX Plant disposal sites; one near the 216-S-20 Crib and another near the 216-S-25 Crib and WMA S-SX.

Concentrations of carbon tetrachloride above the DWS of 5 μg/L were detected in numerous wells. The highest concentrations in the OU occur adjacent to the 200-ZP-1 Groundwater OU and decrease toward the south and east. The carbon tetrachloride plume originated from waste disposal sites associated with the Plutonium Finishing Plant that overlies the 200-ZP-1 OU. Carbon tetrachloride is a mobile dense liquid that migrated horizontally as a liquid in conjunction with the regional groundwater flow or while diffusing laterally through the vadose zone. This migration carried carbon tetrachloride contamination from the original disposal locations in the 200-ZP-1 Groundwater OU into the 200-UP-1 Groundwater OU.

Concentrations of chloroform found in the OU were largely associated with the carbon tetrachloride dechlorination. Chloroform is a degradation product of carbon tetrachloride and tends to occur in the same wells with carbon tetrachloride. Data collected during the RI found no exceedances of the DWS (80 μg/L for total trihalomethanes) and no evidence of a local source of chloroform originating within the 200-UP-1 OU.

The maximum trichloroethene (TCE) concentrations measured during the RI exceeded the DWS of 5 μg/L in eight wells in the northern part of the OU, and in one well downgradient from the 216-S-20 Crib.

Stronium-90 (Sr-90) was found above the DWS of 8 pCi/L in a single well downgradient from the 216-S-1 and 216-S-2 Cribs. The 216-S-1 and 216-S-2 Cribs received highly acidic waste from the REDOX Plant between 1952 and 1956. In 1955, the waste is believed to have corroded the casing of a nearby well (299-W22-3, located 25 m [80 ft] west-northwest of well 299-W22-10), which allowed the effluent to bypass the soil column and flow down the well directly into groundwater. This is the postulated pathway by which Sr-90 reached groundwater at this location.

1,4-Dioxane was detected once during the RI at 120 μg/L in a single well located near the 216-S-20 Crib. This constituent was also detected in the same well in two previous sample events at concentrations of 110 μg/L (January 2002) and 160 μg/L (January 2006). More recently, the constituent has been detected at a concentration of 5 μg/L in a second well located to the east of the 216-S-20 Crib. Based on these multiple detections in different wells, 1,4-dioxane is interpreted to be present in the groundwater with the 216-S-20 Crib being the most likely source. There is no state or federal DWS for this constituent.

F&T modeling was used to assist in the description of estimated future impacts of selected groundwater contaminants in the 200-UP-1 OU and downgradient areas. These simulations/estimations were then used to evaluate potential future impacts to hypothetical receptors at selected locations within the 200-UP-1 Groundwater OU system.

Several contaminants presented in Table ES-1 were selected for transport evaluation in the future conditions portion of the risk assessment. Carbon tetrachloride was not evaluated in these simulations (future conditions), as a ROD is already in place for this 200-ZP-1 Groundwater OU contaminant. The CERCLA Five-year Review Process is also in place for carbon tetrachloride, and it will deal with observed future conditions throughout this plume.

F&T modeling was performed for the contaminants present in 200-UP-1 OU groundwater that contribute most to the overall risk. The results of these modeling simulations under natural conditions (no engineered controls) are as follows:

- The tritium plume decreases from an initial maximum concentration of near 1,000,000 pCi/L to less than 20,000 pCi/L throughout the OU after 75 years of natural attenuation.
- The nitrate plumes decrease from an initial maximum concentration of near 1,700,000 μg/L to less than 45,000 μg/L after 175 years of natural attenuation.
- The I-129 plume, beginning with an initial maximum concentration of 39 pCi/L persists over the simulated timeframe (1,000 years) due to moderate retardation and a long radionuclide half-life. At the end of the simulation period, the maximum calculated I-129 concentration of 1.3 μg/L is just above the DWS of 1 pCi/L.

- The TCE plume decreases from a maximum concentration of 13 μg/L to near 2 μg/L after 75 years.
- The Tc-99 plumes decrease from a maximum concentration of about 135,000 pCi/L to less than 440 pCi/L after 125 years.
- The uranium plume, beginning with an initial maximum concentration of about 600 μg/L persists over the simulated timeframe (1,000 years) due to moderate retardation. At the end of the simulation, the maximum projected concentration is 43 μg/L or about one and one-half times greater than the DWS of 30 μg/L.
- The chromium plumes decrease from a maximum concentration of near 850 μg/L to less than 100 μg/L after 175 years.
- The chloroform plumes decrease from a maximum concentration of near 35 μg/L to less than 1 μg/L after 75 years.

A conceptual exposure model (CEM) was developed for the 200-UP-1 Groundwater OU. The CEM provides a current understanding of the sources of contamination, physical setting, current and reasonably anticipated future land use, groundwater beneficial uses, and identifies the means by which human or ecological receptors may contact contaminants in groundwater. The CEM also addresses potentially complete exposure pathways that may result under current Site conditions and from reasonably anticipated potential future uses of the groundwater within the 200-UP-1 Groundwater OU.

There are currently no known actual exposures of either human or ecological receptors to groundwater within the 200-UP-1 Groundwater OU. Based on the previously mentioned F&T model simulations, it is anticipated that groundwater contaminants will not disperse beyond the boundaries of the Central Plateau; thus, only exposure to human receptors is considered. Potential human receptors, including Native American subsistence users, are assumed to be hypothetical future domestic groundwater users. The following potentially complete exposure pathways were identified:

- Ingestion of contaminated water by drinking or in food preparation
- Inhalation of contaminant vapors during showering or other household activities
- Dermal contact exposure to contaminants in groundwater
- External radiation exposure from radioactive contaminants in groundwater

The purpose of performing the BRA was to determine whether remediation of the contaminants present within the OU is necessary, and to assist in determining which contaminants and exposure pathways need to be remediated. Table ES-2 summarizes the results of the BRA for the 200-UP-1 OU exposure area; it identifies the DWSs that are exceeded under current and estimated future groundwater conditions, as well as a summary of the quantified risk results that would be encountered, should no remedial action be taken. Based on the information provided in the F&T modeling and results of the BRA, it is appropriate to proceed with the FS for the 200-UP-1 Groundwater OU. No actual exposures of human or ecological receptors to conditions exceeding standards are presently occurring due to the current institutional controls implemented by DOE at the Hanford Site. However, the exceedances define a basis for remedial action(s) within this OU to mitigate future potential exposure risks to human health receptors.

The guidance and information used to identify and screen remedial technologies and process options for the 200-UP-1 Groundwater OU are presented in Chapter 7. These technologies and process options were screened and then used to assemble an array of remedial alternatives, which are presented in Chapter 8. An initial screening of the alternatives that considers effectiveness, implementability, and relative costs was also performed in Chapter 8 to determine which alternatives should be carried forward for detailed evaluation.

The list of alternatives retained from this screening included:

- No Action Alternative.
- Alternative 2 – Restoration of Tc-99 (30 years) and uranium (150 years) and hydraulic containment of I-129 until a final remedy is selected.
- Alternative 3 – Restoration of Tc-99 (30 years) and uranium (80 years) and hydraulic containment of I-129 until a final remedy is selected.
- Alternative 4 – Restoration of Tc-99 (25 years) and uranium (28 years) and hydraulic containment of I-129 until a final remedy is selected.

Table ES-2. Summary of Groundwater Conditions in the 200-UP-1 Groundwater OU that Exceed Standards and Present a Basis for Feasibility Study

Contaminant, units	Current Exceedance[a]	Year Projected Concentrations Achieve Groundwater Cleanup Level			HQ at DWS or Cleanup Level	ELCR at DWS or Cleanup Level
		90th Percentile Conc.	Maximum Conc.	Drinking Water Standard or WAC 173-340-720 Groundwater Cleanup Level		
Iodine-129, pCi/L	Yes	2409	NA[c]	1	--	--
Strontium-90, pCi/L	No	NA[d]	NA[d]	8	--	--
Technetium-99, pCi/L	Yes	2034	2084	900	--	--
Tritium, pCi/L	Yes	2059	2059	20,000	--	--
Chromium (total), µg/L	Yes	2034	2184	100	<0.01	--
Uranium, µg/L	Yes	2609	NA	30	0.90	--
1,4-Dioxane, µg/L	Yes[b]	NA[d]	NA[d]	4	--	--
Carbon Tetrachloride, µg/L	Yes	NA[e]	NA[e]	NA[e]	--	--
Chloroform, µg/L	No	2034	2084	1.4	<0.01	1.4×10^{-7}
Tetrachloroethene, µg/L	No	2034	2034	0.081	<0.01	3.7×10^{-8}
Trichloroethene, µg/L	No	2034	NA[c]	0.49	--	4.1×10^{-6}
Nitrate, µg/L	Yes	2134	2409	25,600	0.80	--
Nitrate, µg/L	Yes	2084	2184	45,000	NA	--
Fluoride, µg/L	No	2034	2034	480	<0.01	--
Total Risk					**4.3×10^{-6}**	
Total Hazard Index					**2.2**	

Notes: *Safe Drinking Water Act of 1974*.

WAC 173-340-720.

a. Current Exceedance:

Yes = Calculated groundwater exposure point concentration currently exceeds or is equal to the DWS established by the *Safe Drinking Water Act of 1974*, MTCA, WAC 173-340-720, or WAC 173-340-708 risk threshold of 1 × 10-5 for multiple hazardous substances or the upper NCP threshold of 1×10^{-4}, or a non-cancer hazard index of 1.

No = Calculated groundwater exposure point concentration does not currently exceed applicable standard(s).

b. Although the 90th percentile groundwater concentration of 1,4-dioxane is greater than the groundwater cleanup level, it is a minimal contribution to total risk.

c. Maximum concentrations for uranium and trichloroethene do not attenuate below their target action levels within the 1,000-year F&T simulation period.

d. Future groundwater conditions are not estimated for 1,4-dioxane and Sr-90, as their presence in the 200-UP-1 Groundwater OU is localized and measured in one well (299-W22-20 and 299-W22-10, respectively).

Table ES-2. Summary of Groundwater Conditions in the 200-UP-1 Groundwater OU that Exceed Standards and Present a Basis for Feasibility Study

Contaminant, units	Current Exceedance[a]	Year Projected Concentrations Achieve Groundwater Cleanup Level			HQ at DWS or Cleanup Level	ELCR at DWS or Cleanup Level
		90th Percentile Conc.	Maximum Conc.	Drinking Water Standard or WAC 173-340-720 Groundwater Cleanup Level		

e. Future groundwater conditions are not estimated for carbon tetrachloride measured in the 200-UP-1 Groundwater OU because the carbon tetrachloride originates from the 200-ZP-1 Groundwater OU and is actively being treated as part of the 200-ZP-1 Groundwater OU remedial action.

DWS = drinking water standard
ELCR = Excess Lifetime Cancer Risk
HQ = Hazard Quotient
OU = operable unit
WAC = *Washington Administrative Code*

Alternative 1 – Monitored Natural Attenuation and Institutional Controls was not retained for detailed evaluation because it was judged as ineffective due to the long timeframe (more than 1,000 years) required for remediation. The rationale for individual remedy components, including a description of the common elements, along with detailed descriptions of each alternative are provided in Chapter 8.

Once the remedial alternatives were assembled and screened, a detailed evaluation was performed in accordance with the threshold and balancing criteria specified in 40 Code of Federal Regulations (CFR) 300.430(e)(9)(iii). The findings of the detailed evaluation indicate that the No Action Alternative does not provide overall protection of HHE or comply with applicable or relevant and appropriate requirements (ARARs). Each of the remaining alternatives was found to meet these threshold criteria and perform well against the balancing criteria. The alternatives were then compared to assess relative trade-offs against one another.

Table ES-3 summarizes the results of this evaluation including net present value (NPV) costs for each alternative.

Table ES-3. Comparative Evaluation of Alternatives for 200-UP-1 Groundwater OU

CERCLA Criteria	Remedial Alternatives[a]				
	No Action	1	2	3	4
Threshold Criteria					
Protection of human health/environment	No	NR	Yes	Yes	Yes
Compliance with ARARs	No	NR	Yes[b]	Yes[b]	Yes[b]
Balancing Criteria					
Long-term effectiveness and permanence	●	NR	◐	◐	○
Reduction of toxicity, mobility, or volume through treatment	●	NR	◐	◐	○
Short-term effectiveness and time to achieve RAOs	●	NR	◐	◐	◐
Implementability	●	NR	○	◐	◐
NPV Cost (million)	$0	NR	$137	$225	$316
Modifying Criteria					
State acceptance	To be determined				
Community acceptance	To be determined				
Other Evaluation Factors					
Green-Sustainable Elements	○	NR	○	◐	◐

Notes:

○ = Performs very well against the criterion with no apparent disadvantages or uncertainty

◐ = Performs moderately well against the criterion but with some disadvantages or uncertainty

● = Performs less well against the criterion and may have disadvantages or uncertainty

Alternatives

1. Not retained.

2. Restoration of Tc-99 (30 years) and uranium (150 years) and hydraulic containment of I-129 until a final remedy is selected.

3. Restoration of Tc-99 (30 years) and uranium (80 years) and hydraulic containment of I-129 until a final remedy is selected.

4. Restoration of Tc-99 (25 years) and uranium (28 years) and hydraulic containment of I-129 until a final remedy is selected.

a. None of the alternatives include costs associated with design, installation or operation of the final iodine-129 remedial action. The R&D costs **are** included; therefore this evaluation does not consider this element.

b. Alternative may require an ARAR waiver for tritium in the future following selection of a final remedy for I-129.

ARAR = applicable or relevant and appropriate requirement

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*

RAO = remedial action objective

NPV = net present value

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Terms

AAMS	aggregate area management study
AAMSR	aggregate area management study report
ACL	alternate concentration limit
ALE Reserve	Arid Lands Ecology Reserve
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
BOD	biological oxygen demand
BRA	baseline risk assessment
BWIP	Basalt Waste Isolation Project
CalEPA	California EPA
CCU	Cold Creek Unit
CDI	chronic daily intake
CEM	conceptual exposure model
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	*Code of Federal Regulations*
CLARC	Cleanup Levels and Risk Calculations
CNT	Condensate Neutralization Tank
COC	contaminant of concern
COPC	contaminant of potential concern
CSM	conceptual site model
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
DAD	dermal absorbed dose
DDD	dichlorodiphenyldichloroethane
DDT	dichlorodiphenytrichlorethane
DNAPL	dense non-aqueous phase liquid
DOE	U.S. Department of Energy
DQA	data quality assessment
DQO	data quality objective

DST	double-shell tank
DWS	drinking water standard
ECAP	Ecological Compliance Assessment Program
Ecology	Washington State Department of Ecology
EDE	effective dose equivalent
ELCR	excess lifetime cancer risk
EM	Environmental Management
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ERDF	Environmental Restoration Disposal Facility
ES&H	Environmental Safety & Health
ESD	explanation of significant difference
ETF	Effluent Treatment Facility
F&T	fate and transport
FBR	fluidized bed bioreactor
FS	feasibility study
FY	fiscal year
GAC	granular activated carbon
GIS	geographic information system
GRA	general response action
HCP EIS	Hanford Comprehensive Land-Use Plan Environmental Impact Statement
HEAST	Health Effects Assessment Summary Tables
HEIS	Hanford Environmental Information System
HHE	human health and the environment
HI	hazard index
HMS	Hanford Meteorology Station
HQ	hazard quotient
HSP	Health and Safety Plan
HSU	hydrostratigraphic unit
I-129	iodine-129

IC	institutional control
ICP	inductively coupled plasma
ICRP	International Council for Radiation Protection
IDW	Investigation-derived waste
IRA	interim remedial action
IRIS	Integrated Risk Information System
IRM	interim remedial measure
ISCO	in situ chemical oxidation
ISMS	Integrated Environmental Management System
IX	ion exchange
K_d	distribution coefficient
LDR	land disposal remediation
LFI	limited field investigation
LMU	lower mud unit
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MIBK	methyl isobutyl ketone
MNA	monitored natural attenuation
MS	mass spectrometry
MTCA	*Model Toxics Control Act*
N&E	nature and extent
NBS	National Bureau of Standards
NCEA	National Center for Environmental Assessment
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NEPA	*National Environmental Policy Act of 1969*
NJDEP	New Jersey Department of Environmental Protection
NPDES	National Pollutant Discharge Elimination System
NPDWRs	national primary drinking water regulations
NPL	National Priorities List
NPV	net present value

O&M	operations and maintenance
OEHHA	Office of Environmental Health Hazard Assessment
OES	optical emission spectrometry
OU	operable unit
P&T	pump-and-treat
PCE	tetrachloroethene
PFP	Plutonium Finishing Plant
PMP	Project Management Plan
PNNL	Pacific Northwest National Laboratory
PPE	personal protective equipment
PPRTV	Provision Peer Reviewed Toxicity Values
PRB	permeable reactive barrier
PRG	preliminary remediation goal
PSPL	Puget Sound Power and Light
PUREX	Plutonium-Uranium Extraction (Plant)
QC	quality control
RA	remedial action
RAG	risk assessment guidance
RAIS	Risk Assessment Information System
RAO	remedial action objective
RAWP	Remedial Action Work Plan
RCRA	*Resource Conservation and Recovery Act of 1976*
RCW	*Revised Code of Washington*
REDOX	Reduction-Oxidation (Plant)
RD	remedial design
RfD	reference dose
RI	remedial investigation
RME	reasonable maximum exposure
RO	reverse osmosis
ROD	record of decision

RPD	relative percent difference
RUM	Ringold upper mud
SALDS	State-Approved Land Disposal Site
SAP	sampling and analysis plan
SDWA	Safe Drinking Water Act
SFO	oral slope factor
SRNL	Savannah River National Laboratory
S/S	solidification/stabilization
SST	single-shell tank
SVE	soil vapor extraction
TBC	to be considered
TBP	tributylphosphate
Tc-99	technetium-99
TCE	trichloroethene
TEDF	Treated Effluent Disposal Facility
TI	technical impracticability
TMV	toxicity, mobility, volume
TNC	The Nature Conservancy
TPA	Tri-Party Agreement (*Hanford Federal Facility Agreement and Consent Order)*
TRU	transuranic
TSD	treatment, storage, and disposal
UCL	upper confidence limit
UIC	Underground Injection Control
UPR	unplanned release
USACE	U.S. Army Corps of Engineers
VOCs	volatile organic compounds
VPGAC	vapor-phase granular activated carbon
WAC	*Washington Administrative Code*
WIDS	Waste Site Information Management
WMA	waste management area
WPPSS	Washington Public Power Supply System

1

1 Introduction

The Hanford Site occupies approximately 1,518 km^2 (586 mi^2) of shrub-steppe in southeastern Washington with approximately 80.5 km (50 mi) of the Columbia River flowing through it, near the northern and eastern boundaries. The Site originally occupied an area of 1,735.3 km^2 (670 mi^2) and included buffer areas across the river in Grant and Franklin Counties, some of which have been returned to private use. In 2000, large portions of the Site were turned over to the Hanford Reach National Monument. The remainder of the Site is uninhabited and continues to be closed to public access. Neighboring metropolitan areas include the Tri-Cities to the southeast, comprising Richland, Kennewick, Pasco, and smaller communities; Yakima to the northwest; and Prosser to the southwest.

In 1989, the U.S. Environmental Protection Agency (EPA) placed the 100, 200, 300, and 1100 Areas of the Site on the National Priorities List (NPL) pursuant to the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA).

- The 100 Area is the nuclear reactor operations area, located along the south bank of the Columbia River in the northern portion of the Site.
- The 200 Area is the former irradiated nuclear fuel reprocessing area and central waste management area (WMA) located in the central upland portion of the Site.
- The 300 Area is the reactor nuclear fuel fabrication and research and development area located near the southern Site boundary along the Columbia River.
- The 1100 Area is the site support services area used for equipment and maintenance.

The 200 Area NPL Site is divided into eight waste area groups, largely corresponding to the major processing plants (U Plant, S Plant, B Plant, and T Plant), and a number of isolated operable units (OUs) located in the surrounding 600 Area. The 200 West Area, where the 200-UP-1 Groundwater OU is located (Figure 1-1), is a controlled area of approximately 7.8 km^2 (3 mi^2) near the middle of the Site. It is about 8 km (5 mi) from the Columbia River and 11.3 km (7 mi) from the nearest Site boundary.

The 200-UP-1 Groundwater OU remedial investigation (RI) was completed in accordance with Revision 1 of the 200-UP-1 work plan (DOE/RL-92-76, Rev. 1). The initial 200-UP-1 work plan (DOE/RL-92-76, Rev. 0) was released in 1994 to support a limited field investigation (LFI) (DOE/RL-96-33). The LFI was conducted to refine the conceptual site model (CSM) for risk assessment to support construction of the U Plant interim remedial action (IRA), built in 1997 (EPA/ROD/R10-97/048). The findings from this work (data from groundwater samples collected between 2004 and 2009) were used to support the risk evaluation/assessment and related remedial action (RA) alternatives presented herein for selection of the final 200-UP-1 Groundwater OU remedy.

The RI/feasibility study (FS) activities described in this report are consistent with the requirements of CERCLA. Figure 1-2 presents a general overview of the CERCLA process.

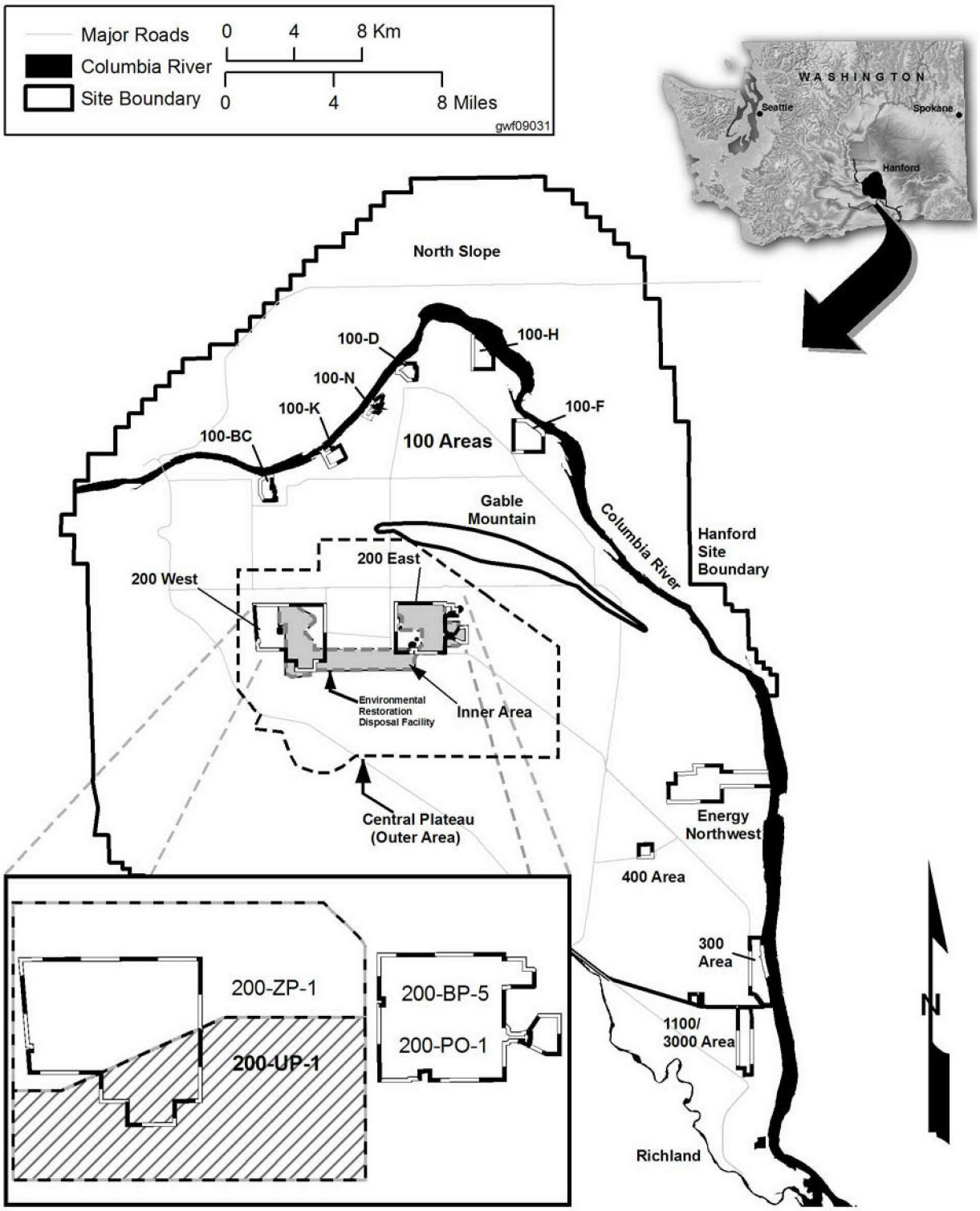

Figure 1-1. Hanford Site Map with 200 Area Groundwater Operable Unit Insert

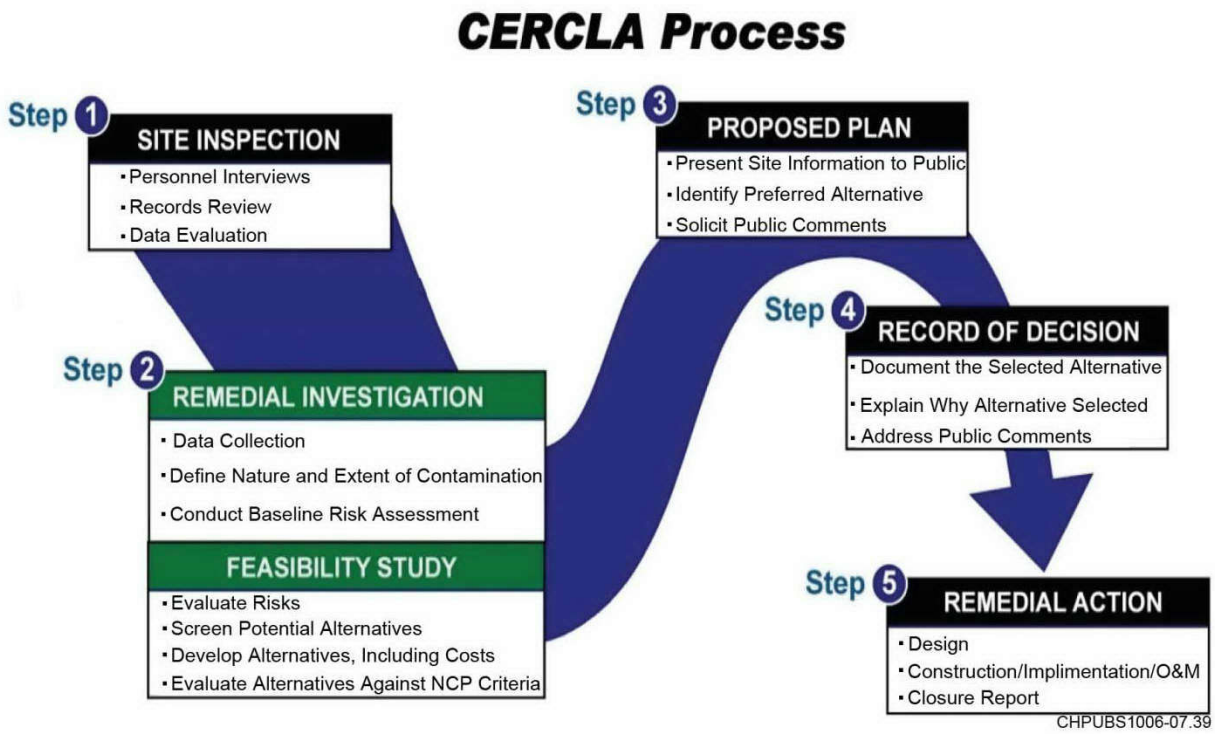

Figure 1-2. Generalized CERCLA Process Employed at the Hanford Site

1.1 The Tentative Agreement

In April 2010, a Tentative Agreement was reached between the Tri-Parties to define the new CERCLA decision structure accompanying the Central Plateau strategy (DOE/RL-2009-81), consistent with the division of decision making between the groundwater OUs and the waste site OUs. The Tentative Agreement recognizes the Inner Area, the Outer Area, and groundwater as the subjects of remediation. As acknowledged in DOE/RL-2002-59 and DOE/RL-2007-20, and then reaffirmed in the 200-ZP-1 Final record of decision (ROD) (EPA et al., 2008), U.S. Department of Energy's (DOE's) goal is to restore Central Plateau groundwater to its beneficial uses, unless restoration is determined to be technically impracticable. This includes the groundwater underlying both the Inner and Outer Areas.

Table 1-1 defines the new decision structure and accompanying OUs for the Inner and Outer Areas and groundwater remediation under the Tentative Agreement.

As this decision structure shows, the 200-UP-1 and 200-ZP-1 Groundwater OU RI/FSs serve as foundation documents to support the new 200 West Groundwater OU proposed in the Tentative Agreement. The Tentative Agreement and accompanying proposed Tri-Party Agreement (TPA) revisions will be finalized after the public comment period commencing on April 26, 2010, and concluding in 2010.

Table 1-1. Proposed Decision Structure and Operable Unit Designations for the 200 Area for the Inner and Outer Areas

Decision Structure/Operable Unit	Scope and Focus
200 West Groundwater/200-ZP-1	Contaminated groundwater associated with T Plant and Z Plant wastes and T, TX, and TY WMAs.
200 West Groundwater/200-UP-1	Contaminated groundwater associated with S Plant, U Plant, S-SX, SY, and U WMAs.
200 East Groundwater/200-BP-5	Contaminated groundwater associated with B Plant and C Plant and B, BX, BY, and C WMAs.
200 East Groundwater/200-PO-1	Contaminated groundwater associated with PUREX) Plant and A, AN, and AX WMAs.
200-PW-1/3/6 and 200-CW-5	Key plutonium-bearing waste sites in the Inner Area.
200 West Inner Area	Majority of the waste sites in the 200 West Area.
200 East Inner Area/Pipelines	Majority of the waste sites in the 200 East Area. Includes the majority of pipelines across the Inner Area (200 East and West Areas).
Deep Vadose Zone	Key waste sites in the Inner Area representing significant deep vadose zone contamination. Many sites are associated with the Central Plateau's tank farms.
200-SW-2 (burial grounds)	The 200 Area Radioactive and Hazardous Waste landfills.
B Plant Canyon and Associated Waste Sites	One of the four remaining canyon decisions.
PUREX Canyon and Associated Waste Sites	One of the four remaining canyon decisions.
REDOX Canyon and Associated Waste Sites	One of the four remaining canyon decisions.
T Plant Canyon and Associated Waste Sites	One of the four remaining canyon decisions.
U Canyon	U Canyon final decision documented in the 2005.
Outer Area	All areas of the Central Plateau beyond the Inner Area.

PUREX = Plutonium-Uranium Extraction (Plant)
REDOX = Reduction-Oxidation (Plant)

1.2 Purpose and Scope of Report

The TPA provides for the integration of RAs under CERCLA and permitting, closure, and/or post closure care for treatment, storage, and disposal (TSD) units under the *Resource Conservation and Recovery Act of 1976* (RCRA). The TSD units that contribute to groundwater contamination at the 200-UP-1 Groundwater OU include the S-10 Pond, S-SX, and U Tank Farms. The flux of contamination from CERCLA and these TSD Unit waste sites is believed to be (in certain cases) a major contributing source of groundwater contamination.

The primary scope of this RI/FS is to:

1. Define the nature and extent (N&E) of groundwater contamination for the key contaminants of concern (COCs) that pose the major risks to human health and the environment (HHE).

2. Evaluate groundwater samples from 93 CERCLA and RCRA wells, and use the last 5 years of available data to prepare a baseline risk assessment (BRA) and FS to meet TPA Milestone M-015-17A for completion of the combined RI/FS and associated Proposed Plan by September 30, 2010.

3. Use additional information on the area stratigraphy and the vertical extent of contamination to refine fate and transport (F&T) modeling input parameters for model development. These parameters include physical and geological properties, hydraulic and geochemical properties, and distribution coefficient (K_d) values for specific COPCs.

The 200-UP-1 drilling, sampling, analysis, and groundwater F&T modeling efforts are currently focused on developing a detailed understanding of the distribution and movement of the major risk-driving COPCs in the saturated zone. The objective of this work is to prepare a BRA to evaluate the risks associated with predicted COPC concentrations at potential exposure locations and to define remedial alternatives for reducing risks estimated or measured to be above acceptable levels.

This RI/FS does not cover dense non-aqueous phase liquids (DNAPLs) associated with the 200-UP-1 Groundwater OU. Data collection for those constituents was covered in work performed by DOE Headquarters EM-50-funded activities (HNF-EP-0063). Soil (source) groundwater investigations for DNAPLs are being conducted under separate RI/FS work plans and characterization activities (DOE/RL-2006-24, Rev. 0 and DOE/RL-2006-58).

Table 1-2 presents the final list of COPCs and COCs for 200-UP-1, as defined by working through the complete RI/FS process. Five COCs resulted from the FS screening process. The COCs are those contaminants highlighted in the table.

Table 1-2. Final List of Contaminants of Potential Concern in the 200-UP-1 Groundwater Operable Unit

General Chemicals and Non-Metals	Metals
Fluoride	Chromium
Nitrate	Chromium (hexavalent)
Volatile Organics	***Uranium***
Trichloroethene	**Radionuclides**
Carbon tetrachloride	***H-3***
Chloroform	***I-129***
Tetrachloroethene	Sr-90
1,4-Dioxane	***Tc-99***

Both past practice units and TSD units have contributed to groundwater contamination. COPCs originating from these TSD units that impacted groundwater have been included in this RI/FS report because the groundwater OU will be remediated under CERCLA. Closure and corrective action at TSD units are not part of this RI/FS process, as these facilities are regulated under RCRA. The Plateau Remediation and the Tank Operations Contractors are responsible for closure and corrective actions at these land disposal and waste management units.

The Sampling and Analysis Plan (SAP) (DOE/RL-92-76) for this RI identified the type, quantity, and quality of data needed to characterize groundwater more accurately in support of the risk assessment and FS process. The SAP included sampling both existing installed and newly drilled RCRA and CERCLA wells (Table 1-3) as defined in CP-15315.

Table 1-3. Remedial Investigation/Feasibility Study Wells—CERCLA and RCRA

CERCLA Wells			
299-W15-37	299-W22-20	699-35-66A	299-W21-2
299-W18-15	299-W22-26	699-35-70	699-30-66
299-W18-21	299-W22-45	699-35-78A	699-40-65
299-W18-22	299-W22-48	699-36-61A	299-W19-104
299-W18-30	299-W22-49	699-36-70A	299-W19-105
299-W18-33	299-W22-83	699-38-65	299-W22-69
299-W19-34A	299-W23-4	699-38-68A	299-W22-72
299-W19-34B	299-W23-9	699-38-70	299-W22-86
299-W19-35	299-W23-10	699-40-62	699-34-72
299-W19-36	299-W23-14	299-W19-46	699-33-74
299-W19-37	299-W23-15	299-W19-48	699-33-75
299-W19-39	299-W23-21	299-W19-50	699-32-76
299-W19-4	299-W26-13	299-W19-47	699-33-76
299-W19-40	299-W26-14	699-38-70C	299-W22-87
299-W19-43	699-32-62	699-38-70B	299-W22-88
299-W22-9	699-32-72A	699-36-70B	
RCRA Wells			
299-W19-107	299-W19-42	299-W22-50	299-W23-19
299-W14-71	299-W19-44	299-W22-79	299-W23-20
299-W18-31	299-W19-45	299-W22-80	299-W27-2
299-W18-40	299-W19-9	299-W22-81	699-36-66B
299-W19-101	299-W22-10	299-W22-82	699-36-67
299-W19-12	299-W22-44	299-W22-84	699-37-66
299-W19-18	299-W22-46	299-W22-85	699-37-68
299-W19-41	299-W22-47		

1.3 Site Background

The following subsections present a description of the 200-UP-1 Groundwater OU project site, a presentation of the operations and contributing sources of groundwater contamination, a brief on current remedial measures in place or being planned, and current and future land use.

1.3.1 Site Description/Operations

The 200 Area, located near the center of the Site, encompasses the 200 West, East, and North Areas, which contain reactor fuel processing and waste management facilities. The 17 process-based OUs located in the 200 West Area are grouped into four aggregate areas: U Plant, Z Plant, S Plant, and T Plant.

The 200 West Area encompasses groundwater impacted by waste disposal operations at each of the four areas. The U Plant and S Plant largely overlie the 200-UP-1 Groundwater OU, which has a vertical extent defined as reaching from the top of the unconfined aquifer to the top of the Ringold Lower Mud unit (LMU). With the exception of the Environmental Restoration and Disposal Facility (ERDF), most of the facilities and waste sites associated with the OU were specifically associated with the operation of S Plant (Reduction-Oxidation [REDOX] Plant) and U Plant; and disposal of the associated process waste liquids.

A detailed discussion of the geology and hydrology of the 200 West area is presented separately in DOE/RL-92-16, with more recent analyses found in PNNL-13858. A summary discussion of the information found in these reports, as well as the new information generated on the geology and hydrogeology for the 200 West Area collected during the RI, is provided in Chapters 2 and 3 of this report.

The 200-UP-1 Groundwater OU extends to the south-southeast of the 200 West Area across the Site. The OU extends east to the 200-PO-1 Groundwater OU interface and north to the 200-ZP-1 Groundwater OU. Figure 1-3 presents the groundwater OUs on the Site. Figure 1-4 shows the principal waste sites in the 200 West Area that overlie the 200-UP-1 Groundwater OU. The RI/FS for the 200-UP-1 Groundwater OU does not address contaminant contributions from waste sources or vadose zone contamination. Remediation of the sites that contributed to the contamination in the 200-UP-1 Groundwater OU will be addressed through separate CERCLA activities.

The western boundary of the OU is defined by the upgradient perimeter of the plume as it extends from sources in the 200 West Area, as described in TPA Change Number M-13-95-01 (Ecology et al., 1989a).

Groundwater in the uppermost-unconfined aquifer of the 200-UP-1 Groundwater OU generally flows easterly toward the western boundary/perimeter of the 200-PO-1 OU. In the northern portion of the 200 West Area (200-ZP-1 OU), the unconfined aquifer flows east-northeast toward Gable Mountain and east to the 200-BP-5 OU boundary (Figure 1-5).

Operations in the 200 West and East Areas were primarily related to separation of special nuclear materials from spent nuclear fuel. Spent nuclear fuel is fuel that has been withdrawn from a nuclear reactor following irradiation. The 200-UP-1 Groundwater OU underlies two main processing areas that were sources of 200-UP-1 Groundwater OU contamination: U Plant and S Plant. The 200 Areas also contain nonradioactive support facilities, including transportation maintenance buildings, service stations, coal-fired powerhouses for process steam production, steam transmission lines, raw water treatment plants, water storage tanks, electrical maintenance facilities, and subsurface sewage disposal systems.

Groundwater contamination in 200-UP-1 occurs predominantly in the upper part of the unconfined aquifer (Ringold unit E), comprising gravels with intercalated sands and silts. Carbon tetrachloride contamination is an exception, with concentrations generally increasing with depth in the eastern part of the 200 West Area.

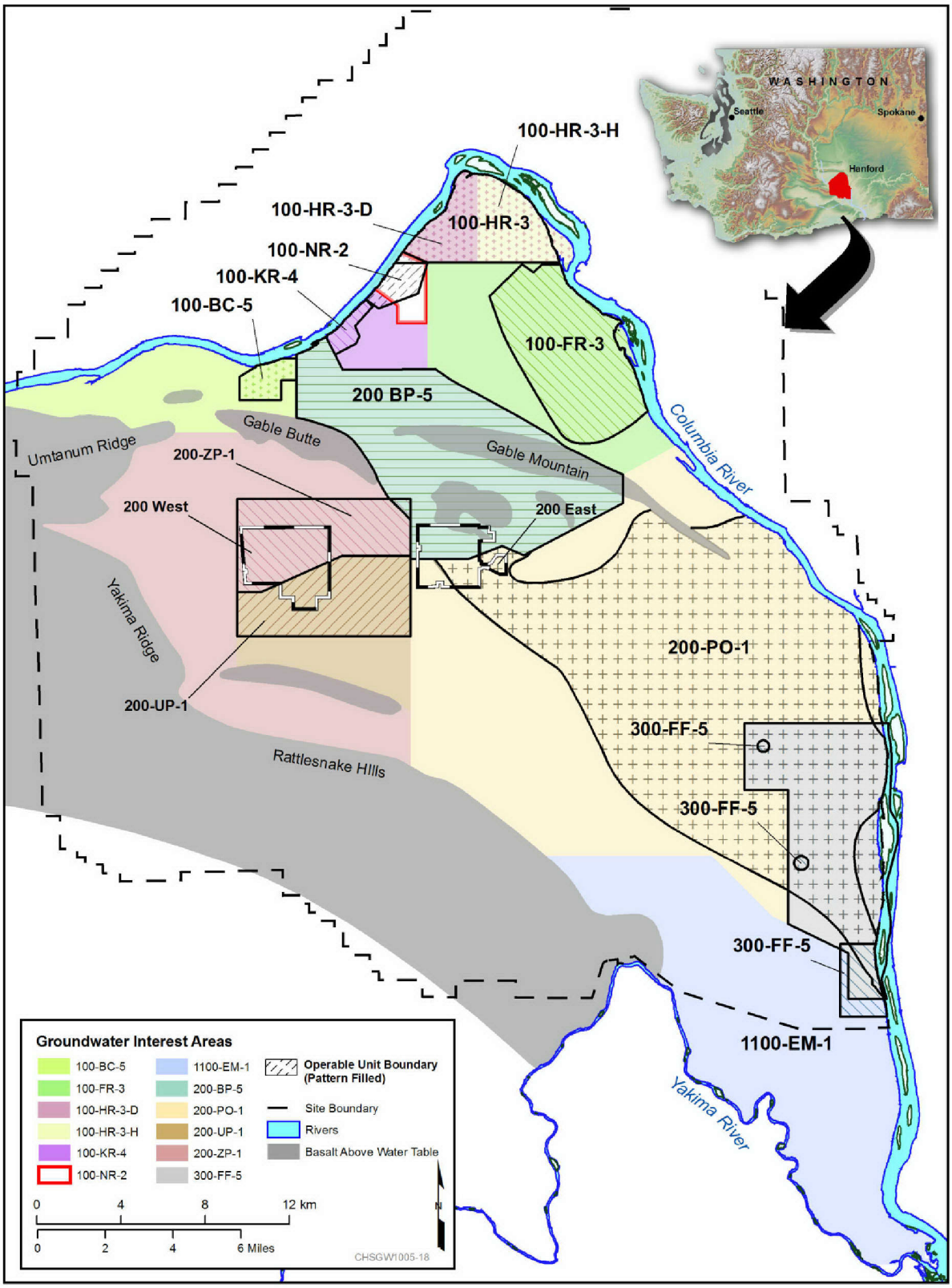

Figure 1-3. Groundwater Operable Unit Boundaries and Interfaces

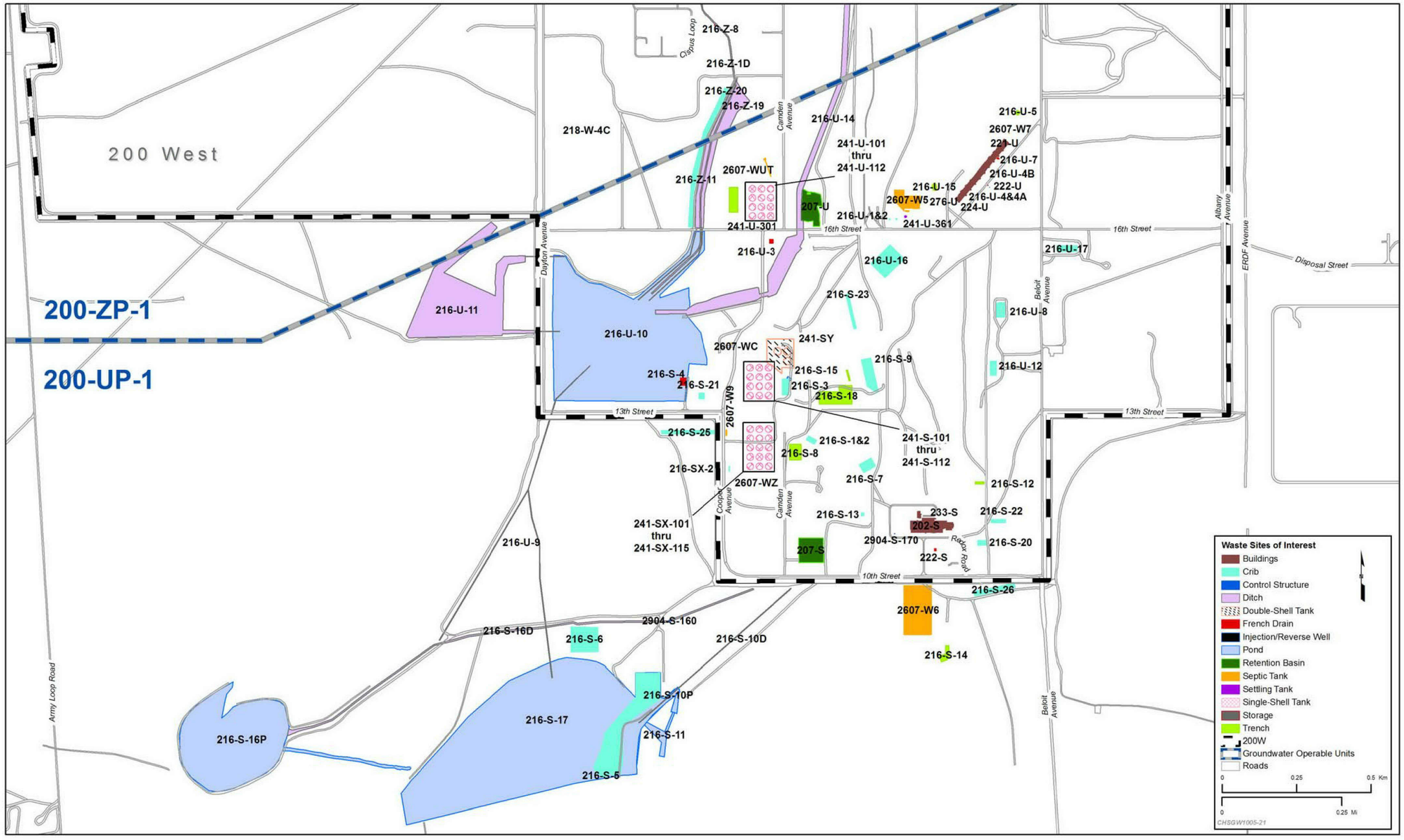

Figure 1-4. 200 West Area Source Sites Overlying the 200-UP-1 Groundwater Operable Unit

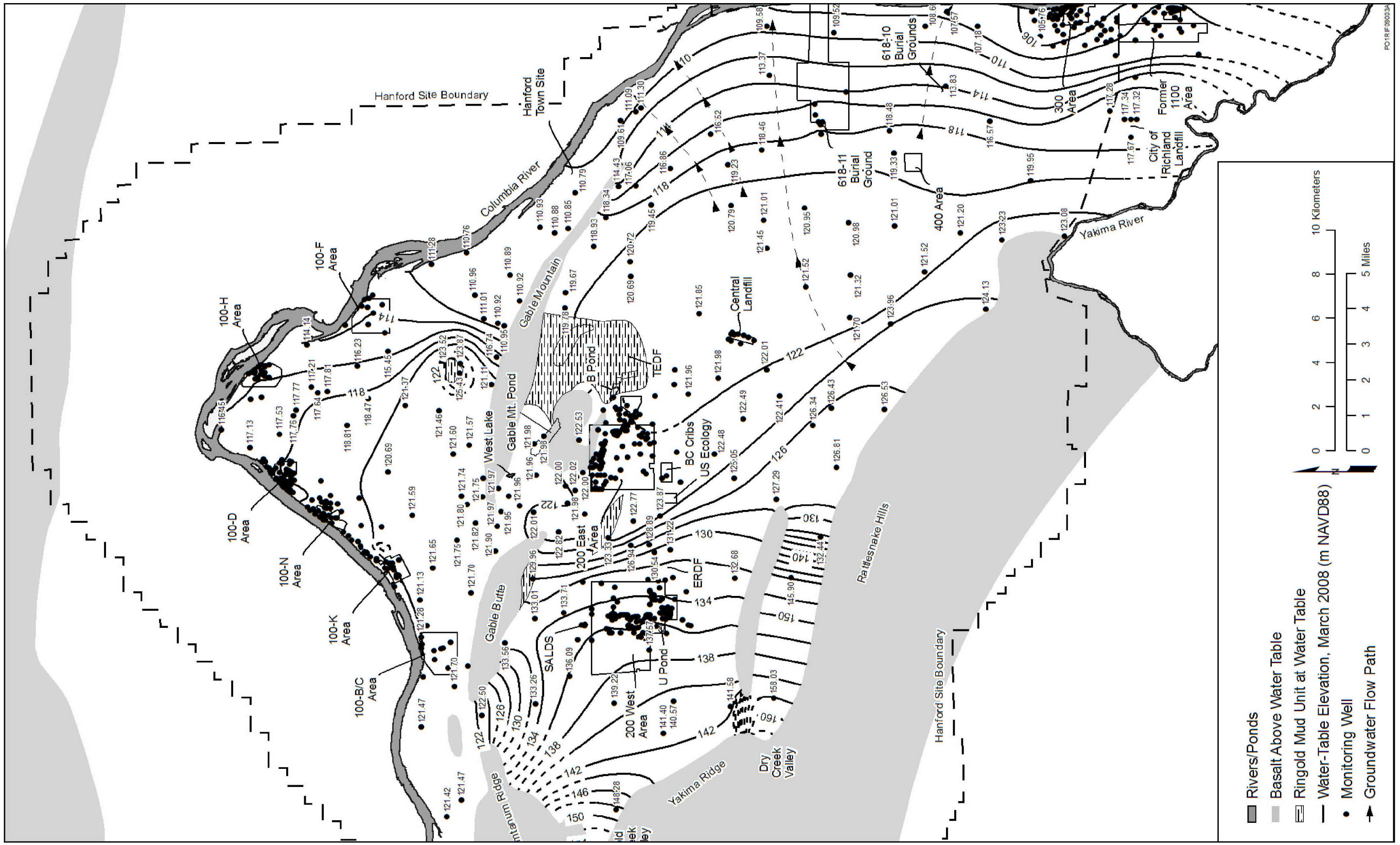

Figure 1-5. Inferred Regional Groundwater Elevation Contours Beneath the Hanford Site (PNNL-18427)

1.3.2 U Plant Source Area

The primary waste-generating processes in the U Plant area were associated with the operation of the 221-U Building and its ancillary support facilities. Operations in the 221-U Building complex included uranium reclamation, uranyl nitrate calcination, and decontamination and reclamation of process equipment. Table 1-4 provides a list of radionuclides, organic chemicals, and inorganic chemicals disposed in the U Plant Source area (DOE/RL-91-52). The primary waste-generating facilities and associated processes include the following:

- 221-U Building (U Canyon) (Uranium Recovery Process)
- 224-U Building (UO_3 Conversion Process)
- 276-U Solvent Facility (Solvent Treatment)
- 222-U Laboratory (Analytical Laboratory Programs)

Table 1-4. Radionuclides and Chemicals Disposed to U Plant Aggregate Area Waste Management Units (DOE/RL-91-52)

Radionuclides		
Actinium-225	Actinium-227	Americium-241
Americium-242	Americium-242m	Americium-243
Antimony-126	Antimony-126m	Astitine-217
Barium-135m	Barium-137m	Bismuth-210
Bismuth-211	Bismuth-213	Bismuth-214
Carbon-14	Cerium-141	Cerium-144
Cesium-134	Cesium-135	Cesium-137
Cobalt-57	Cobalt-58	Cobalt-60
Curium-242	Curium-244	Curium-245
Europium-152	Europium-154	Europium-155
Francium-221	Francium-223	Iodine-129
Iron-59	Lead-209	Lead-210
Lead-211	Lead-212	Lead-214
Manganese-54	Neptunium-237	Neptunium-239
Nickel-63	Nickel-59	Niobium-93m
Niobium-95	Palladium-107	Plutonium-238
Plutonium-239/240	Plutonium-241	Polonium-210
Polonium-213	Polonium-214	Polonium-215
Polonium-218	Potassium-40	Protactinium-231
Protactinium-233	Protactinium-234m	Radium
Radium-223	Radium-225	Radium-226
Ruthenium-103	Ruthenium-106	Samarium-151
Selenium-79	Silver-110m	Sodium-22
Strontium-85	Strontium-90	Technetium-99
Thallium-207	Thorium-227	Thorium-229

Table 1-4. Radionuclides and Chemicals Disposed to U Plant Aggregate Area Waste Management Units (DOE/RL-91-52)

Radionuclides		
Thorium-230	Thorium-231	Thorium-233
Thorium-234	Tin-126	Tritium
Uranium-233	Uranium-234	Uranium-235
Uranium-238	Yttrium-90	Zinc-65
Zirconium-93	Zirconium-95	
Inorganic Chemicals		
Aluminum	Ammonium ion	Ammonium nitrate
Arsenic	Barium	Bismuth
Bismuth phosphate	Boron	Cadmium
Calcium	Carbonate	Cerium
Chloride	Chromium	Copper
Cyanide	Ferric cyanide	Fluoride
Hydroxide	Iron	Lanthanum
Lead	Lithium	Magnesium
Manganese	Mercury	Nickel
Nitrate	Nitric acid	Nitrite
Phosphate	Phosphoric acid	Potassium
Selenium	Silica	Silicon
Silver	Sodium	Sodium hydroxide
Strontium	Sulfamic acid	Sulfate
Sulfuric acid	Thorium	Uranium
Tin	Titanium	Uranium oxide
Uranyl nitrate hexahydrate	Vanadium	Zinc
Zirconium oxide		
Organic Chemicals		
Acetone	Ammonium	Butyl alcohol
Carbon tetrachloride	Chloroform	Citrate
Ethylene diamine tetraacetate	Gylcolate	Kerosene
Methylene chloride	MIBK ("Hexone")	N-(2-hydroxyethyl) ethylenediaminetriacetate
Paraffin hydrocarbons	Other degradation products	Oxalate
Toluene	Trichloroethane	Tributyl phosphate

The **221-U Building**, also known as the 221-U Canyon Building, was the primary location of the uranium recovery program. The 221-U Building was originally designed as a bismuth phosphate separations facility, but was not operated in that manner because B Plant and T Plant had enough capacity to meet the plutonium production requirements. In 1952, the U Plant complex was converted to support the uranium recovery process. The process was designed to use an organic solvent to extract uranium from waste generated by the bismuth phosphate process.

Bismuth phosphate waste sludge was stored in underground single-shell tanks (SSTs) in both the 200 West and 200 East Areas. The sludge was sluiced from the SSTs and transferred to U Plant, where it was dissolved with nitric acid. The uranium in the acidified feed was separated from the bulk of the fission products and small amounts of plutonium in the solvent extraction process. The solvent extraction process used a light phase solvent, tributyl phosphate in a kerosene (paraffin hydrocarbon) diluent, to extract the uranium from the aqueous phase in countercurrent extraction columns. The aqueous phase waste stream from the solvent extraction process was neutralized with sodium hydroxide and transferred to cribs in the B Plant complex. The uranium from the organic phase was stripped using nitric acid and then concentrated to a uranyl nitrate hexahydrate feed to the 224-U Building.

Within the extraction process, an evaporator condensate stream containing radioactive and chemical contaminants was generated in the evaporators that concentrated process liquids. An off-gas stream containing radioactive and chemical contaminants was also generated in the evaporation process and the vessel vent system. The steam condensate stream produced from heating process equipment and tanks was generally uncontaminated. Cooling water from evaporator condensers and process equipment was an additional source of uncontaminated waste.

Spills of process liquids within the building created an additional waste stream source. Sumps collected spilled liquids and other cell drainage and discharged the materials to cribs. Process wastes were discharged to various waste management units including: 216-U-1 Crib, 216-U-2 Crib, 216-U-7 French Drain, 216-U-8 Crib, 216-U-10 Pond, 216-U-14 Ditch, and 216-U-16 Crib.

The **224-U Building** (UO_3 Plant) is immediately southeast of the 221-U Building and is a complex comprising several buildings, tank farms, storage areas, and loading facilities. The building was constructed in 1944 to concentrate plutonium-bearing product solutions for plutonium processing, but was not used for that purpose. It was operated as a training facility from 1944 to 1950 and was converted in 1952 to a uranium reduction facility. It was converted again in 1955 in support of the Plutonium-Uranium Extraction (PUREX) Plant.

The PUREX uranyl nitrate hexahydrate was transferred to the 224-U Building by tanker truck, where it was converted to powdered UO_3. The building produced process condensate waste from the concentration and calcination of uranyl nitrate hexahydrate. The UO_3 Plant process condensate was a highly acidic waste stream containing high concentrations of uranium, nitrate, and Tc-99 during active concentration and calcination operations. The process condensate stream was mixed with other liquid mainly from sumps and rain water collected in radiation areas. After 1980, DOE required neutralization of the UO_3 Plant process condensate prior to disposal. Phosphoric acid and potassium hydroxide were used as buffering and neutralizing agents.

Since 1955, UO_3 Plant wastewater was discharged to the 216-U-10 Pond through the 216-U-14 Ditch and 216-U-1, 216-U-2, 216-U-8, 216-U-12, 216-U-16, and 216-U-17 Cribs. Noncorrosive steam condensate from the building heating systems, process equipment, condensers (cooling water), and natural precipitation/rain from the nonradiation areas was sent through the 207-U Retention Basin to the 216-U-14 Ditch.

The **276-U Solvent Facility** treated used organic solvents from the uranium extraction processes at the 221-U Building. The solvents (particularly tributyl phosphate) were treated and cleaned by a carbonate scrub process and returned to the 221-U Building. A carbonate scrub solution waste was generated that contained sludge materials cleaned from the solvents and discharged to the associated cribs. Spent solvents were also a part of this waste stream. These waste solvents and sludges were disposed to the 216-U-15 trench.

The **222-U Laboratory**, located directly southeast of the 221-U Building, was used from about 1947 to 1970 for laboratory analysis in support of the uranium recovery process and the UO_3 process. This facility disposed of various general laboratory liquid wastes to the 216-U-4 Reverse Well, 216-U-4A French Drain, and 216-U-4B French Drain.

1.3.2.1 Tanks

Sixteen SSTs were operated in the northwest corner of the U Plant Source Area, all of which were contained in the 241-U Tank Farm WMA. Of these tanks, 12 had a 2,014,700 L (533,000 gal) capacity and four had a 208,000 L (55,000 gal) capacity. A number of SSTs in the 241-U Tank Farm WMA have leaked and represent a potential source of groundwater contamination in the 200-UP-1 Groundwater OU. The 241-U Tank Farm WMA continues to store mixed radioactive and hazardous waste.

Settling Tank 241-U-361 is a highly documented tank that served as a settling tank for liquid wastes en route to the 216-U-1 and 216-U-2 Cribs (1951 through 1967). The wastes included cell drainage from the 221-U Building, waste from the UO_3 Plant, contaminated solvent from the 276-U Settling Tank, and decontamination and reclamation wastes from the 221-U Building. Approximately 4,000 kg (8,900 lb) of uranium was discharged to this tank, the bulk of which flowed into the 216-U-1 and 216-U-2 Cribs; it is estimated to contain 104,000 L (27,500 gal) of plutonium sludge with approximately 2,125 Ci beta/gamma.

1.3.2.2 Cribs, French Drains, and Reverse Wells

Cribs, French drains, and reverse wells were designed to dispose of wastewater into the ground without exposure to the open air.

- Cribs are shallow excavations that are either backfilled with permeable material or held open by wood structures. Both types of cribs were covered at ground level with an impermeable material. Water flowed directly into the backfilled material or open space and percolated into the vadose zone soils.
- French drains were generally constructed of steel or concrete pipe and were either open or filled with gravel.
- Reverse wells were vertical drilled columns designed to inject water into the ground at depth.

Full descriptions of the various crib, drain, and reverse well construction details for those sources in the 200-UP-1 Groundwater OU can be found in DOE/RL-91-52 and DOE/RL-91-60. The cribs, drains, and wells received low-level liquids until the specific retention or radionuclide capacity of the unit was met. The following subsections describe the major waste units associated with U Plant operations.

Cribs

The **216-U-1** and **216-U-2 Cribs** are located north of 16th Street and east of the 207-U Retention Basin. Wastes flowed to these cribs from the 241-U-361 Settling Tank. The cribs operated from 1951 until 1967, and 4,000 kg (8,900 lb) of uranium was reportedly discharged there. The uranium reacted with the sediments to form carbonate-phosphate compounds. After 1967, other cribs (notably 216-U-12) were used to dispose of this wastewater. In 1984, a newer crib (216-U-16) was installed south of the 216-U-1/U-2

Cribs. By 1985, liquid discharges to the 216-U-16 Crib formed a perched groundwater zone above a caliche layer. The perched groundwater moved north under the 216-U-1 and 216-U-2 Cribs. Acid wastes discharged to the cribs reacted with the uranium complexes to form compounds that are soluble and relatively non-sorbing on the sediments. The uranium was transported through the caliche layer to the unconfined aquifer and, consequently, uranium concentrations (at the time) rose from about 166 pCi/L to about 72,000 pCi/L in nearby monitoring wells.

The **216-U-8 Crib** is located west of Beloit Avenue and south of 16th Street. The crib operated from 1952 until 1960, receiving approximately 378,000,000 L (100,000,000 gal) of acidic process condensate from the 221-U and 224-U Buildings and the 291-U Stack Drainage System. In 1960, the surface above the 216-U-8 Crib began to subside. In response to this subsidence, the incoming line was blanked off and waste was diverted to the 216-U-12 Crib. *The 216-U-8 Crib reportedly holds the largest inventory of waste uranium of any 200 West Area crib.*

The **216-U-12 Crib** is located southwest of the intersection of Beloit Avenue and 16th Street, operated from 1960 to 1988, and was taken out of service once the crib began to subside. The 216-U-12 Crib reportedly received 150,000,000 L (40,000,000 gal) of liquid waste. Drainage was received from the 291-U Stack Drainage System, the acidic (pH 1) UO_3 Process Condensate System, wastes from the C-5 and C-7 tanks, and storm drain wastes from the 224-U Building. Approximately 3.1 kg (6.9 lb) of thorium was received from the 241-WR Vault in October 1965. The crib was removed from service as the 216-U-17 Crib was placed into service.

The **216-U-16 Crib** is located south of 16th Street and midway between Beloit Avenue and Cooper Avenue. The 216-U-16 Crib is a large, gravel-filled, drain field-type crib that operated from 1984 until 1987, receiving a combined 409,000,000 L (108,201,000 gal) of UO_3 laboratory, process condensate, 271-U Compressor cooling water, 221-U Building chemical sewer waste, 224-U Building process condensate, and chemical sewer waste. By 1985, enough liquid waste had been discharged to the crib to create the perched groundwater zone described previously that moved north below the 216-U-1 and 216-U-2 Cribs and mobilized uranium to the groundwater. The 216-U-15 Trench received miscellaneous liquid waste and interfacial crud from the treatment spent solvent from the 276-U Solvent Facility. The re-conditioned solvent was then returned to U Plant for reuse.

The **216-U-17 Crib** was constructed in 1988 to replace the 216-U-12 Crib, which had received its maximum-allowed inventory of radioactive wastes; 2,110,000 L (558,200 gal) of 224-U Building process condensate was discharged to this crib. A neutralization system maintained the pH within a range of 2.0 to 12.5. After a brief cessation of effluent disposal to the crib in 1991, flows resumed in 1992, limited to 37.5 L/min (10 gal/min). In 1995, disposal to the crib 1995 ceased.

French Drains

The **216-U-3 French Drain** is located south of the 241-U Tank Farm, and operated from 1954 until 1955, receiving approximately 791,000 L (209,000 gal) of low-salt, neutral-basic condensate from the 241-U steam condenser on waste tanks at the 241-U Tank Farm.

The **216-U-4A French Drain** received 222-U Laboratory hood sink wastes after the 216-U-4 Reverse Well began to plug in 1955. From 1955 to 1970, the drain received 545,000 L (144,000 gal) of acidic plutonium and fission product decontamination waste.

The **216-U-4B French Drain** located south of the 222-U Laboratory received hot cell and hood liquid waste from the 222-U Laboratory. It operated from 1960 to 1968, receiving approximately 33,000 L (8,700 gal) of low-salt, neutral/basic lab waste.

The **216-U-7 French Drain** was connected to the U Plant counting box and is located south of the 221-U Building. From 1952 to 1957, the drain received liquid wastes from a counting box floor drain during the metal recovery program at the 221-U Building, with about 140 kg (300 lb) of uranium introduced in the form of uranyl nitrate hexahydrate. The uranyl nitrate hexahydrate introduced to the drain was identified as an unplanned release (UPR).

Reverse Wells

The **216-U-4 Reverse Well** was the only reverse well in the U Plant Area and is located northwest of the west corner of the 222-U Laboratory Building. It was a State of Washington registered underground injection well that operated from 1947 to 1955, receiving 302,400 L (80,000 gal) of decontamination waste from laboratory hood sinks (acidic plutonium and fission product waste). In 1955, the well was deactivated.

1.3.2.3 Ponds, Ditches, and Trenches

The U Plant Area ponds, ditches, and trenches were designed to percolate wastewater into the ground. Until its closure in 1985, the 216-U-10 Pond was at the center of this disposal system and was fed by ditches that originated at the various waste-generation facilities.

The **216-U-10 Pond System** was constructed in 1944 to receive low-level liquid effluent from the Plutonium Finishing Plant (PFP). It originally consisted of two drainage ditches that carried water to the pond. The pond system was active until 1985 and received a total of 1.62×10^{11} L (4.3×10^{10} gal) of contaminated liquid. The system received powerhouse cooling water, steam condensate wastewater laundry wastes, chemical sewer wastes, laboratory wastes, tank condenser water, and Pacific Northwest National Laboratory (PNNL) operations waste (231-Z Laboratory and 242-S Evaporator steam condensate). The large volumes of low-level wastewater and occasional isolated releases of considerably higher levels resulted in the accumulation of transuranic (TRU), fission products, and activation product inventories, estimated to include 8.2 kg (18 lb) of plutonium, 1,500 kg (3,300 lb) of uranium, 15.3 Ci of Cs-137, and 22.6 Ci of Sr-90.

The **216-U-14 Ditch** began operation in 1944 and was an open ditch running from northeast to southwest across about 1.6 km (1 mi) of the 200 West Area. It originated 487.6 m (1,600 ft) north of U Plant and terminated at the 216-U-10 Pond. The ditch was originally known as the laundry ditch because it received wastewaters from the 2724-W Laundry Building. It also received other waste types that included: cooling water, wastewater, chemical sewer liquids, and evaporator condensate. Reportedly, 567,000 L (150,000 gal) of wastewater per day was discharged to this ditch. In 1986, approximately 3,000 L (800 gal) of 50 percent reprocessed nitric acid was released to the ditch. The total release to the ditch was about 102,058 kg (225,000 lb) of corrosive solution (pH <2.0) and 45.36 kg (100 lb) of uranium. In 1992, a portion of the ditch was stabilized in response to the TPA Milestone 17-17B (Ecology et al., 1989a).

The **216-U-11 Trench** was located immediately west of the 216-U-10 Pond. It was active from 1944 to 1957 to receive overflow from the pond. The site contains less than 0.1 Ci beta activity. The site has been covered with soil and seeded. Aliases for this site are U Swamp Extension Ditch, U-12, U-11 Ditch, U-11 Old Ditch, and U-11 New Ditch.

The **216-U-15 Trench** was first used in May 1957 and backfilled almost immediately after receiving wastes. This trench is located north of 16th Street and west of the 271-U Building. The trench was opened to receive about 26,500 L (7,000 gal) of interface crud, activated charcoal, and diatomaceous earth containing about 1 Ci of fission products from 338-U Tank in the 276-U Solvent Storage Area. While the information for this trench varies, it is reported that 40,000 kg (88,000 lb) of hexone, 13,000 kg (29,000 lb) of tributyl phosphate, and possibly paraffin hydrocarbons were disposed. Waste was pumped

to the trench through aboveground lines that were removed after the waste transfer operation was completed.

1.3.2.4 Retention Basin

The **207-U Retention Basin** is the only basin within the U Plant Area. This retention basin consisted of two concrete-lined, open settling ponds where wastewater was held before overflowing into a ditch. The basin started operating in 1952, receiving steam condensate and cooling water from the UO_3 Plant and chemical sewer waste from the 221-U Building. After 1972, the basin received only cooling water from the 224-U Building.

1.3.3 S Plant Source Area

The primary waste-generating processes in the S Plant Area are associated with the operation of the S Plant (202-S REDOX Plant). The REDOX Plant was built around1950 and was shut down in 1967. This was the first process to recover both plutonium and uranium from fission products. It was built to improve the Site's plutonium and uranium recovery process from the initial bismuth phosphate plutonium separations process. The new REDOX process used a continuously operating solvent extraction process (hexone) to extract plutonium and uranium from acidic, fission-product-rich solutions in which the fuel rods had been dissolved. The volumes of concentrated fission-product-rich solutions were much smaller than the solutions produced by the bismuth phosphate process, thereby reducing the volume sent to SSTs. Radioactive decay occurring in these wastes caused self-heating. In some wastes, radioactive decay caused these wastes to boil. The high-heat sludges created wastes known as self-boiling wastes.

The 202-S Building and the 222-S Laboratory generated significant wastes and, depending on the type of wastes, the liquids were discharged to one of 26 waste ponds, cribs, ditches, French drains, and trenches. Open-air ponds and ditches received the highest volumes of generally nonradioactive contact cooling water and steam condensates from the major 202-S process vessels used to heat and cool chemical solutions. More radioactive (and chemical-rich), but less voluminous quantities of condensed process vapors and cell drainage were sent to cribs. The nonradioactive, low-volume chemical sewer wastes were generally sent to ponds and ditches. Very low-volume radioactive waste streams were sent to the French drains. Building septic systems used tile fields to dispose of nonradioactive wastes.

Table 1-5 provides a list of radionuclides, organic chemicals, and inorganic chemicals disposed to the S Plant Source area (DOE/RL-91-60).

Table 1-5. Radionuclides and Chemicals Disposed to S Plant Aggregate Area Waste Management Units (DOE/RL-91-60)

Radionuclides		
Aluminum-28	Americium-241	Antimony-122
Antimony-124	Antimony-125	Antimony-126
Barium-133	Barium-137	Beryllium-7
Beryllium-10	Cadmium-109	Calcium-45
Carbon-14	Cerium-141	Cesium-134
Cesium-137	Chlorine-36	Chromium-51
Cobalt-57	Cobalt-58	Cobalt-60
Curium-243	Einsteinium-254	Europium-152
Europium-154	Europium-155	Gadolinium-153

Table 1-5. Radionuclides and Chemicals Disposed to S Plant Aggregate Area Waste Management Units (DOE/RL-91-60)

Radionuclides		
Germanium-68	Iodine-123	Iodine-125
Iodine-129	Iron-55	Iron-59
Krypton-85	Lead-214	Manganese-54
Lead-212	Niobium-93m	Niobium-94
Molybdenum-93	Nickel-59	Nickel-63
Niobium-95	Phosphorus-32	Plutonium-238
Plutonium-239	Plutonium-241	Potassium-40
Plutonium-240	Polonium-210	Proactinium-231
Promethium-147	Radium-228	Rhenium-187
Rhodium-106	Rubidium-86	Ruthenium-103
Ruthenium-103	Scandium-46	Selenium-75
Silver-108	Silver-110	Sodium-22
Strontium-82	Strontium-90	Sulfur-35
Tantalum-182	Technetium-99	Tellurium-121
Tellurium-125m	Tellurium-127	Tellurium-129
Thallium-204	Thullium-170	Tin-121
Tin-123m	Tritium	Uranium-234
Uranium-235	Uranium-236	Uranium-238
Vanadium-49	Yttrium-87	Yttrium-88
Zinc	Zinc-65	Zirconium-95
Inorganic Chemicals		
Aluminum	Aluminum nitrate	Aluminum oxide
Ammonia	Ammonium fluoride	Ammonium hydroxide
Ammonium nitrate	Ammonium oxalate	Boric acid
Boron	Cadmium	Ceric ammonium nitrate
Ceric sulfate	Chromic nitrate	Copper
Ferrous ammonium sulfate	Ferrous sulfamate	Ferrous sulfate
Hydrazine	Hydrochloride	Hydrochloric acid
Hydrofluoric acid	Hydrogen	Hydroxylamine
Iron	Lead nitrate	Manganese dioxide
Magnesium	Mercuric nitrate	Mercuric thiocyanate
Mercury	Nitric acid	Nitric oxide
Nitrogen dioxide	Oxalic acid	Periodic acid
Potassium dichromate	Potassium fluoride	Potassium oxalate
Potassium permanganate	Silicon	Silicon dioxide

Table 1-5. Radionuclides and Chemicals Disposed to S Plant Aggregate Area Waste Management Units (DOE/RL-91-60)

Inorganic Chemicals		
Silver nitrate	Sodium aluminate	Sodium bismuthate
Sodium carbonate	Sodium dichromate	Sodium fluoride
Sodium hydroxide	Sodium metasilicate	Sodium nitrate
Sodium nitrite	Sulfamic acid	Tetrabromoethane
Tin	Titanium chloride	Xenon
Zinc		
Organic Chemicals		
Acetone	Bromonapthalene	Di-2-ethyl hexyl phosphoric acid
Hydroxyquinoline	Methyl isobutyl carbinal	Methyl isopropyl di-ketone
Mineral oil	Normal paraffin hydrocarbon	O-phenanthroline
Propane	S-diphenyl carbazide	Tetraphenyl boron
Thenoyltrifluoroacetone	Tributyl phosphate	Tri-iso-octylamine
Tri-n-octylamine	Xylene	

The S Plant complex also contained the 222-S Laboratory, 233-S Concentration Facility, and a series of support buildings and waste handling and storage facilities. The 222-S Laboratory supported the 200 Areas for process control and environmental sample analysis. An evaporator (242-S) was added at the S-SX, SY Tank Farm complex in 1973 to aid in tank volume reduction. The following sections discuss the details of the chemicals/materials used and the related major waste disposal locations.

1.3.3.1 Tanks

Several types of tanks are present in the S Plant Source Area including 4 catch tanks, 27 SSTs, 3 double-shell tanks (DSTs), and 1 receiver tank. Catch tanks are generally associated with diversion boxes and other transfer units, and were designed to accept overflows and spills. The receiver tank (frequently called a double-contained receiver tank or vault) received waste from SSTs; SSTs were used to collect and store large quantities of mixed wastes. DSTs also are used to store large quantities of mixed wastes. All SSTs are being evaluated under the SST Closure Program and the DSTs will be evaluated under the Waste Management Program.

Of the 27 SST WMAs in the S Plant Aggregate Area, 12 are contained within the 241-S Tank Farm and 15 are contained within the 241-SX Tank Farm. The three DSTs are located in the 241-SY Tank Farm. The 241-S Tank Farm is located northeast of the Cooper Avenue and 13th Street intersection. The 241-S and 241-SX Tank Farms were constructed from 1950 to 1951 and 1953 to 1954, respectively. The tank designs were very similar in both tank farms with the tanks being vertical cylinders with a domed top, and constructed of reinforced concrete with a carbon steel liner on the base and sides. The tanks are all underground. The 12 tanks in the 241-S Tank Farm are numbered 241-S-101 through 241-S-112, and the 15 tanks in the 241-SX Tank Farm are numbered 241-SX-101 through 241-SX-115. The 241-S Tanks and 241-SX Tanks have a capacity of 3,785,412 L (1,000,000 gal) each.

SSTs in the S and SX Tank Farm WMAs are known contributors to groundwater contamination within the 200-UP-1 Groundwater OU. The high-heat sludges from the REDOX process created self-boiling conditions in a number of S and SX Tank Farm SSTs. These high-temperature conditions caused the tanks to be susceptible to stress corrosion cracking that attacked the welds in the tank walls and bottom, leading to many of these tanks releasing waste into the soil column.

The DSTs in the 241-SY Tank Farm were constructed from 1974 to 1976. The tanks were designed as vertical cylinders with an inner primary tank, an outer secondary tank surrounded by a steel-reinforced concrete shell, and a steel-reinforced domed top. The three tanks in the 241-SY Tank Farm are numbered 241-SY-101 through 241-SY-103, with a capacity of 3,785,412 L (1,000,000 gal) each. None of these DSTs have leaked.

1.3.3.2 Cribs and French Drains

The following subsection presents information on the cribs and trenches in the area that are believed to be the major contributors to groundwater contamination in the southern portion of the OU. Similar to the cribs described previously for U Plant, the S Plant cribs are shallow excavations that are either backfilled with permeable material or held open by wooden structures. Both types of cribs are covered with an impermeable layer at the surface. Wastewater flowed directly into the crib and percolated into the vadose zone soils. French drains were generally constructed of steel or concrete pipe and were either open or filled with gravel. The S Plant Area contained 12 cribs and two French drains. The cribs and drain received low-level waste for disposal and were designed to receive liquid until the unit's specific retention or radionuclide capacity was met.

Cribs

The **216-S-1** and **216-S-2 Cribs** are located northwest of the 202-S Building. The cribs were in service from 1952 to 1956 and received approximately 1.6×10^8 L (4.2×10^7 gal) of cell drainage waste from the D-1 Receiver Tank and redistilled condensate from the D-2 Receiver Tank located in the 202-S Building. These radioactive process condensate wastes were acidic and contained high concentrations of volatile radionuclides including tritium and iodine-129 (I-129).

The **216-S-5 Crib** is located southwest of the 207-S Retention Basin and west of the 216-S-10D Ditch. The crib operated from 1954 to 1957 and was built as a replacement for the contaminated 216-S-17 Pond. The crib received 4.1×10^9 L (1.1×10^9 gal) of acidic process vessel cooling water and steam condensate from the 202-S Building. The unit was deactivated because of insufficient capacity and a series of vessel coil failures, which resulted in operational problems and surface contamination.

The **216-S-6 Crib** was located southwest of the 202-S Building and southwest of the 200 West Area perimeter fence. The crib started receiving waste in 1954 and stopped in 1972. The crib received a total of 4.47×10^9 L (1.18×10^9 gal) of low-salt, neutral/basic liquid waste (DOE/RL-91-60). Until 1967, the crib received process vessel cooling water and steam condensate from the 202-S Building. After 1967, the crib received steam condensate from the D-12 and D-14 waste concentrators in the 202-S Building.

The **216-S-7 Crib** is located northwest of S Plant. The crib began operating in 1956 as the replacement for the 216-S-1 and 216-S-2 Cribs and was retired in 1965. Until 1959, the crib received cell drainage from the D-1 Receiver Tank, process condensate from the D-2 Receiver Tank, and condensate from the H-6 condenser in the 202-S Building. The crib received a total of 3.9×10^8 L (1.0×10^8 gal) of waste. The site was retired in July 1965.

The **216-S-9 Crib** is located east of the 241-S and 241-SY Tank Farms. The crib operated from 1965 to 1969, as the replacement for the 216-S-7 Crib, receiving 5.03×10^7 L (1.33×10^7 gal) of process condensate from the D-2 Receiver Tank. The waste was primarily composed of nitric acid and contained high concentrations of tritium and I-129.

The **216-S-13 Crib** is located west of the 202-S Building and north of 10th Street. The crib was built in 1952 and stopped receiving waste in 1972. Until 1967, it received liquid waste from the 203-S Decontaminated Metal Storage Facility, the 204-S Uranyl Nitrate Hexahydrate facility, and the 276-S Organic Solvent Make-up Facility. After 1967, the crib received occasional sump waste from the 204-S Uranyl Nitrate Hexahydrate facility. The unit received a total of 5.0×10^6 L (1.3×10^6 gal) of low-salt, neutral/basic waste, mainly composed of nitrate, sodium, and sodium dichromate.

The **216-S-20 Crib** is located southeast of the 202-S Building and north of 10th Street. The crib operated from 1952 until 1973, receiving 1.35×10^8 L (3.57×10^7 gal) of waste. Until 1953, the crib received miscellaneous waste from laboratory hoods and decontamination sinks in S Plant via the 219-S Waste Handling Facility. From 1963 to 1969, the crib received miscellaneous waste from laboratory hoods and decontamination sinks in the 222-S Laboratory via the 219-S Waste Handling Facility. After 1969, 300 Area laboratory wastes were rerouted to the 216-T-28 Crib.

The **216-S-21 Crib** is located southeast of the 216-U-10 Pond, north of 13th Street, and west of the 241-S Tank Farm. From 1954 to 1969, the crib received 241-SX Tank Farm condensate generated from self-boiling waste and collected in the condensers in the 401-SX Condenser Facility. The unit was retired in 1969, after receiving 8.7×10^7 L (2.3×10^7 gal) of low-salt and neutral/basic liquid waste. The chemicals disposed were sodium and ammonium nitrate.

The **216-S-25 Crib** is located northwest of the 202-S Building outside the 200 West Area perimeter fence, south and east of the 216-U-10 Pond. The unit began operation in 1973 and received 242-S Evaporator process steam condensate through 1980. From 1980 until 1984, the crib received 3.0×10^8 L (8.0×10^7 gal) of cooling water from the 241-SX Tank Farm. In 1985, the crib was reactivated to receive treated groundwater from the 1985 216-U-1 and 216-U-2 pump-and-treat (P&T).

The **216-S-26 Crib** is located southeast of the 222-S Laboratory outside the 200 West Area perimeter fence. It operated from 1984 to 1988 and received 1.64×10^8 L (4.02×10^7 gal) of steam condensate, equipment cooling water, and sink wastes. The wastes contained a variety of chemicals including acetone, nitrate, nitric acid, and lesser amounts of sulfuric and hydrofluoric acids. The crib also received three or more 4,200 L (1,100 gal) tanker discharges of PFP caustic flush water with a pH of 12.5, which retarded percolation of the fluids and prevented the crib from ever recovering to normal flows.

French Drains

The **216-S-3 French Drain** is located along the east border of the 241-S Tank Farm, east of the 241-S-104 SST. This drain operated from 1953 to 1956 and received 4.2×10^6 L (1.06×10^6 gal) of condensate from the 241-S-101 and 241-S-104 storage tanks in the 241-S Tank Farm. The waste solution was low-salt and neutral/basic liquids.

The **216-S-4 French Drain** was active from 1953 to 1956 and received 1,000,000 L (264,000 gal) of waste from the condensers on the 241-S-101 and 241-S-104 Tanks. It is located north of 13th Street, between the 241-S Tank Farm and the 216-U-10 Pond.

1.3.3.3 Ponds, Ditches, and Trenches

Generally, low-level liquid waste was disposed into the ponds. Ponds typically have natural or diked surface depressions used for disposal of high-volume, low-level liquid effluent and designed to promote percolation of the liquid effluent. As the liquid infiltrated into the ground, many of the radionuclides were absorbed and concentrated by the upper soil layer. The major sites are presented as follows.

Ponds

The **216-S-10P Pond** is located southwest of the 202-S Building and covers approximately 20,300 m^2 (218,000 ft^2). The pond was designed to percolate approximately 567,000 L (150,000 gal) of waste per day. The pond operated from 1954 to 1984 and received approximately 4.12×10^9 L (1.07×10^9 gal) of liquid discharge. Until 1965, the pond received the chemical sewer waste from the S Plant Complex and overflow from the high water tower. In the 1960s, the pond received bearing cooling water from the S Plant Complex. The pond was stabilized in 1984.

The **216-S-11 Pond** is located southwest of the 202-S Building and covers approximately 6,070 m^2 (65,300 ft^2). The pond began operation in 1954 and closed in 1965. The pond received waste from air conditioning drains and chemical sewers from the 202-S Building. In 1965, the 216-S-10D Ditch was dammed, diverting all building effluent to the 216-S-10P Pond. A total of 2.23×10^9 L (5.89×10^8 gal) of liquid waste was discharged to this unit. The pond was covered in 1975.

The **216-S-15 Pond** is located directly east of the 241-S Tank Farm. The pond was built in 1951 and retired in 1952. The pond received 10,000 L (2,600 gal) of condenser spray cooling water from the 241-S-110 SST. The waste was low-salt, neutral/basic, and was mainly composed primarily of nitrate and methyl isobutyl ketone (MIBK).

The **216-S-16P Pond** is located southwest of the 202-S Building. The total unit area is approximately 125,400 m^2 (1,350,000 ft^2) and operated from 1957 to 1975, receiving approximately 4.07×10^{10} L (1.08×10^{10} gal) of liquid waste. The waste included 3.7×10^2 g (0.81 lb) of plutonium. Until 1967, the pond received process cooling water and steam condensate from the S Plant Complex. After 1967, the pond received condenser and vessel cooling water from the concentrator boil-down operations in the 202-S Building.

The **216-S-17 Pond** is located southwest of the 202-S Building. The pond has a total area of approximately 85,000 m^2 (920,000 ft^2). The pond operated from 1951 to 1954, receiving approximately 6.44×10^9 L (1.7×10^9 gal) of liquid waste. Until 1953, it received the process cooling water and steam condensate from the S Plant Complex. After 1953, it received 202-S Building effluent and the overflow from 216-U-10 Pond via the 216-U-9 Ditch. A series of process vessel coil failures beginning in 1952 resulted in the release of high levels of radioactivity to the 207-S Retention Basin and subsequently to the 216-S-17 Pond. This pond has been stabilized.

Ditches

Ditches were long, open, unlined excavations used to transfer low-level liquid wastes from process facilities to ponds. Two ditches in the S Plant Area are discussed as follows:

The **216-S-10D Ditch** is located southwest of the 202-S Building. The ditch operated from 1951 to 1991 and received and transferred 4.3×10^8 L (1.16×10^8 gal) of liquid waste. Discharges were received from the 202-S Building, 241-S Tank Farm, 211-S Valve House, 276-S Solvent Handling Facility, and 2901-S-901 Water Tower. These streams were transferred to the 216-S-10P and 216-S-11 Ponds.

The **216-S-16D Ditch** is located southwest of the 202-S Building. The ditch operated from 1957 to 1975. A total of 4.07×10^8 L (1.1×10^8 gal) of liquid waste was discharged to this unit, including process cooling water and steam condensate from S Plant.

Trenches

Trenches are unlined excavations used for disposing process waste into the subsurface by infiltration. Quantities were limited, as compared to cribs or ponds, and all of the trenches have now been backfilled. No high-priority trenches are located in the S Plant area.

1.3.3.4 Retention Basins

Retention basins were used for intermittent storage of liquid waste before it was transferred to ponds, ditches, or cribs. The 207-S Retention Basin is the highest-priority basin in the S Plant Area.

The **207-S Retention Basin**, also referred to as the 202-S Building Retention Basin, is a concrete structure with a volume of 3,220,000 L (850,000 gal) and a surface area of approximately 230 m^2 (4,600 ft^2). The basin received low-level liquid wastes, such as process cooling water and steam condensate from the 202-S Building, from 1951 through 1954. The wastes were discharged to the 216-S-17 or 216-S-16P Ponds.

1.4 Interactions with Other Hanford Site Programs

Two major activities are underway in the area around the 200-UP-1 Groundwater OU:

1. A number of RCRA TSD Units are either operating or subject to closure and corrective action. These TSD units are assigned either to the Tank Operations Contractor for the operation and closure of the S-SX, SY, and U Tank Farm WMAs or to the Plateau Remediation Contractor for all other non-tank farm WMAs.

2. The Decontamination and Decommissioning Program is operated under the Plateau Remediation Contract. The purpose of this program is to disposition the 221-U Canyon Building and the surrounding ancillary facilities including 224-U Condensate Neutralization Tank (CNT).

These projects are underway as of June 2010 and will require continued coordination throughout the remainder of the CERCLA process for the 200-UP-1 Groundwater OU.

1.5 Current and Future Land Use, Water Use, and Demography

The following subsections present the current and future land use as well as the demography of the area.

1.5.1 Land Use (Current and Future)

Current surface land use in the U and S Plant areas is industrial. The majority of the buildings and operations in the area are inactive and scheduled to undergo decommissioning and cleanup. Future land use in the 200 Areas is anticipated to be industrial-exclusive for at least 50 years and industrial (non-DOE-worker) after that (DOE/RL-91-52). Currently, institutional controls (ICs) restrict access to the Site.

1.5.2 Demography

No residences are located on the Site. The nearest inhabited residences are farm homes on land located 21 km (13 mi) north of the U Plant Aggregate Area. Approximately 411,000 people are living within an 80 km (50 mi) radius of the 200 Areas Plateau. The primary population centers are the Cities of Richland, Kennewick, and Pasco, located southeast of the Site, Yakima to the northwest, and Prosser to the

southwest. Additional information to support this section is included in PNNL-6415, DOE/EIS-0222-F, and USFWS, 2008.

1.6 200 West Area Interim Remedial Action Descriptions

This section presents a summary of the interim cleanup actions taken in the 200 West Area to reduce the mass of contaminants and contain specific groundwater plumes.

In 1995, the Tri-Parties agreed to examine the need for IRAs across the Site to prevent further degradation of Site groundwater and protect at-risk resources. In order to evaluate and screen potential candidate groundwater plumes for interim actions, the Tri-Parties agreed that if a contaminant concentration in a plume exceeded the appropriate standard by greater than a factor of 10, it was highly likely to further degrade the groundwater downgradient. The second step in the screening process was to determine whether treatment processes were readily available and capable of treatment of the COPCs to acceptable levels. For the 200 West Area, it was determined that IRAs were necessary and appropriate for uranium, TC-99, and carbon tetrachloride.

In the 200-UP-1 Groundwater OU, these IRAs include a 1985 P&T action taken near the 216-U-1 and 216-U-2 Cribs for uranium, a subsequent uranium and Tc-99 P&T action in the same area beginning in 1994 as a treatability test, followed by an IRA in 1997, and a specific action for TC-99 near the southern boundary of the S-SX Tank Farm. In the 200-ZP-1 Groundwater OU, two actions were taken to reduce the mass of carbon tetrachloride in the soil and groundwater and to contain the plumes.

1.6.1 216-U-1 and 216-U-2 Groundwater Cleanup Action

An IRA was designed to treat groundwater below these cribs. About 7.9×10^6 L (2.09×10^6 gal) of groundwater was recovered and treated between June and August of 1985, removing 700 kg (1,510 lb) of uranium via an ion exchange column and resulting in a decrease of uranium activity in the groundwater concentration to 17,000 pCi/L.

1.6.2 200-UP-1 Groundwater OU Interim Remedial Action

The U Plant IRA is being implemented under the auspices of the interim ROD for the 200-UP-1 Groundwater OU (PA/ROD/R10-97/048), as amended by an ESD (09-AMCP-0082), prepared by Ecology and approved by the Tri-Parties on February 24, 2009. This IRA consists of a P&T system to remove uranium and Tc-99 from groundwater in the vicinity of the 221-U Building. The RA has been in operation since 1994 (initially as a pilot now turned IRA) and includes operation of extraction wells, transfer of extracted groundwater to the 200 East Effluent Treatment Facility (ETF) for treatment with ultimate infiltration of the treated water at the State-Approved Land Disposal Site (SALDS). The IRA is targeted at selected portions of the groundwater contaminant plumes that exceed the IRA goals by capturing groundwater to minimize continued downgradient migration and removing contaminant mass from the groundwater system. Ecology (2009a) has mandated the following changes, which are presented in the Remedial Design/Remedial Action (RD/RA) work plan (DOE/RL-97-36, Rev. 2):

- The uranium contamination in groundwater will be reduced to 300 μg/L total uranium and 9,000 pCi/L of Tc-99. Ecology (2009a) lowered the IRA target concentration from 480 μg/L to 300 μg/L. This change reflects the change in the federal drinking water maximum contaminant level (MCL) to 30 μg/L; the IRA goal is established in the interim ROD at 10 times the MCL.

- Extracted groundwater will be treated at the ETF. The pumping rate for groundwater extraction wells is changed from the 189 L/min (50 gal/min) specified in the interim ROD to a pumping rate determined by the site-specific conditions (hydrogeologic formation features). This activity will

continue until such time as the groundwater conditions meet the RA goals or the IRA is replaced by a final RA determined by this RI/FS report, related Proposed Plan, and ROD.

1.6.3 200-UP-1 Groundwater OU Enhanced Action

During the performance of the First CERCLA Five-Year Review Process to evaluate the protectiveness of the CERCLA Remedial Actions across the site, it was determined that concentrations of Tc-99 in Well W23-19 south of the SX Tank Farm had risen to levels far above the remedial action objective (RAO) for Tc-99 of 9,000 pCi/L specified in the 200-UP-1 ROD for interim action. In the CERCLA Five Year Review, Action Item 200-5, DOE was instructed to do the following:

> *DOE shall also initiate pumping from Well 299-W23-19 to meet the RAO of 10 times the MCL for Tc-99. DOE shall complete evaluation of the capability of Well 299-W23-19 to achieve RAOs and if that well is not capable of meeting the cleanup level, DOE shall establish a path forward by December 2001 to achieve the goal of the interim remedial action.*

DOE determined and Ecology, as lead agency for 200-UP-1 agreed, to initiate pumping of Well 299-W23-19 at a rate of 3,785 L (1,000 gal) on a quarterly basis in an attempt to achieve the RAO. This approach has failed to meet the RAO and further action will result from this RI/FS, Proposed Plan, and related ROD.

1.6.4 200-PW-1 Operable Unit Removal Action

In October 1991, the Tri-Parties agreed to initiate expedited response actions at three specific locations across the Site. In the 200 West Area, the parties agreed that the mass of carbon tetrachloride in the soil column beneath 216-Z-1A, 216-Z-9, and 216-Z-18 represented a substantial continuing source of future groundwater contamination. Concurrently, EPA issued guidance for the implementation of presumptive remedies (EPA 540/R-96/023). Soil vapor extraction (SVE) was among those presumptive remedies. The conditions suitable for employing SVE as a presumptive remedy were supplied as concentrations in coarse sand or silts with relatively low-moisture contents, and a deep, unsaturated thickness above the water table from which to extract soil vapors. Based on the guidance, 200-PW-1, formerly 200-ZP-2, represented an ideal location for the implementation of SVE. Under the "Action Memorandum: Expedited Response Action Proposal for 200 West Area Carbon Tetrachloride Plume" (Smith and Stanley, 1992), implemented in 1992, SVE has been in operation either on a continuous or seasonal basis and recovered in excess of 5.67×10^5 L (1.5×10^5 gal) of carbon tetrachloride from the soil column beneath the 200 West Area.

1.6.5 200-ZP-1 Operable Unit Interim Remedial Action

In 1996, a groundwater P&T system was implemented as an interim cleanup measure for groundwater. The goals for this interim action were to reduce the mass of carbon tetrachloride in the groundwater and to contain the plume where concentrations exceed 2 ppm. The system treats extracted groundwater using *air stripping* to remove carbon tetrachloride (and other organic constituents) and then injects the treated water into the aquifer upgradient of the extraction area. The contaminated air from the stripping tower is treated with vapor phase carbon. Both interim actions are ongoing and will continue until they are integrated into the final remedy.

1.7 200-ZP-1 Final Remedial Action Basis

The Tri-Parties are planning to incorporate the remedy for 200-UP-1 with the final remedy for 200-ZP-1 through a ROD Amendment. The groundwater removed/extracted from the 200-UP-1 Groundwater OU (if P&T is selected as the preferred alternative) will be transferred to the 200 West Area Groundwater

P&T facility for treatment and treated water management. Much like the 200-UP-1 Area operating history and related contaminants in groundwater, the major waste streams that contributed to groundwater contamination in the 200-ZP-1 Area are associated with plutonium separation operations, as well as plutonium concentration and recovery.

The primary COPCs for 200-UP-1 and COCs for 200-ZP-1 are the same, with the exception that 200-UP-1 will add uranium to the list. The 200 West Area Groundwater P&T system has been designed to treat uranium, specifically for this reason. Chapters 7, 8, and 9 of this RI/FS report present the remedial alternatives under consideration as the Final Remedy.

1.7.1 200-ZP-1 Final Remedial Action Description

The 200 West Area Groundwater P&T facility will employ the following four principal remedial technologies and restoration processes to achieve groundwater cleanup in the 200 West Area:

1. **Groundwater P&T** will be used to capture and treat the contaminated groundwater with a design objective of reducing the mass of carbon tetrachloride by 95 percent in 25 years of active pumping. Carbon tetrachloride concentrations in the groundwater above 100 μg/L correspond to approximately 95 percent of the mass of carbon tetrachloride.

2. **Natural attenuation** processes, for the 5 percent of carbon tetrachloride (and other constituents) not captured by the P&T system, will be used to reduce concentrations to levels below the cleanup level.

3. **Monitoring** will be employed to evaluate the effectiveness of the natural attenuation processes. Fate and transport analyses conducted as part of the FS indicate that the timeframe necessary to reduce the remaining carbon tetrachloride concentrations to acceptable levels through monitored natural attenuation (MNA) will be approximately 100 years.

4. **ICs** will be used as long as contamination remains above the cleanup levels.

2 Study Area Investigations

The RI/FS work plan (DOE/RL-92-76, Rev. 1) describes the study area investigation activities planned to improve the understanding of threats and possible remedies to contamination for this OU. The following subsections describe the implementation of the work plan activities performed to characterize the 200-UP-1 Groundwater OU. The type, quantity, and quality of data needed to characterize groundwater to support the RI/FS process were identified in Appendix A of DOE/RL-92-76, Rev. 1, which is the associated *Remedial Investigation/Feasibility Study Work Plan for the 200-UP-1 Groundwater Operable Unit* SAP.

2.1 Historical Information and Remedial Action Review

Historical documents reviewed to support this RI/FS are listed in the annotated bibliography (Appendix B). Figure 2-1 illustrates the chronology of 200-UP-1 investigation activities through present day. Active evaluations of the source term, vadose zone, and groundwater subsequent to 1993 led to the groundwater interim ROD, DOE/RL-97-36, Rev. 2, and preparation of DOE/RL-92-76, Rev. 1 (200-UP-1 Groundwater OU RI/FS Work Plan) in 2005.

An IRA, referred to in Appendix B, was undertaken to address the high-concentration uranium and Tc-99 plumes in the vicinity of U Plant. The IRA has a complete group of work plans, sampling requirements, and data assessment requirements that were not part of the scope of the RI (DOE/RL-92-76, Rev. 0). Information collected as a part of the IRA, however, was used to support this RI/FS.

A pilot-scale treatability test was constructed and operated between March 1994 and September 1995. The treatability test consisted of an onsite P&T system constructed in the vicinity of 216-U-17 Crib; extraction and injection wells were used to capture the highest-concentration portions of the plume. P&T operations continued following completion of the treatability test.

The ROD for the 200-UP-1 Interim Remedial Measure (IRM) (EPA/ROD/R10-97/048) was issued on February 25, 1997, for the 200-UP-1 Groundwater OU P&T operations. RAOs were established for uranium and Tc-99 at concentrations equal to 10 times the MCL or Washington State risk-based concentrations. The selected remedy consisted of pumping from the highest-concentration zone of the uranium and Tc-99 groundwater plumes and routing the groundwater to ETF in the 200 East Area for treatment. Effluent from the treatment plan is discharged to the SALDS.

In 2004, monitoring of the interim action indicated that the RAOs specified in the interim ROD were met. The 200-UP-1 P&T system was turned off on January 26, 2005, to perform a rebound study to evaluate the stability of the observed conditions. Following the rebound study, the P&T system was restarted and the decision-making parties undertook an explanation of significant difference (ESD) to define and implement changes in operating conditions and performance requirements for the interim remedial action at 200-UP-1 OU. The ESD resulted in specification of several changes, including:

- The interim action RAO for uranium in groundwater was changed to 300 ug/L to reflect the establishment of a new MCL for uranium in drinking water at 30 ug/L. The RAO was established at 10 times the MCL.
- The required pumping rate for extraction wells was reduced from 50 gpm to a sustainable rate to be determined by site aquifer conditions.
- A list of OU-specific ICs was identified to be implemented at 200-UP-1 Groundwater OU.

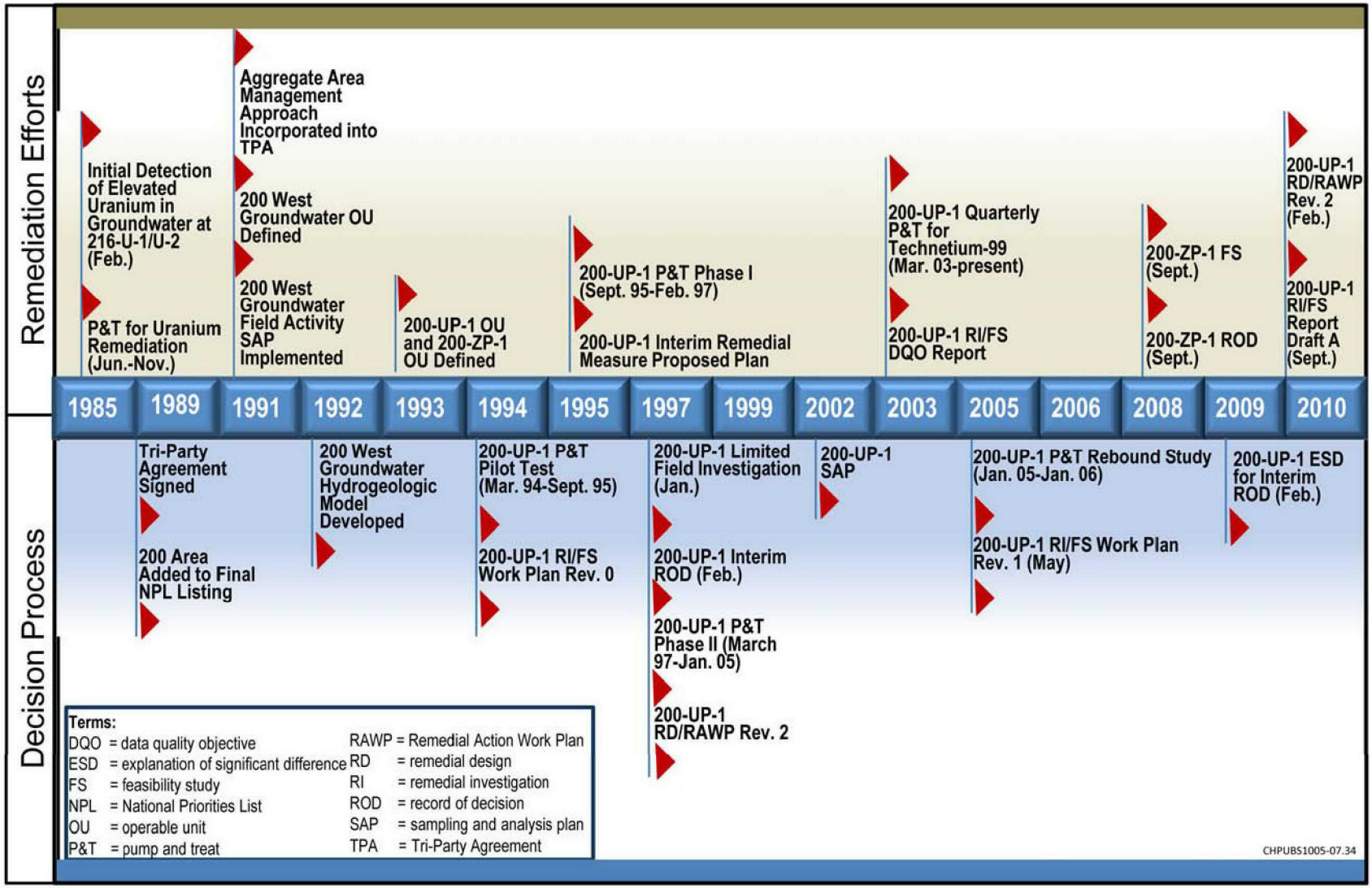

Figure 2-1. Timeline of Major Activities for the 200 UP-1 Groundwater Operable Unit

- Continuation of quarterly 3,000 L (1,000 gal) purges from a well located within WMA S-SX to provide additional removal of contaminants from the aquifer in that vicinity.

The following subsections summarize the most relevant historical documents for this RI/FS.

2.1.1 Aggregate Area Management Study Reports

In 1991, the Aggregate Area Management Study (AAMS) approach was incorporated into the TPA, and the 200 West and 200 East groundwater aggregate areas were defined. Summaries of historical operations, disposal practices, geology, and hydrogeology were presented in Aggregate Area Management Study Reports (AAMSRs). In 1993, the AAMSRs provided significant characterization information to support the field investigations that followed. The *200 West Groundwater Aggregate Area Management Study Report* (DOE/RL-92-16) discussed groundwater impacts resulting from liquid waste disposal operations from four source aggregate areas: U Plant, S Plant, T Plant, and Z Plant. The U Plant and S Plant source aggregate areas associated with the 200-UP-1 Groundwater OU are presented in the following subsections.

2.1.1.1 200 West Groundwater Aggregate Area Management Study Report

The *200 West Groundwater Aggregate Area Management Study Report* (DOE/RL-92-16) summarized information about groundwater contaminants beneath the 200 West Area and provided recommendations for prioritizing, investigating, and remediating various contaminants and plumes. The document also provided a detailed description of contaminant plumes including uranium, Tc-99, and nitrate in the 200-UP-1 Groundwater OU. The 200 West Groundwater AAMSR recommended that the three contaminants/plumes containing the highest concentrations of uranium, Tc-99, and nitrate be addressed under an IRA to reduce some of the more severe potential risks of contaminants in the groundwater. Tritium was recommended for a direct risk assessment path due to lack of proven technology at the scale needed to implement an IRA.

2.1.1.2 U Plant Aggregate Area Management Study Report

The *U Plant Source Aggregate Area Management Study Report (*DOE/RL-91-52) detailed the operations and processes designed to recover uranium from the bismuth-phosphate process wastes stored in SST farms. The process used a continuous tributylphosphate (TBP)-based solvent extraction chemistry to separate uranium from solutions with large quantities of fission products. DOE/RL-91-52 provides background, environmental setting, and known contamination data to support development of a preliminary conceptual model and for assessing health and environmental concerns.

2.1.1.3 S Plant Aggregate Area Management Study Report

The *S Plant Aggregate Area Management Study Report* (DOE/RL-91-60) detailed the operations and processes conducted at the REDOX Plant in the S Area (S Plant) that represented a significant improvement in the recovery of plutonium and uranium over the bismuth-phosphate plutonium separations process. Hexone was used as a diluent to extract plutonium and uranium from acidic, fission-product-rich solutions in which the fuel rods had been dissolved. DOE/RL-91-60 provides background, environmental setting, and known contamination data to support development of a preliminary conceptual model and for assessing HHE concerns.

2.1.2 Investigation Documents

The following sections describe the investigation documents used in this RI/FS.

2.1.2.1 RI/FS Work Plan (DOE/RL-92-76, Rev. 0)

The *Remedial Investigation/Feasibility Study Work Plan for the 200-UP-1 Groundwater Operable Unit, Hanford Site, Richland, Washington* (DOE/RL-92-76, Rev. 0) was issued in January 1994 to provide a plan for implementing interim remedial measures and investigating groundwater contaminants designated for a LFI in the 200 West AAMSR (DOE/RL-92-16).

The work plan identified 26 high-priority groundwater contaminants for LFI based on a review of groundwater data from 1988 through 1990.

- Fifteen organic compounds, including 1,2-dichloroethane, 1,1-dichlorethene, carbon tetrachloride, chloroform, trichloroethene (TCE), bis(2-ethylhexyl)phthalate, n-nitrosodimethylamine, and the pesticides aldrin, dichlorodiphenyldichloroethane (DDD), dichlorodiphenytrichlorethane (DDT), dieldrin, endrin, endrin aldehyde, gamma-BHC (Lindane), and heptachlor
- Six radionuclides, including potassium-40 (K-40), Sr-90, I-129, plutonium-238 (Pu-238), gross alpha, and gross beta
- Five inorganic constituents, including arsenic, cadmium, chromium, fluoride, and selenium

The work plan also identified three groundwater contaminants designated for IRA to include Tc-99, uranium, and nitrate.

2.1.2.2 Limited Field Investigation (DOE/RL-96-33)

The *Limited Field Investigation for the 200-UP-1 OU* (DOE/RL-96-33) was based on DOE/RL-92-76, Rev. 0. These two historical documents provided valuable information in the understanding of the 200-UP-1 Groundwater OU. The LFI focused on evaluation of the contaminated aquifer soils and groundwater within the 200-UP-1 Groundwater OU. The primary objective of the LFI was to refine the site conceptual model and provide data for the performance of a risk assessment.

To assess the N&E of contamination, data for groundwater contaminants from 105 wells from 1990 through 1996 were evaluated. The wells shown in Table 2-3 and Figure 3-4 of the LFI (DOE/RL-96-33) were used for the risk assessment and included data from 45 of the 49 wells listed in DOE/RL-92-76, Rev. 0 (Table 4-11) and all groundwater data obtained during 1995 sampling of the 200-UP-1 Groundwater OU.

Ten organic compounds (bis[2-ethylhexyl]phthalate, n-nitrosodimethylamine, and the pesticides: aldrin, DDD, DDT, dieldrin, endrin, endrin aldehyde, gamma-BHC [Lindane], and heptachlor) were eliminated as high-priority groundwater contaminants based on one-time detection criteria. The following two criteria were used to evaluate the remaining 16 high-priority groundwater contaminants.

- The constituent must be present in at least three adjacent wells to constitute a plume; detection in single wells does not constitute a plume.
- The constituent must be present in concentrations that exceed background or a drinking water standard (DWS).

K-40, Pu-238, and selenium were detected multiple times above background, but the minimums, maximums, and averages were below the MCL.

Of the 26 LFI groundwater contaminants, 13 were detected above the groundwater standards of the *Safe Drinking Water Act*, the *Washington Administrative Code* (WAC) *Model Toxics Control Act* (MTCA), WAC 173-340, or the *Uranium Mill Tailings Radiation Control Act of 1978*. The contaminants exceeding

the standards include 1,1-dichlororethene, 1,2-dichloroethane, arsenic, cadmium, carbon tetrachloride, chloroform, chromium, fluoride, I-129, Sr-90, Tc-99, TCE, and uranium. The distributions occurred as plumes and sporadic occurrences.

As discussed in the LFI, the future risk scenario assumed a residential scenario. The risk analysis attributed most of the future and current risk to carbon tetrachloride. Carbon tetrachloride was recommended for inclusion in the 200-ZP-1 IRA. Other 200-UP-1 groundwater contaminants were not recommended for IRA because F&T analysis suggested that concentrations present little risk.

2.1.2.3 The Work Plan (DOE/RL-92-76, Rev. 1)

Issued in May 2005, this work plan described actions to be completed for the 200-UP-1 RI/FS following two responses and plume extent and concentration changes over time. The first response was an IRA started in 1994 for groundwater contamination P&T operations with uranium and Tc-99. The second response was for tank farm and vadose zone remediation to eliminate or mitigate all releases, or treat releases to the groundwater. The purpose of this plan was to describe the approach for completing the RI/FS to support selection of a final remedy for the 200-UP-1 Groundwater OU. The project scope included the collection of additional characterization data to better define the groundwater contamination and the collection of missing data needed to support risk modeling and screening of remedial alternatives. In addition to the evaluation of documented historical information, more recent monitoring data contained in the Hanford Environmental Information System (HEIS) was evaluated to supplement the determination of COPCs to support the RI/FS. The results of the data evaluation provided in Appendix C of this document were used to prepare the SAP in Appendix A for use during the RI. Chapter 5 described the plan for an enhanced monitoring network and presented depth-discrete groundwater sample analysis results collected during installation of new monitoring wells. Twenty-two monitoring wells were identified for installation to complete the 200-UP-1 OU monitoring network and to complete the data needs for the CERCLA RI/FS process.

2.1.2.4 Sampling and Analysis Plans for the 200-UP-1 Groundwater Monitoring Well Network

Because of P&T operations and the general decrease in groundwater elevation due to stoppage of effluent release from facilities, the shapes of the contaminant plumes in the 200-UP-1 Groundwater OU changed. A SAP (DOE/RL-2002-10) was developed to characterize the status of the plumes more accurately, including a reassessment of the wells to sample, the COPCs, and the analytical methods. DOE/RL-2002-10 presented a list of wells similar to those in Appendix A of DOE/RL-92-76, Rev. 0. The COPCs listed in DOE/RL-2002-10 included carbon tetrachloride, chloroform, TCE, total chromium, arsenic, cadmium, Sr-90, I-129, Tc-99, uranium, tritium, and nitrate. DOE/RL-2002-10 was used for monitoring until a new SAP was provided in Appendix A of DOE/RL-92-76, Rev. 1 in 2005. The results from the sampling programs have been presented annually in interim action monitoring reports.

2.1.3 Historical Information Review Summary

The shapes and concentrations of the COPC plumes within the 200-UP-1 Groundwater OU have changed over time as a result of the following events:

- P&T operations
- Natural groundwater flow
- Source term variability
- Decline in groundwater levels
- Discharge of other waste streams (cooling water)
- Natural attenuation

In addition, the changes in groundwater plumes and water levels have affected the monitoring wells used to evaluate contaminant plumes and migration. Additional information collected during the RI has been used to address the nature of the groundwater flow regime more accurately, and to support more accurate modeling of plume migration.

2.2 Geologic Investigations

Ten new monitoring wells were installed in accordance with DOE/RL-92-76, Rev. 1 and per the planning/data quality objective (DQO) process, plus 12 additional wells that were installed at Ecology's request. Twenty two (22) wells plus one replacement well were installed. The 10 new monitoring wells are: 299-W19-46, 299-W19-50, 299-WI9-47, 699-38-70C, 699-38-708, 299-W21-2, 699-40-65, 299-W19-48, 699-36-708, and 699-30-66. The 12 Ecology-requested wells are: 299-W19-107, 299-W19-105, 299-W22-69, 299-W22-72, 299-W22-86, 699-34-72, 699-33-74, 699-33-75, 699-32-76, 699-33-76, 299-W22-87, and 299-W22-88. Well 299-W19-107 was developed as a replacement for Well 299-W19-104. Data for the risk assessment were taken from all 23 wells, plus other wells. The 12 wells installed at Ecology's request were installed between 2006 and 2008. Well 299-W19-107 was developed as a replacement for Well 299-W19-104, which was damaged during drilling. The casing for the damaged well was abandoned, and the borehole was decommissioned. Geological descriptions were collected during installation of all 13 wells (12 new and one replacement), and the descriptions were evaluated for consistency with the current conceptual model. WMP-29656 and SGW-38141 provide detailed geologic information for the 12 new wells. A summary of the drilling activities, including information such as screen interval, borehole logs, and other well development data, are included in WMP-29656 and SGW-38141.

2.3 Groundwater Investigations

Groundwater sampling conducted specifically to support DOE/RL-92-76, Rev. 1 began in January 2004 and ended in March 2009. Table 2-1 provides a summary of the groundwater sampling activities and the associated status.

Groundwater sampling specific to the work plan was generally conducted according to requirements described in DOE/RL-92-76, Rev. 1. Some deviations were made to the sample well location and frequency from those specified in the SAP (Appendix A of DOE/RL-92-76, Rev. 1) due to various reasons, such as dry wells, modification requested by Ecology, sample frequency reductions for new wells, and additional sampling needs. During the drilling of the new groundwater monitoring wells, depth-discrete groundwater samples were collected to assist in defining the three-dimensional distribution of COPCs within the aquifer (WMP-29656 and SGW-38141). Details of depth-discrete groundwater sampling results and findings from other groundwater monitoring activities for the 200-UP-1 Groundwater OU are included in PNNL-15070, PNNL-15670, PNNL-16346, DOE/RL-2008-01, and DOE/RL-2008-66.

Table 2-1. Status Summary of 200-UP-1 RI Activities

	Activity	Status
Routine Monitoring Activities	Analysis of routine COPCs listed in Table A1-1 of the Work Plan/SAP (DOE/RL-92-76, Rev. 1, Appendix A[a]) for existing wells per Section A1.3.2 and frequencies shown in Table A3-1 of the Work Plan/SAP. If any of the additional COPCs are detected above the detection limits, these COPCs will be added to the routine sampling program per Section A1.3.3 of the Work Plan/SAP.	Ongoing; comparison of additional COPCs concentrations with the associated detection limits was conducted on a continuous basis as new data became available. Three of the additional COPCs (carbon-14 [C-14], 1,4-dioxane, and selenium-79 [Se-79]) were persistently detected, and were thus added to the routine sampling for selected wells.
Supplemental Data Collection	Collect supplemental information per Section A1.3.7 of the Work Plan/SAP.	With the exception of DNAPL investigations and quality assurance activities (co-sampling), supplemental information identified in Section A1.3.7 of the Work Plan/SAP was collected.
Microscopic Contaminant Characterization	Incorporate microscopic contaminant characterization data from the RI scoping studies identified in Section A1.3.8 of the Work Plan/SAP during the selection of remedial alternatives.	RI scoping studies were conducted and results were included in PNNL-15502.
Enhanced Monitoring Well Network	Install 12 new groundwater monitoring wells (UP-1 to UP-12) per Section A1.3.1 of the Work Plan/SAP.	12 new groundwater monitoring wells, UP-1 to UP-12 (299-W19-107, 299-W19-105, 299-W22-69, 299-W22-72, 299-W22-86, 699-34-72, 699-33-74, 699-33-75, 699-32-76, 699-33-76, 299-W22-87, and 299-W22-88) were installed between 2006 and 2009. Well 299-W19-107 was developed as a replacement well for 299-W19-104 (UP-1/C4967), which was damaged and decommissioned.
Depth-Discrete Groundwater Sampling to Assist in Defining the Three-Dimensional Distribution of COPCs	Collection of five depth-discrete groundwater samples from selected new wells included in Section A1.3.5 of the Work Plan/SAP and onsite analysis for Tc-99 and volatile organics.	Depth-discrete groundwater samples were collected per Section A1.3.5 of the Work Plan/SAP and results are summarized in the corresponding Hanford Site Groundwater Monitoring Report.
Modeling Input Parameter Collection	Collection of additional modeling input data (well development and aquifer testing) following well installation for selected wells (299-W19-48, 699-30-66, and 699-36-70B) per Section A1.3.4 of the Work Plan/SAP. Conduct one to three hydrologic tests (slug tests, slug interference tests, constant rate discharge tests, and tracer tests) per Section A1.3.6 at multiple depth intervals at each of approximately three well locations. Select depth intervals and hydrologic parameters, and develop a final detailed hydrologic test plan per Section A1.3.6 of the Work Plan/SAP.	Slug tests were conducted at multiple depth intervals for all three wells per Section A1.3.4 of the Work Plan/SAP and results are summarized by PNNL-19482.
New Well Monitoring for Routine COPCs	Analysis of routine COPCs listed in Table A1-1 of the Work Plan/SAP for all new wells and frequencies shown in Table A3-1 of the Work Plan/SAP.	Samples were collected and analyzed per Table A3-1 of the Work Plan/SAP.

Table 2-1. Status Summary of 200-UP-1 RI Activities

Activity			Status
New Well Monitoring for Additional COPCs	Analysis of additional COPCs listed in Tables A2-1 and A2-2 of the Work Plan/SAP for selected new wells and frequencies listed in Table A3-2 of the Work Plan/SAP.		Samples were collected at frequencies listed in and analyzed for additional COPCs identified in Table A3-2 of the Work Plan/SAP, and according to methods included in Table A2-1 of the Work Plan/SAP. Comparison of additional COPC concentrations with detection limits specified in Table A2-1 of the Work Plan/SAP were conducted on a continuous basis as new data became available.
New Well Initial Sampling	Drilled to the top of the Ringold Lower Mud unit.	299-W19-107 (UP-1/C5193) 699-34-72 (UP-5/C4972) 299-W22-88 (UP-12/C4978)	Depth-discrete groundwater samples were collected during well drilling and each discrete sample was analyzed for the parameters specified in Section A1.3.5 of the Work Plan/SAP. Appropriate screen interval was selected per instruction included in Section A1.3.1 of the Work Plan/SAP. Discrete sample results are summarized in PNNL-16346.
	Drilled 36.6 m (120 ft) below the water table.	299-W19-105 (UP-2/C4968) 299-W22-69 (UP-3/C4969) 299-W22-72 (UP-4/C4970) 299-W22-86 (UP-5/C4971) 699-33-74 (UP-7/C4973) 699-33-75 (UP-8/C4974) 699-32-76 (UP-9/C4975) 699-33-76 (UP-10/C4976) 299-W22-87 (UP-11/C4977)	Depth-discrete groundwater samples were collected during well drilling and each discrete sample was analyzed for the parameters specified in Section A1.3.5 of the Work Plan/SAP. Appropriate screen interval was selected per instruction included in Section A1.3.1 of the Work Plan/SAP. Discrete sample results are summarized in DOE/RL-2008-66.

a. The reference for every mention of the Work Plan/SAP in this table is DOE/RL-92-76, Rev. 1, Appendix A.

2.4 Field and Laboratory Activity Documentation

From October 1, 2003, to March 31, 2009, groundwater samples were collected from 93 wells identified to support the 200-UP-1 Groundwater OU RI/FS. Monitoring requirements for field parameters, such as conductivity, REDOX potential, pH, temperature, dissolved oxygen, and turbidity, were not specified in the SAP (Appendix A of DOE/RL-92-76, Rev. 1). Field parameters are generally measured during each monitoring event, and a summary of the field data quality assessment (DQA) is discussed in the 200-UP-1 Groundwater OU DQA report (SGW-43140).

The wells selected for sampling in DOE/RL-92-76, Rev. 1, include those from the monitoring well network of the 200-UP-1 Groundwater OU, as established in Appendix A of DOE/RL 92-76, Rev. 1, as well as RCRA monitoring wells from the U, SSX, and 216-S-10 WMAs, and are listed in Appendix A of SGW-43140.

The SAP, in Appendix A of DOE/RL-92-76, Rev. 1, includes COPCs identified through DQO processes conducted in 1992 and again in 2003. These DQO processes resulted in a comprehensive list of COPCs that was revised to a final list of 56 COPCs.

In addition to target analytes for RI/FS characterization or RD/remedial action work plan (RAWP) process monitoring, additional constituents have been reported through method-based analysis. The data set used for this DQA includes 259 individual analytical parameters.

The analytical data for all groundwater monitoring samples and their associated field quality control (QC) samples are maintained in the HEIS; the data are summarized in annual groundwater monitoring reports. The most recent of these reports is *Hanford Site Groundwater Monitoring for Fiscal Year 2008* (DOE/RL-2008-66).

2.4.1 Field Quality Control

During the period of October 1, 2003, through March 31, 2009, a total of 24,290 Field QC results were generated; approximately 35 percent of the total groundwater samples collected. These consisted of 3,911 field duplicate results; 957 field split results; and 19,422 blanks results, consisting of a combination of field transfer blanks, equipment rinsate blanks, full trip blanks, and trip blanks. (A "Full Trip Blank" is a trip blank to be analyzed for all constituents, rather than just the volatiles.) Table 5-5 in SGW-43140 provides a breakdown of these results by analyte and field QC type.

2.4.1.1 Field Duplicate Samples

The analytical precision requirement is ≤25 percent for all RI/FS COPCs, as documented in the RI/FS work plan SAP. Field duplicate samples are collected to evaluate the laboratory measurement precision. The usual measure of precision is the relative percent difference (RPD) between duplicate pairs. The RPD is calculated for a field duplicate sample only when one result or the other is at least five times the detection limit. Table 5-5 in SGW-43140 shows field duplicate results by constituent.

There are 3,911 pairs of field duplicates, and all RI/FS COPCs had some duplicate data. Sixty-one (1.6 percent) of these had RPDs that exceeded the required criteria of 25 percent. One constituent, lead, exhibited a high percentage of unacceptable duplicate performance (71 percent).

2.4.1.2 Split Samples

Field split samples are collected from a sampling location on the same day and time, and submitted to two different laboratories for analysis. The purpose of such samples is to monitor the comparability of the data generated by different laboratories. The acceptance criterion is an RPD of the two laboratories' results of 20 percent or less. The 200-UP-1 data set contained 957 pairs of split samples, of which 23 (2.4 percent) exceeded 25 percent RPD. Table 5-5 in SGW-43140 shows field split sample results by constituent.

Only two constituents exhibited high percentages of split data exceeding the QC criteria: gross beta (100 percent) and fluoride (43 percent). There were no laboratory splits for lead, lithium, mercury, Cs-137, cobalt-60 (Co-60), neptunium-237 (Np-237), uranium-234 (U-234), uranium-235 (U-235), uranium-238 (U-238), phenols, TPA, 1,4-dioxane, ethyl acetate, ammonia/ammonium, cyanide, nitrite, or sulfide.

2.4.1.3 Field Blank Samples

Three types of field blanks were gathered during the collection of 200-UP-1 groundwater samples equipment rinsate blanks, field transfer, and trip blanks. Equipment rinsate blanks are water samples used in the final rinse of sampling equipment before the equipment is reused to collect another sample. These blanks are not required for sampling events that use disposable or dedicated sampling equipment.

Field transfer blanks are generated by pouring laboratory water into sample containers in the field during a sampling event to detect any contaminants that may be introduced into samples during the bottle-filling activities. Trip blanks are clean water samples that are prepared in the lab and taken into the field with the sampling crew. Trip blanks are a measure of potential contamination associated with sample collection and transportation to the laboratory.

For the purpose of the DQA, all blank results were pooled. Table 5-5 in SGW-43140 displays the blank data by constituent of the 19,422 individual blank results, 672 exceeded the QC threshold of twice the method detection limit or minimum detectable activity. Constituents with high percentages of positive blanks include oil and grease (100 percent), calcium (31 percent), and methylene chloride (28 percent).

2.4.2 Laboratory Quality Control

This section summarizes the review of the laboratory QC associated with the data set from the past 5 years. Laboratory contamination, accuracy, completeness, and comparability are evaluated.

The data set consists of 178,019 laboratory QC results, which includes 51,737 blanks; 17,820 duplicates; 43,137 laboratory control standards; 44,771 matrix spikes; and 20,554 surrogate recovery results. Of these, 21,622 (12 percent) could not be evaluated because the data set did not include a reference to the associated method detection limit or minimum detectable activity data, which were necessary for evaluation. The lab QC results are applicable to the data set but cannot be associated with specific well sample results. Further details are provided in Section 5.7 of SGW-43140.

2.4.3 Data Usability

Data from each category of information are summarized in the following QC categories:

- Five percent of the characterization data between October 1, 2003, and March 31, 2009, were selected for formal validation
- Five previous years of data from the annual groundwater report
- Summary of all field QC from October 2003 to March 2009
- Summary of all laboratories QC from October 2003 to March 2009
- Summary of the detection limit evaluation

2.4.3.1 Formal Validation

No major deficiencies were identified in the validated semivolatiles, pesticides, or inorganics data.

Thirty-one samples (volatiles, nitrate, nitrite, phosphate, and biological oxygen demand [BOD]) were rejected, wholly or in part, due to severe holding time accidents. Two radiochemistry samples were rejected due to lack of traceability of the standards used to quantitate the result. Many minor deficiencies were identified that resulted in the application of J or UJ flags. Overall completeness is estimated at 98 percent. All flags identified during the validation process have been applied and corrected in the HEIS.

2.4.3.2 Annual Groundwater Report Review

Comparison of the 200-UP-1 data set with the overall Site groundwater data set, as described in the annual Hanford Site groundwater monitoring reports, showed that the 200-UP-1 data are at least as good, in terms of accuracy, precision, and blank contamination, as the overall site groundwater data set. Both field and laboratory performance parameters are equal to or better than those for the Site groundwater data as a whole.

2.4.3.3 Summary of Field QC

Field QC consisted of field blanks, field duplicates, and field splits. Overall performance was very good and is further described in Section 6.3 in SGW-43140.

2.4.3.4 Summary of Laboratory QC

Laboratory QC includes lab blanks, duplicates, laboratory control standards, matrix spikes, and surrogates. Overall, the laboratory performance was very good and is further described in Section 6.4 in SGW-43140.

Although the overall laboratory performance was excellent, some isolated data batches exhibited problems. These were qualified in HEIS. Data users that rely on single data results should ensure they understand the qualifiers identified in HEIS and validate that laboratory batch data associated with the specific result is also good.

2.4.3.5 Detection Limits

Using non-detect data to demonstrate performance to a specific threshold requires the laboratory reporting limit to be less than the threshold. The 200-UP-1 data set contains non-detect data for many constituents that do not meet this criterion. Table 6-3 shows the constituents for which more than 25 percent of the non-detects exceeded the identified risk-based, potentially applicable, action limits defined in Section 1 of SGW-43140.

3 Physical Characteristics of the Study Area

The hydrogeologic CSM for the 200-UP-1 Groundwater OU is described in the following subsections in terms of the physical characteristics of the OU.

The areal extent of the 200-UP-1 Groundwater OU is defined by a geographically created polygon (Figure 1-3) that includes the southern portion of the 200 West Area and a portion of the 600 Area between the 200 East and West Areas. This OU boundary splits the 200 West Area contaminant plumes between the 200-ZP-1 and 200-UP-1 Groundwater OUs. 200-ZP-1 covers the northern half of the 200 West Area (coincident with the bulk of the carbon tetrachloride contaminant plume), and the 200-UP-1 Groundwater OU covers the southern portion of the 200 West Area. Originally, the 200-UP-1 Groundwater OU was dominated by a persistent, artificially elevated, groundwater mound that developed under the 216-U-10 Pond (U Pond), located on the western side of the 200 West Area (Figure 3-1). Discharges of liquid effluent to the ground within the OU were discontinued in 1986, and the groundwater mound began to dissipate. The groundwater elevations within the OU remain elevated above background conditions (Pre-Hanford) and are declining at a rate of about 1 m (3.3 ft) per year.

The primary aquifer system of interest for the 200-UP-1 Groundwater OU is the uppermost unconfined aquifer that is encountered mainly within the Ringold Fm unit E, a thick sequence of semi-consolidated silty, sandy gravel. Near the eastern extent of the OU, at the downgradient groundwater boundary, a hydrogeologic transition occurs where older Ringold Fm sediment has been removed and/or reworked by ancestral Columbia River fluvial and Pleistocene cataclysmic flooding. The subsequent deposition left younger, more permeable, and less consolidated, Hanford fm and cold creek unit (CCU) silt, sand, and gravel adjacent to the Ringold Fm sediment.

Information describing the physical characteristics of the 200-UP-1 Groundwater OU has been derived from measurements and observations collected during the OU RI, as well as information collected from previously published investigations. The *National Environmental Policy Act of 1969* (NEPA) characterization report (PNNL-6415) describes the major features of the Site environment. Much of the following description of the setting and climate is excerpted from PNNL-6415. Figure 3-2 shows the 200-UP-1 groundwater OU surface topography.

3.1 Surface Features

The Site is located in the Columbia Basin of the Pacific Northwest. The Columbia Basin is an intermontane basin between the Cascade Range and the Rocky Mountains, and forms the northern part of the Columbia Plateau physiographic province and the Columbia River flood basalt province. Most of the geologic activity producing features visible in the Basin occurred during the last 18 million years of the Cenozoic Era, but events as far back as the late Precambrian (2.3 billion years ago) had significant influence on the Cenozoic history of the area.

The Site lies within the Pasco Basin (Figure 3-3), which is located in the Yakima Fold Belt along the western margin of the Palouse Slope. The Saddle Mountains form the northern boundary of the Pasco Basin, while Rattlesnake Mountain forms part of the southern boundary. The main Site WMAs, located in the 200 East and 200 West Areas, lie in the Cold Creek syncline between Yakima Ridge and Umtanum Ridge in the central portion of the Pasco Basin. The physiographic setting of the Site is relatively low-relief, resulting from river and stream sedimentation filling the synclinal valleys and basins between the anticlinal ridges.

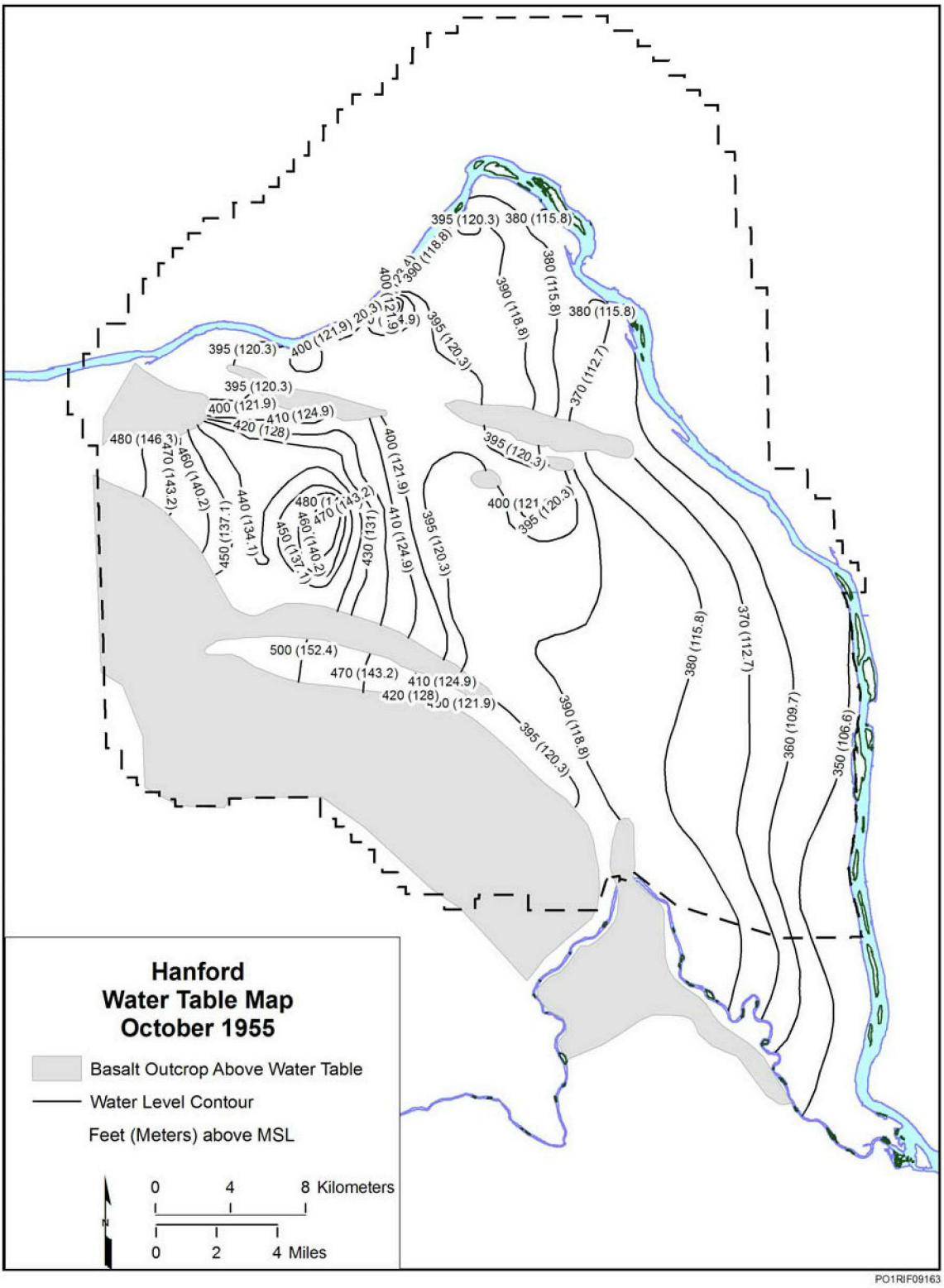

Figure 3-1. Historical Groundwater Mound Beneath U Pond, 200-UP-1 Groundwater Operable Unit

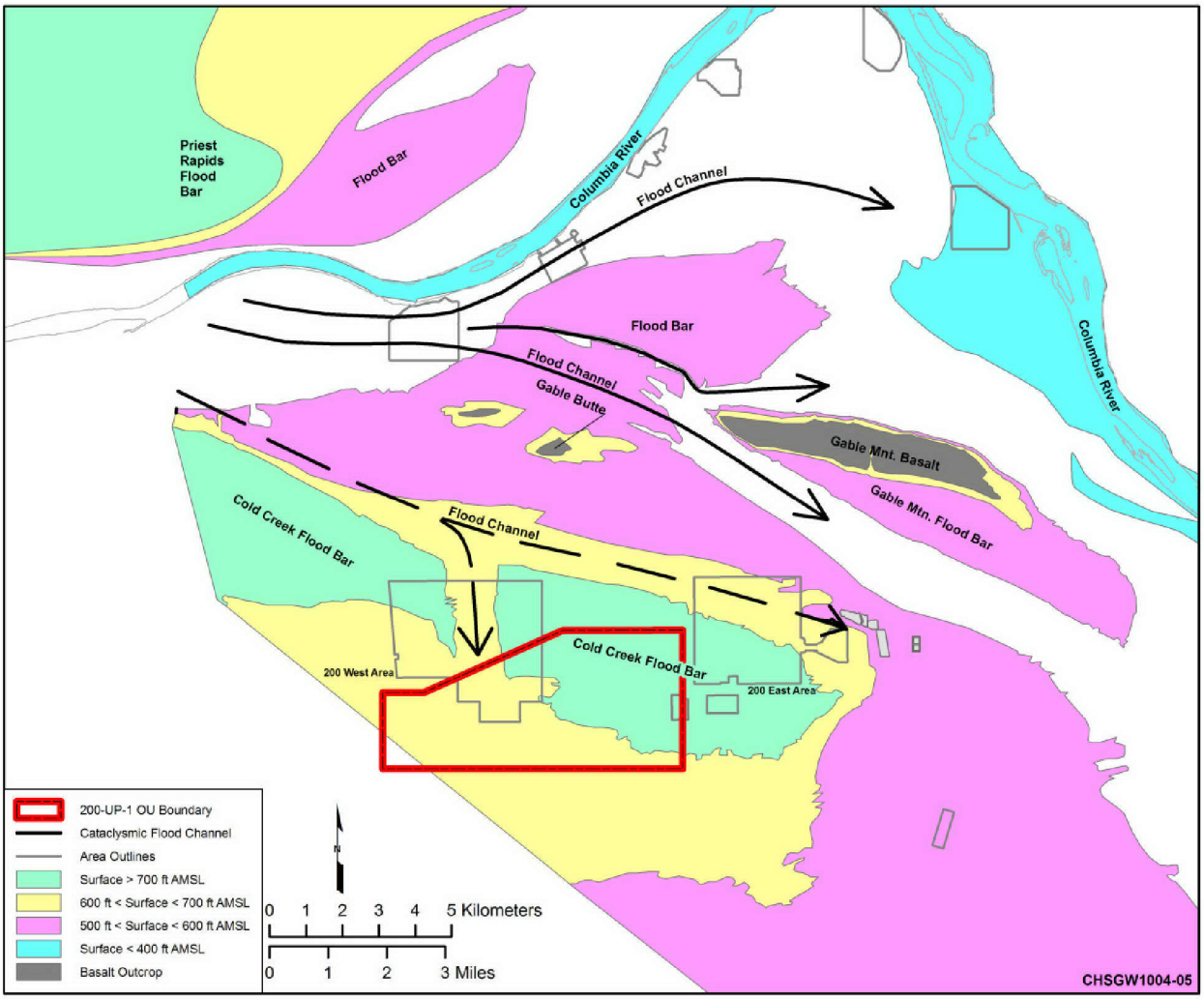

Figure 3-2. Topography of the 200-UP-1 Groundwater Operable Unit and Surrounding Area

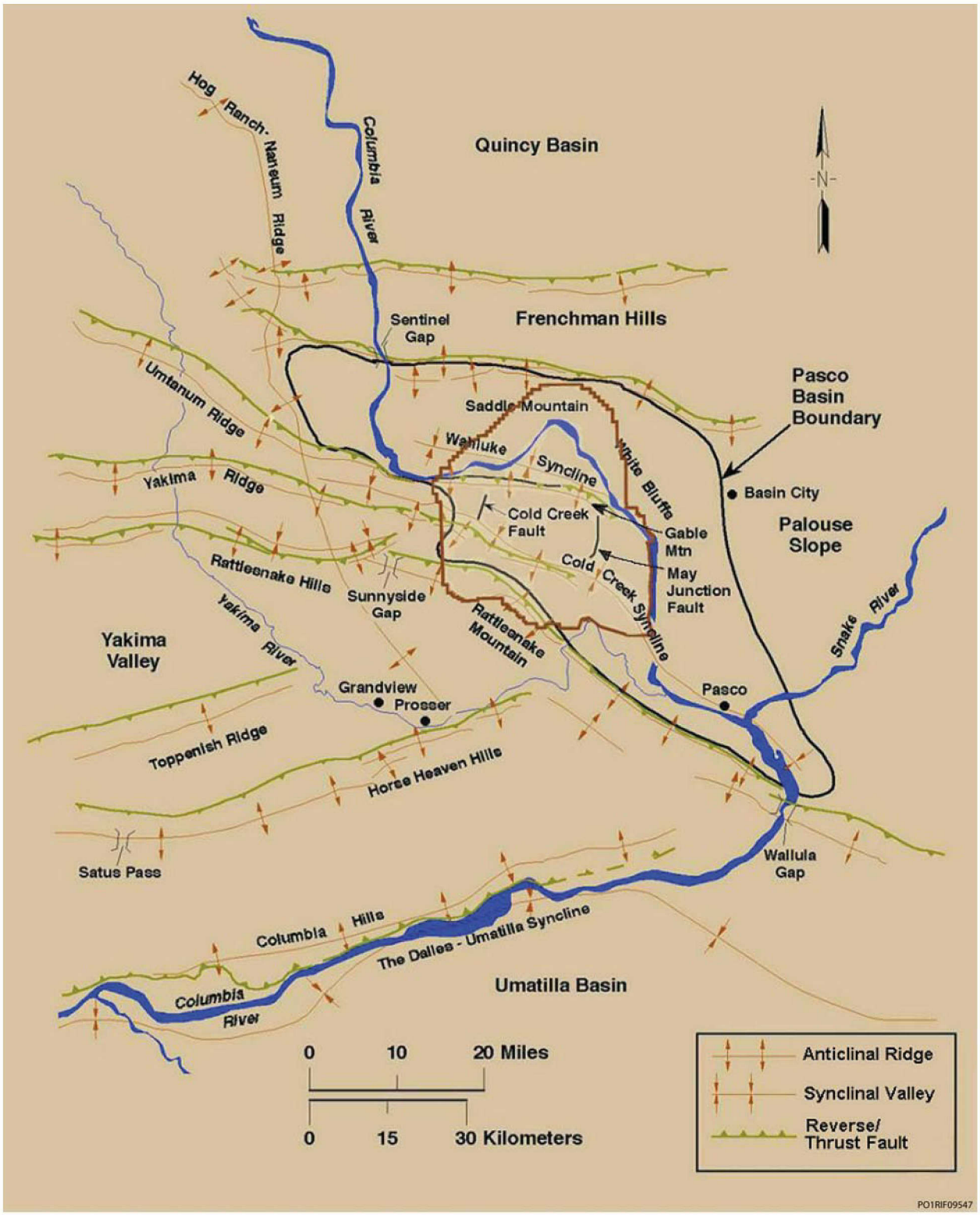

Figure 3-3. Generalized Structure Map of the Pasco Basin (Modified from PNNL-6415)

Site topography has been modified within the past several million years by Pleistocene cataclysmic flooding, Holocene eolian activity, and landsliding. Pleistocene floods eroded sediments and scoured basalt bedrock, forming "scabland" topography visible north of the Pasco Basin, and left large-scale erosional channels and flood bars visible within the Central Plateau at the Site (Figure 3-2).

The topography above the 200-UP-1 Groundwater OU is relatively flat to gently rolling, with a surface elevation ranging from about 183 to more than 213 m (600 and 700 ft) MSL (Figure 3-2). The topography across the 200-UP-1 Groundwater OU reflects the remnant terrain associated with the Cold Creek Bar, a large-scale paleo-flood feature that dominates the area (Figure 3-2). Groundwater beneath the OU is much deeper in this portion of the Site due to the increased vadose thickness associated with the paleo-bar deposits.

Manmade features visible on the ground surface of 200-UP-1 Groundwater OU are limited to industrial structures related to the historical nuclear material production activities at the Site, the ERDF, and the U.S. Ecology Site. The 200-UP-1 Groundwater OU includes the following major historical structures:

- 221-U Building (U Plant), utilized historically for recovery of uranium from high-level radioactive waste
- 224-U Building (UO_3 Plant), utilized historically for production of uranium tri-oxide from reactor fuel reprocessing wastes
- Various associated cribs, ponds, ditches, and the S-SX and U Tank Farms, utilized historically for waste disposal
- 202-S (S Plant, REDOX), utilized historically to extract plutonium and uranium from fuel rods irradiated by Site reactors

3.2 Meteorology

The Pacific Ocean moderates temperatures throughout the Pacific Northwest, and the Cascade Range (approximately 113 km [70 mi] west of the Site) generates a rain shadow that limits rain and snowfall in the eastern half of Washington State. The Cascade Range also serves as a source of cold air drainage, which has a considerable effect on the wind regime of the Site. The Rocky Mountains to the north and east of the region shield the area from the severe winter storms and frigid air masses that move southward across Canada.

Climatological data for the Site are compiled at the Hanford Meteorology Station (HMS), which is located on the Central Plateau, just outside the northeast corner of the 200 West Area and about 4 km (3 mi) west of the 200 East Area. To characterize meteorological differences accurately across the Site, the HMS operates a network that currently contains 30 monitoring stations (Figure 3-4). Data are collected and processed at each station, and information is transmitted to the HMS every 15 minutes. This monitoring network has been in full operation since the early 1980s. Data from the HMS capture the general climatic conditions for the region and describe the specific climate of the Central Plateau. Meteorological measurements have been made at the HMS since late 1944. Before the HMS was established, local meteorological observations were made at the old Hanford Townsite (1912 through late 1943) and in Richland (1943–1944).

Meteorological data collected at the HMS are considered to be representative of conditions in the 200-UP-1 Groundwater OU. Historical and statistical Hanford meteorological data are compiled and reported in PNNL-14242.

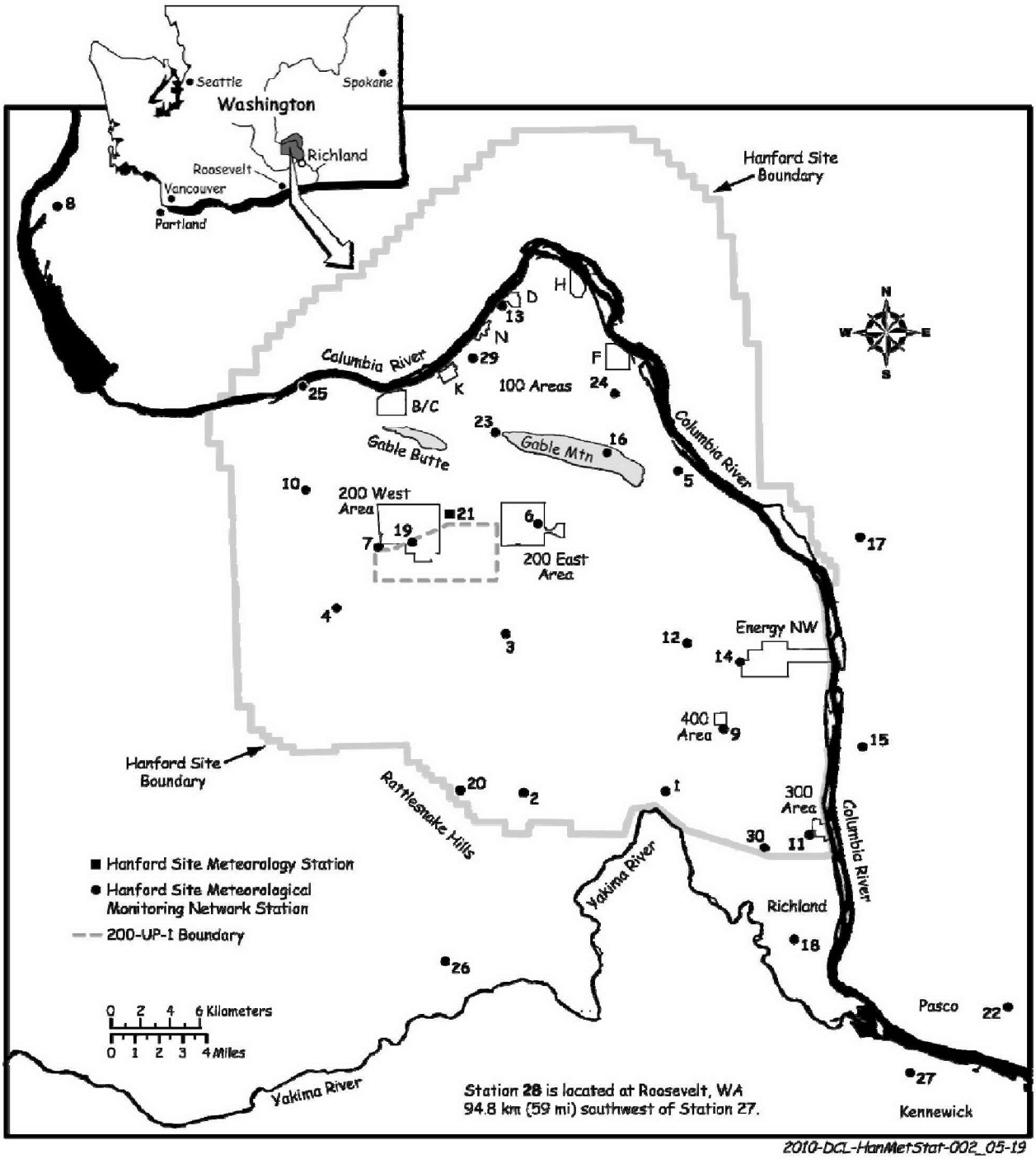

Figure 3-4. Hanford Meteorological Monitoring Network Location Map

3.2.1 Wind

The prevailing surface winds on Hanford's Central Plateau are from the northwest, and occur most frequently during the winter and summer. Winds from the southwest are also common on the Central Plateau (Figure 3-5).

The Cascade Mountains have a considerable effect on the wind regime at the Site by serving as a source of cold (more dense) air drainage. This gravity drainage results in a northwest to west-northwest prevailing wind direction. Between 1945 and 2004, monthly average wind speeds 15.2 m (50 ft) above the ground are lower during the winter months, averaging 2.7 to 3.1 m/s (6 to 7 mph), and faster during the spring and summer, averaging 3.6 to 4.0 m/s (8 to 9 mph). The fastest wind speeds at the HMS are usually associated with flow from the southwest; however, the summertime drainage winds from the northwest frequently exceed speeds of 13 m/s (30 mph). The maximum speed of the drainage winds (and their frequency of occurrence) tends to decrease moving toward the southeast across the Site. Surface features have less influence on winds aloft than on winds near the surface.

3.2.2 Temperature and Humidity

The average monthly temperatures at the HMS range from a low of -0.7°C (31°F) in January to a high of 24.7°C (76°F) in July, based on data collected from 1946 through 2004. Daily maximum temperatures at the HMS vary from an average of 2°C (35°F) in late December and early January to 36°C (96°F) in late July. On average, 52 days during the summer months have maximum temperatures greater than or equal to 32°C (90°F) and 12 days with maxima greater than or equal to 38°C (100°F). The largest number of consecutive days on record with maximum daily temperatures greater than or equal to 32°C (90°F) is 32 days. The record maximum temperature, 45°C (113°F) occurred at the HMS on July 23, 2006, July 13, 2002, and August 4, 1961.

From mid-November through early March, the average daily minimum temperature is below freezing; the daily minimum in late December and early January is -6°C (21°F). On average, the daily minimum temperature of less than or equal to -18°C (approximately 0°F) occurs only 3 days per year; however, only about one winter in two experiences such low temperatures. The annual average relative humidity at the HMS is 55 percent; it is highest during the winter months, averaging about 76 percent, and lowest during the summer, averaging about 36 percent.

3.2.3 Precipitation

Average annual precipitation at the HMS is 17 cm (6.8 in.). Most precipitation occurs during the late autumn and winter, with more than half of the annual amount occurring from November through February. Average snowfall ranges from 0.25 cm (0.1 in.) during October to a maximum of 13.2 cm (5.2 in.) during December, decreasing to 1.3 cm (0.5 in.) during March. Snowfall accounts for about 38 percent of all precipitation from December through February.

3.2.4 Fog and Visibility

Fog has been recorded during every month of the year at the HMS; however, 89 percent of the occurrences are from November through February. The average number of days per year with fog (visibility less than or equal to 9.6 km [6 mi]) is 48, while those with dense fog (visibility less than or equal to 0.4 km [0.25 mi]) number 25. Other phenomena causing restrictions to visibility (visibility less than 9.6 km [6 mi]) include dust, blowing dust, and smoke from field burning and naturally occurring wildfire in the region.

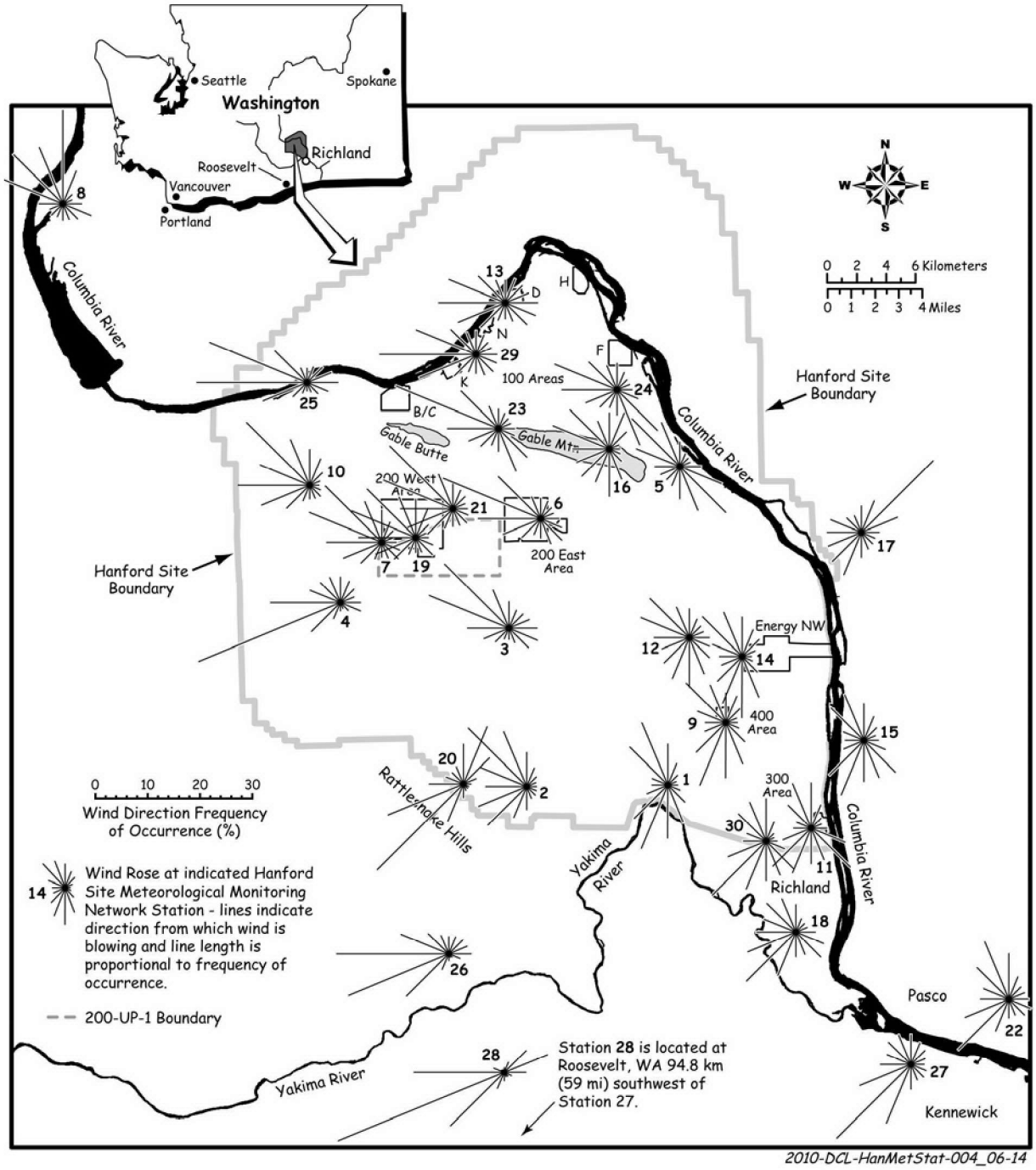

Figure 3-5. Wind Roses at the 9.1 m (30 ft) Level of the Hanford Meteorological Monitoring Network, Washington, 1982 Through 2006

3.2.5 Severe Weather

Concerns about severe weather usually center on hurricanes, tornadoes, and thunderstorms. Fortunately, Washington does not experience hurricanes and tornadoes are infrequent and generally small in the northwestern portion of the United States. In the counties closest to the Site, only 24 tornadoes have been recorded from 1950 through November 2004. Of these, 17 tornadoes had maximum wind speeds estimated to be in the range of 18 to 32 m/s (40 to 72 mph), four had maximum wind speeds in the range of 33 to 50 m/s (73 to 112 mph), and three had maximum wind speeds in the range of 51 to 71 m/s (113 to 157 mph). No deaths or substantial property damage (in excess of $50,000) were associated with any of these tornadoes. The estimated probability of a tornado striking a point on the Site is 9.6×10^{-6}/yr (NUREG/CR-4461).

The average occurrence of thunderstorms in the vicinity of the HMS is 10 per year. They are most frequent during the summer; however, they have occurred in every month. High-speed winds at the Site are more commonly associated with strong cold frontal passages. In rare cases, intense low-pressure systems can generate winds of near-hurricane force.

3.3 Surface Water Hydrology

Natural occurring surface water at the Site (Figure 3-6) includes the Columbia River, springs, and ponds. Intermittent surface streams, such as Cold Creek, may also contain water after large precipitation or snowmelt events. In addition, the Yakima River flows along a short section of the southern boundary of the Site and surface water associated with irrigation is located to the west, east, and north of the Site.

The Columbia River flows through the northern part and along the eastern border of the Site. Except for the Columbia River estuary, the only unimpounded stretch of the river in the United States is the Hanford Reach, which extends from Priest Rapids Dam (located upstream of the Site) downstream approximately 82 km (51 mi) to the northern upstream extent of Lake Wallula (formed by McNary Dam), which begins above Richland. The Hanford Reach of the Columbia River was recently incorporated into the land area established as the Hanford Reach National Monument.

River flow through the Hanford Reach fluctuates significantly and is controlled primarily by operations at upstream storage dams (Grand Coulee in the United States, and Mica and Keenleyside in Canada). Flows in the Hanford Reach are directly affected by releases from Priest Rapids Dam; however, Priest Rapids operates as a run-of-the-river dam rather than a storage dam. Flows are controlled to generate power and promote salmon egg and embryo survival. Several drains and intakes are also present along the Hanford Reach, including irrigation outfalls from the Columbia Basin Irrigation Project, Energy Northwest, and Site intakes for onsite water use. Much of the northern and eastern parts of the Site drain to the Columbia River.

The annual average flow of the Columbia River downstream of Priest Rapids Dam is estimated to be approximately 3,400 m^3 (120,000 ft^3) per second. In 2008, the Columbia River had below-normal flows; the average daily flow rate downstream of Priest Rapids Dam was 3,069 m^3 (108,400 ft^3) per second (PNNL-18427). As a result of fluctuation in discharges, the depth of the river varies significantly over time. The river stage (water-surface level) may change along the Hanford Reach by up to 3 m (10 ft) within a few hours. Seasonal changes of approximately the same magnitude are also observed. River-stage fluctuations measured at the 300 Area are approximately one-half the magnitude of those measured near the 100 Areas because of the effect of the pool behind McNary Dam (PNL-8580) and the relative distance of each area from Priest Rapids Dam. The width of the river varies from approximately 300 to 1,000 m (980 to 3,300 ft) as it passes through the Site.

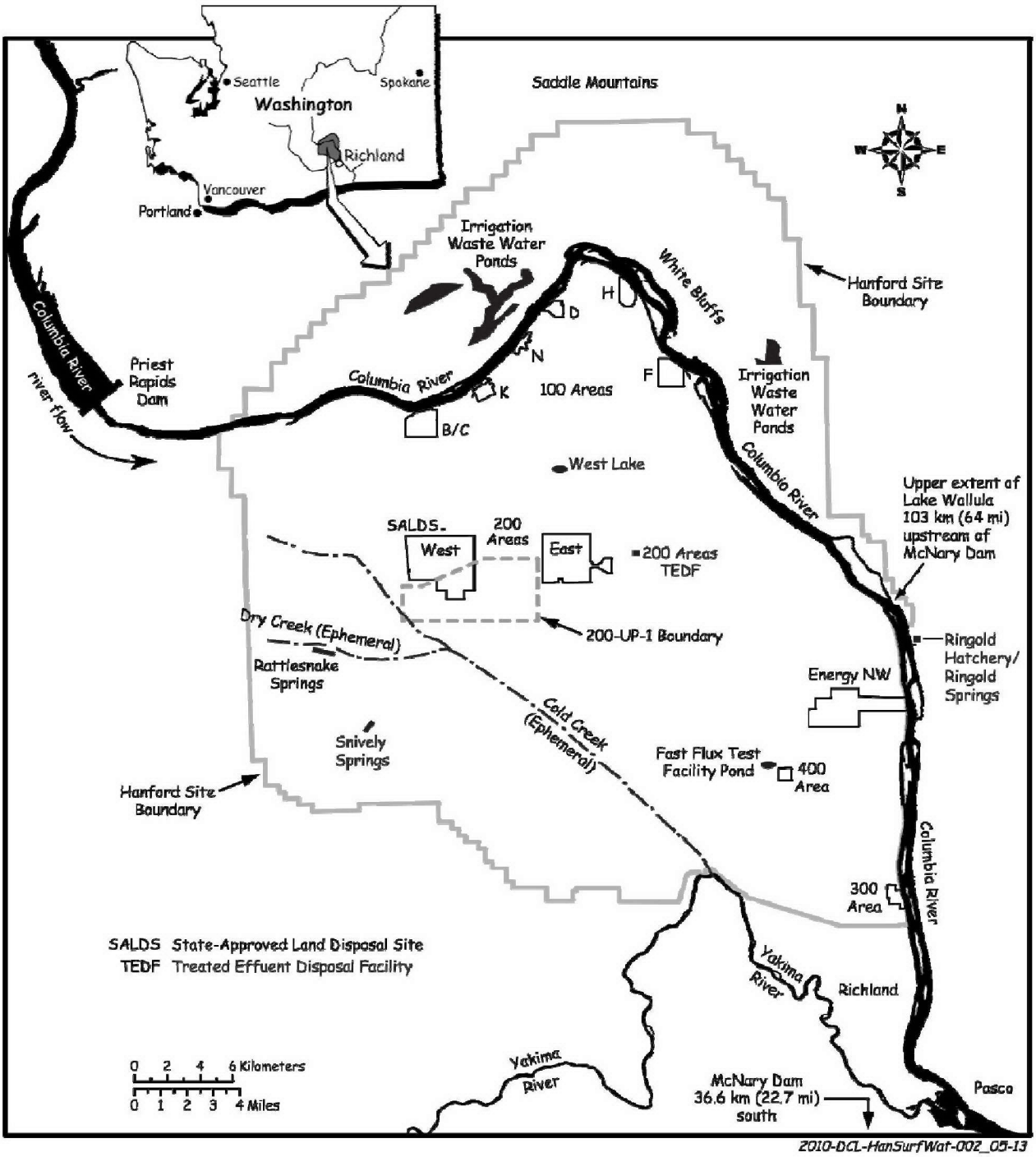

Figure 3-6. Surface Water Features of the Hanford Site (Modified from PNNL-6415)

Approximately one-third of the Site is drained by the Yakima River system. Cold Creek and its tributary, Dry Creek, are ephemeral streams on the Site that are within the Yakima River drainage system. Both streams drain areas along the western part of the Site and cross the southwestern part of the Site toward the Yakima River. Surface flow, which may occur during spring runoff or after heavier-than-normal precipitation, infiltrates and disappears into the surface sediments. Rattlesnake Springs, located on the western part of the Site, forms a small surface stream that flows for about 2.9 km (1.8 mi) before infiltrating into the ground.

Mean annual runoff from the Pasco Basin is estimated to be less than 3.1×10^7 m^3/yr (2.5×10^4 acre-ft/yr), or approximately 3 percent of the total precipitation. The remaining precipitation is assumed to be lost through evapotranspiration with a small component (perhaps less than 1 percent) recharging the groundwater system (DOE/RW-0164).

As a result of the arid climate and rapidly draining surface sediment, no surface drainage pattern has developed throughout the 200-UP-1 Groundwater OU. The OU is not in a designated floodplain, and calculations of probable maximum floods for the Columbia River indicate the 200-UP-1 Groundwater OU is not expected to be inundated under maximum flood conditions (RHO-BWI-C-120/PNL-4219).

Historical Site activities discharged contaminated effluent to liquid waste sites, which caused the groundwater table to rise on the Central Plateau (DOE/RL-2001-54) creating artificial ponds and wetlands. In 1995, these management practices ceased, eliminating all man-made wetlands, with the exception of a small wetland identified in the 200 East Area during the 2001 Ecological Compliance Assessment Program (ECAP) survey.

3.3.1 Water Quality of the Columbia River

The water quality of the Columbia River from Grand Coulee Dam to the Washington–Oregon border, which includes the Hanford Reach, has been designated as Class A, Excellent (WAC 173-201A) by Washington State (PNNL-14295). Class A waters are suitable for essentially all uses, including raw drinking water, recreation, and wildlife habitat. State and federal DWSs apply to the Columbia River.

In 2008, Columbia River water samples were collected from fixed-location monitoring stations at Priest Rapids Dam and in Richland, Washington, and from cross-river transects and near-shore locations near the Vernita Bridge, 100-N Area, 100-F Area, Hanford Townsite (within the 200-PO-1 Groundwater OU), 300 Area, and Richland. Columbia River water sample data show a statistical increase in concentrations of tritium, nitrate, uranium, and I-129 between samples taken upriver of the Site at the Vernita Bridge and below (downriver) the Site at the Richland Pump House (PNNL-18427). These constituents are known to be entering the river from contaminated groundwater beneath the Site.

Transect measurements for tritium showed higher concentrations near the shoreline relative to mid-river for samples from the 100-N Area and the Richland Pump House. The highest tritium concentration measured during 2005 in water samples from cross-river transects was 95 ± 9.5 pCi/L (3.5 ± 0.35 Bq/L), which was detected along the shoreline at the Richland Pump House (PNNL-18427). The federal DWS for tritium is 20,000 pCi/L. The highest total uranium concentration (1.5 ± 0.23 pCi/L [0.056 ± 0.0085 Bq/L] equivalent to approximately 4.46 μg/L natural uranium) was measured for the Richland transect at the southern boundary of the 300 Area on the Benton County shoreline (PNNL-18427). This concentration is well below the federal DWS for uranium (30 μg/L).

3.3.2 Yakima River

The Yakima River follows a portion of the southwestern boundary of the Site and has much lower flows than the Columbia River (Figure 3-6). The average flow, based on 70 years of daily flow records (USGS, 2005), is about 100 m^3/s (3,530 ft^3/s), with an average monthly maximum of 497 m^3/s (17,550 ft^3/s) and minimum of 4.6 m^3/s (165 ft^3/s). Average daily flow during 2006 was 100 m^3/s (3,530 ft^3/s) (USGS, 2007).

The Yakima River System drains surface runoff from approximately one-third of the Site. Groundwater is expected to flow from the Yakima River into the aquifer underlying the Site rather than from the aquifer into the river because, based on well water level measurements, the elevation of the river surface is higher than the adjacent water table (PNL-10195). Therefore, groundwater contaminants from the Site do not reach the Yakima River.

3.3.3 Springs and Streams

Springs are found on the slopes of Rattlesnake Hills (Figure 3-6) along the western edge of the Site (DOE/RW-0164). An alkaline spring is located at the east end of Umtanum Ridge (TNC, 1998). Rattlesnake and Snively Springs form small surface streams (Figure 3-6). Water discharged from Rattlesnake Springs flows in Dry Creek for about 3 km (1.6 mi) before disappearing into the ground. Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system in the southwestern portion of the Site. These streams drain areas to the west of the Site and cross the southwestern part of the Site toward the Yakima River. When surface flow occurs, it infiltrates rapidly and disappears into the surface sediments in the western part of the Site. The quality of water in these springs and streams varies depending on the source; they are upgradient of Hanford waste sites and groundwater contamination plumes.

3.3.4 Columbia Riverbank Springs

During the early 1980s, researchers identified 115 springs along the Benton County shoreline of the Hanford Reach (PNL-5289). Seepage occurs both below the river surface and on the exposed riverbank, particularly at low-river stage. Riverbank springs flow intermittently, apparently influenced primarily by changes in river level. In many areas, water flows from the river into the aquifer at high river stage and then returns to the river at low river stage. This "bank storage" phenomenon has been modeled numerically for the 100-H Area (PNNL-13674). In areas of contaminated groundwater, riverbank springs are also generally contaminated. The concentrations in seeping water along the riverbank may be lower than groundwater, however, the mixing between river water and the contaminated aquifer contributed to the fluctuating bank storage phenomenon.

Contamination historically has been detected in near-shore samples downstream from riverbank springs (PNNL-15892). Riverbank springs are monitored for radionuclides at each of the 100 Areas, the Hanford Townsite, and the 300 Area. Detected radionuclides include Sr-90, Tc-99, I-129, U-234, U-235, and U-238, and tritium, as well as arsenic, chromium, chloride, fluoride, nitrate, and sulfate.

Metals and anions (chloride, fluoride, nitrate, and sulfate) were detected in spring water from samples collected in 2005. Concentrations of volatile organic compounds (VOCs) were near or below their detection limits in all samples. TCE was detected (1.4 μg/L) in one sample from the 300 Area and was the only analyte detected at all shoreline spring sampling locations. TCE has been consistently detected at low concentrations in the 300 Area shoreline spring water (PNNL-15892).

3.3.5 Runoff and Net Infiltration

Total estimated precipitation over the Pasco Basin is about 9×10^8 m^3 (3.2×10^{10} ft^3) annually (DOE/RW-0164). Precipitation varies both spatially and temporally with higher amounts generally falling at higher elevations. Mean annual runoff from the Pasco Basin is estimated at 3.1×10^7 m^3/yr (1.1×10^9 ft^3/yr), or approximately 3 percent of the total precipitation (DOE/RW-0164). Most of the remaining precipitation is lost through evapotranspiration; however, a portion of the precipitation that infiltrates the soil eventually recharges the groundwater flow system. The amount of recharge varies spatially based primarily on soil texture and vegetation (Gee et al., 1992). Natural recharge also varies temporally with the majority occurring in the winter and spring. Some evidence exists that the most significant recharge events are associated with rapid melting of relatively large snowpacks, which may only occur a few times in a decade (PNNL-14744). Estimates of man-made (artificial) recharge to the area are discussed in Section 3.7.8 of this report.

3.3.6 Flooding

Although large Columbia River floods have occurred in the past (DOE/EIS-0113), the likelihood of recurrence of large-scale flooding has been reduced significantly by the construction of several flood control/water storage dams upstream of the Site. Major floods on the Columbia River are typically the result of rapid melting of the winter snowpack over a wide area augmented by above-normal precipitation. The exceptionally high runoff during the spring of 1996 resulted in a maximum discharge of nearly 11,750 m^3/s (415,000 ft^3/s) (USGS, 2007).

The probable maximum flood for the Columbia River downstream of Priest Rapids Dam has been calculated to be 40,000 m^3/s (1.4 million ft^3/s) and is greater than the 500-year flood. This flood would inundate parts of the 100 Area adjacent to the Columbia River, but the central portion of the Site would remain unaffected (DOE/RW-0070). The U.S. Army Corps of Engineers (USACE) has derived the Standard Project Flood with both regulated and unregulated peak discharges given for the Columbia River downstream of Priest Rapids Dam (USACE, 1989). The regulated Standard Project Flood for this part of the river is given as 15,200 m^3/s (54,000 ft^3/s) and the 100-year regulated flood as 12,400 m^3/s (440,000 ft^3/s) (DOE/RL-97-56). Impacts to the Site are negligible and would be less than the probable maximum flood.

The USACE evaluated a number of scenarios on the effects of failures of Grand Coulee Dam, assuming flow conditions of 11,000 m^3/s (400,000 ft^3/s). The discharge or flood wave resulting from an instantaneous 50 percent breach at the outfall of the Grand Coulee Dam was determined to be 600,000 m^3/s (21 million ft^3/s). In addition to the areas inundated by the probable maximum flood, the remainder of the 100 Area, the 300 Area, and nearly all of Richland would be flooded (DOE/RW-0070, RLO-76-4). The 50 percent scenario was believed to represent the largest realistically conceivable flow resulting from either a natural or human-induced breach (DOE/RW-0070). It was also assumed that a scenario such as the 50 percent breach would occur only as the result of direct explosive detonation, and not because of a natural event such as an earthquake, and that even a 50 percent breach under these conditions would indicate an emergency situation in which there might be other overriding major concerns.

Fewer than 20 major floods have occurred on the Yakima River since 1862 (DOE/RW-0070). The most severe occurred during November 1906, December 1933, May 1948, and February 1996; discharge magnitudes at Kiona, Washington, were 1,870 m^3/s (66,000 ft^3/s); 1,900 m^3/s (67,000 ft^3/s); 1,050 m^3/s (37,000 ft^3/s); and 1,300 m^3/s (45,900 ft^3/s); respectively. The average flow of the Yakima River is 104 m^3/s (3,665 ft^3/s), and the average monthly maximum is 490 m^3/s (17,500 ft^3/s). The recurrence intervals for the 1933 and 1948 floods are estimated at 170 and 33 years, respectively. The development

of irrigation reservoirs within the Yakima River Basin has considerably reduced the flood potential of the river. The southern border of the Site could be susceptible to a 100-year flood on the Yakima River.

During 1980, a flood risk analysis of Cold Creek was conducted as part of the characterization of a basaltic geologic repository for high-level radioactive waste. In lieu of 100- and 500-year floodplain studies, a probable maximum flood evaluation was performed based on a large rainfall or combined rainfall/snowmelt event in the Cold Creek and Dry Creek watershed (RHO-BWI-C-120/PNL-4219). The probable maximum flood discharge rate for the lower Cold Creek Valley was 2,265 m^3/s (80,000 ft^3/s) compared to 564 m^3/s (19,900 ft^3/s) for the 100-year flood. Modeling indicated that State Route 240, along the Site's southwestern and western areas would not be usable.

3.3.7 Non-Riverine Surface Water

Active ponds on the Site include West Lake, the SALDS, and the 200 Area Treated Effluent Disposal Facility (TEDF) disposal ponds (Figure 3-6). West Lake is north of the 200 East Area and is a natural feature recharged from groundwater (ARH-CD-775 and PNL-7662). West Lake has not received direct effluent discharges from Site facilities; rather, its existence is caused by the intersection of the elevated water table with the land surface in the topographically low area. Water levels of West Lake fluctuate with water table elevation, which is influenced by wastewater discharge in the 200 Areas. The water level and size of the lake has been decreasing over the past several years because of reduced wastewater discharge.

TEDF is east of the 200 East Area and consists of two disposal ponds. These ponds are each 0.02 km^2 (0.008 mi^2) in size and receive industrial wastewater permitted in accordance with WAC 173-216. The wastewater evaporates into the air or percolates into the ground from the disposal ponds.

Several naturally occurring vernal ponds are located near Gable Mountain and Gable Butte (TNC, 1998). The formation of these ponds in any particular year depends on the amount and temporal distribution of precipitation and snowmelt events. The vernal ponds range in size from about 20 ft × 20 ft to 150 ft × 100 ft (6.1 m × 6.1 m to 45.73 m × 30.5 m), and were found in three clusters. Approximately 10 were documented at the eastern end of Umtanum Ridge, 7 were observed in the central part of Gable Butte, and 3 were found at the eastern end of Gable Mountain.

3.4 Geology

The subsurface geology forms the framework that affects the locations of aquifers and the release and subsurface movement of contaminants and groundwater. The physiographic setting, stratigraphy, and geologic structure of the 200-UP-1 Groundwater OU are described in this section. Hydrostratigraphic cross sections and descriptions of unconsolidated sediments and basalt bedrock are included to describe the nature of the aquifer sediment and illustrate the lateral continuity and/or variations that occur across the 200-UP-1 Groundwater OU.

The geology of the Site has been extensively characterized as a result of various past investigation activities. These activities have included the siting of nuclear reactors (Washington Public Power Supply System [WPPSS], 1981 and Puget Sound Power and Light [PSPL], 1982), the site characterization efforts of the Basalt Waste Isolation Project (BWIP) (DOE/RW-0164), support for waste management operations (DOE/EIS-0113), and the recent environmental remediation activities.

Geologic and geophysical investigations within the 200-UP-1 Groundwater OU have included regional and Site surface mapping, borehole/well sediment logging, field and laboratory sediment classification, surface and borehole geophysical studies (including radiological borehole logging and various seismic and electromagnetic surveys), and in situ and laboratory hydrogeologic properties testing.

3.4.1 General Geologic Setting of the Operable Unit

The 200-UP-1 Groundwater OU is located in the central part of the Pasco Basin. Figure 3-3 presents a generalized structural geologic map of the Pasco Basin, showing the broad structural and topographic basin. Over the last 16 million years, the basin filled with materials that form bedrock (volcanic lava flows) and unconsolidated sediments (silt, sand, and gravel). Beneath the ground surface, major geologic units of interest (from oldest to youngest) include: (1) the Elephant Mountain Member basalt of the Saddle Mountains Basalt Fm and related interbeds within the Columbia River Basalt Group, (2) the Ringold Fm, (3) CCU, (4) the Hanford fm, and (5) Holocene surficial deposits.

Previous studies containing geologic interpretations and related maps and cross sections pertaining to the 200-UP-1 Groundwater OU include the 200 West AAMSR (DOE/RL-92-16) and the 200-PO-1 RFI (DOE/RL-95-100), which included cross sections from BHI-00184. The updated hydrogeology is based on the revised hydrogeology of the 200 West Area (PNNL-13858).

Unconsolidated and partly consolidated fluvial (river-derived), lacustrine (lake), and cataclysmic flood sediments of the Miocene through Holocene age (approximately 8.5 million years to the present) overlie the basalts. The 200-UP-1 Groundwater OU is focused on these sedimentary suprabasalt units above the basalt bedrock because this sediment contains the uppermost unconfined aquifer system within the region. Figure 3-7 presents a generalized stratigraphic column of the Site and the 200-UP-1 Groundwater OU.

3.4.2 Elephant Mountain Member Basalt

Basalt is an igneous rock ejected from the earth during volcanic events. The basalt flows of the Columbia River Basalt Group were deposited during Miocene time from source vents in southeastern Washington, northern Oregon, and western Idaho and form the basement for overlying sedimentary deposits (Figure 3-7). Beneath the 200-UP-1 Groundwater OU, the youngest and uppermost basalts present are members of the Saddle Mountains Basalt Fm (RHO-BWI-ST-4). The Saddle Mountains Basalt is divided into the Ice Harbor, Elephant Mountain, Pomona, Esquatzel, Asotin, Wilbur Creek, and Umatilla Members. The Elephant Mountain Member is the uppermost basalt unit and is approximately 35 m (115 ft) thick beneath most of the Site, except in the vicinity of the 300 Area, where the overlying Ice Harbor Member is present and forms the top of the Saddle Mountains Basalt. The Rattlesnake Ridge interbed of the Ellensburg Fm is present between the Elephant Mountain Member and the underlying Pomona Member and comprises the uppermost basalt confined aquifer beneath the 200-UP-1 Groundwater OU.

In the central portion of the Pasco Basin (200-UP-1), the Ellensburg Fm interbed ranges from 1.5 to 15 m (5 to 50 ft) in thickness and is composed of clayey basalt conglomerates, fluvial floodplain deposits, and ash tuffs and tuffites (RHO-RE-ST-12P).

Within the 200-UP-1 Groundwater OU, the basalt surface is interpreted as the basal hydrogeologic boundary for the overlying (suprabasalt) aquifer system that has been impacted by past Site liquid effluent disposal practices (Figure 3-7).

3.4.3 Suprabasalt Geology

Unconsolidated and partly consolidated sediments of the Miocene through Holocene (approximately 8.5 million years to the present) ages overlie the basalts (DOE/RL-95-100). The 200-UP-1 Groundwater OU RI/FS is focused on the suprabasalt sedimentary units because these sediments contain the vadose interval and uppermost unconfined aquifer system within the region. Figure 3-7 presents a generalized geologic column of the Site, including the 200-UP-1 Groundwater OU.

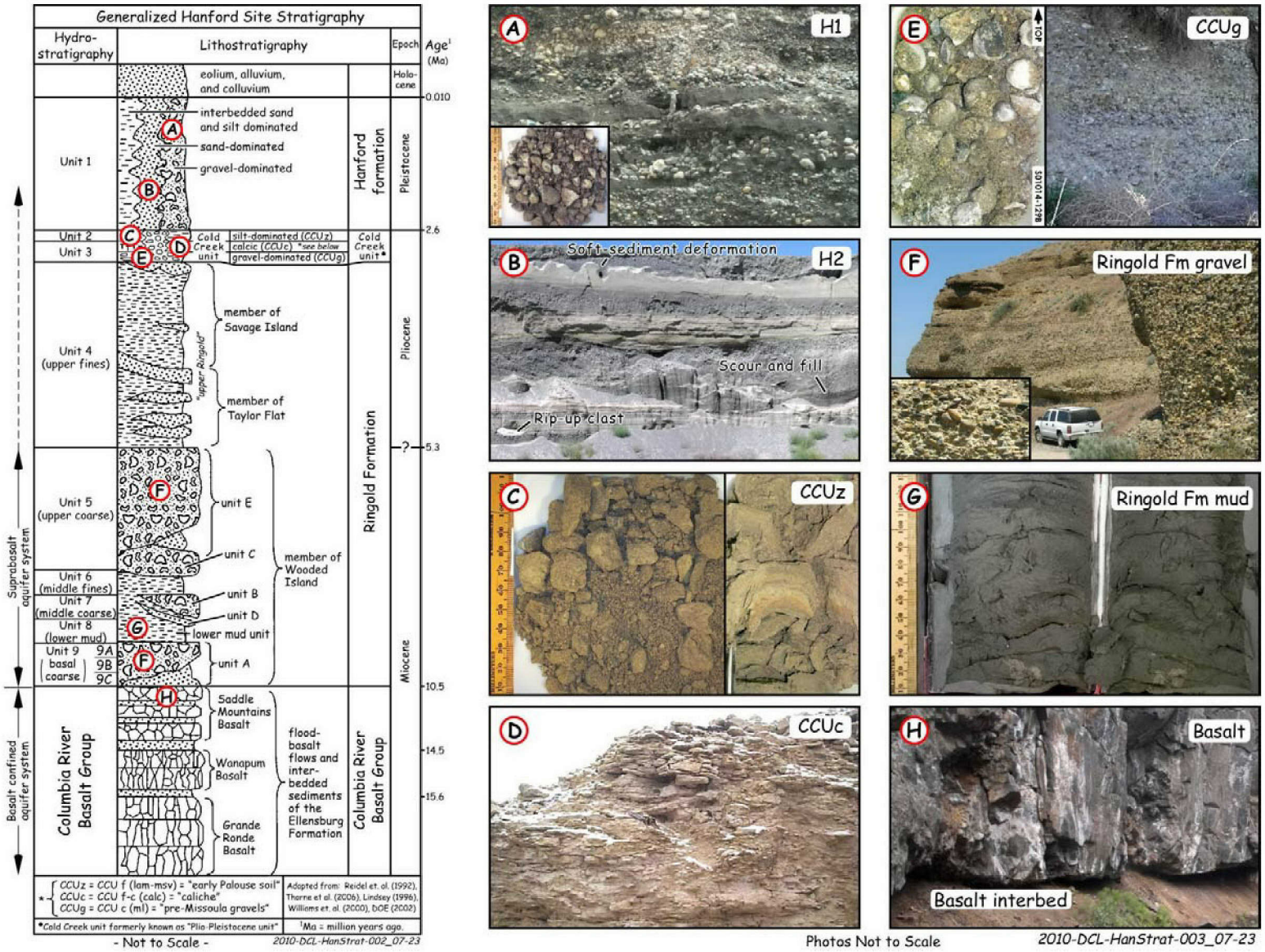

Figure 3-7. Generalized Stratigraphy of the Hanford Site Including the Central Plateau (PNNL-6415)

The geology of the suprabasalt sediments is well defined in the 200 East Area and 200 West Area due to characterization data obtained from many closely spaced wells across the Central Plateau. The suprabasalt sediments beneath the 200-UP-1 Groundwater OU are dominated by extensive fluvial and lacustrine deposits, assigned to the Miocene to Pliocene age Ringold Fm, which are deposited on top of the basalt surface. The Ringold Fm is overlain by the CCU (which includes the formerly named early Palouse soil), which is overlain with coarse-grained Pleistocene age paleo-flood deposits of the Hanford fm.

The suprabasalt sedimentary sequence ranges up to 215 m (700 ft) thick in the center of the basin and contains the uppermost unconfined aquifer, which controls groundwater contaminant migration across the 200-UP-1 Groundwater OU.

3.4.3.1 Ringold Formation

The Ringold Fm comprises the oldest suprabasalt sediment, is deposited unconformably on the basalt surface, and is the primary sequence of units making up the suprabasalt aquifer system (Figure 3-7). The Ringold Fm is a semi-consolidated to unconsolidated sedimentary sequence composed of fluvially deposited conglomeratic gravel-dominated units, designated as Units A, B/D, C, and E (from oldest to youngest). These high-energy deposits may be separated by fine-grained lacustrine and/or overbank deposits designated as the LMU, Ringold upper mud (RUM) unit, and upper Ringold unit. Within the 200-UP-1 Groundwater OU, only four Ringold Fm units are present (from oldest to youngest): the fluvial gravel unit A, LMU, fluvial gravel unit E, and upper Ringold unit. These geologic units have been designated in ascending order as hydrostratigraphic units (HSUs) 9, 8, 5, and 4, respectively (Figure 3-8). A detailed lithologic description of these units can be found in PNNL-13858 and is discussed further in Section 3.7.2.

Ringold Fm fluvial gravel unit A (HSU 9) directly overlies the Saddle Mountains Basalt (Figure 3-8) and displays a relatively flat surface that dips toward the axis of the Cold Creek syncline (south-southwesterly). Unit A ranges in thickness up to about 30 m (100 ft) beneath the OU. Cross sections (Figure 3-9 and Figure 3-10) depict the hydrogeology and general structural and depositional relationships of the Ringold Fm and overlying CCU and Hanford fm sediment. The Ringold Fm LMU (HSU 8) is a relatively thick, low-permeability fine-grained sequence of overbank, paleosol, and lacustrine silt and clay with minor sand and gravel (Figure 3-7 and Figure 3-8). Where the LMU (HSU 8) occurs below the water table, it forms a confining unit within the suprabasalt aquifer system, separating the lower saturated Ringold Fm unit A gravel (HSU 9) from the overlying saturated Ringold Fm unit E (HSU 5) (Figure 3-9 and Figure 3-10). Where the LMU is at or above the water table, it creates a relative aquitard—a no-flow groundwater boundary. The uppermost unconfined aquifer within the suprabasalt sedimentary sequence is contained within the geologic units overlying the LMU (Ringold Fm unit E), where it is present, or the top of basalt where the LMU is missing.

Well data suggest that the LMU is present beneath the entire 200-UP-1 Groundwater OU (Figure 3-9 and Figure 3-10). The LMU sequence thickens and dips to the south into the Cold Creek syncline, similar to the underlying Ringold unit A. The LMU sequence is very thin to absent through the very northernmost portion of the 200 West Area (within the 200-ZP-1 OU). The LMU sequence ranges in thickness from about 8 m (26 ft) to more than 26 m (85 ft) in the 200-UP-1 Groundwater OU. Northeast of the 200-UP-1 Groundwater OU near the 200 East Area boundary, well data suggest that a portion of the LMU is elevated at or above the water table, creating a hydraulic barrier to groundwater movement eastward out of the northern portion of the 200 West Area. The presence of the LMU near the water table in this area is believed to create a groundwater diversion, splitting groundwater (and any constrained contamination) into two main flow paths: one north to northeast near the Gable Gap (within 200-ZP-1 OU), and the other more easterly (within the 200-UP-1 OU).

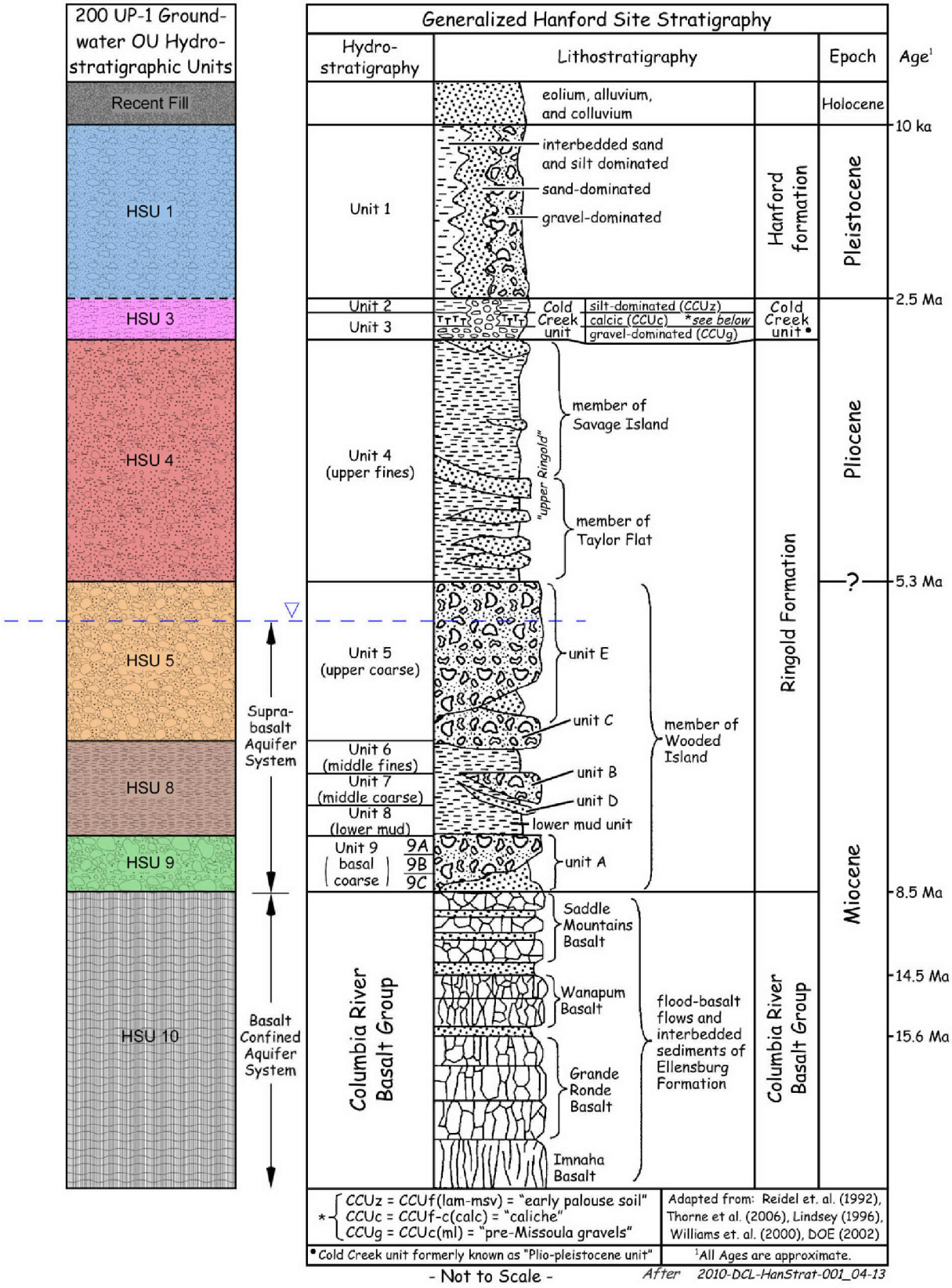

Figure 3-8. Hydrogeologic Nomenclature Comparison for the 200-UP-1 Groundwater Operable Unit

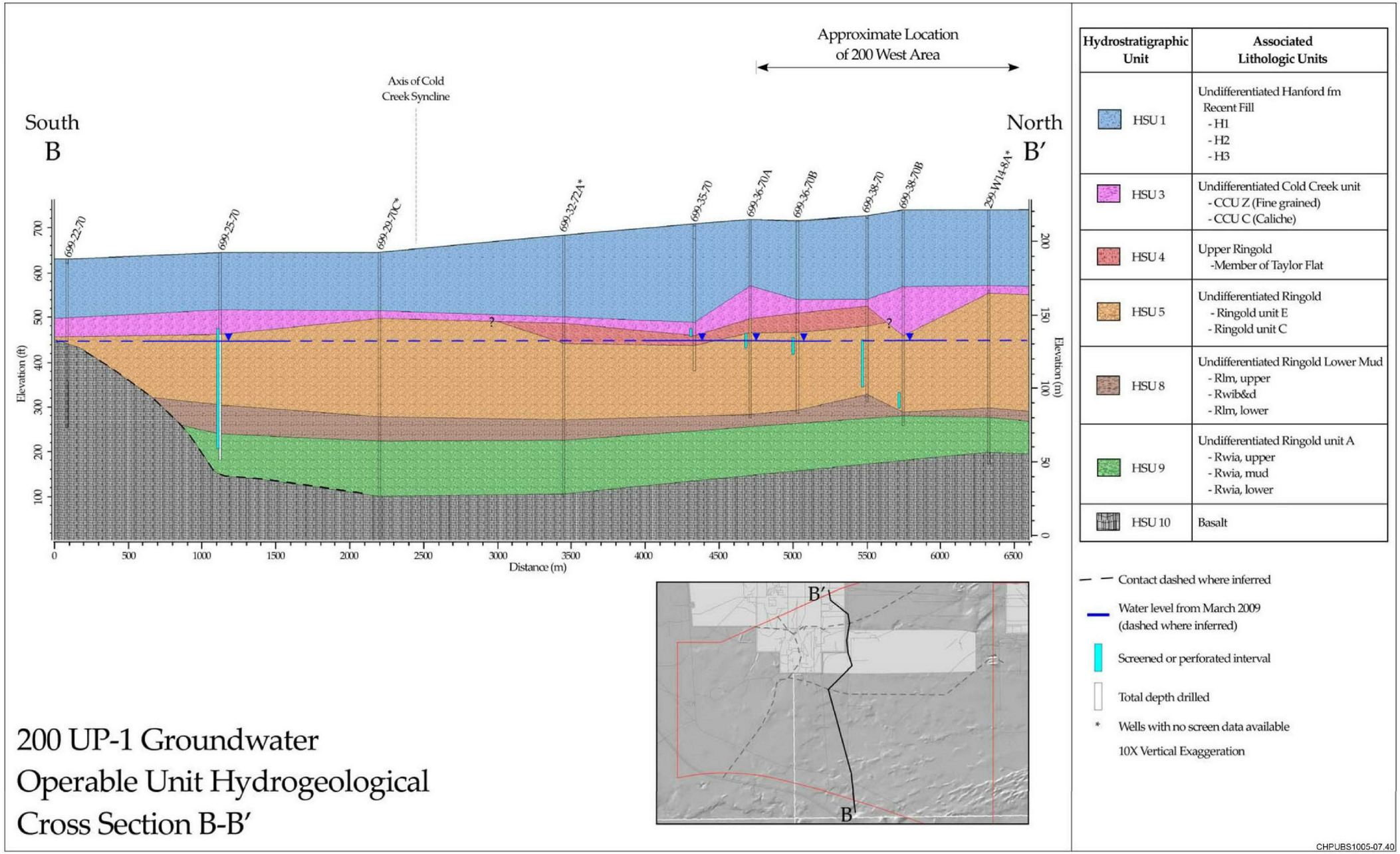

Figure 3-9. Cross Section B-B' Illustrating Hydrogeology Beneath the 200-UP-1 Groundwater Operable Unit

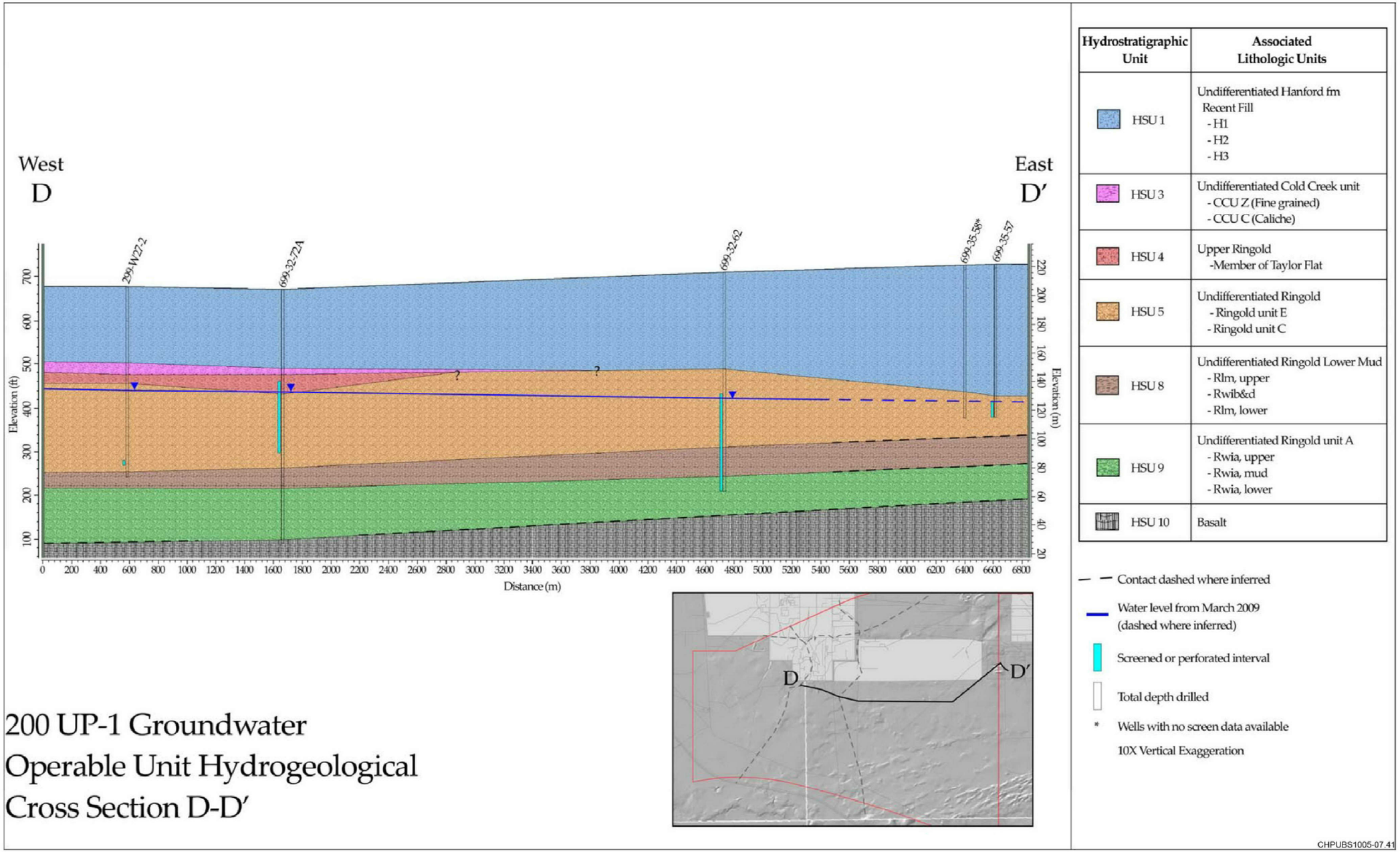

Figure 3-10. Cross Section D-D' Illustrating Hydrogeology Beneath the 200-UP-1 Groundwater Operable Unit

Within the 200 West Area, including the 200-UP-1 Groundwater OU, the Ringold Fm unit E (HSU 5) is the uppermost geologic unit within the unconfined aquifer and is composed of fluvial silty, sandy gravel. Ringold Fm unit E overlies the LMU (Figure 3-7 and Figure 3-8). The Ringold Fm unit E is present throughout the OU (Figure 3-9 and Figure 3-10). Most known contaminant plumes that emanate from the 200 West Area migrate eastward through this unit and into the adjacent and overlying Hanford fm sediment near the 200 East Area erosional truncation (Figure 3-11). The Ringold Fm unit E is thickest near the southwestern portion of the 200-UP-1 Groundwater OU and gradually thins to the east until it is truncated within the 200 East Area (Figure 3-11). The Ringold Fm unit E ranges in thickness to more than 90 m (295 ft) (PNNL-13858) near the western margin of the 200-UP-1 Groundwater OU.

Regional Miocene-Pliocene age basalt uplift along the Umtanum-Gable structural axis and the subsequent depositional thinning and/or paleo-flood erosion have created a sequence of uplifted Ringold sediment within the east-northeastern 200-UP-1 Groundwater OU that results in older and presumably less-permeable sediment comprising the uppermost aquifer at the downgradient margin of the OU (Figure 3-10 and Figure 3-11). Therefore, groundwater flowing eastward, and downgradient across the 200-UP-1 Groundwater OU, moves through older and older sediment until it emerges at the erosional boundary within the 200 East Area. The reduced hydraulic conductivity of the older units, as well as the reduction in the aquifer's thickness due to the uplifted sediment (HSU 8), causes restrictions in groundwater flow including contaminant movement. These conditions are manifested by the historical increase in water table elevation and gradient in the lower permeable Ringold age sediments and the abrupt steepening (elevation drop) in the water table gradient in the region where saturated younger, more-permeable sediment (Cold Creek and/or Hanford fm) occupies the uppermost aquifer interval (near the 200 East Area) (Figure 3-11 and Figure 3-12).

The Ringold Fm unit E (HSU 5) grades upward into interbedded fluvial sand and silt of the overlying upper Ringold unit (HSU 4). The upper Ringold unit (HSU 4) is located within the vadose zone and is only locally present in the 200-UP-1 Groundwater OU. Detailed descriptions of this unit are provided in BHI-00184 and BHI-01311.

3.5 Cold Creek Unit

The CCU (HSU 3) includes several post-Ringold Fm and pre-Hanford fm units present beneath portions of the 200 East and West Areas (DOE/RL-2002-39). The CCU includes the sediments formerly identified as the Plio-Pleistocene unit, caliche, early Palouse soil, pre-Missoula gravels, and side stream alluvial facies in previous site reports. Beneath the 200 West area, the CCU comprises fluvial, eolian (wind derived), and paleosol (soil) deposits that are divided into two separate units designated the lower caliche unit (CCU_c or Unit 3) and the overlying silt unit (former early Palouse soil) (CCU_z or Unit 2) (Figure 3-7). The Caliche layer formed during subareal exposure of the upper portions of the underlying sediment (Ringold Fm unit E and/or the upper Ringold unit) and extended into overlying CCU_z sediment. The CCU_c caliche deposit is composed of precipitated calcium carbonate that accumulated in available pore spaces between sediment grains (sand, silt, and/or gravel). The caliche forms a secondary mineral coating or cement that binds the sediment grains together, forming one or more "hardpan" layers. The stratigraphic location and amount of calcium carbonate cement are variable, so the physical properties of this unit vary from "soil-like" to "rock-like." For the purpose of this report, these two intervals (Unit 2 and Unit 3) are grouped together on cross sections, maps, and model layers and designated as HSU 3 (Figure 3-8).

The CCU is present only in the vadose zone beneath the 200 West Area (Figure 3-9 and Figure 3-11) and is an important unit because these cemented deposits are extensive, relatively impermeable, deeply buried, and impede and/or perch the downward migration of liquid and contaminants in the vadose zone beneath the waste sites. These two CCU intervals (CCU_c and CCU_z) are absent beneath the 200 East Area (Figure 3-11) because of nondeposition and/or Pleistocene-aged cataclysmic flood erosion subsequent to deposition.

3.5.1 Hanford Formation

The Hanford fm (HSU 1) is the informal stratigraphic name given to the Pleistocene cataclysmic flood deposits in the Pasco Basin (DOE/RL-2002-39). The cataclysmic floodwaters eroded and/or reworked much of the pre-existing Ringold Fm and CCU sediment across the Gable Gap area and unconformably deposited sediments of the Hanford fm, locally reshaping the topography of the Pasco Basin (Figure 3-3). The floodwaters deposited a thick sand and gravel bar (Cold Creek Bar) that constitutes the Central Plateau and includes the 200-UP-1 Groundwater OU. Remnant erosional channels, preserved during the waning stages of the paleo-floods, remain north of the 200 Areas in the area currently occupied by West Lake and the former Gable Mountain Pond.

The Hanford fm (Figure 3-7) consists predominantly of unconsolidated sediments that range from boulder-size gravel to sand, silty sand, and silt. The sorting ranges from poorly sorted (for gravel facies) to well sorted (for fine sand and silt facies). The Hanford fm is divided into three main facies associations: interbedded sand- to silt-dominated (formerly called the Touchet beds or slack water facies), sand-dominated (formerly called the sand-dominated flood facies), and gravel-dominated (formerly called the Pasco gravels) (DOE/RL-2002-39). These units vary vertically and laterally across the region and are difficult to correlate. The gravel-dominated facies are cross-stratified, coarse-grained sands and granule-to-boulder gravel. The gravel is uncemented and matrix-poor. The sand-dominated facies are well-stratified fine- to coarse-grained sand and granule gravel. Silt in these facies is variable and may be interbedded with sand. Where the sand and silt content is low in the gravel-dominated facies, an open-framework texture is common. The Hanford fm sediment exhibits extremely high permeability and hydraulic conductivity.

Beneath the 200-UP-1 Groundwater OU, the Hanford fm sediments were deposited on the older Cold Creek and/or Ringold units (unit E, LMU, and unit A) and may comprise the uppermost portion of the unconfined aquifer at the very eastern margins of the OU (Figure 3-11). Within the 200 West Area, the Hanford fm overlies the CCU_z and is entirely within the vadose zone (Figure 3-11).

The Hanford fm is important because it is the thickest geologic unit (comprising most of the vadose zone thickness) and lies directly beneath the waste sites through which contamination passed to reach the CCU and groundwater.

Clastic dikes are common discontinuities in the Hanford fm but are rare in the Ringold Fm (DOE/RL-98-28; DOE/RL-2002-39). They normally appear as crosscutting, vertically oriented cracks, or fissures that are filled with sand, silt, clay, and minor coarser debris (Figure 3-13). Their origin is likely associated with natural hydraulic injection during or immediately following Pleistocene cataclysmic flooding, mass wasting, earthquakes, and other geologic processes. Clastic dikes occurring in vadose zone sediments have the potential to influence soil moisture and contaminant movement (BHI-01103). No data exist regarding the potential influence of clastic dikes within the aquifer.

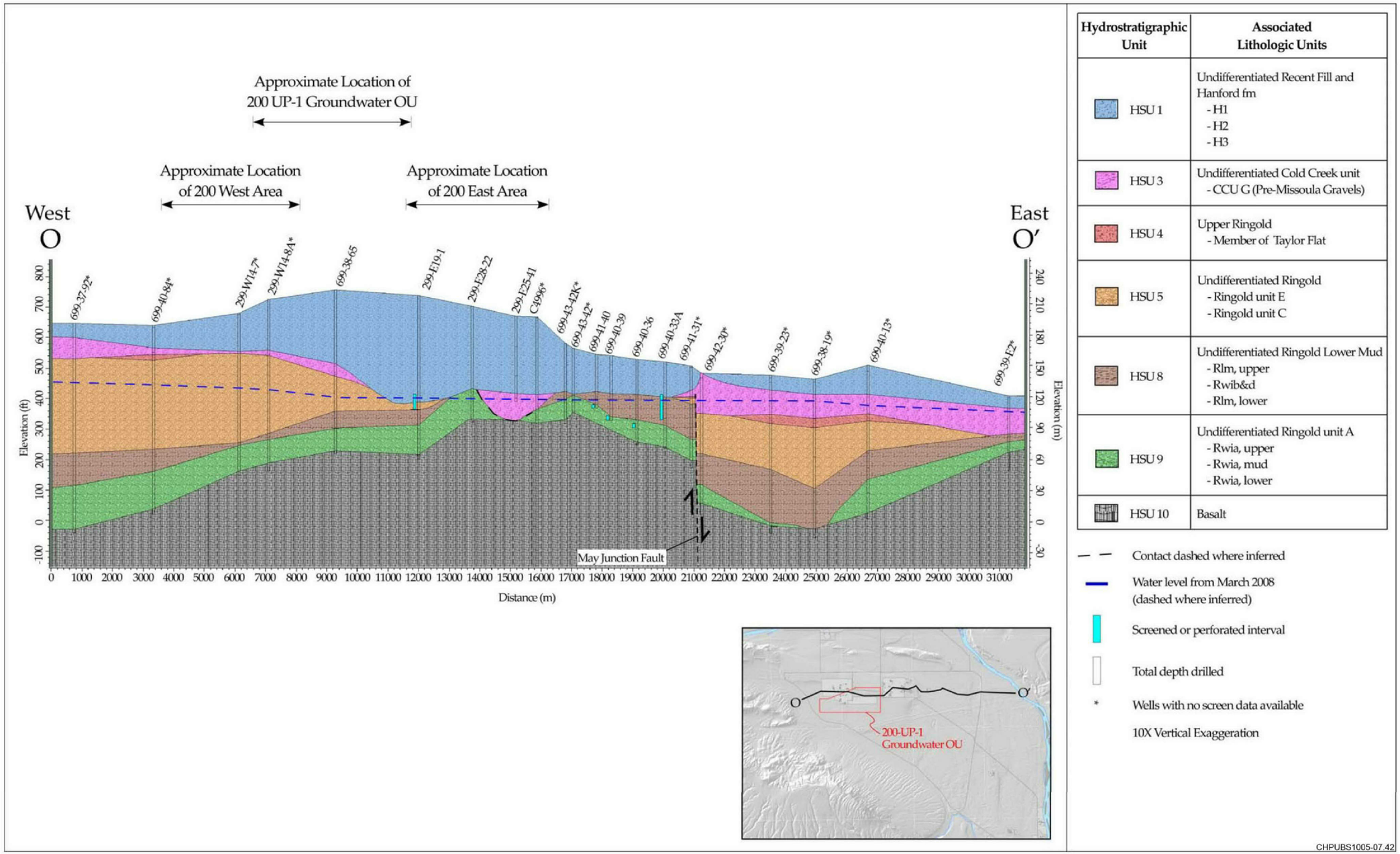

Figure 3-11. Hydrogeology Across the Central Plateau Illustrating Various Aquifer Boundaries

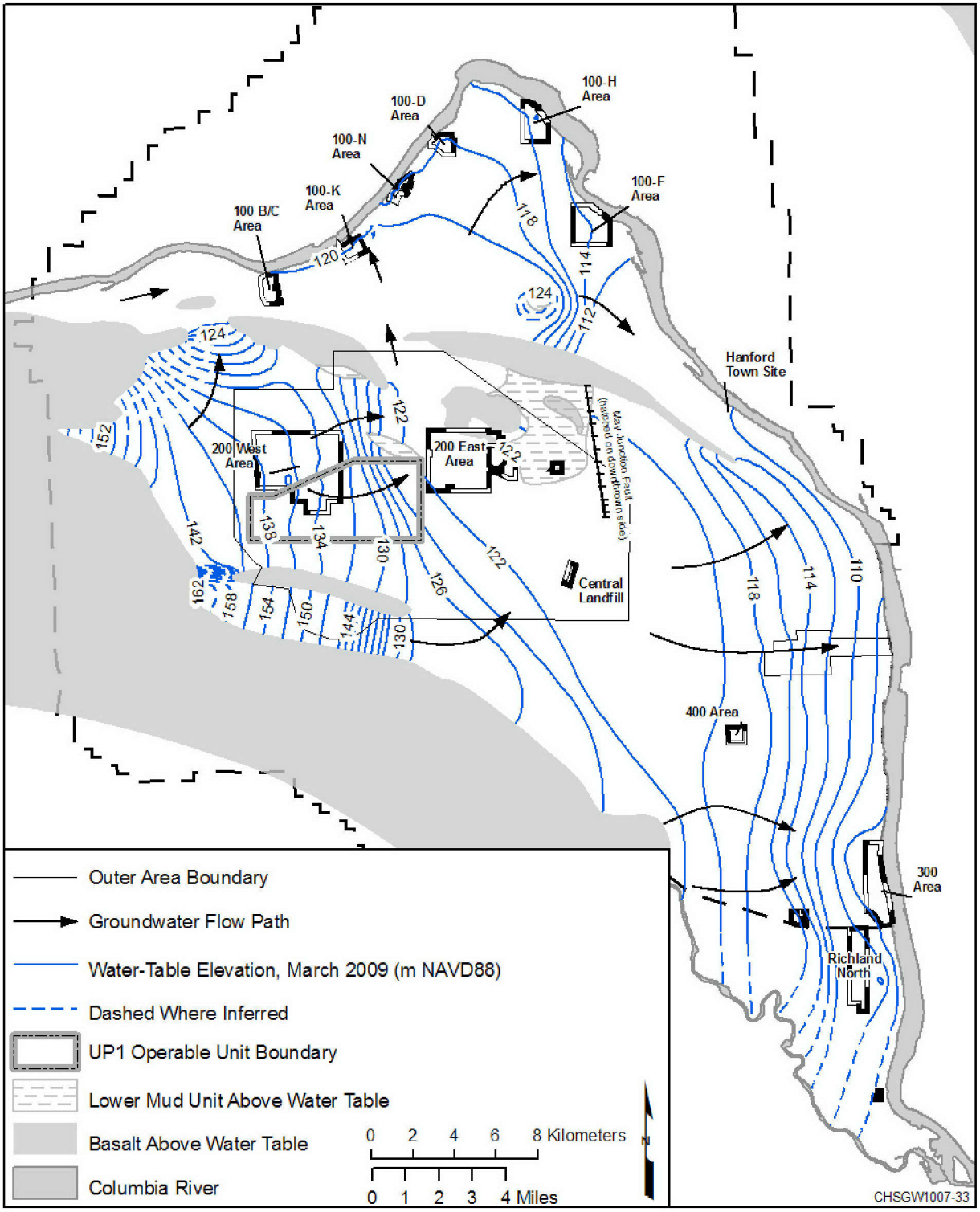

Figure 3-12. Hanford Site Groundwater Elevations and Flow Patterns (DOE/RL-2008-66)

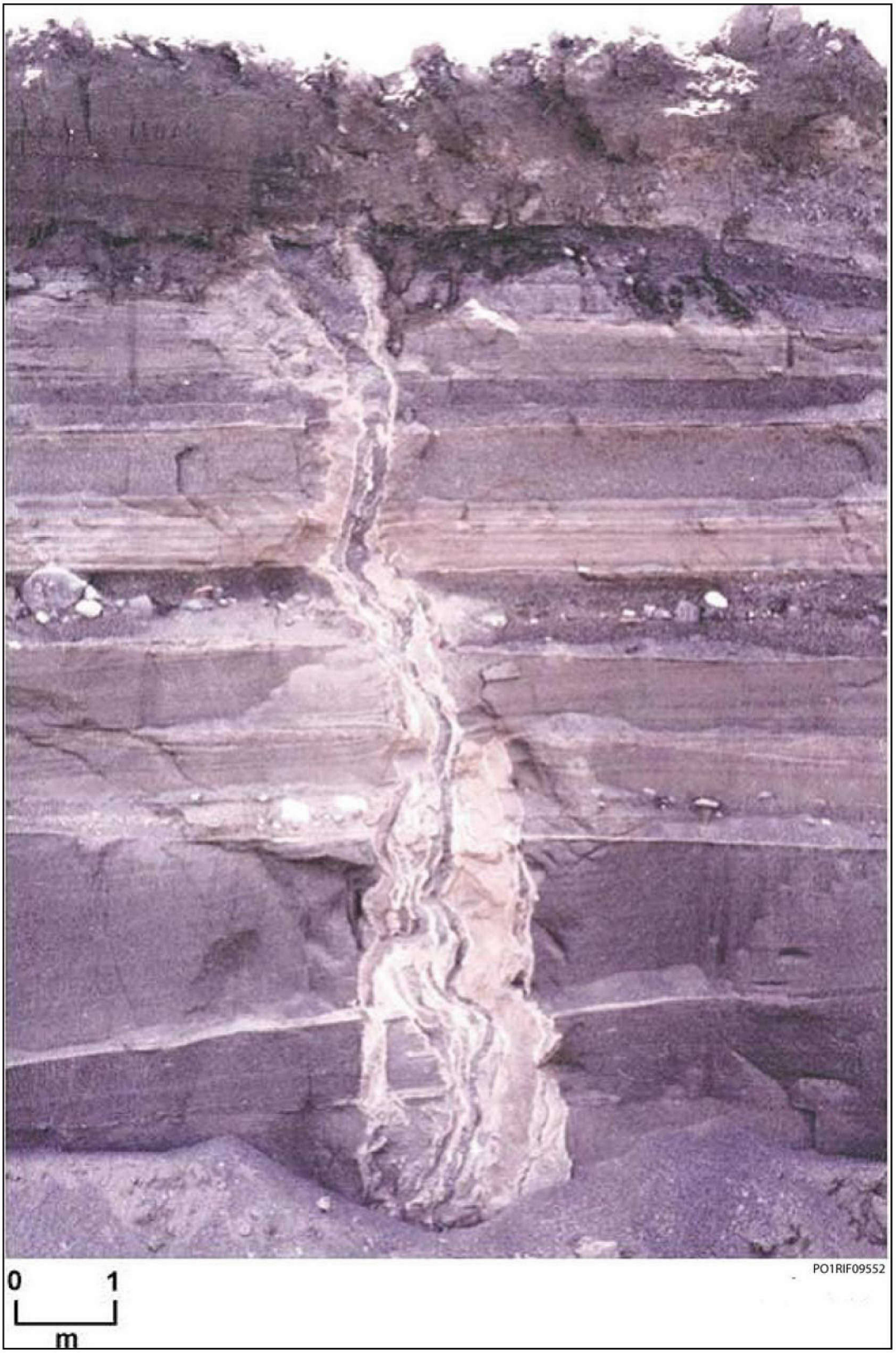

Figure 3-13. Clastic Dike in the Hanford Formation

3.5.2 Holocene Surficial Deposits

Recently deposited surficial deposits that mostly comprise eolian (windblown) silt and sand overly the Hanford fm. Only about 6 percent of Site land has been disturbed or is actively used by DOE for waste disposal and storage. Most of the land area is relatively undisturbed, due to the long-standing management practices of DOE. However, these deposits were removed and/or reworked extensively over much of the 200 Area by construction activities.

3.6 Soils

Groundwater OUs at the Site are administratively separated from vadose zone OUs where contaminant sources are located. This RI Report discusses groundwater in the saturated zone of the 200-UP-1 Groundwater OU. The unconsolidated sediments of the vadose zone that overlie the 200-UP-1 Goundwater OU saturated zone are addressed in detail in documents for the overlying source OUs.

3.7 Hydrogeology

Groundwater migration is the primary contaminant transport pathway for this OU. Because the groundwater OUs at the Site are administratively segregated from the overlying source OUs, including related vadose zone contamination, this hydrogeologic discussion is focused primarily on the aquifer system(s).

3.7.1 Summary of Aquifer Systems in the 200-UP-1 Groundwater Operable Unit

This section describes the hydrostratigraphic and groundwater flow characteristics of the 200-UP-1 Groundwater OU; specifically, the confined basalt aquifers, semi-confined to unconfined suprabasalt aquifer system, and overlying vadose zone. Groundwater contamination moves within the uppermost (suprabasalt) aquifer system within the 200-UP-1 Groundwater OU. The suprabasalt aquifer system beneath the Site, generally is unconfined to semi-confined, depending on depth below the water table. This aquifer system is located within the unconsolidated to indurated sand and gravel that may include the Hanford fm, CCU, and Ringold Fm, which overlie basalt bedrock. In some areas, layers of silt and clay confine and separate portions of the suprabasalt aquifer. In the 200-UP-1 Groundwater OU, the suprabasalt aquifer system is almost entirely within Ringold Fm sediment (Figure 3-8).

Confined aquifers occur within the underlying basalt flows and their sedimentary interbeds. These interbed aquifers are confined by the overlying competent basalt layer(s) and the Ringold Fm LMU where this unit is directly on top of basalt (300 Area).

The vadose zone overlying the 200-UP-1 Groundwater OU is composed primarily of laterally discontinuous, highly permeable Hanford fm sediment, the CCU, the upper Ringold, and upper portions of the Ringold Fm unit E.

Groundwater beneath the Site flows primarily from recharge areas along the elevated western and southwestern margins of the Site to the east and north toward the Columbia River (watershed sink). Groundwater flow patterns historically were modified by groundwater mounds created by the discharge of large volumes of process water from Site activities (Figure 3-14). The water table near the former U Pond, located within the 200 West Area, increased to more than 18 m (59 ft) above background conditions during the 1960s and 1970s. Because large discharges no longer occur at most of the liquid waste disposal sites, the water table in the impacted areas is returning to pre-Hanford conditions (DOE/RL-97-36, Rev. 3). Within the 200-UP-1 Groundwater OU, the 200 West Area recharge mound is dropping, leaving many monitoring wells dry, and changing groundwater flow patterns and gradients across the Central Plateau. Subsequently, the water table in the 200 West Area has a relatively lower gradient than during years of peak liquid disposal/discharge to ground.

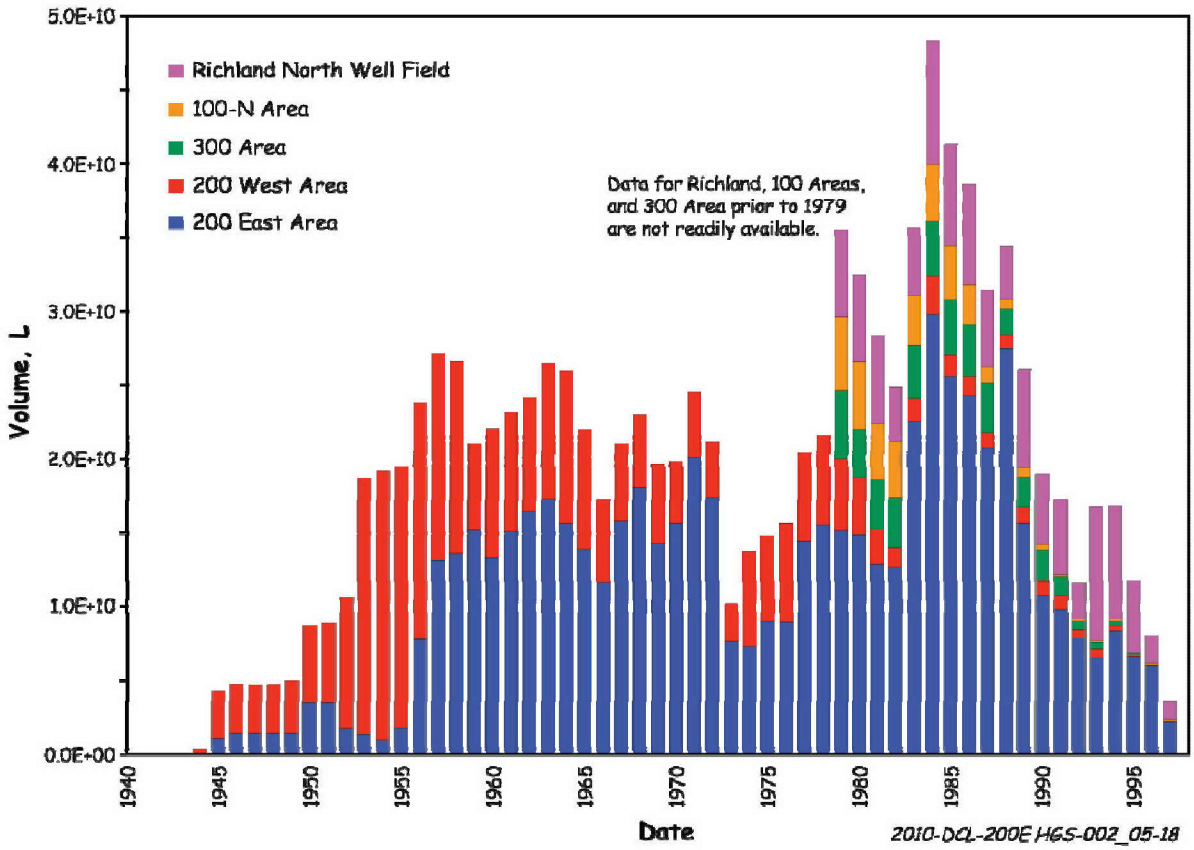

Figure 3-14. Liquid Effluent Disposal Activities Across the Hanford Site

Within the 200-UP-1 Groundwater OU, the water table still remains several meters above pre-Hanford conditions (Figure 3-12). Limited permitted effluent releases still occur at the 200 Area SALDS located north of the 200 West Area within the adjacent 200-ZP-1 OU. In addition, injection wells operating as part of the 200-ZP-1 OU P&T system to remove carbon tetrachloride and other contaminants via groundwater extraction are also locally impacting groundwater conditions within the 200-ZP-1 OU and the northern part of the 200-UP-1 Groundwater OU. For instance, there is some drawdown of water levels at WMA U due to the 200-ZP-1 groundwater extraction wells, but the flow direction is not appreciably affected. The 200-ZP-1 P&T system is undergoing a substantial expansion. It is expected that this will affect groundwater and contaminant migration across the northern portion of the 200-UP-1 Groundwater OU in the future.

3.7.2 200-UP-1 Groundwater OU Hydrostratigraphy

Within the 200-UP-1 Groundwater OU, the geologic units that form the hydrogeologic framework for the area are re-defined as HSUs, which are used to facilitate groundwater modeling and contaminant F&T modeling. In some cases, the geologic units may be combined based on similarities in hydraulic properties or in areas where uncertainty exists about the correlation and extent of the geologic units. The primary HSUs defined within the 200-UP-1 Groundwater OU are, from oldest to youngest (Figure 3-8), defined as follows:

- **Columbia River Basalt** – The Rattlesnake Ridge interbed and deeper interbeds of the Ellensburg Fm, which form confined aquifer flow zones (HSU 10). HSU 10 also includes the Elephant Mountain

Member basalt and deeper lava flows of the Saddle Mountains Basalt, which form the basalt-confining horizons. Locally these basalts may contain fractured interflow zones.

- **Ringold Fm** – From oldest to youngest, Ringold Fm unit A (HSU 9) is a silty, sandy gravel, which contains locally confined to unconfined aquifer flow zones and directly overlies HSU 10. HSU 9 is confined and separated by the Ringold Fm LMU (or HSU 8) from the overlying Ringold Fm unit E (HSU 5) that makes up most of the unconfined suprabasalt aquifer system. The upper Ringold unit (HSU 4), located within the vadose zone, overlies HSU 5.
- **CCU (HSU 3)** – This unit is only present in the vadose zone, within the boundary of the 200-UP-1 Groundwater OU. It is undifferentiated and defined as a combination of HSU 2 and HSU 3 (Figure 3-7).
- **Hanford fm (HSU 1)** – The Hanford fm unconsolidated silt, sand, and gravel (HSU 1) is present only in the vadose zone except near the very eastern, downgradient boundary of the OU where HSU 1 represents a highly permeable, unconfined aquifer flow zone when saturated.

3.7.3 Basalt Aquifers

Several regional confined aquifers exist within the Saddle Mountains Basalt-Ellensburg Fm HSU 10 in the 200-UP-1 Groundwater OU. The confined water-bearing zones occur in the sedimentary interbeds of the Ellensburg Fm and in interflow and fractured intraflow intervals within the basalts. The uppermost regional confined aquifer in the vicinity is generally within the Rattlesnake-Ridge interbed (Ellensburg Fm), but may also include the fractured flow top and bottom of the enclosing basalt flows.

The upper basalt-confining unit within the 200-UP-1 Groundwater OU is the Elephant Mountain basalt. Within the neighboring 200-PO-1 Groundwater OU, wells monitoring the basalt-confined aquifers indicate an upward hydraulic head; however, monitoring of wells within the confined aquifer beneath the 200-UP-1 Groundwater OU reflects a generally downward hydraulic head (Figure 3-15). Based on groundwater chemistry results and separation from contaminated groundwater by the overlying lower-permeability HSU 8, it is unlikely that contamination occurring in the suprabasalt aquifer system beneath the 200-UP-1 Groundwater OU has migrated down into these basalt-confined aquifers or has significantly impacted these confined aquifers. Figure 3-16 shows a potentiometric surface map of the basalt confined aquifer (Rattlesnake-Ridge Interbed). Groundwater flow within the HSU 10 confined aquifer generally moves to the east-northeast beneath the OU.

3.7.4 Suprabasalt Aquifer System

The suprabasalt aquifer system comprises the uppermost aquifer system in the 200-UP-1 Groundwater OU. This aquifer system is defined primarily by two intervals: the uppermost unconfined interval contained within HSU 5 and the deeper semi-confined to confined interval within the basal Ringold HSU 9. These two aquifer intervals are separated and isolated within the 200-UP-1 Groundwater OU by the Ringold Fm LMU (HSU 8) confining unit. HSU 5 and HSU 9 are composed of semi-indurated and partially cemented silty sandy gravel.

The depth to the uppermost unconfined aquifer (the thickness of the vadose zone) ranges from approximately 53 m (175 ft) within the 200 West source area, to more than 106.7 m (300 ft) near the southeastern boundary of the 200-UP-1 Groundwater OU. This variation in vadose zone thickness reflects the relative relief of the large paleo-flood deposited Cold Creek Bar that forms the elevated Central Plateau.

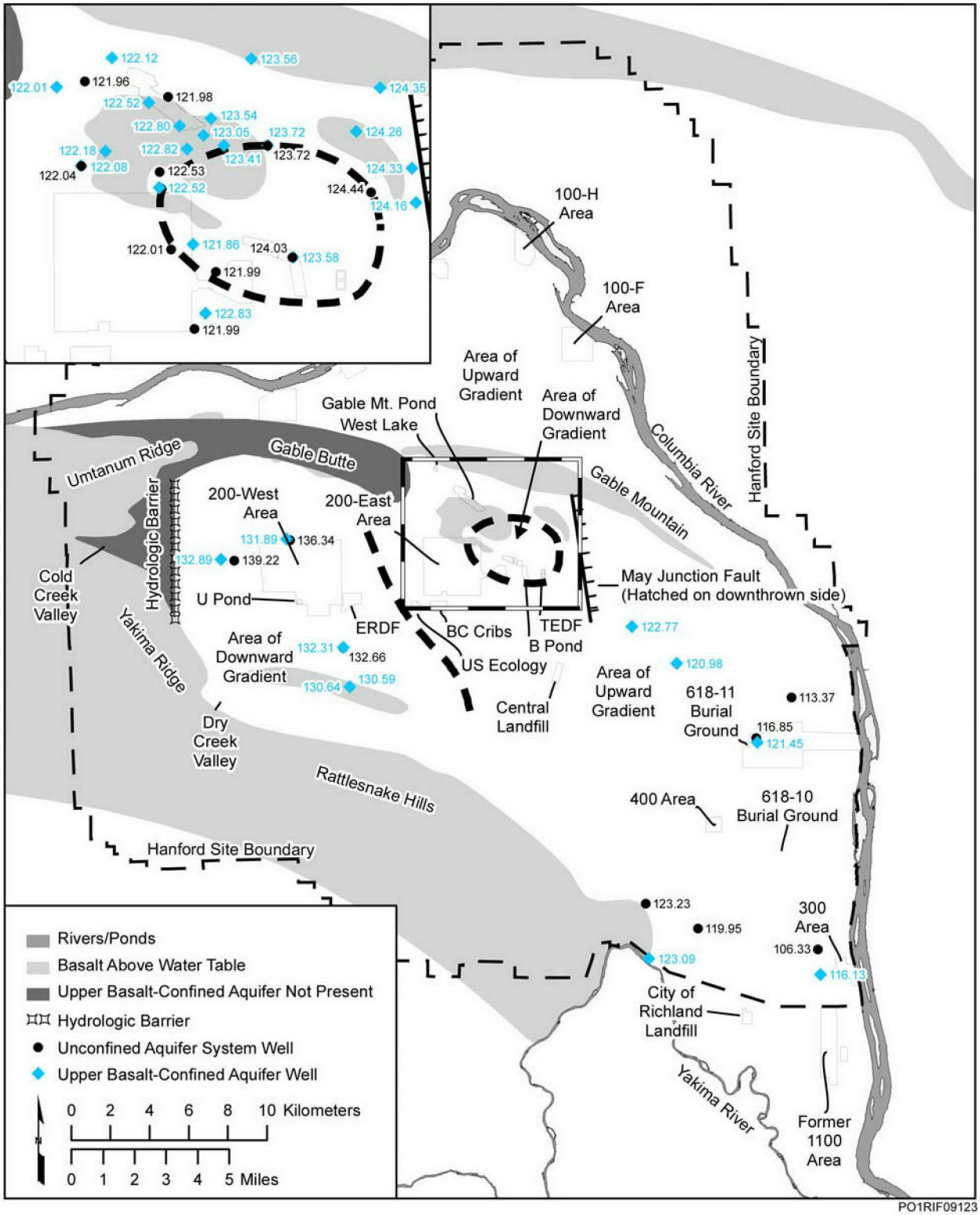

Figure 3-15. Head Differences Between the Unconfined and Basalt Confined Aquifer Systems

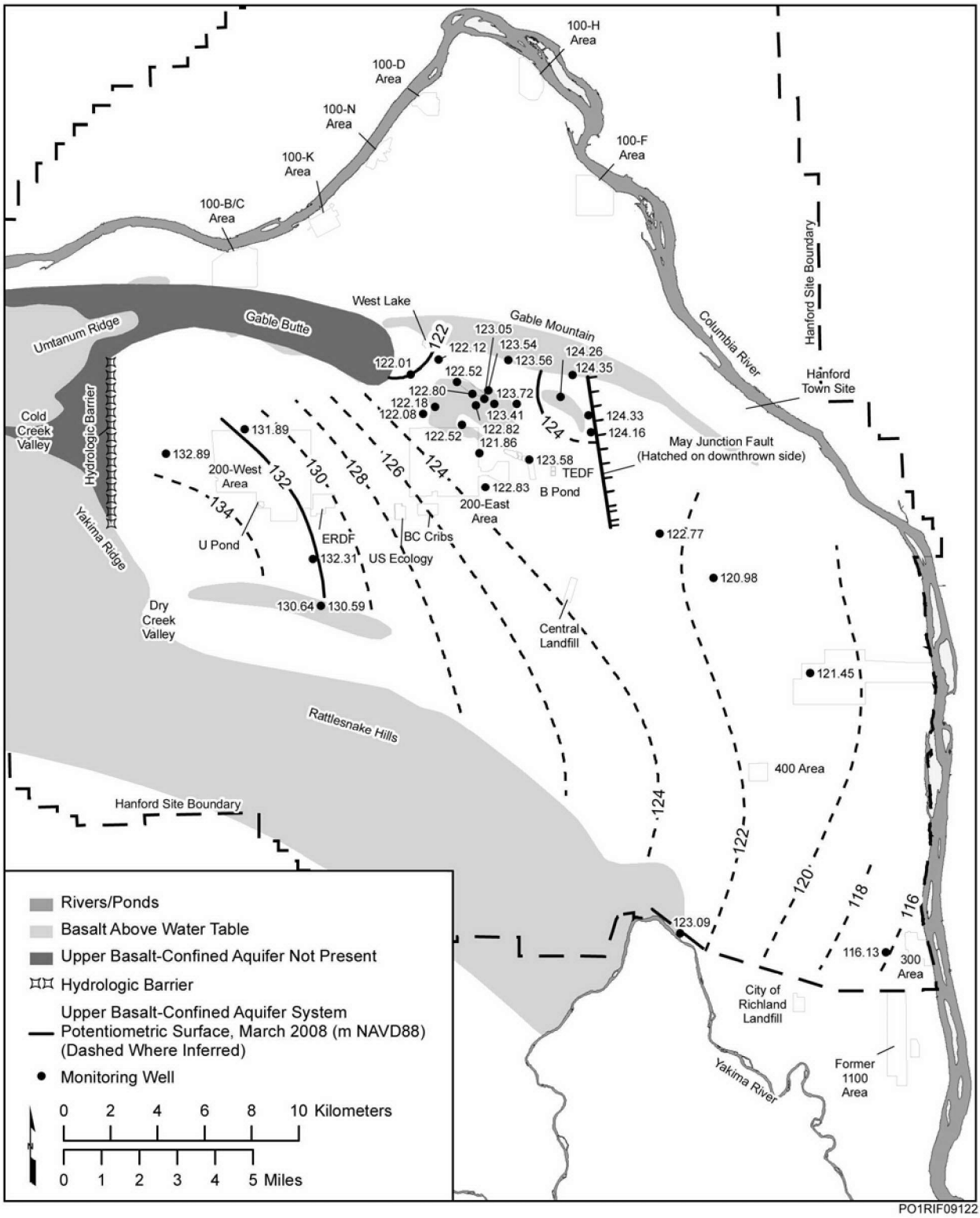

Figure 3-16. Potentiometric Map of the Basalt Confined Aquifer (Rattlesnake-Ridge Interbed)

The surface of the Ringold Fm LMU (HSU 8) represents the base of the unconfined suprabasalt aquifer throughout the 200-UP-1 Groundwater OU (Figure 3-9 and Figure 3-10). In 2002 (PNNL-13858), the uppermost unconfined aquifer thickness (the saturated thickness of HSU 5) ranged from more than 72 m (236 ft) near U Pond (upgradient) to less than 10 m (33 ft) at the northeastern boundary of the OU (downgradient). Figure 3-17 illustrates current suprabasalt aquifer conditions within the OU. The total thickness of the suprabasalt aquifer (including the saturated portions of HSU 5, HSU 8, and HSU 9) ranges from approximately 144 m (472 ft) at the upgradient western margin of the OU to less than 35 m (115 ft) near the downgradient northeastern margin of the OU. Figure 3-18 shows the total suprabasalt aquifer thickness for the 200-UP-1 Groundwater OU.

Regional Miocene-Pliocene age basalt uplift along the Umtanum-Gable structural axis (located north of the 200-UP-1 Groundwater OU) and subsequent depositional thinning and/or paleo-flood erosion have created a sequence of uplifted Ringold sediment within the east-northeastern 200-UP-1 Groundwater OU, which results in older and presumably less-permeable sediment (of HSU 5) comprising the uppermost aquifer near the downgradient margin of the OU (Figure 3-11 and Figure 3-17). Therefore, groundwater flowing eastward, and downgradient across the 200-UP-1 Groundwater OU, moves through progressively older HSU 5 sediment until it emerges at the erosional boundary within the 200 East Area. The reduced hydraulic conductivity of the older sediment, as well as the reduction in the aquifer's thickness due to the shallower confining sediment (HSU 8), creates physical restrictions in groundwater flow at the eastern edge of the 200-UP-1 Groundwater OU (Figure 3-11); however, the very uppermost portion of the unconfined aquifer encounters the lower portion of the Hanford fm and/or CCU (HSU 1 and/or HSU 3), which unconformably overlies the Ringold Fm (HSU 9 or HSU 5). The younger, more-permeable HSU 1 and/or HSU 3 provide opportunity for preferential groundwater flow within the very uppermost portion of the unconfined aquifer because of the higher hydraulic conductivity of the younger HSU 1 and/or HSU 3 relative to the adjacent and underlying HSU 5. These unconfined aquifer conditions are manifested by the historical increase in water table elevation and gradient created by the low-permeability Ringold (HSU 9-5) sediments and the abrupt steepening (elevation drop) in the water table gradient in the region where saturated younger, and highly permeable sediment (HSU 1 and/or HSU 3) occupies the uppermost aquifer interval (near the 200 East Area) (Figure 3-11 and Figure 3-12).

3.7.5 Aquifer Intercommunication

Throughout most of the 200-UP-1 Groundwater OU, groundwater in the uppermost unconfined aquifer (HSU 5) is isolated from groundwater in the lower confined interval (HSU 9) and the lower basalt confined aquifers by the Ringold Fm LMU (HSU 8) and/or other lesser-defined mud/silt layers. The hydraulic head below HSU 8 is usually slightly lower than the unconfined aquifer system above HSU 8, thereby creating a downward gradient or the potential for downward groundwater flow.

Outside of the 200-UP-1 Groundwater OU, to the north and northeast, depositional thinning and/or erosion has removed HSU 8, resulting in exposure of the lower confined aquifer system (HSU 9 and/or HSU 10) to the uppermost unconfined aquifer system in some areas (HSU 9, HSU 5, and/or HSU 1). This northern region is known to have intercommunication based on the vertical distribution of contamination within the aquifer system (Figure 3-19). No apparent intercommunication occurs between the lower confined (the basalt HSU 10 and/or HSU 9 intervals) and the upper unconfined HSU 5 beneath the 200-UP-1 Groundwater OU. Figure 3-15 illustrates variations in measured head values between confined and unconfined wells in the surrounding area. These data suggest that there is a net downward head between the uppermost unconfined (HSU 5) and deeper basalt confined aquifer systems (HSU 10) within the 200-UP-1 Groundwater OU. The increased elevation in unconfined groundwater head is most likely due to the artificially elevated water table created during the decades-long liquid waste disposal that occurred during the Site's operational years.

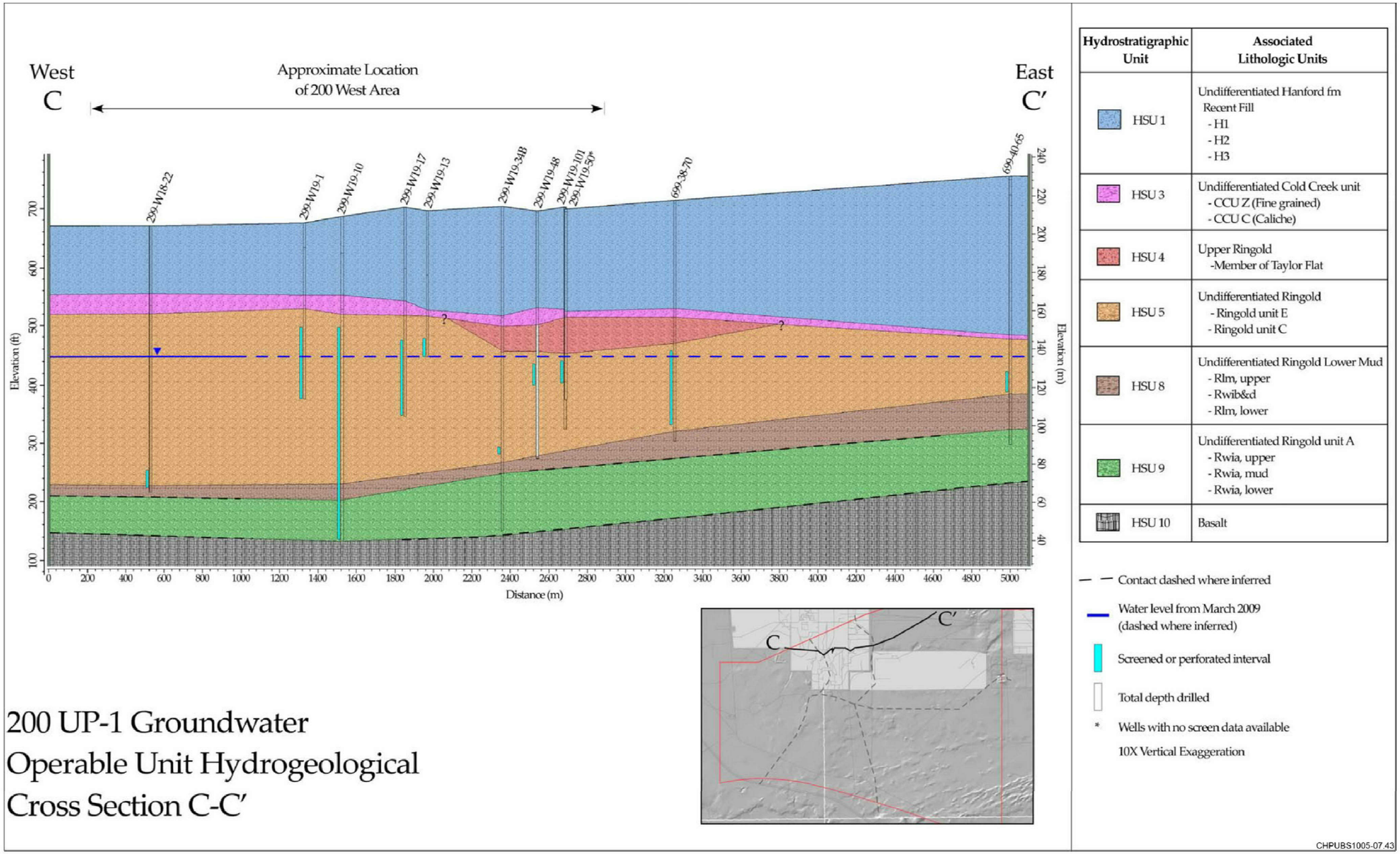

Figure 3-17. Suprabasalt Aquifer System Within the 200-UP-1 Groundwater Operable Unit

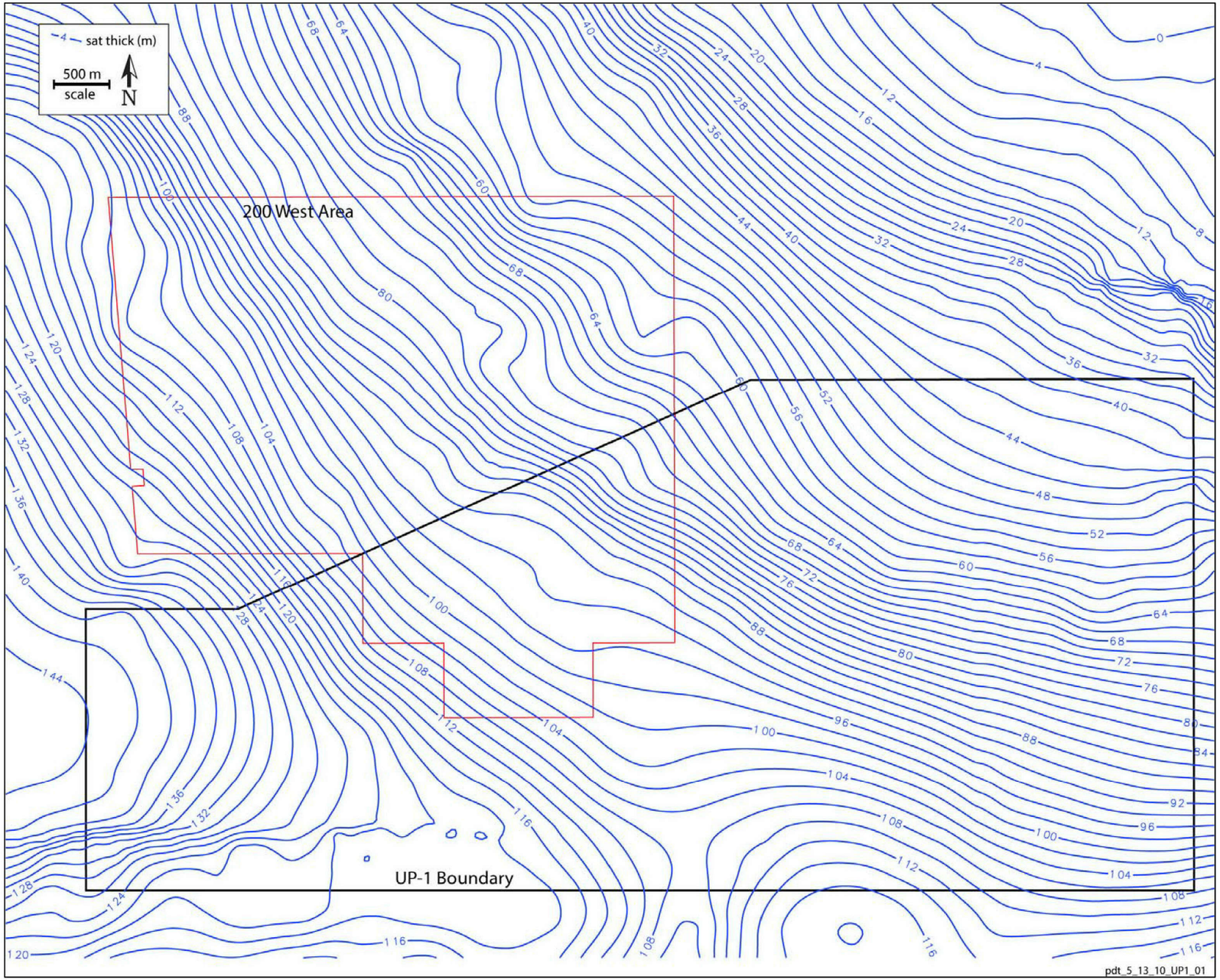

Figure 3-18. Suprabasalt Aquifer Thickness Map, 200-UP-1 Groundwater Operable Unit

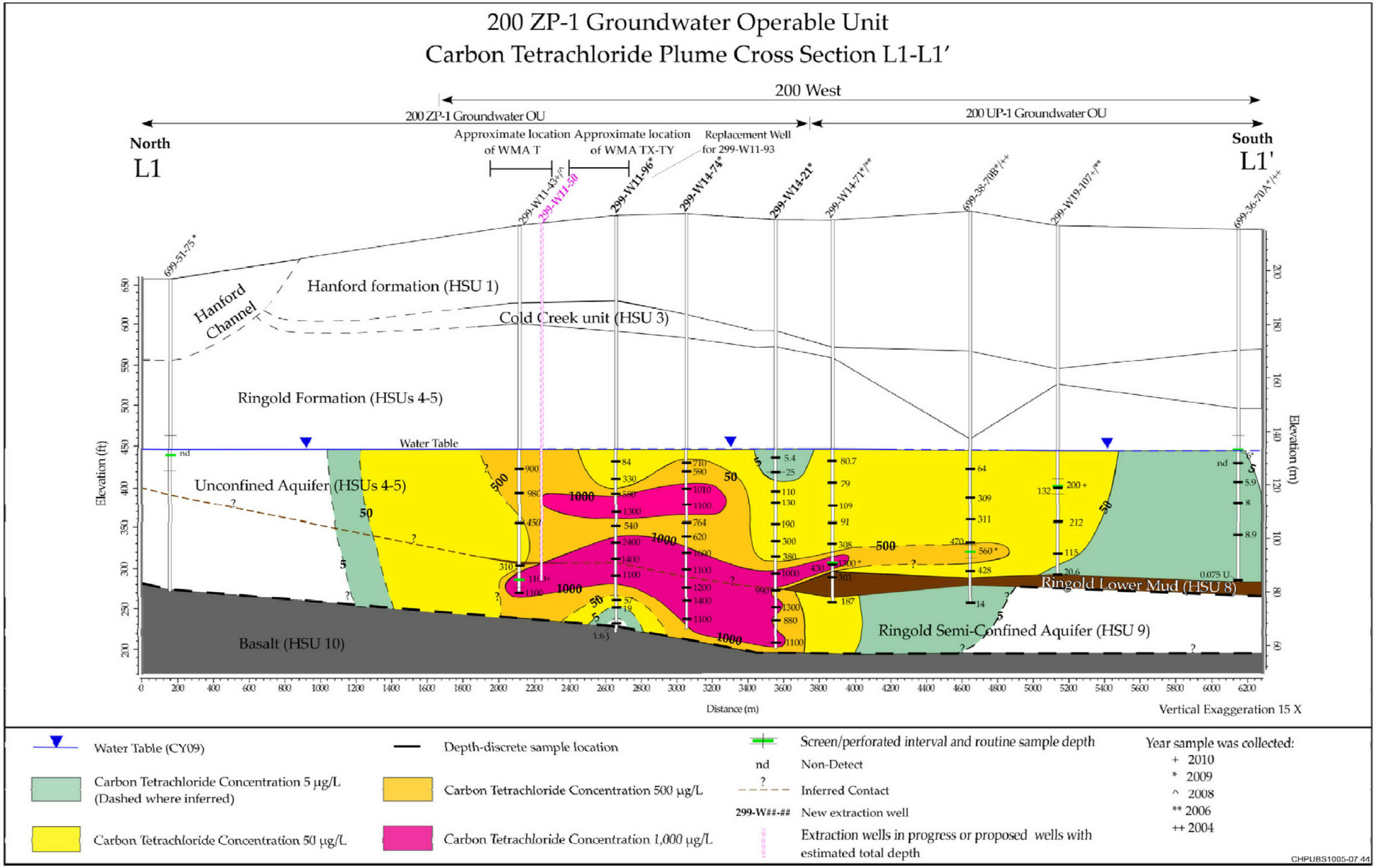

Figure 3-19. Suprabasalt Aquifer Intercommunication, 200-ZP-1 Groundwater Operable Unit

The distribution (position and extent) of hydrogeologic units at or near the water table is a result of Miocene-Pliocene age (Ringold Fm) geologic uplift, and subsequent Pleistocene cataclysmic flood and ancestral Columbia River erosion. Figure 3-20 depicts the distribution of hydrogeologic units at the water table during 2006. For the 200 West Area (200-UP-1 Groundwater OU), this figure illustrates that Ringold Fm HSU 5 is the primary hydrogeologic unit that comprises the unconfined aquifer. Near the eastern border of the OU, the Hanford fm HSU 1 is the uppermost hydrogeologic unit defined at the water table. This region of change between HSU 5 and HSU 1 is the area coincident with the steep water table gradient reflective of groundwater flow from upgradient within the lower-permeability HSU 5 into the higher-permeability HSU 1.

Subsequently, two geologic features are believed to influence the observed behavior of groundwater plumes across the 200-UP-1 Groundwater OU. These geologic features limit the thickness of the unconfined aquifer and constrain the movement of groundwater and contaminants at the downgradient edge near the eastern border of the 200-UP-1 Groundwater OU.

Within the 200-UP-1 Groundwater OU, the relative thickness, and geometric shape of the unconfined aquifer can be described as a basin or wedge that generally reflects the dipping surface of HSU 8. HSU 8 forms the base of the unconfined aquifer and dips gently into the Cold Creek syncline to the south and southwest of the OU (upgradient direction), forming a thick wedge of saturated HSU 5 sediment above HSU 8. Downgradient, toward the east-northeastern margin of the OU, HSU 8 has been uplifted on tilted basalt beds, which creates thinning of the overlying saturated HSU 5 sediment interval (forming the conceptual lip of the basin). The structural rise in HSU 8 across this area is more than 50 m (164 ft). In 2002 (PNNL-13858), the uppermost unconfined aquifer thickness (the saturated thickness of HSU 5) ranged from more than 72 m (236 ft) near U Pond (upgradient) to less than 10 m (33 ft) at the northeastern boundary of the OU (downgradient). The thickest portion of the uppermost contaminated aquifer is beneath the 200 West sources, where HSU 8 is structurally the deepest and the water table mound is the highest. Depth-discrete groundwater samples from multiple wells indicate that some contamination extends throughout the saturated interval to the bottom of the unconfined aquifer (top of HSU 8) (Figure 3-21). It is interesting to note that without a significant head (gradient) acting as a driving force to flush or sweep out the contaminated groundwater that lies deepest and within the thickest portion of the aquifer—below the elevation of the updip edge of the saturated HSU 5 aquifer—there may be no mechanism acting to move this deeper contamination. This absence of a lateral groundwater force deep in the aquifer could create a zone of stagnation in which groundwater is isolated or trapped by structural and hydraulic influences, ultimately creating significantly longer contaminant travel times out of this region.

At the eastern, downgradient margin of the groundwater OU, the Hanford-Ringold contact forms the second significant hydrogeologic interface related to the distribution and movement of groundwater contaminants across the 200 Central Plateau (200 West and 200 East Areas). Fluvial erosion and paleo-flooding have shaped the contact between the Hanford fm and underlying Ringold Fm sediments (Hanford-Ringold contact). Regionally, this Hanford-Ringold contact is fairly flat relative to the underlying geologic units (Figure 3-10), with exceptions where fluvial or paleo-flooding eroded into the underlying Ringold Fm and scoured larger channels (Figure 3-22).

The results of hydraulic testing from many boreholes across the Site have revealed a significant permeability (hydraulic conductivity) difference between the Hanford fm (HSU 1), the CCU (HSU 3), and the underlying Ringold Fm (HSU 5 and HSU 9) sediments. This hydraulic conductivity contrast creates preferential groundwater flow through the very uppermost portion of the unconfined aquifer within the younger Hanford fm and/or CCU sediments where they occur at or below the water table.

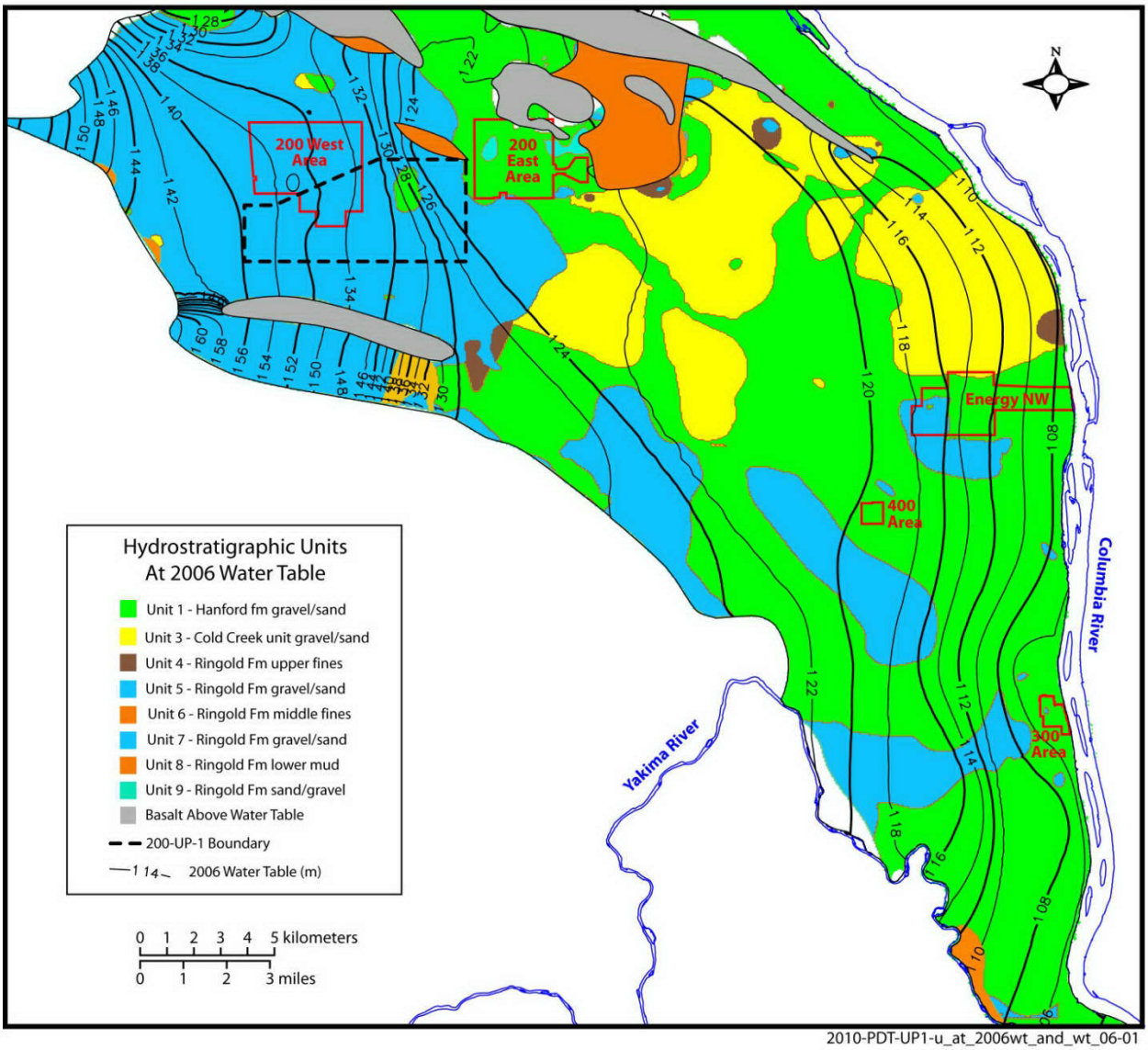

Figure 3-20. Distribution of Hydrogeologic Units at the Water Table, 200-UP-1 Groundwater Operable Unit

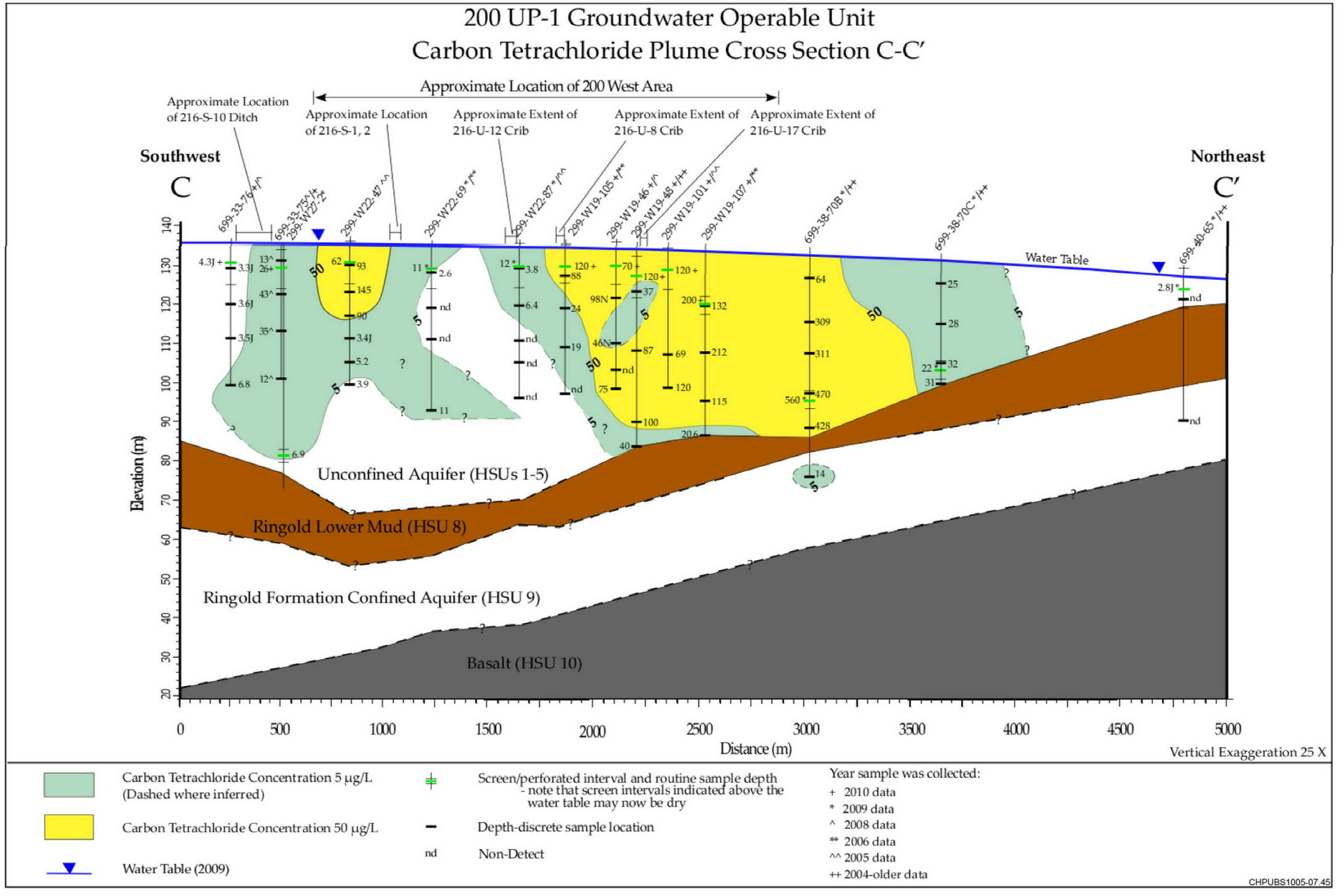

Figure 3-21. Depth Distribution of Carbon Tetrachloride Contamination Within the Unconfined Aquifer, 200-UP-1 Groundwater Operable Unit

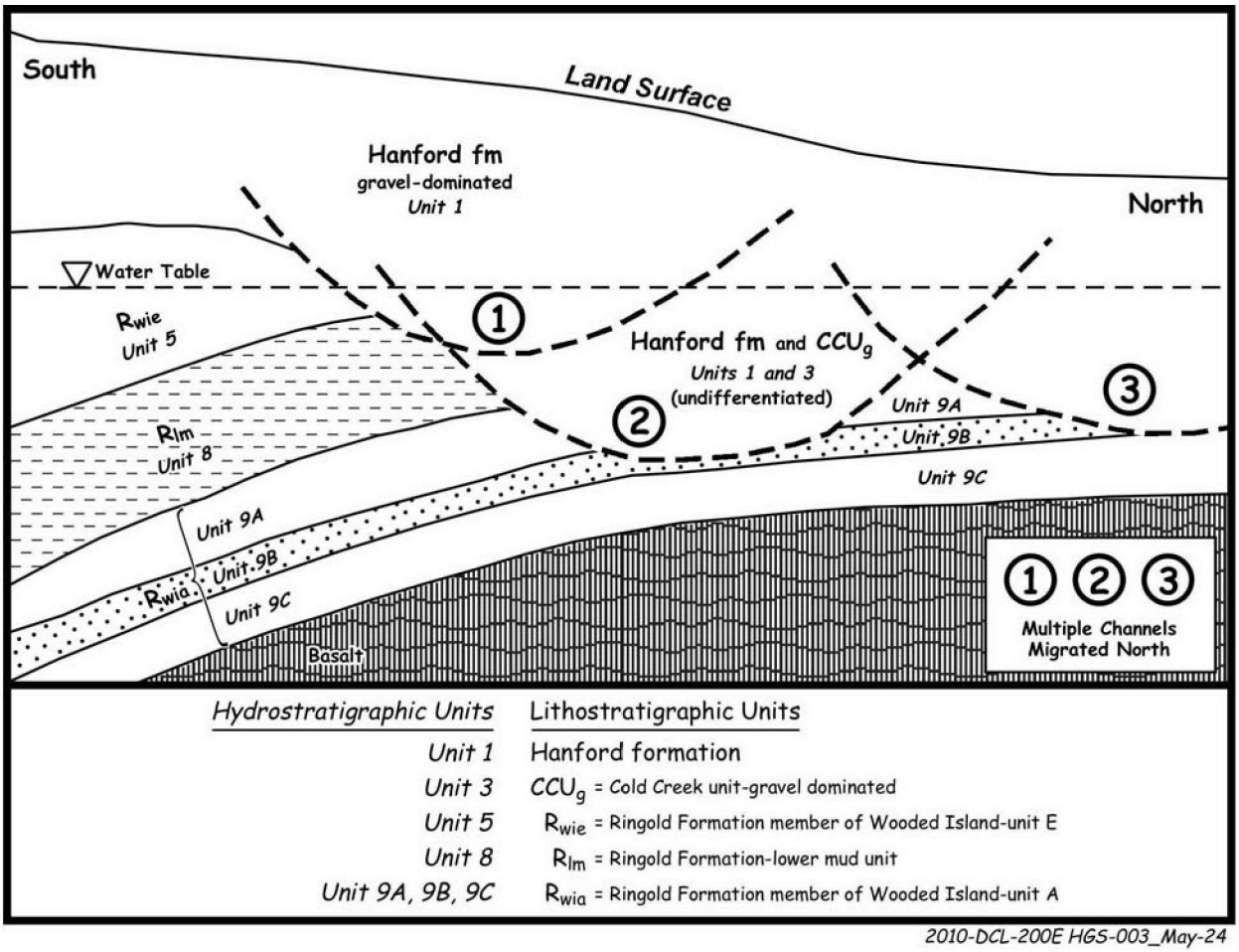

Figure 3-22. Conceptualization of Paleo-Flood Erosion and Channeling into Older Ringold Formation Sediment

During operational years at the Site, when artificial groundwater mounds were the dominant cause of high gradients across the Central Plateau, groundwater and dissolved contaminants were driven much faster across the 200-UP-1 Groundwater OU. These contaminants dispersed either eastward across the 200 East Area (into the adjacent 200-PO-1 Groundwater OU) or north and northeastward through the 200 East Area Gable Gap area (into the adjacent 200-BP-5 Groundwater OU). The resultant flow path(s) of contaminants in groundwater were influenced by artificial gradients in the 200 East Area and the location of the source(s) in the 200 West Area. Because of the general shape of the water table mound that exists beneath the 200 West Area, contamination from sources in the southern half of the 200 West Area track eastward toward the 200-PO-1 Groundwater OU, and contamination from sources in the northern half of the 200 West Area track more north to northeasterly into the 200-BP-5 Groundwater OU. Today, there is no measureable remnant groundwater mound within the 200 East Area. Within the 200 West Area, the water table still reflects remnant mounding and remains elevated above the 200 East Area. The variation between the elevation of the residual mound in the 200 West Area (200-UP-1 Groundwater OU) and the elevation of the water table within the 200 East Area (200-PO-1 and BP-5 Groundwater OUs) is partly due to the difference in aquifer properties between the saturated HSU 5 and HSU 1 and HSU 3, respectively (Figure 3-20). The groundwater mound that existed beneath the 200 East Area, dominated by saturated high-permeability HSU 1 and HSU 3 sediment, declined and re-equilibrated at a much faster rate than the mound in the 200 West Area. Today, the combination of the older, lower-permeability units

within the 200-UP-1 Groundwater OU, coupled with the lower to flat water table gradient between the 200-UP-1 Groundwater OU and the downgradient 200-PO-1 Groundwater OU, will result in a dramatic slowing of groundwater/contaminant movement beyond the UP-1 Groundwater OU. In other words, the rapidly falling heads within the 200 West Area and subsequent lowering of the water table into older, less-permeable HSU 5 sediment will result in slower movement and increasing lateral constraint on the remaining groundwater and contamination within that portion of the aquifer. In addition, groundwater that does flow beyond the HSU 5/HSU 1 contact (Hanford-Ringold contact) boundary at the eastern edge of the 200-UP-1 Groundwater OU will be slowed dramatically due to the flat gradient in this region (200-PO-1 Groundwater OU). Combined, these effects result in slowing and potentially increased residence time for residual contaminants emanating from within the 200-UP-1 Groundwater OU.

3.7.6 Conceptual Site Model

The 200-UP-1 Groundwater OU CSM is a combined interpretation of the Site's hydrogeology, along with a description of the known distribution of groundwater contamination from beneath the 200 West Area (source area) to the eastern, downgradient portion of the OU. The model describes the geologic and hydrogeologic features comprising the suprabasalt aquifer system and how this system controls groundwater contaminants migrating across the area.

The CSM of the hydrogeology of the 200-UP-1 Groundwater OU is described in PNNL-13858. This study concluded that two aquifers exist within the suprabasalt sediment of the 200 West Area. The upper unconfined aquifer occurs in the sediment of HSU 5 (unit E of the Ringold Fm), the lower portion of HSU 1, and/or HSU 3. Currently, groundwater in the unconfined portion of the suprabasalt aquifer (HSU 5) generally flows easterly across the Central Plateau toward the 200 East Area (200-PO-1 Groundwater OU) and toward the Columbia River (Figure 3-11).

An underlying confined aquifer consists of HSU 9 sediment separated from the overlying unconfined aquifer by HSU 8. The resulting fluvial silty, sandy gravel aquifer forms the lower suprabasalt (Ringold Fm) confined aquifer. Within the 200-UP-1 Groundwater OU, groundwater flow in the Ringold Fm confined aquifer (HSU 9) appears to be isolated from the overlying HSU 5 (Figure 3-10). At the eastern boundary of the 200-UP-1 Groundwater OU, however, groundwater from HSU 9 and groundwater within HSU 5 converge from the west and south (Figure 3-11), potentially upwelling and mixing with the unconfined aquifer where Hanford fm sediment (HSU 1) juxtapose the Ringold Fm sediments exposed within erosional channel(s) (Figure 3-11) that trend across the 200 East Area.

A deeper confined aquifer system also exists in the Columbia River Basalt Group (HSU 10) underlying the Ringold Fm (PNNL-13858). The upper basalt confined aquifer occurs within fractured basalt and sedimentary interbeds of the Upper Saddle Mountains Basalt, which directly underlies the Ringold Fm confined aquifer. Groundwater generally flows from west to east within the upper basalt confined aquifer (Figure 3-16). Vertical gradients are downward within this confined aquifer system beneath the 200-UP-1 Groundwater OU (Figure 3-15). Groundwater within the basalt confined aquifer is isolated from groundwater in the overlying suprabasalt aquifer beneath the 200-UP-1 Groundwater OU.

All of the groundwater contamination in the 200-UP-1 Groundwater OU originated within the 200 West Area and vicinity. The monitoring SAP lists waste sites grouped around three major facilities as the primary contributors to groundwater contamination in the 200-UP-1 Groundwater OU: S Plant, S Cribs and Trenches Area where U Plant waste was disposed, and U Plant (Figure 3-23). Three RCRA TSD units are also located in the 200-UP-1 Groundwater OU: SST WMAs S-SX, and U, and the 216-S-10 Pond and Ditch.

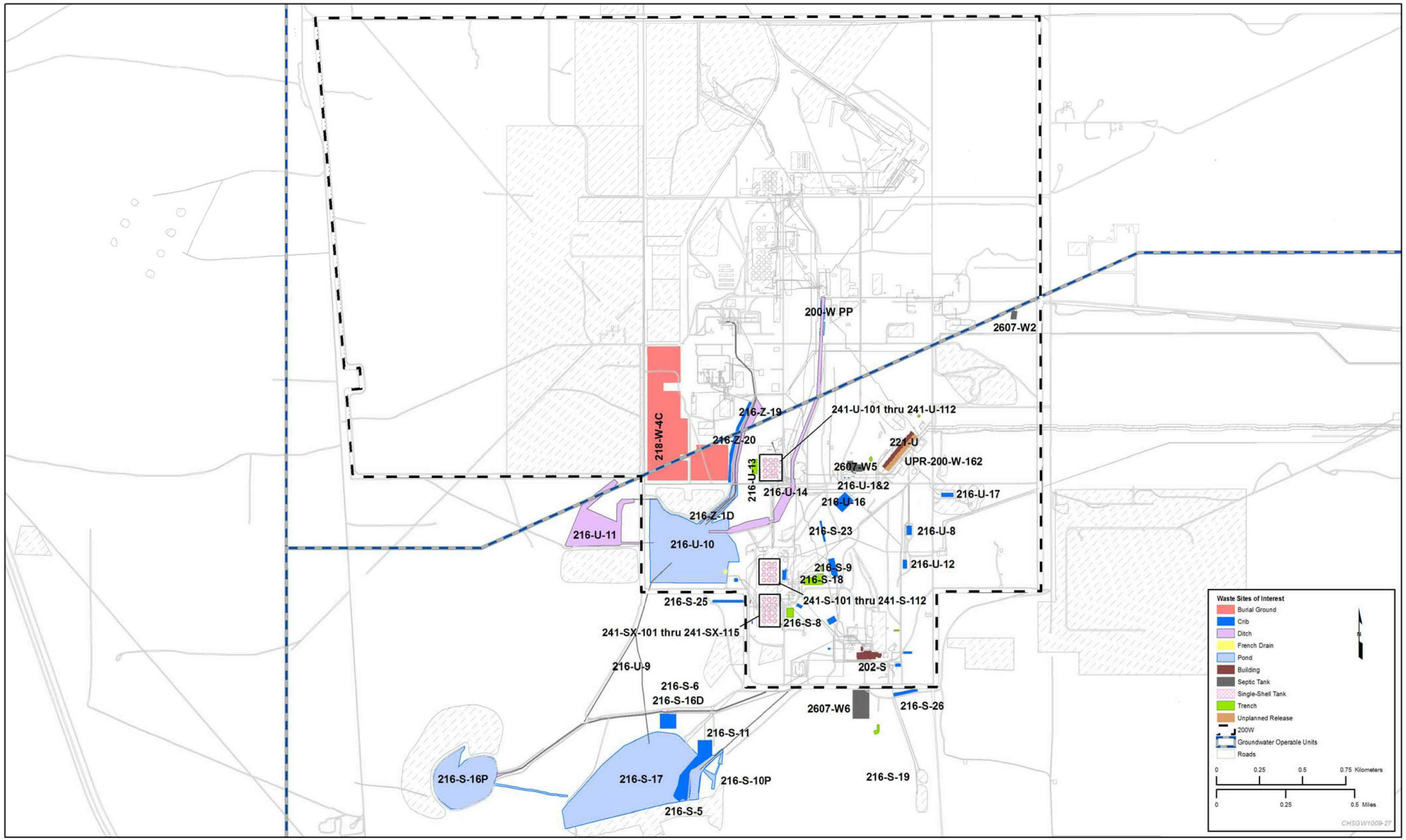

Figure 3-23. 200-UP-1 Groundwater Operable Unit Waste Sites

Sufficient effluent volumes were disposed at U Pond and other waste sites resulting in a persistently elevated water table, providing the gradient to move contaminants away from the sources. Liquid effluent initially migrated vertically downward beneath the waste sites through the thick vadose sediments composed primarily of permeable Hanford fm sand and gravel (HSU 1) until they contacted the CCU (HSU 3). Many contaminants reacted and sorbed to the sediment above and/or within HSU 3 and do not present a hazard to groundwater. The more mobile contaminants (tritium, I-129, and nitrate) were dispersed across HSU 3 as the liquid effluent backed up or perched on top and within the unit, until sufficient hydraulic head and/or pathways through HSU 3 were presented. HSU 3 created a natural vertical barrier that spread perched water from multiple nearby disposal sources and most likely caused mixing and commingling of contaminants within the vadose zone before the effluent reached groundwater, making the identification of sources problematic.

Contaminated effluent eventually reached the water table and impacted the aquifer below several liquid waste disposal areas within the 200-UP-1 Groundwater OU. The resulting groundwater mound has influenced groundwater flow rate and direction over the entire 200 West Area and vicinity for more than four decades. During peak disposal, the groundwater mound under U Pond caused an estimated additional 18 m (59 ft) of hydraulic head. The resulting downward gradient and radial flow pattern increased the rate of groundwater flow toward the 200 East Area. The downward gradient generated during disposal operations also most likely resulted in a more extensive vertical distribution of contaminants beneath the source area, forcing contaminants lower within the thick uppermost suprabasalt aquifer (HSU 5). Where effluent and groundwater encountered the underlying and relatively impermeable HSU 8, it most likely was diverted laterally from source areas and spread downgradient (easterly and southeasterly) through saturated HSU 5 sediment. Farther east, near the boundary of the 200-UP-1 Groundwater OU, the Ringold Fm sediments (HSU 5) are replaced with Hanford fm and/or CCU (HSU 1 and/or HSU 3) sediment located at or near the water table. The contaminated groundwater most likely will continue to move downgradient within the upper Ringold sediment (HSU 5) and into the adjacent Hanford fm and/or CCU (HSU 1/3) sediment beyond the boundary of the OU.

Figure 3-24 conceptually illustrates the hydrologic units identified beneath the 200-UP-1 Groundwater OU, the artificial recharge and mounding, and the groundwater contaminant plumes from the 200 West source areas. This figure represents the period of highest liquid waste disposal to the ground. All liquid effluent disposal to the ground beneath the 200-UP-1 Groundwater OU and most of the associated artificial groundwater recharge ceased by 1987. Since that time, much of the groundwater mound within the unconfined aquifer that was located beneath the 200 West Area has declined. Figure 3-25 provides the CSM under current conditions within the OU.

3.7.7 Groundwater Recharge

Movement of contaminants in groundwater at the Site is heavily dependent on recharge to the unconfined aquifer. As the effects of past artificial discharges dissipate, the water table is expected to return to more natural conditions, and natural recharge will become the driving force when evaluating future groundwater flow conditions and related contaminant transport. Previous work on the relationship of natural recharge to groundwater movement at the Site has focused on direct recharge from infiltrating rainfall and snowmelt within the area, as discussed in PNNL-14717.

Except for the SALDS, the 200 Area TEDF, and septic drain fields, substantial artificial recharge to the vadose zone ended in the mid-1990s. The recharge to the aquifer from the septic systems is considered small compared to other liquid waste disposal sites within the OU.

Currently, the principal sources of natural recharge are precipitation and runoff infiltration along the periphery of the Pasco Basin. Part of the groundwater recharge at the Site is provided by flow from the Greater Cold Creek watershed, a large drainage area on the western boundary of the Site that includes Cold Creek Valley, Dry Creek Valley, and the Hanford side of Rattlesnake Mountain. Small ephemeral streams such as Cold Creek and Dry Creek also lose water to the ground as they spread out on the valley plain.

Natural precipitation infiltration at or near the waste management units may provide a driving force for the mobilization of contaminants previously introduced to surface or subsurface soils. Previous field studies have been designed to assess precipitation, infiltration, water storage changes, and evaporation to evaluate the natural water balance during the recharge process. Gee et al. (1992) and Fayer et al. (1996) estimate that recharge rates from precipitation across the Site range from near zero to more than 100 mm/year (3.94 in./yr). Recharge is variable both spatially and temporally. It is greatest for coarse-textured soils bare of deep-rooted vegetation, and in years with rapid snowmelt events and precipitation during cool months. The magnitude of recharge at a particular location is influenced by five main factors: climate, soils, vegetation, topography, and springs and streams. Various field studies conclude that less than 25 percent of the precipitation falling on typical Site soils actually infiltrates to any depth. The fraction of annual precipitation that actually contributes to aquifer recharge is very small and difficult to quantify.

Between 1944 and the mid-1990s, the volume of artificial recharge from Site wastewater disposal was significantly greater than recharge from precipitation. An estimated 1.68×10^{12} L (4.44×10^{11} gal) of liquid was discharged to disposal ponds, trenches, and cribs during this period. Wastewater discharge has decreased since 1984 and currently contributes a volume of recharge in the same range as the estimated natural recharge from precipitation. Because of the reduction in discharges, groundwater levels are falling, particularly around the operational areas (PNNL-16346).

After the beginning of Site operations during 1943, the water table rose about 27 m (89 ft) under the U Pond disposal area in the 200 West Area and about 9.1 m (30 ft) under disposal ponds near the 200 East Area. The volume of water that was discharged to the ground at the 200 West Area was actually less than that discharged at the 200 East Area. The lower hydraulic conductivity of the aquifer near the 200 West Area inhibited groundwater movement in this area, resulting in a higher groundwater mound. The presence of the groundwater mounds locally affected the direction of groundwater movement, causing radial flow from the discharge areas. Zimmerman et al. (PNL-5506) documented changes in water table elevations between 1950 and 1980. Until about 1980, the edge of the mounds migrated outward from the sources over time.

Although the reduction of wastewater discharges has caused water levels to drop significantly, a residual groundwater mound remains beneath the 200 West Area.

The depth to groundwater beneath liquid disposal sites within the 200 West Area and throughout most of the 200-UP-1 Groundwater OU is approximately 91 m (300 ft) below ground surface (bgs). Liquid disposal was the driving force for contaminant migration from the disposal sites in the 200 West Area. In 1992, the 200 West Groundwater AAMSR (DOE/RL-92-16) evaluated surface sites for potential contaminant migration to groundwater. This evaluation estimated possible groundwater impact by comparing vadose zone moisture retention capacity to the volume of liquid disposed. Those sites receiving liquid volumes greater than the retention capacity, were identified as having the potential to impact groundwater. Since 1992, RIs have progressed by source OU and are being evaluated for contributions and recharge to groundwater.

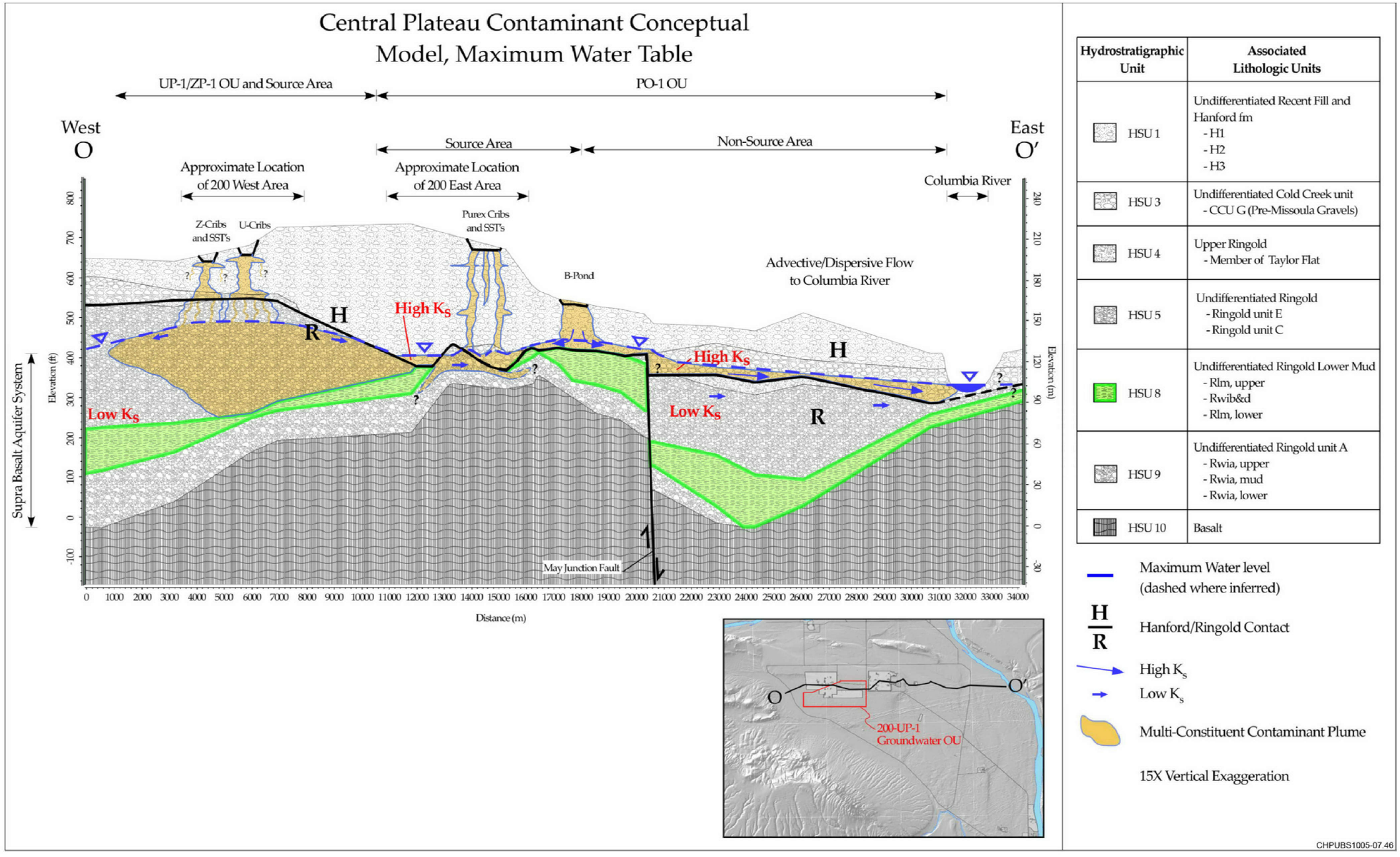

Figure 3-24. Conceptual Site Model Representing Past Peak Liquid Effluent Disposal, 200-UP-1 Groundwater Operable Unit

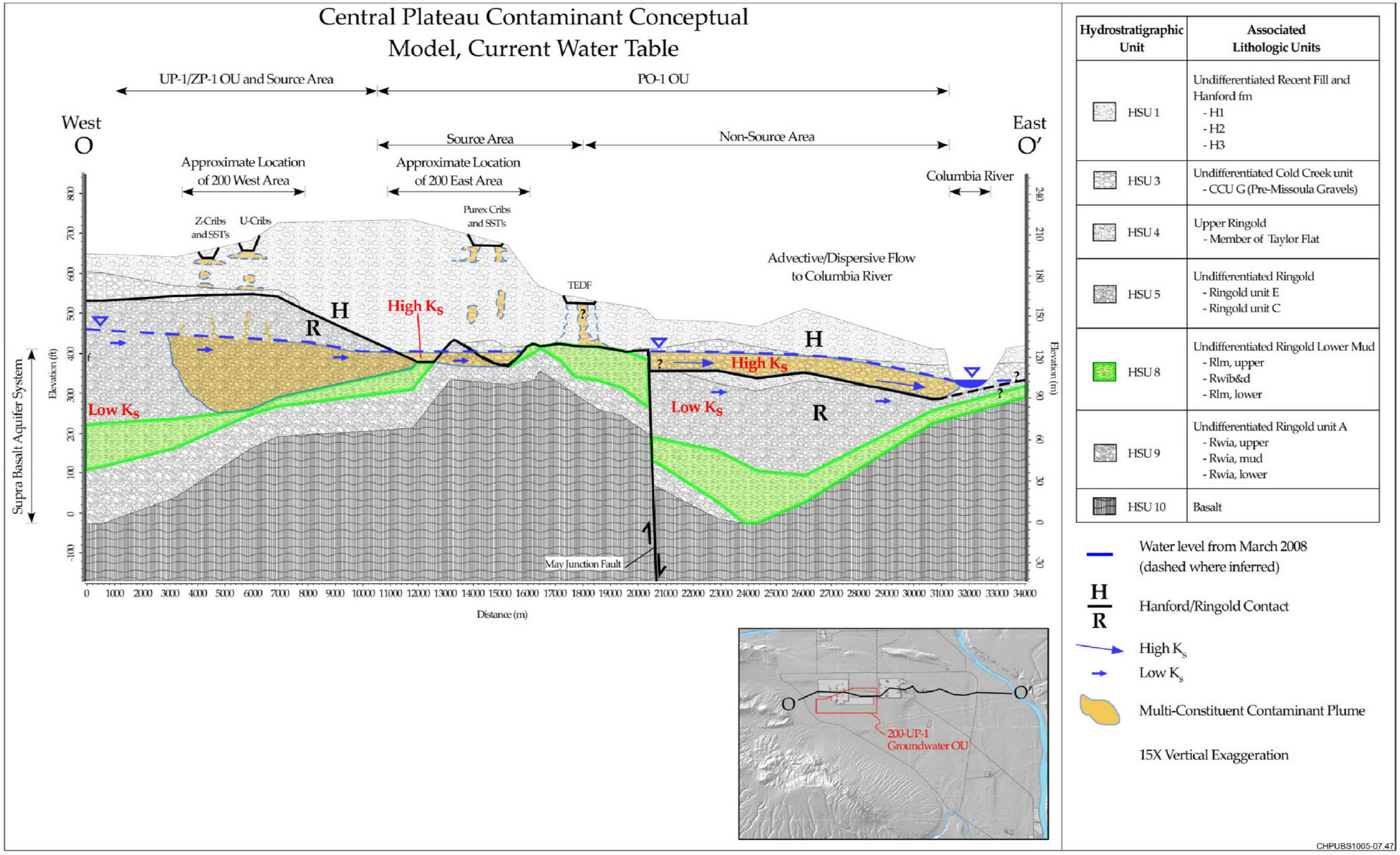

Figure 3-25. Conceptual Site Model Representing Current Groundwater Conditions, 200-UP-1 Groundwater Operable Unit

Figure 3-26 summarizes the current and historical discharge volumes for major sources of artificial recharge to the 200-UP-1 Groundwater OU unconfined aquifer. Figure 3-27 and Figure 3-28 show the changes in groundwater elevation at the 200-UP-1 Groundwater OU due to artificial recharge. The selected wells illustrated in Figure 3-28 represent a west to east cross section of water table elevations in wells extending from the immediate vicinity of 216-U-10 Pond (Well 699-35-78A) in the downgradient direction, ending with Well 699-32-62, located approximately 5,000 m (16,405 ft) to the east. The hydrographs shown in Figure 3-28 illustrate the dramatic extent of the groundwater mound associated with discharges to 216-U-10 Pond, as well as the temporal variations in hydraulic gradient between wells across the width of 200-UP-1 Groundwater OU.

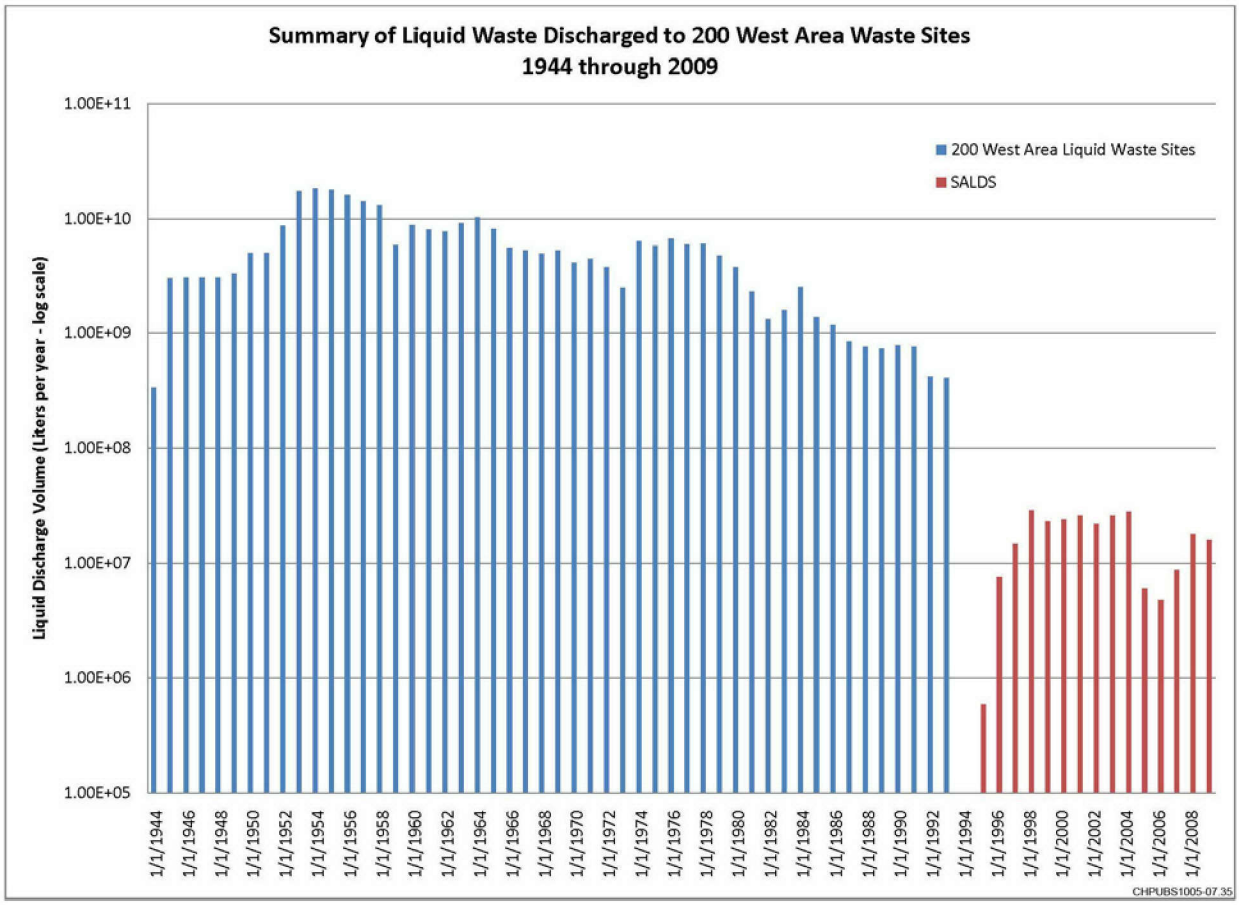

Figure 3-26. Summary of Annual Waste Discharged to the Ground in the 200 West Area

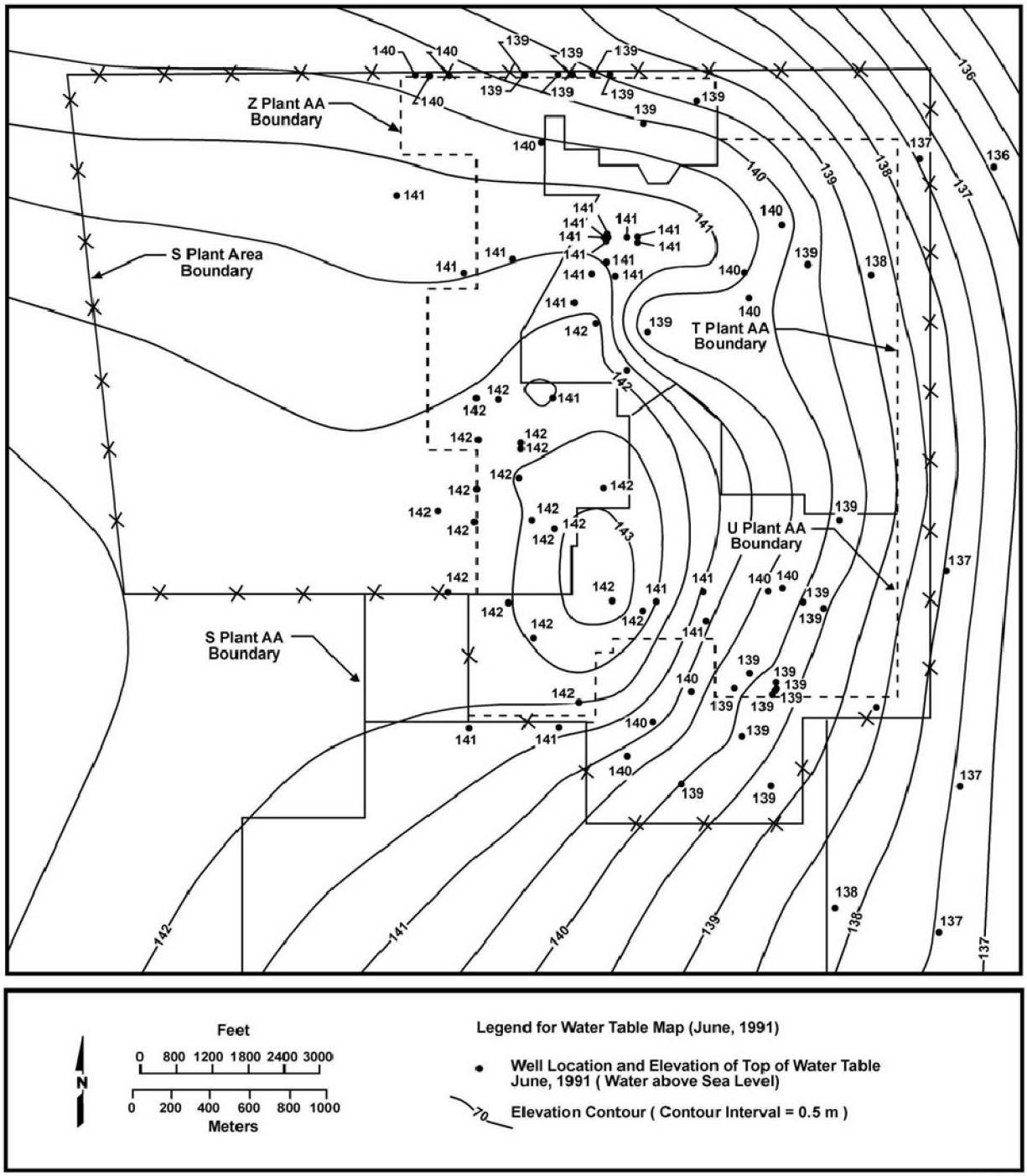

Figure 3-27. 200 West Area Water Table Elevation Map, June 1991 (DOE/RL-92-76, Rev. 1)

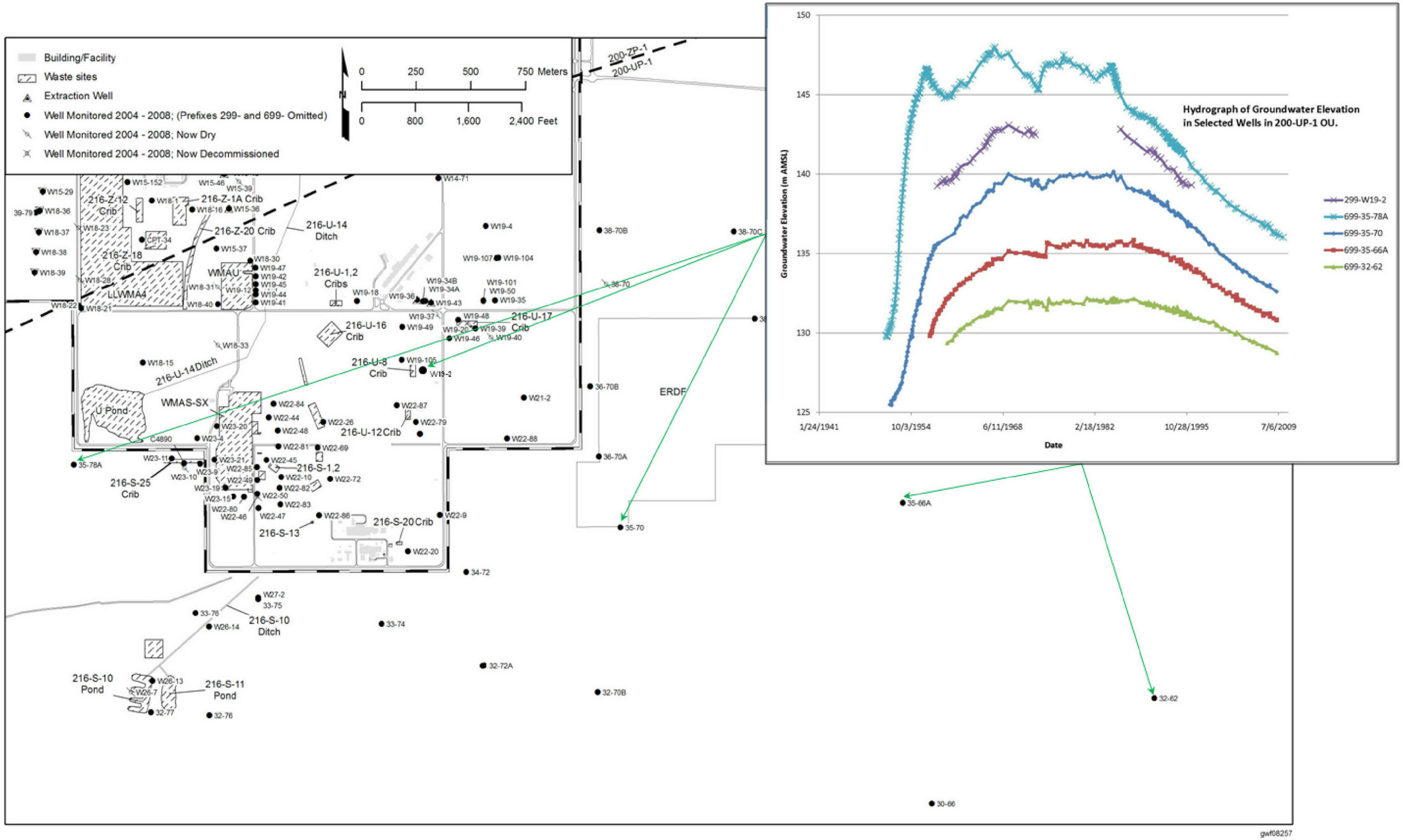

Figure 3-28. Changes in Groundwater Elevation in Selected Wells Within the 200-UP-1 Groundwater Operable Unit

3.7.8 Groundwater Velocity and Travel Time

Large liquid volumes were discharged to the vadose zone overlying the 200-UP-1 Groundwater OU during Site operations (Figure 3-26). The impact of substantial artificial recharge on the 200-PO-1 Groundwater OU unconfined aquifer system can be seen by inspecting the hydrographs for selected wells within the OU. Figure 3-28 illustrates the dramatic change in hydraulic gradient between wells across the OU that is the result of groundwater mounding beneath discharge sites.

Groundwater velocity within the shallow, unconfined aquifer of the 200-UP-1 Groundwater OU, between the eastern boundary of the 200 West Area and the boundary between the 200-UP-1 and 200-PO-1 Groundwater OUs during the period of plant operations, is estimated by inspection of arrival times of tritium concentration peaks at monitoring wells along an identified flow pathway downgradient of the apparent source areas (Figure 3-29). The estimated groundwater velocity during the period examined ranged from about 79 m/yr (259 ft/yr) to about 105 m/yr (344 ft/yr), with an average apparent velocity of about 90 m/yr (295 ft/yr). Groundwater flow velocity over the general area of the 200-UP-1 Groundwater OU is expected to continue to decline as the historic 200 West Area groundwater mound continues to decay, the shallow aquifer returns to historic recharge and flow patterns, and gradient decreases across the OU. Table 3-1 shows the estimated groundwater velocities, based on tritium peak arrivals in monitoring wells for selected portions of the unconfined aquifer.

Table 3-1. Estimated Groundwater Velocity in the 200-UP-1 Groundwater Operable Unit Unconfined Aquifer, Based on Arrival of Tritium Concentration Peaks

Aquifer Portion	Wells Inspected for Tritium Peaks and Time Period	Estimated Groundwater Velocity
Upgradient, near the middle of 200 West Area	MW 299-W19-2 and MW-699-35-70, 1962 to 1975	~79 m/yr (~259 ft/yr)
Midway between 200 West Area and 200 East Area	MW 699-35-70 and MW 699-35-66A, 1975 to 1986	~105 m/yr (~344 ft/yr)
Downgradient, near 200 East Area	MW 699-35-66A, MW 699-32-62, and MW 699-36-61A, 1986 to 2005	~83 m/yr (272 ft/yr) and ~92 m/yr (302 ft/yr)

3.8 Water Use

Groundwater and surface water is not removed for extensive use in the vicinity of the 200-UP-1 Groundwater OU for drinking water, process applications, or irrigation. Groundwater is not currently withdrawn for industrial, sanitary, or potable uses in the 200-UP-1 area. Groundwater is withdrawn for dust supression in the 600 Area, for backup fire and sanitary water supply at the Columbia Generating Station, and for backup sanitary and potable water supply at the Laser Interferometer Gravitational Wave Observatory. Three wells are designated as water supply wells, but only one (499-S1-8J) provides drinking water to the 400 Area.

3.8.1 Surface Water Use in the Vicinity of the 200-UP-1 Groundwater Operable Unit

The Columbia River is used as a source of both drinking water and industrial water for several Site facilities (PNNL-15892). The water systems of Richland, Pasco, and Kennewick withdrew a large portion of the 48.8 billion L (12.9 billion gal) used during 2006 from the Columbia River. Each city operates its own supply and treatment system, located downgradient and downriver of the Site. The Richland water supply system derives about 82 percent of its water directly from the Columbia River, while the

remainder is split between a well field in North Richland (that is recharged from the river) and groundwater wells.

The City of Richland's total water usage during 2006 was 20.1 billion L (5.3 billion gal). The Kennewick system uses two wells and the Columbia River for its water supplies. These wells serve as the sole source of water between November and March and can provide approximately 40 percent of the total maximum supply of 94.6 billion L/day (25 million gal/day). Total 2006 usage in Kennewick was 13.4 billion L (3.5 billion gal). A significant number of Kennewick's residents (about 22,000 residential customers) draw irrigation water from the Kennewick Irrigation District, which has the Yakima River as its source. The City of Pasco system also draws from the Columbia River for its water needs. During 2006, Pasco consumed 15.3 billion L (4.1 billion gal). Energy Northwest operates the Columbia Generating Station northeast of the 400 Area and within the geographic boundaries of the 200-PO-1 Groundwater OU. Energy Northwest uses Columbia River water for both potable and process/cooling water applications.

3.9 Ecology

The Site has a mid-latitude semi-arid climate. Terrestrial portions of the Site are characterized as a shrub-steppe ecosystem, composed of a shrub overstory and grass understory. The last free-flowing section of the Columbia River within the United States is located above McNary Dam and flows through the Site, providing a unique habitat.

Only about 6 percent of Site land has been disturbed or is actively used by DOE for waste disposal and storage. Most of the land area is relatively undisturbed due to the long-standing management practices of DOE. Thus, the native terrestrial and aquatic ecological resources found on the Site are becoming increasingly rare and highly valuable as agricultural, industrial, and residential development continues to grow throughout the region.

The terrestrial setting (ecological setting) at the Site is representative of the terrestrial environment. The vegetation of the Central Plateau uplands is characterized by native shrub-steppe, interspersed with large areas of disturbed ground dominated by annual grasses and forbs (PNNL-6415). Disturbed areas of the Central Plateau are primarily non-vegetative gravel or asphalt, or sparsely covered with nonnative species. The ecological setting is a compilation of ecological data obtained from many biological inventories of plant and wildlife species and ecological characterizations from the following reports:

- The Nature Conservancy (TNC) of Washington completed sitewide Geographic Information System (GIS)-based plant community mapping for all areas outside the facility boundaries, and conducted biodiversity surveys of mammals, birds, reptiles, amphibians, insects, and plants between 1994 and 1998. TNC produced three annual reports (TNC, 1995; TNC, 1996; and TNC, 1998) with a final report in 1999 (TNC, 1999).
- A characterization of vegetative communities associated with the 200 Area facilities at the Site (WHC-SD-EN-TI-216).
- The Hanford Biological Resource Management Plan used the TNC reports and other characterization reports to identify four levels of habitat value and assign appropriate management strategies for the Site (DOE/RL-96-32).

Although plumes in the 200-UP-1 Groundwater OU are not a direct risk to terrestrial receptors, terrestrial ecology is being considered because future potential groundwater remediation processes may have direct impacts to local ecology. The discussion is general to the Central Plateau because the 200-UP-1 Groundwater OU is an arbitrarily defined area on the Central Plateau used to describe groundwater plumes, rather than based on natural physical or ecological boundaries.

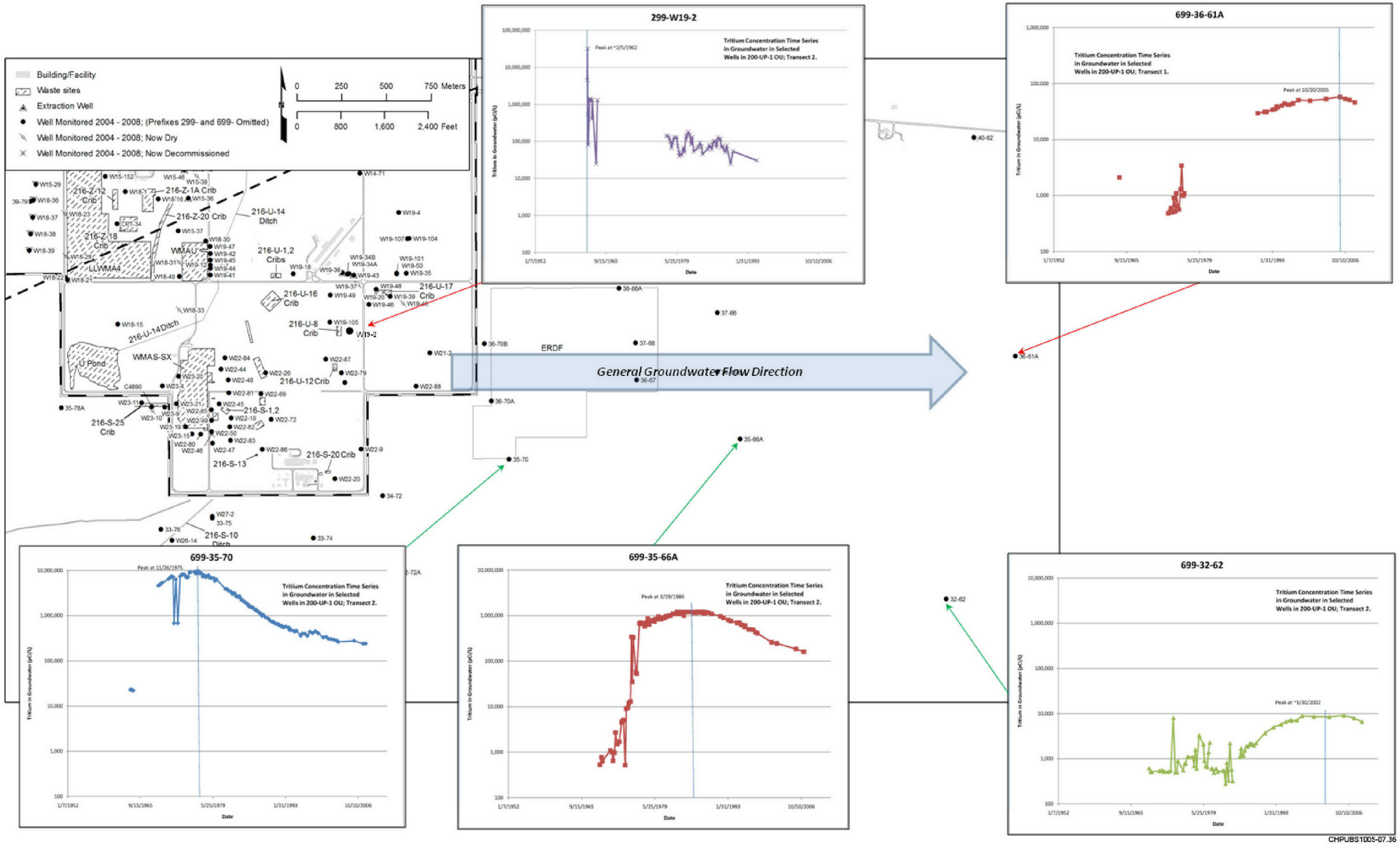

Figure 3-29. Arrival Peaks for Tritium in Selected Groundwater Monitoring Wells in the 200-UP-1 Groundwater Operable Unit

PNNL has conducted ecological characterization on the Site since the early 1970s. The most recent characterization for the 200 Area, performed under the ECAP, is reported in the "200 Areas Ecological Data Compilation," and includes community descriptions and species identifications, estimated frequencies of occurrence of plants and wildlife, and mapping data, including rare plant and sensitive habitat locations (PNNL-13230, PNNL-13331, PNNL-13487, and PNNL-13745). Other ecological reports include the "200 Areas Ecological Data Compilation," included in the Hanford Site Environmental Reports (PNNL-11795, PNNL-12088, PNNL-13487, PNNL-13910, PNNL-14295, PNNL-14687, PNNL-15222, PNNL-16623, PNNL-17603), PNNL-13688, and PNNL-14233.

3.9.1 Native Shrub-Steppe Habitat

In the native shrub-steppe habitat, the most prevalent shrub is big sagebrush (*Artemisia tridentata*). The understory is dominated by the native perennial, Sandberg bluegrass (*Poa secunda* formerly *sandbergii*), and the introduced annual cheatgrass (*Bromus tectorum*). Of the native species observed during the ECAP survey conducted by PNNL in 2001, Sandberg bluegrass (*Poa secunda* formerly *sandbergii*), hoary aster (*Machaeranthera canescens*), and rabbitbrush (*Chrysothamnus* sp. and *Ericameria* sp.) were the most widely distributed. Figure 3-30 and Figure 3-31, respectively, show the distribution of vegetation types before the 2000 wildfire and the burn area after the wildfire.

3.9.2 Disturbed Habitat

Areas of disturbed habitat include bare ground, gravel, or asphalt areas that may have sparse vegetation, and areas planted with non-native wheatgrasses. The disturbed habitat communities are primarily the result of either range fires or mechanical disturbance (from road clearing or construction). Large portions of vegetation and some dunes were burned during a June–July 2000 range fire. Most perennial plants have returned; however, big sagebrush (*Artemisia tridentata*) may take considerably longer to recover than perennial bunchgrass areas (PNNL-6415). Reestablishment for mature sagebrush stands will most likely take 10 to 20 years and in some areas has been augmented by planting. In addition, some of the burned areas continue to be invaded by non-indigenous plant species such as Russian thistle (*Salsola kali*) and tumble mustard (*Sisymbrium altissimum*).

Other disturbed and non-vegetated (gravel or asphalt) areas have minimal vegetative cover and are primarily colonized by nonnative annual species, such as Russian thistle (*Salsola kali*), tumble mustard (*Sisymbrium altissimum*), and cheatgrass (*Bromus tectorum*) (DOE/RL-2001-54). The vegetation around former waste ponds and ditches has mostly died off, due to stabilization activities, but may include black cottonwood (*Populus balsamifer* ssp. *trichocarpa*), willows (*salix* sp.), sedges (*Carex* sp.), and cattails (*Typha latifolia*).

3.9.3 Animal Species Inhabiting the Native Shrub-Steppe Habitat

Species lists have been compiled for the major classes of vertebrates that have been observed on the Site or within the Hanford Reach of the Columbia River and include 46 species of mammals, 145 species of birds, 10 species of reptiles, 5 species of amphibians, and 45 species of fish (PNNL-6415). The shrub and grassland habitat of the Site supports many groups of terrestrial wildlife. Table 3-2 presents some of the more common and representative species with associated habitat found at or near the Central Plateau. The most abundant mammal is the Great Basin pocket mouse (*Perognathus parvus*). Many of the rodent species and some predators (badgers [*Taxidea taxus*]) construct burrows on the Site. In addition, other non-burrowing animals that may utilize abandoned burrows include Nuttall's cottontail (*Sylvilagus nuttallii*), black-tailed jackrabbits (*Lepus californicus*), and snakes. The burrowing owl (*Athene cunicularia*) has been known to do both.

3.9.4 Bird Species Inhabiting the Native Shrub-Steppe Habitat

Shrub-steppe and grassland provide nesting and foraging habitat for many passerine bird species, including 41 species that are dependent on undisturbed habitat. The most common species include the western meadowlarks (*Sturnella neglecta*) and horned larks (*Eremophila alpestris*) (PNNL-6415). Long-billed curlews (*Numenius americanus*) and vesper sparrows (*Pooecetes gramineus*) were the most commonly occurring species in shrub-steppe habitat. Species that are dependent on undisturbed habitat include sage sparrows (*Amphispiza belli*), sage thrashers (*Oreoscoptes montanus*), and loggerhead shrikes (*Lanius ludovicianus*). Common upland gamebird species that occur in shrub and grassland habitat include chukar (*Alectoris chukar*), partridge (*Perdix perdix*), California quail (*Callipepla californica*), and ring-necked pheasant (*Phasianus colchicus*).

Greater sage grouse (*Centrocercus urophasianus*) were historically abundant on the Site; however, the June 2000 fire destroyed the habitat, and it is unlikely that the grouse will return until the vegetation has recovered to a point where it can support them. Trees, while not normally found in arid steppe habitat, are now used for roosting, loafing, and breeding in areas that previously did not support populations of herons and raptors. Among the more common raptor species that use shrub and grassland habitat are the ferruginous hawk (*Buteo regalis*)—a state threatened species—Swainson's hawk (*Buteo swainsoni*), and the red-tailed hawk (*Buteo jamaicensis*). Table 3-3 presents representative avian species associated with specific habitat type.

3.9.5 Amphibians, Reptiles, and Insect Species Inhabiting the Native Shrub-Steppe Habitat

The side-blotched lizard (*Uta stansburiana*) is the most abundant reptile species occurring on the Site (PNNL-6415). The most common snake species include gopher snake (*Pituophis catenifer*), eastern racer (*Coluber constrictor*), and western rattlesnake (*Crotalus viridis*). Many species of insects are found throughout all habitats of the Site—butterflies, grasshoppers, and darkling beetles (*Eleodes* sp.) being among the most conspicuous. A total of 1,509 species-level identifications have been completed, and the collection of 40,000 specimens has resulted in the identification of 43 new taxa and 142 new findings in the State of Washington (TNC, 1999). The high diversity of insect species on the Site reflects the size, complexity, and relatively undisturbed quality of the shrub-steppe habitat. Table 3-4 shows the representative species associated with specific habitat types.

3.9.6 Animal Species Inhabiting Disturbed Habitat

The disturbed-ground habitat provides little to no vegetative cover and low diversity of plant species. Overall animal diversity is low; however, transplanted trees associated with ponds and ditches, and structures and fences associated with buildings, attract bird species that are less common in other habitat types (Say's phoebe [*Sayornis saya*], western kingbird [*Tyrannus verticalis*], and hawks) (DOE/RL-2002-69). Mammals associated with these buildings and facilities include Nuttall's cottontail (*Sylvilagus nuttallii*), house mice (*Mus musculus*), Norway rats (*Rattus norvegicus*), and various bat species (DOE/RL-2001-54).

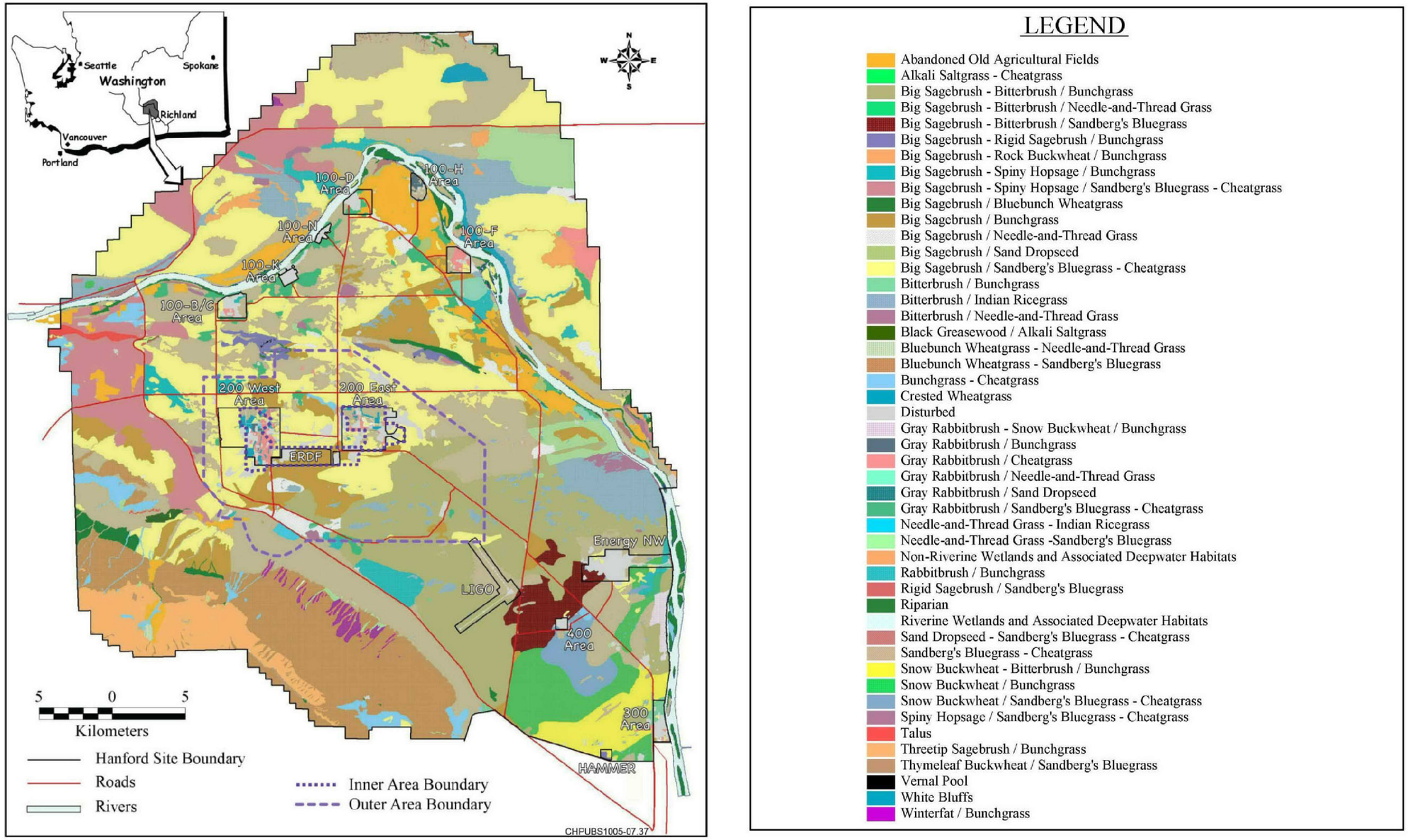

Figure 3-30. Distribution of Vegetation Types and Areas Before the 2000 Fire (Modified from PNNL-6415)

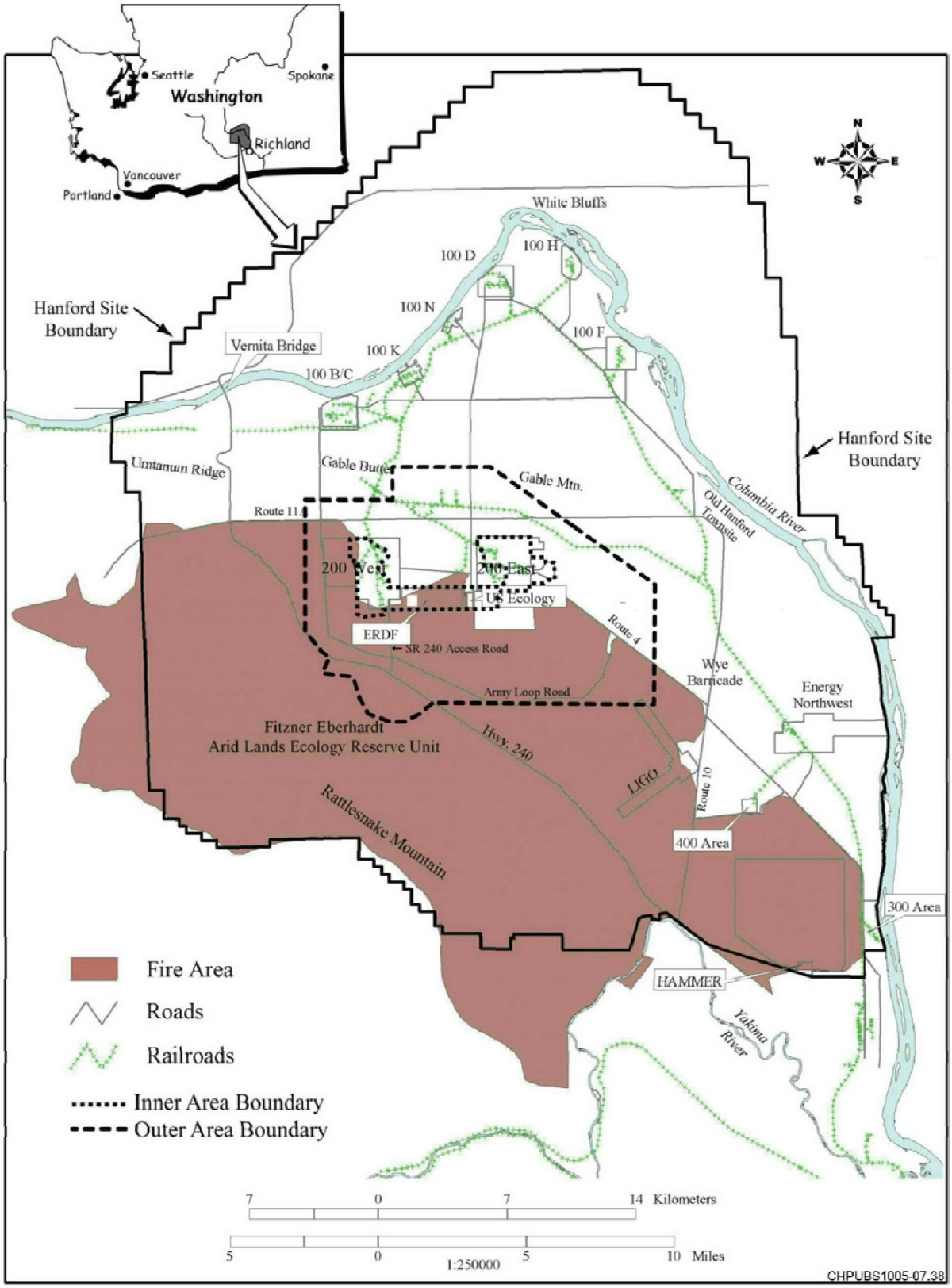

Figure 3-31. Burned Area After the June 27–July 2, 2000, Fire (Modified from PNNL-6415)

Table 3-2. Representative Mammals with Associated Central Plateau Habitat (DOE/RL-2001-54)

Feeding Guilds	Scientific Name	Shrub	Grass/Forbs	Disturbed Revegetated[a]	Disturbed Other[b]
Herbivores					
Black-tailed jackrabbit	*Lepus californicus*	X	X	X	
Bushy-tailed woodrat	*Neotoma cinerea*	X	X	X	X
Elk	*Cervus elaphus*	X	X	X	
Great Basin pocket mouse	*Perognathus parvus*	X	X	X	
Ground squirrel	*Spermophilus* sp.	X	X	X	
Mule deer	*Odocoileus hemionus*	X	X	X	
Northern pocket gopher	*Thomomys talpoides*		X	X	
Nuttall's cottontail	*Sylvilagus nuttallii*	X	X	X	
Sagebrush vole	*Lemmiscus curtatus*	X			
Omnivores					
Deer mouse	*Peromyscus maniculatus*	X	X	X	X
House mouse	*Mus musculus*			X	X
Insectivores					
Little brown bat	*Myotis lucifugus*				X
Long-legged myotis	*Myotis volans*				X
Northern grasshopper mouse	*Onychomys leucogaster*	X			
Pallid bat	*Antrozous pallidus*				X
Silver-haired bat	*Lasionycteris noctivagans*				X
Western pipistrelle	*Pipistrellus hesperus*				X

Table 3-2. Representative Mammals with Associated Central Plateau Habitat (DOE/RL-2001-54)

Feeding Guilds	Scientific Name	Shrub	Grass/Forbs	Disturbed Revegetated[a]	Disturbed Other[b]
Carnivores					
Badger	*Taxidea taxus*	X	X	X	
Bobcat	*Lynx rufus*	X	X	X	
Coyote	*Canis latrans*	X	X	X	

a. Re-vegetated annuals and grasses

b. Planted trees, power lines, buildings, fences, gravel, and asphalt

Table 3-3. Representative Birds with Associated Central Plateau Habitat (DOE/RL-2001-54)

Feeding Guilds	Scientific Name	Shrub	Grass/Forb	Disturbed/ Revegetated[a]	Disturbed Other[b]
Herbivores					
American goldfinch	*Carduelis tristis*				X
California quail	*Callipepla californica*		X		
Chukar	*Alectoris chukar*	X	X	X	
House finch	*Carpodacus mexicanus*		X		X
House sparrow	*Passer domesticus*	X	X	X	X
Mourning dove	*Zenaida macroura*	X	X		X
Rock dove	*Columbia livia*				X
Sage sparrow	*Amphispiza belli*	X			
Vesper sparrow	*Pooecetes gramineus*	X	X		
Omnivores					
American robin	*Turdus migratorius*	X	X	X	X
Brown-headed cowbird	*Molothrus ater*		X	X	
Dark-eyed junco	*Junco hyemalis*	X	X	X	
Eastern kingbird	*Tyrannus tyrannus*	X	X	X	
European starling	*Sturnus vulgaris*				X
Horned lark	*Eremophila alpestris*	X	X		X
Northern flicker	*Colaptes auratus*				X
Ring-billed gull	*Larus delawarensis*				X

Table 3-3. Representative Birds with Associated Central Plateau Habitat (DOE/RL-2001-54)

Feeding Guilds	Scientific Name	Shrub	Grass/Forb	Disturbed/ Revegetated[a]	Disturbed Other[b]
Ring-necked pheasant	*Phasianus colchicus*		X		
Ruby-crowned kinglet	*Regulus calendula*				X
Sage thrasher	*Oreoscoptes montanus*	X			
Varied thrush	*Ixoreus naevius*	X			X
Western kingbird	*Tyrannus verticalis*	X	X	X	X
Western meadowlark	*Sturnella neglecta*	X	X	X	
Insectivores					
Barn swallow	*Hirundo rustica*		X	X	X
Common nighthawk	*Chordeiles minor*				X
Killdeer	*Charadrius vociferous*		X	X	X
Loggerhead shrike	*Lanius ludovicianus*	X			X
Long-billed curlew	*Numenius americanus*		X	X	
Red-winged blackbird	*Agelaius phoeniceus*		X		X
Rock wren	*Salpinctes obsoletus*				X
Yellow warbler	*Dendroica petechia*				X
Carnivores					
American kestrel	*Falco sparverius*	X			X
Barn owl	*Tyto alba*				X
Burrowing owl	*Athene cunicularia*	X			X
Common raven	*Corvus corax*	X	X	X	X
Long-eared owl	*Asio otus*				X
Northern harrier	*Circus cyaneus*	X	X	X	
Red-tailed hawk	*Buteo jamaicensis*	X			X
Sharp-shinned hawk	*Accipiter striatus*	X			X

a. Re-vegetated annuals and grasses

b. Planted trees, power lines, buildings, fences, gravel, and asphalt

Table 3-4. Representative Amphibians and Reptiles with Associated Central Plateau Habitat (DOE/RL-2001-54)

Feeding Guilds	Scientific Name	Shrub	Grass/Forbes	Disturbed/ Revegetated[a]	Disturbed Other[b]
Insectivores					
Great Basin spadefoot toad	*Scaphiopus intermontana*				X
Sagebrush lizard	*Sceloporus graciosus*	X			
Side-blotched lizard	*Uta stansburiana*	X	X	X	
Woodhouse's toad	*Anaxyrus woodhousii*				X
Carnivores					
Eastern racer	*Coluber constrictor*	X	X	X	
Gopher snake	*Pituophis catenifer*	X	X	X	
Western rattlesnake	*Crotalus viridis*	X			X

a. Re-vegetated annuals and grasses

b. Planted trees, power lines, buildings, fences, gravel, and asphalt

3.9.7 Special Status Species

Multiple species of concern (state endangered, threatened, sensitive, review group 1, or review group 2 by the Washington National Heritage Program and/or the Washington Department of Fish and Wildlife) may occur on the Central Plateau (Table 3-5) (WDFW, 2009; WHNP, 2009; and PNNL, 2009). Species that are associated with specific localities, altitude, not within the Central Plateau, or riparian and river habitat are omitted from this list, with the exceptions of the bald eagle (*Haliaeetus leucocephalus*), the peregrine falcon (*Falco peregrinus*), and the golden eagle (*Aquila chrysaetos*). While these species are dependent on the river corridor, they are occasionally observed on the Central Plateau. Additionally, although the pygmy rabbit (*Brachylagus idahoensis*), a federal and state endangered species, has not been observed on the Central Plateau, it has been seen on the Arid Lands Ecology Reserve (ALE Reserve) and is included in Table 3-5.

Fauna are managed by the Washington Department of Fish and Wildlife, and all migratory birds are also protected by the *Migratory Bird Treaty Act of 1918* (WNHIS, 2009). The species of concern were determined by comparison of the flora list from the Washington Natural Heritage Program: List of Plants Tracked by the Washington Natural Heritage Program, current through January 2009; the fauna list from the Washington Department of Fish and Wildlife Species of Concern: Species of Concern in Washington State, current through June 1, 2009; and the lists of species that were identified on the Site according to PNNL. These lists were then screened for the Central Plateau based on their habitat, where they have been found in the past, and input from subject matter experts.

Table 3-5. Species of Concern That May Occur on the Central Plateau

Common Name(s)	Scientific Name(s)	State Classification	Federal Classification
Plants			
Great Basin gilia	*Aliciella leptomeria*	Threatened	None
Geyer's milk-vetch	*Astragalus geyeri*	Threatened	None
Rosy pussypaws/rosy calyptridium	*Cistanthe rosea*	Threatened	None
Desert dodder	*Cuscuta denticulata*	Threatened	None
Loeflingia	*Loeflingia squarrosa* var. *squarossa*	Threatened	None
Small-flowered evening primrose/ small-flowered desert primrose	*Camissonia minor*	Sensitive	None
Dwarf evening-primrose/dwarf desert primrose	*Camissonia pygmaea*	Sensitive	None
Gray cryptantha	*Cryptantha leucophaea*	Sensitive	None
Piper's daisy	*Erigeron piperianus*	Sensitive	None
Suksdorf's monkey-flower	*Mimulus suksdorfii*	Sensitive	None
Coyote tobacco	*Nicotiana attenuata*	Sensitive	None
Birds			
Sage sparrow	*Amphispiza belli*	Endangered	None
Sandhill crane	*Grus canadensis*	Endangered	None
Ferruginous hawk	*Buteo regalis*	Threatened	Species of concern
Greater sage grouse	*Centrocercus urophasianus*	Threatened	Candidate
Burrowing owl	*Athene cunicularia*	Candidate	Species of concern
Golden eagle	*Aquila chrysaetos*	Candidate	None
Loggerhead shrike	*Lanius ludovicianus*	Candidate	Species of concern
Sage thrasher	*Oreoscoptes montanus*	Candidate	None
Bald eagle	*Haliaeetus leucocephalus*	Sensitive	Species of concern
Peregrine falcon	*Falco peregrinus*	Sensitive	Species of concern

Table 3-5. Species of Concern That May Occur on the Central Plateau

Common Name(s)	Scientific Name(s)	State Classification	Federal Classification
Mammals			
Pygmy rabbit	*Brachylagus idahoensis*	Endangered	Endangered
Black-tailed jackrabbit	*Lepus californicus*	Candidate	None
White-tailed jackrabbit	*Lepus townsendii*	Candidate	None
Merriam's shrew	*Sorex merriami*	Candidate	None
Townsend's ground squirrel	*Spermophilus townsendii*	Candidate	Species of concern
Washington's ground squirrel	*Spermophilus washingtoni*	Candidate	Candidate
Amphibians and Reptiles			
Striped whipsnake	*Masticophis taeniatus*	Candidate	None
Northern sagebrush lizard	*Sceloporus graciosus*	Candidate	Species of concern

4 Nature and Extent of Contamination

This chapter presents a comprehensive interpretation of the spatial distribution of groundwater contamination within the 200-UP-1 Groundwater OU. The data used for this interpretation consisted of the results of groundwater sampling conducted to support the RI (DOE/RL-92-76, Rev. 1), additional sampling conducted under RCRA, and additional groundwater monitoring performed under CERCLA for the ERDF. The monitoring program for the 200-UP-1 RI/FS was guided by an extensive list of COPCs, which were presented in DOE/RL-92-76, Rev. 1. These constituents were grouped into two categories: high-priority COPCs identified during a previous DQO process (BHI-01576) and additional COPCs identified specifically for the RI (CP-15315, DOE/RL-92-76, Rev. 1).[1] The high-priority COPCs are arsenic, cadmium, carbon tetrachloride, chloroform, chromium (total), I-129, nitrate, Sr-90, Tc-99, TCE, tritium, and uranium (total). The additional COPCs included an extensive list of VOCs, metals, anions, ammonium ion, ammonia, cyanide, sulfide, cresols, phenols, total petroleum hydrocarbons (kerosene range), and several radionuclides: beta emitters C-14 and Se-79, alpha emitters Np-237, protactinium-231 (Pa-231), U-234, U-235, and U-238, and gamma emitters Cs-137 and Co-60. The high-priority constituents were sampled extensively in wells throughout much of the OU, while sampling for the additional constituents was largely, but not entirely, focused on the newly installed wells. Much of the groundwater sampling performed for the RI was directed toward identifying whether the COPCs were present in groundwater, and if so, to determine their concentration levels and spatial extent.

The following subsections provide information on background concentrations for the COPCs (Section 4.1), the current spatial distribution of contamination within the OU (Section 4.2), and a summary of the IRAs (Section 4.3). Potential sources of groundwater contamination within the OU were discussed in Section 1.2. Specific sources of groundwater contamination, where known, are also described in the following subsections.

4.1 Background Concentrations

Information on background concentrations of the COPCs are needed for two purposes. First, comparison of groundwater sampling results with background concentration levels is fundamental to determining whether a particular constituent in the groundwater is a result of waste disposal operations. If a constituent occurs in groundwater at concentrations substantially above the range of background values and there is sufficient process knowledge, it may be concluded that the constituent is a contaminant. Second, background concentrations are used as a lower bound on cleanup levels. For example, if a cleanup level determined under the MTCA (WAC 173-340) is below the natural background concentration, the cleanup level will be adjusted upward to the natural background concentration (or the practical quantitation limit, whichever is higher).

The two types of background concentrations include natural and anthropogenic. Ecology defines natural background as "the concentration of hazardous substance consistently present in the environment that has not been influenced by localized human activities" (WAC 173-340-200). Thus, radionuclides in the groundwater as a result of global fallout are considered natural because they are not a result of localized activity. Anthropogenic background is a constituent concentration level, upgradient from the facility under consideration, resulting from waste disposal operations at another facility. For example, levels of a contaminant detected above the natural background in an upgradient well at a waste site monitored under RCRA constitute an anthropogenic background, because the contaminant did not originate from the facility being monitored. Concentrations in the downgradient wells would be compared to this

[1] A third category consists of six constituents that were added as COPCs during preparation of this RI/FS: aluminum, bromodichloromethane, chloromethane, styrene, thallium, and trans-1,3-dichloropropene.

anthropogenic background concentration to determine if the facility itself has impacted groundwater. Some contaminants present in the groundwater at the 200-UP-1 Groundwater OU are interpreted to have originated from disposal facilities in the adjacent 200-ZP-1 Groundwater OU, particularly carbon tetrachloride, chloroform, and TCE. Establishing anthropogenic background concentrations for these contaminants is important for determining whether the 200-UP-1 Groundwater OU may also have been a source of these contaminants. Anthropogenic background concentrations are not used as a lower bound on cleanup levels; only natural background concentrations are used for this purpose.

Natural background concentrations of inorganic chemicals and radionuclides for the Site were presented in DOE/RL-96-61, and were determined by evaluating historical sample results and analysis of new sample results collected from a network of Site monitoring wells. The monitoring wells were chosen through a systematic process of identifying wells in the unconfined aquifer not impacted by contaminants originating from the Site. Because the sample results from these wells exhibited a range of values and a skewed right distribution, the background concentration levels were statistically specified by the geometric mean, geometric standard deviation, minimum, maximum, 90th, and 95th percentiles. Table 4-1 shows these values for the inorganic and radionuclide COPCs. Organic compounds that are not naturally present in the environment, such as carbon tetrachloride, are assumed to have natural background concentrations of zero. The maximum, 90th, and 95th percentile natural background concentrations for nitrate are relatively high at 28, 27, and 42 mg/L, respectively (Table 4-1). This is the result of nitrate migrating onto the Site from offsite sources. Since this nitrate did not originate from local activities (Site activities), it was considered part of the natural background in DOE/RL-96-61.

Representative anthropogenic background concentrations for the organic constituents interpreted to have originated from the 200-ZP-1 Groundwater OU are difficult to determine. Current concentrations within the 200-ZP-1 Groundwater OU do not necessarily reflect the concentration levels of the contaminants that had migrated into the 200-UP-1 Groundwater OU in the past, especially since operation of the 200-ZP-1 IRA P&T system has resulted in lower constituent concentrations. Examining historical concentrations within the 200-ZP-1 Groundwater OU would be more appropriate, but determining the time period to examine is not straightforward. Therefore, to simplify the determination of anthropogenic background concentrations, sampling results within the 200-ZP-1 Groundwater OU covering the time period of the RI (2004–2008) were analyzed to estimate anthropogenic background levels. Such concentrations are to be used in conjunction with scientific judgment to determine whether the 200-UP-1 Groundwater OU may also have been a source of organic constituents in the groundwater.

Table 4-1. Natural Background Concentrations for Inorganic and Radionuclide Contaminants of Potential Concern[a] (DOE/RL-96-61)

Constituent	Units	Number of Samples	Geometric Mean	Geometric Standard Deviation	Minimum	Maximum	90th Percentile	95th Percentile
Aluminum (filtered)	µg/L	32	1.23	3.92	0.5	187	7.11	11.7
Ammonia	µg/L	32	26.2	3,120	5	882	113	170
Antimony (filtered)	µg/L	15	23.8	1.92	9.47	53.9	55.1	69.8
Arsenic (filtered)	µg/L	29	1.83	3.11	0.5	8.81	7.85	11.8
Cadmium (filtered)	µg/L	32	0.274	2.57	0.05	0.5	0.916	1.29
Cesium-137	pCi/L	17	2.26	0.00226	0.000643	0.0295	0.00843	0.0122
Chromium (total, filtered)	µg/L	27	0.893	2.16	0.5	4.41	2.4	3.17
Cobalt (filtered)	µg/L	32	0.274	2.57	0.05	0.5	0.916	1.29
Cobalt-60	pCi/L	17	0.00109	0.00243	0.000404	0.023	0.0225	0.0447
Cyanide	µg/L	25	5.43	1,407	5	26.7	8.41	9.52
Fluoride	mg/L	28	0.491	0.0018	0.267	5.85	1.047	1.298
Iodine-129	pCi/L	9	0.0000288	0.00000251	0.0000063	0.0000961	0.0000939	0.000131
Iron (filtered)	µg/L	22	55.3	6.17	6	7,225	570	1,104
Lead (filtered)	µg/L	31	0.271	2.59	0.05	0.5	0.917	1.3
Magnesium (filtered)	µg/L	25	11,245	1.85	825	39,600	24,816	31,051
Manganese (filtered)	µg/L	32	2.22	9.25	0.05	94.4	38.5	86.4
Mercury (filtered)	µg/L	27	0	5.34	0	0.012	0.003	0.006
Nitrate	mg/L	26	5.681	3.361	0.085	28.063	26.871	41.723
Strontium-90	pCi/L	14	0.00478	0.00239	0.000641	0.0156	0.0146	0.02
Sulfide	mg/L	32	0.00171	0.00121	0.0016	0.00321	0.00219	0.00235

Table 4-1. Natural Background Concentrations for Inorganic and Radionuclide Contaminants of Potential Concern[a] (DOE/RL-96-61)

Constituent	Units	Number of Samples	Geometric Mean	Geometric Standard Deviation	Minimum	Maximum	90th Percentile	95th Percentile
Technetium-99	pCi/L	5	0.447	1.62	0.271	0.752	0.83	0.988
Thallium (filtered)	µg/L	4	1.14	1.35	0.883	1.73	1.67	1.87
Tritium	pCi/L	15	63.9	1.63	27.8	131	119	142
Uranium	µg/L	25	2.57	2.85	0.5	12.8	9.85	14.4
Uranium-234	pCi/L	2	0.75	1.1	0.7	0.803	0.849	0.88
Uranium-235	pCi/L	17	0.0231	0.00334	0.00155	0.114	0.108	0.167
Uranium-238	pCi/L	17	0.721	0.00189	0.15	2.44	1.63	2.05
Vanadium (filtered)[b]	µg/L	32	1.83	4.19	0.5	16.7	11.5	19.3

a. The organic COPCs 1,1-dichloroethene, 1,2-dichloroethane, 1,4-dioxane, bromodichloromethane, carbon tetrachloride, chloroform, chloromethane, styrene, tetrachloroethene, trans-1, 3-dichloropropene, and trichloroethene are assumed to have natural background concentrations of zero.

b. Sample results during the RI suggest that the vanadium natural background values presented in this table are too low to be representative of the natural background for the 200-UP-1 Groundwater OU.

To estimate anthropogenic background concentrations, sample results for each organic COPC within the southern part of the 200-ZP-1 Groundwater OU were examined. For each 200-ZP-1 Groundwater OU well within the 200 West Area and within 500 m (1,640 ft) of the boundary between the 200-UP-1 and 200-ZP-1 Groundwater OUs, the maximum sampled concentration between 2004 and 2008 was determined. These values were statistically analyzed to determine the arithmetic mean, arithmetic standard deviation,[2] minimum, maximum, and 90th, and 95th percentiles for each constituent; these values are presented in Table 4-2. Three constituents had a mean concentration above their respective DWSs: carbon tetrachloride at 1,680 μg/L (5 μg/L DWS), chloroform at 87 μg/L (80 μg/L DWS), and TCE at 7 μg/L (5 μg/L DWS). The sample results for 1,2-dichloroethane, 1,4-dioxane, styrene, and trans-1,3-dichloropropene were essentially all non-detects, so the anthropogenic background concentrations for these constituents are considered to be zero and they are not shown in Table 4-2.

4.2 Well Locations and Distribution of Contaminants

Table 4-3 summarizes the results of groundwater sampling within the 200-UP-1 Groundwater OU during the RI. For each COPC, this table shows the total number of analyses performed, the number of detections, the median and maximum values of the detections, the number of detections that exceeded the natural background concentration (where available), and the number of detections that exceeded a DWS (where applicable). For the high-priority COPCs, all are present in groundwater above background levels except for arsenic and cadmium. Arsenic occurs naturally in groundwater at concentrations above the laboratory detection limit, so this constituent was frequently detected. Only a few detections of cadmium were found, and these may very well have been false-positive analytical results. The only additional COPCs that occur in the groundwater at concentrations substantially above the natural background are 1,4-dioxane, bromodichloromethane, C-14, chloromethane, hexavalent chromium, magnesium, methylene chloride, Se-79, tetrachloroethene (PCE), U-234, U-235, and U-238.

The detailed results of groundwater sampling performed during the RI for the high-priority COPCs are presented in Sections 4.2.1 through 4.2.8. The groundwater sampling results for the additional COPCs are presented in Section 4.2.9. Unless otherwise noted, the groundwater plume maps represent constituent concentrations in the upper part of the unconfined aquifer, based on average concentrations for samples collected during FY 2008. They are the same as those presented in DOE/RL-2008-66, except the chromium plume east-southeast from the 200 West Area was re-interpreted as part of this RI. Cross-sectional plume interpretations are largely based on depth-discrete sampling during drilling of newly installed monitoring wells. In addition, more recent sample results from each well are shown. Thus, the data shown on these cross sections were collected over a period of several years and may not be exactly representative of current conditions because of plume concentration changes over time. The cross sections are consistent with the FY 2008 plume maps, which represent the plume distribution at the water table. Table 4-4 lists the depth-discrete sampling results obtained during drilling. The DWS plume contours for the high-priority COPCs are shown collectively on Plate 1 (Appendix A). Well and cross section locations are shown in Figure 4-1 and on Plate 1 (Appendix A).

[2] The sample results were not skewed right as the data used for the natural background, so the arithmetic mean and standard deviation were used to represent these data instead of their geometric counterparts.

Table 4-2. Anthropogenic Background Concentrations for the Organic Contaminants of Potential Concern*

Constituent	Units	Number of Samples	Arithmetic Mean	Arithmetic Standard Deviation	Minimum	Maximum	90th Percentile	95th Percentile
1,1-Dichloroethene	µg/L	18	0.2	0.3	0.02	1.0	0.5	0.7
Bromodichloromethane	µg/L	8	1.2	1.7	0.09	5.3	2.7	4.0
Carbon tetrachloride	µg/L	19	1,680	1,390	2.1	4,096	3,660	3,920
Chloroform	µg/L	19	87	248	0.2	1,100	119	218
Chloromethane	µg/L	9	3.8	6.8	0.045	21	9.6	15.3
Methylene chloride	µg/L	18	10	20	0.05	77	15.3	30
Tetrachloroethene	µg/L	19	2.0	1.9	0.04	6.4	4.2	4.6
Trichloroethene	µg/L	19	7	8	0.0185	36	13	17

* 1,2-Dichloroethane, 1,4-dioxane, styrene, and trans-1,3-dichloropropene were not detected in the southern 200-ZP-1 Groundwater OU and, therefore, have anthropogenic background concentrations of zero.

Table 4-3. Summary of Sample Results for Contaminants of Potential Concern[a]

Constituent	Number of Analyses	Number of Detections	Median of Detections[b]	Maximum of Detections[b]	Natural Background (95th Percentile)	Number of Results Above Background[b]	Drinking Water Standard	Number of Results Above Drinking Water Standard[b]	Comment
High-Priority Contaminants of Potential Concern									
Arsenic (filtered), µg/L	222	149	3.36	27.5	11.8	1	10	1	Maximum result is likely a false positive
Arsenic (unfiltered), µg/L	125	87	3.31	6.9	--	--	10	0	
Cadmium (filtered), µg/L	909	3	2.2	4.5	1.29	2	5	0	
Cadmium (unfiltered), µg/L	364	1	N/A	N/A	--	--	5	0	Single detection flagged as "suspect"
Carbon tetrachloride, µg/L	693	639	57	1,600	0	614	5	529	
Chloroform, µg/L	696	581	2.6	35	0	562	80	0	
Chromium (filtered), µg/L	922	567	9.15	1,750	3.17	511	100	90	
Chromium (unfiltered), µg/L	376	237	20.7	1,100	--	--	100	39	
Iodine-129, pCi/L	540	193[c]	2.42	38.7	0.000131	191	1	180	
Nitrate, mg/L	1,248	1,248	42.2	1,740	41.723	565	45	538	
Strontium-90, pCi/L	157	13	1.04	32	0.02	11	8	2	
Technetium-99, pCi/L	1,245	1,122	292	137,000	0.988	1,098	900	351	
Trichloroethene, µg/L	696	295	1.1	13	0	291	5	52	
Tritium, pCi/L	540	401	13,000	1,020,000	142	398	20,000	143	
Uranium (total), µg/L	940	891	4.79	613	14.4	304	30	260	
Additional Contaminants of Potential Concern Identified in the RI/FS Work Plan (DOE/RL-92-76, Rev. 1)									
1,1,1-Trichloroethane, µg/L	695	0	N/A	N/A	0	0	200	0	
1,1-Dichloroethene, µg/L	636	1	0.11	0.11	0	1	--	--	Single detection is most likely a false-positive result
1,2-Dichloroethane, µg/L	695	2	0.66	0.66	0	1	--	--	One detection flagged to indicate a QC problem
1,4-Dioxane, µg/L	390	1	120	120	0	1	--	--	
4-methyl-2-Pentanone, µg/L	695	1	4.3	4.3	0	1	--	--	Single detection is most likely a false-positive result
Acetone, µg/L	695	63	1.8	29	0	53	--	--	Common laboratory contaminant
Ammonia, µg/L	37	6	N/A	N/A	170	0	--	--	All six detections flagged to indicate a QC problem
Ammonium ion, µg/L	49	21	15.7	42.6	--	--	--	--	
Antimony (filtered), µg/L	909	16	3.7	41	69.8	0	6	3	Results above the DWS are most likely false positives
Antimony (unfiltered), µg/L	364	13	3.3	3.7	--	--	6	0	
Butanol (1-butanol), µg/L	574	1	N/A	N/A	0	0	--	--	Single detection flagged as "suspect"
Carbon disulfide, µg/L	695	23	0.46	3.1	--	--	--	--	
Carbon-14, pCi/L	135	17	12.1	32.9	--	--	2,000	0	

Table 4-3. Summary of Sample Results for Contaminants of Potential Concern[a]

Constituent	Number of Analyses	Number of Detections	Median of Detections[b]	Maximum of Detections[b]	Natural Background (95th Percentile)	Number of Results Above Background[b]	Drinking Water Standard	Number of Results Above Drinking Water Standard[b]	Comment
Cesium-137, pCi/L	146	0	N/A	N/A	0.0122	0	200	0	
Chromium (hexavalent, filtered, and unfiltered), µg/L	144	89	10	236	--	--	100	5	
Cobalt (filtered), µg/L	909	90	4.35	16.3	1.29	57	--	--	
Cobalt (unfiltered), µg/L	364	30	6.0	15.5	--	--	--	--	
Cobalt-60, pCi/L	146	0	N/A	N/A	0.0447	0	100	0	
Cresols (total), µg/L	49	0	N/A	N/A	0	0	--	--	
Cyanide, µg/L	81	3	6.5	25.1	9.52	1	200	0	
Ethyl acetate, µg/L	73	0	N/A	N/A	0	0	--	--	
Fluoride, mg/L[d]	1,248	1,231	0.35	0.69	1.298	0	2	0	
Iron (filtered), µg/L	909	443	30.1	314	1,104	0	300	1	
Iron (unfiltered), µg/L	364	303	89	3,780	--	--	300	46	High concentrations generally associated with high-turbidity samples
Kerosene, µg/L	75	0	N/A	N/A	0	0	--	--	
Lead (filtered), µg/L	143	5	2.0	3.3	1.3	4	15	0	
Lead (unfiltered), µg/L	100	7	2.0	37.7	--	--	15	1	Single result above the DWS is likely a false positive
Lithium (filtered), µg/L	89	46	5.3	12.8	--	--	--	--	
Lithium (unfiltered), µg/L	66	48	5.5	13.5	--	--	--	--	
Magnesium (filtered), µg/L	909	909	9,900	98,600	31,051	23	--	--	
Magnesium (unfiltered), µg/L	364	364	10,250	44,700	--	--	--	--	
Manganese (filtered), µg/L	909	453	3.6	372	86.4	6	50	11	
Manganese (unfiltered), µg/L	364	139	7.3	88.5	--	--	50	6	
Mercury (filtered), µg/L	106	7	0.07	0.08	0.006	4	2	0	
Mercury (unfiltered), µg/L	63	3	0.06	0.08	--	--	2	0	
Methyl ethyl ketone (2-Butanone), µg/L	695	4	2	2	0	4	--	--	Common laboratory contaminant
Methylene chloride, µg/L	695	69	2	16	0	66	5	8 (?)	Common laboratory contaminant
Neptunium-237, pCi/L	82	4	0.028	0.033	--	--	--	--	
Nitrite, mg/L	1,248	120	0.164	1.61	--	--	3.3	0	68% of the detections flagged as outliers or have QC problems
Phenols, µg/L	67	7	N/A	N/A	0	0	--	--	All detections flagged to indicate a QC problem
Protactinium-231, pCi/L	64	0	N/A	N/A	--	--	--	--	

Table 4-3. Summary of Sample Results for Contaminants of Potential Concern[a]

Constituent	Number of Analyses	Number of Detections	Median of Detections[b]	Maximum of Detections[b]	Natural Background (95th Percentile)	Number of Results Above Background[b]	Drinking Water Standard	Number of Results Above Drinking Water Standard[b]	Comment
Selenium-79, pCi/L	156	38	51.2	2,080	--	--	--	--	
Sulfide, mg/L	70	4	1.4	1.6	0.00235	4	--	--	
Tetrachloroethene, µg/L	695	54	0.34	3.8	0	49	5	0	
Toluene, µg/L	695	0	N/A	N/A	0	0	--	--	Common laboratory contaminant
Uranium-234, pCi/L	42	42	0.81	166	0.88	18	--	--	
Uranium-235, pCi/L	42	7	0.54	7.14	0.167	7	--	--	
Uranium-238, pCi/L	42	39	0.52	170	2.05	8	--	--	
Vanadium (filtered), µg/L	921	910	25.7	45.5	19.3 (?)	725 (?)	--	--	
Vanadium (unfiltered), µg/L	376	374	26.2	45.8	--	--	--	--	
Xylene, µg/L	695	4	0.36	0.45	0	4	--	--	
Additional Contaminants of Potential Concern Identified for this RI/FS Report									
Aluminum (filtered), µg/L	374	192	41.1	114	11.7	47	50	8	Many results are probably false positives
Aluminum (unfiltered), µg/L	71	44	48.6	109	--	--	50	12	Many results are probably false positives
Bromodichloromethane, µg/L	189	32	0.2	1.1	0	32	80	0	
Chloromethane, µg/L	189	25	0.34	1.3	0	22	--	--	
Styrene, µg/L	189	2	0.20	0.23	0	2	--	--	
Thallium (filtered), µg/L	22	3	9.2	9.2	1.87	1	2	1	Two of the detections flagged to indicate a QC problem
Thallium (unfiltered), µg/L	22	2	N/A	N/A	--	--	2	0	Both detections flagged to indicate a QC problem
trans-1,3-Dichloropropene, µg/L	189	1	0.1	0.1	0	1	--	--	

a. Does not include samples collected for characterization purposes during well drilling.

b. Excludes results flagged as "suspect" or "reject" or otherwise flagged to indicate a laboratory QC problem.

c. All results greater than or equal to 1 pCi/L counted as detections.

d. Fluoride was added as a contaminant of potential concern by Ecology in the RI/FS work plan approval letter.

Table 4-4. Depth-Discrete Sampling Results During Well Drilling Within the 200-UP-1 Operable Unit

Well Name and Sample Date Range	Sample Depth		Sample Results										
			Field Parameters					Other Chemicals			Radionuclides		
	Below Land Surface (ft)	Below Water Table (m)	Specific Conductance (µS/cm)	Dissolved Oxygen (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Trichloroethene (µg/L)	Chromium (µg/L)	Nitrate (mg/L)	Uranium (µg/L)	Technetium-99 (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)
299-W14-71	284	2.2	N/A	N/A	N/A	(2)	(ND)	N/A	N/A	N/A	N/A	N/A	N/A
9/14/06-10/13/06	296	5.8	N/A	6,700	(80.7)	(4.76)	(ND)	N/A	12.8 (13)	0.716	ND	ND	ND
	322	13.8	N/A	8,000	(77.9)	(5.5)	(ND)	N/A	10.9 (12)	0.654	17.1	ND	ND
	347	21.4	N/A	7,250	(100)	(3.3)	(ND)	N/A	4.07 (10.5)	0.354	49.6	ND	ND
	367	27.5	N/A	8,200	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	396	36.4	N/A	7,100	(308)	(6.16)	(2.4)	N/A	(6)	0.593	ND	N/A	N/A
	418	43.1	N/A	N/A	1,600	33	13	N/A	8.9	N/A	ND	ND	ND
	421	44	N/A	7,400	(421)	(10)	(3.27)	N/A	6.6 (7)	0.632	ND	ND	ND
	435	48.2	N/A	5,300	(303)	(27)	(2.88)	N/A	(6)	0.466	ND	N/A	N/A
	467	57.9	N/A	N/A	(187)	(16.3)	(ND)	N/A	N/A	0.463	82.1	N/A	N/A
299-W19-101/50	277.5	5.8	N/A	N/A	32.5	1.7	ND	N/A	N/A	78.2	924	N/A	N/A
8/8/05-8/23/05	297.5	11.9	N/A	N/A	89	3.9	4	N/A	N/A	6.6	ND	N/A	N/A
	320	18.7	N/A	N/A	120	3.5	5.7	N/A	N/A	7.62	ND	N/A	N/A
	351	28.2	N/A	N/A	69	7	4.2	N/A	N/A	1.1	ND	N/A	N/A
	380	37	N/A	N/A	120	8.8	4.9	N/A	N/A	1.11	ND	N/A	N/A
299-W19-105	280	7.2	N/A	N/A	(88)	(2.2)	(ND)	N/A	N/A	9.02	205	N/A	N/A
1/11/06-1/16/06	308	15.8	N/A	N/A	(24)	(ND)	(ND)	N/A	N/A	2.66	85.5	N/A	N/A
	339	25.2	N/A	N/A	(19)	(ND)	(ND)	N/A	N/A	1.88	196.5	N/A	N/A
	379	37.4	N/A	N/A	(ND)	(5.4)	(ND)	N/A	N/A	1.04	34.2	N/A	N/A
299-W19-107	287	5	N/A	4,500	(118)	(5.5)	(2.2)	N/A	(21)	4.6	ND	N/A	N/A
3/28/06-4/10/06	300	8.9	N/A	8,900	(156)	(3.5)	(2.3)	N/A	(41)	0.994	ND	N/A	N/A
	320	15	N/A	7,600	(132)	(4.1)	(3.5)	N/A	(44)	1.35	ND	N/A	N/A
	360	27.2	N/A	9,500	(201.5)	(5.85)	(4.8)	N/A	(31)	0.952	ND	N/A	N/A
	400	39.4	N/A	10,300	(115)	(9.7)	(7)	N/A	(16)	0.935	ND	N/A	N/A
	429	48.3	N/A	9,300	(20.6)	(8.4)	(5)	N/A	(13)	0.813	ND	N/A	N/A
299-W19-46	269	4.1	N/A	N/A	N/A	N/A	N/A	N/A	55.8	23.4	153	N/A	ND
11/19/02-11/21/02	280	7.4	N/A	N/A	N/A	N/A	N/A	N/A	30.1	131	163	N/A	597
	300	13.5	357	N/A	98	2	0.46	N/A	35.4	134	212	N/A	ND

Table 4-4. Depth-Discrete Sampling Results During Well Drilling Within the 200-UP-1 Operable Unit

Well Name and Sample Date Range	Sample Depth		Sample Results										
			Field Parameters					Other Chemicals			Radionuclides		
	Below Land Surface (ft)	Below Water Table (m)	Specific Conductance (µS/cm)	Dissolved Oxygen (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Trichloroethene (µg/L)	Chromium (µg/L)	Nitrate (mg/L)	Uranium (µg/L)	Technetium-99 (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)
	320	19.6	N/A	N/A	N/A	N/A	N/A	N/A	179	22.9	1,360	N/A	ND
	340	25.7	453	N/A	46	6.1	2.1	N/A	65.5	2.26	715	N/A	ND
	360	31.8	N/A	N/A	ND	ND	ND	N/A	15.1	0.88	55.7	N/A	ND
	379	37.6	395	N/A	75	8	4	N/A	21.2	1.57	215	N/A	ND
299-W19-48	290	11	N/A	N/A	37	4.25	ND	N/A	332	147	1,450	1.62	490
11/30/04-12/16/04	342.5	27	N/A	N/A	75	10.575	2.5	N/A	21.175	1.275	140	1.07	ND
	400	44.5	N/A	N/A	100	10.85	3.5	N/A	14.1	0.965	33	ND	ND
	414.1	48.8	N/A	N/A	40	8.6	1.2	N/A	15.35	1.63	37	ND	ND
299-W19-49	279	7.6	N/A	N/A	23	1.4	ND	N/A	N/A	111	ND	N/A	N/A
9/1/05-9/6/05	295	12.5	N/A	N/A	63	3.4	ND	N/A	N/A	48	ND	N/A	N/A
	315	18.6	N/A	N/A	130	5	ND	N/A	N/A	30.3	ND	N/A	N/A
	349	29	N/A	N/A	120	3.6	ND	N/A	N/A	2.72	1,320	N/A	N/A
	379	38.1	N/A	N/A	100	5.5	1.6	N/A	N/A	1.6	ND	N/A	N/A
299-W21-2	289	8.4	N/A	N/A	(16)	(ND)	(ND)	N/A	N/A	4.63	257	N/A	N/A
11/24/04-12/7/04	309	14.5	N/A	N/A	(6.5)	(ND)	(ND)	N/A	N/A	2.54	ND	N/A	N/A
	334	22.2	N/A	N/A	(6.4)	(3.5)	(ND)	N/A	N/A	0.92	ND	N/A	N/A
	349	26.7	N/A	N/A	(13)	2.9 (3.1)	1.1 (ND)	N/A	N/A	1.46	ND	N/A	N/A
	369	32.8	N/A	N/A	16 (11)	3.6 (3.2)	1.2 (ND)	N/A	N/A	1.12	34.2	N/A	N/A
	381	36.5	N/A	N/A	13 (8.15)	3.2 (ND)	ND (ND)	N/A	N/A	0.902	51.3	N/A	N/A
299-W22-47	231	0.5	N/A	N/A	N/A	N/A	N/A	1.15[a]	39.67	N/A	306	N/A	N/A
1/10/05-1/21/05	235	1.7	N/A	N/A	N/A	N/A	N/A	0.98[a]	103.13	N/A	10,455	N/A	N/A
	240	3.2	N/A	N/A	N/A	N/A	N/A	0.76 [a]	106.24	N/A	16,575	N/A	N/A
	243	4.1	N/A	N/a	N/A	N/A	N/A	0.73[a]	121.18	N/A	11,135	N/A	N/A
	248	5.7	N/A	N/A	93 (36)	3.4	ND	196	107.92	N/A	19,550	N/A	N/A
	253	7.2	N/A	N/A	N/A	N/A	N/A	32.6[a]	110.52	N/A	20,060	N/A	N/A
	258	8.7	N/A	N/A	N/A	N/A	N/A	18.4[a]	110.01	N/A	20,230	N/A	N/A
	263	10.2	N/A	N/A	N/A	N/A	N/A	4.44[a]	107.76	N/A	20,230	N/A	N/A
	269	12.1	N/A	N/A	96 (145)	3.6	ND	235	108.81	N/A	20,740	N/A	N/A

Table 4-4. Depth-Discrete Sampling Results During Well Drilling Within the 200-UP-1 Operable Unit

Well Name and Sample Date Range	Sample Depth		Sample Results										
			Field Parameters					Other Chemicals			Radionuclides		
	Below Land Surface (ft)	Below Water Table (m)	Specific Conductance (µS/cm)	Dissolved Oxygen (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Trichloroethene (µg/L)	Chromium (µg/L)	Nitrate (mg/L)	Uranium (µg/L)	Technetium-99 (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)
	273	13.3	N/A	N/A	N/A	N/A	N/A	50.1[a]	73.79	N/A	14,042	N/A	N/A
	278	14.8	N/A	N/A	N/A	N/A	N/A	74.3[a]	79.56	N/A	15,011	N/A	N/A
	283	16.3	N/A	N/A	N/A	N/A	N/A	49.1[a]	90.26	N/A	16,490	N/A	N/A
	288	17.9	N/A	N/A	81 (90)	3	ND	142	81.79	N/A	15,215	N/A	N/A
	293	19.4	N/A	N/A	N/A	N/A	N/A	1.05[a]	48.71	N/A	11,118	N/A	N/A
	298	20.9	N/A	N/A	N/A	N/A	N/A	2.65[a]	76.36	N/A	12,393	N/A	N/A
	303	22.4	N/A	N/A	N/A	N/A	N/A	1.32[a]	14.28	N/A	1,989	N/A	N/A
	308	23.9	N/A	N/A	3.4 (3.1)	ND	ND	0.87	4.03	N/A	272	N/A	N/A
	313	25.5	N/A	N/A	N/A	N/A	N/A	1.09[a]	6.67	N/A	629	N/A	N/A
	318	27	N/A	N/A	N/A	N/A	N/A	1.01[a]	4.42	N/A	323	N/A	N/A
	323	28.5	N/A	N/A	N/A	N/A	N/A	1.04[a]	2.24	N/A	85	N/A	N/A
	328	30	N/A	N/A	3.7 (5.2)	ND	ND	0.76	8.33	N/A	340	N/A	N/A
	333	31.6	N/A	N/A	N/A	N/A	N/A	1.17[a]	2.19	N/A	85	N/A	N/A
	338	33.1	N/A	N/A	N/A	N/A	N/A	0.95[a]	1.75	N/A	51	N/A	N/A
	343	34.6	N/A	N/A	N/A	N/A	N/A	0.99[a]	1.36	N/A	51	N/A	N/A
	348	36.1	N/A	N/A	2.6 (3.9)	ND	ND	0.80	1.47	N/A	51	N/A	N/A
299-W22-50	215	0.0	Rejected	N/A	13	2.3	ND	ND	58.0	0.78	4,240	N/A	31,400
11/23/99-1/12/00	241	6.6	235	N/A	5.6	0.91	ND	ND	12.8	3.34	812	N/A	19,900
	258	11.8	228	N/A	0.94	0.69	ND	ND	2.12	1.09	ND	N/A	969
	313	28.6	242	N/A	1.5	0.80	ND	ND	1.15	0.58	ND	N/A	304
	393	53.0	307	N/A	5.6	0.78	ND	ND	3.19	0.79	ND	N/A	ND
	441	67.6	323	N/A	0.89	0.76	ND	ND	12.8	0.43	ND	N/A	ND
	545	99.3	234	N/A	ND	ND	ND	ND	4.87	30.9	ND	N/A	ND
299-W22-69	259.75	7.2	N/A	N/A	(2.6)	(ND)	(ND)	N/A	N/A	2.01	1,080	N/A	N/A
1/30/06-2/8/06	288.5	16	N/A	N/A	(ND)	(ND)	(ND)	N/A	N/A	1.89	ND	N/A	N/A
	316.5	24.5	N/A	N/A	(ND)	(ND)	(ND)	N/A	N/A	1.24	ND	N/A	N/A
	375	42.4	N/A	N/A	(11)	(ND)	(ND)	N/A	N/A	1.05	ND	N/A	N/A

Table 4-4. Depth-Discrete Sampling Results During Well Drilling Within the 200-UP-1 Operable Unit

Well Name and Sample Date Range	Sample Depth		Sample Results										
			Field Parameters					Other Chemicals			Radionuclides		
	Below Land Surface (ft)	Below Water Table (m)	Specific Conductance (µS/cm)	Dissolved Oxygen (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Trichloroethene (µg/L)	Chromium (µg/L)	Nitrate (mg/L)	Uranium (µg/L)	Technetium-99 (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)
299-W22-72	251	4.2	N/A	9,500	(3.5)	(ND)	(ND)	N/A	N/A	0.715	ND	N/A	N/A
2/23/06-2/28/06	270	10	N/A	10,700	(ND)	(ND)	(ND)	N/A	2.8	0.89	ND	N/A	N/A
	290	16.1	N/A	8,000	(ND)	(ND)	(ND)	N/A	2.5	1.1	ND	N/A	N/A
	310	22.2	N/A	3,600	(ND)	(ND)	(ND)	N/A	N/A	1.23	ND	N/A	N/A
	319.5	25.1	N/A	7,800	(3.8)	(ND)	(ND)	N/A	N/A	1.3575	ND	N/A	N/A
	357.8	36.8	N/A	8,000	(5.3)	(ND)	(ND)	N/A	N/A	1.12	ND	N/A	N/A
299-W22-86	250	4.8	N/A	9,300	(10)	(ND)	(ND)	N/A	(23)	3.29	2,000	N/A	N/A
3/13/06-3/16/06	267	10	N/A	9,000	(11.6)	(ND)	(ND)	N/A	(18.5)	1.601	1,300	N/A	N/a
	290	17	N/A	8,700	(ND)	(ND)	(ND)	N/A	(15)	4.124	645	N/A	N/A
	310	23.1	N/A	8,700	(ND)	(ND)	(ND)	N/A	N/A	0.997	161	N/A	N/A
	320	26.2	N/A	8,250	(ND)	(ND)	(ND)	N/A	(7)	1.277	134.25	N/A	N/A
	350	35.3	N/A	8,500	(2.25)	(ND)	(ND)	N/A	(5.5)	0.313	94.05	N/A	N/A
299-W22-87	269	5.6	N/A	N/A	(3.8)	(ND)	(ND)	N/A	N/A	1.08	ND	N/A	N/A
12/20/05-12/27/05	299.5	14.9	N/A	N/A	(6.4)	(ND)	(ND)	N/A	N/A	1.25	ND	N/A	N/A
	329	23.9	N/A	N/A	(ND)	(ND)	(ND)	N/A	N/A	0.82	ND	N/A	N/A
	379.5	39.3	N/A	N/A	(ND)	(ND)	(ND)	N/A	N/A	2.76	ND	N/A	N/A
299-W22-88	277.5	5	N/A	N/A	3.6	N/A	ND	N/A	N/A	N/A	ND	N/A	N/A
2/13/08-2/28/08	307	14	N/A	N/A	9.8	2	ND	N/A	N/A	N/A	ND	N/A	N/A
	347	26.2	N/A	N/A	14	2.2	ND	N/A	N/A	N/A	ND	N/A	N/A
	387	38.4	N/A	N/A	22	N/A	ND	N/A	N/A	N/A	ND	N/A	N/A
	438	53.9	N/A	N/A	8.8	1.6	ND	N/A	N/A	N/A	ND	N/A	N/A
699-30-66	275	6.3	N/A	N/A	ND (ND)	1.5	ND	49/ND[b]	15.7	0.196	ND	ND	18,000
9/8/04-10/12/04	312	17.6	N/A	N/A	ND (ND)	Nd	ND	ND/1.36[b]	21.1	1.06	ND	ND	570
	342	26.7	N/A	N/A	ND (ND)	2.25	ND	9/26.5[b]	22.4	1.47	3.4	ND	ND
	387	40.4	N/A	N/A	ND (5.4)	4.3	ND	ND/4.73[b]	17.3	1.32	ND	ND	ND
699-32-76	244	5.4	307	9,980	ND	N/A	ND	N/A	N/A	N/A	N/A	N/A	N/A
12/6/07-12/14/07	273	14.2	355	9,430	ND	N/A	ND	N/A	N/A	N/A	N/A	N/A	N/A
	299	22.1	371	7,580	ND	N/A	ND	N/A	N/A	N/A	N/A	N/A	N/A
	342	35.2	381	N/A	ND	N/A	ND	N/A	N/A	N/A	N/A	N/A	N/A

Table 4-4. Depth-Discrete Sampling Results During Well Drilling Within the 200-UP-1 Operable Unit

Well Name and Sample Date Range	Sample Depth		Sample Results										
			Field Parameters					Other Chemicals			Radionuclides		
	Below Land Surface (ft)	Below Water Table (m)	Specific Conductance (µS/cm)	Dissolved Oxygen (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Trichloroethene (µg/L)	Chromium (µg/L)	Nitrate (mg/L)	Uranium (µg/L)	Technetium-99 (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)
699-33-74	258	7.3	N/A	N/A	6.1	1	ND	N/A	N/A	N/A	701	N/A	N/A
3/18/08-3/24/08	288	16.4	N/A	N/A	2	N/A	ND	N/A	N/A	N/A	958	N/A	N/A
	318	25.6	283	13,400	ND	N/A	ND	N/A	N/A	0.58	902	N/A	N/A
	358	37.7	286	9,040	2.1	1.1	ND	N/A	N/A	0.5	481	N/A	N/A
699-33-75	242	2.2	542	10,400	13	1.1	ND	N/A	N/A	N/A	N/A	N/A	N/A
1/16/08-1/22/08	277	12.9	N/A	N/A	43	1.5	ND	N/A	N/A	N/A	N/A	N/A	N/A
	307	22	N/A	N/A	35	1.3	ND	N/A	N/A	N/A	N/A	N/A	N/A
	346	33.9	N/A	N/A	12	N/A	ND	N/A	N/A	N/A	N/A	N/A	N/A
699-33-76	243	6.2	N/A	N/A	3.3	N/A	ND	N/A	N/A	N/A	ND	N/A	N/A
3/3/08-3/6/08	273	15.3	N/A	N/A	3.6	N/A	ND	N/A	N/A	N/A	ND	N/A	N/A
	302	24.2	N/A	N/A	3.5	N/A	ND	N/A	N/A	N/A	ND	N/A	N/A
	342	36.3	N/A	N/A	6.8	N/A	ND	N/A	N/A	N/A	ND	N/A	N/A
699-34-72	261	7.9	N/A	N/A	ND	N/A	ND	N/A	N/A	1.62	85.5	N/A	N/A
2/28/08-3/10/08	287.4	15.9	N/A	N/A	ND	N/A	ND	N/A	N/A	1.33	ND	N/A	N/A
	328.4	28.4	N/A	N/A	1.4	N/A	ND	N/A	N/A	0.403	ND	N/A	N/A
	368.8	40.7	N/A	N/A	3.4	N/A	ND	N/A	N/A	0.251	ND	N/A	N/A
	417	55.4	N/A	N/A	ND	N/A	ND	N/A	N/A	N/A	ND	N/A	N/A
699-36-70A	286	9.8	309	N/A	ND	0.70	ND	ND	26	0.60	5.85	N/A	74,600
9/30/94-11/2/94	307	16.2	499	N/A	5.9	0.62	0.13	ND	63	1.98	29.9	N/A	56,900
	334	24.4	N/A	N/A	8.0	0.64	0.11	ND	72	1.99	33.6	N/A	56,900
	372	36.0	468	N/A	8.9	1.3	0.27	ND	62	2.84	12.1	N/A	77,300
	400	44.5	Rejected	N/A	N/A	ND	N/A	N/A	N/A	0.75	6.55	N/A	20,100
	430	53.6	370	N/A	ND	0.65	ND	ND	15	14.8	ND	N/A	1,010
699-36-70B	270	1.5	N/A	N/A	ND (ND)	6.55	ND	N/A	103	1.17	250	ND	8,800
8/18/04-9/24/04	304	11.9	N/A	N/A	1.1 (ND)	1.7	ND	N/A	40	0.598	ND	N/A	1,200
	340	22.9	N/A	N/A	ND (ND)	3.1	ND	N/A	ND	ND	ND	ND	1,000
	375	33.5	N/A	N/A	8.5 (7.2)	3.5	ND	N/A	N/A	1.59	30	N/A	N/A
	417	46.3	N/A	N/A	ND (ND)	1.55	ND	N/A	5.5	0.11	ND	ND	325

Table 4-4. Depth-Discrete Sampling Results During Well Drilling Within the 200-UP-1 Operable Unit

Well Name and Sample Date Range	Sample Depth		Sample Results										
			Field Parameters					Other Chemicals			Radionuclides		
	Below Land Surface (ft)	Below Water Table (m)	Specific Conductance (µS/cm)	Dissolved Oxygen (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)	Trichloroethene (µg/L)	Chromium (µg/L)	Nitrate (mg/L)	Uranium (µg/L)	Technetium-99 (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)
699-38-70B	312	7.3	N/A	N/A	(55)	3.6	3	N/A	N/A	1.45	10	N/A	N/A
2/4/04-2/27/04	348	18.3	N/A	N/A	(309)	9.6	5.1	N/A	N/A	1.04	ND	N/A	N/A
	379	27.7	N/A	N/A	(311)	9.9	5.7	N/A	N/A	0.97	ND	N/A	N/A
	408	36.6	N/A	N/A	(470)	9.3	7.9	N/A	N/A	0.74	ND	N/A	N/A
	439	46	N/A	N/A	(428)	22	7.15	N/A	N/A	0.7	ND	N/A	N/A
	478	57.9	N/A	N/A	(14)	ND	ND	N/A	N/A	1.38	ND	N/A	N/A
699-38-70C	329	6.4	N/A	N/A	(25)	2.1	4.9	N/A	N/A	3.02	1,600	N/A	N/A
2/18/04-2/20/04	370	18.9	N/A	N/A	(28)	ND	9.1	N/A	N/A	2.76	970	N/A	N/A
	399	27.7	N/A	N/A	(32)	2.7	8.4	N/A	N/A	2.67	1,200	N/A	N/A
	415	32.6	N/A	N/A	(31)	2.7	6.9	N/A	N/A	2.79	1,200	N/A	N/A
699-40-65	358	6.4	N/A	N/A	ND	ND	ND	N/A	N/A	1.54	190	N/A	N/A
12/18/03-12/31/03	459	37.2	N/A	N/A	ND	ND	ND	N/A	N/A	2.92	ND	N/A	N/A

Notes: Values in parentheses are field analyzed results, which are generally not as accurate as laboratory analyzed results.

a. Chromium sample results for Well 299-W22-47 were collected by the air-lift method and are considered suspect. According to PNNL-15670, *Hanford Site Groundwater Monitoring for Fiscal Year 2005*, "Air-lifted samples were deemed non-representative because the water samples were in contact with sediment in a collection bottle for up to several days before a filtered sample was collected. During this time, the chromium in solution is believed to have been reduced by freshly exposed sediment surfaces (ground up basalt particles) and precipitated from solution, resulting in artificially low chromium concentrations. Chromium concentrations in all of the air-lifted samples were much lower than adjacent pumped samples."

b. Two values are provided: the first is hexavalent chromium and the second is total chromium. Chromium results for Well 699-30-66 are artificially low due to reducing conditions induced by the drilling process. Chromium results in the finished well are ~100 µg/L.

ND = not detected

N/A = not analyzed

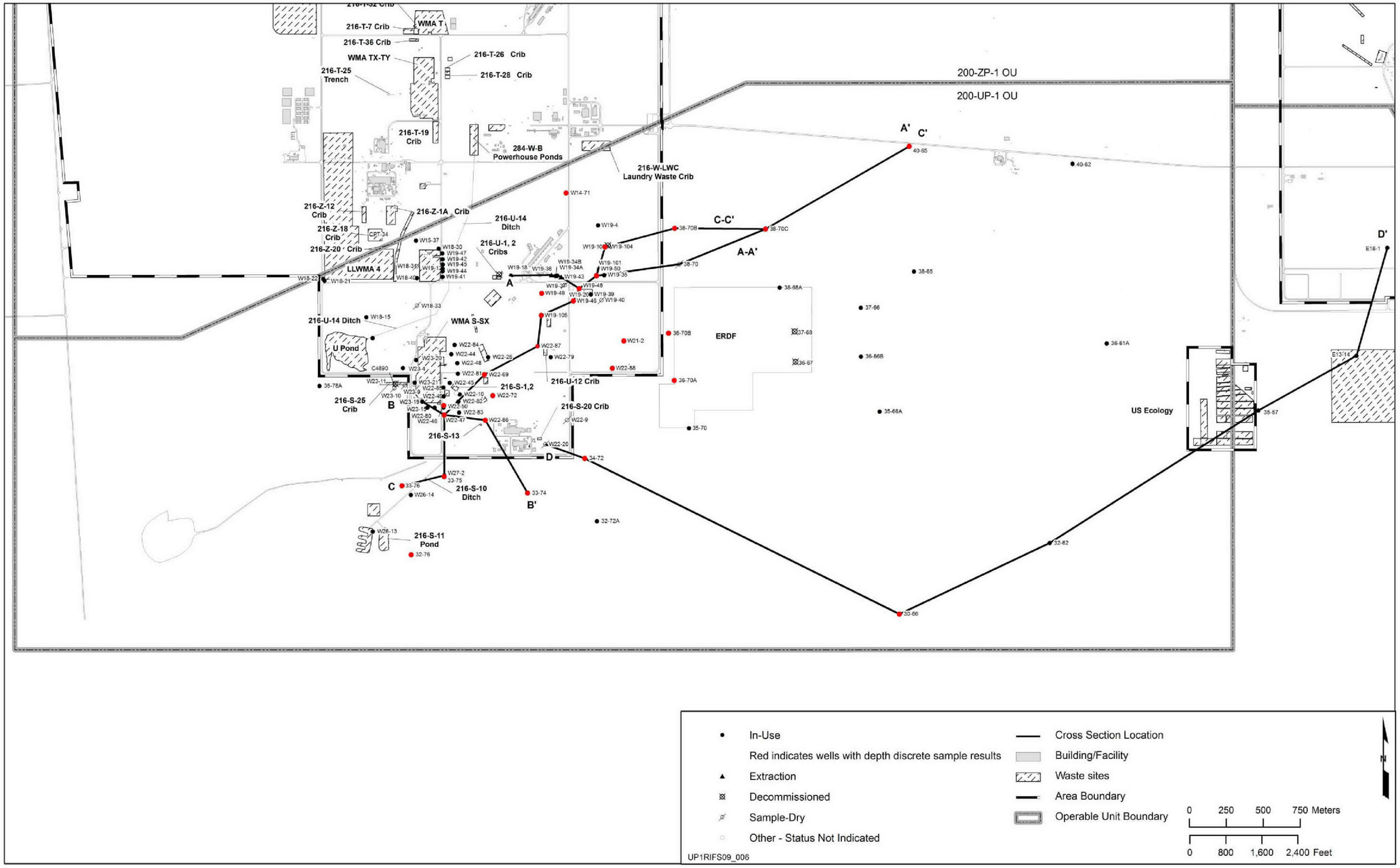

Figure 4-1. Wells and Cross Section Locations for the 200-UP-1 Operable Unit

4.2.1 Technetium-99

During the RI, extensive groundwater sampling was performed for Tc-99 throughout the OU. Figure 4-2 shows all the wells sampled for Tc-99 (regardless of completion depth) and categorizes the maximum concentration observed between 2004 and 2009 as either not detected (blue), detected but less than the DWS (900 pCi/L) (green), greater than the DWS but less than 10 times the DWS (yellow), or greater than 10 times the DWS (red). Tc-99 concentrations were found above the DWS at and downgradient (east) from the 216-U-1 and 216-U-2 Cribs, at RCRA WMA S-SX, and at WMA U, with concentrations exceeding 10 times the DWS downgradient from the 216-U-1 and 216-U-2 Cribs and WMA S-SX. To the east of the 200 West Area, Tc-99 was detected in groundwater, but generally at concentrations below the DWS. Tc-99 was not detected in the monitoring wells at the 216-S-10 Pond and Ditch.

Figure 4-3 shows the Tc-99 plumes at the water table within the OU, based on average groundwater sample results for FY 2008. The Tc-99 plume downgradient from the 216-U-1 and 216-U-2 Cribs originates from the cribs, which received nearly 16 million L (4.2 million gal) of effluent between 1951 and 1961 (ARH-CD-745). Additional contaminant mass was added to the plume when effluent disposed at the nearby 216-U-16 Crib in 1984 and 1985 migrated north along a caliche layer and mobilized the Tc-99 and uranium in the soil column beneath the 216-U-1 and 216-U-2 Cribs (DOE/RL-92-76, Rev. 1). The highest Tc-99 concentrations in groundwater occur between ~300 to ~900 m (~1,000 to ~2,000 ft) downgradient (east) of the cribs, but another region of the plume above the DWS is interpreted to occur ~1.5 to ~2 km (~0.9 to ~1.2 mi) east-northeast near Well 699-38-70C. Historically, the highest measured Tc-99 concentration in this plume was 41,000 pCi/L in Well 299-W19-24 (west of the 216-U-17 Crib) during October 1989.

To characterize the vertical extent of contamination within the 216-U-1 and 216-U-2 Cribs plume, depth-discrete groundwater sampling was performed during drilling of all new wells installed since FY 2003. In addition, wells 299-W19-34A and 299-W19-34B, located between the P&T system extraction wells 299-W19-36 and 299-W19-43, are screened below the water table and provide additional information on the vertical distribution of contamination. Figure 4-4 shows a cross section of the Tc-99 plume from the 216-U-1 and 216-U-2 Cribs (cross section locations are shown in Figure 4-1), and Figure 4-5 shows Tc-99 and uranium sample results from wells in this area.

At 699-38-70C, Tc-99 was found to exceed the DWS throughout the entire thickness of the unconfined aquifer (33 m [108 ft]), from near the water table to the top of the Ringold Fm LMU. The highest concentration was 1,600 pCi/L near the water table, but the concentration in the deepest sample above the lower mud was 1,200 pCi/L. Vertical dispersion is the likely mechanism by which this plume became fully mixed vertically throughout the aquifer at this distance from the source (~2.0 km [~1.2 mi]). At wells 299-W19-46 and 299-W19-49, the highest Tc-99 concentrations (1,360 and 1,320 pCi/L, respectively) occurred between 20 and 30 m (65 and 100 ft) below the water table. At the remaining locations within the plume where depth-discrete sample results were available (wells 299-W19-43, 299-W19-48, and 299-W19-101), the plume was limited to the upper 10 to 20 m (30 to 65 ft) of the aquifer.

An IRA P&T system has been operating in the highest-concentration part of the 216-U-1 and 216-U-2 Cribs plume since 1994, and the system has been successful in reducing Tc-99 concentrations in the aquifer. As of FY 2008, Tc-99 concentrations exceeded the 900 pCi/L DWS in both extraction wells, 299-W19-36 and 299-W19-43, but were below the DWS at all of the compliance wells (299-W19-34A, 299-W19-34B, 299-W19-35, 299-W19-39, 299-W19-46, 299-W19-48, 299-W19-49, and 299-W19-101). Concentrations in the extraction wells (299-W19-36 and 299-W19-43) have been below the IRA goal of 9,000 pCi/L since January 2008. Operation of this system has resulted in the separation of the Tc-99 plume into two parts, because the portion of the plume not captured by the system continued to migrate east into the 600 Area. Section 4.3 provides additional discussion of the IRA.

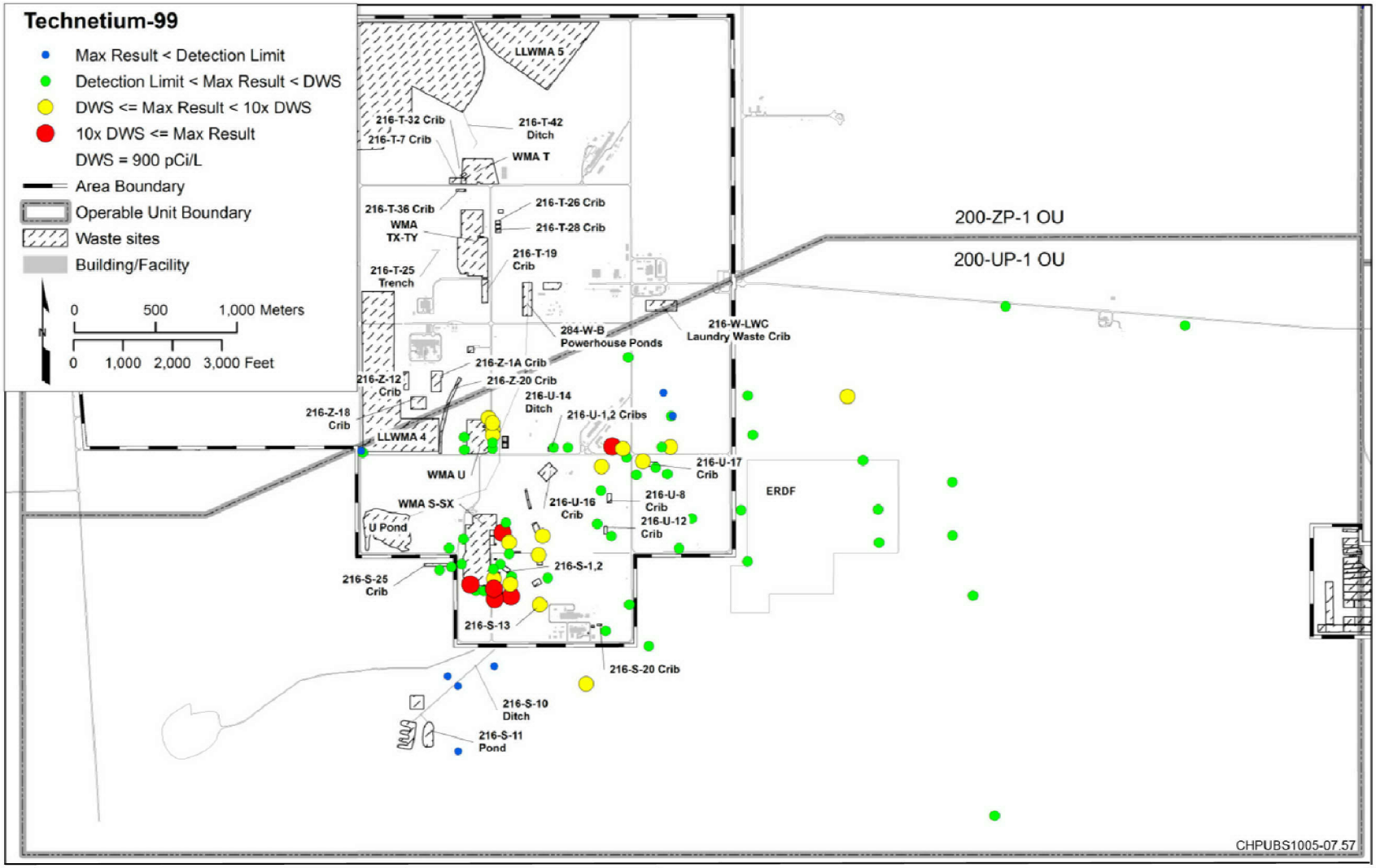

Figure 4-2. Maximum Sample Results for Technetium-99 During the Remedial Investigation

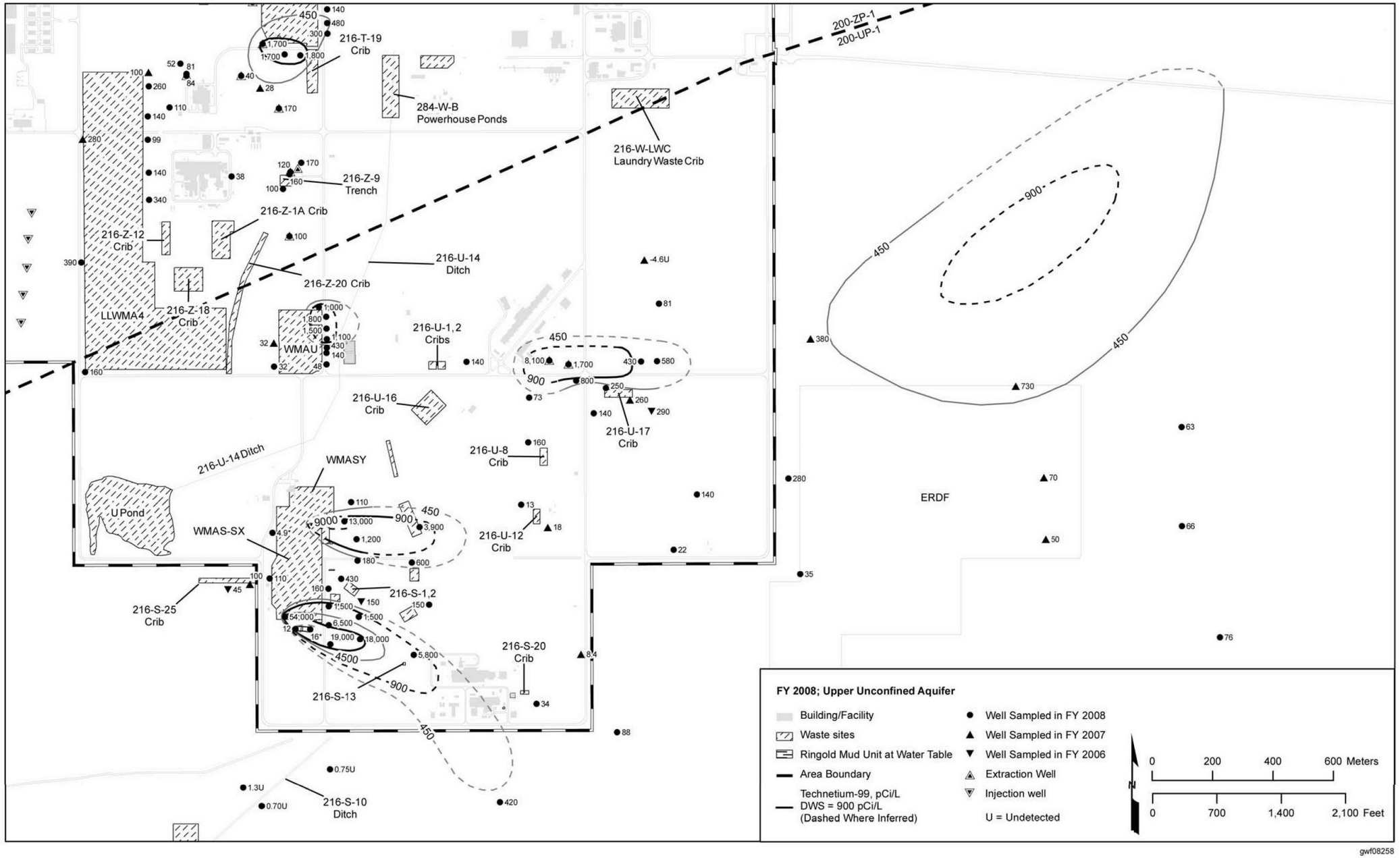

Figure 4-3. Average FY 2008 Technetium-99 Concentrations in the 200-UP-1 Operable Unit, Upper Part of Unconfined Aquifer (DOE/RL-2008-66)

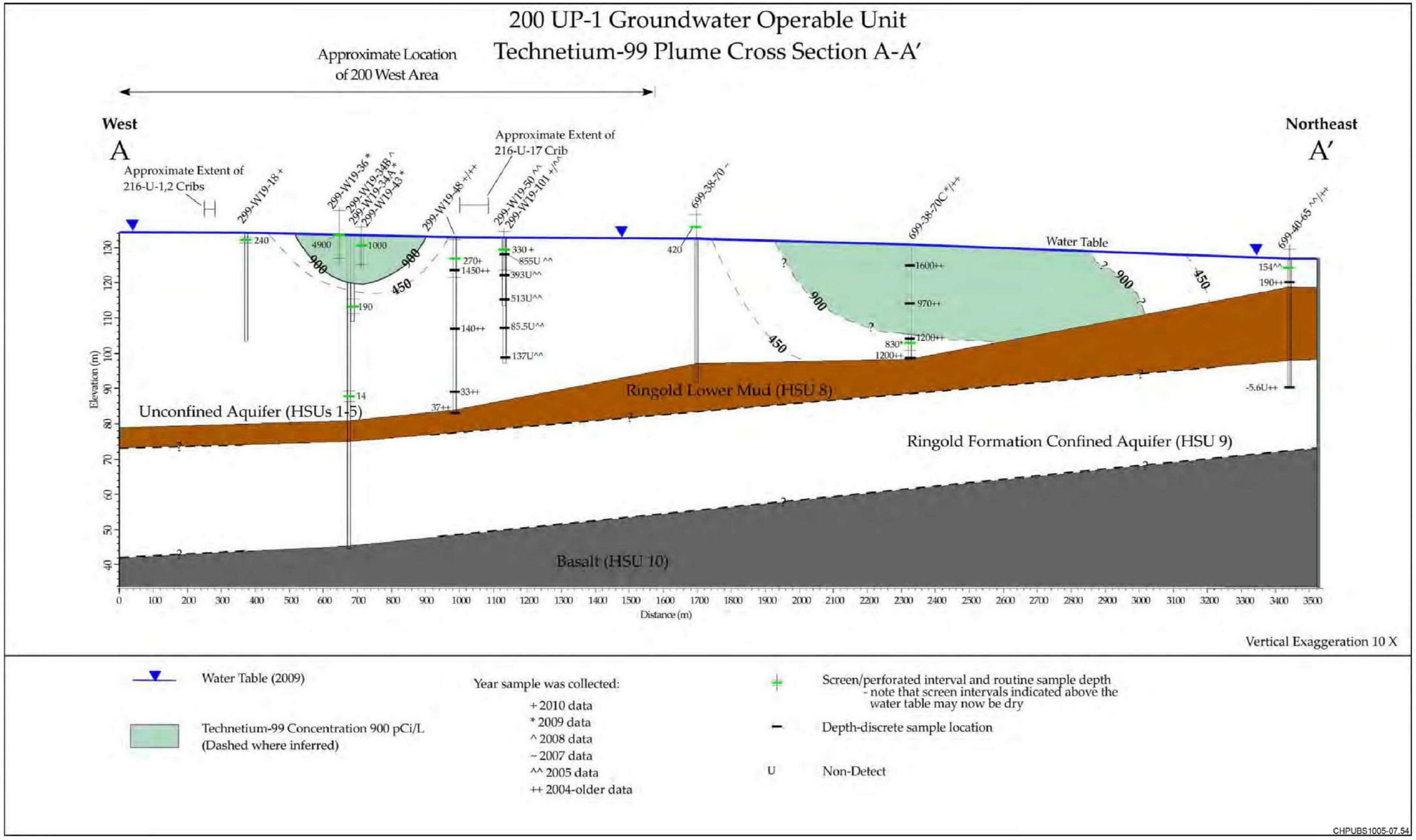

Figure 4-4. Cross Section of the Technetium-99 Plume from the 216-U-1 and 216-U-2 Cribs

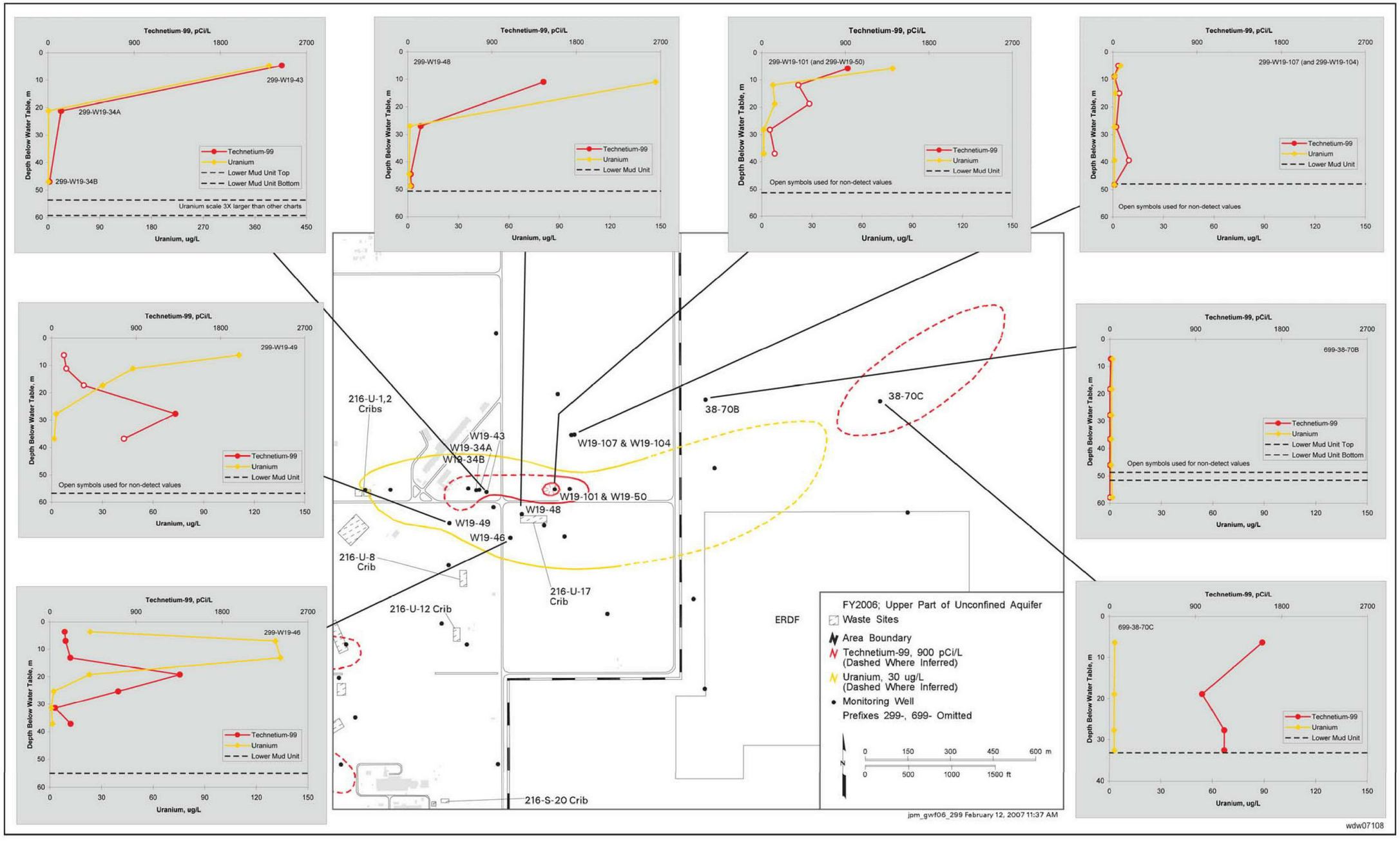

Figure 4-5. Depth-Discrete Sampling Results for Technetium-99 and Uranium in the Northern Part of the 200-UP-1 Operable Unit (PNNL-16346)

At WMA S-SX, a Tc-99 plume originates from the SX Tank Farm in the southwestern corner of the WMA and another plume originates from the S Tank Farm in the north part of the WMA. The highest Tc-99 concentrations within the OU occur in the south plume at Well 299-W23-19 (located inside the SX Tank Farm). This well is within the source area and the Tc-99 concentration in this well has varied substantially (between 30,000 and 188,000 pCi/L) since sampling began in 1999, probably due to the episodic nature of contaminant migration from the vadose zone to the groundwater (Figure 4-6). Tank 241-SX-115 is the most likely source of this contamination (PNNL-13441). Concentrations near the water table are interpreted to occur above the DWS from the source area to between ~500 and ~600 m (~1,600 and ~2,000 ft) downgradient. Beyond this, the plume orientation is southeastward toward Well 699-33-74 at concentrations generally below the DWS at the water table (concentrations slightly above the DWS may occur just below the water table). This southeastward orientation is due to the historical influence of the water table mound beneath the 216-U-10 Pond and later the 216-U-14 Ditch, which caused a more southerly groundwater flow direction prior to the mid-1990s. The southwestern boundary of the plume near and immediately downgradient from the source (WMA S-SX) is not well defined. Well 299-W22-47 was installed in 2005 with the goal of bounding the plume to the southwest. However, Tc-99 concentrations were higher at this location than in the wells to the north (299-W22-50 and 299-W22-49).

A low-concentration area occurs in the southern Tc-99 plume from WMA S-SX around wells 299-W22-80 and 299-W23-15. The FY 2008 average Tc-99 concentrations in these wells were 16 and 12 pCi/L, respectively. Higher concentrations are expected in these wells, because they are near the source area and high concentrations occur to the southeast at Well 299-W22-47 (FY 2008 average of 19,000 pCi/L). An in-well tracer test at Well 299-W22-80, as well as time-series sampling during extensive purging, has indicated that relatively clean water may be migrating into the bottom of the well, moving up the wellbore, and diluting the Tc-99 concentration in the upper part of the plume (PNNL-14113, PNNL-15070). A similar process is assumed to be occurring at Well 299-W23-15.

Figure 4-7 shows the vertical extent of the southern Tc-99 plume from WMA S-SX. Data for three of the four wells used in this cross section, 299-W19-47 (installed during 2005), 299-W22-86 (2006), and 699-33-74 (2008), were obtained by depth-discrete sampling during drilling. The cross section shows that the Tc-99 plume occurs in the upper part of the unconfined aquifer; concentrations above the DWS occur no lower than 25 m (82 ft) below the water table.

The northern Tc-99 plume at WMA S-SX originates from the S Tank Farm in which tank 241-S-104 is the only tank known or assumed to have leaked (overfill event). Concentrations in groundwater above the DWS are interpreted to occur from the source area to ~400 m (~1,300 ft) downgradient to the east near Well 299-W22-26. Tc-99 concentrations have remained low in upgradient Well 299-W23-20, confirming that the S Tank Farm is the source of this plume. Concentrations began increasing rapidly at two wells within this plume during FY 2007: 299-W22-44 and 299-W22-26 (Figure 4-8). During June 2009, the concentration at 299-W22-44 was 17,000 pCi/L, and the concentration at 299-W22-26 was 4,800 pCi/L. Figure 4-9 shows the results of depth-discrete sampling for Tc-99 and uranium at the newly installed wells in the southern 200 West Area. Well 299-W22-69 is the only newly installed well near the north plume from WMA S-SX. The depth-discrete samples collected at this location indicate that Tc-99 occurs near the water table.

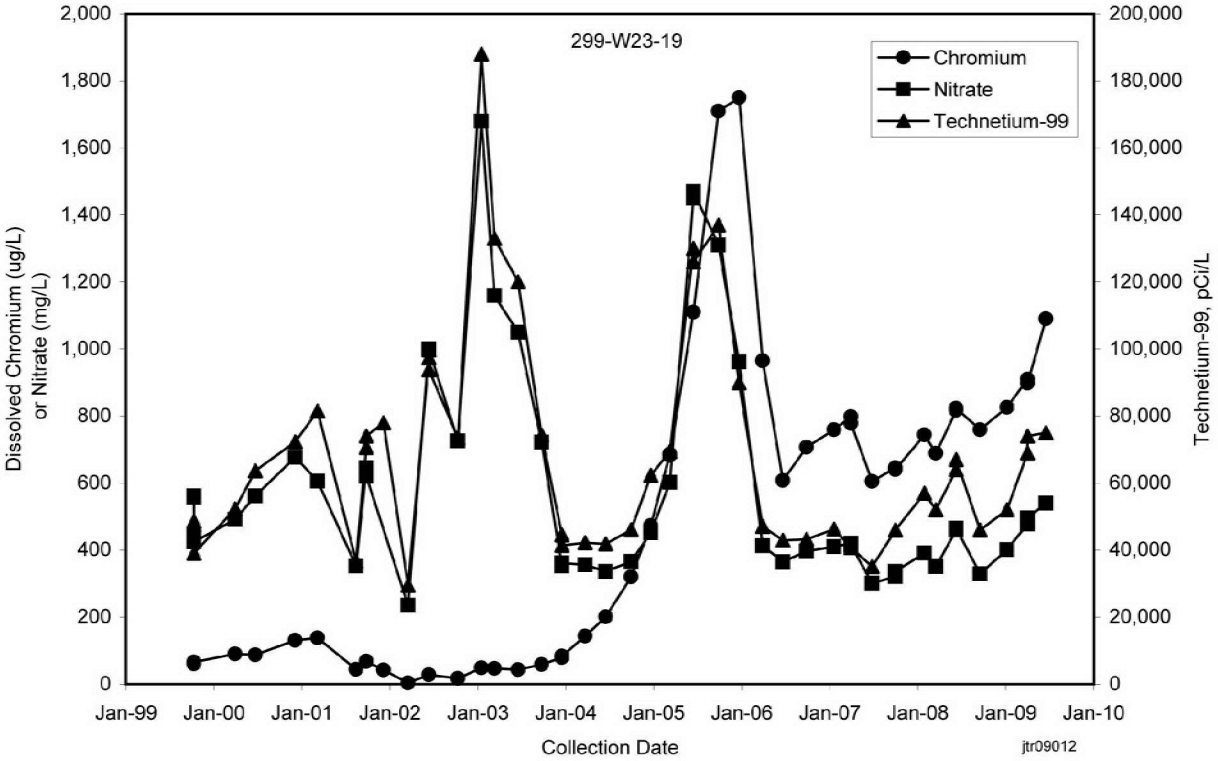

Figure 4-6. Chromium, Nitrate, and Technetium-99 Concentrations in Well 299-W23-19, Southern Portion of Waste Management Area S-SX

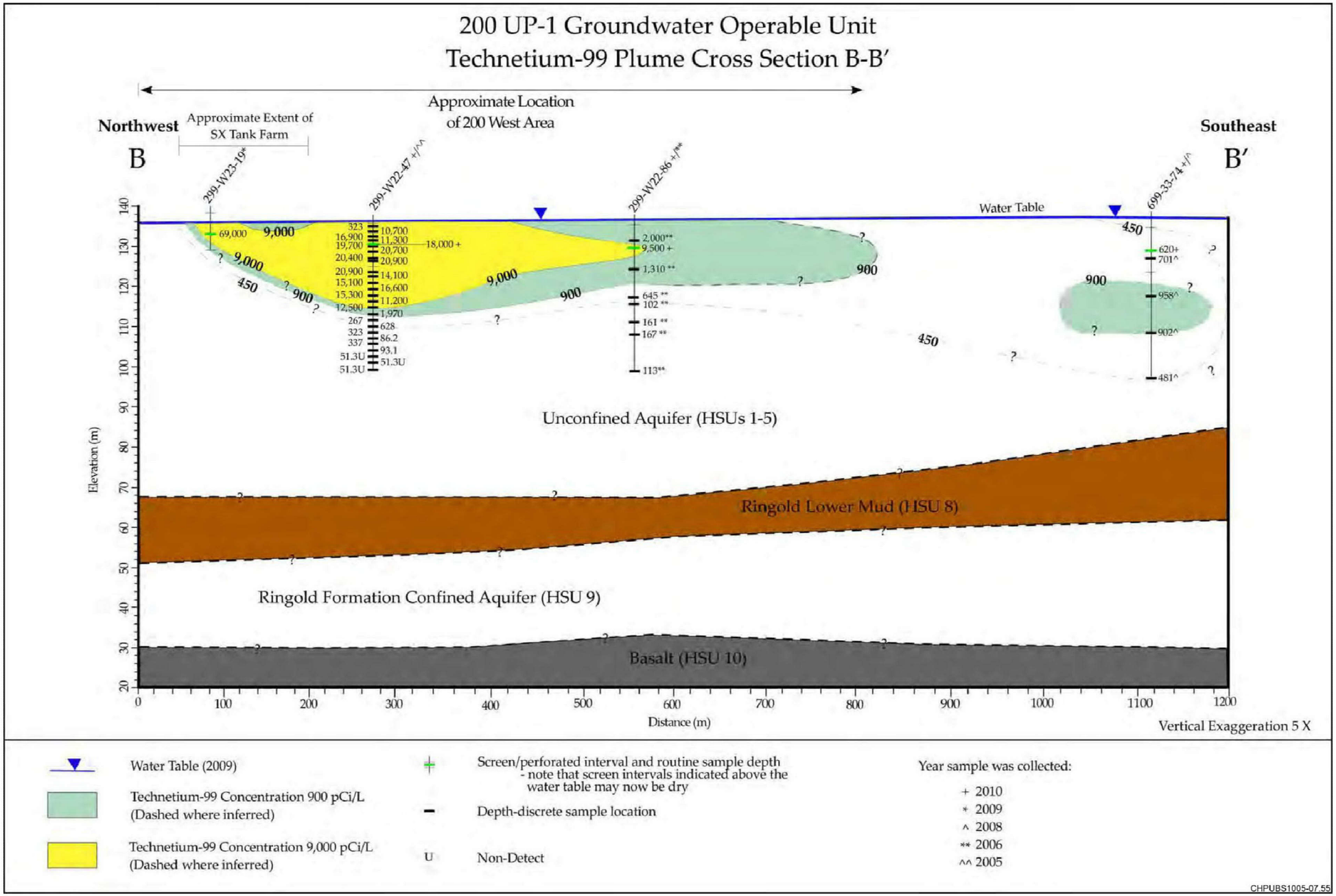

Figure 4-7. Cross Section of the Southern Technetium-99 Plume from Waste Management Area S-SX

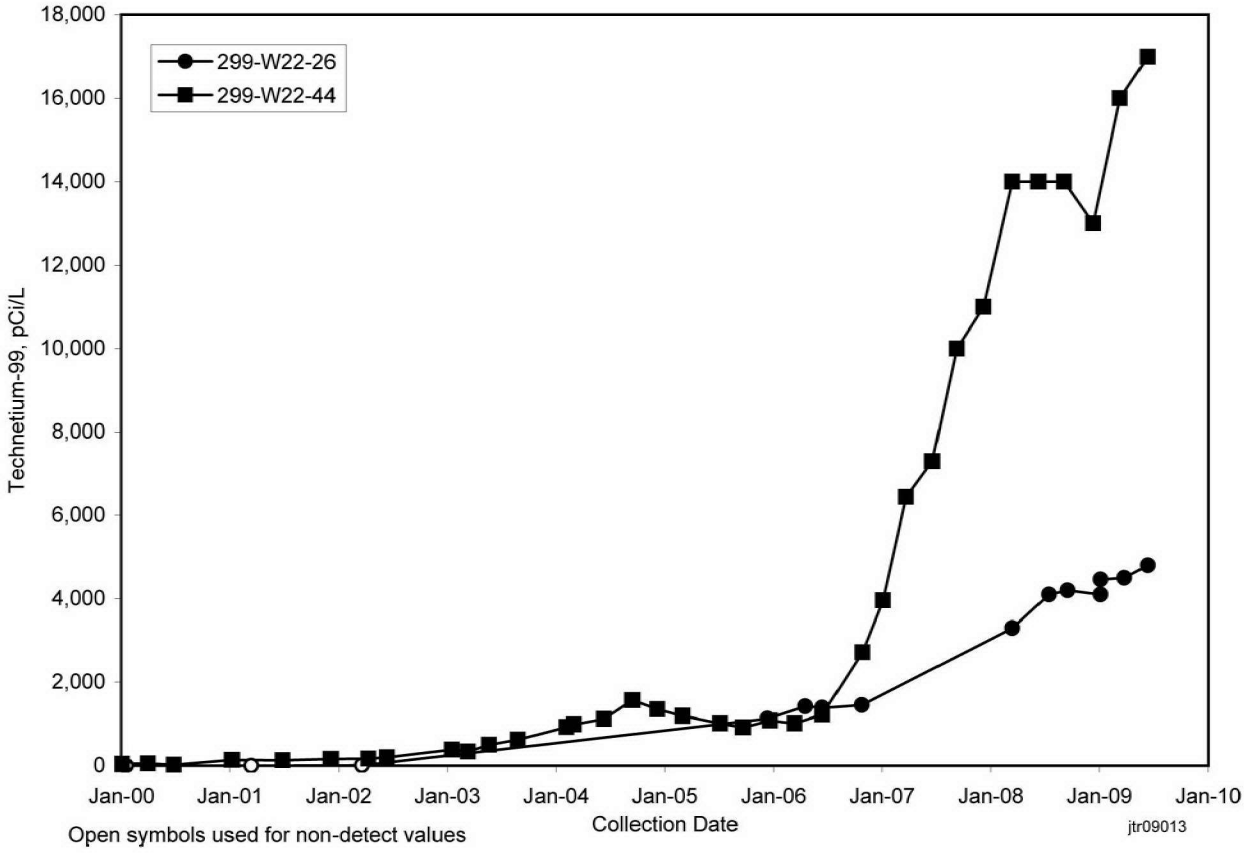

Figure 4-8. Technetium-99 Concentrations in Wells 299-W22-26 and 299-W22-44 Downgradient from the 241-S Tank Farm

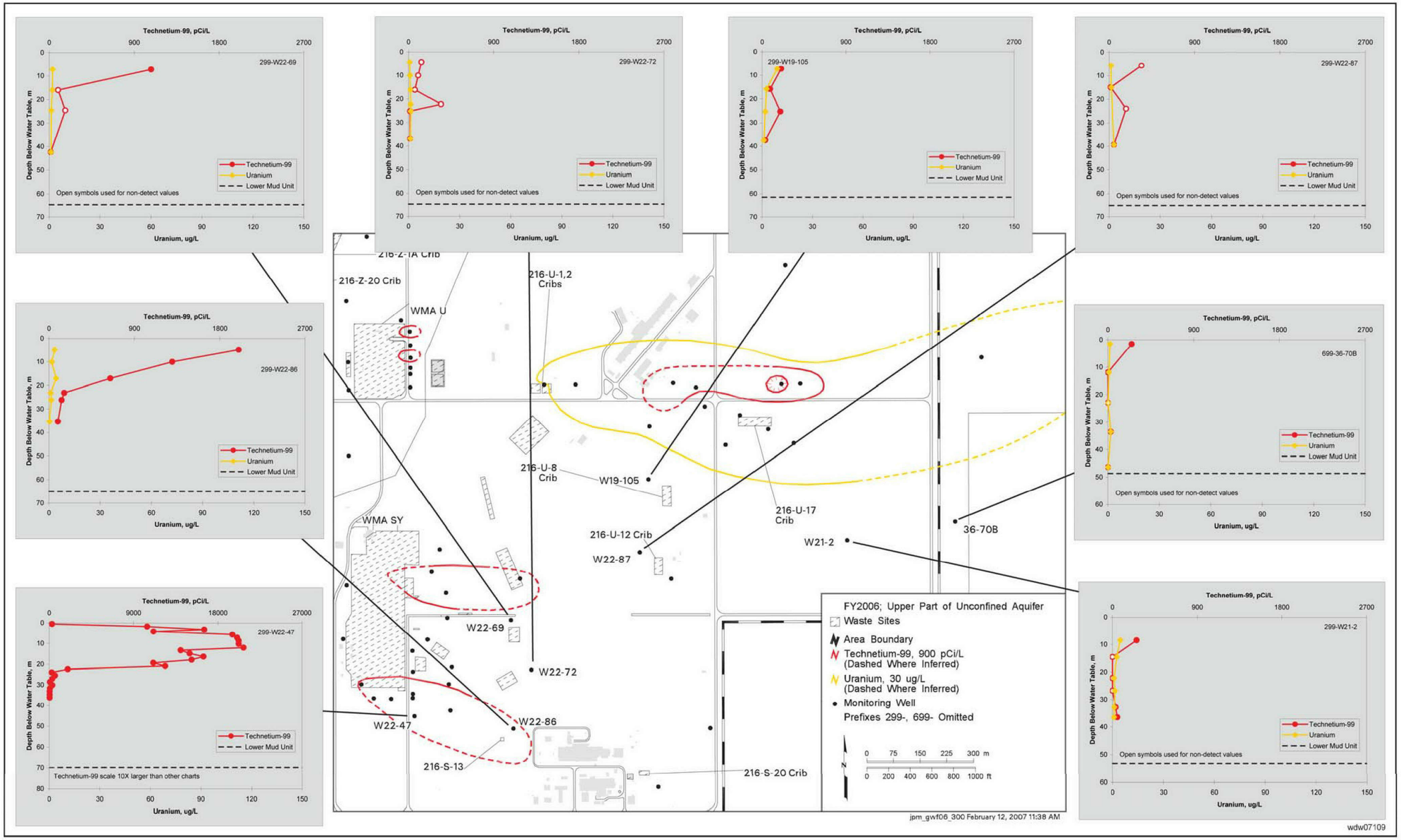

Figure 4-9. Depth-Discrete Sampling Results for Technetium-99 and Uranium in the Southern Part of the 200-UP-1 Groundwater Operable Unit (PNNL-16346)

Tc-99 concentrations in the downgradient wells at WMA U are elevated compared to concentrations in the upgradient wells. This indicates the U Tank Farm is a source of Tc-99 contamination (PNNL-13282). However, concentrations are very low compared to WMA S-SX. The DWS (900 pCi/L) was exceeded in four wells during sampling in April 2009: 299-W18-30 at 1,100 pCi/L; 299-W19-42 at 1,700 pCi/L; 299-W19-45 at 1,500 pCi/L; and 299-W19-47 at 1,800 pCi/L. Concentrations are slowly increasing in these four wells (Figure 4-10). There is no information on the vertical distribution of contamination at WMA U.

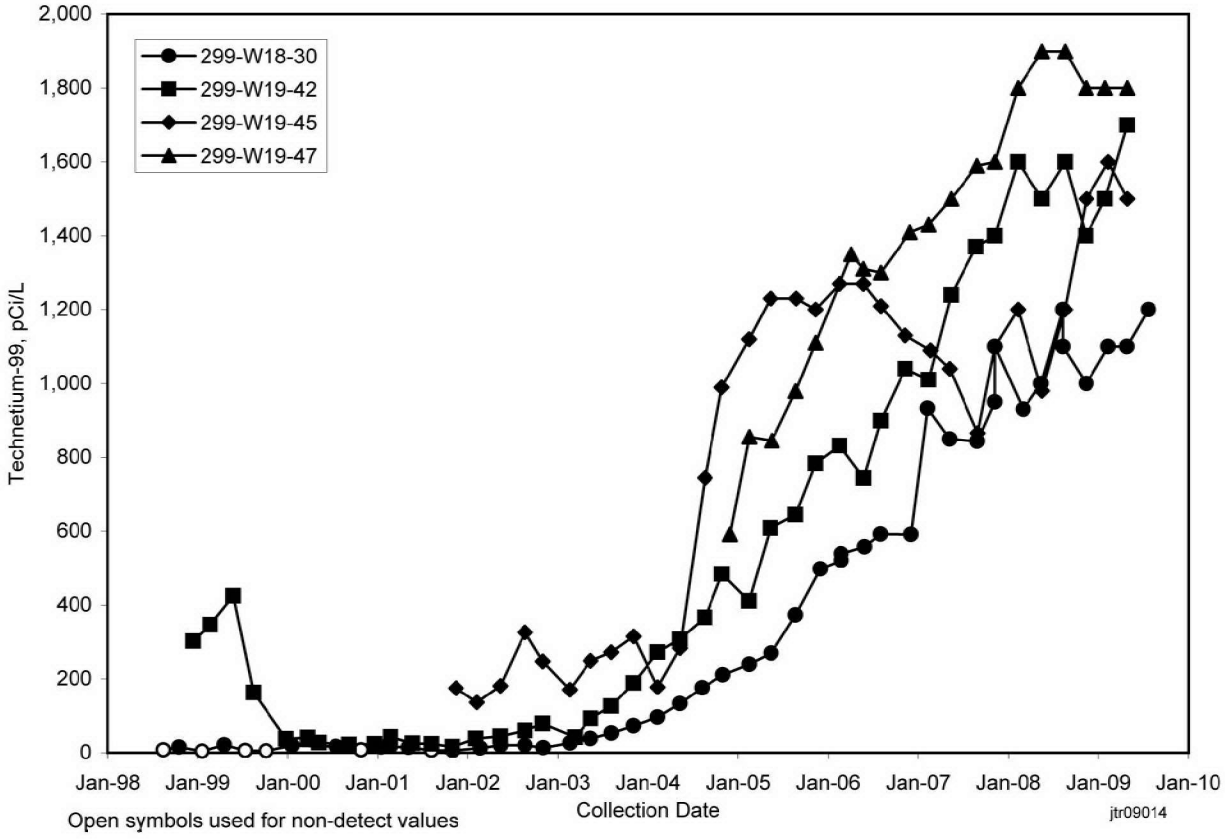

Figure 4-10. Technetium-99 Concentrations in Wells Downgradient from Waste Management Area U

4.2.2 Uranium

Extensive sampling for uranium was performed throughout the OU during the RI. Figure 4-11 categorizes the maximum uranium concentration in each well sampled between 2004 and 2009. Uranium is naturally present in groundwater at levels above the laboratory detection limit, so it was detected in every sample. However, uranium concentrations exceeded the DWS (30 µg/L) in only two areas of the OU: downgradient from the 216-U-1 and 216-U-2 Cribs, and in the vicinity of the 216-U-10 Pond. Some of the uranium sample results exceeded 10 times the DWS in the 216-U-1 and 216-U-2 Cribs plume.

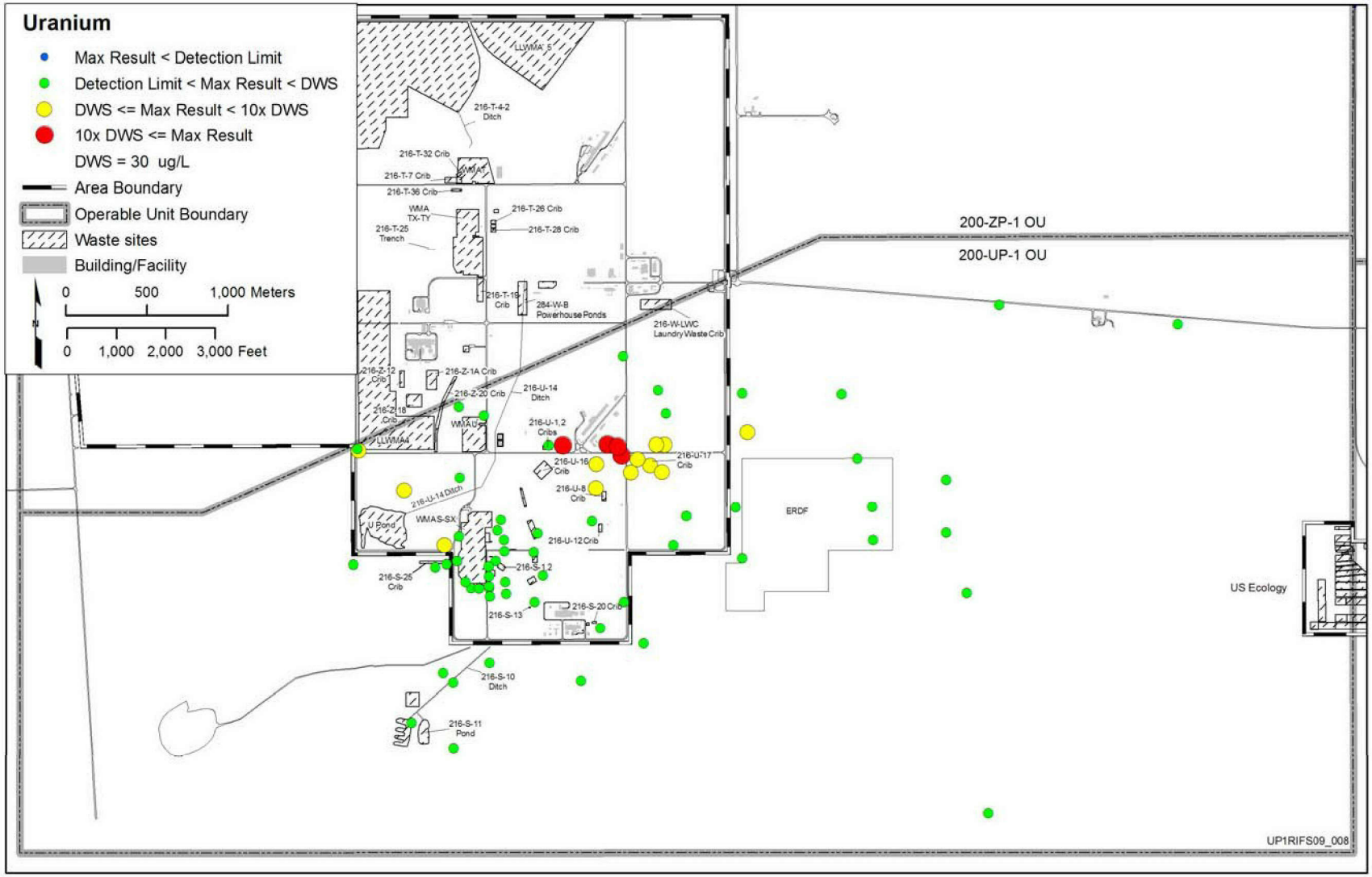

Figure 4-11. Maximum Sample Results for Uranium During the Remedial Investigation

The uranium plume from the 216-U-1 and 216-U-2 Cribs extends a total of ~1.5 km (~0.9 mi) to the east at levels above the 30 µg/L DWS (Figure 4-12). Similar to Tc-99, the uranium originated from the cribs when they were active from 1951 to 1961. Additional mass was added to the groundwater plume when effluent that was disposed at the nearby 216-U-16 Crib in 1984 and 1985 migrated north along a caliche layer in the vadose zone and mobilized the Tc-99 and uranium in the soil column beneath the 216-U-1 and 216-U-2 Cribs (DOE/RL-92-76, Rev. 1). One-dimensional simulations of uranium transport beneath these cribs suggest that the uranium bypassed the CCU by migrating to groundwater through an erosional window or along a wellbore (HNF-45099).

An IRA P&T system has been operating in the highest-concentration part of the 216-U-1 and 216-U-2 Cribs plume since 1995. While the system has been successful in reducing the uranium concentration to below the RAO of 300 µg/L, concentrations at all the water table monitoring wells in the baseline plume area continue to exceed the DWS of 30 µg/L. Uranium is less mobile in the aquifer compared to Tc-99, so uranium has not responded as well to the P&T system. Section 4.3 provides a more thorough discussion of the IRA.

Figure 4-5 and Figure 4-9 show the results of depth-discrete sampling for uranium during well installation. Figure 4-13 shows a cross section of the 216-U-1 and 216-U-2 Cribs plume. The data indicate that uranium in the 216-U-1 and 216-U-2 Cribs plume is limited to the upper ~20 m (~65 ft) of the aquifer. No exceedances of the DWS below 20 m (65 ft) depth occurred. Even in those wells in which Tc-99 was found above the DWS, relatively deep in the aquifer (299-W19-46, 299-W19-49, and 699-38-70C), uranium was not elevated at the same depths.

Near the source of the 216-U-1 and 216-U-2 Cribs plume, uranium continues to be elevated in Well 299-W19-18, although the concentration has decreased in recent years (Figure 4-14). The uranium concentration in this well during March 2009 was 407 µg/L, greater than 10 times the DWS. The persistence of uranium at this location may be due to an ongoing source of contaminant mass to the aquifer water, such as continued leaching from the vadose zone beneath the cribs or desorption of uranium from the aquifer sediment.

Uranium has been detected at concentrations slightly above the DWS in the vicinity of the 216-U-10 Pond in wells 299-W23-4, 299-W18-21, and 299-W18-15. The maximum concentration in these wells between 2004 and 2009 was 35 µg/L in 299-W23-4 during March 2009. The source of this uranium is not known, but one possibility is slow leaching of uranium from the vadose zone soil beneath the 216-U-10 Pond. It has been estimated that the effluent disposed to this pond may have contained a total of ~2,100 kg (4,600 lbs) of uranium (RPP-26744).

4.2.3 Iodine-129

I-129 in the 200-UP-1 Groundwater OU originates from both the U Plant and REDOX Plant disposal facilities. Sample results from many wells exceeded the DWS (1 pCi/L) during the RI, and results from four wells east of the 200 West Area exceeded 10 times the DWS (Figure 4-15). I-129 was not detected upgradient from the U Plant and REDOX Plant cribs or south of the 200 West Area.

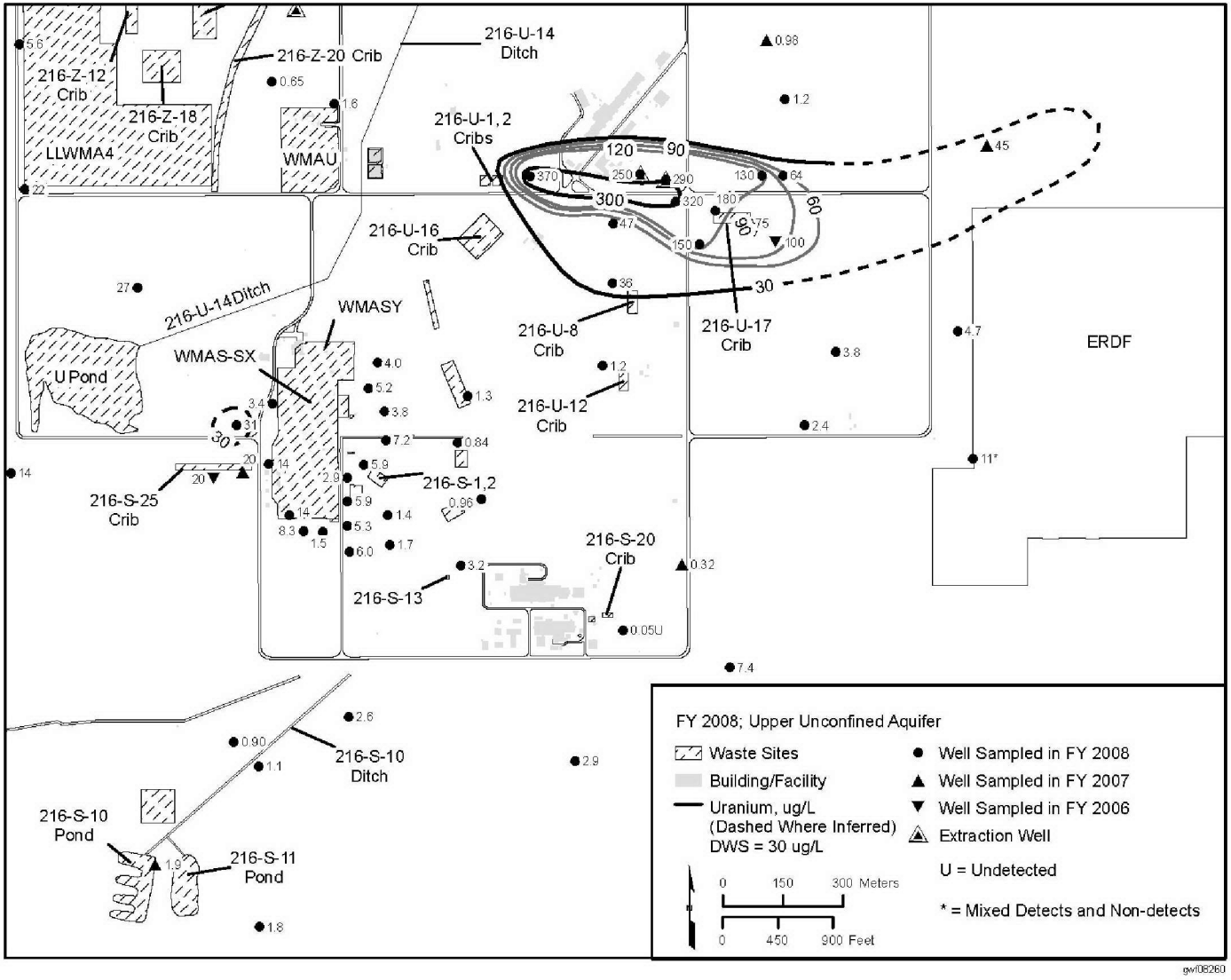

Figure 4-12. Average FY 2008 Uranium Concentrations in the 200-UP-1 Operable Unit, Upper Part of Unconfined Aquifer (DOE/RL-2008-66)

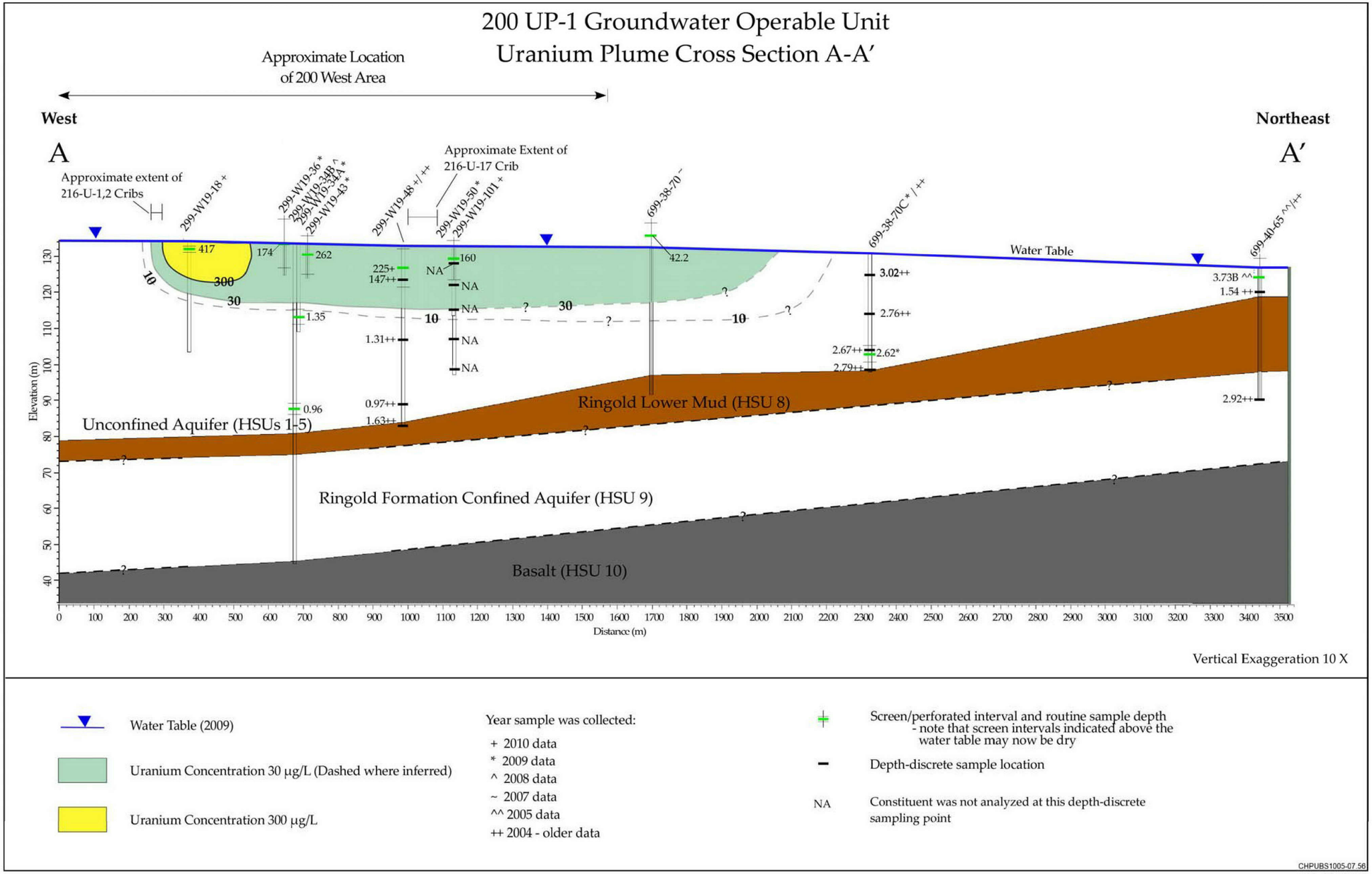

Figure 4-13. Cross Section of the Uranium Plume from the 216-U-1 and 216-U-2 Cribs

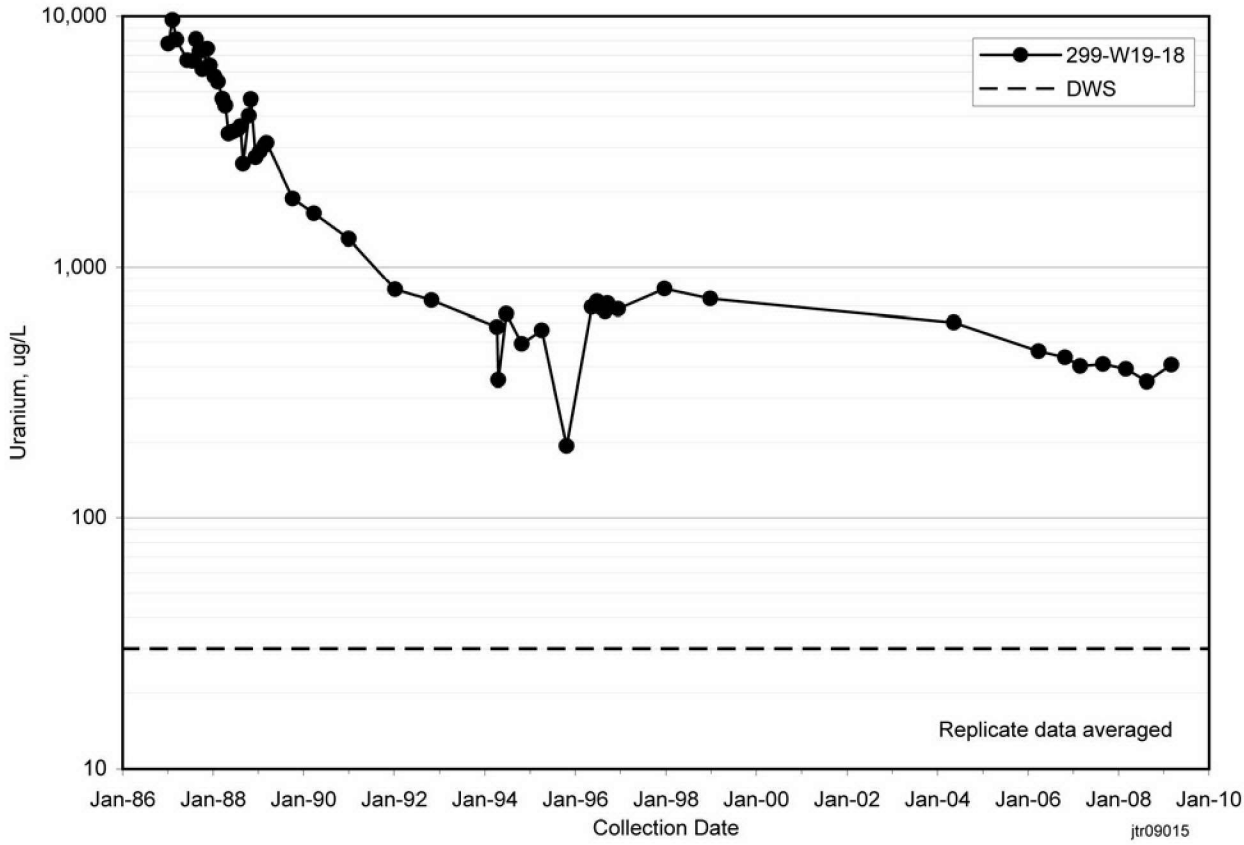

Figure 4-14. Uranium Concentrations in Well 299-W19-18, Downgradient from the 216-U-1 and 216-U-2 Cribs

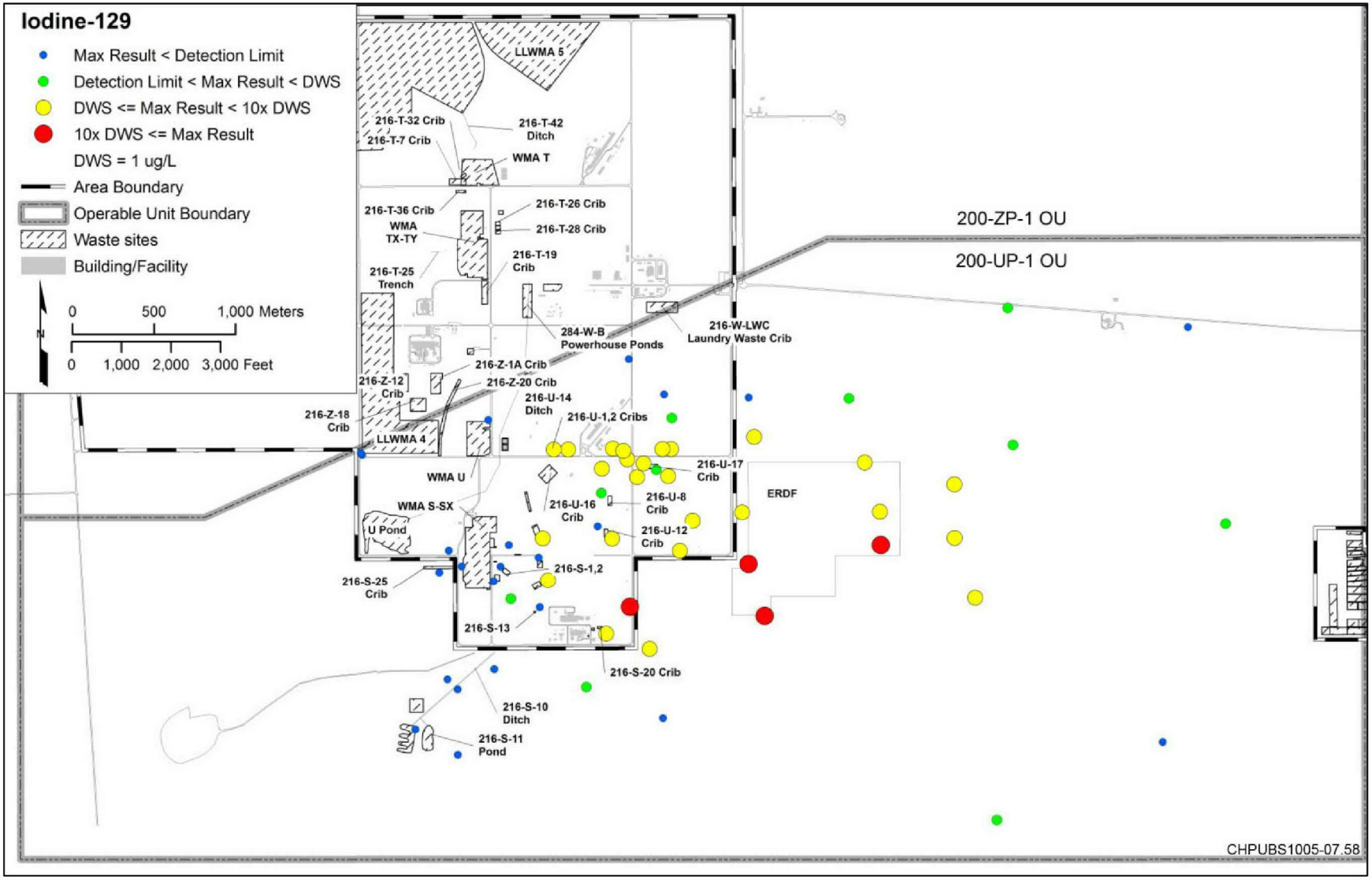

Figure 4-15. Maximum Sample Results for Iodine-129 During the Remedial Investigation

Figure 4-16 shows the I-129 plumes for FY 2008. One plume appears to originate from the 216-U-1 and 216-U-2 Cribs, while another originates from the southern part of the 200 West Area. At the current level of monitoring detail, these plumes merge downgradient and become indistinguishable. This combined plume (as defined by the 1 pCi/L contour) extends to the east a total distance of ~3.5 km (~2.2 mi). Groundwater sampling results near and downgradient from the 216-U-1 and 216-U-2 Cribs and the 216-S-9 Crib are flagged as not detected but are believed to represent valid approximations of the I-129 concentration in the aquifer. In the past, the analytical laboratory was conservative, by requiring confirmation through the presence of a secondary (less-sensitive) energy peak, prior to considering the I-129 detected (DOE/RL-2008-66). Oftentimes, this secondary peak was not observed at low I-129 concentrations. Beginning in 2009, the laboratory no longer required the secondary peak to be present, so I-129 detection limits are now frequently less than 1 pCi/L.

Figure 4-17 shows the vertical extent of the I-129 plume from the 216-U-1 and 216-U-2 Cribs. This plume occurs at shallow depths near the P&T system and becomes fully mixed vertically approximately ~1.5 to ~2 km (~0.9 to ~1.2 mi) from the source. Vertical dispersion appears to be the likely mechanism by which the plume becomes fully mixed vertically.

The 216-S-1, 216-S-2, 216-S-7, and 216-S-9 Cribs were the most substantial sources of I-129 within the OU (RPP-26744). It is likely that these sources account for the highest concentrations within the I-129 plume east of the 200 West Area. The area of this plume, 10 times above the DWS (inside the 10 pCi/L contour), is interpreted to be ~1.1 km^2 (~0.4 mi^2). No information is available on the thickness of this plume. The maximum measured I-129 concentration during the RI was 39 pCi/L in Well 699-35-70 during September 2007 (Figure 4-18). This well is now dry and can no longer be sampled.

4.2.4 Chromium

Figure 4-19 summarizes the maximum sample results for chromium during the RI. Chromium was found to exceed the DWS (100 µg/L) in three regions of the 200-UP-1 Groundwater OU: WMA S-SX Tank Farms, 216-S-20 Crib, and the 600 Area east and southeast of the 200 West Area. Concentrations in a total of eight wells exceeded the DWS, with concentrations in one well at the 241-SX Tank Farm (299-W23-19) exceeding 10 times the DWS.

Figure 4-20 shows the interpreted chromium plumes for FY 2008 (the contours are based on dissolved chromium—analyses for total chromium in filtered samples). The most substantial sources of chromium in the OU are the WMA S-SX Tank Farms, 216-S-20 Crib, and 216-S-10 Pond and Ditch (RPP-26744).[3] During the RI, samples from four wells at WMA S-SX exceeded the DWS (100 µg/L). The highest concentration occurred at Well 299-W23-19 (1,750 µg/L during December 2005) (Figure 4-21), which is near the plume source. The portion of this plume above the DWS is estimated to extend ~375 m (~1,200 ft) from the source area to the east. Depth-discrete sampling during drilling of Well 299-W22-47 indicated the distribution of chromium with depth is similar to Tc-99; concentrations above the DWS occur within the upper 20 m (65 ft) of the aquifer (Figure 4-22). A second plume occurs in the north part of WMA S-SX, downgradient from the S Tank Farm. At Well 299-W22-44, the filtered total chromium concentration began increasing during 2007 (Figure 4-23), and the concentration reached 690 µg/L during March 2009. The other mobile tank waste constituents (Tc-99 and nitrate) also have increased substantially during this time. In general, chromium concentrations are increasing at WMA S-SX and the areal extents of both the northern and southern plumes are growing.

[3] A substantial amount of chromium was estimated to have been released to the 216-U-10 Pond, but the volume of effluent was so large that the average source concentration was quite low (~15 µg/L). A large amount of chromium also was estimated to have been released to the 216-S-8 Crib (adjacent to the SX Tank Farm), but groundwater sampling results do not indicate that this chromium has reached groundwater.

A chromium plume occurs in the 600 Area east-southeast of the 200 West Area. During the RI, the maximum measured chromium concentration in this plume was 160 μg/L in an unfiltered sample from Well 699-32-62 during March 2009. Chromium also was elevated in Well 699-30-66 (102 μg/L in February 2006), which is completed deep in the aquifer just above the Ringold Fm LMU. This suggests that chromium occurs throughout the aquifer thickness in this region. Figure 4-24 shows a cross section of this plume. Figure 4-25 shows the results of a particle tracking analysis using a transient groundwater flow model. Particle tracks originating from the 216-S-10 Pond and Ditch and the 216-S-20 Crib in 1951 end in 2009 near the present position of the chromium plume. Further, it has been estimated that ~5,900 kg (13,007 lb) of chromium was released to the 216-S-20 Crib; ~3,000 kg (6,613 lb) was released to the 216-S-10 Pond and Ditch; and ~650 kg (1,433 lb) was released to the 216-S-19 Pond (RPP-26744). The estimated average source concentrations were much higher at the 216-S-20 Crib (~43,000 μg/L) compared to the 216-S-10 Pond and Ditch (~400 μg/L) and 216-S-19 Pond (~500 μg/L), due to the volume of effluent released at each site. Thus, the 216-S-20 Crib is the most probable source for the 600 Area chromium plume, although effluent from the 216-S-10 Pond and Ditch and 216-S-19 Pond may also have contributed. Elevated chromium concentrations (above the natural background) continue near these sites today. For example, maximum chromium concentrations during the RI were 560 μg/L in a filtered sample from 299-W22-20 at the 216-S-20 Crib (September 2004) and 61 μg/L in an unfiltered sample from 299-W26-13 at the 216-S-10 Pond and Ditch (January 2008). Natural background concentrations are ~2 to ~4 μg/L (Table 4-1). No recent chromium sampling has been conducted near the 216-S-19 Pond. Concentrations at Well 699-32-62 have been declining since chromium was first analyzed at this well in 1992 (Figure 4-26). The long-term rate of decline (for the filtered samples) is ~70 μg/L per decade. This may be due to advection of the plume beyond this well, hydrodynamic dispersion, or both.

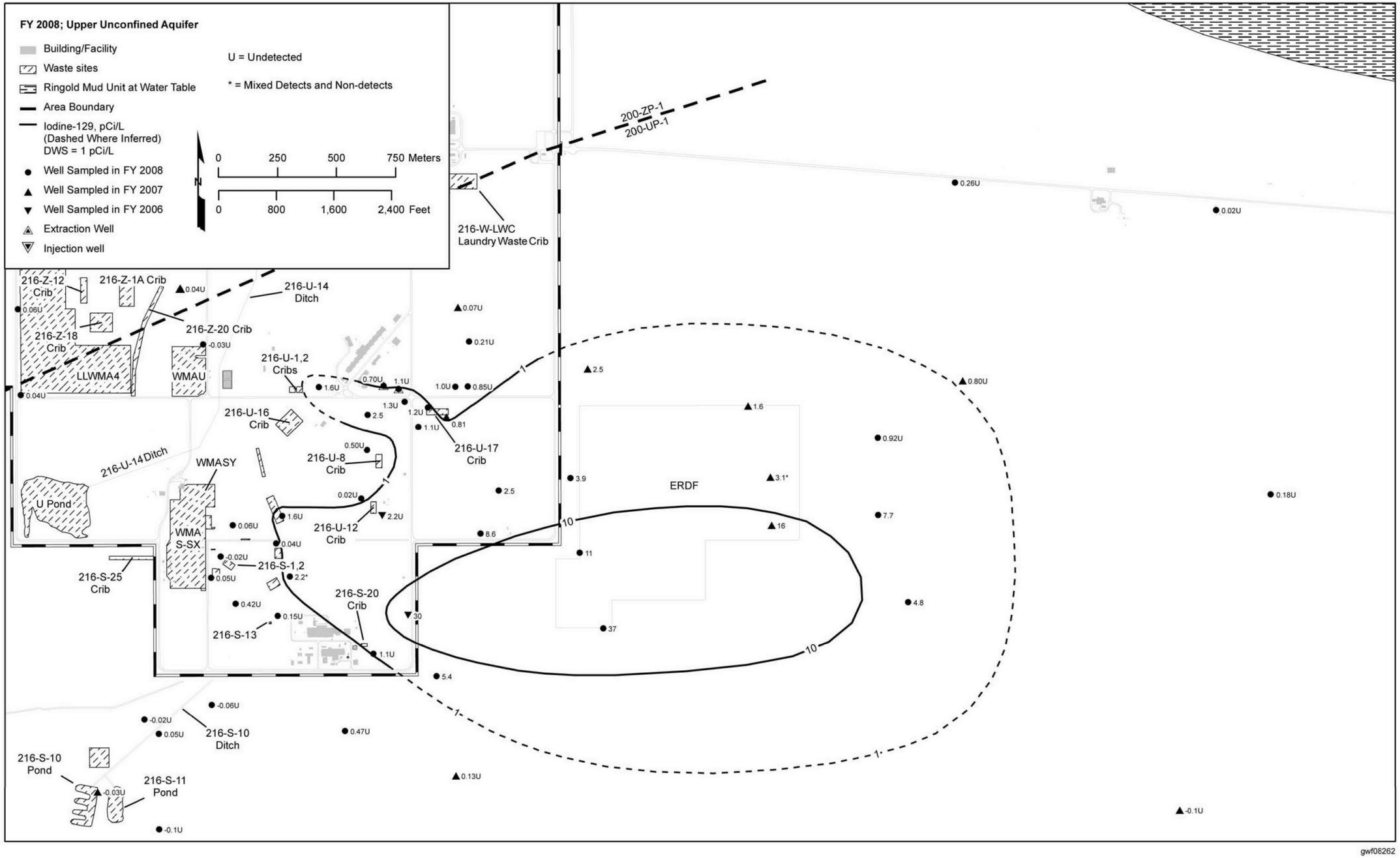

Figure 4-16. Average FY 2008 Iodine-129 Concentrations in the 200-UP-1 Groundwater Operable Unit, Upper Part of Unconfined Aquifer (DOE/RL-2008-66)

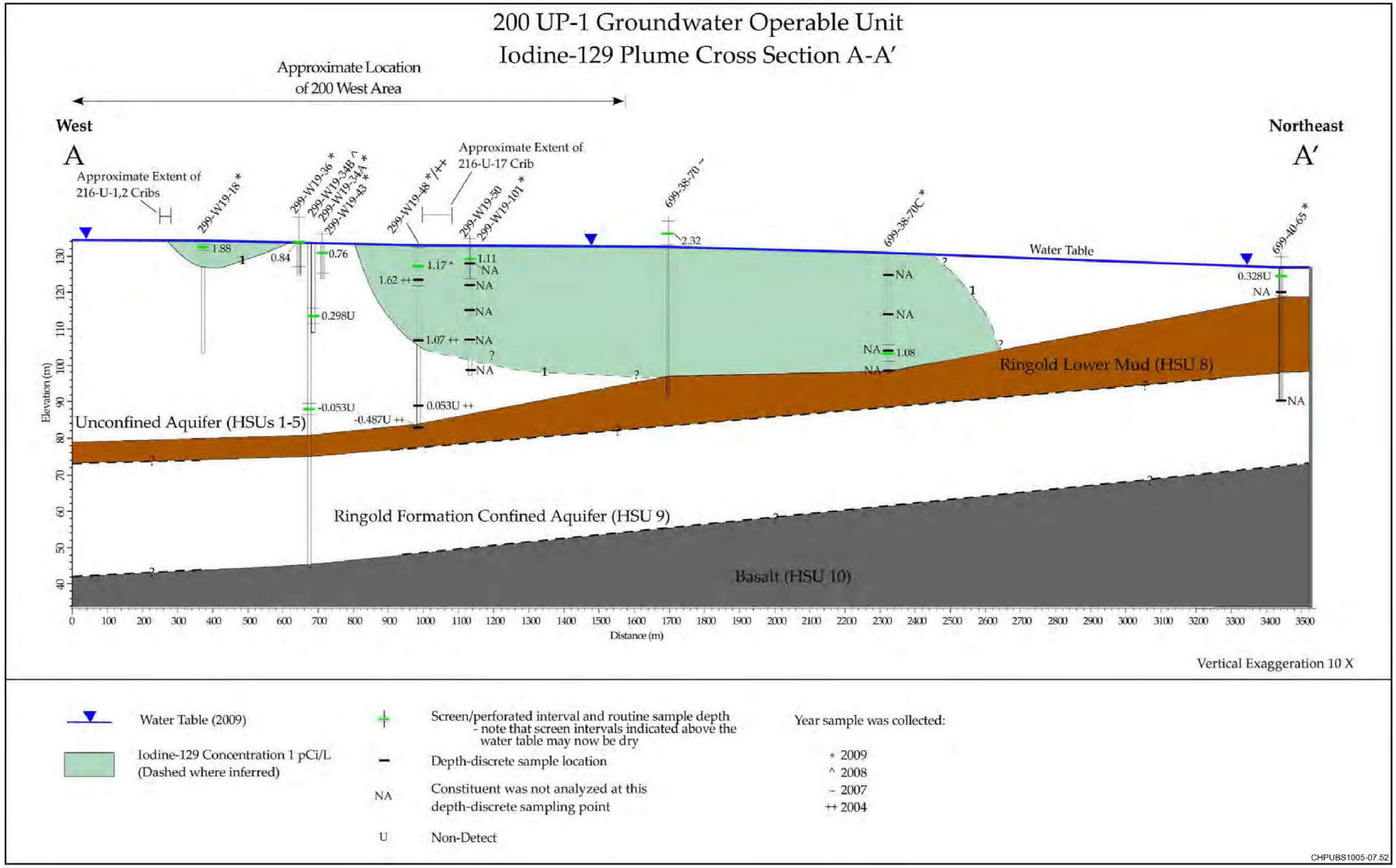

Figure 4-17. Cross Section of the Iodine-129 Plume from the 216-U-1 and 216-U-2 Cribs

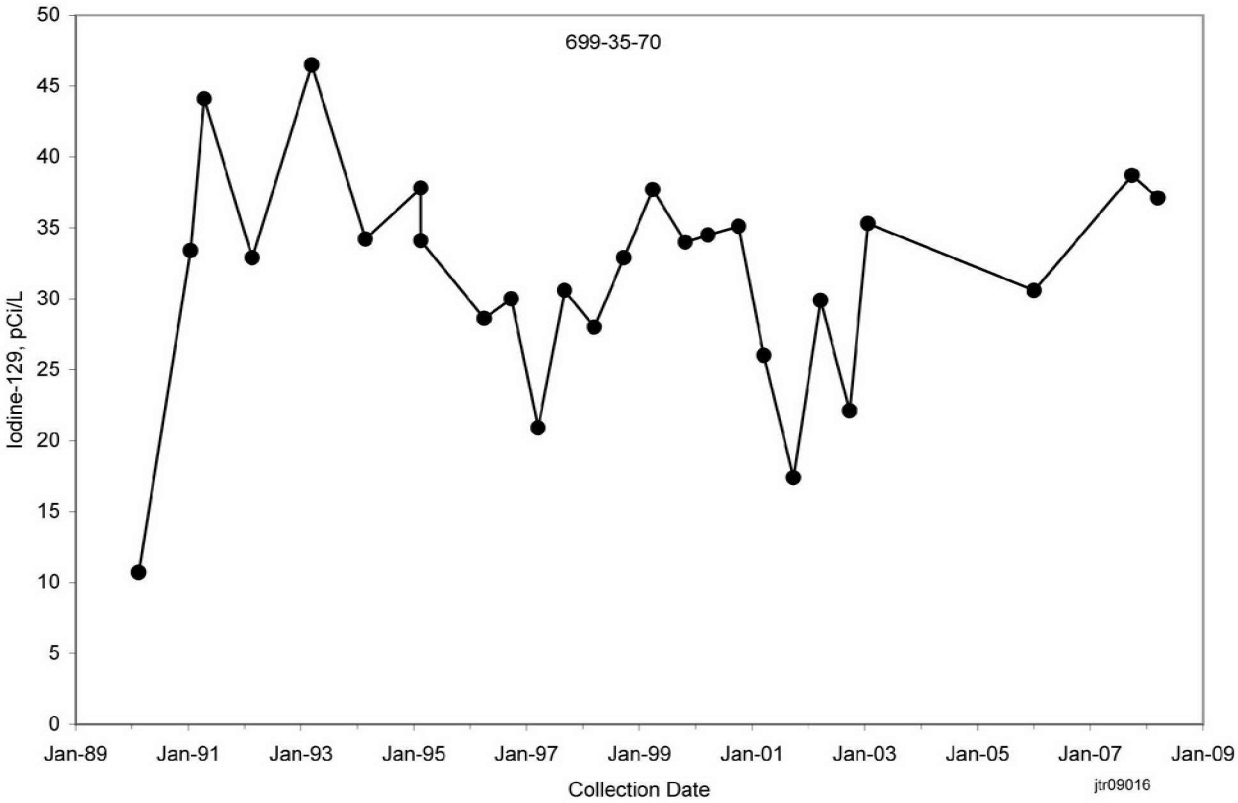

Figure 4-18. Iodine-129 Concentrations in Well 699-35-70, East of the 200 West Area

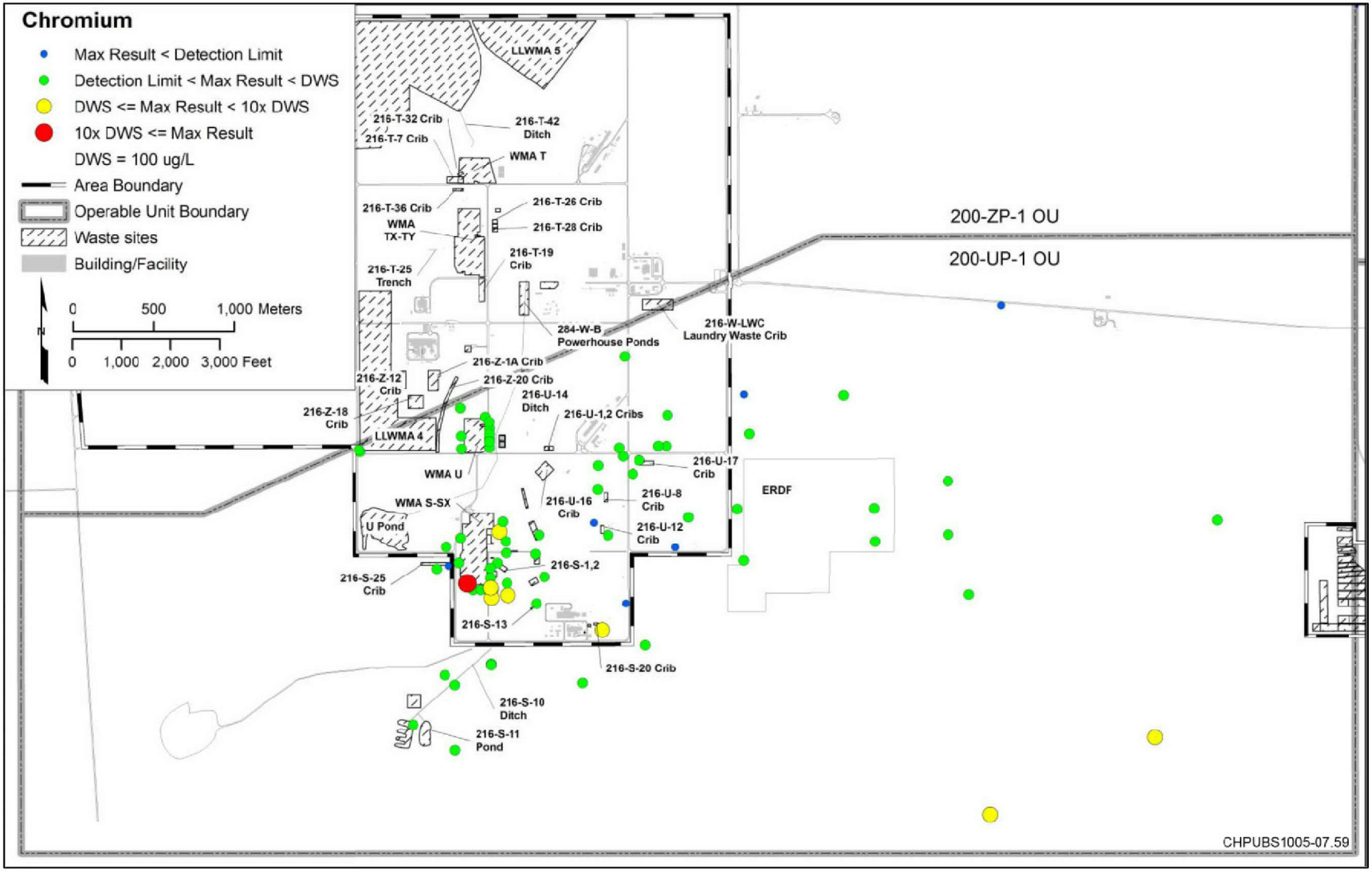

Figure 4-19. Maximum Sample Results for Chromium During the Remedial Investigation

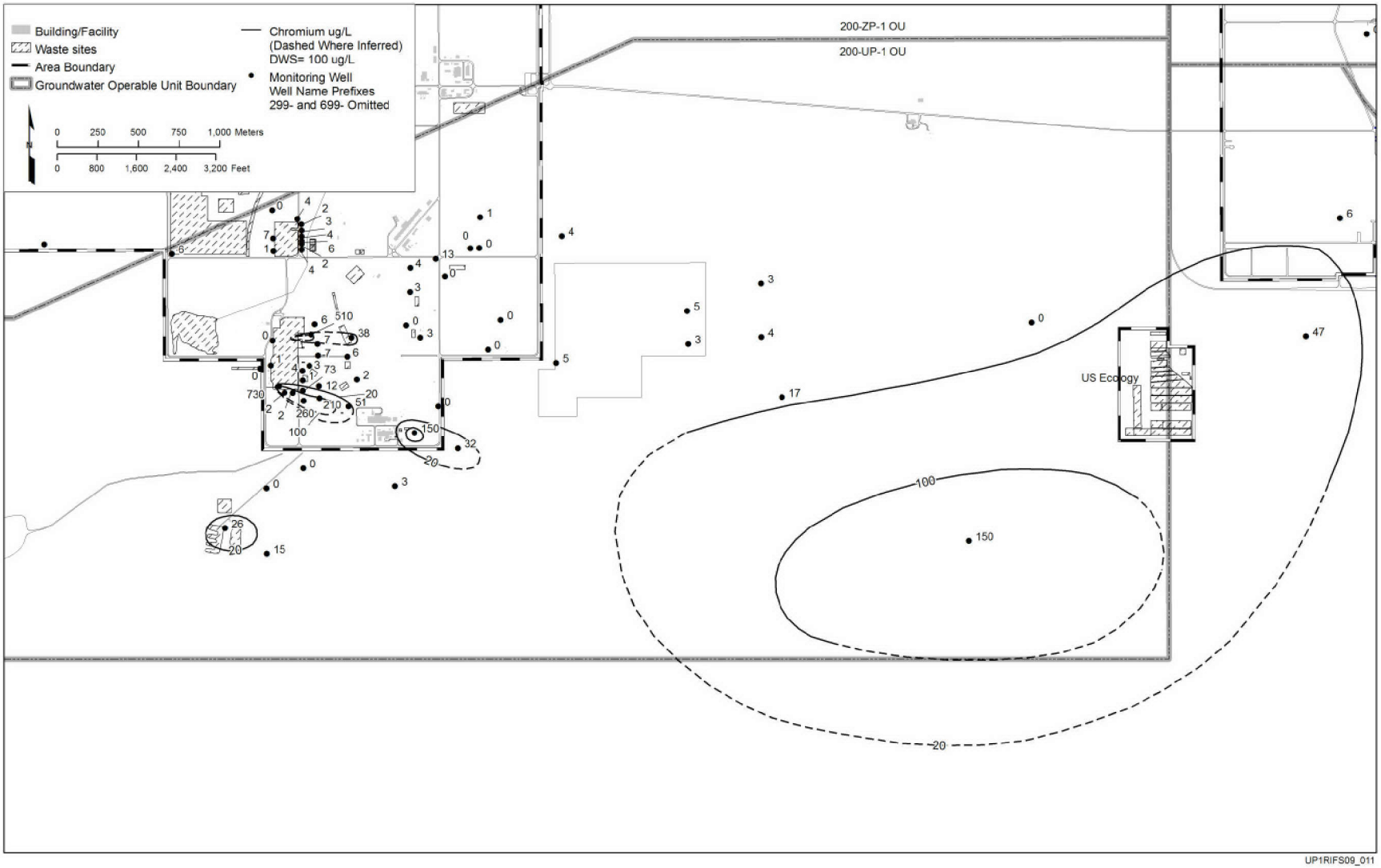

Figure 4-20. Average FY 2008 Chromium Concentrations in the 200-UP-1 Operable Unit, Upper Part of Unconfined Aquifer

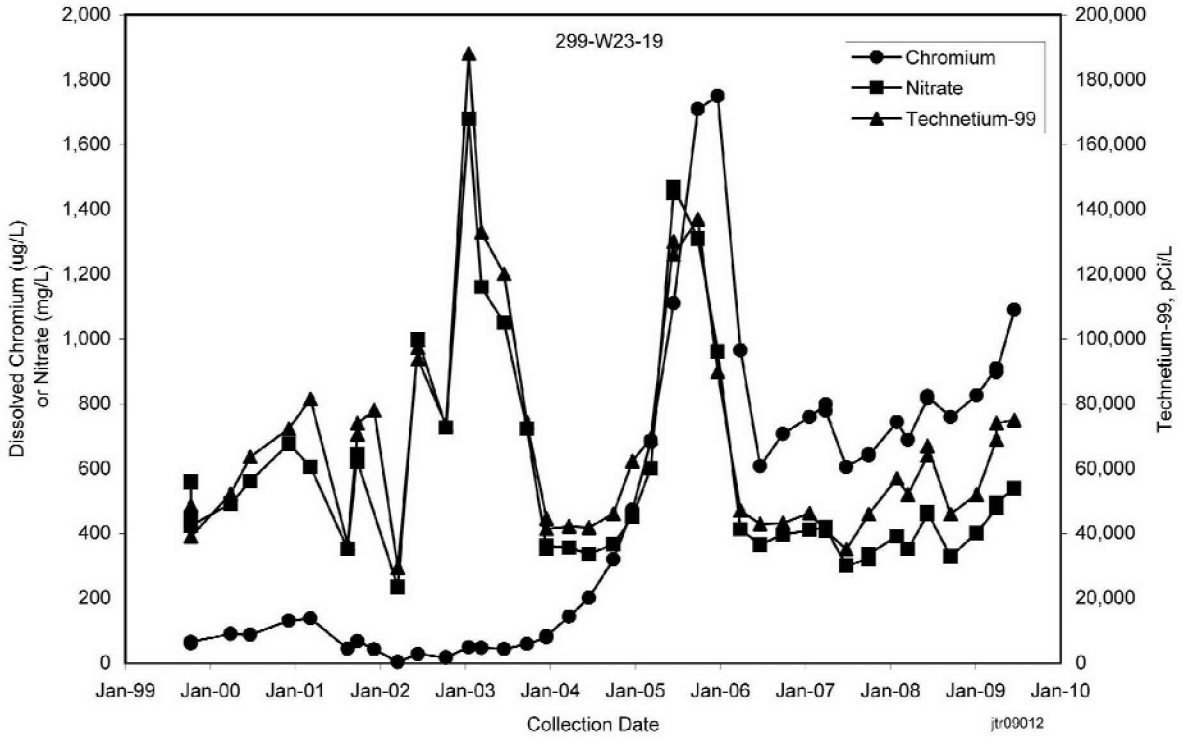

Figure 4-21. Chromium, Nitrate, and Technetium-99 Concentrations in Well 299-W23-19, Southern Portion of Waste Management Area S-SX

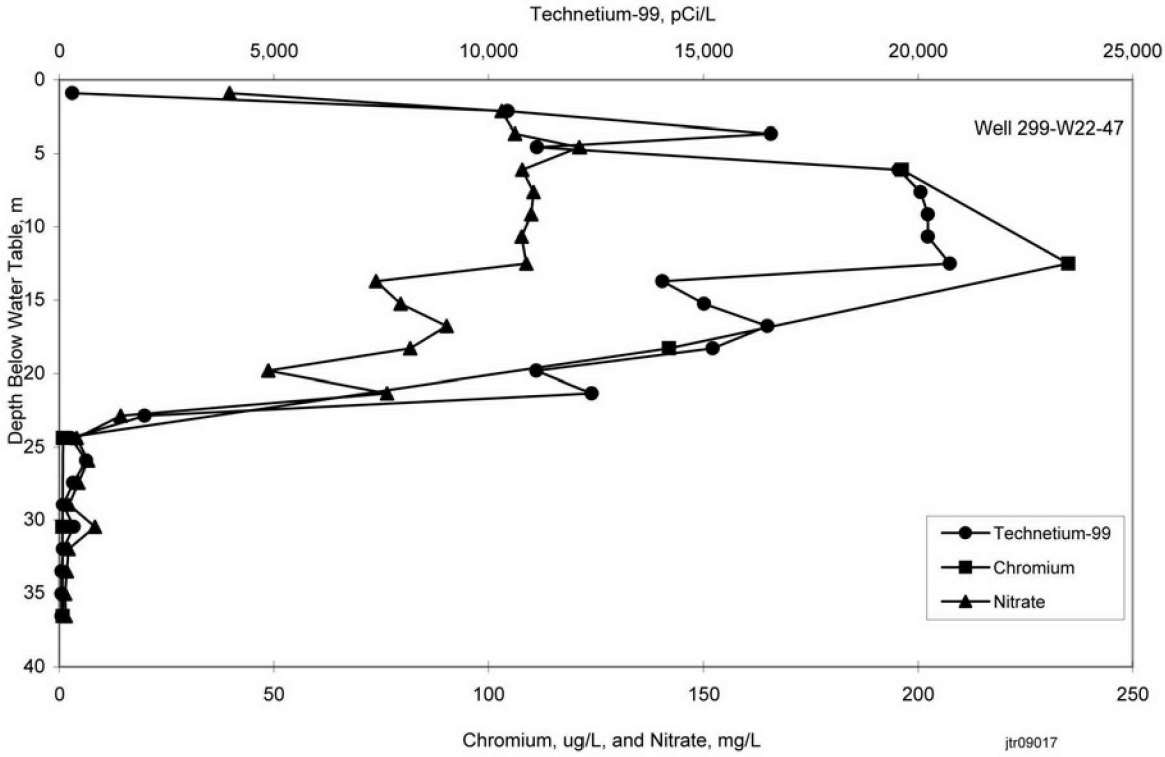

Figure 4-22. Depth-Discrete Sample Results for Chromium and Nitrate in Well 299-W22-47 at Waste Management Area S-SX; Samples Collected During Drilling in January 2005

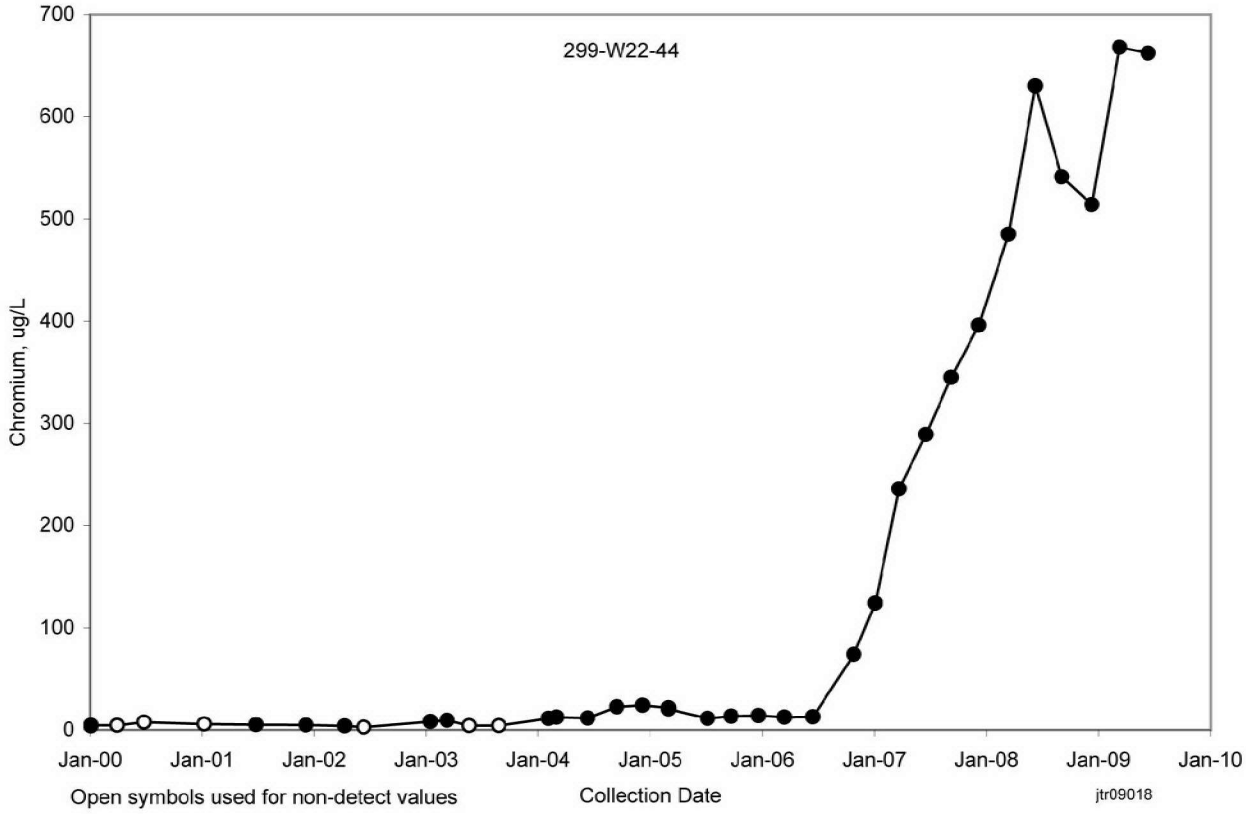

Figure 4-23. Chromium Concentrations in Well 299-W22-44, Downgradient from the 241-S Tank Farm

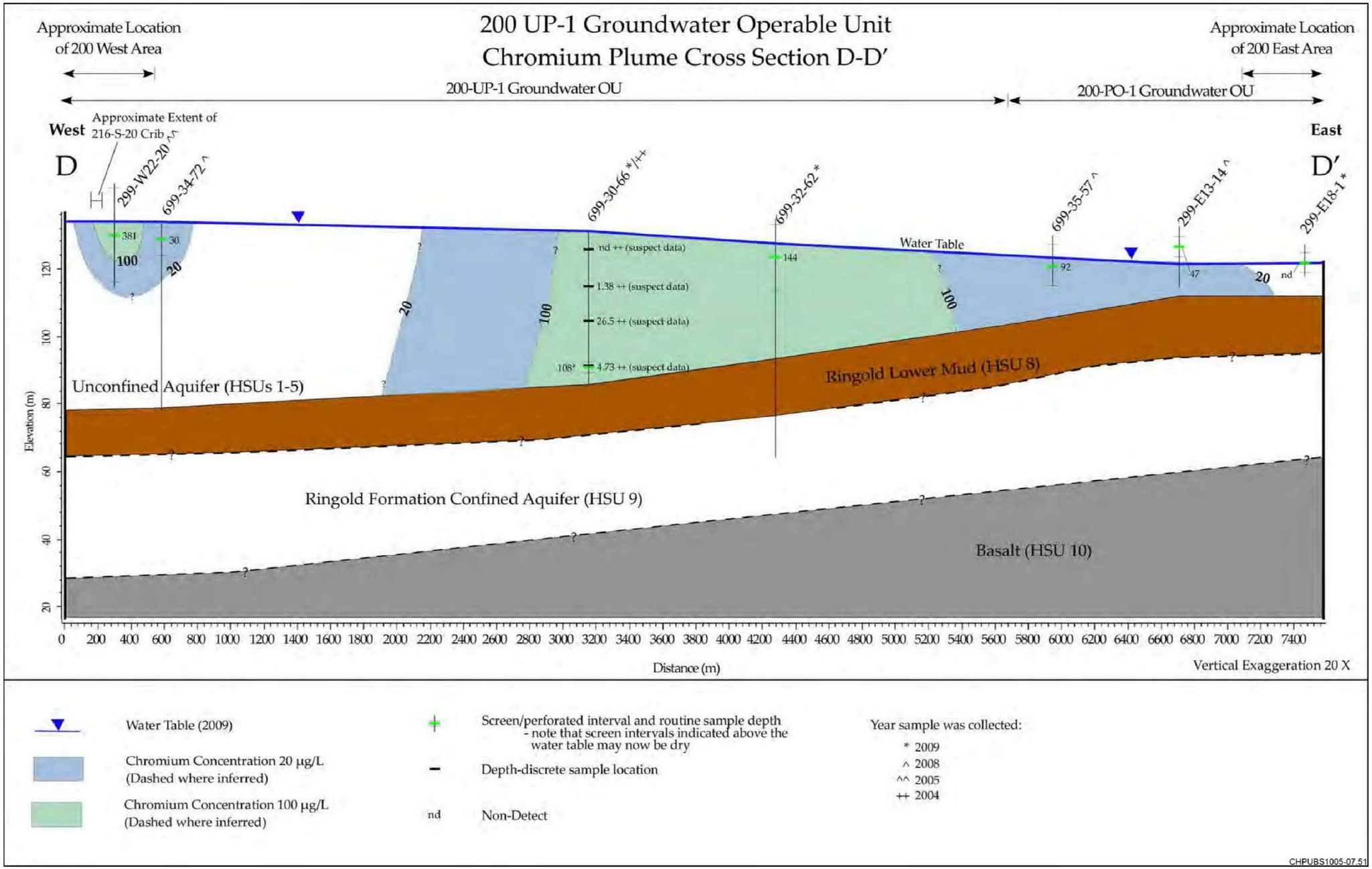

Figure 4-24. Cross-Section of the Chromium Plume East-Southeast of the 200 West Area

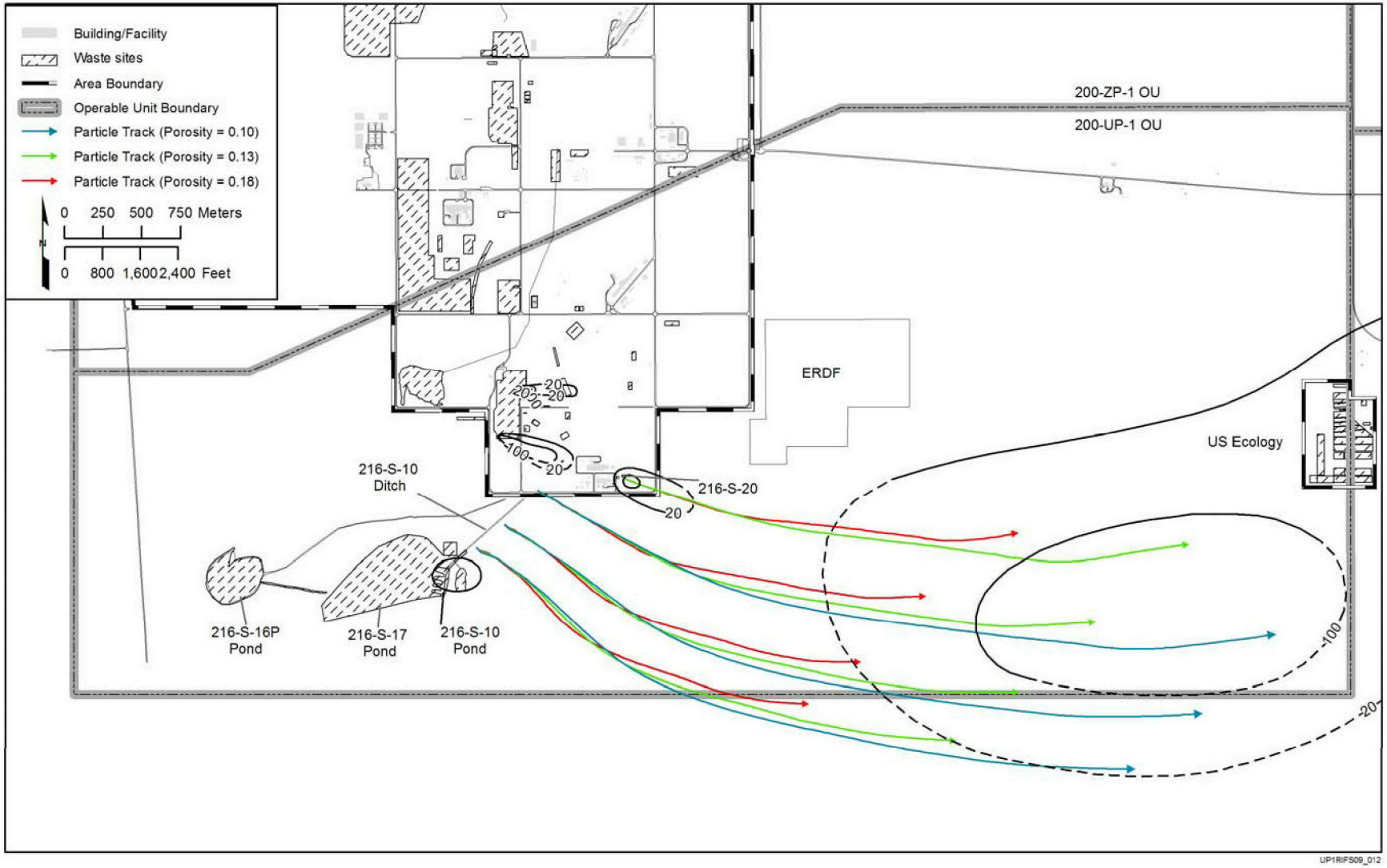

Figure 4-25. Simulated Particle Movement Between 1951 and 2009 from the 216-S-20 Crib and 216-S-10 Ditch

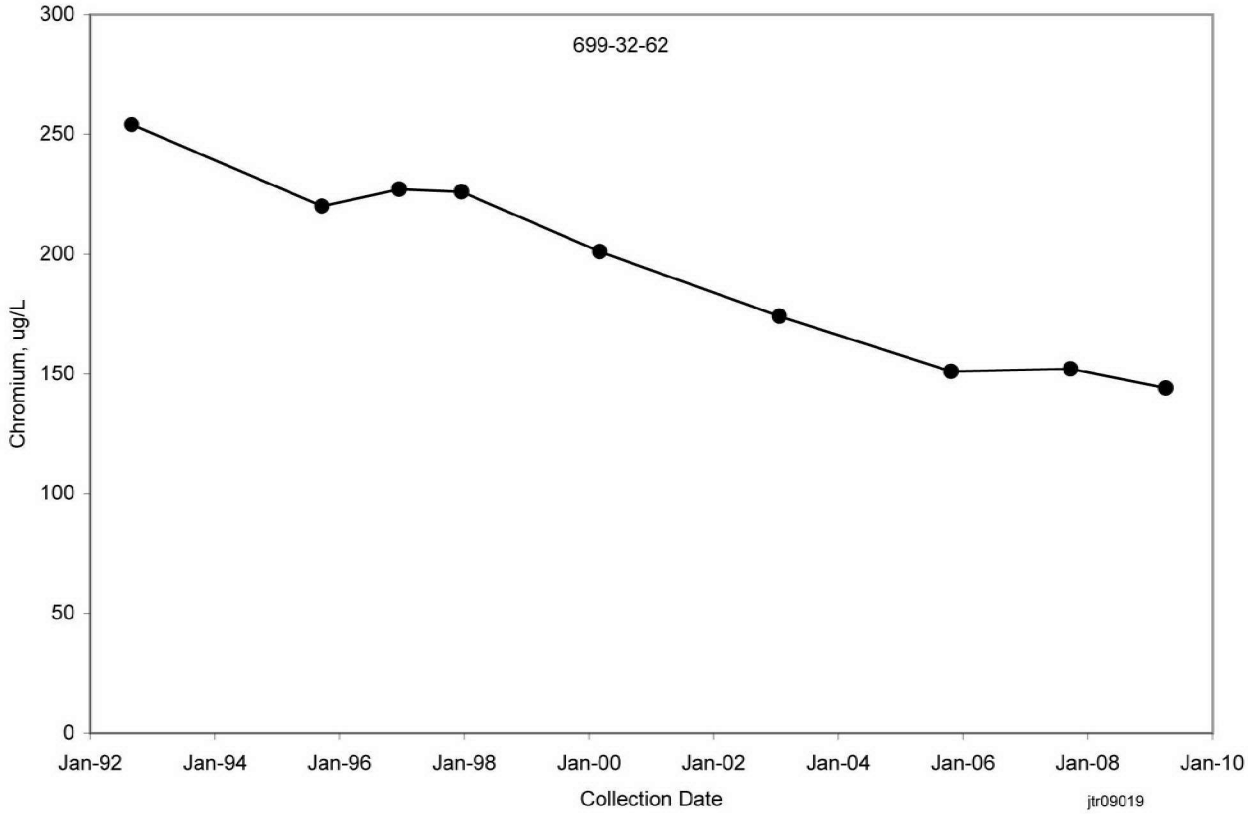

Figure 4-26. Chromium Concentrations in Well 699-32-62, East-Southeast of the 200 West Area

4.2.5 Tritium

Disposal facilities associated with the REDOX Plant are the primary sources of tritium in the 200-UP-1 groundwater interest area. The REDOX Plant operated from 1952 until 1967, although effluent releases continued to occur after that time. The most substantial sources were the 216-S-1, 216-S-2, 216-S-7, 216-S-21, and 216-S-25 Cribs (RPP-26744). In addition, substantial tritium inventories are estimated for the 216-U-8 and 216-U-12 Cribs. Figure 4-27 shows the maximum sampling results for tritium observed during the RI. Concentrations above the DWS (20,000 pCi/L) occur in the vicinity of the REDOX Plant cribs and downgradient to the east-northeast into the 600 Area. Concentrations exceeded 10 times the DWS in four wells during the RI: 299-W22-9 (1,020,000 pCi/L during December 2005); 299-W22-20 (480,000 pCi/L during December 2005); 699-35-70 (277,000 pCi/L during January 2006); and 299-W23-9 (218,000 during October 2005).

Figure 4-28 shows the interpreted tritium plume. A large tritium plume originates from the REDOX Plant cribs in the southern part of the 200 West Area and extends ~5 km (~3 mi) toward the east and northeast at levels above the 20,000 pCi/L DWS. Two high-concentration areas occur within this region; a large plume extends to the east and northeast from the 200 West Area and a smaller plume extends ~550 m (~1,800 ft) to the east-southeast from the 216-S-25 Crib.

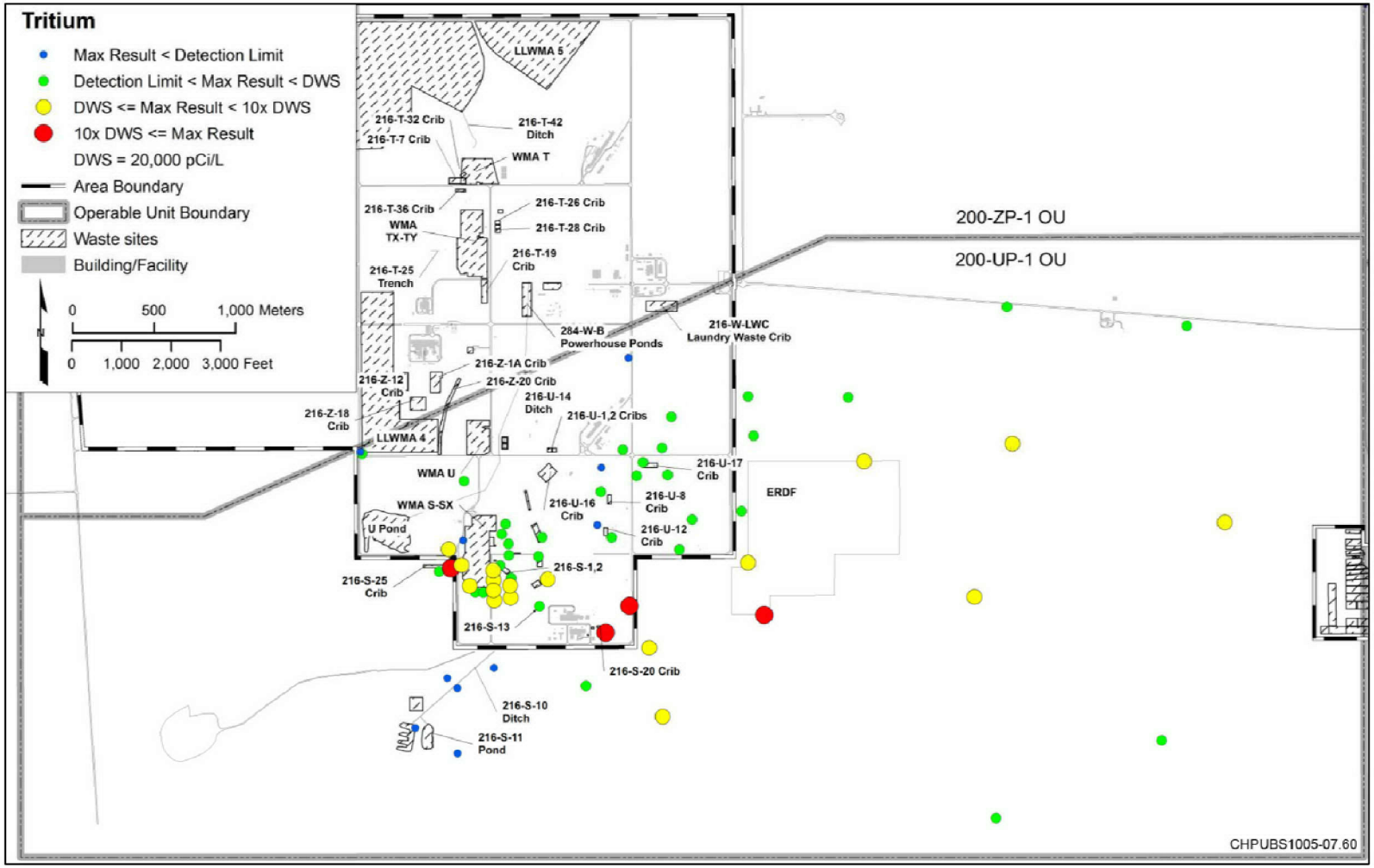

Figure 4-27. Maximum Sample Results for Tritium During the Remedial Investigation

1

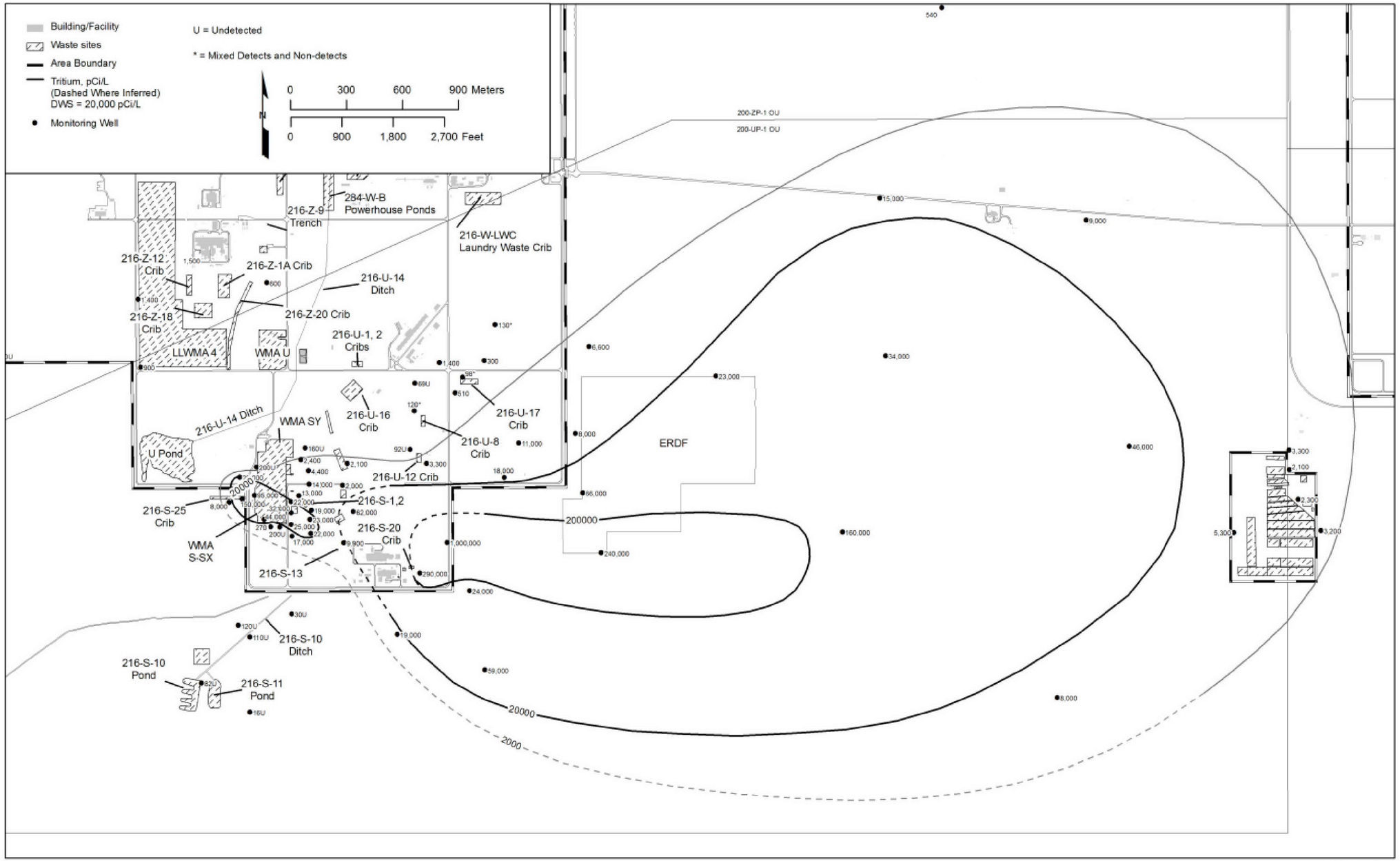

Figure 4-28. Average FY 2008 Tritium Concentrations in the 200-UP-1 Groundwater Operable Unit, Upper Part of Unconfined Aquifer (DOE/RL-2008-66)

In the eastern high-concentration area, tritium concentrations are generally declining at six wells and increasing at three, indicating that the plume has localized areas of high concentrations. When these areas pass by wells, increasing concentrations may temporarily occur. Figure 4-29 shows tritium concentration trends for three wells within this plume: 699-35-66A, 699-35-70, and 699-36-61A. Declining trends occur at 699-35-70 and 699-35-66A, while a slight increasing trend occurs at 699-36-61A. Thus, concentrations are increasing slightly at the plume front, but not nearly as rapidly as they are declining in the central part of the plume. The plume exhibits declining concentrations overall and the areal extent, as defined by the 2,000-pCi/L contour, has changed little over many years, indicating natural attenuation by dispersion and radiological decay.

Tritium occurs above the DWS in eight wells downgradient of the 216-S-25 Crib. Historical concentrations fluctuated in a single well (299-W23-9) on the downgradient side of the crib, but this well has gone dry and can no longer be sampled. Farther downgradient, trends are declining or stable in all but one well (299-W23-21), which shows an increasing trend. Radioactive liquid effluent was disposed to this crib from 1973 through 1980, and effluent from a P&T system at the 216-U-1 and 216-U-2 Cribs was disposed to this crib in 1985. In the vadose zone beneath this crib, tritium in the residual soil moisture may be migrating slowly to the water table, which would account for the fluctuating tritium concentration trend in Well 299-W23-9.

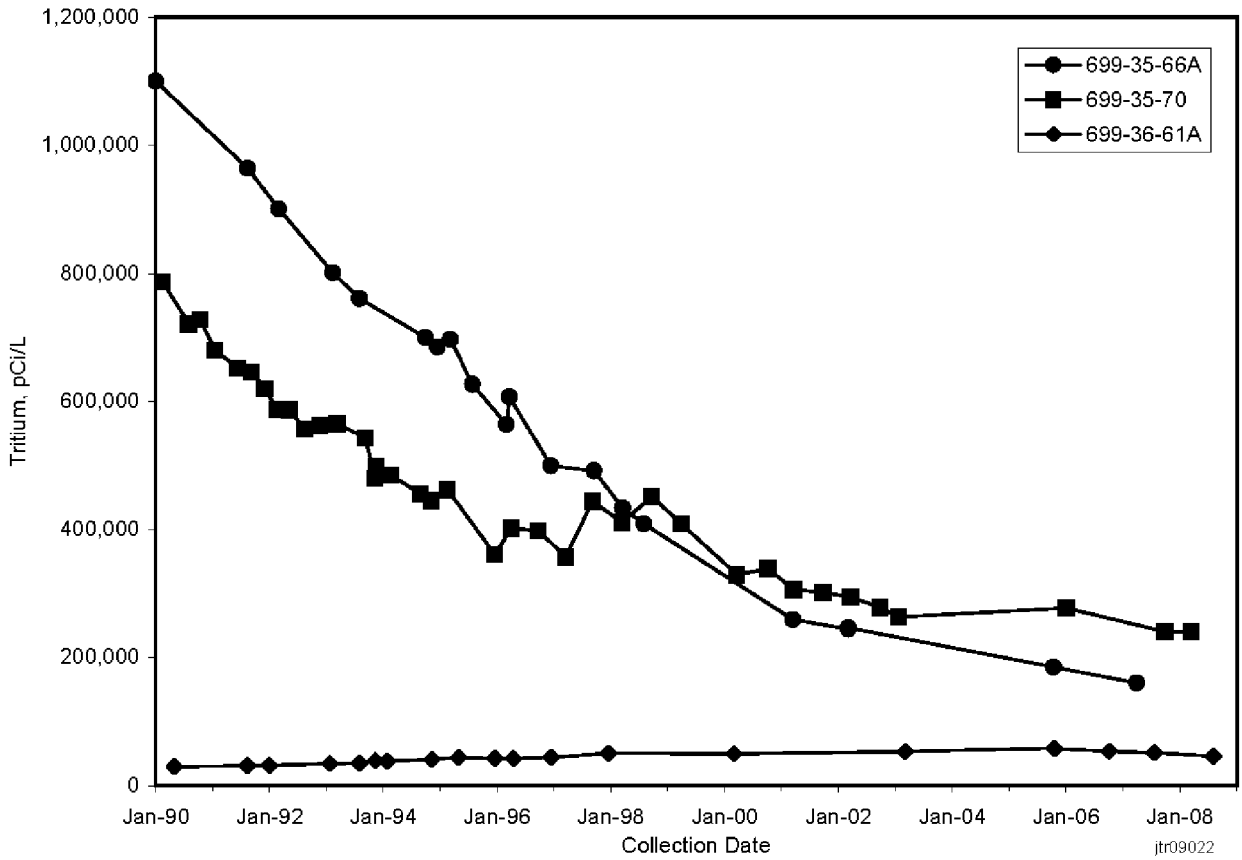

Figure 4-29. Tritium Concentrations in Wells 699-35-66A, 699-35-70, and 699-36-61A, East of the 200 West Area

4.2.6 Nitrate

The occurrence of nitrate above the DWS (45 mg/L) is widespread within the OU. During the RI, nitrate concentrations were found above the DWS at the WMA S-SX Tank Farms, WMA U Tank Farm, near and/or downgradient from the 216-S-20, 216-S-25, 216-U-1, and 216-U-2 Cribs, and in a large region extending from the 200 West Area into the 600 Area (Figure 4-30). Concentrations greater than 10 times the DWS occurred in two wells at WMA S-SX (299-W23-19 and 299-W22-47) and in two wells at the IRA P&T area downgradient from the 216-U-1 and 216-U-2 Cribs (299-W19-43 and 299-W19-37).

Nitrate plumes in the 200-UP-1 Groundwater OU originate from both the U Plant and REDOX Plant disposal facilities, the most substantial of which were probably the 216-U-8 and 216-U-12 Cribs (RPP-26744). The nitrate plumes from these sources merge downgradient into a single large plume, which extends to the east and northeast a total distance of ~4 km (~2.5 mi) (Figure 4-31). The 600 Area plume occurs more to the north than the tritium, I-129, and chromium plumes. This observation is consistent with the U Plant cribs being the primary source of the 600 Area nitrate plume, whereas REDOX Plant disposal facilities to the south are largely the sources of the other plumes. Figure 4-32 shows some representative nitrate trends for the 600 Area plume. Figure 4-33 shows the vertical extent of the nitrate plume from the 216-U-1 and 216-U-2 Cribs through the P&T area and into the 600 Area. Similar to the Tc-99 and I-129 plumes in this area, nitrate occurs at shallow depths near the source and becomes fully mixed vertically between ~1.5 to ~2 km (~0.9 to ~1.2 mi) downgradient of the source, most likely due to vertical dispersion.

WMA U is a source of nitrate to groundwater. Nitrate concentrations in several of the downgradient wells exceed the concentration in the upgradient well (299-W18-40). The maximum nitrate concentration measured at the U Tank Farm during the RI was 109 mg/L in Well 299-W19-44 (August 2006). Nitrate occurs in two small plumes associated with REDOX Plant disposal facilities: one near the 216-S-20 Crib and another near the 216-S-25 Crib and WMA S-SX. From 1952 through 1972, the 216-S-20 Crib received waste from laboratory hoods and decontamination sinks in the 222-S Building, along with laboratory waste from the 300 Area. At Well 299-W22-20 (downgradient of the 216-S-20 Crib), the maximum nitrate concentration measured during the RI was 144 mg/L in December 2005. At a new well, 699-34-72, which is located about 320 m (~1,000 ft) downgradient from the 216-S-20 Crib, the average nitrate concentration was 32 mg/L during FY 2008. Thus, nitrate from this crib at concentrations exceeding the DWS appears to be localized to the crib vicinity.

The nitrate plume originating from the 216-S-25 Crib merges with the nitrate plume from WMA S-SX, and the portion of this combined plume above the DWS is interpreted to extend ~500 m (~1,600 ft) to the east-southeast. The maximum concentration measured in this plume during the RI was 1,460 mg/L in Well 299-W23-19 during June 2005 (Figure 4-34). Concentrations in this well have since declined, ranging from ~300 to ~540 mg/L between 2007 and 2009. Depth-discrete sampling during drilling at 299-W22-47 indicated the nitrate occurs within the upper 20 m (65 ft) of the aquifer, similar to Tc-99 and chromium (Figure 4-35).

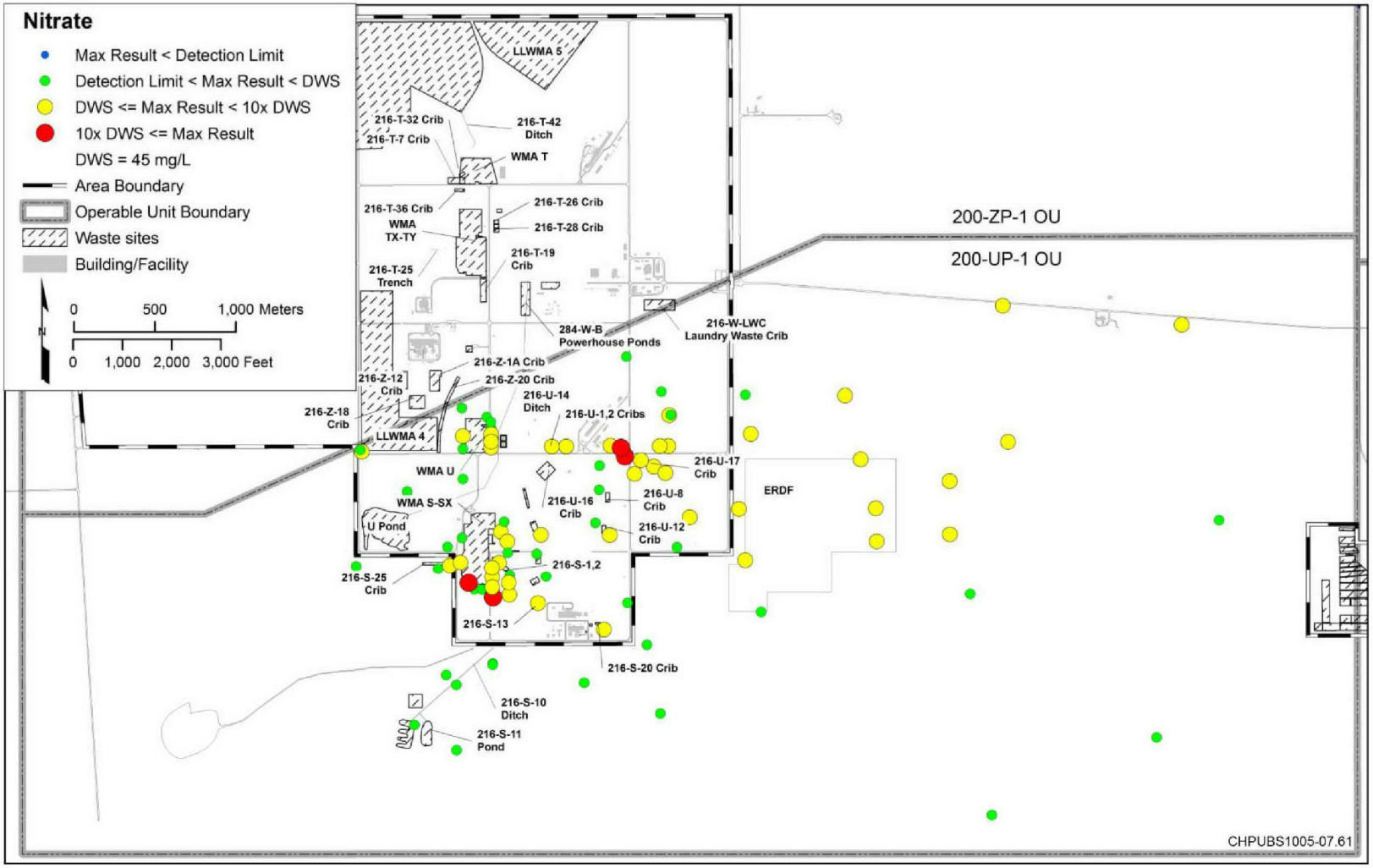

Figure 4-30. Maximum Sample Results for Nitrate During the Remedial Investigation

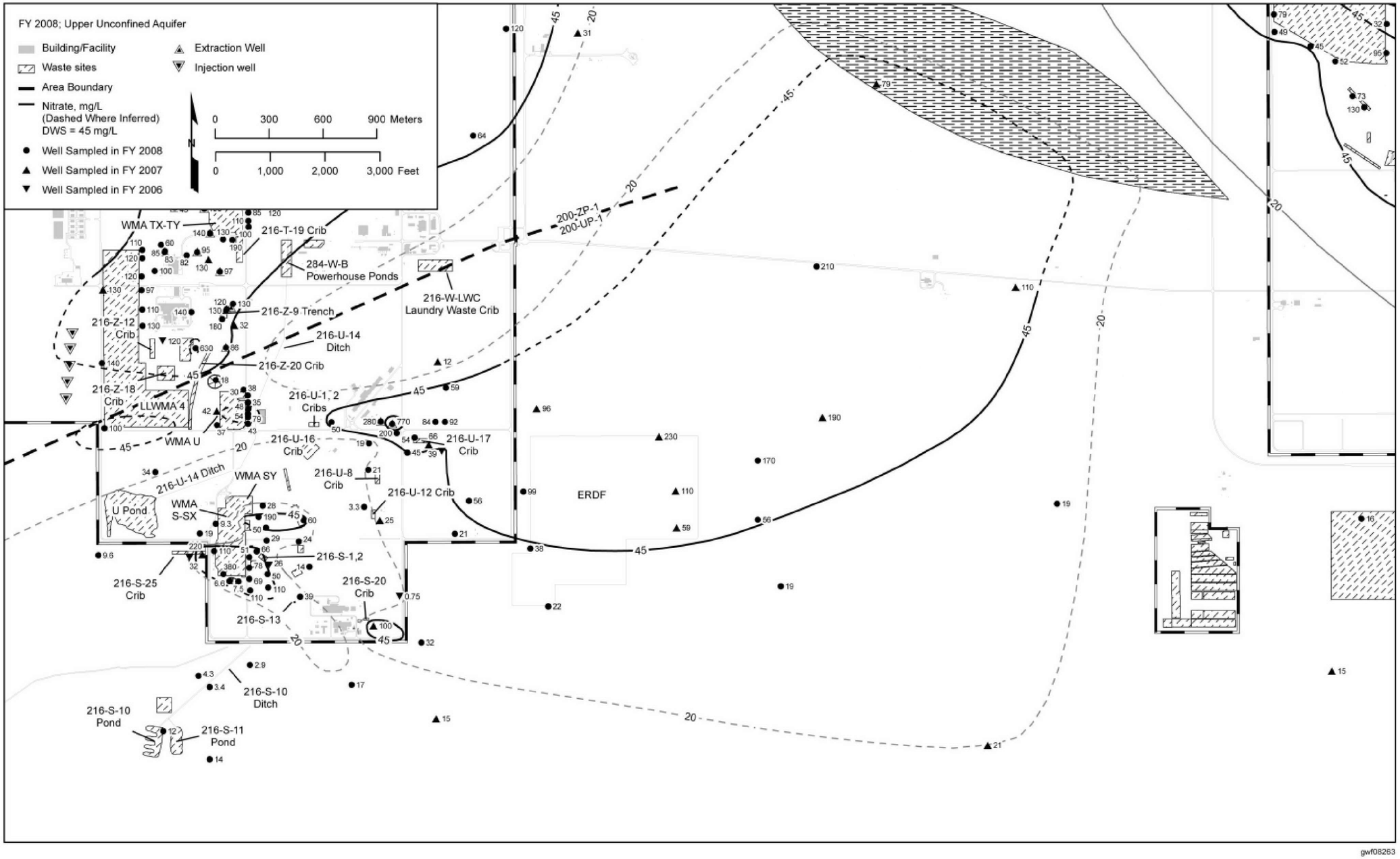

Figure 4-31. Average FY 2008 Nitrate Concentrations in the 200-UP-1 Groundwater Operable Unit, Upper Part of Unconfined Aquifer (DOE/RL-2008-66)

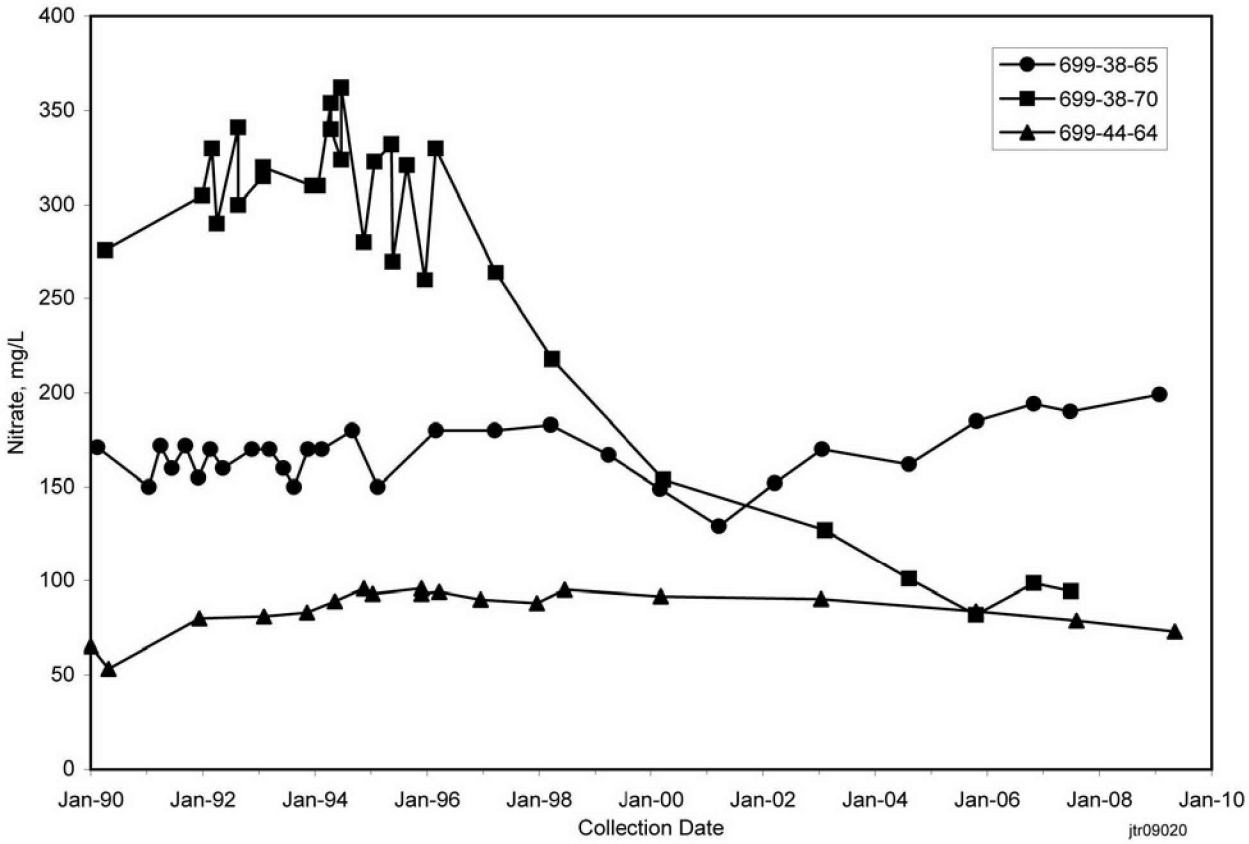

Figure 4-32. Nitrate Concentrations in Wells 699-38-65, 699-38-70, and 699-44-64 East of the 200 West Area

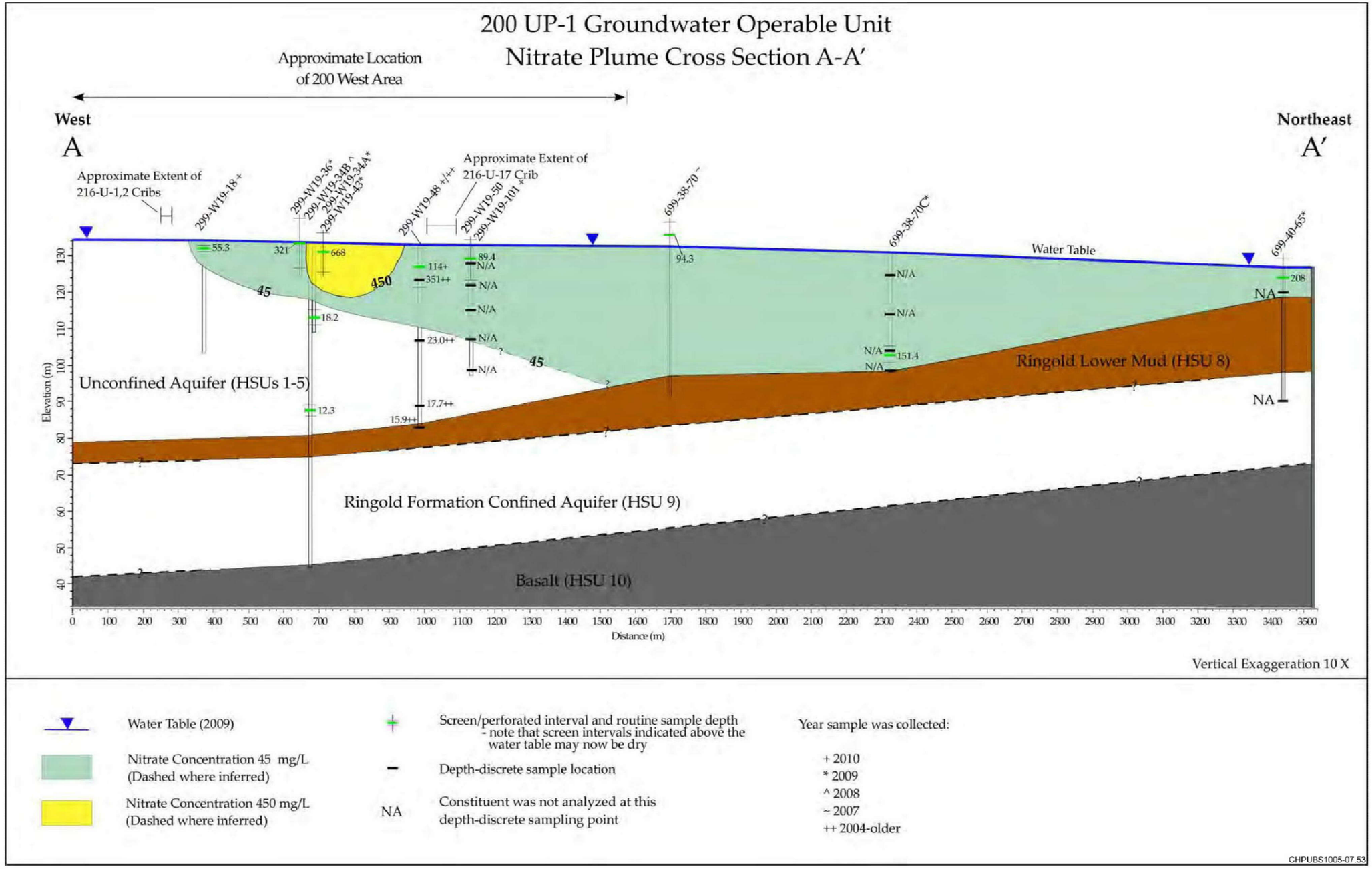

Figure 4-33. Cross Section of the Nitrate Plume from the 216-U-1 and 216-U-2 Cribs

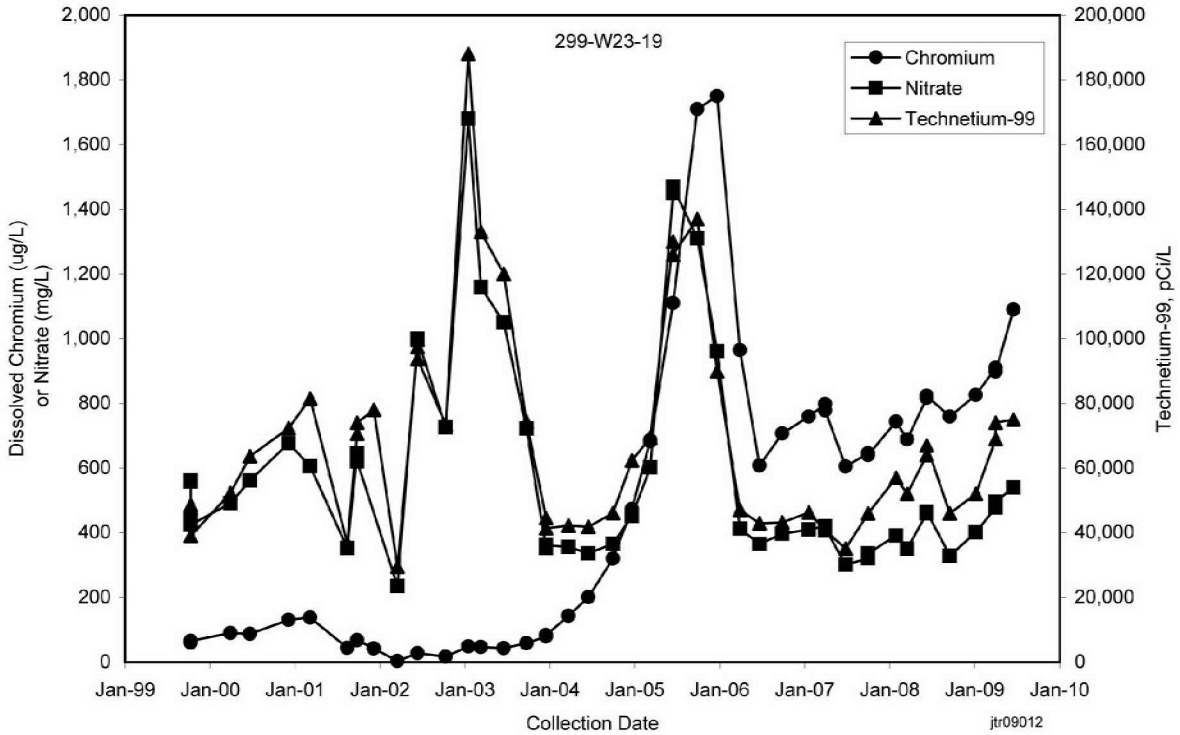

Figure 4-34. Chromium, Nitrate, and Technetium-99 Concentrations in Well 299-W23-19, Southern Portion of Waste Management Area S-SX

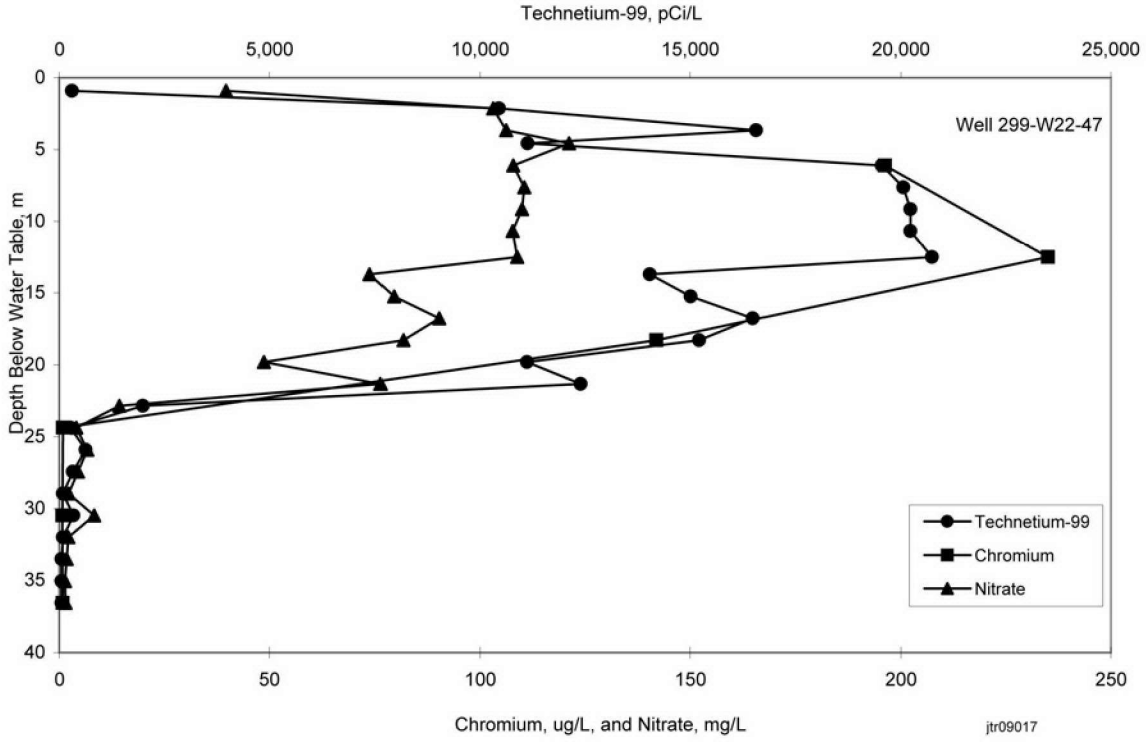

Figure 4-35. Depth-Discrete Sample Results for Chromium, Nitrate, and Technetium-99 in Well 299-W22-47 at Waste Management Area S-SX; Samples Collected During Drilling in January 2005

4.2.7 Carbon Tetrachloride, Chloroform, and Trichloroethene

Carbon tetrachloride occurs above the DWS (5 μg/L) in numerous wells within the 200-UP-1 Groundwater OU; the maximum concentration in 34 wells exceeded 10 times the DWS (Figure 4-36). The highest concentrations in the OU occur adjacent to the 200-ZP-1 Groundwater OU and decrease toward the south and east. At the water table, the plume is widespread in the south 200 West Area, and extends ~1 km (~0.6 mi) east into the 600 Area (Figure 4-37).

Examination of operational process records and DOE/RL-91-32 indicate the carbon tetrachloride plume originated from waste disposal sites associated with the PFP in the 200-ZP-1 Groundwater OU. Historically, carbon tetrachloride was used in mixtures with other organics to recover plutonium from aqueous streams containing plutonium nitrate. The degraded or contaminated organic solvents containing carbon tetrachloride were disposed to the 216-Z-9 Trench during the period of operations at the 234-5 (Recuplex) Plant (1955 through 1962). Carbon tetrachloride containing solvents that originated from the later Plutonium Recovery Facility (PRF) operations at the 236-Z Building were disposed to the 216-Z-1A tile field from 1964 to 1969, and to the 216-Z-18 Crib from 1969 through May 1973. After this date, these wastes were routed to tank farms (DOE/RL-91-32). Figure 4-38 and Figure 4-39 illustrate the carbon tetrachloride plume and the associated chloroform plume as depicted in PNL-8073. These contour maps, generated from the limited data available before the 200-ZP-1 IRA was initiated, show a strong correlation between the groundwater contaminant concentrations and the previously listed disposal sites.

Results of the early site characterization activities are presented in WHC-SD-EN-TI-248, along with a discussion of the mechanisms by which carbon tetrachloride and associated degradation products could migrate south and eastward from the original 216-Z-9, 216-Z-1A, and 216-Z-18 disposal sites into the area now defined as the 200-UP-1 Groundwater OU. Later characterization work that refined the conceptual model was conducted as part of DOE/RL-96-33 as well as the installation of local groundwater monitoring wells. The refined CSM for carbon tetrachloride, chloroform, and TCE in the 200-UP-1 groundwater is presented in BHI-01576. Oostrom et al. (2007) present a recent discussion of carbon tetrachloride flow and transport in the area of the 216-Z-9 trench. The salient feature of these discussions is that carbon tetrachloride is a mobile DNAPL that was able to migrate horizontally as a liquid in conjunction with the regional groundwater flow or while diffusing laterally through the vadose zone in the vapor phase. This migration carried carbon tetrachloride contamination from the original disposal locations into the 200-UP-1 Groundwater OU.

The maximum measured carbon tetrachloride concentration within the 200-UP-1 Groundwater OU during the RI was 1,600 μg/L in Well 299-W14-71 (April 2007). This is comparable to the mean anthropogenic background concentration of 1,680 μg/L for the 200-ZP-1 Groundwater OU (Table 4-2), consistent with the 200-ZP-1 Groundwater OU being the source of this contamination. Concentration trends are variable, with individual wells having increasing, decreasing, or stable trends. No clear spatial pattern is evident among wells having increasing or decreasing trends.

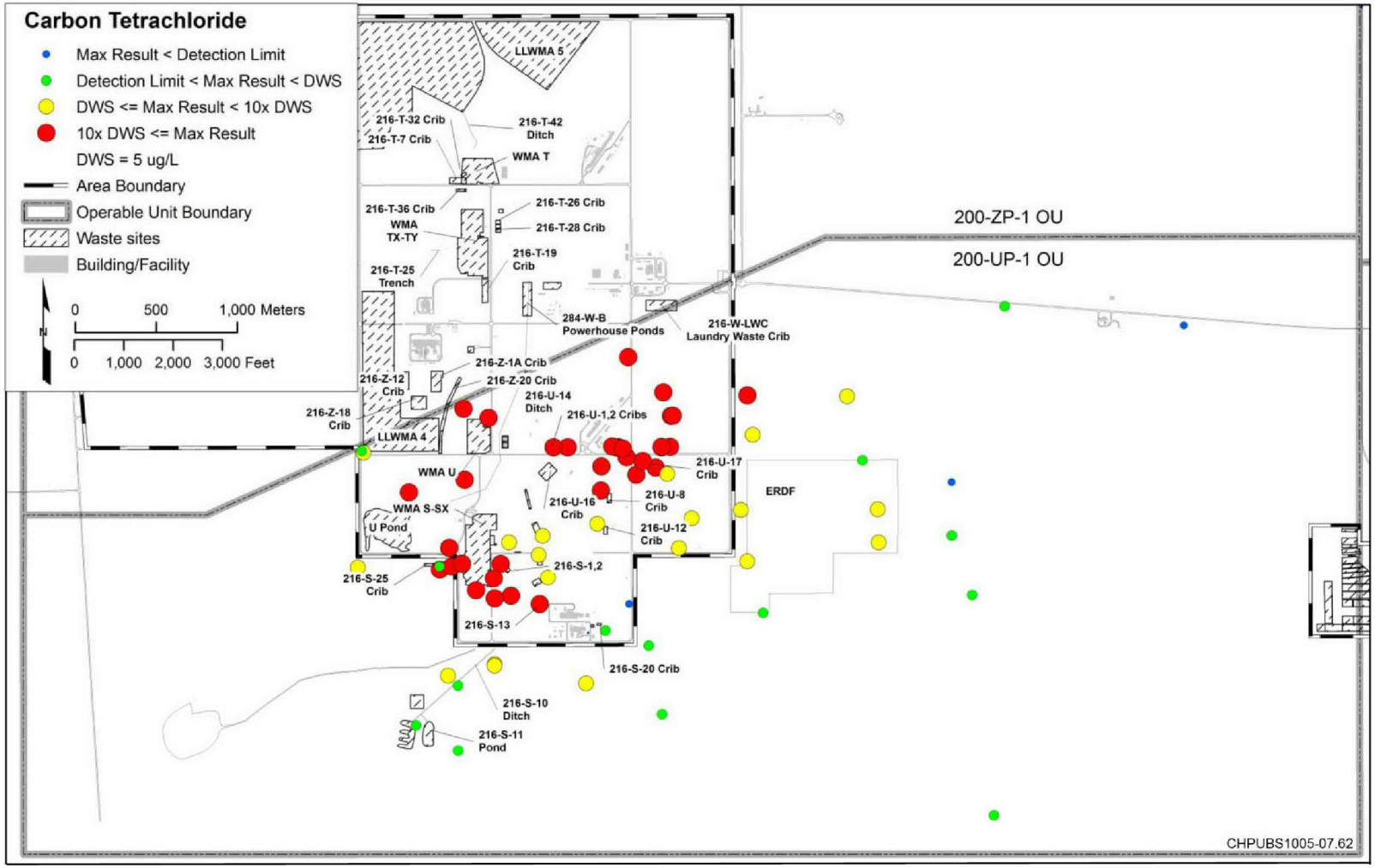

Figure 4-36. Maximum Sample Results for Carbon Tetrachloride During the Remedial Investigation

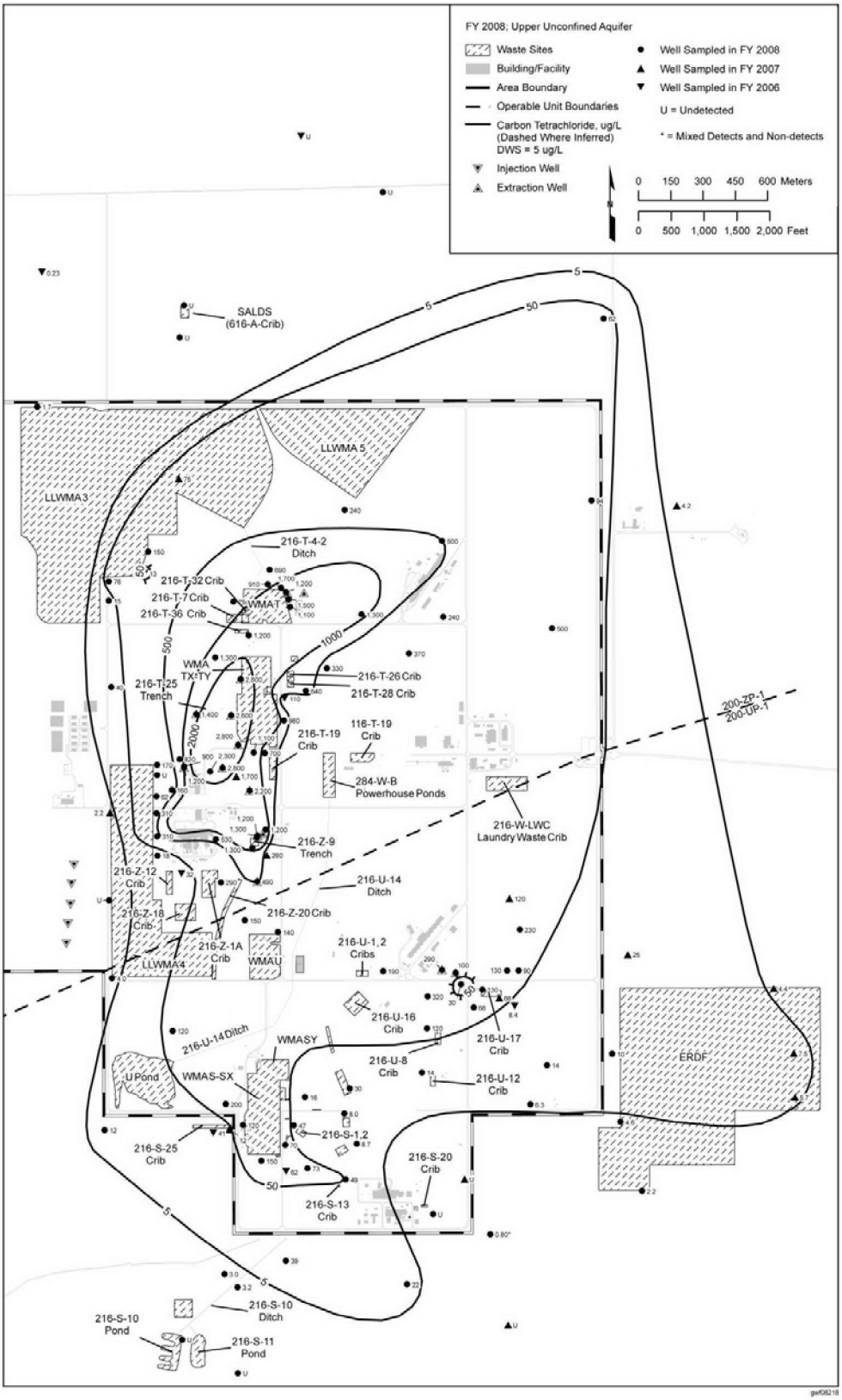

Figure 4-37. Average FY 2008 Carbon Tetrachloride Concentrations in the 200 West Area, Upper Part of Unconfined Aquifer (DOE/RL-2008-66)

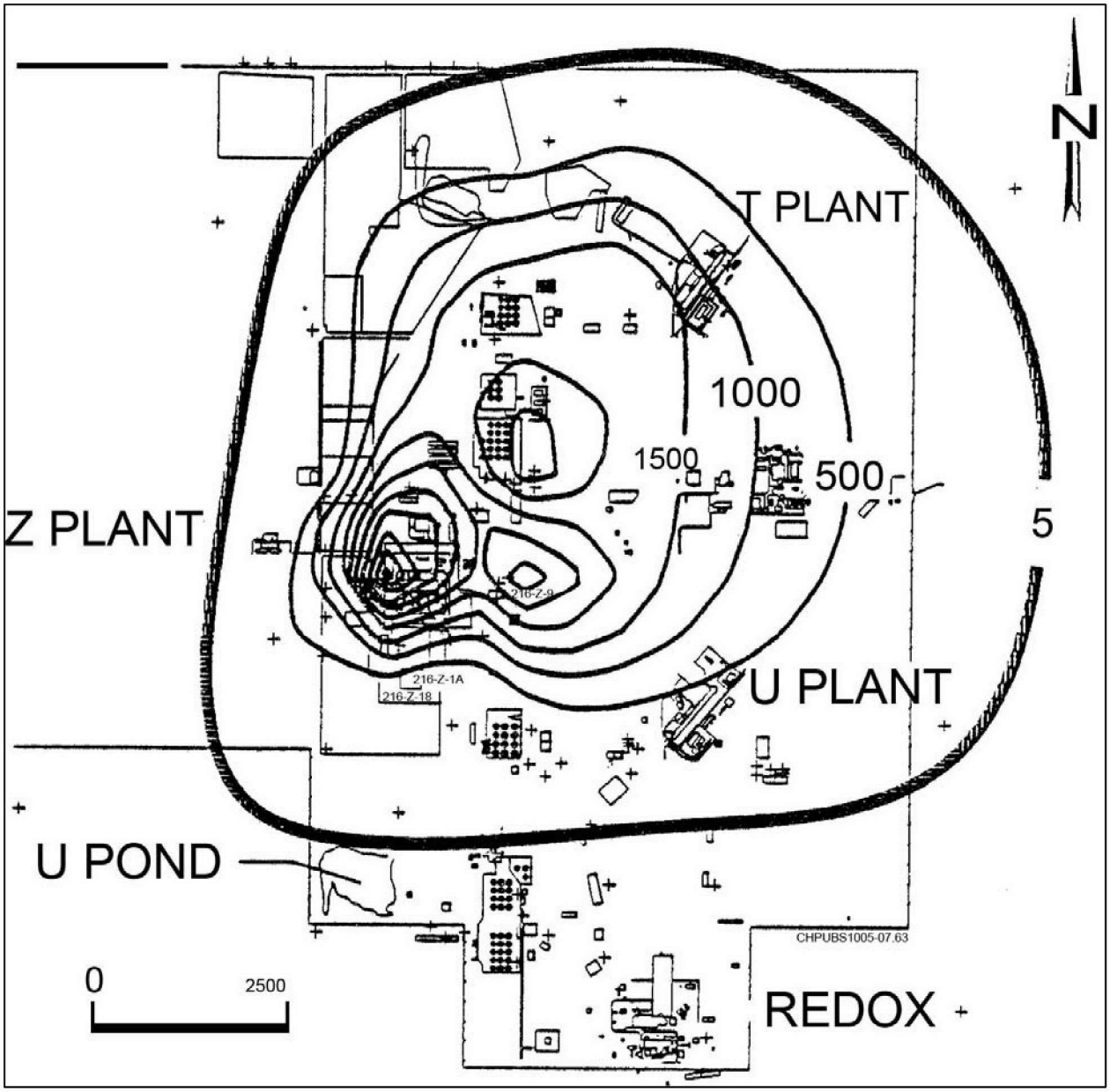

Figure 4-38. 200 West Area Carbon Tetrachloride Plume Map for 1990 (µg/L) (PNL-8073)

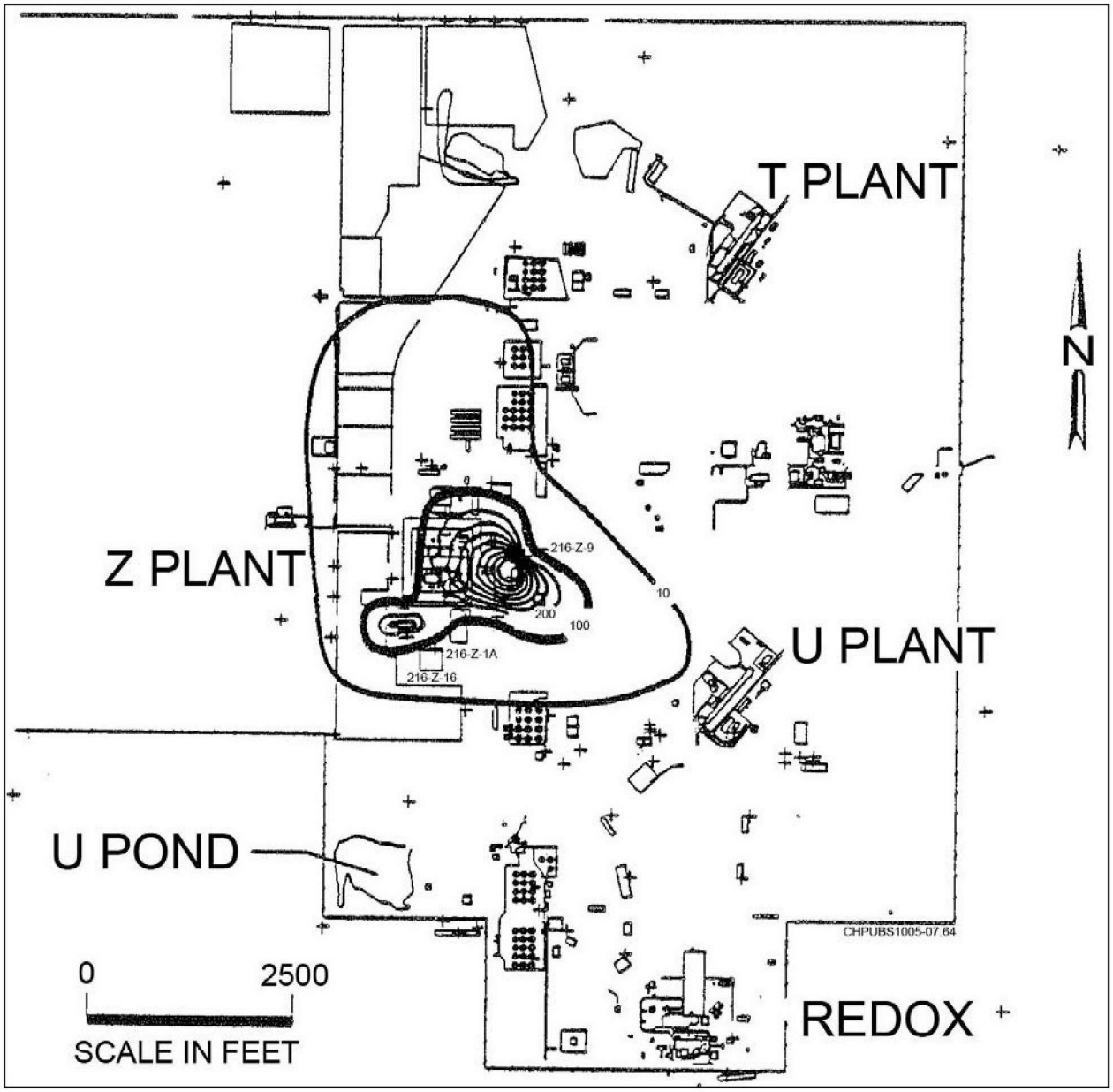

Figure 4-39. 200 West Area Chloroform Plume Map for 1990 (µg/L) (PNL-8073)

Much of the depth-discrete carbon tetrachloride sampling performed within the OU is summarized in Figure 3-21, which shows a cross section of the plume from southwest to northeast through the southern 200 West Area into the 600 Area. Carbon tetrachloride concentrations exceed 10 times the DWS (is greater than 50 μg/L) in two areas of the cross section: a small area near Well 299-W22-47 in the vicinity of WMA S-SX; and a large area between Well 299-W19-105, near the 216-U-8 Crib, and Well 699-38-70B just outside the 200 West Area boundary to the east. At 299-W22-47, the highest carbon tetrachloride concentrations occur in the upper part of the aquifer near the water table (maximum value of 96 μg/L at 11 m [36 ft] below the water table). At the middle depth of the aquifer, concentrations decline to below the DWS. The situation is different in the eastern part of the cross section, where concentrations generally increase with depth to the Ringold Fm LMU. This is most apparent in the sample results for wells 299-W19-48 and 699-38-70B. The maximum measured value in the eastern part of the cross section was 470 μg/L in Well 699-38-70B at 36.5 m (120 ft) below the water table. These results are consistent with previous interpretations of the depth distribution of carbon tetrachloride, in which the maximum concentrations occur deeper in the aquifer in the eastern part of the plume (DOE/RL-2006-24).

Two wells on the carbon tetrachloride cross section, Wells 699-38-70B and 699-40-65, were drilled to below the Ringold Fm LMU, and one groundwater sample was collected from each well at this depth. Carbon tetrachloride was not detected in Well 699-40-65, but was reported at 14 μg/L in 699-38-70B. This concentration was substantially below the reported result of 428 μg/L for the sample collected just above the mud unit. It is not known whether carbon tetrachloride is actually present below the mud unit at this location. It is possible that some carbon tetrachloride may have been dragged down to the bottom of the borehole during drilling. However, it is also possible that there is a nearby erosional window through the mud that has allowed some carbon tetrachloride to migrate into the Ringold Fm confined aquifer. This situation is known to have occurred in the southern 200-ZP-1 Groundwater OU at Well 299-W13-1, located about 800 m (2,600 ft) north-northwest from 699-38-70B (DOE/RL-2006-24).

Chloroform is a degradation product of carbon tetrachloride and tends to occur in the same wells with carbon tetrachloride. Thus, some degradation of carbon tetrachloride may be occurring, although chloroform may also have been introduced to the aquifer from source areas in the 200-ZP-1 Groundwater OU. Chloroform is widespread within the 200-UP-1 Groundwater OU, but there were no exceedances of the DWS (80 μg/L for total trihalomethanes) in samples collected during the RI (Figure 4-40). The maximum measured concentration was 35 μg/L in Well 299-W14-71 (August 2007). This is lower than the mean anthropogenic background concentration of 87 μg/L for the 200-ZP-1 Groundwater OU. Thus, there is no evidence of a local source of chloroform within the 200-UP-1 Groundwater OU (other than possible degradation of carbon tetrachloride). Similar to carbon tetrachloride, depth-discrete sampling has shown that chloroform concentrations tend to increase with depth.

TCE is found within the 200-UP-1 Groundwater OU largely in association with the carbon tetrachloride plume. The maximum concentrations measured during the RI exceeded the DWS (5 μg/L) in eight wells in the northern part of the OU, and in one well (299-W22-20) downgradient from the 216-S-20 Crib (Figure 4-41). No sample results exceeded 10 times the DWS. The maximum measured concentration was 13 μg/L in Well 299-W14-71 (April 2007), the same well with the highest carbon tetrachloride and chloroform concentrations. Depth-discrete sampling results show that concentrations tend to increase with depth, similar to carbon tetrachloride and chloroform. Concentrations have generally declined over time. For example, in FY 2008, sample results exceeded the DWS in only three wells: 299-W14-71, 699-38-70B, and 699-38-70C. All of these wells are screened deep within the unconfined aquifer just above the Ringold Fm LMU. During FY 2008, there were no exceedances of the DWS in wells monitoring the upper part of the aquifer near the water table.

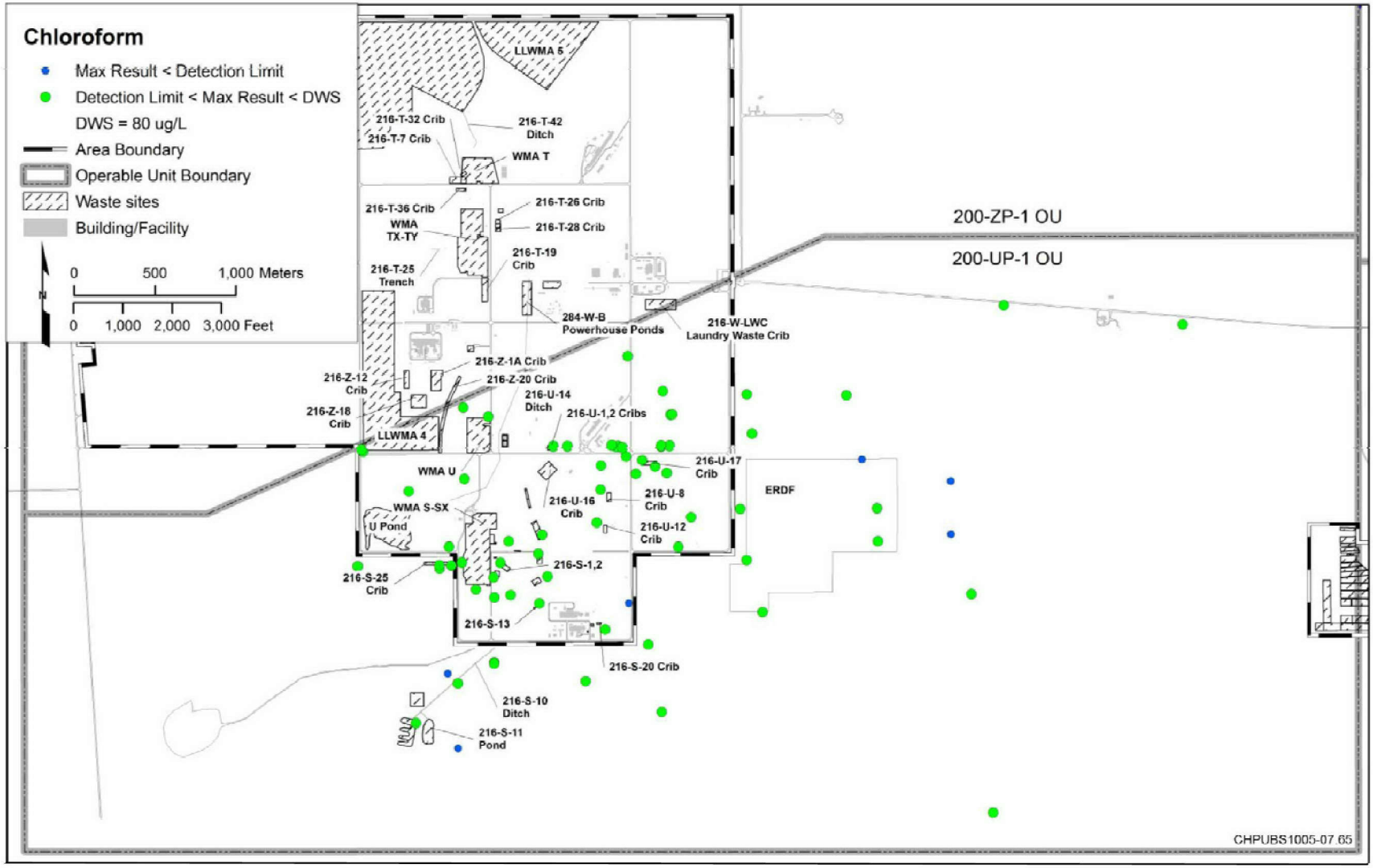

Figure 4-40. Maximum Sample Results for Chloroform During the Remedial Investigation

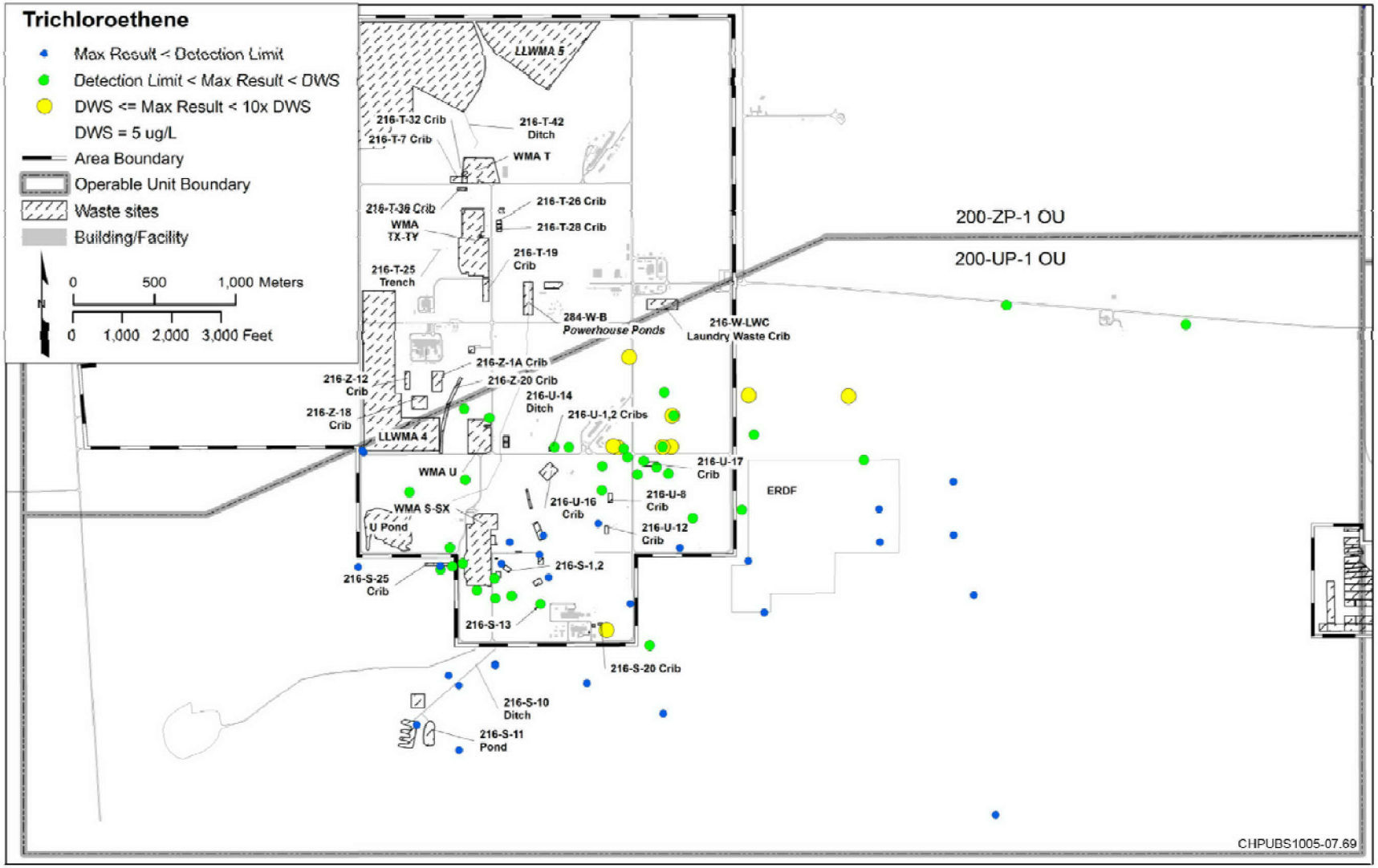

Figure 4-41. Maximum Sample Results for Trichloroethene During the Remedial Investigation

4.2.8 Arsenic, Cadmium, and Strontium-90

Other high-priority COPCs not discussed in the previous sections are arsenic, cadmium, and Sr-90; only the latter occurs in the 200-UP-1 OU groundwater as a contaminant. Sr-90 was found above the DWS (8 pCi/L) in a single well during the RI, 299-W22-10, downgradient from the 216-S-1 and 216-S-2 Cribs (Figure 4-42). The maximum measured concentration in this well during the RI was 32 pCi/L (December 2004). The 216-S-1 and 216-S-2 Cribs received highly acidic waste from the REDOX Plant between 1952 and 1956. In 1955, the waste is believed to have corroded the casing of a nearby well (299-W22-3, located 25 m [80 ft] west-northwest of Well 299-W22-10), which allowed the effluent to bypass the soil column and flow down the well directly into groundwater. This is the postulated pathway by which Sr-90 reached groundwater at this location.

Arsenic occurs naturally in the groundwater at concentrations above the laboratory method detection limit (0.4 μg/L) (DOE/RL-2008-66), so there were numerous detections of arsenic during the RI (Figure 4-43). Natural background arsenic concentrations have a geometric mean of 3.11 μg/L and a 95th percentile of 11.8 μg/L (Table 4-1). The maximum measured arsenic concentration during the RI was 7.3 μg/L in Well 299-W23-4 (February 2006), which is within the natural background range and below the DWS (10 μg/L). Thus, there is no evidence of arsenic contamination in the groundwater within the 200-UP-1 Groundwater OU.

Natural background concentrations for cadmium have a geometric mean of 0.274 μg/L and range up to 1.29 μg/L (95th percentile) (Table 4-1). These values are below the recent laboratory method detection limit of 4 μg/L (DOE/RL-2008-66), so cadmium was not detected in most wells within the OU. Single detections occurred in four wells ranging from 0.22 to 2.2 μg/L in 2004 and 2006 when detection limits were lower (Figure 4-44). The lack of consistent detections in these wells indicates that at least some of these results could be false positives. Further, all these results are below the 5 μg/L DWS. Thus, there is no evidence of cadmium contamination in the groundwater.

4.2.9 Additional Contaminants of Potential Concern

Table 4-3 lists the additional COPCs identified in DOE/RL-92-76, Rev. 1, and those identified specifically for this RI report. As mentioned in the introduction to Section 4.2, 1,4-dioxane, bromodichloromethane, C-14, chloromethane, hexavalent chromium, magnesium, methylene chloride, Se-79, PCE, U-234, U-235, and U-238 are the only additional COPCs that apparently occur in the groundwater at concentrations substantially above the natural background. Chromium occurs in the groundwater in the soluble hexavalent (6+) form, and this constituent was discussed in Section 4.2 as total chromium.

1,4-Dioxane was detected once during the RI at 120 μg/L in Well 299-W22-20 (August 2006), located near the 216-S-20 Crib. This constituent also was detected in two previous sample events in this well at 110 μg/L (January 2002) and 160 μg/L (January 2003) (Figure 4-45), and it also has been detected at a very low concentration in Well 699-34-72 (east of 299-W22-20 and the 216-S-20 Crib) at 5.8 μg/L (March 2010). Because of these multiple detections in different wells, this constituent is interpreted to be present in the groundwater; the 216-S-20 Crib is the most likely source. From 1952 through 1972, this crib received waste from laboratory hoods and decontamination sinks in the 222-S Building, along with laboratory waste from the 300 Area. A federal DWS has not been established for 1,4-dioxane.

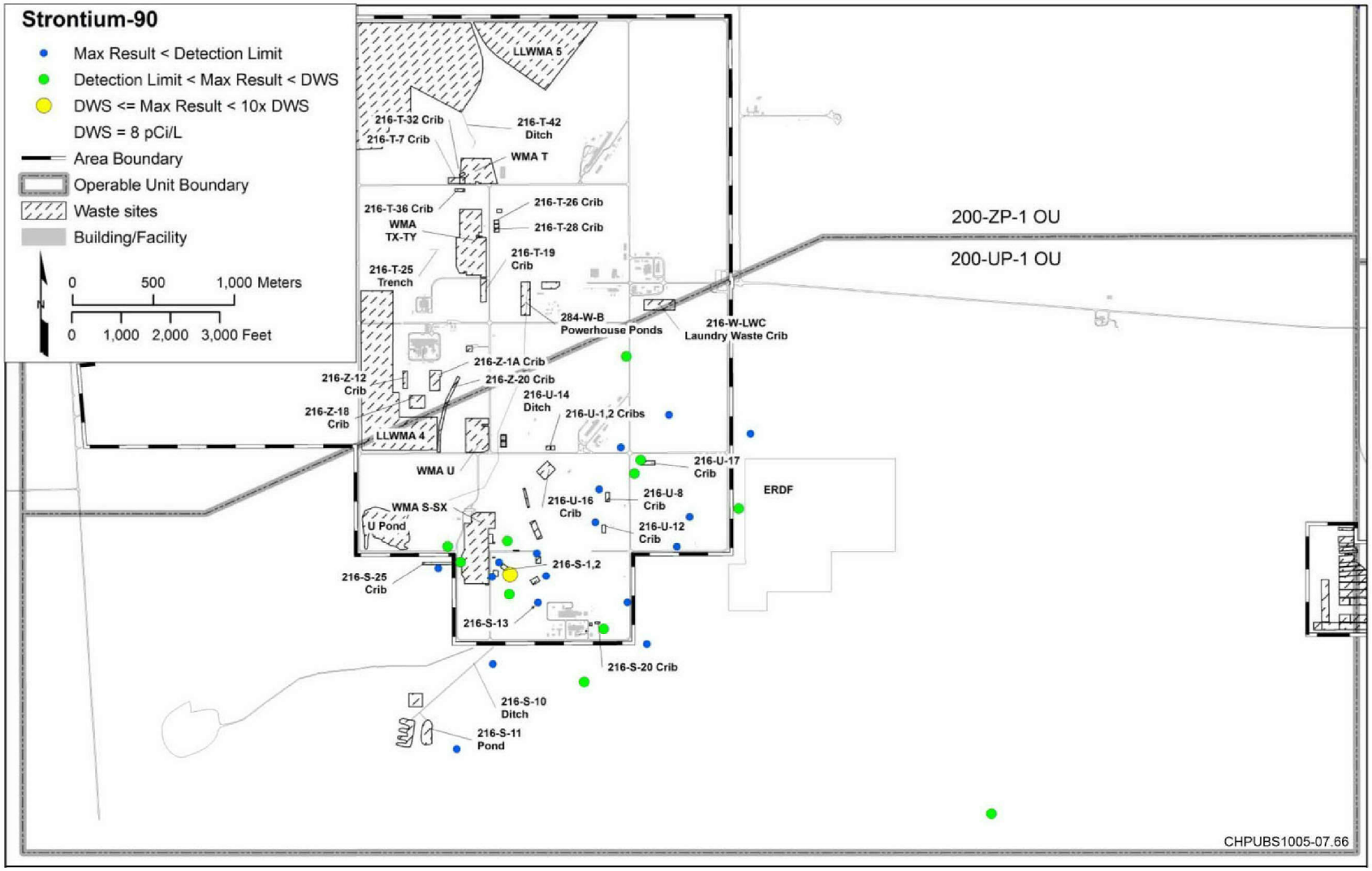

Figure 4-42. Maximum Sample Results for Strontium-90 During the Remedial Investigation

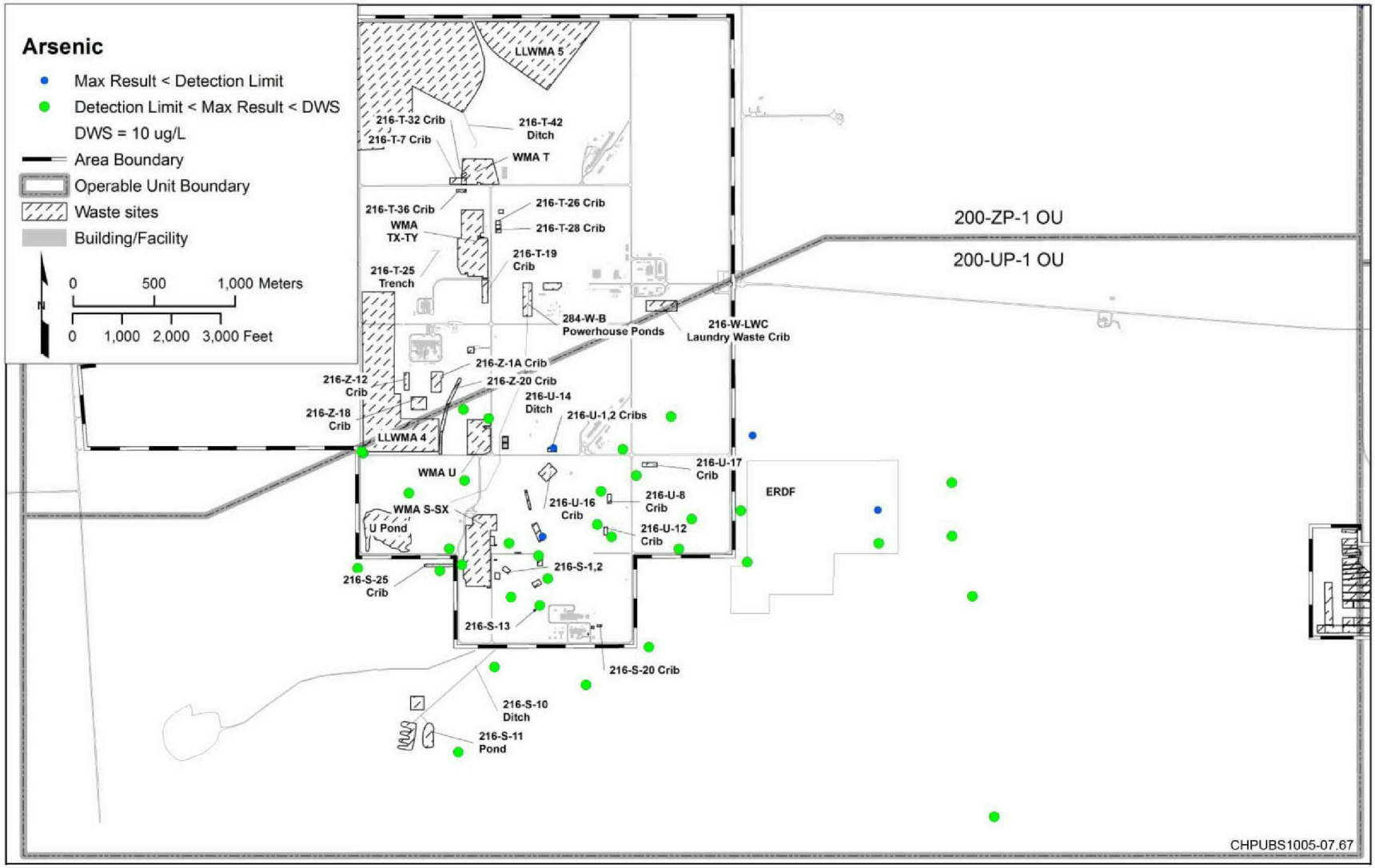

Figure 4-43. Maximum Sample Results for Arsenic During the Remedial Investigation

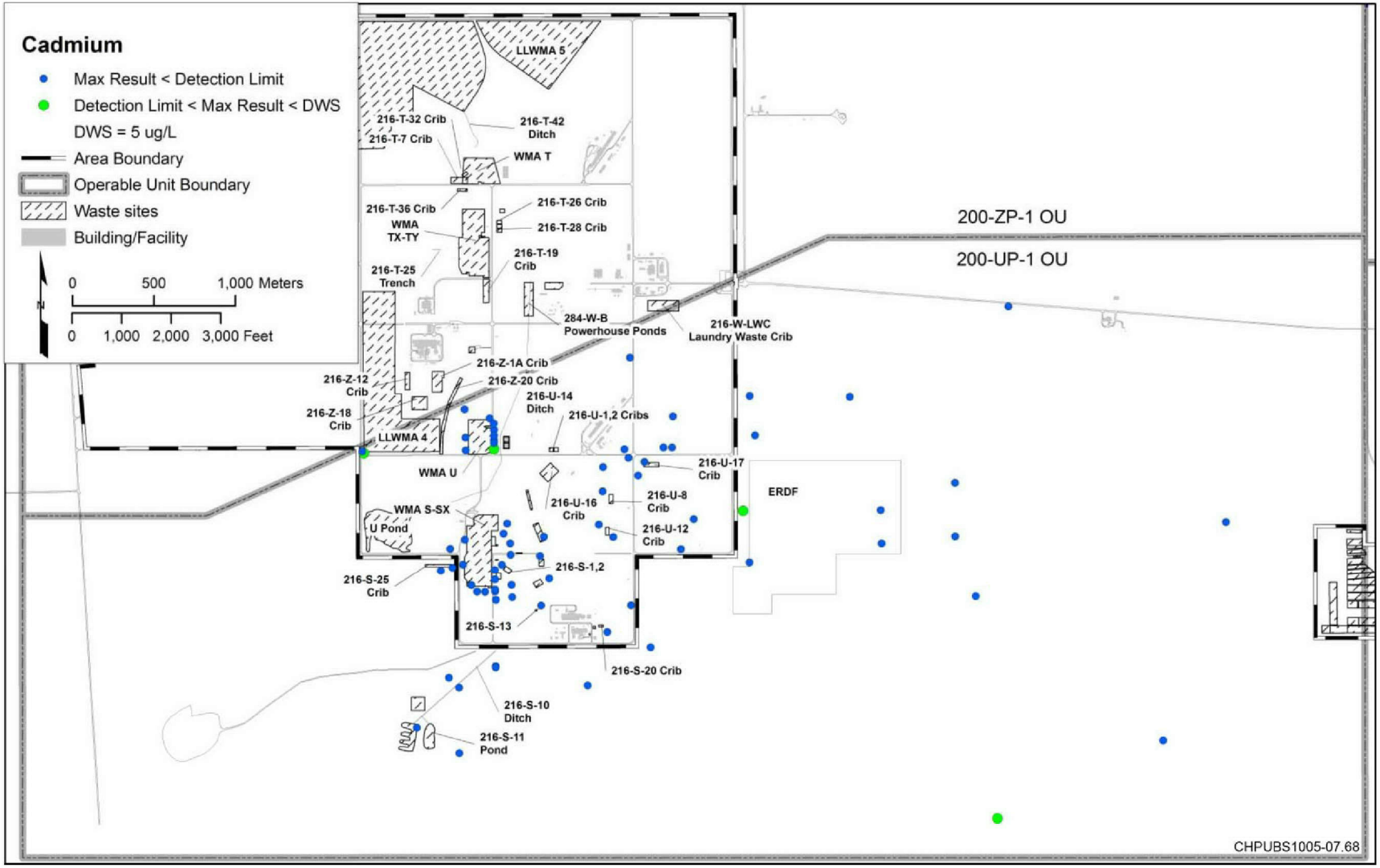

Figure 4-44. Maximum Sample Results for Cadmium During the Remedial Investigation

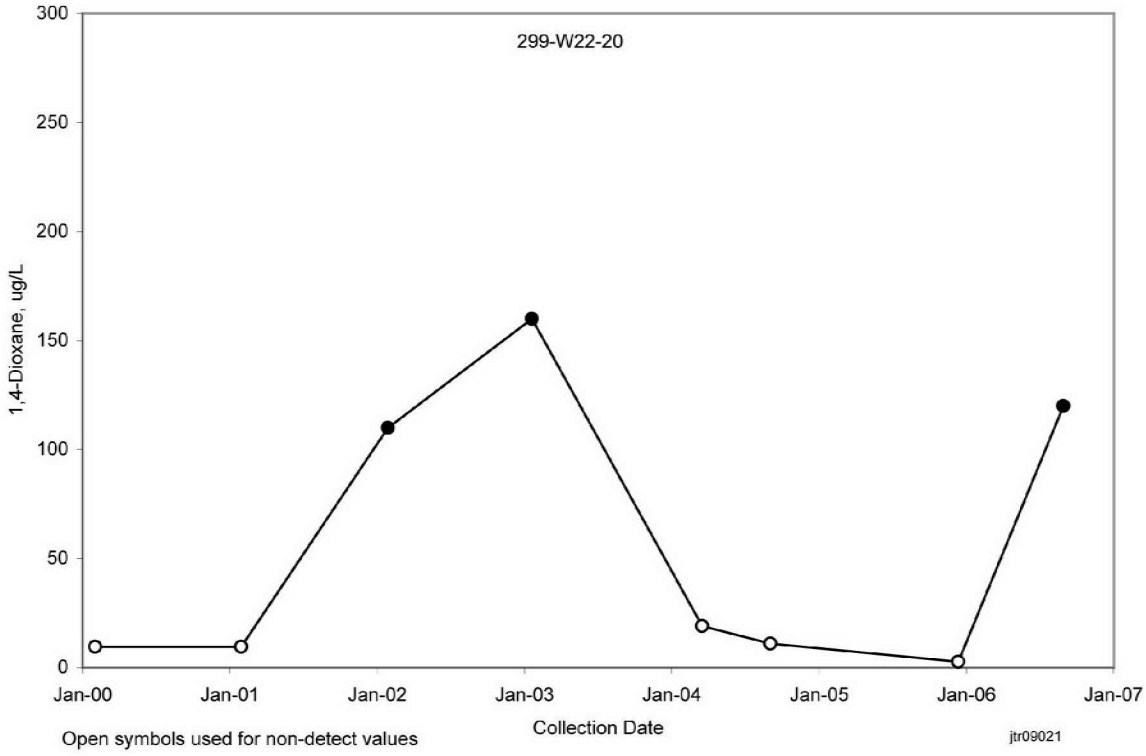

Figure 4-45. 1,4-Dioxane Concentrations in Well 299-W22-20, Near the 216-S-20 Crib

There were 32 detections of bromodichloromethane and 25 detections of chloromethane from the nearly 200 analyses performed for each of these constituents during the RI. All of the chloromethane detections, and all but one of the bromodichloromethane detections, were flagged as estimated values near the method detection limit (detection limits ranged from 0.064 to 0.088 µg/L for bromodichloromethane and 0.036 to 0.1 µg/L for chloromethane) (DOE/RL-2008-66). The maximum reported values were 1.1 µg/L for bromodichloromethane in Well 699-38-70B (August 2005) and 1.3 µg/L for chloromethane in Well 299-W19-48 (August 2005). These values are below the anthropogenic background mean concentrations of 1.3 and 3.8 µg/L, respectively, for the 200-ZP-1 Groundwater OU (Table 4-2). The applicable DWS for bromodichloromethane is 80 µg/L for total trihalomethanes, and there is no DWS for chloromethane. These constituents are probably in the groundwater at very low levels and apparently migrated into the 200-UP-1 Groundwater OU from the 200-ZP-1 Groundwater OU. Chloromethane also may have originated within the 200-UP-1 Groundwater OU as a degradation product of carbon tetrachloride.

Of the 17 detections of C-14 found during the RI, 9 were in Well 299-W22-72. The maximum concentration was 33 pCi/L (June 2008), which is well below the 2,000 pCi/L DWS. Two detections occurred in 299-W23-21, and single detections occurred in 6 other wells. This constituent is apparently present in the groundwater, especially at 299-W22-72, but concentrations are very low. The source is not known.

PCE was detected in 54 of the nearly 700 analyses for this constituent during the RI. The maximum detected value was 3.8 µg/L in Well 299-W19-107 (December 2008), which is higher than the anthropogenic background mean value of 2.0 µg/L, but less than the 95th percentile background concentration of 4.6 µg/L (Table 4-2). The DWS is 5 µg/L. Of the 54 detections, only 6 are not flagged to indicate a laboratory QC problem or an estimated value near the method detection limit (1 µg/L; DOE/RL-2008-66). Similar to bromodichloromethane and chloromethane, this constituent occurs at low

levels in the groundwater and may have migrated into the 200-UP-1 Groundwater OU from the 200-ZP-1 Groundwater OU.

Magnesium occurs naturally in the groundwater, but 23 of the sample results during the RI were above the 95th percentile natural background concentration of 31,051 μg/L (Table 4-1). Magnesium typically occurs at concentrations above the natural background in association with contaminant plumes. The source of the magnesium is thought to be cation exchange reactions where sodium in waste liquids replaces both calcium and magnesium in sediment during transport through the vadose zone, resulting in elevated concentrations of calcium and magnesium in the groundwater (PNNL-11810).

Se-79 was detected in several wells downgradient from the WMA S-SX Tank Farms. The maximum concentration was 2,080 pCi/L in Well 299-W23-19 during June 2005; more recent concentrations in this well have been substantially lower, ranging from 278 to 311 pCi/L. Se-79 occurs in association with the other mobile tank waste constituents, chromium, nitrate, and Tc-99. DOE has established a derived concentration guide for Se-79 at 20,000 pCi/L (100 mrem/yr dose).

The isotopes U-234, U-235, and U-238 were all found in groundwater during the RI. The highest concentrations occurred in Well 299-W19-18, within the uranium plume downgradient from the 216-U-1 and 216-U-2 Cribs. For the March 2006 sample event in this well, U-234 was reported at 166 pCi/L, U-235 at 7.14 pCi/L, and U-238 at 170 pCi/L. All of these results are below their respective DOE-derived concentration guides of 500, 600, and 600 pCi/L, for U-234, U-235, and U-238, respectively.

Examination of Table 4-3 shows that other constituents were found in groundwater samples at concentrations apparently above background levels, but many of these results are interpreted as not being representative of actual groundwater conditions. For example, laboratory analyses for aluminum have historically been problematic. Aluminum analyses by inductively coupled plasma-optical emission spectrometry (ICP-OES, Method 6010C, SW-846) "do not appear to be reliable at the low levels found in most of the groundwater samples" at the Site, and many results from this method are biased high (PNNL-15670). A comparison between ICP-OES and the more sensitive method, inductively coupled plasma-mass spectrometry (ICP-MS, Method 6020A, SW-846), was conducted during FY 2006 by analyzing 20 routine groundwater samples at the same laboratory by both methods. The results generally confirmed that the ICP-OES method produces a high percentage of false-positive results for aluminum (PNNL-16346). Thus, detections of aluminum by the ICP-OES method, especially above the secondary DWS of 50 to 200 μg/L, should be viewed as probable false positives. PNNL-16346 stated that future analyses for aluminum would be performed using the ICP-MS method.

Aluminum was reported as detected in about one-half of the nearly 500 analyses for aluminum performed during the RI on samples from the 200-UP-1 Groundwater OU. For all but five of these detections, the ICP-OES method was used, and the results are considered to be false positives. Many, but not all of these results, are flagged in the HEIS by a laboratory or review qualifier to indicate a QC problem. The other five detections were from use of the ICP-MS method, and the reported aluminum concentrations ranged from 6.4 to 39.8 μg/L, which is below the secondary DWS of 50 μg/L. Further, only two of the detections were above the 95th percentile natural background concentration of 11.7 μg/L (Table 4-1). Thus, the weight of the evidence indicates that there is no aluminum contamination of groundwater within the 200-UP-1 Groundwater OU.

Several results for iron were reported above the secondary DWS of 300 μg/L, but most of these results were in unfiltered samples. Iron concentrations can be quite variable in unfiltered samples due to the level of turbidity and the nature of the sediment, but high turbidity often results in high reported iron concentrations. Much of the turbidity in unfiltered groundwater samples is due to fine sediment mobilized

during the sampling process, and this sediment is not actually mobile in the aquifer. Thus, iron concentrations in unfiltered samples are regarded as generally not representative of aquifer conditions.

Several manganese results also were reported above the secondary DWS of 50 µg/L, but most of these exceedances occurred for only a short time period in newly installed wells. Fresh sediment surfaces are created during the drilling process, and manganese is apparently released from these surfaces in a chemical reaction until the sediments re-weather. This sometimes causes elevated manganese concentrations in the groundwater adjacent to newly completed wells, which then decline over time (Figure 4-46). These concentrations are localized to the wells and are not representative of ambient aquifer conditions.

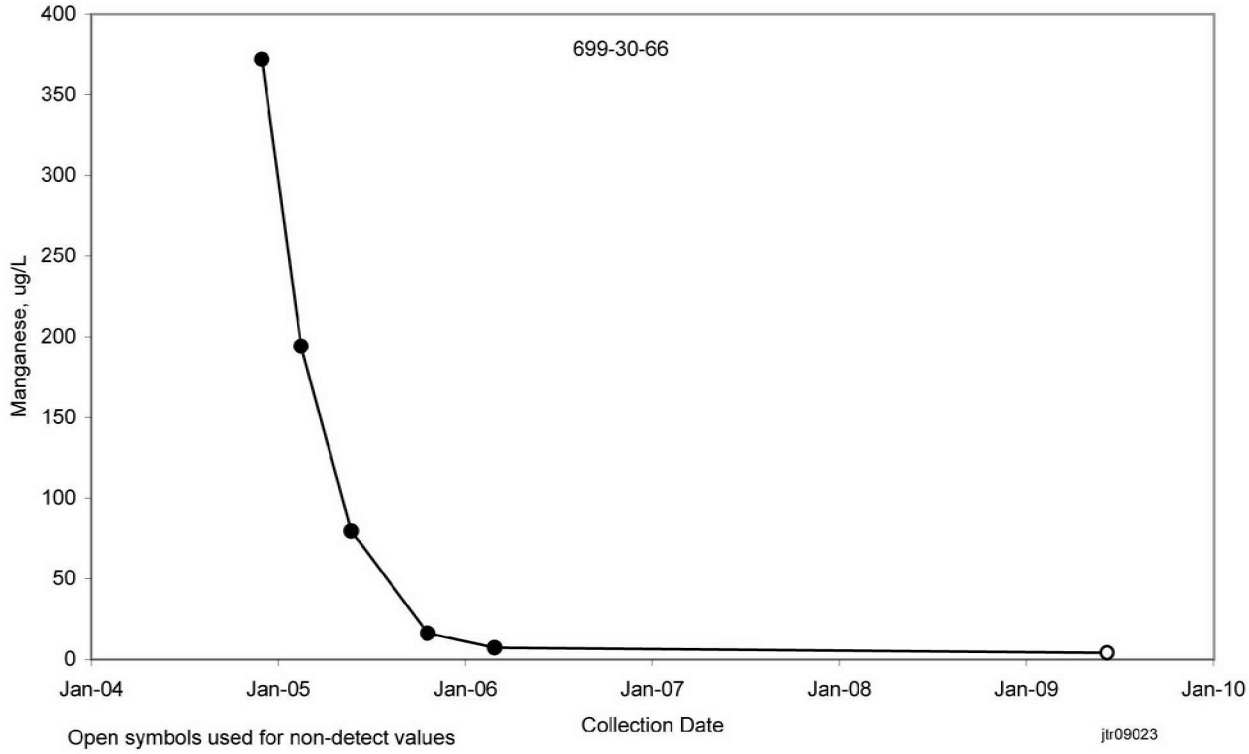

Figure 4-46. Manganese Concentrations in Well 699-30-66, Southeast of the 200 West Area

Methylene chloride was reported for several groundwater samples at concentrations that exceeded the 5 µg/L DWS. This constituent is a common analytical laboratory contaminant and almost all of the detections are flagged to indicate contamination in the associated method blanks. However, methylene chloride is also a degradation product of carbon tetrachloride, so its presence in groundwater would not be unexpected. Thus, it is not straightforward to conclude whether the detections represent actual groundwater conditions. Methylene chloride is detected in a greater percentage of samples in the 200-UP-1 and 200-ZP-1 groundwater interest areas compared to other areas of the Site (Table 4-5). The detection rate is ~10 percent in the 200-UP-1 and 200-ZP-1 areas, compared to an average rate of 2.5 percent in other areas. If the presence of methylene chloride in groundwater samples was solely caused by laboratory contamination, the detection rate should be similar across the Site. Thus, it appears that methylene chloride is likely present in the groundwater at the 200-UP-1 Groundwater OU, but the reported concentrations may generally be higher than actual groundwater concentrations because of the laboratory contamination. The maximum measured concentration during the RI was 16 µg/L in Well 699-37-68 (during March 2006). This is below the 95th percentile anthropogenic background

concentration of 30 µg/L (Table 4-2), indicating that methylene chloride apparently migrated into the 200-UP-1 Groundwater OU from the 200-ZP-1 Groundwater OU, although this constituent may also have originated within the 200-UP-1 Groundwater OU as a carbon tetrachloride degradation product.

Table 4-5. Summary of Methylene Chloride Detections in Groundwater at Hanford from 2004 to 2009

Interest Area	Number of Analyses	Number of Detections	Percent Detected
100-FR-3	59	2	3.4
100-KR-4	36	1	2.8
100-NR-2	6	0	0.0
200-BP-5	77	2	2.6
200-PO-1	434	8	1.8
300-FF-5	941	30	3.2
1100-EM-1	183	11	6.0
100-HR-3-D	9	0	0.0
		Average:	**2.5**
200-UP-1	697	67	9.6
200-ZP-1	1,174	120	10.2
		Average:	**9.9**

4.3 Interim Remedial Action Results and Effects

Two IRAs are operating in the 200-UP-1 Groundwater OU: a P&T system for the Tc-99 and uranium plume downgradient from the 216-U-1 and 216-U-2 Cribs, and extended purging during sampling of Well 299-W23-19 at WMA S-SX. Each of these actions is described in the following subsections. During 1985, a P&T system operated for 6 months at the 216-U-1 and 216-U-2 Cribs after high concentrations of uranium were found in the groundwater. This system is described in WHC-EP-133.

4.3.1 200-UP-1 Pump-and-Treat System

This section describes the 200-UP-1 IRA P&T system, including the history of operations and system effectiveness.

4.3.1.1 History of Operations

In 1993, it was recommended that an IRA be conducted on the Tc-99 and uranium plumes downgradient from the 216-U-1 and 216-U-2 Cribs, due to the potential carcinogenic risk posed by these contaminants should the groundwater be used as a drinking water source (DOE/RL-92-16). A P&T system treatability test was conducted between March and November 1994 near the 216-U-17 Crib (BHI-00951). Water was extracted from Wells 299-W19-23 and 299-W19-24 at a total rate of 57 L/min (15 gpm), treated onsite using an ion exchange (IX) treatment system, and then returned to the aquifer using Well 299-W19-25. The treatment system was effective in removing Tc-99 and uranium from the water, with an overall removal efficiency of greater than 99 percent. The system also included granular activated carbon (GAC)

treatment to remove VOCs beginning in July 1994. This system continued, to operate until August 17, 1995, at which time operations were suspended for construction of a Phase I P&T system.

The Phase I system used Well 299-W19-39 for extraction and Well 299-W19-36 for injection, which allowed for a 190 L/min (50 gpm) capacity. Onsite treatment continued using IX for removal of Tc-99 and uranium, and GAC for removal of VOCs, primarily carbon tetrachloride. The Phase I system operated from September 25, 1995, to February 7, 1997, when the system was shut down for construction of a Phase II system (DOE/RL-98-38).

During February 1997, a ROD was issued for an IRA on the high-concentration portions of the Tc-99 and uranium plumes at the P&T system (EPA/ROD/R10-97/048). The selected remedy consisted of extraction of groundwater (at a minimum of 190 L/min [50 gpm]) and transfer to ETF in the 200 East Area for treatment with subsequent disposal to the SALDS north of the 200 West Area. The specific RAOs include the following:

- Reduce contamination in the area of highest concentrations of uranium and Tc-99 to below 10 times the cleanup level under the MTCA for uranium, and below 10 times the DWS for Tc-99 (below 480 μg/L for uranium and below 9,000 pCi/L for Tc-99).
- Reduce potential adverse human health risks through reduction of contaminant mass.
- Prevent the further movement of uranium and Tc-99 from the high-concentration area.
- Provide information that will lead to development and implementation of a final remedy.

The cleanup level for uranium was based on the MTCA cleanup level (48 μg/L) because a DWS for uranium had not yet been established at the time the ROD was issued. The area targeted for remediation consisted of the portion of the Tc-99 plume at a concentration above 9,000 pCi/L, and the portion of the uranium plume above 480 μg/L (DOE/RL-97-36, Rev. 2). This region was referred to as the baseline plume area. In addition to these contaminants, the ETF also removed the secondary contaminants nitrate and carbon tetrachloride from the groundwater.

The Phase II system began operating on March 31, 1997, at 190 L/min (50 gpm) using a single extraction well, 299-W19-39. On December 27, 2001, an additional extraction well, 299-W19-36, was brought online (DOE/RL-2002-67), probably to compensate for reduced pumping capacity caused by declining water levels. During May 2003, Well 299-W19-43 was converted to an extraction well (DOE/RL-2003-58), and all three extraction wells continued to operate until January 26, 2005. At this time, all measured Tc-99 and uranium concentrations within the baseline plume area were below their RAOs, and the system was shut down to commence a rebound study.

Extraction wells 299-W19-36 and 299-W19-43 were restarted on April 19, 2007, after 27 months of inactivity (DOE/RL-2008-01). The restart was prompted by the expectation that an Explanation of Significant Differences (ESD) would be issued to lower the uranium RAO cleanup level from 480 to 300 μg/L, which is 10 times the uranium DWS. While uranium concentrations in the baseline plume area were below 480 μg/L, some were above 300 μg/L.

The ESD was issued during February 2009 (09-AMCP-0082), and the interim action ROD was modified as follows:

- The RAO for uranium was reduced to 300 μg/L.
- The requirement to extract groundwater at a rate of 190 L/min from existing extraction wells was replaced by a requirement to extract groundwater from existing or new extraction wells in accordance

with an approved RD/RAWP until the concentration of uranium and Tc-99 are less than or equal to their respective RAOs for four consecutive quarters.

- A requirement was added to sample well 299-W23-19 at WMA S-SX for Tc-99 quarterly, and to purge a minimum of 3,785 L (1000 gal) of water during each sample event until the Tc-99 concentration is less than or equal to 9,000 pCi/L for four consecutive quarters (see Section 4.3.2).
- The national primary DWS of 30 µg/L for uranium was added as an applicable or relevant and appropriate requirement (ARARs) for the treatment of the extracted groundwater.
- ICs were revised.
- The cost estimate for the remedial action was revised.

4.3.1.2 System Effectiveness

Three metrics can be used to evaluate the effectiveness of the P&T system: changes in constituent concentrations within the baseline plume area, changes in plume areal extent, and total constituent mass recovered. Figure 4-47 and Figure 4-48 show Tc-99 and uranium concentrations, respectively, in selected wells within the baseline plume area since the startup of the treatability test in 1994. These figures also indicate when the various phases of the P&T system were operating. Concentrations of both constituents have declined substantially since the Phase I system was operating in the mid-1990s. During Phase I operations, Tc-99 concentrations were as high as 37,800 pCi/L in 299-W19-30, and uranium was 3,920 µg/L in 299-W19-37. For comparison, the maximum concentrations during the first half of FY 2009 were 8,000 pCi/L for Tc-99 and 290 µg/L for uranium, both in 299-W19-36.

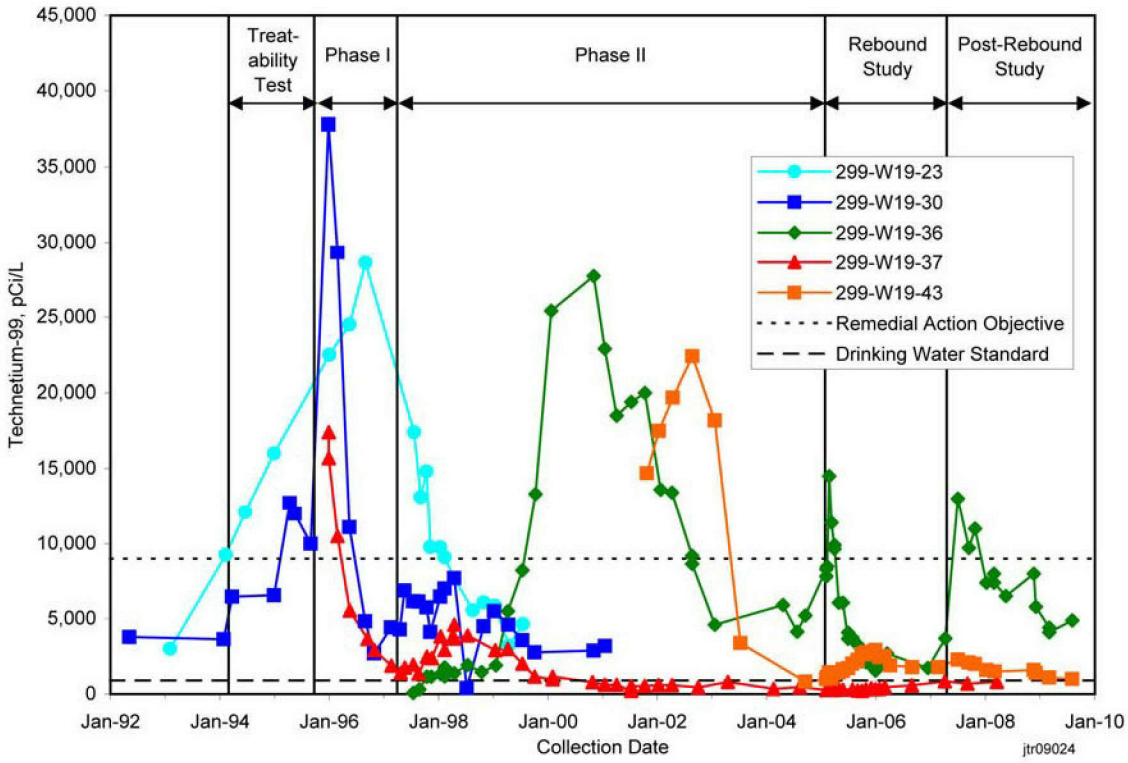

Figure 4-47. Technetium-99 Concentrations in Selected Wells in the 200-UP-1 Pump-and-Treat System Baseline Plume Area

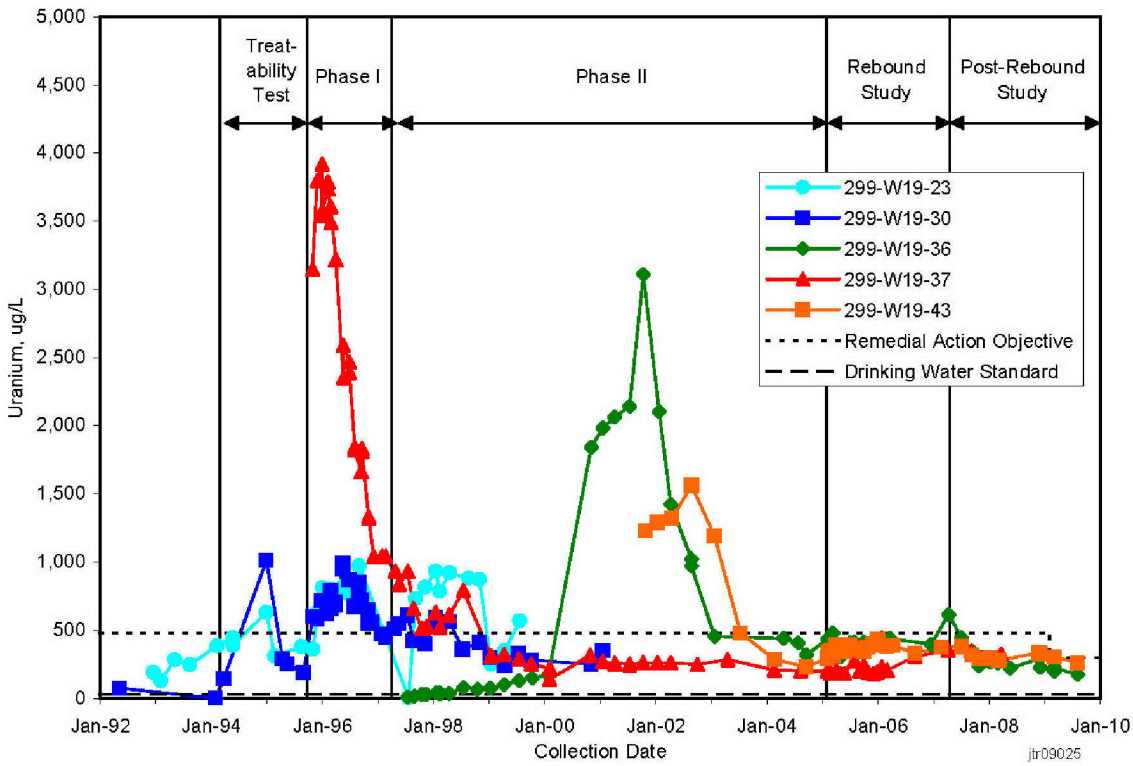

Figure 4-48. Uranium Concentrations in Selected Wells in the 200-UP-1 Pump-and-Treat System Baseline Plume Area

The system has been successful in reducing concentrations to below the interim RAOs. Tc-99 concentrations in all monitoring wells within the baseline plume area have been below 9,000 pCi/L since January 2008, and uranium concentrations have been below 300 µg/L since February 2008 (the uranium concentration at 299-W19-18 exceeds 300 µg/L). The Tc-99 concentration in extraction Well 299-W19-36 increased abruptly when pumping ceased at the start of the rebound study, but then quickly declined to below 9,000 pCi/L. A similar short-lived increase occurred when pumping was restarted in April 2007. Without these temporary increases, Tc-99 concentrations would have been below 9,000 pCi/L since August 2002. The reason for the short-lived increases at Well 299-W19-36 is not known.

Figure 4-49 and Figure 4-50 show comparisons of plume extents between 1995 and 2008 for Tc-99 and uranium, respectively. The Tc-99 plume has decreased substantially in areal extent, whereas the overall extent of the uranium plume has not decreased. This difference is also evident when comparing concentrations in the baseline plume area to the DWS. As of early FY 2009, wells 299-W19-36 and 299-W19-43 were the only wells within the baseline plume area with a Tc-99 concentration above the 900 pCi/L DWS (8,000 pCi/L for 299-W19-36 and 1,600 pCi/L for 299-W19-43), whereas all water table monitoring wells within the baseline plume area have uranium concentrations above its 30 µg/L DWS.

In 1997, the dissolved mass for Tc-99 was estimated at 0.16 kg (0.35 lb) (2.7 Ci), and the dissolved mass for uranium was estimated at 130 kg (287 lb) (DOE/RL-97-36, Rev. 2). Table 4-6 shows the masses of Tc-99, uranium, carbon tetrachloride, and nitrate reported as removed from the aquifer. The total mass of Tc-99 removed, 0.124 kg (0.273 lb) (2.1 Ci), is 77 percent of the estimated initial dissolved mass. The mass of uranium removed, 216 kg (476 lb), is 166 percent of the estimated initial dissolved mass. Thus, the system has been effective in removing contaminant mass from the aquifer.

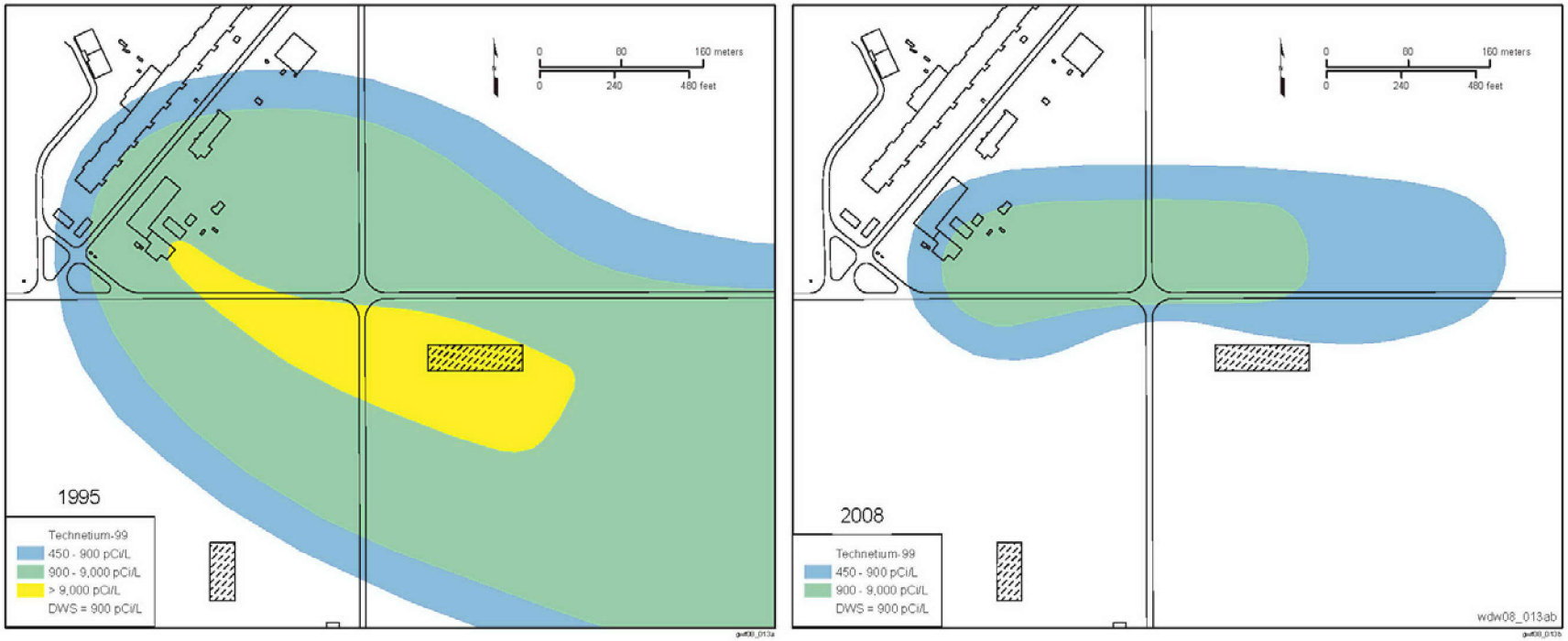

Figure 4-49. Comparison of the Extent of Technetium-99 Contamination in the Unconfined Aquifer at the 200-UP-1 Pump-and-Treat System Between 1995 and 2008 (DOE/RL-2008-66)

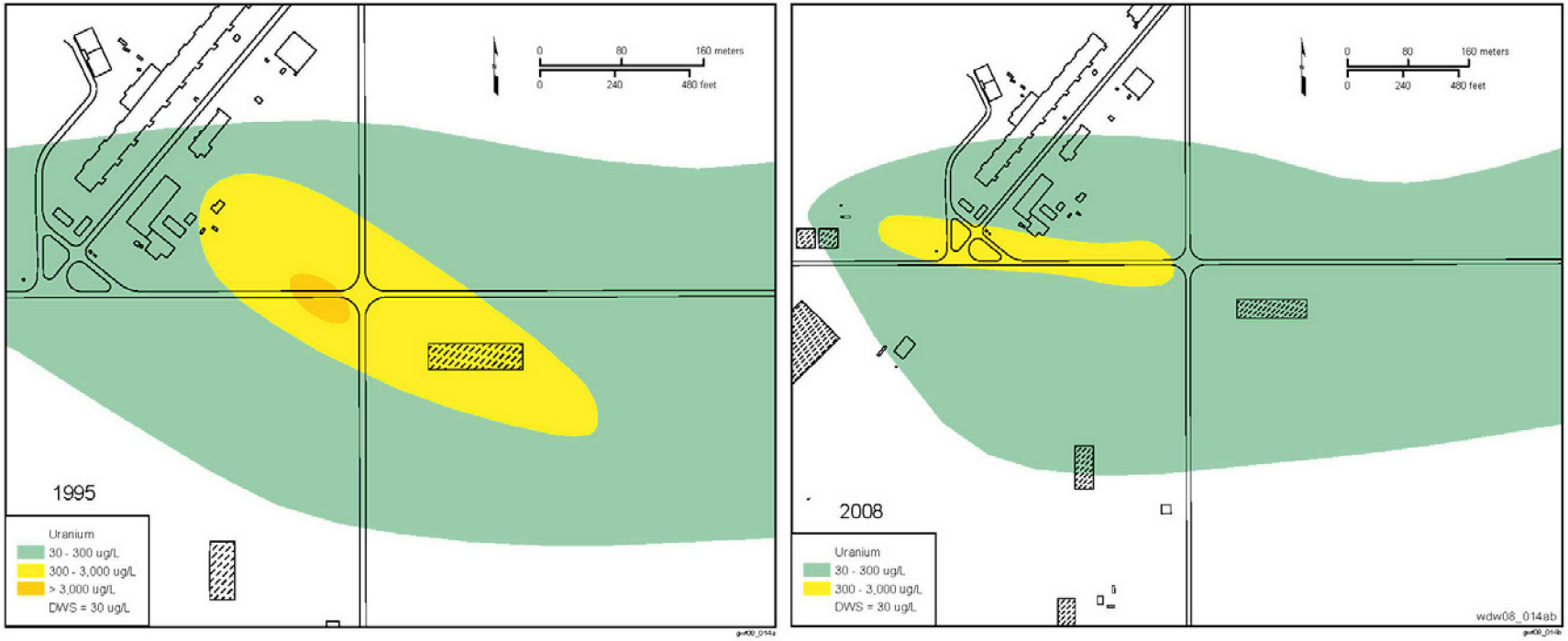

Figure 4-50. Comparison of the Extent of Uranium Contamination in the Unconfined Aquifer at the 200-UP-1 Pump-and-Treat System Between 1995 and 2008 (DOE/RL-2008-66)

Table 4-6. Mass of Contaminants Removed by the 200-UP-1 Interim Remedial Action Pump-and-Treat System

Time Period	Volume Treated (L)	Mass Technetium-99 Removed (kg)	Mass Uranium Removed (kg)	Mass Carbon Tetrachloride Removed (kg)	Mass Nitrate Removed (kg)
3/1994 – 11/1994	3,898,550	0.00341	4.422	Not reported	N/A
12/1994 – 8/1995	11,391,491	0.00779	9.831	0.992	N/A
9/1995 – 9/1996	93,339,346	0.02241	24.979	6.598	N/A
Fiscal Year 1997	55,382,081	0.00976	17.570	3.941	2,260
Fiscal Year 1998	100,067,035	0.01054	23.450	2.235	5,650
Fiscal Year 1999	93,471,260	0.00781	20.700	2.002	4,859
Fiscal Year 2000	63,229,380	0.00562	13.640	1.659	2,807
Fiscal Year 2001	102,475,318	0.00837	17.128	2.744	3,924
Fiscal Year 2002	85,886,455	0.01450	26.420	2.747	3,686
Fiscal Year 2003	98,343,000	0.01182	21.175	2.799	4,157
Fiscal Year 2004	93,764,659	0.01210	23.540	5.447	5,207
Fiscal Year 2005	52,125,123	0.00476	8.877	3.504	2,166
Fiscal Year 2006	0	0	0	0	0
Fiscal Year 2007	2,064,214	0.00027	1.129	0.053	359
Fiscal Year 2008	13,463,380	0.00453	3.470	3.024	6,415
Totals	**868,901,292**	**0.124**	**216.331**	**37.745**	**41,490**

Source: DOE/RL-2008-77

N/A = not applicable

The additional mass removed for uranium over the initial estimated dissolved mass may be due to desorption of this constituent from sediment grains, advection of additional uranium into the baseline plume area from upgradient, or both. In FY 2001, MSE Technology Applications, Inc., was funded by DOE to develop a geochemical model of uranium mobility in the 200-UP-1 Groundwater OU. This study was completed in FY 2004 (HNF-45099), and it was shown that at the range of pH for groundwater in the Ringold Fm unit E (7 to 8), uranium occurs largely as carbonate complexes and it sorbs to iron oxide minerals. Laboratory batch tests and geochemical model simulations suggest that between ~30 percent and ~50 percent of the uranium in groundwater is sorbed to the sediment. Desorption of uranium from the sediment, as groundwater of a lower aqueous uranium concentration migrates into the plume area, may explain the persistence of the uranium plume. Simulations also suggest that some uranium may be desorbing from the sediment in the vadose zone beneath the 216-U-1 and 216-U-2 Cribs and migrating to the groundwater. This process also may be a factor in the persistence of the uranium plume.

4.3.2 Sample and Purge of Well 299-W23-19

In response to high Tc-99 concentrations in Well 299-W23-19 at WMA S-SX, the feasibility of converting this well to a P&T extraction well to remove Tc-99 from the aquifer was investigated during FY 2002. After performing an aquifer test, it was concluded that the production capacity was too small for a P&T system (RPP-10757). As an interim remedy, the practice of extended purging during sampling at this well was agreed to by DOE, EPA, and Ecology and started in 2003 (03-WMD-0101). After samples are collected each quarter, purging of the well is continued at a higher flow rate until a minimum of 3,785 L (1,000 gal) of water is removed from the aquifer. This water is transferred to the ETF for treatment and disposal. This practice was more formally documented in the ESD issued during February 2009, and will continue until the Tc-99 concentration is less than 9,000 pCi/L for four consecutive quarters or until a final remedy is implemented.

Table 4-7 presents the date, amount of water purged, and a calculation of the activity and mass of Tc-99 removed from the aquifer for each sample event since the start of this treatment in 2003. A total of ~0.0064 Ci (~0.00038 kg [~0.00083 lb]) of Tc-99 has been recovered from the aquifer through FY 2008.

Table 4-7. Mass of Technetium-99 Removed by Sample and Purge of Well 299-W23-19

Date	Volume Treated (L)	Technetium-99 Concentration (pCi/L)	Activity of Technetium-99 Removed (Ci)	Mass of Technetium-99 Removed (kg)
3/12/2003	2,725	133,000	3.62E-04	2.14E-05
6/18/2003	4,028	120,000	4.83E-04	2.85E-05
9/23/2003	4,013	74,300	2.98E-04	1.76E-05
12/16/2003	3,944	43,000	1.70E-04	9.99E-06
3/22/2004	4,845	42,200	2.04E-04	1.20E-05
6/15/2004	3,989	41,800	1.67E-04	9.83E-06
9/29/2004	4,111	46,100	1.90E-04	1.12E-05
12/20/2004	3,849	62,300	2.40E-04	1.41E-05
3/9/2005	3,789	69,400	2.63E-04	1.55E-05
6/14/2005	3,785	128,000	4.84E-04	2.86E-05
9/27/2005	3,785	137,000	5.19E-04	3.06E-05
12/21/2005	3,785	89,900	3.40E-04	2.01E-05
3/29/2006	6,284	47,100	2.96E-04	1.74E-05
6/21/2006	5,390	42,900	2.31E-04	1.36E-05
9/27/2006	5,451	43,200	2.35E-04	1.39E-05
1/19/2007	4,936	46,300	2.29E-04	1.35E-05
3/30/2007	5,451	40,800	2.22E-04	1.31E-05
6/26/2007	5,224	35,100	1.83E-04	1.08E-05
10/1/2007	4,315	46,000	1.98E-04	1.17E-05

Table 4-7. Mass of Technetium-99 Removed by Sample and Purge of Well 299-W23-19

Date	Volume Treated (L)	Technetium-99 Concentration (pCi/L)	Activity of Technetium-99 Removed (Ci)	Mass of Technetium-99 Removed (kg)
1/29/2008	4,346	57,000	2.48E-04	1.46E-05
3/17/2008	5,451	52,000	2.83E-04	1.67E-05
6/9/2008	5,527	65,500	3.62E-04	2.13E-05
9/16/2008	4,860	46,000	2.24E-04	1.32E-05
Totals	**103,883**	**N/A**	**6.4E-03**	**3.8E-04**

5 Contaminant Fate and Transport and Conceptual Exposure Model

F&T modeling was used to assist in the description of estimated future impacts of groundwater contamination at the 200-UP-1 Groundwater OU. These estimations were then used to evaluate potential future impacts to hypothetical receptors at selected locations within the groundwater system.

A three-dimensional numerical model was used to evaluate F&T within the OU and the adjacent downgradient areas. This technique utilizes a set of numerical models (CHPRC versions of MODFLOW-2000 and MT3DMS) to describe groundwater movement as well as contaminant F&T in three dimensions within the Hanford Central Plateau aquifer system. The model domain incorporates the entire Hanford Central Plateau area, which includes both the 200 East and 200 West Areas and a large contiguous surrounding area. The relatively broad domain area allows for evaluation of the uncertainty posed by potential impacts from contaminant plumes that originate outside the 200-UP-1 Groundwater OU.

The modeling activities and results of the simulations are summarized in the following subsections. Details of the groundwater F&T modeling for this OU are described in calculation briefs ECF-HANFORD-10-0371 and ECF-200UP1-10-0373.

5.1 Groundwater Modeling Process

The F&T model for the 200-UP-1 Groundwater OU was developed following a systematic approach that implemented the following fundamental steps:

- Prepare an updated geologic description of the model domain describing the distinct HSUs, their thickness, distribution within the domain, and the elevation of the contacts between units.
- Prepare and calibrate a groundwater flow model of the Central Plateau vicinity.
- Assemble plume maps that describe the distribution of selected contaminants within the Central Plateau aquifer system and identify contaminant transport characteristics.
- Estimate future groundwater contaminant concentrations and their geographic layers within the Central Plateau model domain using a calibrated three-dimensional F&T model.

5.1.1 Contaminants of Potential Concern Characteristics

F&T of selected 200-UP-1 Groundwater OU COPCs (namely, chromium [total and hexavalent], uranium, Tc-99, tritium, I-129, nitrate, PCE, TCE, chloroform, fluoride, and Sr-90) was simulated to evaluate future impacts to the unconfined aquifer. These contaminants were selected for transport evaluation due to their discernable presence in this OU, broadly distributed groundwater plumes demonstrating that they have exhibited mobility in the past, and presence in groundwater plumes with known elevated potential for future migration. Table 5-1 summarizes the characteristics of these contaminants. These contaminants include both radioactive and nonradioactive contaminants, organic and inorganic contaminants, and metallic and non-metallic contaminants. The contaminants evaluated in F&T simulations exhibit the common characteristic of being present as dissolved constituents in groundwater.

5.1.2 Contaminant Mobility

The COPCs in the 200-UP-1 Groundwater OU exhibit varying levels of mobility in groundwater. Each of the COPCs are sufficiently water soluble, so their solubility is not a limiting factor to transport in the 200-UP-1 Groundwater OU aquifer system. Maximum observed concentrations for all of the contaminants examined in this simulation were below their apparent solubility limits in water.

The contaminants of interest for this OU fall into three general categories of mobility in groundwater: highly mobile, moderately mobile, and slightly mobile. The primary physical process that describes contaminant mobility in the 200-UP-1 Groundwater OU is interaction of the contaminants with the solid phase portion of the aquifer system (sorption of contaminants to geologic aquifer materials). This characteristic determines the mass of dissolved contaminants in groundwater at any particular time and/or location. The sorption process is described by the contaminant-specific K_d. The K_d is defined as the ratio of the concentration of contaminant sorbed onto the solid phase portion of the aquifer to the concentration of contaminant in solution in the aquifer groundwater in an equilibrium condition. Mathematically, the K_d is defined simply as the ratio of the sorbed phase concentration (c_{sorbed}) to the solution phase concentration $c_{solution}$ at equilibrium:

$$K_d = \frac{c_{sorbed}}{c_{solution}}$$

Dimensionally, the units for c_{sorbed} are expressed as ug of sorbed contaminant per g of solids (soil matrix), while the units for $c_{dissolved}$ are expressed as ug of dissolved contaminant per mL of water:

$$K_d \text{units} = \frac{ug/g}{ug/mL} = mL/g$$

The K_d value may be determined experimentally through laboratory batch or column leaching tests using samples of aquifer solids and actual or simulated groundwater. Alternatively, K_d may be determined through measurement of relative contaminant concentrations in groundwater and associated aquifer solids collected from a single representative location.

Contaminants classified in this study as highly mobile move freely with the water in which they are dissolved, exhibiting no direct interaction with the solid phase portion of the aquifer that would remove contaminant mass from the groundwater as it moves through the aquifer. The highly mobile contaminants exhibit a K_d of 0 (no retardation). Tritium is an example of a highly mobile contaminant.

Contaminants classified in this study as moderately mobile move readily with groundwater, but also exhibit a moderate degree of interaction with aquifer solids. Sorptive processes generally tend to slow the rate of migration of these contaminants through the aquifer; their observed concentration in groundwater decreases with migration downgradient through the aquifer system. The definition of moderately mobile is clearly subjective; for the purposes of this study, moderately mobile contaminants are identified as those exhibiting K_d values greater than 0 but less than 1. I-129 is an example of a moderately mobile contaminant.

Those contaminants classified in this study as slightly mobile exhibit a high degree of interaction with aquifer solids and, as a result, migrate slowly through the aquifer. Their dissolved concentration in groundwater decreases dramatically with distance from a source or release point due to the relatively large fraction of the contaminant that becomes sorbed to the aquifer solids. For this study, slightly mobile contaminants are identified as those contaminants that exhibit K_d values greater than one. Sr-90 is an example of a slightly mobile contaminant.

Sorption processes in any particular aquifer may include electrostatic ion exchange (cationic or anionic), precipitation reactions, physical adherence on particle surfaces, or combinations of multiple processes. The sorption processes may exhibit varying degrees of reversibility, as well as variations in the rate of reversibility. The K_d of groundwater contaminants varies, generally as a function of differences in the content of fine-textured materials (silt and clay-sized particles) in the aquifer solids; as the content of fine materials in the aquifer solids increases, K_d tends to increase. As a result, contaminants tend to exhibit lower K_d in coarse-textured aquifer materials (sandy or gravelly materials) and higher K_d in fine-textured formations (silty and clayey materials). Table 5-1 and Table 5-2 present general descriptions of the

COPCs, along with the contaminant-specific K_d values for the 200-UP-1 COPCs. The contaminant K_d values used for this study were selected from published reports describing experimental determination of K_d values for specific contaminants of interest conducted on samples of aquifer materials that represent aquifer conditions within the 200-UP-1 Groundwater OU.

Table 5-1. Physical Characteristics of Contaminants of Potential Concern

Chemical Name	CAS Number	Chemical Group	MW (g/mole)	Radioactive Half Life (yr)
Iodine-129	15046841	Radionuclide	129.91	16,000,000
Nitrate	14797558	Nutrient	62.00	N/A
Technetium-99	14133767	Radionuclide	98.91	210,000
Trichloroethene	79016	Volatile	131.39	N/A
Tritium*	10028178	Radionuclide	6.03	12.33
Uranium, soluble salts	N/A	Metal	238.03	NA
Chromium	7440473	Metal	51.99	NA
Tetrachloroethene	127184	Volatile	165.8	NA
Chloroform	67663	Volatile	119.38	NA
Strontium-90	10098972	Radionuclide	87.62	28.9
Fluoride	7782414	Inorganic	18.99	NA

* Tritium is generally present as tritiated water.
MW = Molecular Weight
N/A = not applicable

Table 5-2. Contaminant Distribution Coefficients for Contaminants of Potential Concern in Fate and Transport Modeling

Contaminant	K_d (mL/g)	Contaminant	K_d (mL/g)
Tritium	0	Trichloroethene	0.0250
Iodine-129	0.1	1,1-Dichloroethene	0
Technetium-99	0	Fluoride	0
Strontium-90	12	Chromium	0
Uranium	0.4	Chloroform	0.0084
Nitrate	0	Tetrachloroethene	0.0749

K_d = distribution coefficient

5.1.3 Fate and Transport Models and Approach to Simulations

Simulation of contaminant migration in the 200-UP-1 Groundwater OU was performed following the general process described as follows. A detailed discussion of the contaminant F&T model development and the results of the F&T simulations, as applied to the 200-UP-1 Groundwater OU, are presented in the following two environmental calculation briefs:

- Central Plateau Version 3 MODFLOW Model (ECF–Hanford-10-0371)
- 200-UP1 Remedial Investigation Report; Groundwater Contaminant Fate and Transport Model (ECF-200UP-1-10-0373)
- Development and evaluation of remedial alternatives for Iodine, uranium and nitrate plumes in the 200-UP-1 OU using Central Plateau groundwater model, Version 3 (ECF-200UP1-10-0374)

The MODFLOW and MT3DMS software were used to simulate groundwater flow and contaminant transport, respectively. MODFLOW solves the groundwater flow equation to calculate hydraulic heads and groundwater flow velocities. MT3DMS uses the resultant groundwater flow velocities, along with transport characteristics of the aquifer and contaminants, to solve the groundwater advection-dispersion equation, yielding concentrations in time and space.

Two general categories of natural physical processes affect the concentration of contaminants in a groundwater plume over time: advection-diffusion processes related to the movement of water through the aquifer, and processes that are specific to the individual contaminants. For this modeling study, it was assumed that there would be no continuing releases to the aquifer from the vadose zone. Section 5.2 includes a discussion of the uncertainties related to modeling assumptions, including uncertainty related to the potential for continuing releases from the vadose zone.

The following physical processes provide the primary effects on the estimated contaminant concentrations over time and distance in the 200-UP-1 Groundwater OU and include the following F&T solutions:

- Dilution of the contaminants, with a reduction in groundwater concentration, occurs as additional uncontaminated water enters the aquifer. This can include uncontaminated groundwater entering the model domain from the lateral domain boundaries, meteoric water entering the aquifer from the top of the domain as a fraction of the annual precipitation falling on the ground surface, and clean water discharges to the aquifer from continuing operations at the Site.
- Dispersion of the dissolved contaminants, with a reduction in groundwater concentrations occurs as groundwater moves through the aquifer system. Contaminants tend to become more dispersed at decreasing concentrations as groundwater flows through a porous medium. Dispersion occurs due to small, localized variations in the water flow velocity at locations within the groundwater. This results in a more widespread distribution of the contaminant mass as distance from the point of origin increases. This process is defined by the coefficient of hydrodynamic dispersion (D).
- Diffusion of dissolved contaminants occurs as a result of concentration gradients within the aquifer. The result of diffusion is similar to that of dispersion; the original contaminant mass becomes more widespread throughout the aquifer with time, and overall concentrations are reduced. This process is quantified by the coefficient of molecular diffusion (D_m).

In addition to the advective-diffusive processes described previously, selected contaminant-specific processes also affect groundwater contaminant concentrations over time and distance. These processes were included in the F&T simulations:

- Radioactive decay of radionuclides (I-129, Tc-99, and tritium) active contaminants as quantified by the half-life of each isotope.
- Interaction of the contaminants with the solid phase portion of the aquifer system (sorption of contaminants to geologic aquifer materials) reduces the mass of dissolved contaminants at any particular time and/or location. This process is quantified by the contaminant-specific K_d.

Losses from the aquifer through volatilization of VOCs (PCE, TCE, and chloroform) were not considered in this simulation due to groundwater depth below ground surface.

The following steps were performed for contaminant F&T simulations for the 200-UP-1 Groundwater OU:

1. A representative data set describing the geological structure and hydraulic properties of the model domain was prepared through assembly of measurements and geologic observations from well and boring logs, as well as integration of surface geophysical survey data.
2. The geological structure data were used to prepare digital maps of the HSU surfaces within the aquifer that were the subject of the modeling exercise. Figure 5-1 shows a plan view of the Central Plateau model domain. Figure 5-2 through Figure 5-4 show generalized hydrogeologic cross sections of the model domain.
3. A historical data set of groundwater elevations in groundwater monitoring wells across the model domain was assembled for use in model calibration; Figure 5-5 shows these wells.
4. The COPC plumes in groundwater were described using digital plume maps that can be integrated with the hydraulic model of the aquifer. Plumes were established for the initial simulation conditions using observed contaminant concentrations from data collected during FY 2008; supplemented with 2005 through 2009 data where necessary. Chapter 3 provides additional information on development of initial conditions.

A model calibration was performed to compare the MODFLOW-calculated aquifer water levels to the observed historical measurements within the Central Plateau.

5.1.4 Central Plateau Conceptual Model Development

The aquifer is composed of a series of unconsolidated fluvial deposits that accumulated over the past several million years, with the most recent deposits formed by cataclysmic flooding of the Columbia Basin within the last 20,000 years (the Missoula floods). In the western portion of the domain, the saturated aquifer is composed of a sequence of deposits known as the Ringold Fm. For modeling purposes, the Ringold deposits have been grouped into three HSUs. The Ringold A HSU, a relatively coarse-grained sand and gravel formation, lies directly above the basalt bedrock. Next in the sequence is the Lower Ringold Mud HSU composed of a mix of coarse- and fine-grained deposits bounded above and below by fine-grained deposits; the Lower Ringold Mud HSU forms a substantial restriction to vertical movement of water where it occurs. The coarser-grained Ringold E HUS is located above the Lower Ringold Mud.

In the eastern portion of the model domain, the Ringold deposits have been incised by later erosional/ depositional events that have resulted in the formation of highly conductive channels. These channels are filled by the western portion of the Cold Creek HSU (pre-Missoula gravels) and later by Missoula flood deposits of the Hanford coarse-grained HSU. The western CCU and Hanford fm are separate HSUs in the model. A sixth HSU is used to represent the fine-grained western portion of the Hanford fm.

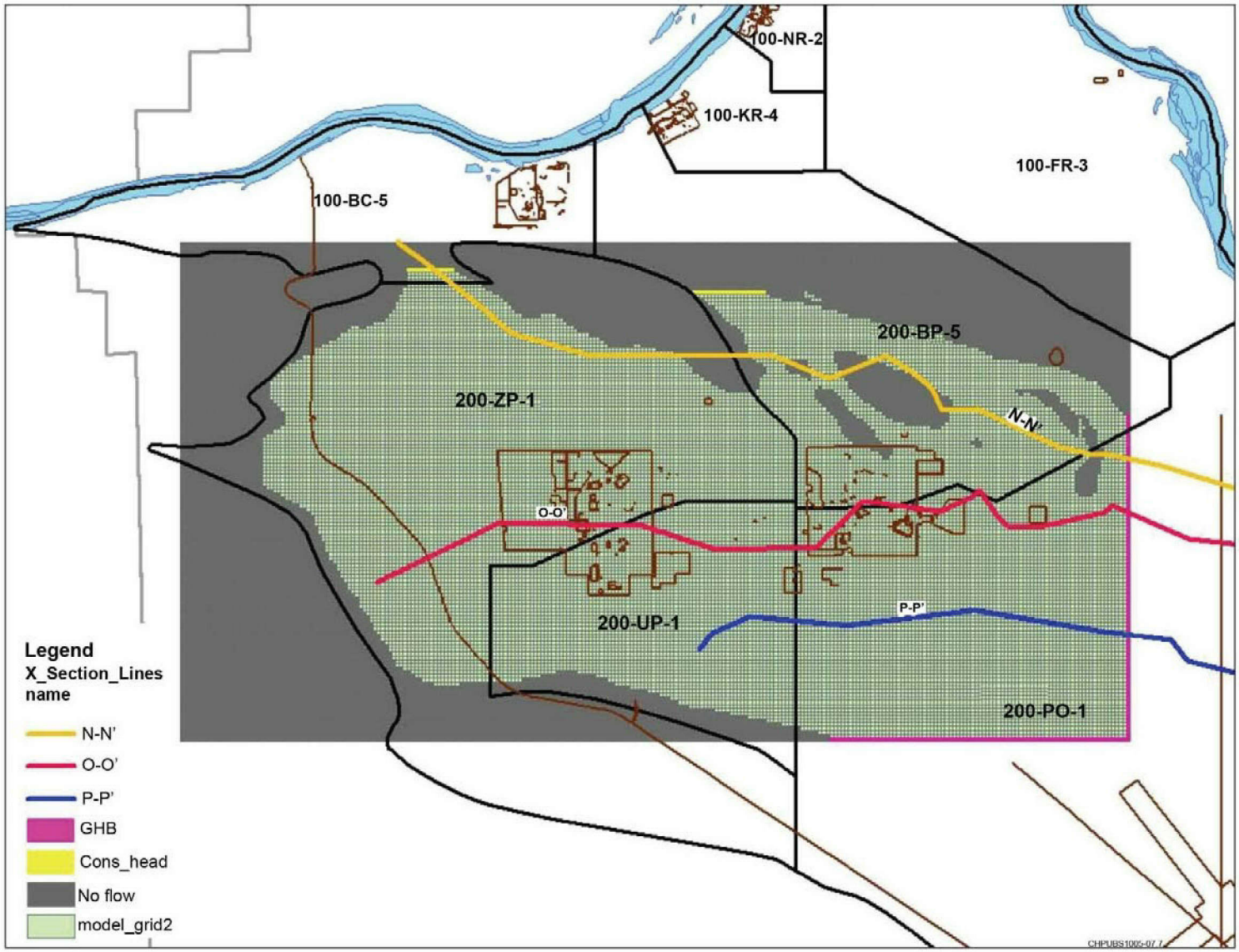

Figure 5-1. Plan View of Central Plateau MODFLOW Model Domain Boundary and Cross Section Locations

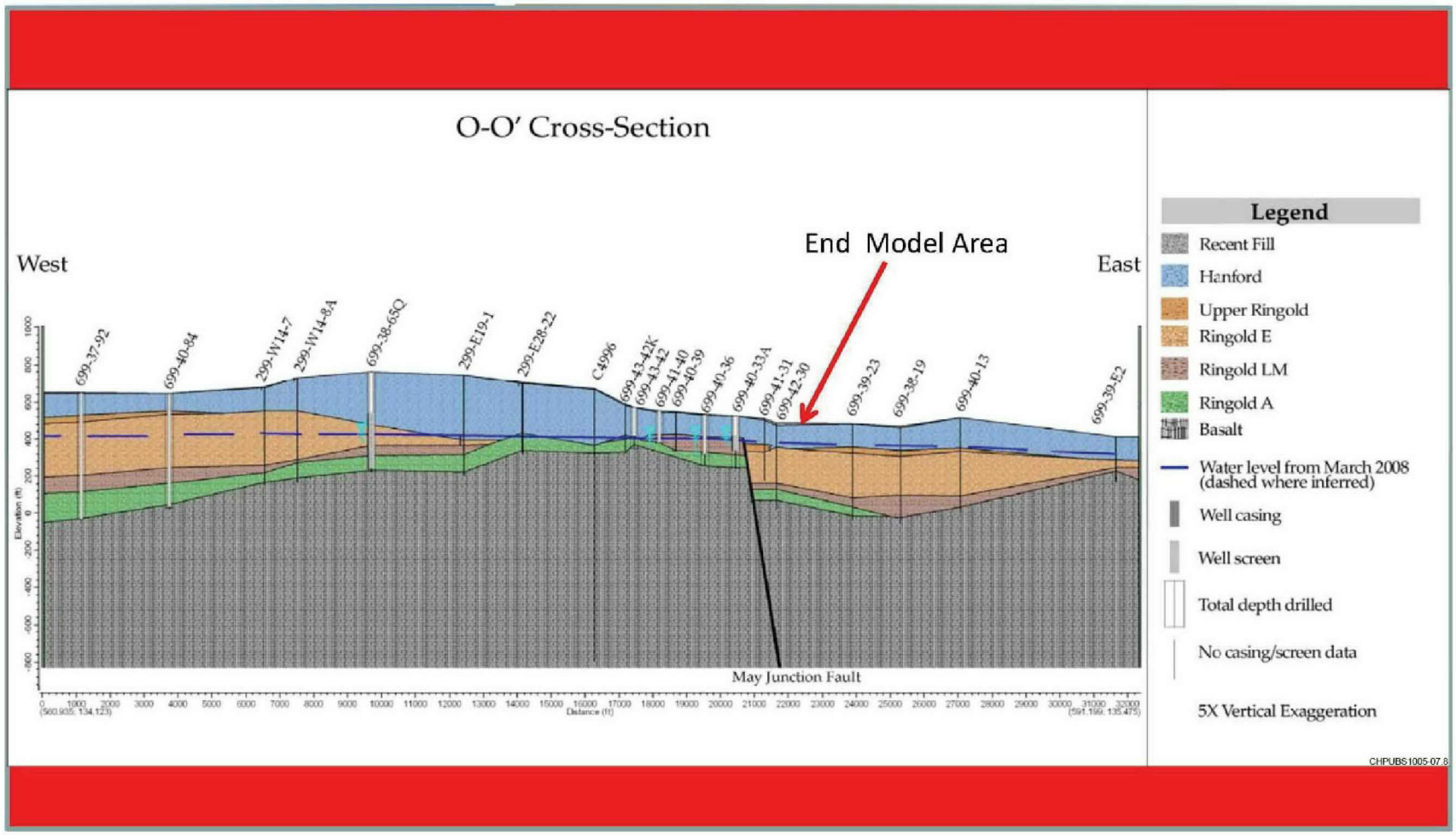

Figure 5-2. Geologic Cross Section O-O'

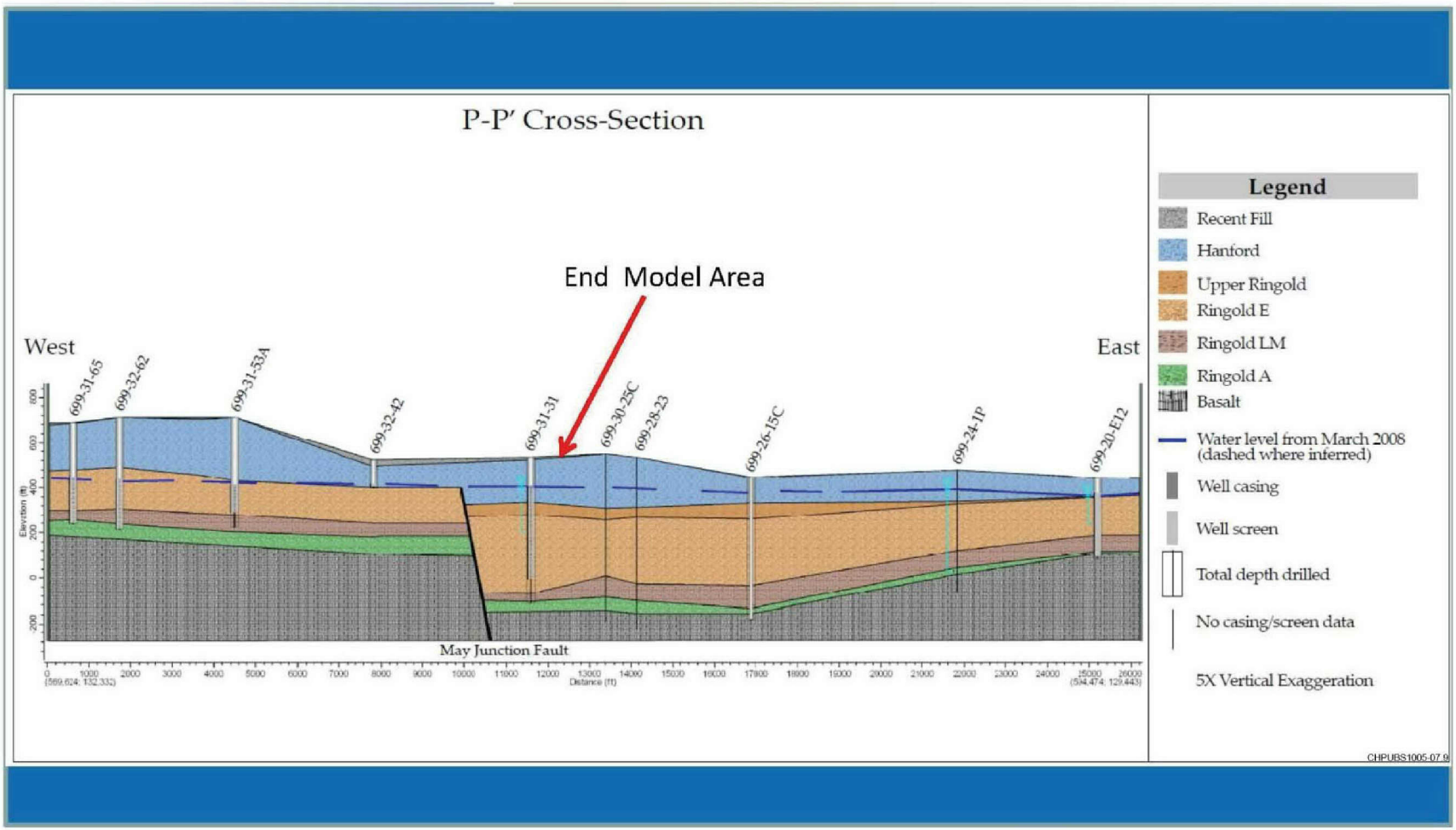

Figure 5-3. Geologic Cross Section P-P'

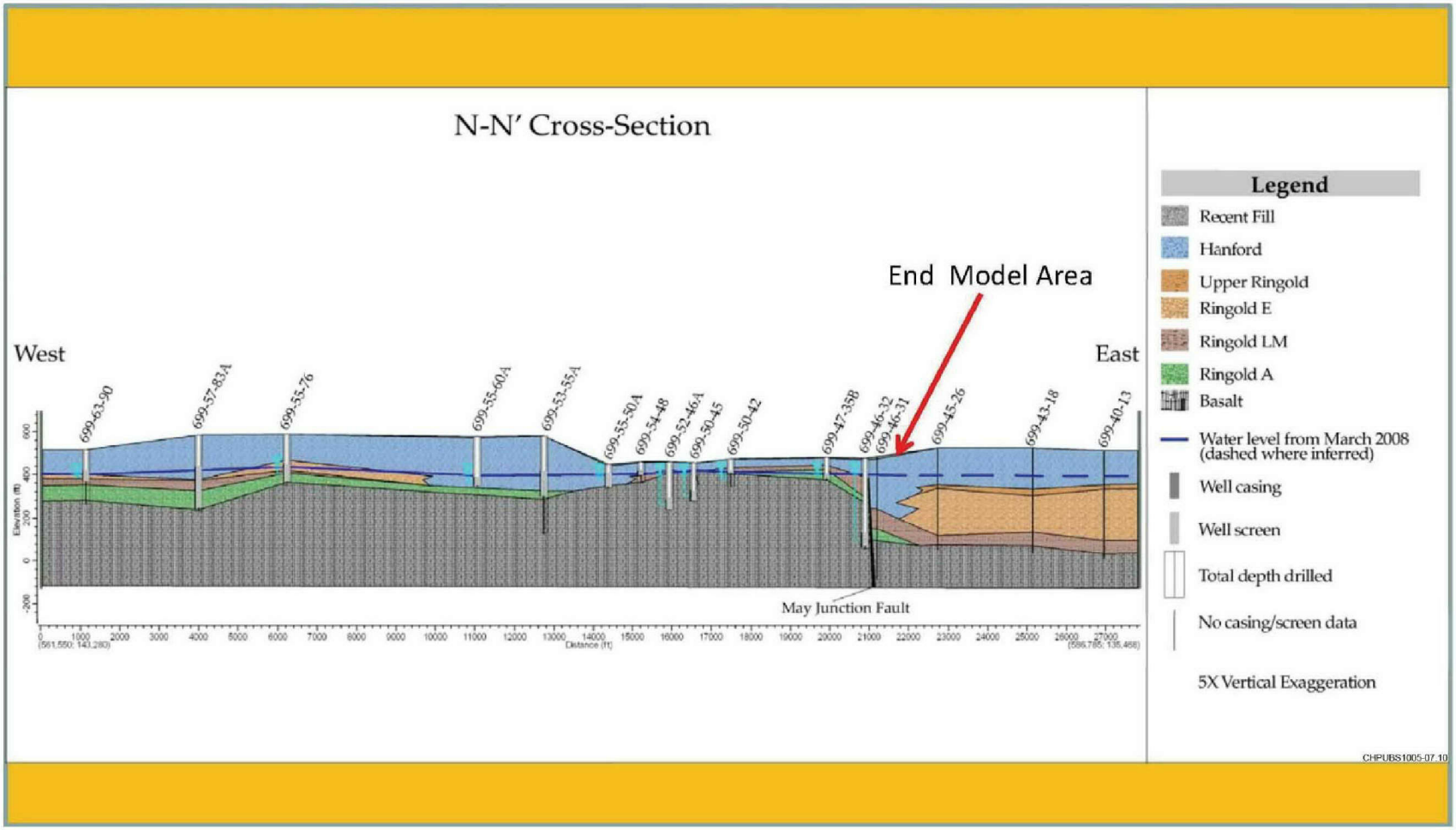

Figure 5-4. Geological Cross Section N-N'

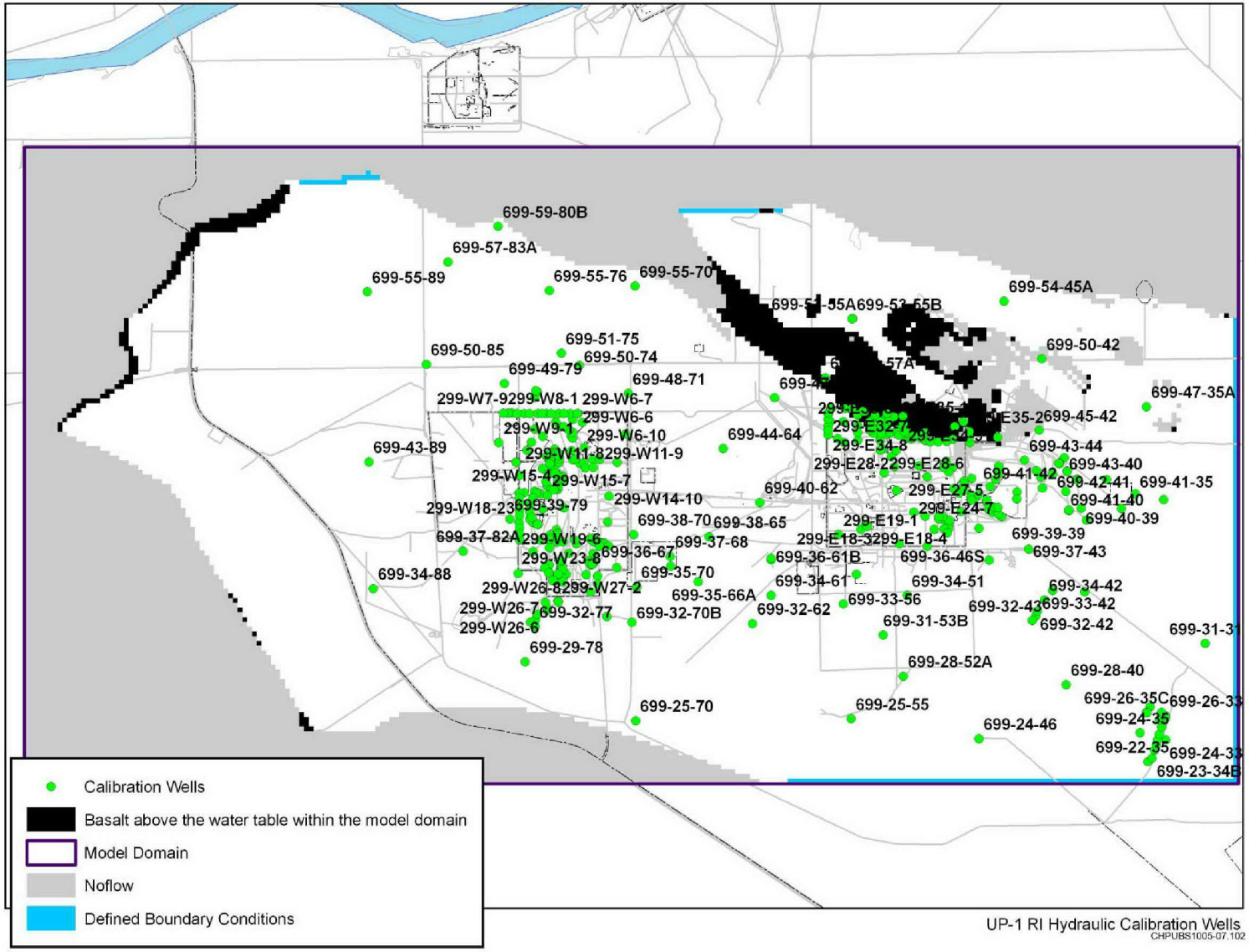

Figure 5-5. Wells Used for Model Calibration

The distribution of each HSU within the model domain was determined by interpolating the contacts between HSUs from well cores and logs onto the entire model grid. These interpolated surfaces were then used to set the top and bottom elevations of the layers within the model. The seven model layers vary in elevation so that the varying elevations and thicknesses of each unit are explicitly represented. As a result, the HSU was represented by individual layer changes within the model domain (Figure 5-5). To reiterate, layers do not represent individual continuous HSUs, nor do they represent a constant elevation slice through the aquifer.

Contaminant migration in the subsurface is driven primarily by groundwater flow. Groundwater flow directions and velocities are, in turn, a function of fluid inputs to the aquifer and aquifer hydraulic properties. The model domain is surrounded and underlain by basalt formations that are assumed to contribute a negligible amount of water to the flow system. Seven localized regions were identified that are significant inflow and outflow boundaries: two gaps in the basalt sub-crops along the northern boundary of the model domain; two subsurface stream flows that enter the domain along the surface of the basalt; natural recharge to the aquifer from precipitation; artificial recharge arising from the disposal of water in ponds, cribs, and shallow wells; and a broad region of outflow along the southeastern and eastern edges of the model domain.

To establish representative hydraulic properties values for heterogeneous HSUs, calibration was performed using historic water level measurements. The Central Plateau has a large number of monitored wells with long records of measurement of both groundwater elevation and contaminant concentrations. Some of these records date back to 1948, when the weapons material production facilities were first being constructed on the Central Plateau. The representative hydraulic conductivity of the various HSUs was adjusted to match simulated hydraulic heads to well records. The calibration was complicated by uncertainty in the boundary condition along the southeastern and eastern boundary. A mixed (Cauchy-type) boundary condition was applied to represent the hydraulic character of this long boundary. Mixed boundary conditions are known as general head boundary conditions in MODFLOW simulations. The boundary condition is specified by two terms: a reference head value and a conductance term representing the hydraulic connection of the reference head to the boundary. Along the eastern portion of the boundary, the average Columbia River stage was used for the reference head, and the conductance was set so that: (1) flow directions through the boundary were consistent with those implied by historical contaminant plume maps, and (2) the historical observed hydraulic heads at monitoring wells near the boundary were matched by the simulation. Along the southeastern boundary, two mixed boundary condition terms were superimposed to represent the net effect of two fluxes: one to the Columbia River, as for the eastern boundary, and another to represent inflow from the Dry Creek-Rattlesnake Ridge depression in the basalt bedrock. These two terms were set using the same criteria used for the eastern boundary.

With calibrated parameters established, the calibrated flow model was revised to support the contaminant transport simulations by changing boundary conditions to represent future conditions. Incoming stream flow, natural recharge rates, and the hydraulic heads at the two gaps were assumed to remain unchanged over the 1,000 years simulated for F&T. Future planned use of the SALDS and TEDF facilities would represent the only sources of artificial recharge, in contrast to the historical period used for model calibration when many other large liquid discharges were included. Current and planned future use of the 200-ZP-1 P&T system were included. Current pumping for interim remediation of the 200-UP-1 U Plant, and S and SX facility plumes was intentionally not included, nor was pumping for future 200-UP-1 (as yet unplanned) final remediation. The MODFLOW groundwater flow software creates a file of transient simulated fluxes to and from each cell in the flow model. These were used, along with porosity values, to calculate groundwater velocities in the MT3DMS transport simulations.

Five sources of contaminant distribution information were used in estimating the initial concentration distributions: measurements from screened wells, depth-discrete samples acquired during drilling or special sampling surveys, a composite data set created for the 200-ZP-1 Groundwater OU RI/FS, measurements acquired from Ecology, and contaminant plume contours interpreted for the 2008 and 2009 annual groundwater monitoring reports. Current contaminant distributions were prepared for the F&T simulations by interpolating measurements across the model domain using two calculation methods. The first method (Method 1) was used to determine initial concentrations for all of the COPCs; upon review it was determined that for five of the COPCs, the first method was overly conservative. A second method (Method 2) was developed for the five COPCs: chromium, I-129, nitrate, uranium, and Tc-99.

Method 1

A kriging technique proposed by Reed et al. (2004) was adopted for the interpolation algorithm to establish initial conditions.[1] This technique was previously used for the 200-ZP-1 RI/FS to define contaminant distributions. A significant feature of this technique is the use of a transformation to limit the influence of very large concentration measurements, which is a common problem with contaminant data. Some significant differences exist between the application of kriging to the 200-ZP-1 Groundwater OU and a similar application to the 200-UP-1 Groundwater OU. The most important of these is that contaminant distributions were estimated within the entire model domain for the 200-UP-1 Groundwater OU F&T simulations and only in the proximity of the 200-ZP-1 OU for the 200-ZP-1 RI/FS. The 200-PO-1 and 200-BP-5 Groundwater OUs tend to have a predominant groundwater flow direction that is almost perpendicular to the predominant flow directions in the 200-ZP-1 and 200-UP-1 Groundwater OUs. To accommodate the tendency for contaminant plumes to align with predominant flow directions, the major principal kriging directions were oriented at 45 degrees east of North in the 200-ZP-1 and 200-UP-1 Groundwater OUs and 135 degrees east of North in the 200-PO-1 and 200-BP-5 Groundwater OUs. In both cases, the exponential variogram tended to be about twice as long in the major direction as in the minor direction.[2] Longer variograms were used to estimate the distribution of contaminants that tended to have large plumes; shorter variograms were used to estimate contaminants with smaller plumes.

Contours of contaminant concentration from the 2008 groundwater monitoring report were used to assess the kriged contaminant distributions and to guide the placement of control points. Control points were used to overcome the symmetry inherent in kriging variograms. Contaminant distributions tend to be high in a source area, diminish rapidly with distance upgradient of the source area, and diminish slowly with distance in the direction of flow. To force this tendency in the estimates of plume distributions, control points with small values were used to constrain the upgradient extent of contaminants from source areas. Contaminant contours from the 2008 groundwater monitoring report were used to identify source areas. Control points were used to connect high concentrations. Separate measurements of high values in the contaminant contours from the 2008 annual groundwater monitoring report indicated a single region of high concentration rather than isolated plumes. Therefore, the data input to define existing contaminant distributions is both complex and slightly subjective. Subjectivity enters from the choice of control point location and value and from the contaminant contours from the 2008 groundwater monitoring report, which themselves were guided subjectively by historical knowledge and familiarity with the source area processes.

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[1] Kriging is a group of geostatistical techniques to interpolate the value of a random field (the elevation, z, of the landscape as a function of the geographic location) at an unobserved location from observations of its value at nearby locations.

[2] In spatial statistics, the theoretical variogram $2\gamma(x,y)$ is a function describing the degree of spatial dependence of a spatial random field or stochastic process $Z(x)$. It is defined as the expected squared increment of the values between locations x and y (Wackernagel, 2003).

The vertical profile of contaminant data was only sufficient to determine a three-dimensional distribution of carbon tetrachloride in the 200-UP-1 Groundwater OU. As an expedient approximation for other contaminants, only measurements that were acquired from well screens or discrete samples taken in the Ringold E HSU were used to estimate a horizontal extent of the contamination. This estimate was then used as the initial contaminant distribution in Ringold E. Initial contamination was assumed to be absent in the Ringold mud and Ringold A. Future transport into these HSUs occurred via the three-dimensional flow fields.

Measurements of contaminant concentrations tend to be located where contamination occurs at levels of concern. Hence, contaminant measurements at the scale of the 200-UP-1 Groundwater OU are biased toward large values leaving regions of low concentration with relatively sparse measurements. In addition, the treatment of non-detect measurements as one-half of the detection limits biases the measurements upward away from contaminated areas. The kriging algorithm estimates tend toward the average of measured values where measurements are lacking. Therefore, away from regions of high concentration, the kriged results are biased toward large values. To reduce the impact on the estimates of total contamination in the 200-UP-1 Groundwater OU, the kriged estimates were truncated at values of one-half of the contaminant's MCL. Below one-half of the MCL value, contaminant concentrations were set to zero.

Method 2

Three-dimensional plume volumes were generated using three-dimensional software. The software uses radial basis functions to interpolate three-dimensional numerical models using X, Y, Z, and concentration data.[3]

Coordinate, elevation, and concentration data were provided for each COPC (SGW-46971 FESI Format Final). All COPC data were retrieved from HEIS as depth-discrete samples and routine annual groundwater monitoring samples. Data from HEIS were queried for the 200-UP-1 Groundwater OU monitoring wells from 1990 to 2009. Preference was placed on 2009 data, but where there were none, the next closest year for each well was used. Three-dimensional plume volumes were produced at one-half the MCL, the MCL, 10 times the MCL, and 100 times the MCL thresholds for each COPC using the Hydro model. The plume models provided a method to visualize concentration data in three-dimension with each volume enclosing concentrations greater than or equal to its threshold or "contour" value. Concentration data were transformed into initial contaminant distributions by using the maximum concentration of the three-dimensional plume within each model cell. Below one-half the MCL value, contaminant concentrations were set to zero. The three-dimensional plume volumes were truncated at the upper surface of the Ringold mud HSU to reflect hydrologic interpolation that there has been no contamination migration into this HSU.

Initial contaminant distributions were combined with the groundwater flow solution from the modified MODFLOW program, along with porosity and the transport parameters described in Section 5.1 to form the F&T model for the 200-UP-1 Groundwater OU. The MT3DMS software was used to solve the groundwater advection-dispersion equations for the identified COPCs to predict how the initial contamination in the 200-UP-1 Groundwater OU may move during operation of the 200-ZP-1 P&T system and up to 1,000 years in the future. It is important to understand that the model simulations did not include source contributions for COPCs from the vadose zone soil column, located above the groundwater plumes. The OUs where these source conditions reside will be addressed within the CERCLA process by each specific OU.

[3] A radial basis function (RBF) is a real-valued function whose value depends only on the distance from the origin.

5.2 Groundwater Impacts

Historical releases of liquid wastes within the Hanford Central Plateau area have impacted groundwater, altering the flow system and creating contaminant plumes of varying size and concentration. The F&T simulation techniques described in Section 5.1 were applied to the known groundwater plumes to create an estimate of future plume migration and concentration trends. The future impact evaluation includes assessment of changes in the location and concentration of groundwater contaminants resulting from migration of the contaminants in groundwater and the attenuating processes that affect them.

Section 5.2.2 presents the results of F&T analysis for the UP-1 portion of the Central Plateau. Section 5.2.3 presents a discussion of uncertainties in the estimates of future conditions.

5.2.1 Simulation of Flow

An overview of the flow solution is presented in this section. Figure 5-6 displays the initial (present day) hydraulic head (groundwater elevation) distribution used as the initial condition in the model. The outline of the model domain is shown with a dark band. The grey areas just inside the boundary are regions that are not actively used in the model. These are mostly regions where basalt sub-crops above the water table, but small regions in the northern part of the model that are between the domain boundary and the fixed hydraulic head boundaries of the model are also included.

The model interior is shown in white, black, and grey. White indicates regions where at least one layer in the model is partially saturated. Black is used for regions of the model domain where all the layers are unsaturated (above the water table) during the transport simulations. These regions had saturated layers during the peak water table elevations during the historic period used for model calibration. Grey is used to depict small regions where the water table never rises above the basalt even during the calibration period. Roads of the Central Plateau are also shown in grey. Within the model domain, red lines indicate boundaries of the active model that are open to flow. Contour lines with a 1 m (3 ft) interval for the simulated water table are shown in blue.

Prominent features of the head distribution are the relatively flat gradients in most of the 200-PO-1 OU, especially under the 200 East Area. In the northeast portion of the 200-PO-1 Groundwater OU, the gradients dip steeply to the northeast. These steep gradients indicate flow blockage caused by the Ringold mud HSU in this region. The extensive black regions in the northern portion of the model reveal that the connection of the 200 East region to the Gable gap has been nearly severed by the water table dropping below the basalt surface. Thus, flow from the northern edge of the western portion of the model domain is simulated to move southeast rather than north, as was true in the past.

In and west of the 200 West Area, the gradient is mostly slightly north of east. The steeper gradient is caused by the much lower hydraulic conductivity of Ringold A and Ringold E compared to the Hanford and the Cold Creek HSUs.

Near the western gap, the influence of a small patch of saturated Hanford fm is causing the flat gradient next to the gap. Divergence of fluxes from the Cold Creek stream and the much smaller Dry Creek are clearly evident along the western boundary of the domain. The extreme northeast corner of the model shows residual high heads due to the very low-conductivity Ringold mud. The same phenomenon is causing elevated heads in the western portion of the model, just at the southern edge.

During the 200-ZP-1 P&T operation, 25 years into the simulation (Figure 5-7), the pumping and extraction wells form prominent features in the hydraulic head distribution in the 200 West Area. Outside of the 200-ZP-1 P&T operation, a slight decline in the water table is barely noticeable. After another 50 years (Figure 5-8), the predicted flow has completely recovered from the 200-ZP-1 P&T operation.

The basic pattern has the same basic shape as the initial conditions but the gradients in the western portion of the domain are slightly less steep. Figure 5-9 shows that the simulated water table in the 200 West Area has changed little from year 75 to year 125 of the simulation. At year 125, the Central Plateau aquifer simulation has almost entirely recovered from the water table built from the 200-ZP-1 P&T operational period.

5.2.2 Simulation of Contaminant Migration

F&T simulations were performed to prepare estimates of future groundwater contaminant concentrations within the unconfined aquifer in the 200-UP-1 Groundwater OU. These simulations were performed using the numerical model implemented with MT3DMS described in this section. The following COPCs were simulated:

- Tritium
- Nitrate
- I-129
- TCE
- PCE
- Tc-99
- Sr-90
- Uranium
- Chromium (total and hexavalent)
- Fluoride
- Chloroform

No information is presented in this report on carbon tetrachloride, as a ROD is already in place for this COC, along with a remedial action plan and an engineered retrieval and treatment system. The CERCLA 5-year review process is also in place for carbon tetrachloride, and it will deal with observed future conditions throughout this plume.

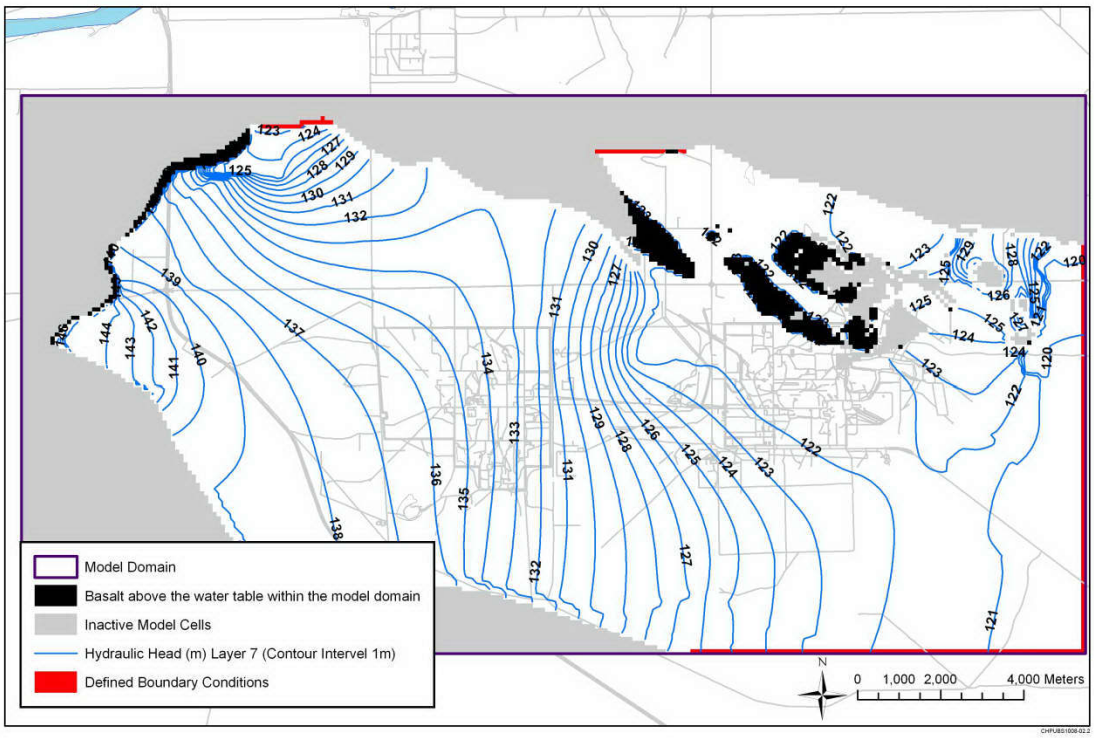
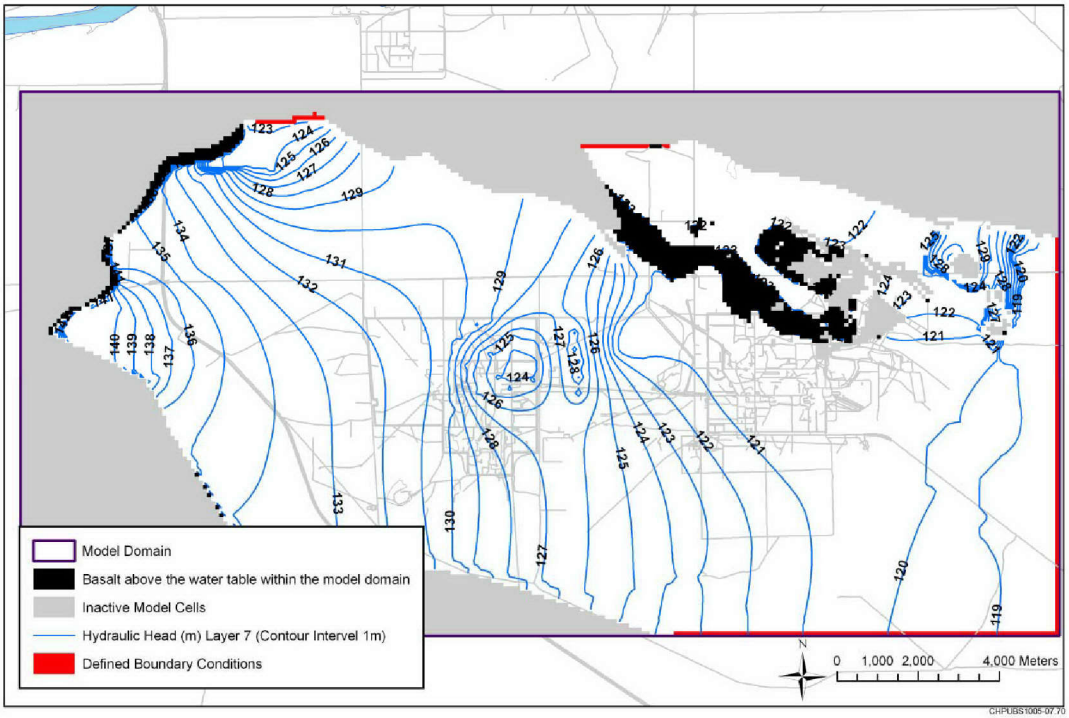
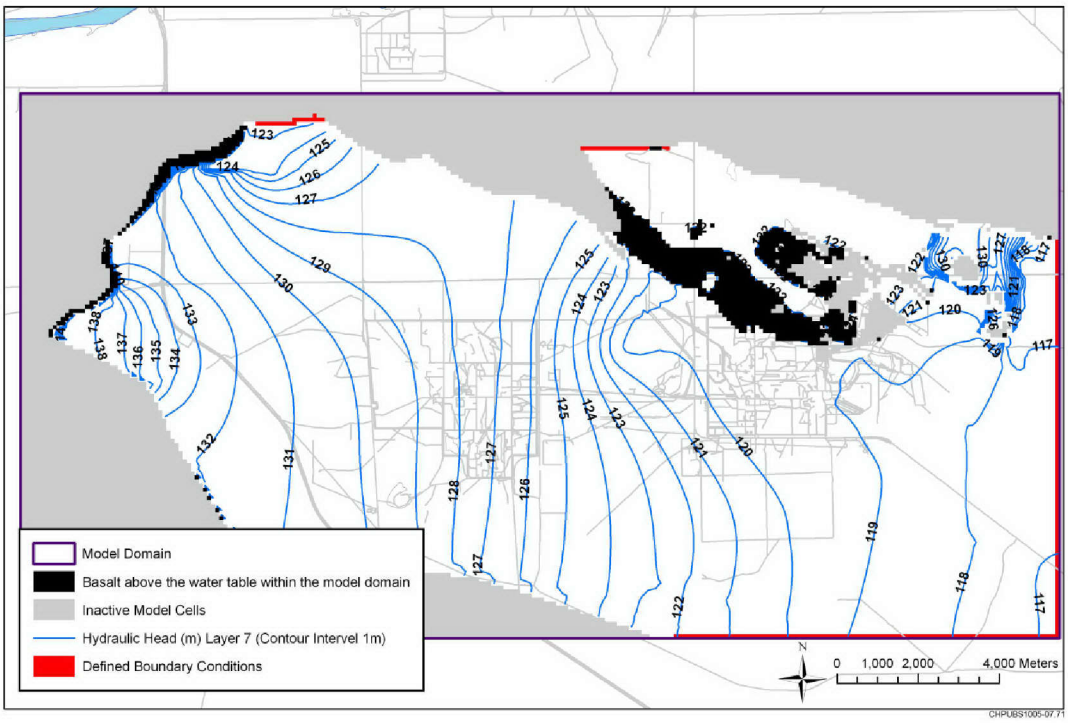


Figure 5-6. Initial Hydraulic Head Distribution (2009)



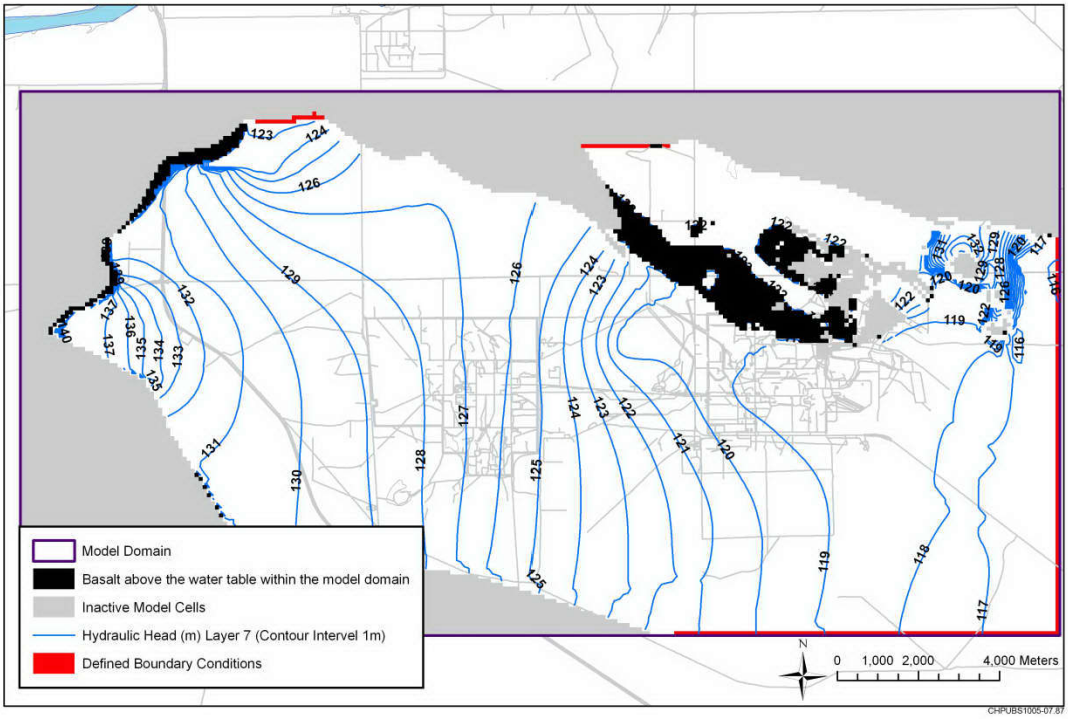
UP-1 RI 25 Year Head

Figure 5-7. Hydraulic Head Distribution for 2034



UP-1 RI 75 Year Head

Figure 5-8. Hydraulic Head Distribution for 2084



UP-1 RI 125 Year Head

Figure 5-9. Hydraulic Head Distribution for 2134

The estimated COPC concentrations in groundwater were developed at the initial condition. Predicted concentration values have been recorded at selected future time steps in the simulations. The plume maps at selected time steps are presented for each COPC to provide a basis for comparison of future impacts on groundwater under conditions where no active groundwater remedial action is applied. All of the displays of contaminant concentration presented as follows use the same color scheme. Concentrations between one-half MCL and MCL are presented in green. Pink is used to display concentrations between MCL and 10 times the MCL. Burgundy is used from 10 times the MCL to 100 times the MCL. The concentration ranges, therefore, depend on the contaminant displayed. The concentration range is reported in the legend of the figure. Fluoride and chloroform displays are not presented, as the areas of contamination from these COPCs in the 200-UP-1 Groundwater OU are too small. The area of future Sr-90 contamination is also too small, but the initial concentration for Sr-90 is shown for information purposes.

5.2.2.1 Tritium

Figure 5-10 presents the estimated current/initial tritium distribution. A very large plume of tritium in the 200-UP-1 Groundwater OU above the MCL is shown, with a large region above 10 times the MCL. Figure 5-11 displays the simulated plume after 50 years (year 2059) of transport and decay where it is below the MCL. This is primarily due to the 12.3-year half-life of radioactive decay of tritium, although the influence of the 200-ZP-1 P&T system is also significant.

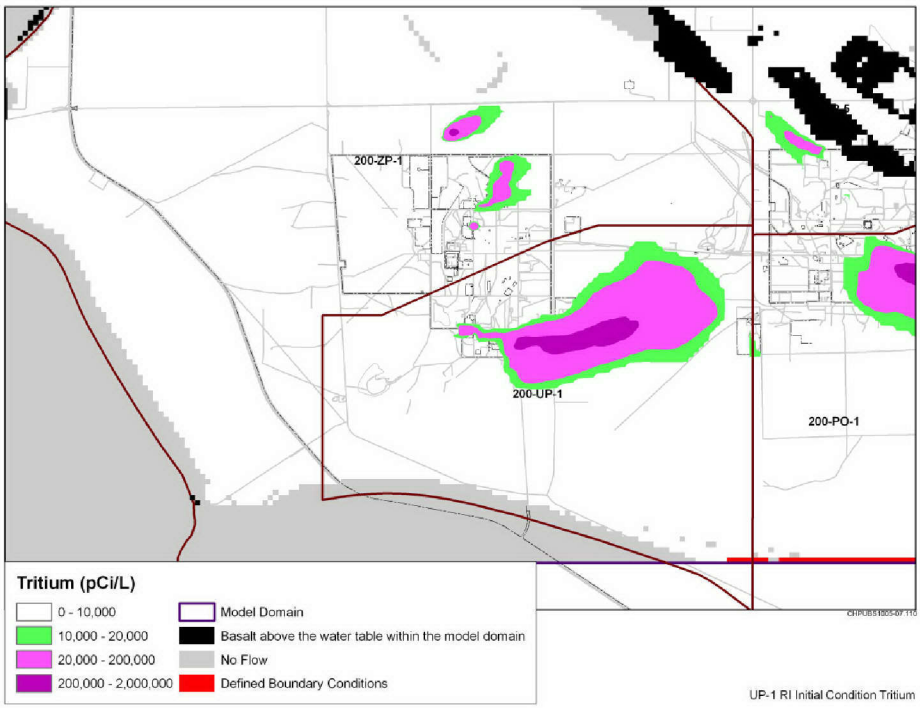


Figure 5-10. Initial Tritium Distribution

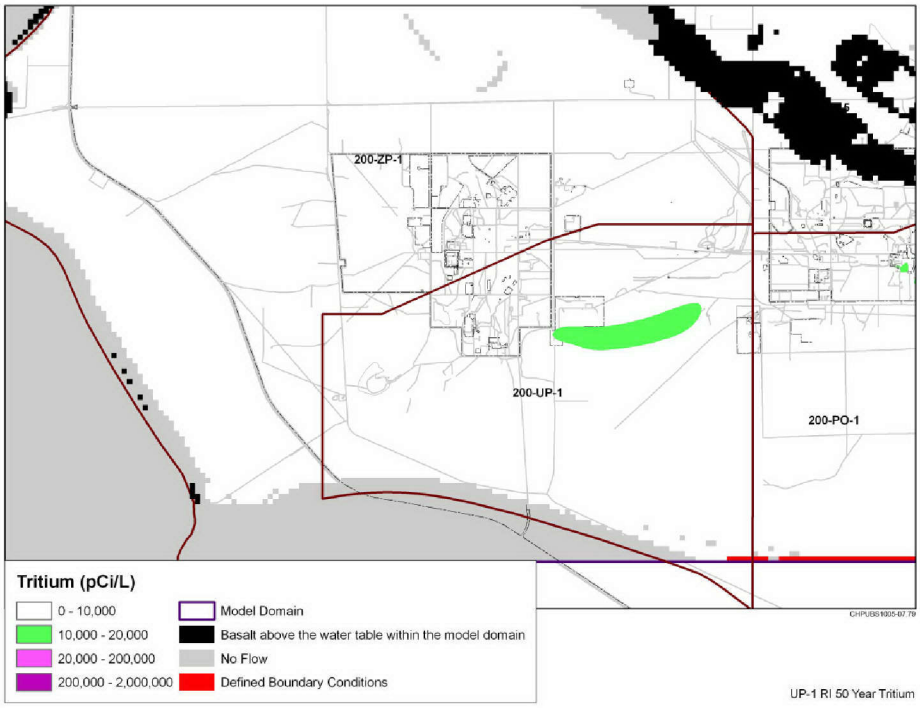


Figure 5-11. Tritium Distribution After 50 years (2059)

5.2.2.2 Nitrate

Within the 200-UP-1 Groundwater OU, nitrate exists above the MCL in a vast area in and east of the 200 West Area and in smaller plumes within the 200 West Area as shown in Figure 5-12. The plume comingles with the tritium plume, but is centered closer to the 200-ZP-1 OU and significantly larger. The blunt eastern edge of the plume is caused by the intersection of the water table with the Ringold lower mud, essentially blocking flow to the northeast at this location. Figure 5-13 indicates that 25 years of 200-ZP-1 P&T operation will have a dramatic influence on the distribution of nitrate in the 200 West Area and in the northern edge of the 200-UP-1 Groundwater OU. The simulated plume has begun to migrate around the southern limit of the intersection of the water table and the Ringold Mud and entered the highly conductive coarse-grained Hanford fm HSU in the 200-PO-1 Groundwater OU, where it moves more rapidly and gets dispersed below one-half the MCL. The western edge of the plume has been pulled into the 200-ZP-1 Groundwater OU.

The plume migrates eastward after 75 years of succession of the 200-ZP-1 P&T operation and subsequent recovery of the unconfined aquifer flow system (Figure 5-14; year 2084). At 125 years (Figure 5-15; year 2134), the plume has continued to move eastward into the Hanford fm. Some northern movement along the water table-mud intersection is also evident. The simulation shown in Figure 5-16 indicates continued northeast and southeast movement of nitrate plume dropping below MCL everywhere by 2184, but remaining above one-half the MCL for about 300 years (Figure 5-17; year 2309).

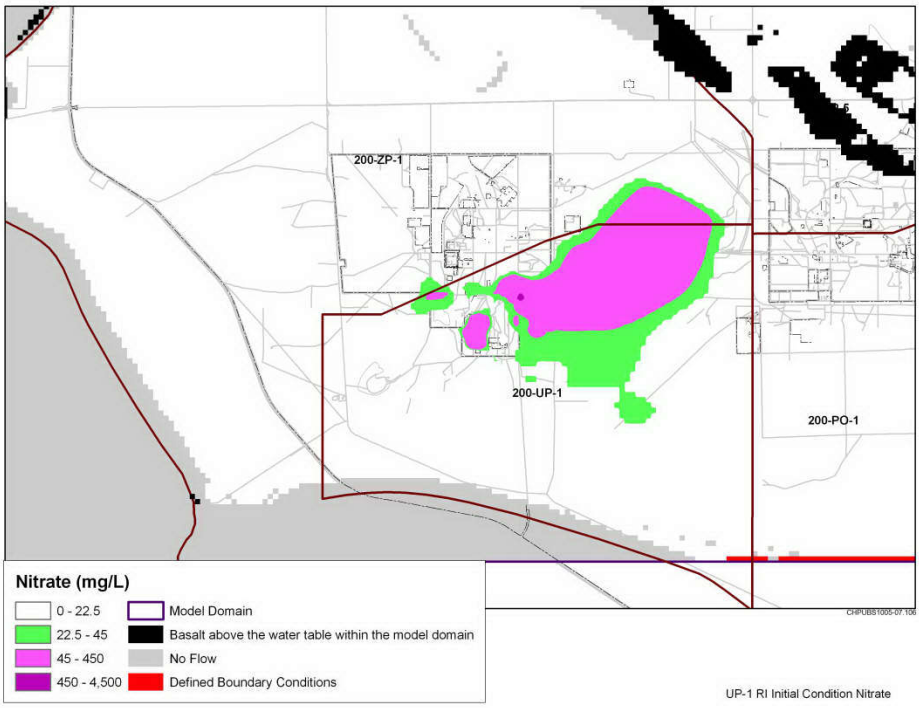


Figure 5-12. Initial Distribution of Nitrate (2009)

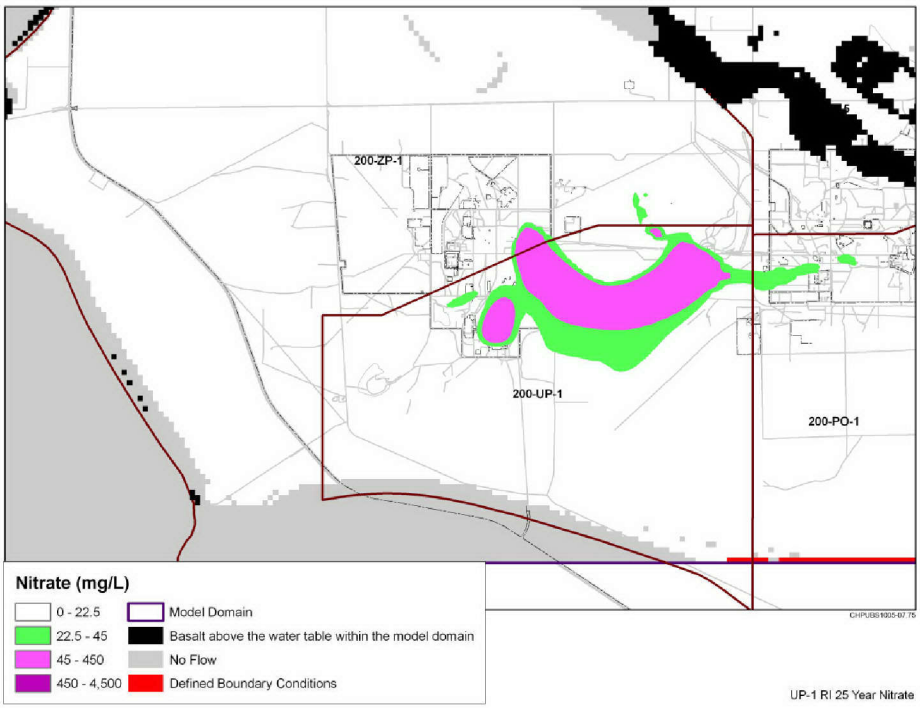


Figure 5-13. Distribution of Nitrate After 25 Years (2034)

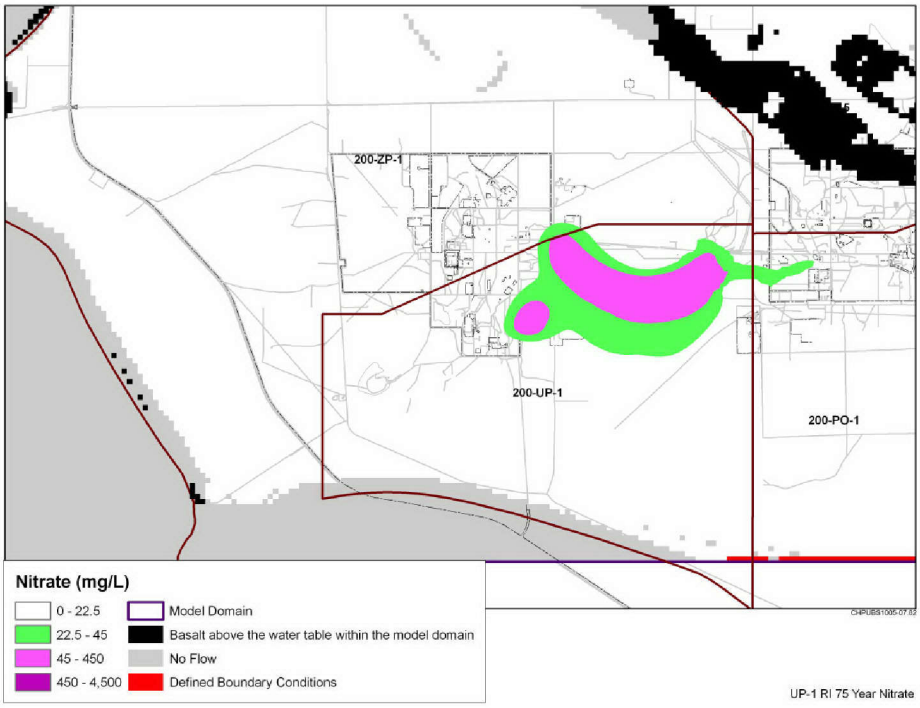


Figure 5-14. Distribution of Nitrate After 75 Years (2084)

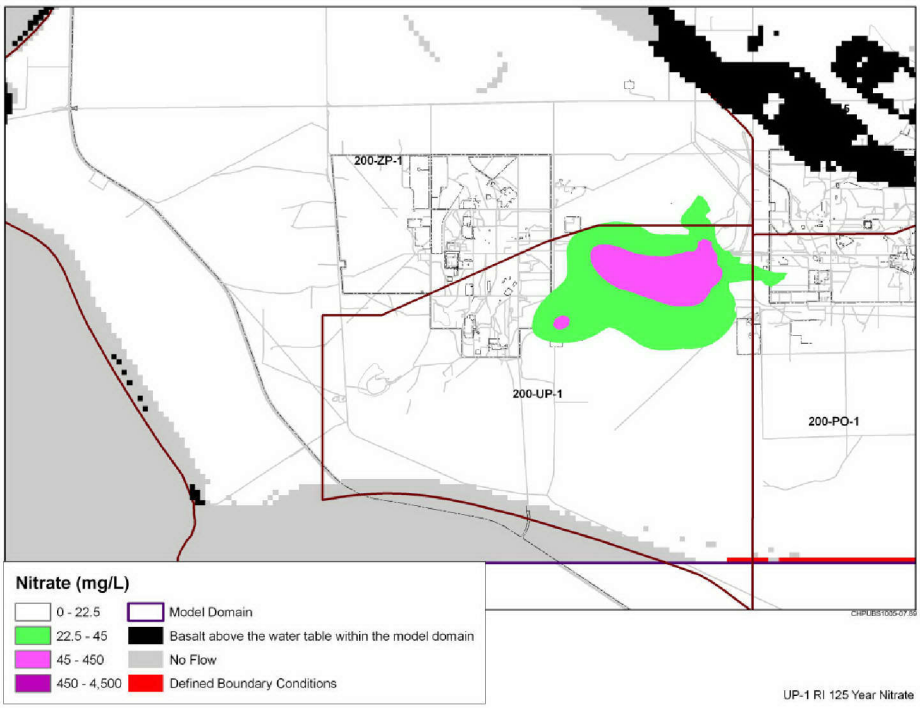


Figure 5-15. Distribution of Nitrate After 125 Years (2134)

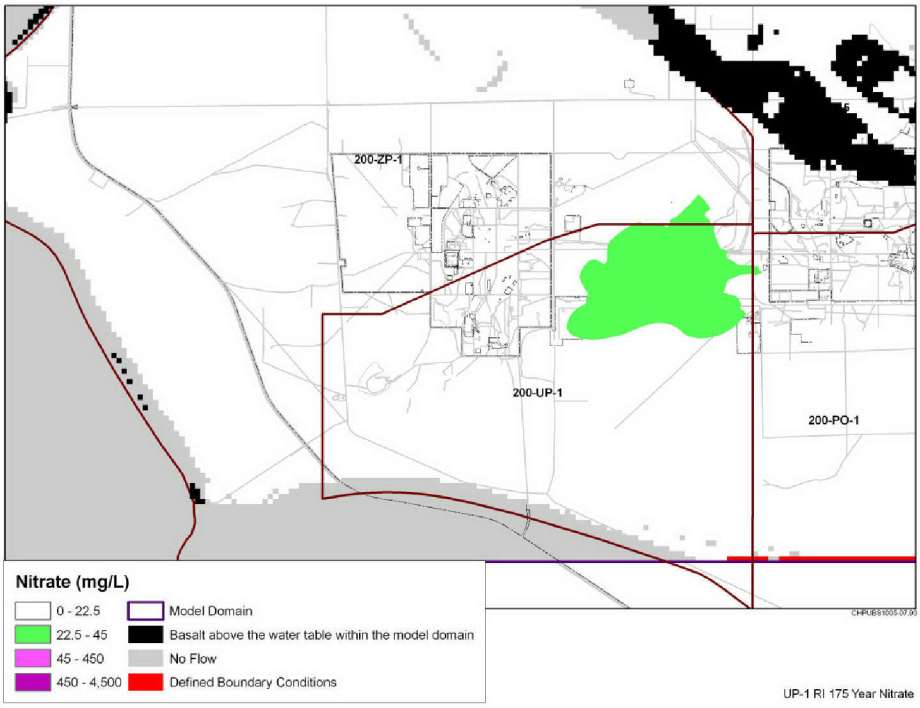


Figure 5-16. Distribution of Nitrate After 175 Years (2184)

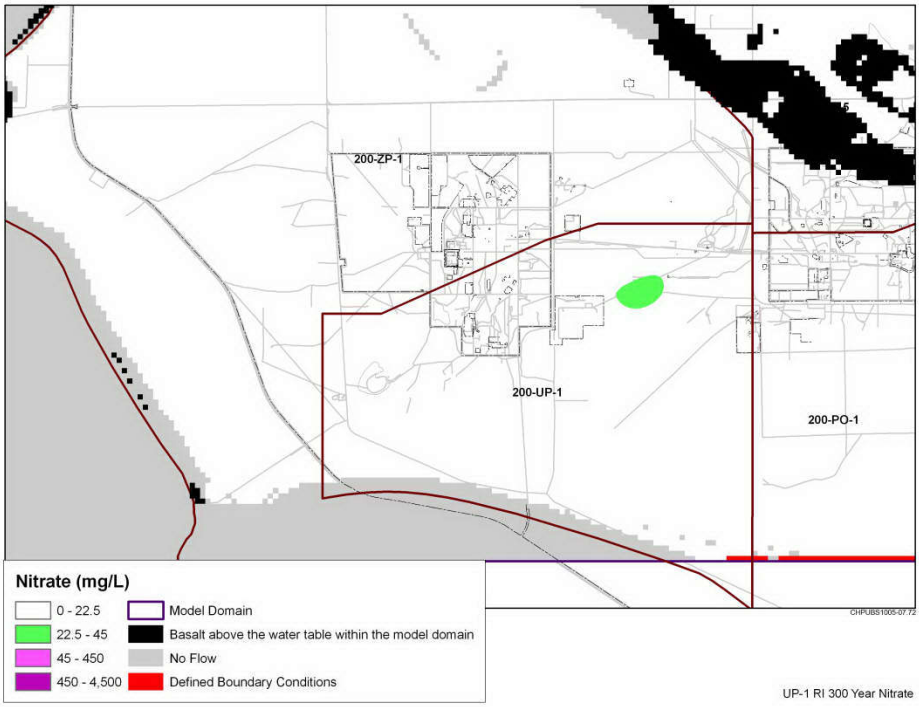


Figure 5-17. Distribution of Nitrate After 300 Years (2309)

5.2.2.3 Iodine-129

Figure 5-18 displays the initial iodine concentrations for the simulation. Iodine forms a large plume above the MCL in the 200-UP-1 Groundwater OU, comingling with the tritium and nitrate plumes, but centered slightly south of the tritium plume. A large portion of the plume is above 10 times the MCL. The bulk of the plume is far enough south that the 200-ZP-1 P&T operation is predicted to have only a small influence on most of the plume. In Figure 5-19 (25 years, year 2034), the northwestern portion of the plume has been pulled north and the eastern edge has been pushed southeast by 200-ZP-1 P&T operations. By 2084, 75 years of simulation (Figure 5-20), the groundwater flow has transported the plume's leading edge farther east so that it is close to the Hanford fm channel. After 125 years of simulation (Figure 5-21 [125 years, year 2134]), the eastern edge of the simulated plume is near the Hanford fm channel at concentrations above the MCL, with concentrations above 10 times the MCL in the 200-UP-1 Groundwater OU. After 175 years, in year 2184 (Figure 5-22), the simulation still indicates a region of concentrations above 10 times the MCL and further expansion into the Hanford fm. The eastern edge of the iodine plume is predicted to move into the Hanford fm channel and into the 200-PO-1 Groundwater OU at concentrations above the MCL by year 2184. By year 2309 (Figure 5-23), the plume exceeds the MCL in a large portion of the 200-UP-1 and 200 PO-1 Groundwater OUs. This plume is moving north of a residual body of uneroded Ringold E. Figure 5-24 (500 years, year 2509) shows extensive concentration in the 200-UP-1 Groundwater OU persists and has moved east. The simulated concentrations above MCL have nearly surrounded the patch of Ringold E with concentrations above one-half the MCL entering the southwest high-conductivity channel area. Figure 5-25 displays the plume after 1,000 years of transport; concentrations above the MCL are present in the patch of Ringold E, the concentrations surrounding this patch are reduced below one-half the MCL before entering the southwest high-conductivity channel area.

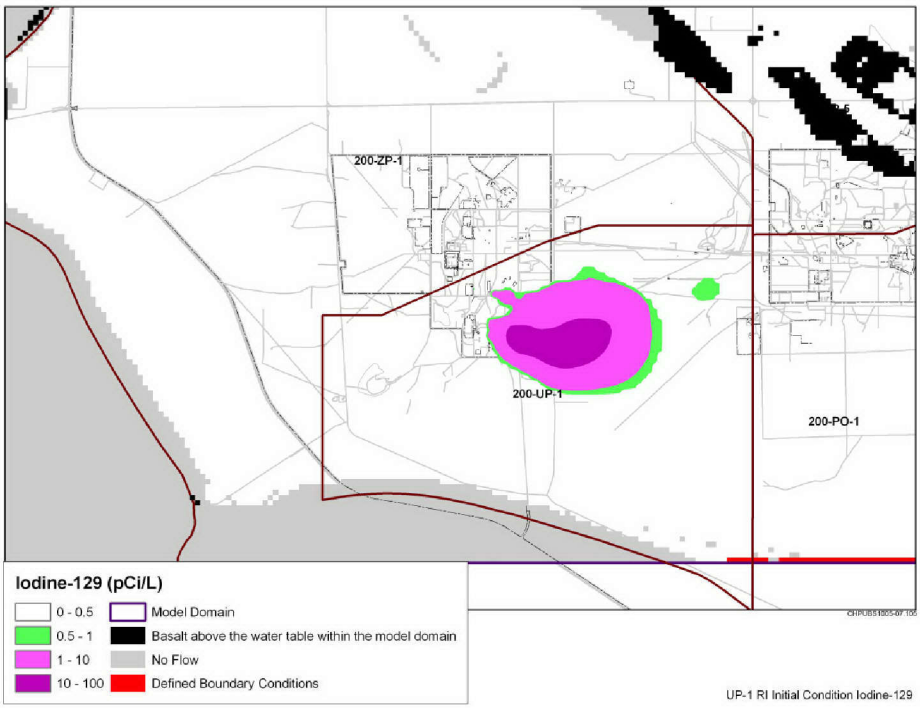


Figure 5-18. Initial Distribution of Iodine-129 (2009)

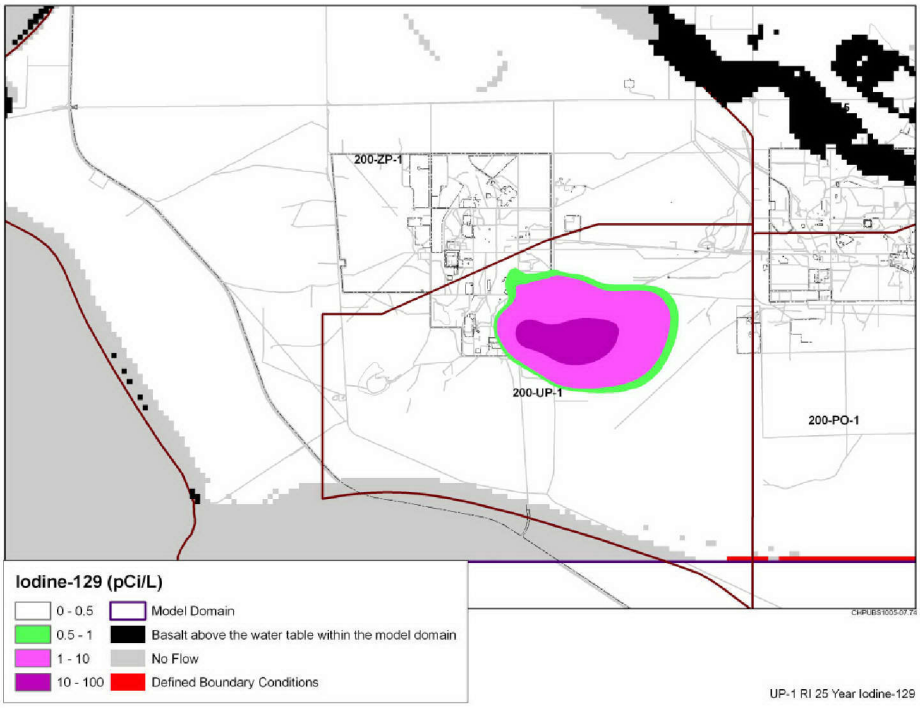


Figure 5-19. Distribution of Iodine-129 After 25 Years (2034)

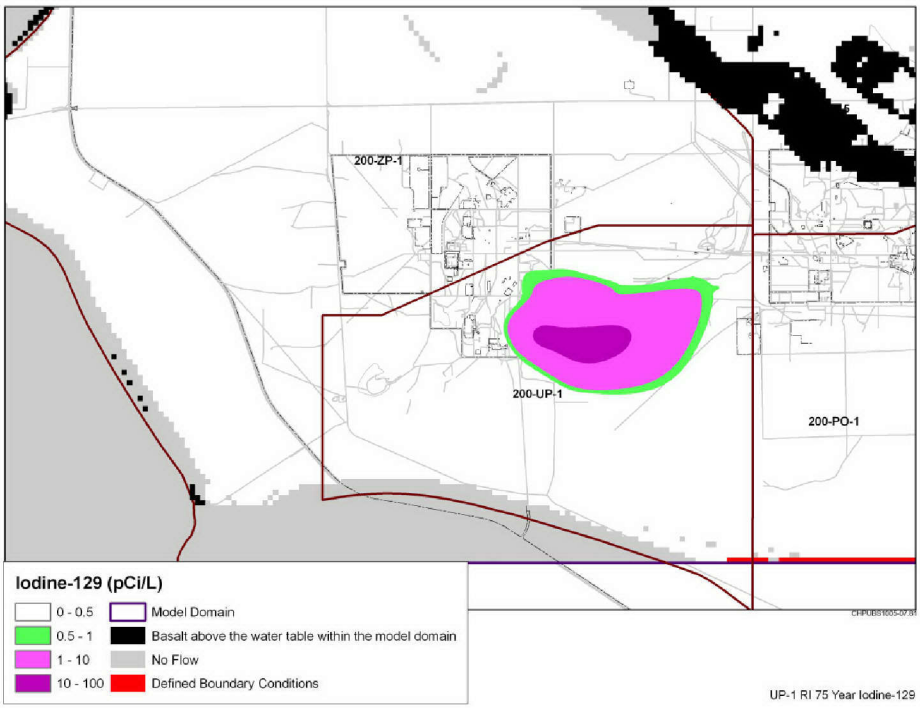


Figure 5-20. Distribution of Iodine-129 After 75 Years (2084)

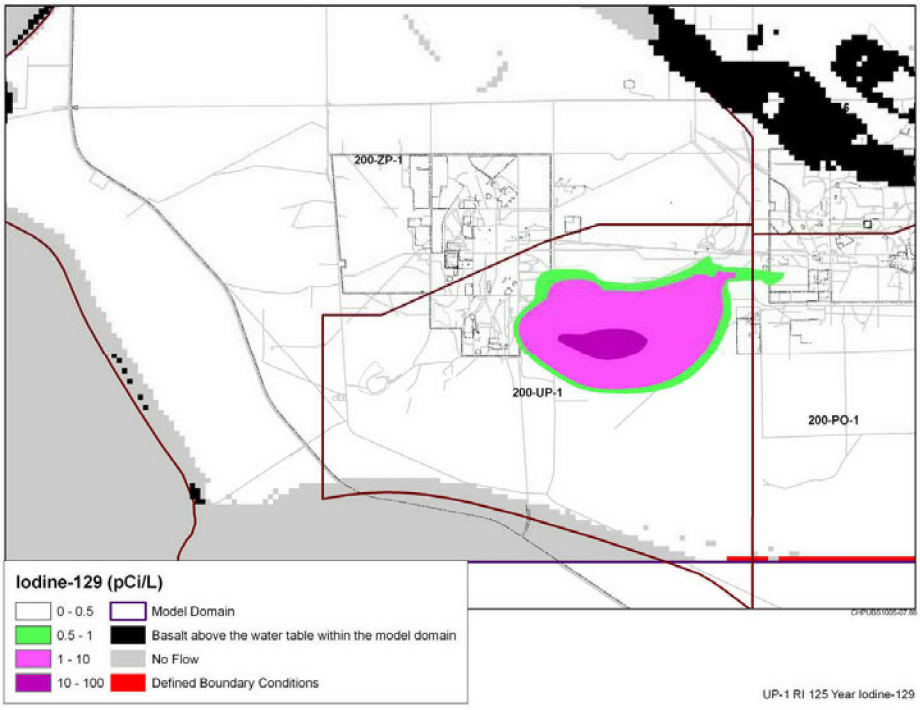


Figure 5-21. Distribution of Iodine-129 After 125 Years (2134)

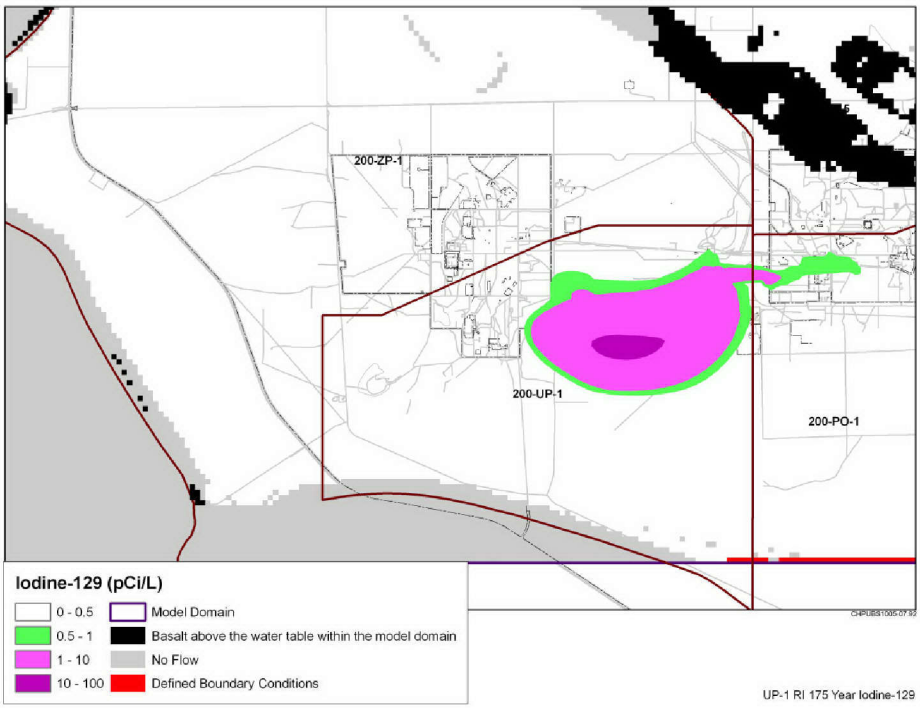


Figure 5-22. Distribution of Iodine-129 After 175 Years (2184)

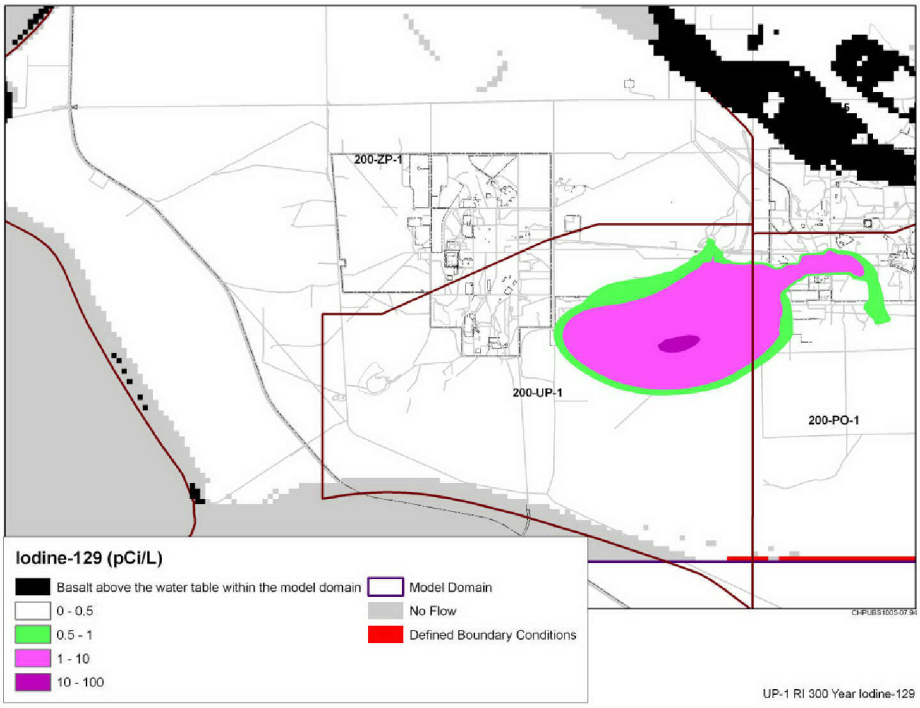


Figure 5-23. Distribution of Iodine-129 After 300 Years (2309)

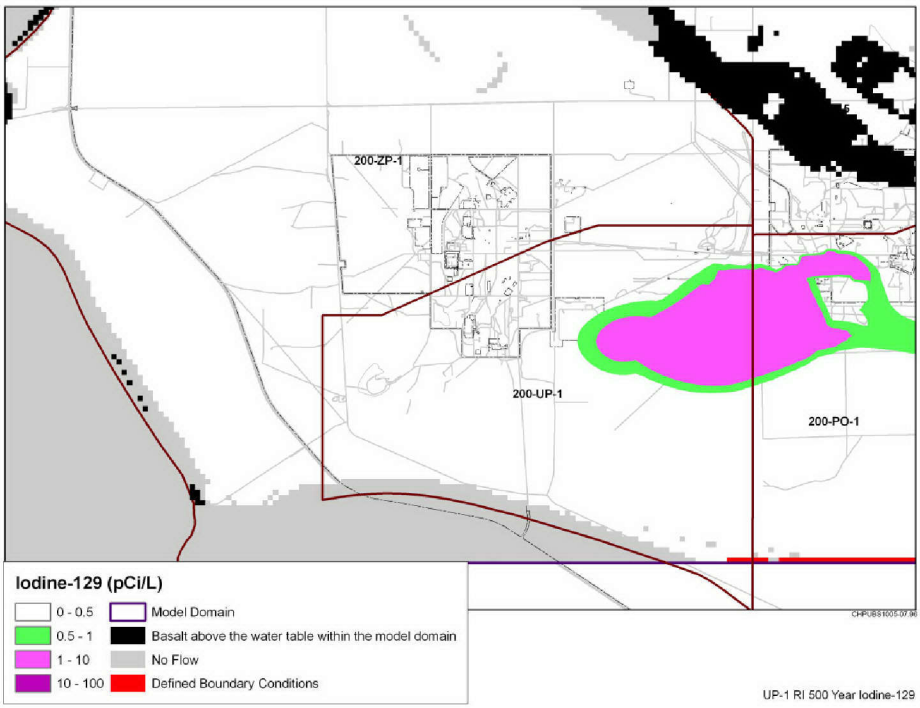


Figure 5-24. Distribution of Iodine-129 After 500 Years (2509)

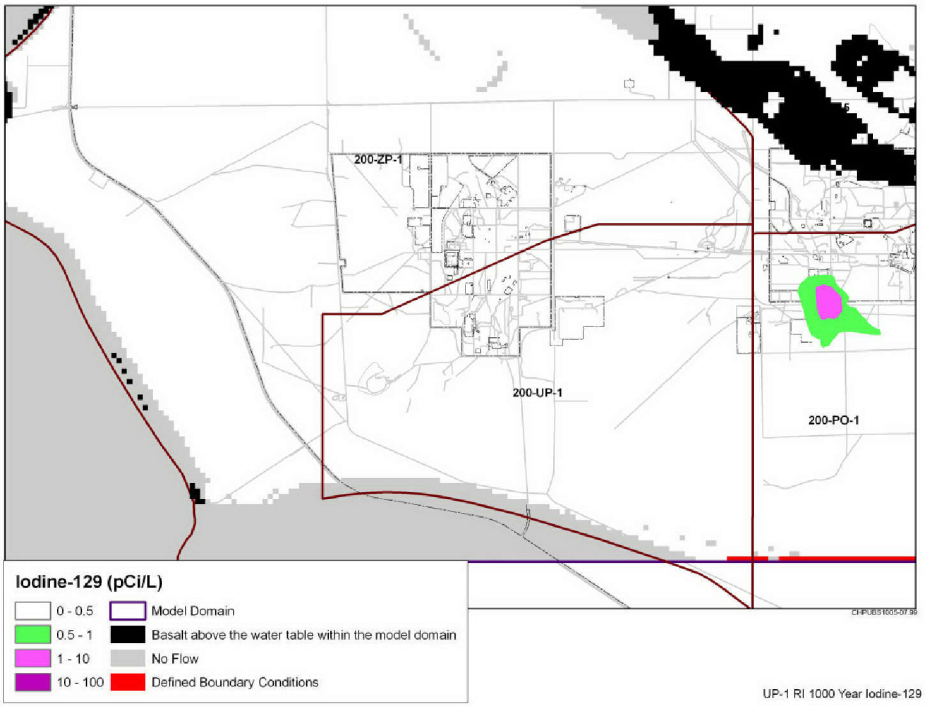


Figure 5-25. Distribution of Iodine-129 After 1,000 Years (3009)

5.2.2.4 Trichloroethene

TCE contamination (Figure 5-26) within the 200-UP-1 Groundwater OU is at depth under 21-W-LWC (near the 200-UP-1/200-ZP-1 boundary) and under UPR-600-20 (just south of the boundary). These plumes do not exist near the MCL at the water table, but they have been conservatively introduced into the simulation throughout the Ringold E HSU. The plumes are in a region that is part of the 200-ZP-1 P&T system and indicate strong reduction in concentration to below MCL everywhere after 25 years of operation (Figure 5-27 [25 years, year 2034]). Within the next 50 years (no figure presented), the maximum TCE concentration in 200-UP-1 is predicted to be below one-half the MCL.

5.2.2.5 Technetium-99

Tc-99 exists in groundwater in the 200-UP-1 Groundwater OU in concentrations above the MCL in a number of small plumes (Figure 5-28). Only the southernmost of these plumes have Tc-99 concentrations above the MCL after 25 years of operation of the 200-ZP-1 P&T (Figure 5-29). These plumes have moved eastward and merged to form a single plume above one-half the MCL. Figure 5-30 depicts concentrations in 2084 (75 years) and indicates that the plume has drifted to the east and no longer has concentrations above the MCL. It should be noted here that DOE acknowledges the need for source control in the WMA S-SX. Source control is a component of the specific remedial alternatives for Tc-99 listed in Section 8.l.

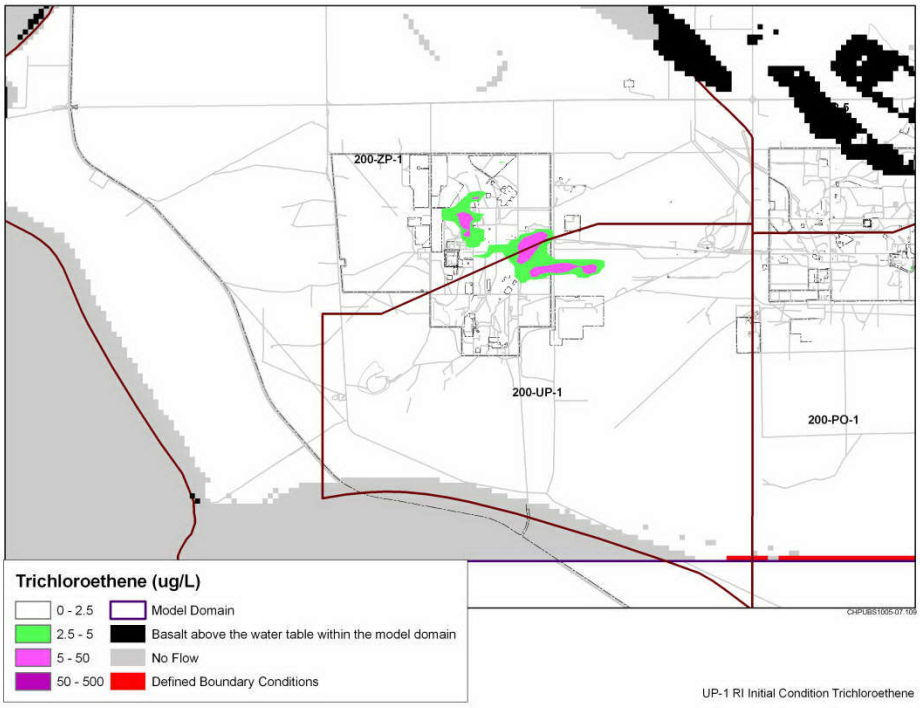


Figure 5-26. Initial Distribution of Trichloroethene (2009)

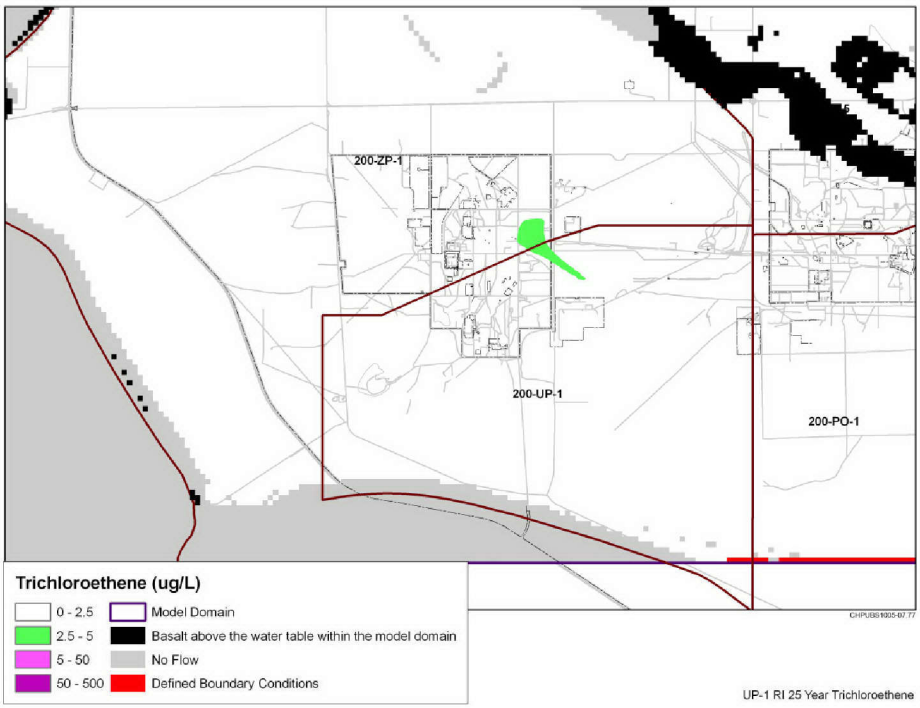


Figure 5-27. Distribution of Trichloroethene After 25 Years (2134)

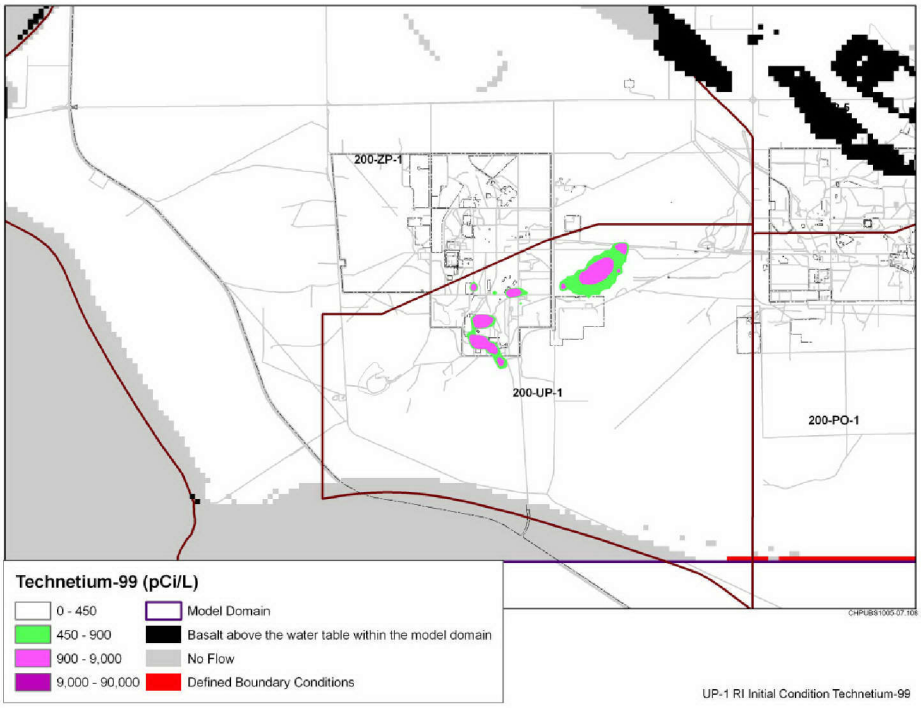


Figure 5-28. Initial Distribution of Technitium-99 (2009)

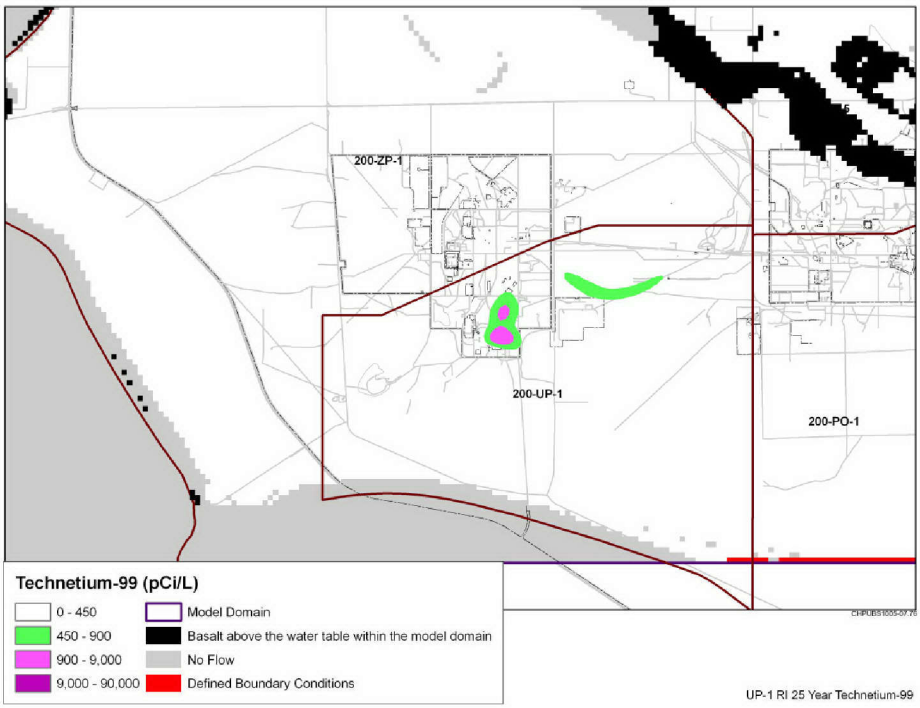


Figure 5-29. Distribution of Technitium-99 After 25 Years (2034)

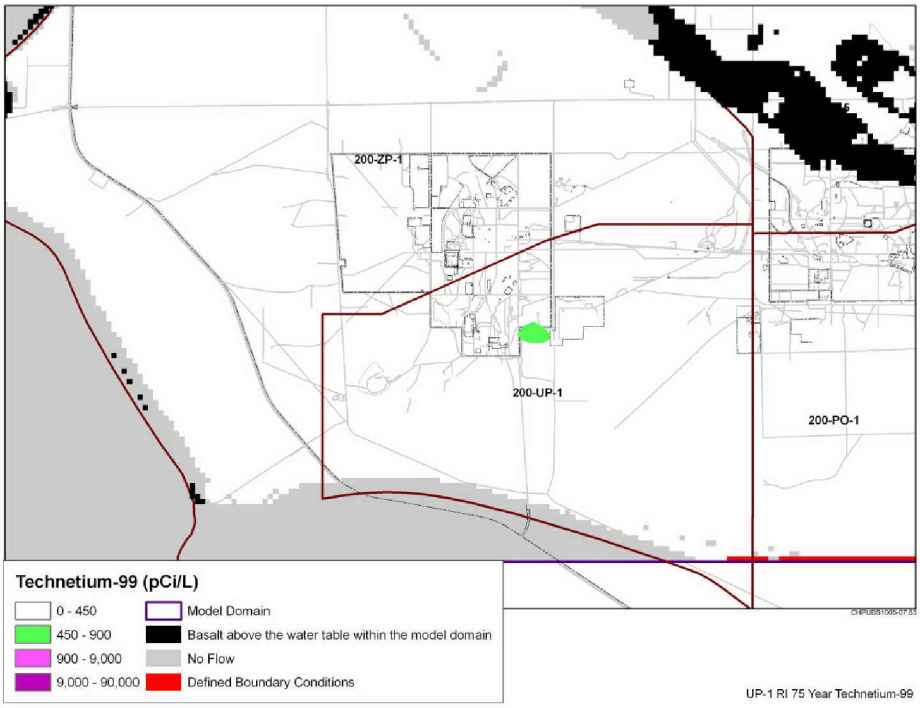


Figure 5-30. Distribution of Technitium-99 After 75 Years (2084)

5.2.2.6 Uranium

Uranium exists in concentrations above the MCL in a large plume below the 241-U-361 and 216-U-17 source areas, where concentrations reach 10 times the MCL (Figure 5-31). A plume is located above one-half the MCL to the MCL below the U Pond area. Figure 5-32 shows the extent of the uranium plumes after 25 years of 200-ZP-1 P&T system operation. The northward flux of water toward the 200-ZP-1 extraction wells has broadened the outline of the plume above the MCL to the north. The plume around the U Pond has been reduced to below one-half the MCL.

Figure 5-33 shows the plume under 216-U-17 has been reduced in the footprint to10 times the MCL, to a single cell by 2084 (75 years), but the plume remains above the MCL with roughly the same footprint. Some movement to the east is evident by year 2134 (125 years, Figure 5-34), but the retardation of uranium transport has limited the eastward movement of the MCL region to a barely discernable amount. By year 2309 (300 years), the scenario is similar, slow eastward movement (Figure 5-35). Figure 5-36 shows the spreading-caused reduction of the MCL footprint which is evident 500 years into the simulation. The MCL is not met after 1,000 years of simulation. Figure 5-37 and Figure 5-38 present the 800- and 1,000-year simulation plots, respectively.

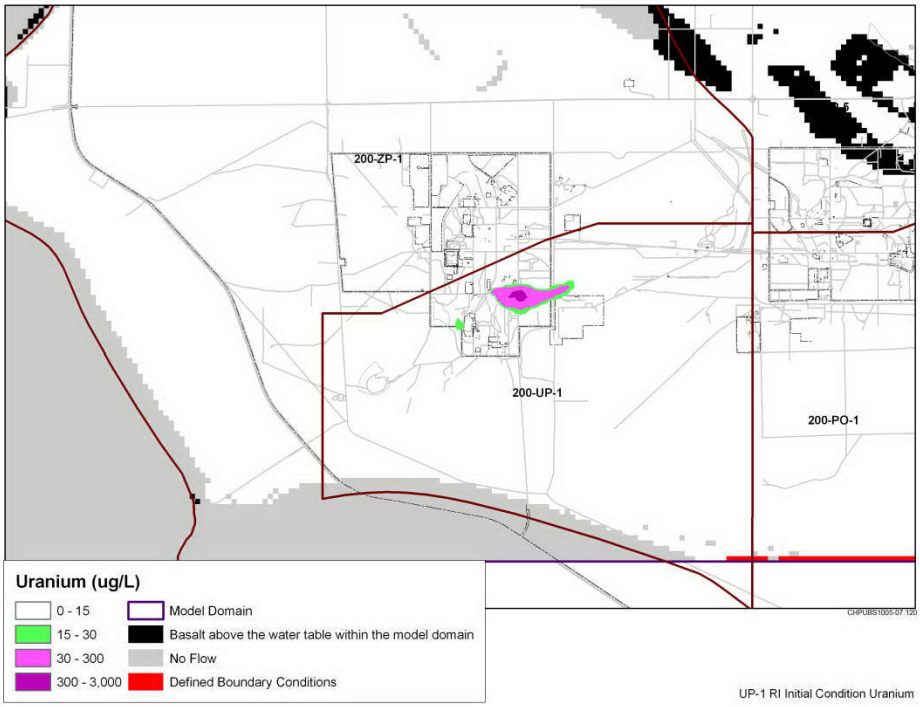


Figure 5-31. Initial Distribution of Uranium (2009)

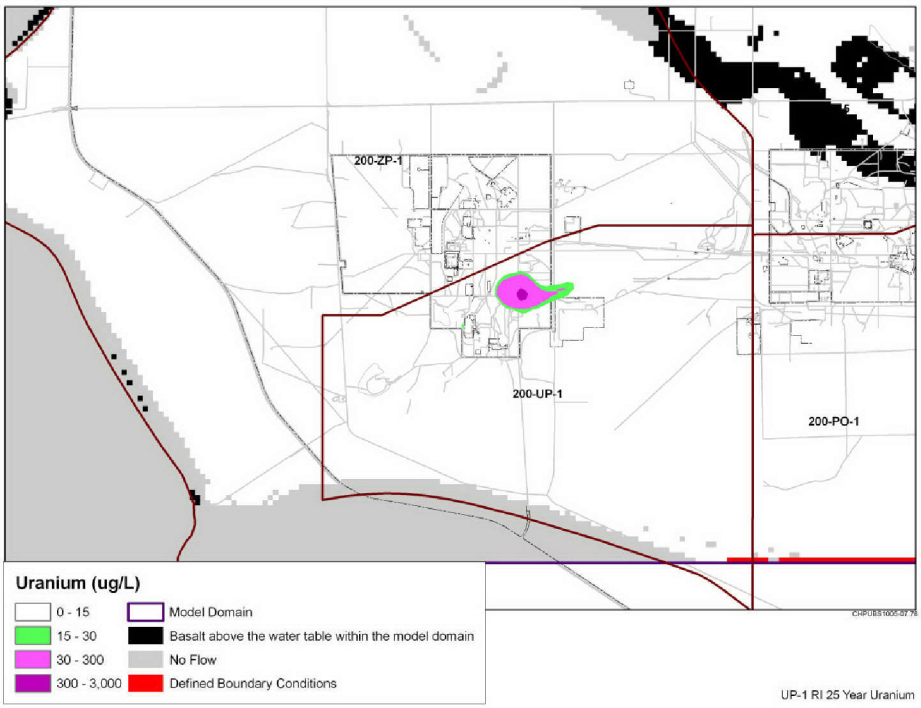


Figure 5-32. Distribution of Uranium After 25 Years (2034)

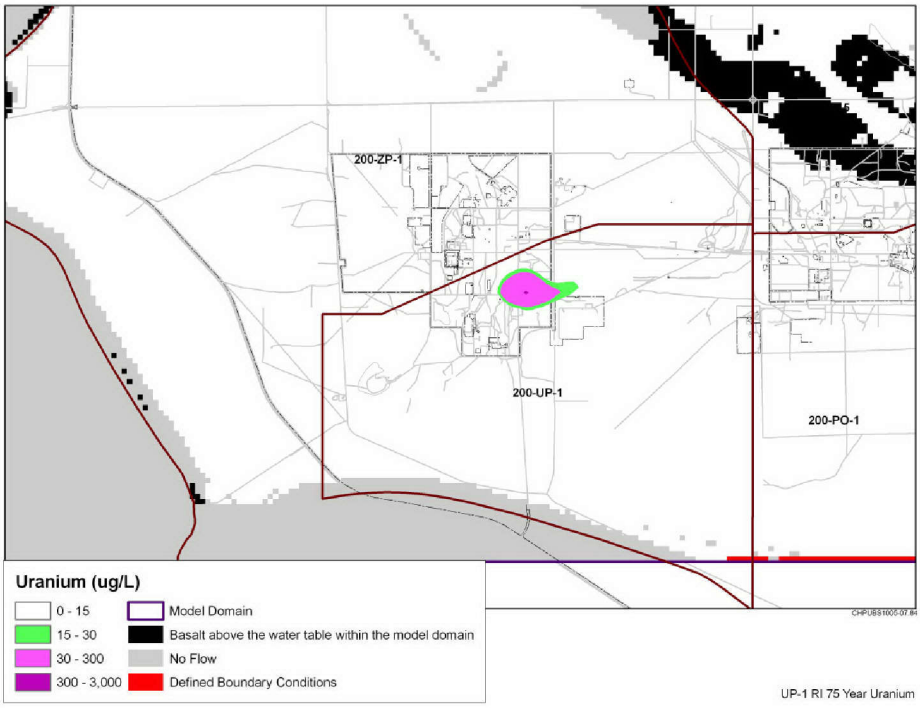


Figure 5-33. Distribution of Uranium After 75 Years (2084)

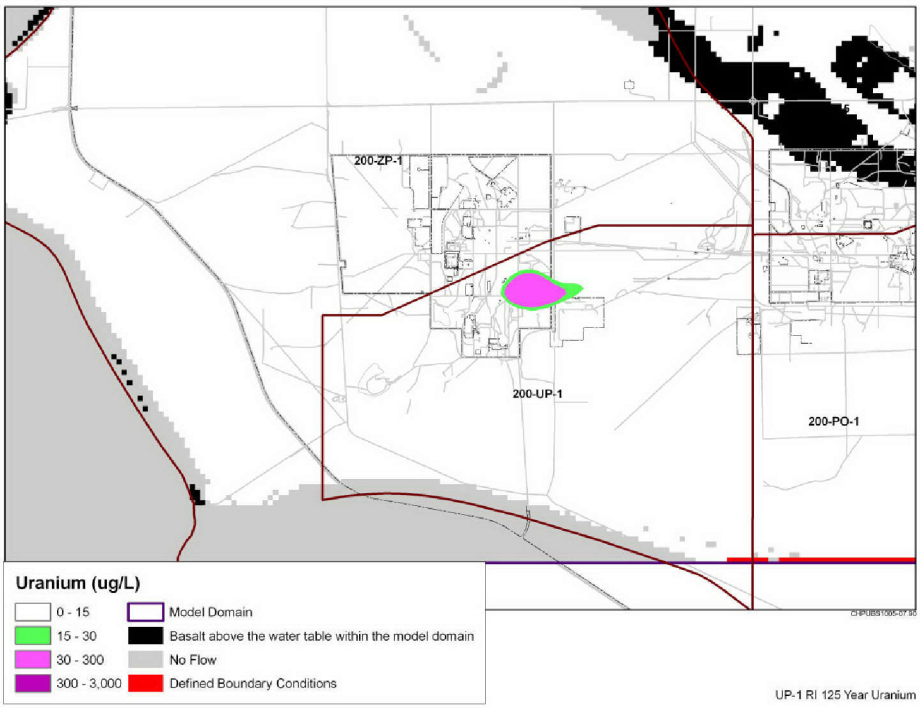


Figure 5-34. Distribution of Uranium After 125 Years (2134)

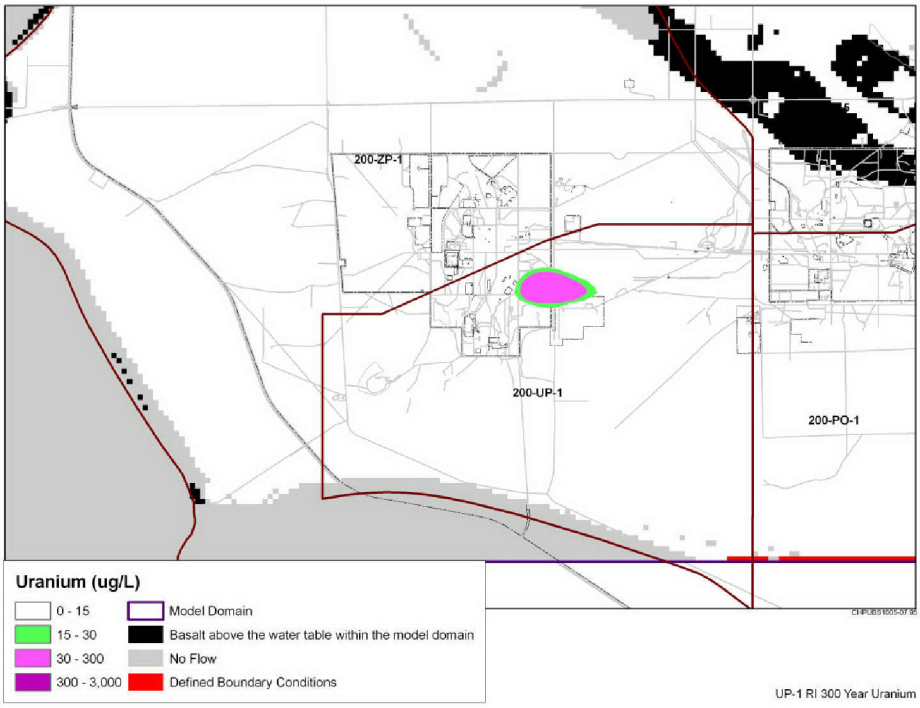


Figure 5-35. Distribution of Uranium After 300 Years (2309)

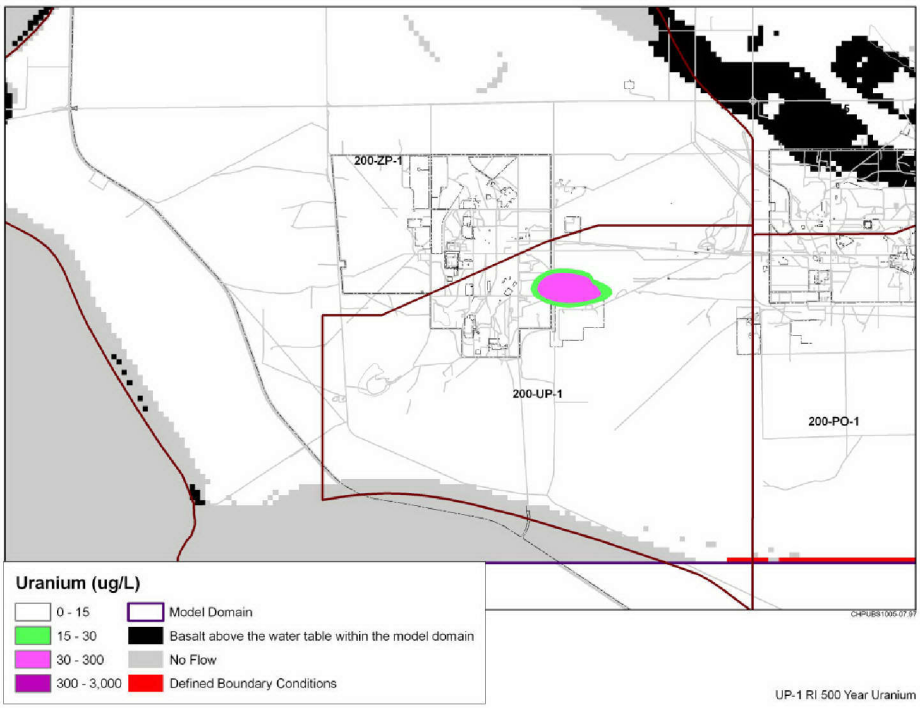


Figure 5-36. Distribution of Uranium After 500 Years (2509)

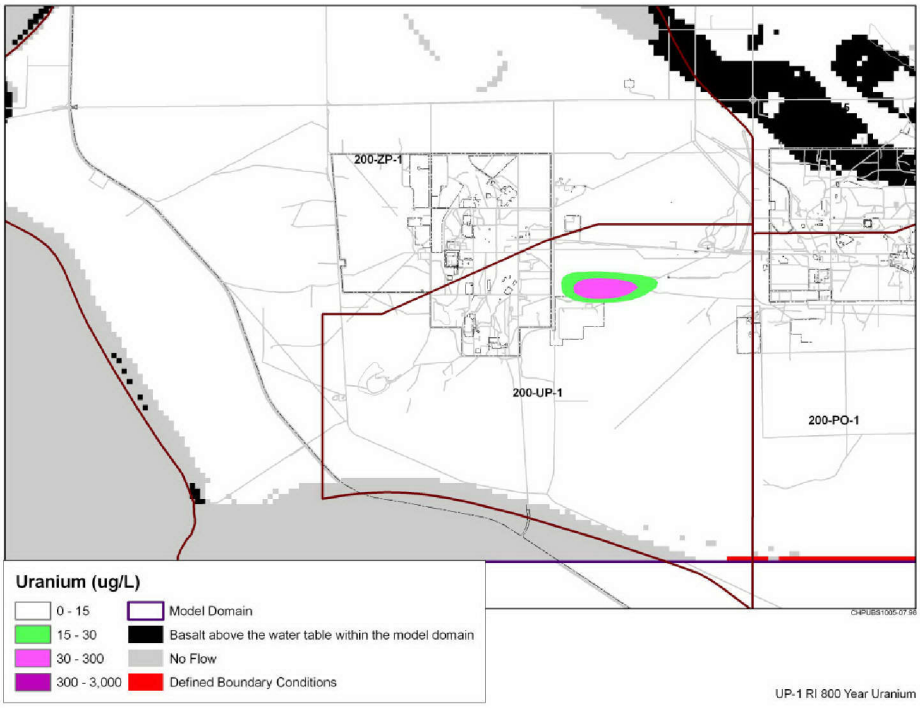


Figure 5-37. Distribution of Uranium After 800 Years (2809)

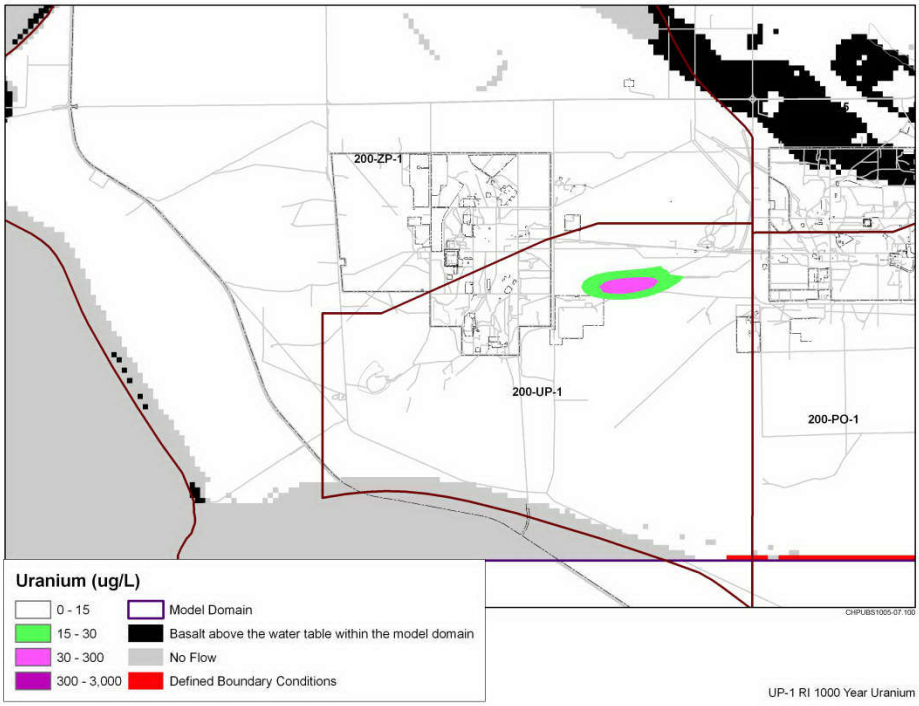


Figure 5-38. Distribution of Uranium After 1000 Years (3009)

5.2.2.7 Strontium-90

In 2008, Sr-90 was measured above the MCL in only a single 200-UP-1 Groundwater OU monitoring well (299-W22-10) and is represented in the initial distribution above the MCL in a single model cell (Figure 5-39). The simulated concentration in this cell is estimated to be below one-half the MCL after a single year of operation of the 200-ZP-1 P&T system. Representation of contamination with a single cell is below the scale of resolution for the transport simulations.

5.2.2.8 Chromium

Chromium has been inferred to exist in concentrations above the MCL in a large plume that was pushed, by disposal of water in U Pond, a large distance from the source area of the plume. Figure 5-40 (initial conditions) shows this plume straddling the boundary between the 200-UP-1 and 200-PO-1 Groundwater OUs. Two smaller plumes are located in the 200 West Area. The transport simulation predicts that these two smaller plumes will be reduced below the MCL by the operation of the 200-ZP-1 P&T system (Figure 5-41, 25 years). The eastern injection wells of the 200-ZP-1 system push the simulated chromium plume to the southwest. Figure 5-42 indicates eastward and northeast movement reaching the Hanford fm channel below one-half the MCL after 75 years of simulation. Figure 5-43 indicates that transport into the channel will significantly reduce the size of the greater-than-MCL footprint of this plume between the years 2084 and 2134. In Figure 5-44 (year 2184, 175 years) simulated chromium concentrations of this plume are below the MCL at all locations.

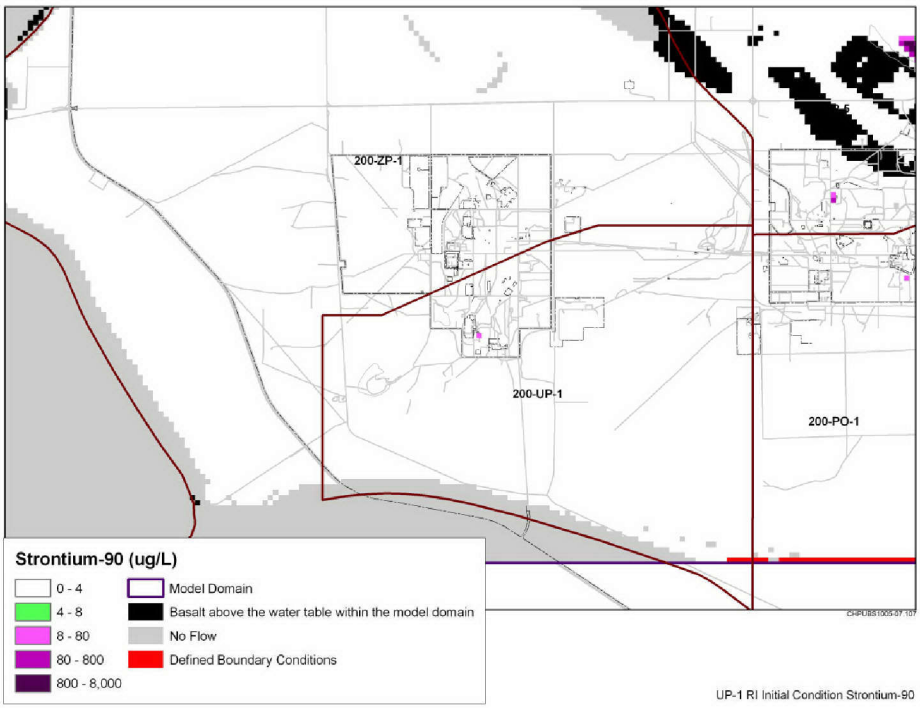


Figure 5-39. Initial Distribution of Strontium-90

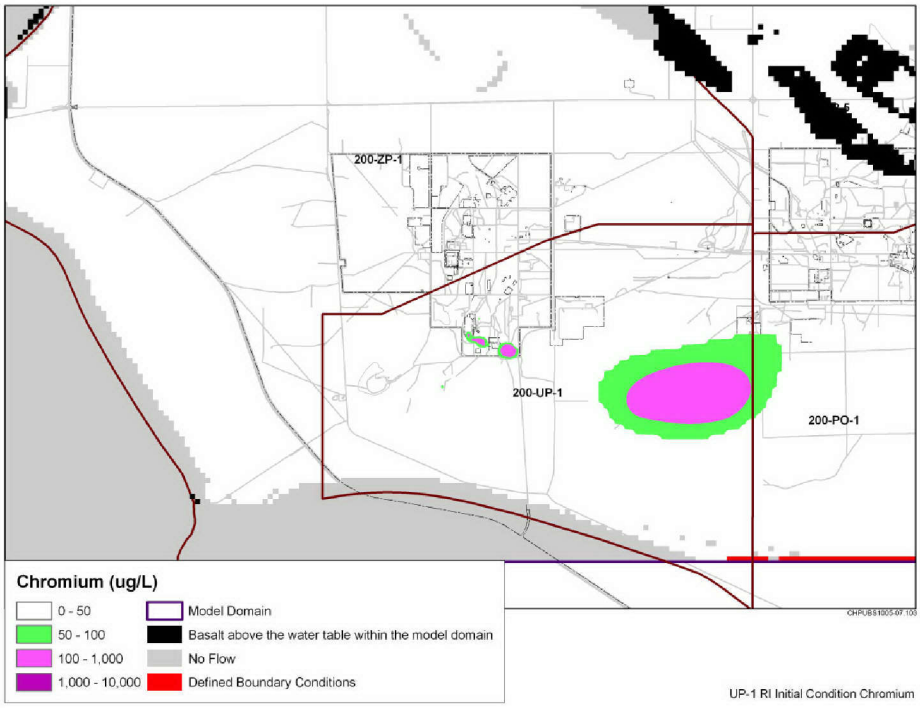


Figure 5-40. Initial Distribution of Chromium (2009)

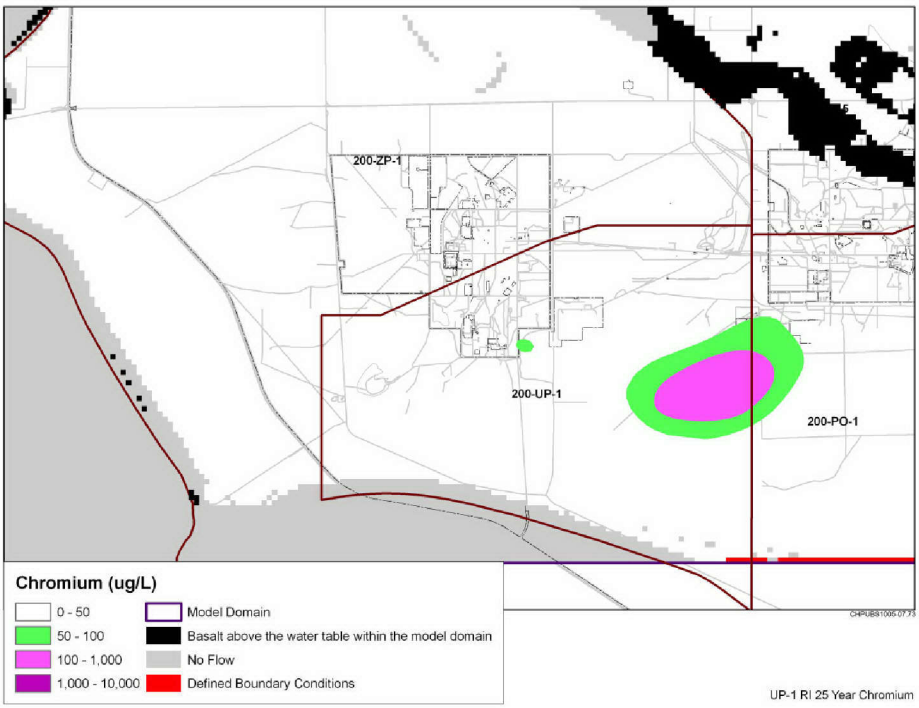


Figure 5-41. Distribution of Chromium After 25 Years (2034)

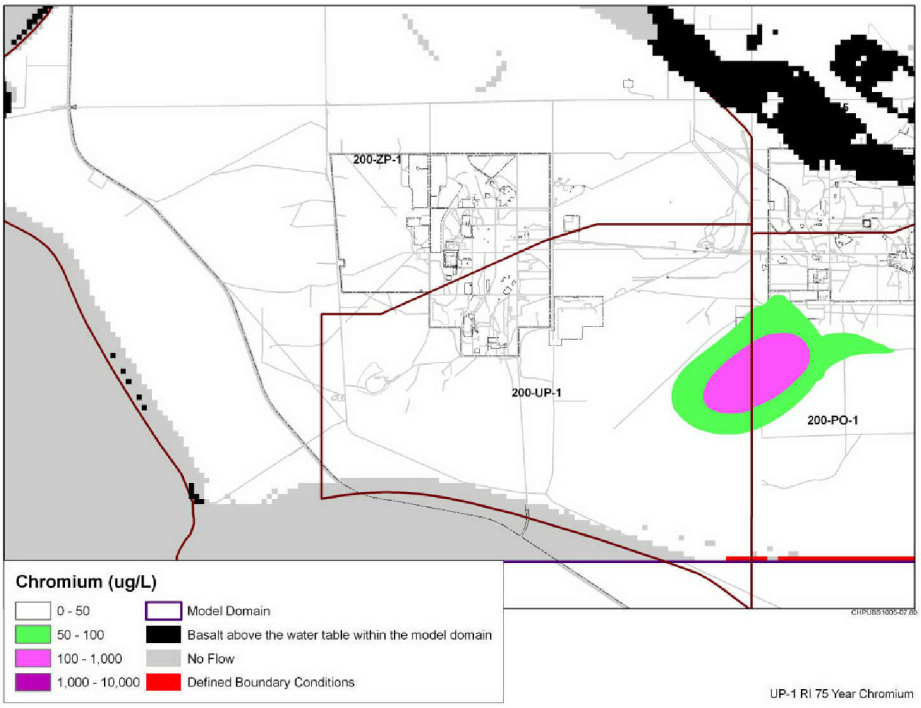


Figure 5-42. Distribution of Chromium After 75 Years (2084)

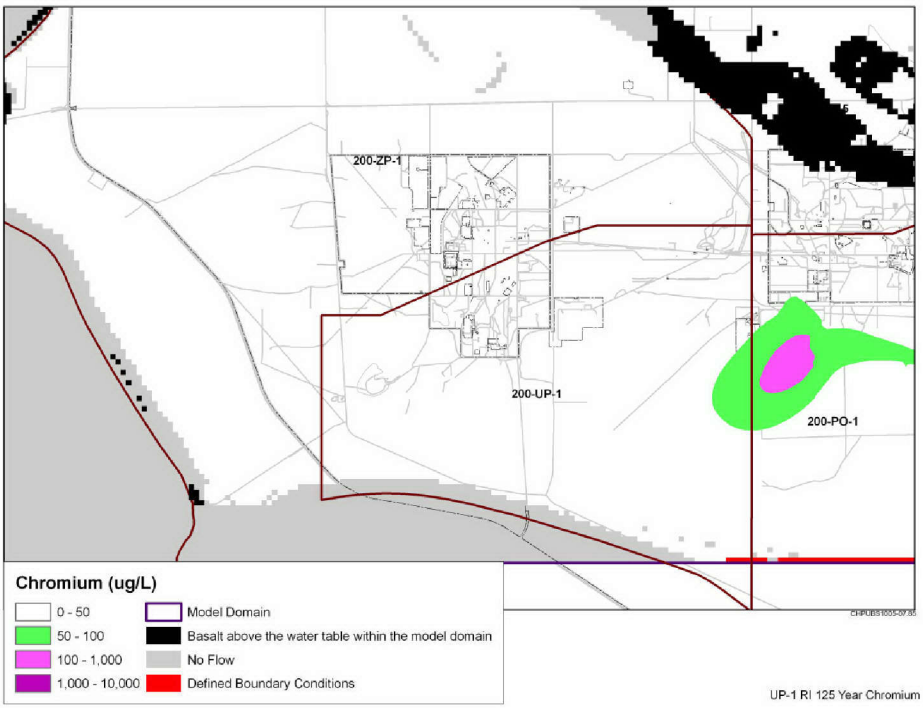


Figure 5-43. Distribution of Chromium After 125 Years (2134)

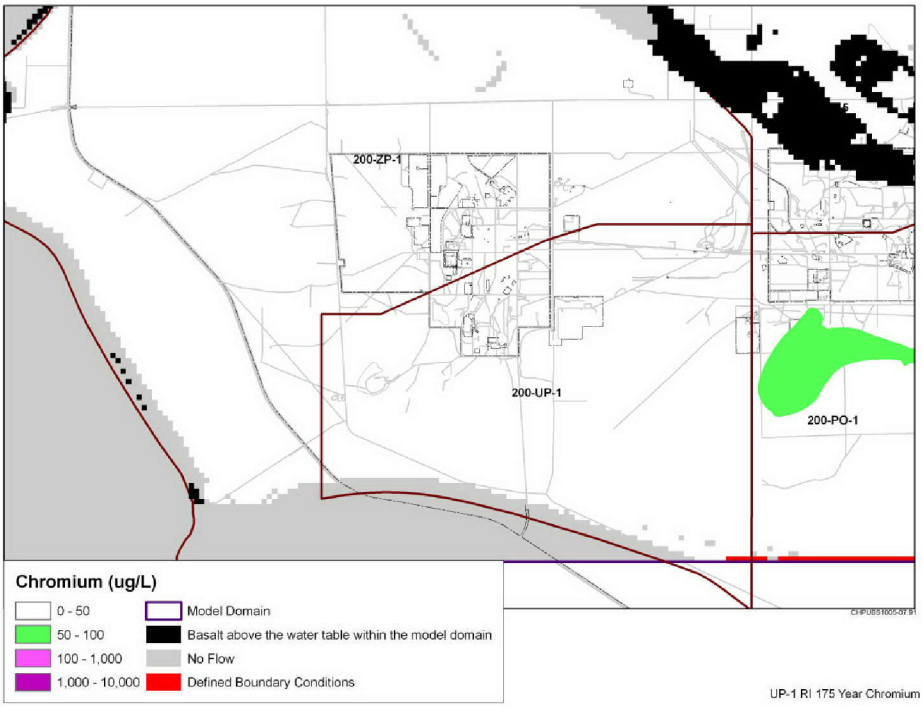


Figure 5-44. Distribution of Chromium After 175 Years (2184)

5.2.2.9 Concentrations at Risk Analysis Well Locations

The plots of simulated contaminant concentrations are presented in this section without comment. In Figure 5-45, a shaded rectangle is used to depict the region from where maximum concentrations within the 200-UP-1 Groundwater OU are determined for each contaminant, the results of which are presented in Section 4.2. A horizontal line is used in each plot to depict the MCL concentration for the contaminant displayed. Concentration plots are not shown for chloroform and fluoride due to the very limited extent of contamination from these constituents.

Figure 5-46 presents the concentration of contaminants as a function of time, which is also presented for selected wells, the results of which are presented in Section 4.2 (the well names are indicated at the top of the figures). For each well, the contaminant concentration is determined in each model layer that coincides with the screened interval of the well. If a well screen is found in multiple model layers, the maximum concentration is used in the plot. The plot for a well is not displayed if the simulated concentrations for that contaminant are less than 10 percent of the MCL for all time periods.

Figure 5-47 through Figure 5-52 present the constituent concentrations at the respective groundwater monitoring wells.

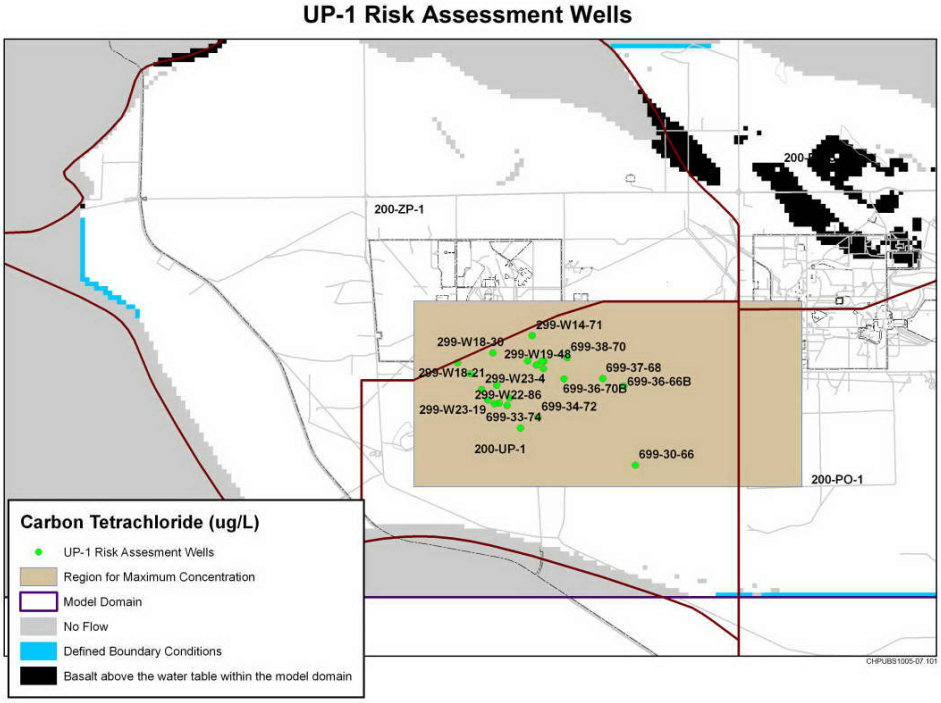


Figure 5-45. Concentration Plot – Well Locations

Maximum Concentrations

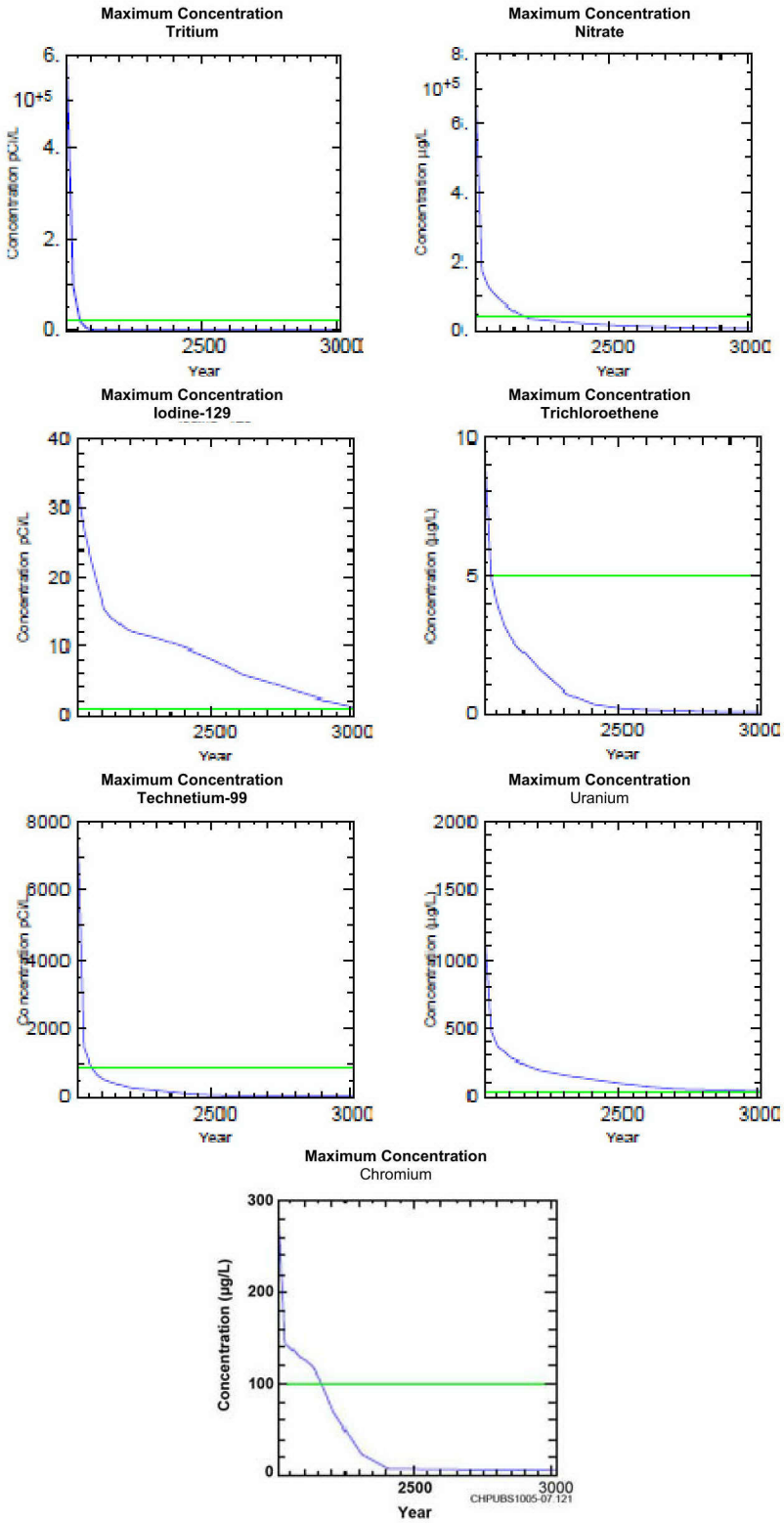


Figure 5-46. Maximum Concentrations

Tritium

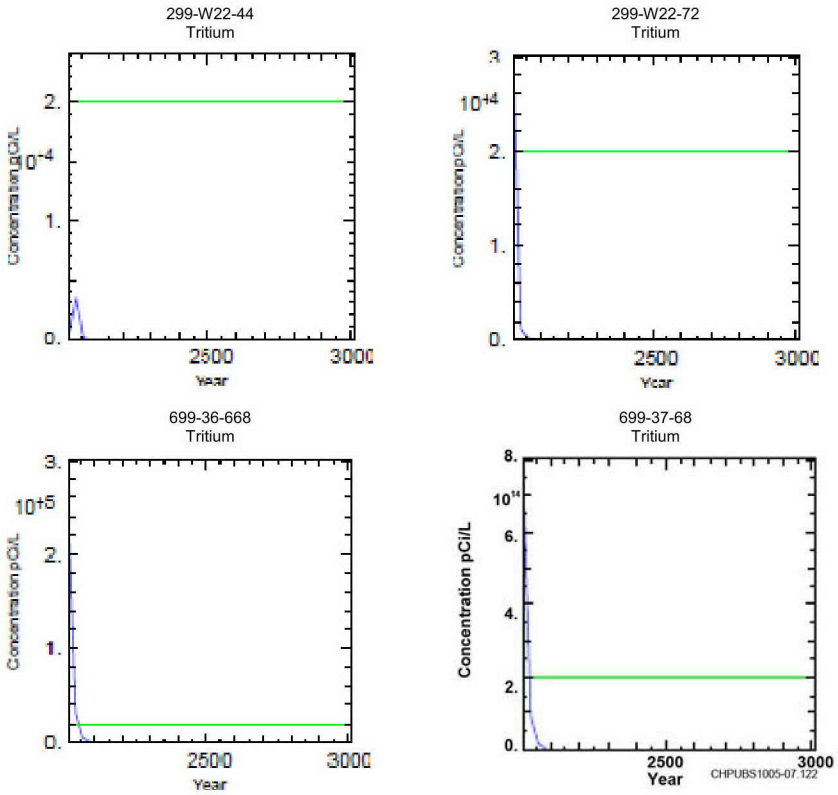


Figure 5-47. Tritium Concentrations at Monitoring Wells

Nitrate

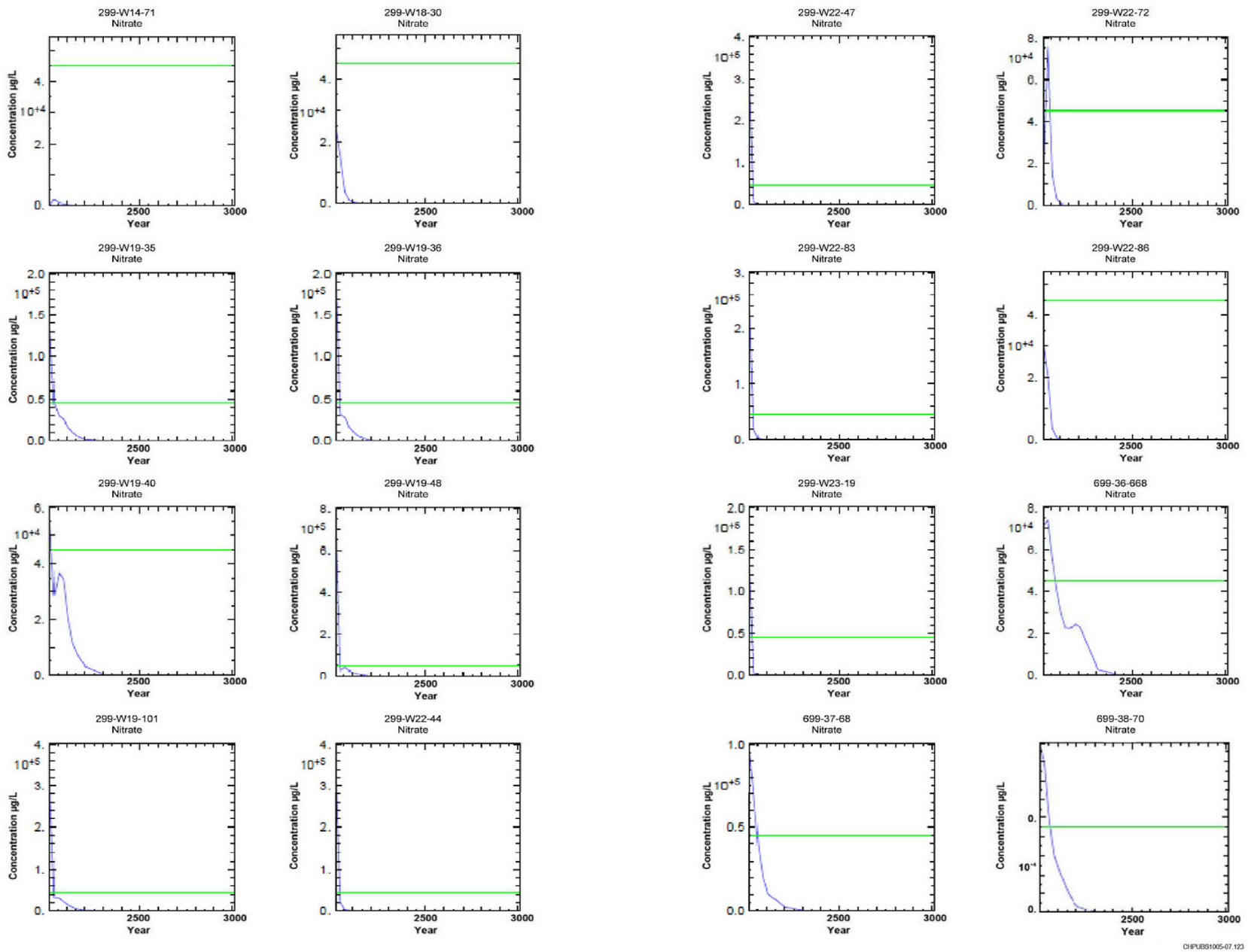


Figure 5-48. Nitrate Concentrations at Monitoring Wells

Iodine-129

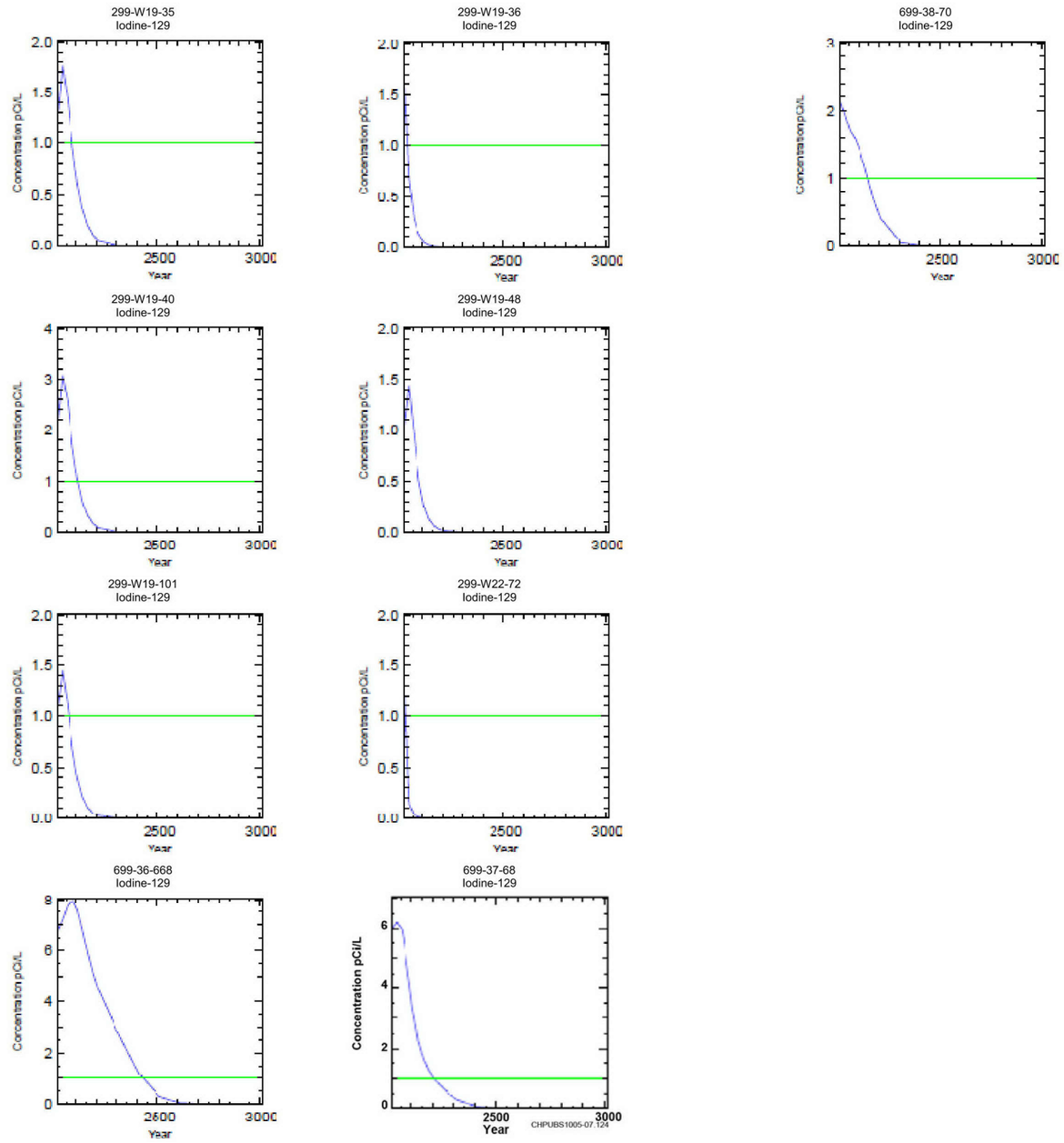


Figure 5-49. Iodine-129 Concentrations at Monitoring Wells

Trichloroethene

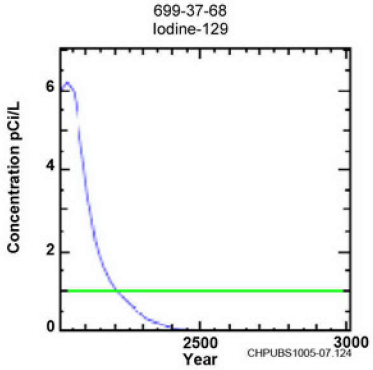


Figure 5-50. Trichloroethene Concentrations at Monitoring Wells

Technetium-99

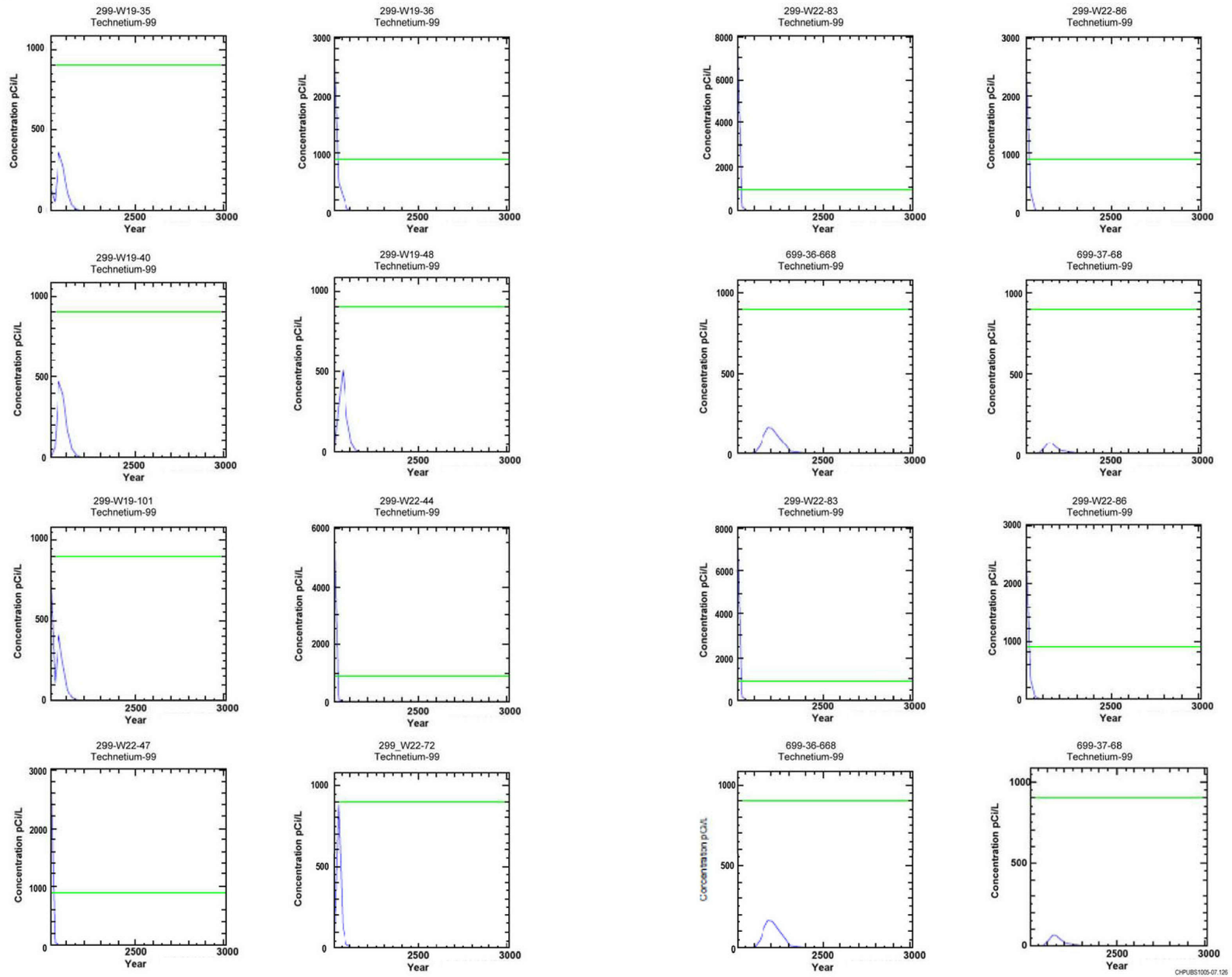


Figure 5-51. Technetium-99 Concentrations at Monitoring Wells

Uranium

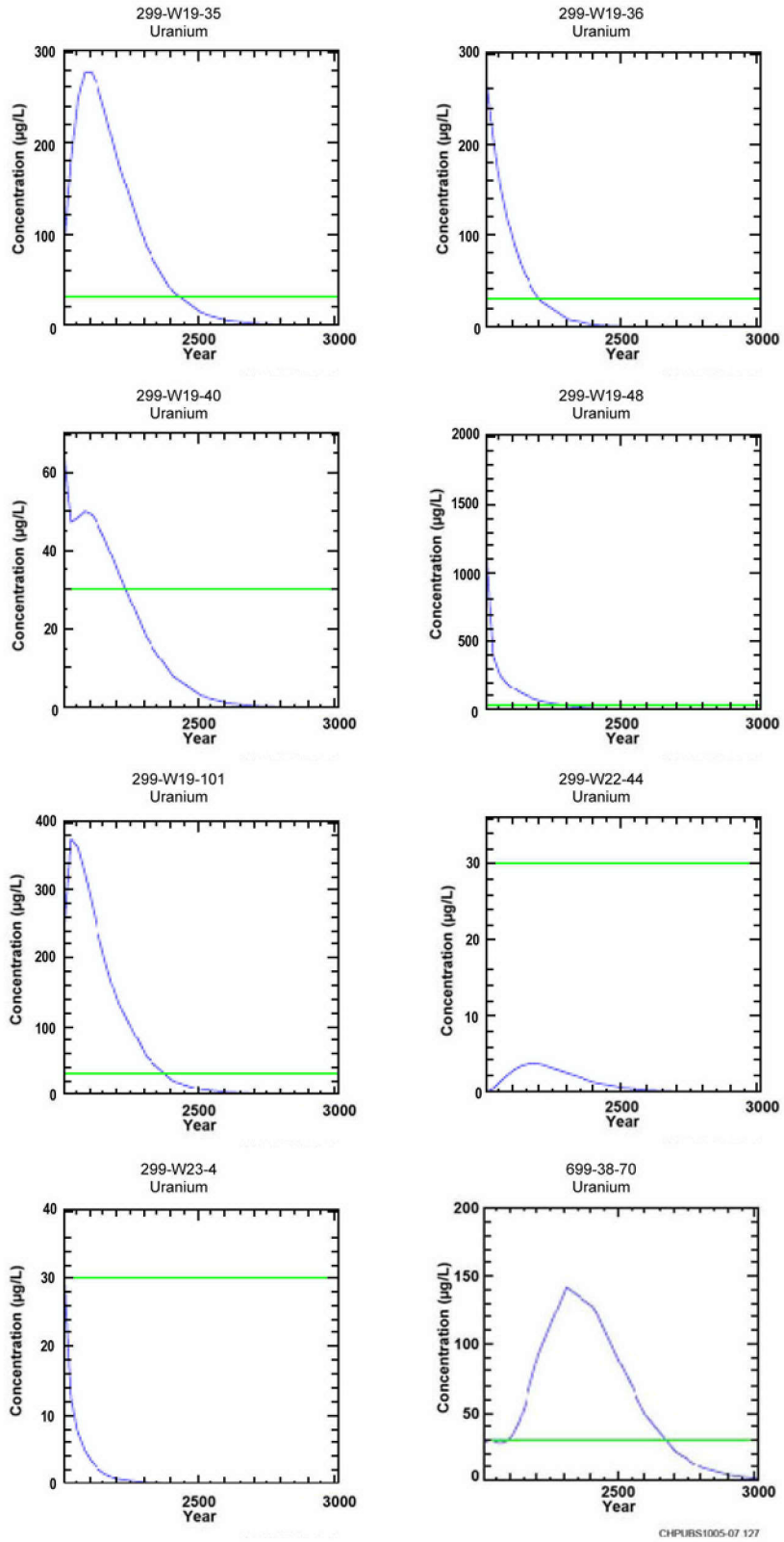


Figure 5-52. Uranium Concentrations at Monitoring Wells

Chromium

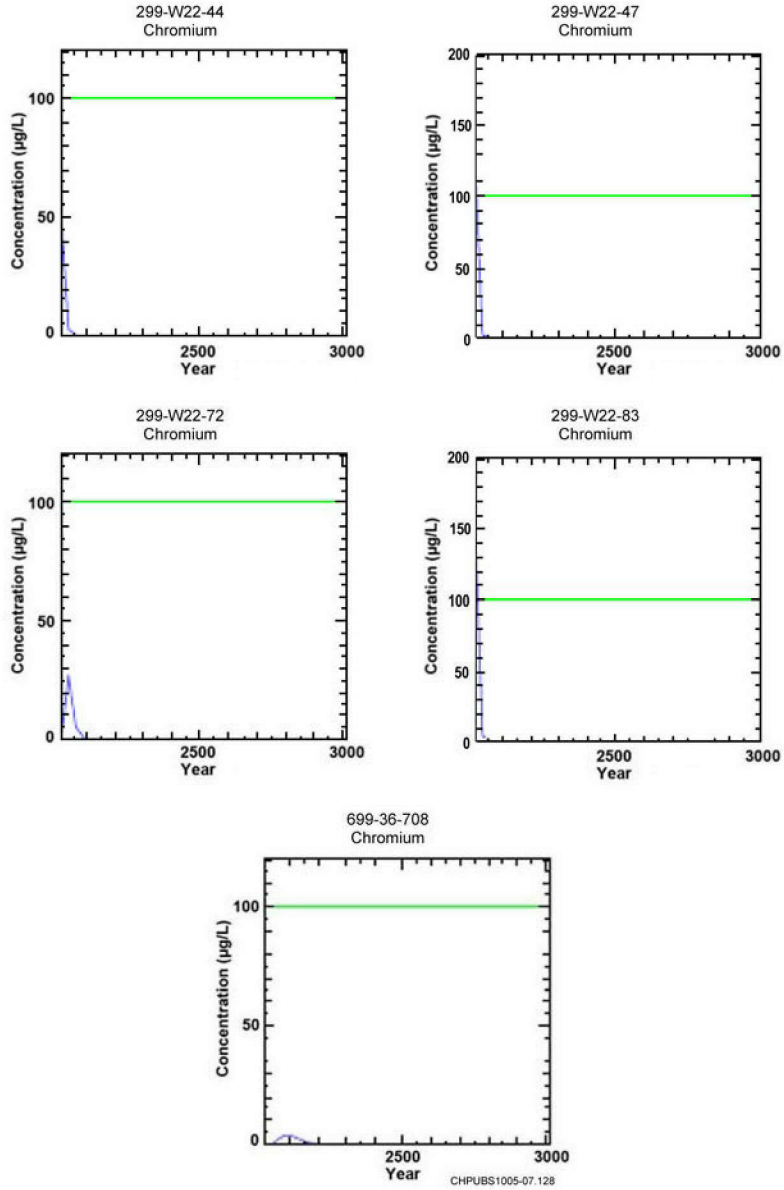


Figure 5-53. Chromium Concentrations at Monitoring Wells

5.2.2.10 Concentrations Along Selected Locations

Figure 5-54 through Figure 5-60 present the concentration time history plots for select locations (grid nodes) for the various contaminants evaluated in this study. The locations are selected approximately around the observed maximum concentration pathway taken by the contaminant over the simulated time period. This approach allows presentation of both the spatial component of the center of contaminant plume movement and the simulated breakthrough curve for the locations adjacent to the pathway.

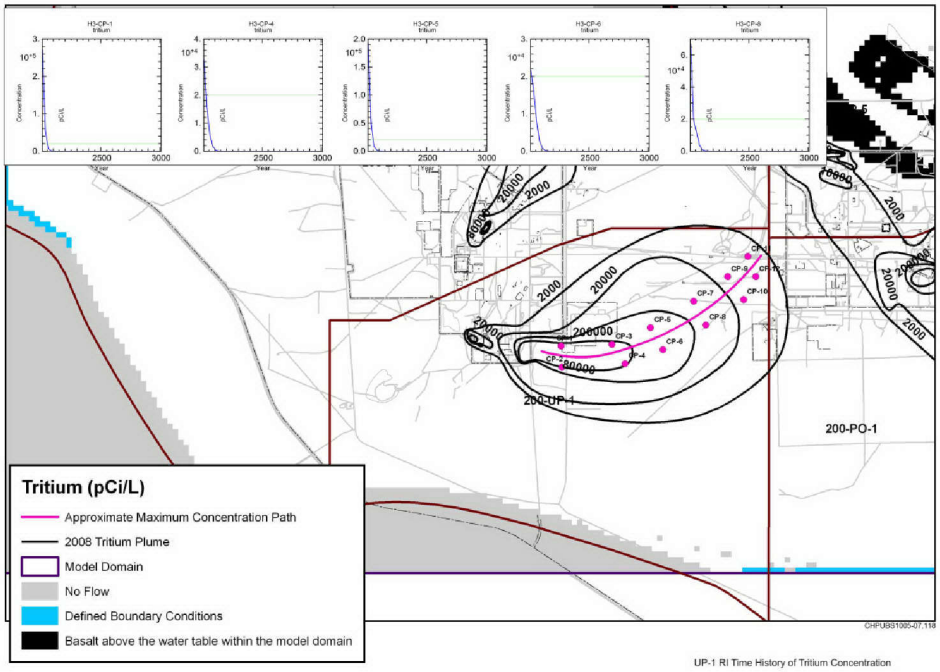


Figure 5-54. Concentration Time History for Selected Locations Along with the Path of Approximate Maximum Concentration for Tritium

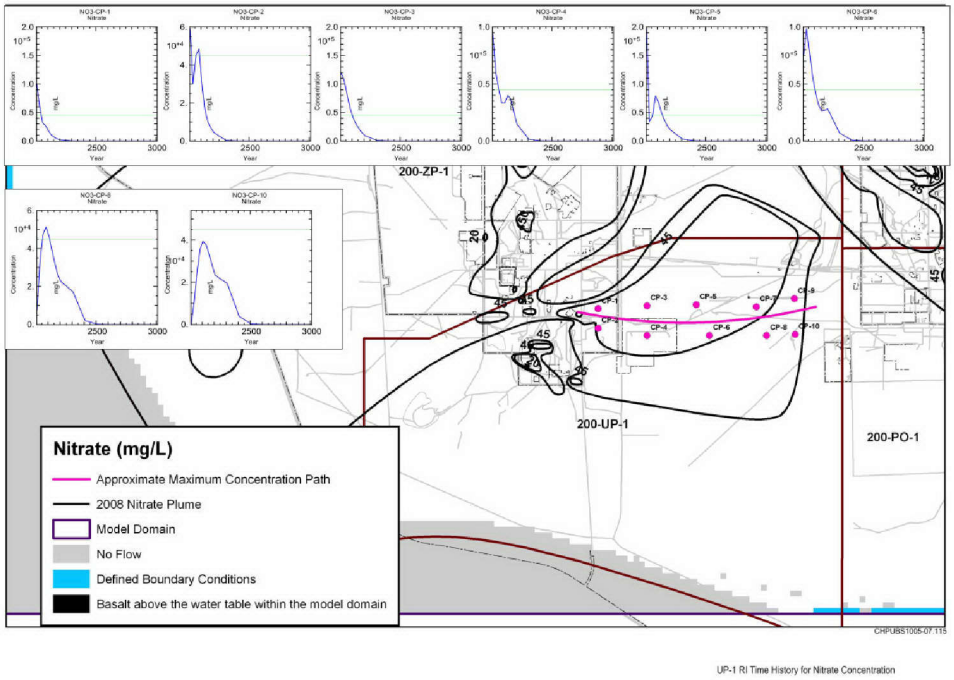


Figure 5-55. Concentration Time History for Selected Locations Along with the Path of Approximate Maximum Concentration for Nitrate

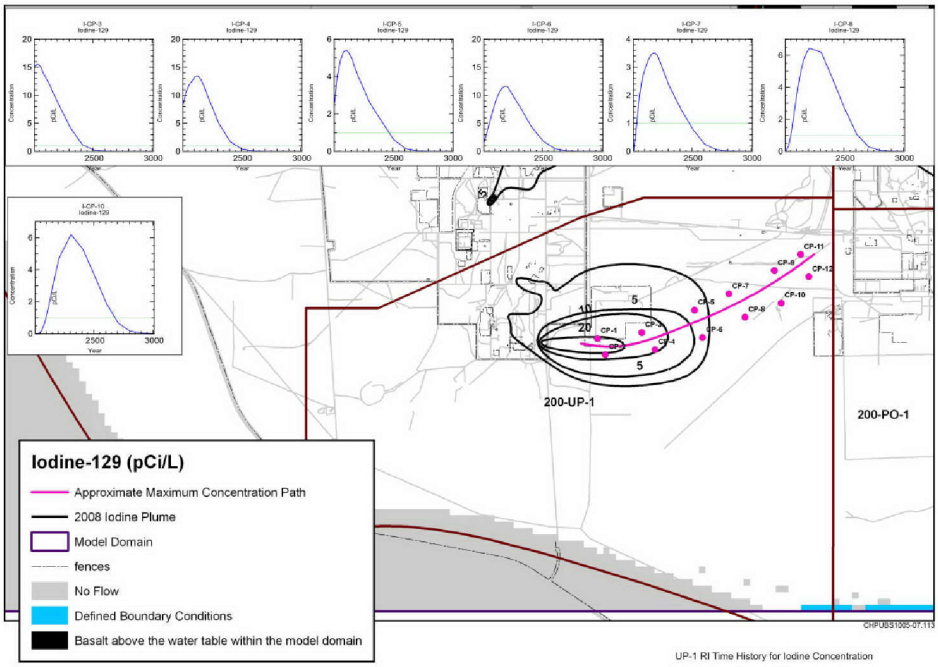


Figure 5-56. Concentration Time History for Selected Locations Along with the Path of Approximate Maximum Concentration for Iodine-129

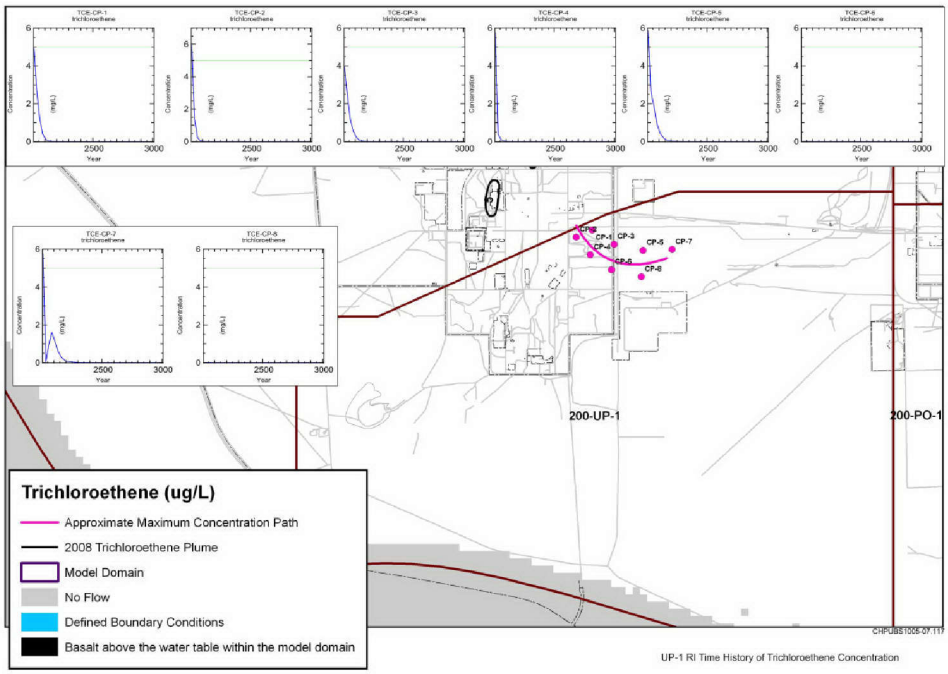


Figure 5-57. Concentration Time History for Selected Locations Along with the Path of Approximate Maximum Concentration for Trichloroethene

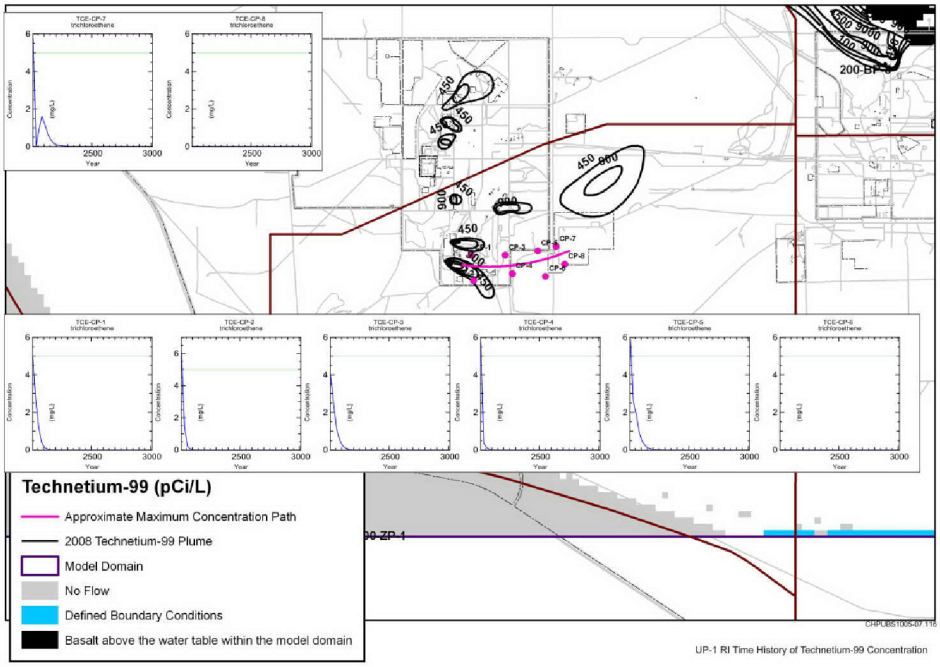


Figure 5-58. Concentration Time History for Selected Locations Along with the Path of Approximate Maximum Concentration for Technetium-99

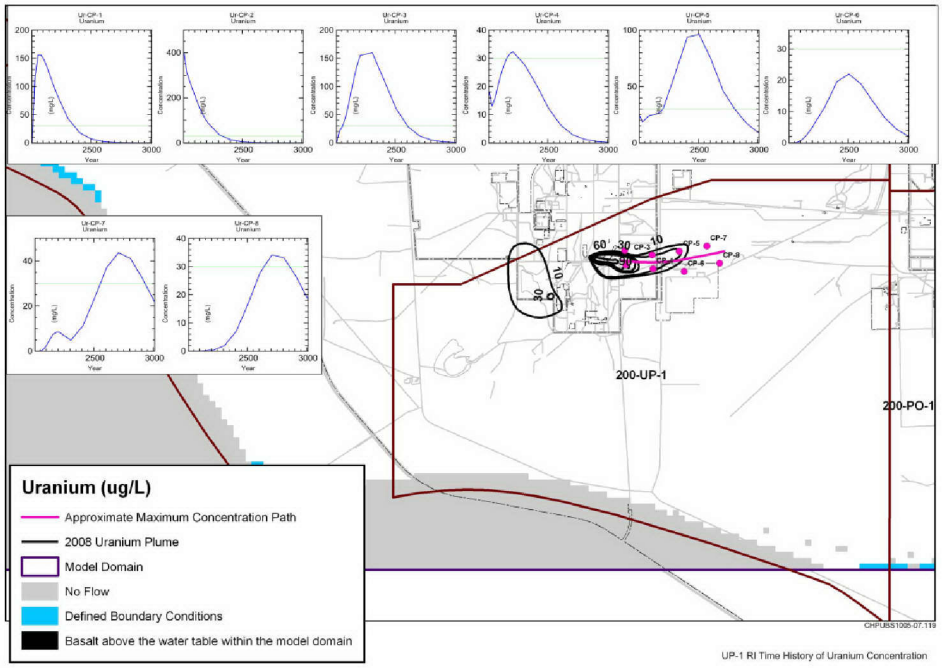


Figure 5-59. Concentration Time History for Selected Locations Along with the Path of Approximate Maximum Concentration for Uranium

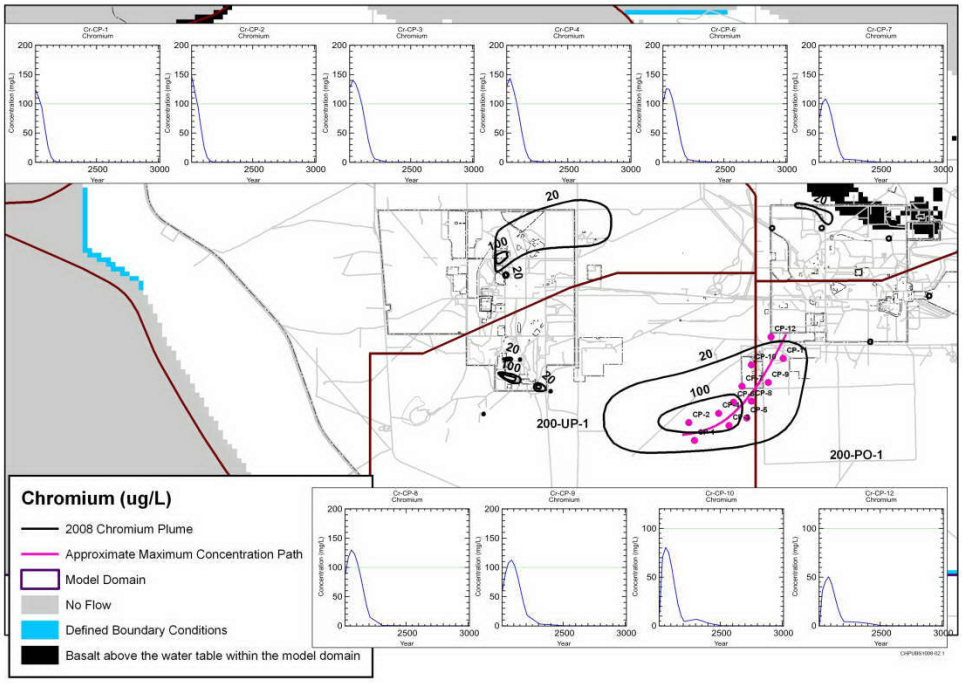


Figure 5-60. Concentration Time History for Selected Locations Along with the Path of Approximate Maximum Concentration for Chromium

5.2.3 Uncertainty in Simulated Future Conditions

This report does not attempt to quantify uncertainty in the F&T simulations. A qualitative discussion of sources of uncertainty in the simulations and how those uncertainties might influence the predictions of future contaminant distributions follows. Five sources of uncertainty are identified that can affect the F&T calculation results: (1) uncertainty in representing initial contaminant concentration distribution; (2) uncertainty caused by neglecting future contaminant sources; (3) conceptual model uncertainty in flow and transport modeling; (4) hydraulic parameter value uncertainty; and (5) parameter uncertainty.

The uncertainty discussion is based on the current modeling objectives, using the model to evaluate future conditions under a no action scenario and to demonstrate whether a need for action exists. As the model is used in FSs to compare remedial alternatives, a more-thorough calibration will be undertaken to support these evaluations. Further refinements of the model are also expected, as the model is used for design of remedial alternatives. At that stage, a formal quantitative evaluation of model uncertainties will be presented.

5.2.3.1 Uncertainty in Initial Contaminant Distribution

The representation of initial distribution of contaminant concentrations is affected by the following uncertainties:

- Uncertainties in reported concentration measurements
- Errors in reported concentration measurements
- Variability in estimates of measurement detection limits
- Method used to assimilate non-detect measurements into the measurement data set
- Representativeness of individual samples with respect to the region surrounding the sample

- Biases and variability introduced by the kriging algorithm
- Choice and influence of control points
- Truncation of the kriging estimates below one-half the MCL
- Lack of three-dimensional contaminant concentration measurements and modeling assumptions made to define the initial plumes in three dimensions

For most contaminants, uncertainty in contaminant measurements is probably a negligible factor when interpreting the results of F&T calculations. The exception may be I-129, for which large uncertainties exist even with a large number of measurements. The probability of large measurement errors is typically very low due to stringent quality controls applied by various analytical laboratories. However, sometimes measurement errors do occur. For example, one 2009 measurement of technetium that has a very large value in the data from HEIS has been identified as an error. The same sample is now reported to be below the detection limit.

The method used to accommodate samples below detection limits is uncertain. Non-detect measurements are identified as such in the data received from HEIS. If the non-detect flag is set, the measurement value in the data is set to the non-detect value for nonradioactive constituents. Concentrations that are not measured by radioactive decay products are treated as if the contaminant level were one-half of the measurement detection limit, except for nitrate, which is treated as if the contaminant level were at the detection limit. Measurements using decay products are treated as if the reported measurement is correct, unless the reported value is negative. These rules create an intentional bias toward larger estimates in the vicinity of regions where contamination is detected compared to treating non-detects as zero concentration. It also introduces a similar bias in measurements that are farther distance from known regions of contamination. The distal bias contributes to overestimation of contaminant concentration beyond the region that would be deemed as acceptable. Therefore, the estimated contaminant concentrations are truncated at levels below one-half the MCL.

Truncation greatly reduces uncertainty introduced by measurement detection limits and the treatment of samples below the detection limits. For contaminants with typical non-detect values larger than the MCL, the intentional bias toward larger estimates of contaminated regions is retained. If the detection limits are below one-half the MCL, uncertainty due to the treatment of non-detect measurements is probably overwhelmed by the bias introduced by truncation of the contamination estimates at one-half the MCL.

Representativeness of fluid samples acquired from a wellbore with respect to defining contamination in the region of the wellbore is far too complex an issue to discuss in detail in this report. Contaminant concentrations may be affected by disturbances in the aquifer resulting from well emplacement. The actual placement of a monitoring well within the aquifer may induce local changes to the flow regime and migration of contaminants. Also, a larger proportion of the sample may come from high-conductivity layers in the formation. This condition could introduce a bias in concentration if there are local variations in concentration due to contaminant migration pathways. Representativeness of samples could be a source of significant uncertainties in individual measurements and could potentially introduce consistent biases in a region.

Another component of the representativeness and comparability of samples is related to collection of samples at varying times. For establishing initial plume concentrations, for the purpose of performing F&T calculations, a simple selection criterion was introduced. The selection criterion was to apply the 2008 sample data preferentially rather than averaging all the data acquired at a location. For locations that do not have 2008 sample data, the most recent measurement was used if it was after 2005. In all cases,

multiple samples acquired during a given year were averaged. Note that the strategy of reducing temporal uncertainty is consistent with the assumption that individual measurement uncertainties are small. Given the scale and dynamics of contaminant migration, the time-based sampling strategy has probably reduced uncertainty due to when samples were acquired to negligible levels.

Developing initial plume configuration from a limited spatial data set also leads to uncertainty in initial concentration. The kriging-based interpolation routine was introduced to reduce this uncertainty. The issue is how far a sample result can be extrapolated away from the wellbore or model cell containing the wellbore. Kriging uses a diminishing influence with distance as defined by the exponential variogram structure. Kriging reduces but cannot eliminate uncertainty due to sparse sampling, as it does not represent the physics of the processes that caused contaminants to migrate in the subsurface. It is instead an interpolation algorithm. To reflect the influence of fluid flow direction on contaminant distribution shape, a bias in the kriging algorithm was introduced by making the variogram longer in the average direction of flow than in other directions and the shortest perpendicular to this direction. The average groundwater flow direction was determined to be consistent with contaminant contours within about 30 degrees of azimuth. This was kept constant within each of the eastern and western portions of the Central Plateau model domain. Thus, it only approximates flow direction at the scale of the individual contaminant plume, sometimes inadequately. A particular problem with using kriging to define contaminant distributions is that while flow is in a particular direction, kriging is symmetric with respect to the measurement point (the influence is the same in the direction of flow, as it is in the opposite direction). One of the reasons for using control points was to reduce the influence of this limitation.

Control points allow the imposition of the analyst's subjective bias into the interpolation. Control points were used to accomplish the following four goals:

- Overcome the directionality problem described previously.
- Connect regions of large concentration that were shown connected in the plume maps presented in the 2008 groundwater annual report.
- Force very small regions of contamination above MCL (often few single cell blocks in the finite difference grid) to be represented above MCL.
- Define contaminant plumes that have been inferred by limited measurements and knowledge of distributions or process knowledge as represented in the 2008 groundwater annual report contaminant contours.

Control points introduce bias and uncertainty because their placement and interpretation of their influence is subjective. Control points are mainly used to apply professional judgment where insufficient data exist to fully describe site conditions. The net effect of control points is to reduce bias and uncertainty, while defining plume configurations that are consistent with the 2008 groundwater annual report.

As with the introduction of control points, truncation of the plume estimates at one-half the MCL reduces the overall bias and uncertainty in the contaminant distribution but also introduces its own bias; where measurements do not exist, concentrations are set to zero. Truncation does not affect regions of large contaminant concentrations, but does result in a probable underestimate of total contaminant mass to avoid a much larger overestimate than would occur if truncation were not used. A counter bias could be the utilization of plume configuration in the topmost three layers in the transport model. This is more likely to overestimate the simulated plume mass, discussed as follows.

There are more measurements that represent contaminant concentrations in near water table conditions than there are for deep water table conditions. Only carbon tetrachloride was deemed to have enough measurements at depth to provide a basis for determining separate concentrations for each model layer and only in the western part of the model domain. For other contaminants, measurements representative of the upper three layers were used to define a single contaminant distribution that was then applied equally to the top three layers of the model. This introduces bias in that the larger number of measurements near the surface dominates the estimates so that estimated contamination near the water table is propagated to greater depth. It is expected that this results in an overestimate of total contaminant mass. Assuming no contamination exists in the Ringold mud and Ringold A HSUs obviously biases the contaminant estimates in these layers in a non-conservative fashion, but this is supported by the absence of observed concentrations in the deeper parts of the groundwater aquifers.

5.2.3.2 Uncertainty from Neglecting Future Contribution from Vadose Contaminant Sources to Groundwater

The current analysis is limited to the estimation of the effects of current groundwater contamination on future groundwater contamination and the resultant risk to HHE caused by that contribution. The influence of future movement of contaminant presently in the vadose zone down to the saturated aquifer is outside the scope of this analysis and, therefore, does not account for the magnitude and timing of any future, or continuing contaminant contributions from this source. Not all of the observed groundwater contaminant plumes in the 200-UP-1 Groundwater OU are associated with continuing vadose source contributions. For example, the chromium plume, located in the southeastern portion of the 200-UP-1 Groundwater OU, does not underlie potential continuing source contributions. Some plumes do underlie locations of historical releases to the surface of the ground that may exhibit continuing vadose contributions to groundwater contamination.

The evaluation and remediation of secondary contaminant sources within the vadose zone falls under the responsibility of the specific source OUs. Since the direct contribution of residual vadose sources to future contaminant concentrations is outside the scope of this analysis, the major source of uncertainty within the scope of the analysis is the result of possible non-linear influences on F&T. The conceptual model for transport of current contamination assumes that the important processes are linear; that is, changes in the magnitude of contamination propagate as changes in magnitude only; not as changes in how the processes function. For small concentrations, this is a good assumption, it is doubtful that additional discharge from the vadose zone to the aquifer will impact the validity of linearity assumption. Continuing contributions from vadose zone sources, however, could affect the overall magnitude of contaminant mass (as resulting concentration) in groundwater, as well as the longevity of the high-concentration portions of groundwater plumes.

5.2.3.3 Conceptual Model Uncertainty

It is often argued that conceptual model uncertainty is usually the dominant form of uncertainty in a modeling exercise, which may hold true for this model as well. The most important source of uncertainty is the assumption that planned use of the Central Plateau will be accurate for the next 1,000 years, roughly 20 times the time period that the Site has been maintained by the federal government to date. Changes in use of the Central Plateau could alter the current artificial and natural recharge estimates in the model and thus impact the groundwater flow velocities. The few after-the-fact audits of long-term predictions that have been conducted have indicated that assumptions of future use are typically (if not invariably) the major cause of prediction error. Such uncertainty can lead in either conservative or non-conservative directions with equal likelihood. The impact of conceptual model-related uncertainties can be investigated through sensitivity analyses.

The next most important source of uncertainty is probably the assumption of spatially invariant hydraulic properties of the HSUs. The fluvial environments that lead to deposition of most of the aquifer are associated with heterogeneous structures, especially for the Hanford and Cold Creek units. Local variations in properties can cause local regions of relatively large flow rates and, hence, faster transport of contaminants. These can be significant, as evidenced by the experience obtained from calibrating the model. During the calibration, the CCU near the 200 East Area was found to be more permeable than a representative value would allow. The hydrologic unit definition of this portion of the CCU was changed to the Hanford fm to provide a more accurate reflection of the very permeable, coarse-grained nature of this portion of the CCU. This region was identified, as it was very important to the flow calibration. Other, smaller regions may have had less impact on the hydraulic calibration but still could have a strong but more localized influence on flows.

A source of uncertainty in the transport predictions derives from the assumption of constant effective porosity value for a given HSU. The effective porosity is used in converting water mass flux calculated by MODFLOW to groundwater velocity used in MT3DMS for F&T calculations. Heterogeneity in the form of lenses, bar structures, and overbank deposits is common at a scale below the 100 m (328 ft) by 100 m (328 ft) grid size of the Central Plateau model and could lead to varying effective porosity values and groundwater velocities. Furthermore, some of these features can create preferential pathways and lead to faster contaminant movement locally than predicted by the current model.

The conceptual model and parameterization of boundary conditions has a major influence on groundwater flow and hence transport of contaminants. Representing the two gaps along the northern border of the model with specified heads is uncertain because the values must be predicted from past trends. Two major sources of uncertainty influence the importance of the gap. The first is the uncertainty of how much flow is entering the model domain from the western streams, from surface infiltration, and through leakage upward from the basalt. Of these, flux from the western streams dominates. The values obtained from calibration of the 200-ZP-1 groundwater flow model were used for these terms. The second source of uncertainty is non-equilibrium storage in the aquifer. The Central Plateau is not in equilibrium with respect to inflow and outflow. The Central Plateau unconfined aquifer still exhibits more outflow than inflow because of the remaining fraction of the tremendous buildup of stored water in the aquifer during the operational period of the Site. The aquifer is still attenuating this buildup that ended with termination of production activities at the Site in 1989.

Fluid flow and, therefore, transport is extremely sensitive to the interpretation of geology in the entire portion of the model east and southeast of the 200 East Area. This region is complex geologically and there is not a one-to-one correspondence between geologic formation and proper hydraulic representation, as previously described in this section. Strict reliance on geologic characterization was found to be incorrect. Almost as much variation of hydraulic conductivity may exist within the Hanford fm and within the CCU as exists between representative values for these HSUs. To create a model that matched historical head data, interpretation of some drilling logs required re-examination, and many of the logs that were re-examined could be, and needed to be, interpreted differently than had been done previously. The conceptual model of hydrostratigraphy was influenced by historic contaminant plume interpretations that indicate the presence of a large conductive channel from just south of the 200 East Area to the southeast corner of the Central Plateau groundwater model domain. The hydraulic head data strongly correlates with this interpretation; however, little geologic data from well log interpretation exists to corroborate this interpretation. While there is enough evidence to support a highly conductive channel, there is insufficient evidence to accurately define its shape and size; this uncertainty implies that there is insufficient evidence to provide good constraint of the velocity of groundwater flow in the channel. Potentially, examination of historic plume movement could help constrain flow velocities in the channel, but this has not been done.

5.2.3.4 Hydraulic Parameter Value Uncertainty

The aspects of conceptualization of HSUs as homogeneous features with effective single-valued properties have been discussed. The present discussion focuses on the selection of the effective values. Hydraulic parameters comprise hydraulic conductivity, specific storage, and specific yield. Hydraulic conductivity values were established through calibration. The match to hydraulic head difference between Well 299-E23-1 near the 200 East Area and Well 699-24-33 was very sensitive to the hydraulic conductivity of the Hanford unit. This well pair was selected because of the perceived importance of the Hanford unit in defining the conductive channel. The sensitivity ensured that only a narrow range of effective hydraulic conductivity of the Hanford fm would result in a good match. However, because the fluid flux moving through the channel is uncertain and the size of the channel is uncertain, the representativeness of the effective parameter for the hydraulic conductivity of the Hanford fm is also uncertain. In terms of transport velocity uncertainty, the uncertainty in a value of the hydraulic conductivity for the Hanford unit is relatively unimportant compared to the fluid mass flux uncertainty and uncertainty in the size of the channel.

The existence of a channel, as indicated by maps of historic contaminant distributions, indicates that there is a significant difference between the Hanford fm hydraulic conductivity and the effective hydraulic conductivity of the CCU. The calibration resulted in an effective hydraulic conductivity of 100 m/day (328 ft/day) for the CCU and 8,500 m/day (27,887 ft/day) for the Hanford fm. The hydraulic head difference between Well 299-E23-1 and Well 699-24-33 was not sensitive to changes in the hydraulic conductivity of the CCU, as long as it was significantly less than the Hanford fm. It is expected that, in terms of the most important aspects, contaminant transport is not sensitive to CCU hydraulic conductivity.

The effective values for hydraulic conductivity of the Ringold A and Ringold E units were selected in the calibration by matching the hydrograph of Well 299-W12-1 during 1976. This was done after selection of values for the Hanford unit and the CCU. It is expected that the effective values are less well constrained than for the Hanford fm in the channel but much better than for the CCU. The relative hydraulic conductivity between the Ringold A and Ringold E units is probably not well constrained and is important to transport uncertainty. However, the resultant uncertainty is probably much smaller than the uncertainty due to effective porosity.

The calibration was insensitive to changes in the conductivity of the Ringold Mud unit. The Ringold Mud may act as a much greater barrier to flow into the Ringold A unit than is currently simulated. While it is unlikely that would have much influence on transport in the 200-PO-1 Groundwater OU, it may have a non-conservative impact on transport from the 200-UP-1 Groundwater OU to the 200-PO-1 Groundwater OU.

5.2.3.5 Uncertainty in Transport Parameters

As advection is the primary transport mechanism in the current modeling study, the transport parameters of interest are primarily effective porosity, bulk density, and K_d. These parameters are used to determine the retardation factor that is applied to various COPCs. Only best estimate values are considered in the modeling study because of lack of available information on spatial variability of these parameters.

The effective porosity and bulk density values applied in the transport model are representative of the sandy gravel sediment type of the Hanford fm and the Ringold Fm (PNNL-18564). Although HSUs are composed of sediment layers of varying grain sizes (from gravel to mud size), because the transport of contaminants is expected to preferentially occur along the coarser-grained, higher hydraulic conductivity portion of the aquifer, applying the sandy gravel sediment property to the HSUs is deemed adequate. Furthermore, because of the long transport distances modeled, averaging of the properties over large rock volumes is reasonable, as it leads to reduced uncertainty range.

The K_d of the contaminants is generally highly variable and depends primarily on the available sorption sites on the sorbent (function of surface area), dissolved concentration of contaminant, and chemical parameters such as pH, partial pressure of CO_2, and so forth. Each of these parameters can vary over time and space and affect the K_d of the contaminant and thereby the uncertainty in its estimate. Because of the large transport distances considered and the coarse discretization of the model grid, the best estimate approach for K_d is considered. The K_d values for COPCs reported for the uncontaminated sandy gravel sediment type is used in the model to be consistent with the effective porosity and bulk density estimates. For carbon tetrachloride, the K_d values are calculated based on the batch sorption experiments on uncontaminated sediments (rather than desorption experiments on the contaminated sediments), while for other chlorinated hydrocarbons, K_d is based on empirical calculation assuming low organic carbon fraction. In almost all cases, the K_d value estimation is based on the assumption of dilute concentrations in groundwater that interacts with the sandy gravel sediments are largely uncontaminated.

The degradation of chlorinated hydrocarbons is also uncertain and depends on the biogeochemical conditions in the aquifer. A conservative assumption of no degradation of chlorinated hydrocarbons (except for carbon tetrachloride) is considered, which is reasonable for the current modeling objective.

5.2.3.6 Summary of Uncertainty in Fate and Transport Simulations

A review of sources of simulation uncertainty has been presented. Many of these sources are relatively unimportant. The most important sources are listed as follows (the list is not in a ranked order):

- Initial contaminant distribution, especially with respect to depth
- Effective transport porosity
- Distribution coefficients
- Heterogeneity in HSU properties
- Future use of the Central Plateau

5.3 Conceptual Exposure Model

The conceptual exposure model (CEM) identifies the means by which human or ecological receptors may contact contaminants in groundwater. It addresses potential exposures that may result under current Site conditions and from reasonably anticipated potential uses of the groundwater within the OU. The following subsections describe the CEM as well as the results of F&T simulations.

This section provides the CEM for the 200-UP-1 Groundwater OU. The CEM provides a current understanding of the sources of contamination, physical setting, current and reasonably anticipated future land use, groundwater beneficial use, and identifies potentially complete human and ecological exposure pathways for the 200-UP-1 Groundwater OU. Site information from previous investigations and work plans has been incorporated into the CEM to identify potential exposure scenarios. The physical characteristics of the study area and expectations for restoring groundwater to its highest beneficial use are described in detail in Chapter 3 of the RI Report; current and reasonably anticipated future land use is described in Chapter 1.

5.3.1 Current and Reasonably Anticipated Future Land Use

Anticipated land use plays a key role in CERCLA cleanup decisions. DOE is responsible for designating the land use of the Site. As the lead agency for CERLCA cleanup of the Site, DOE is also responsible for identifying future land uses that will guide CERCLA risk assessment and cleanup decisions. DOE used the NEPA Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP-EIS) to examine land use alternatives and conducted this process with nine cooperating agencies and consulting

Tribal governments as a basis for determining future anticipated land uses.[4,5] This effort resulted in the HCP that DOE adopted and implemented in the ROD published on November 2, 1999 (64 FR 61615). The HCP must be reviewed periodically to ensure it remains current. The first review since adoption and implementation was documented in a supplemental analysis that resulted in DOE issuing an amendment to the ROD (73 FR 55824) on September 26, 2008.

The Hanford Comprehensive Land-Use Plan ROD (64 FR 61615) designated land uses for the Site. The 2008 amended ROD (73 FR 55824) maintained those anticipated land uses. The following selected land use designations are relevant to the CERCLA cleanup decision:

- 100 Areas—Conservation-Mining. An area reserved for protection of archeological, cultural, ecological, and natural resources.
- 300 Area—Industrial. An area suitable for industrial activities such as reactor operations and manufacturing.
- Central Plateau (200 Areas)—Industrial-Exclusive. An area suitable for TSD of hazardous and/or radioactive waste under federal control.
- Wahluke Slope, Saddle Mountains, Fitzner/Eberhardt ALE Reserve, Gable Mountain, and Gable Butte—Preservation. An area managed for the preservation of archeological, cultural, ecological, and natural resources.
- Columbia River Corridor—High-Intensity Recreation, Low-Intensity Recreation, Conservation Mining, and Preservation. High- and Low-Intensity Recreation allow for a range of visitor-serving activities and facilities.

In June 2000, most of the lands that are designated as "preservation" were permanently withdrawn and protected by presidential proclamation (65 FR 37253) with the establishment of the Hanford Reach National Monument. The monument is superimposed over approximately 195,000 ac (78,975 ha) of the 1,518 km^2 (586-mi^2) DOE Hanford Site.

Hanford Site lands, including the Hanford Reach National Monument, are expected to remain under federal ownership and control for the foreseeable future.[6] The federal government will retain ownership of the conservation and preservation areas of the Site for the foreseeable future. These areas are not expected to be defined as excess to DOE missions. Access to these areas will be controlled, as necessary, to protect human health and safety as long as active waste management operations are being conducted.

DOE recognizes that permanent disposal, isolation, and protection of disposed inventories will be required. Within this area, DOE intends to decrease the region requiring permanent isolation and control to be much smaller than the current 51.8 km^2 (20 mi^2) area. Consistent with other DOE and non-DOE

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[4] 52 FR 2923, "Executive Order 12580: Superfund Implementation" designated DOE as the "lead agency" for CERCLA cleanup at DOE sites.

[5] The cooperating entities were the U.S Department of the Interior (Bureau of Land Management, Bureau of Reclamation, and the U.S. Fish and Wildlife Service); the City of Richland; Benton, Franklin, and Grant Counties: the Nez Perce Tribe; and the Confederate Tribes of the Umatilla Reservation (CTUIR). Although not a cooperating agency, the Yakama Nation participated at points throughout the 7-year-long EIS process.

[6] Further information on Hanford land use designations and processes can be found in the *Hanford Comprehensive Land-Use Plan EIS*, the corresponding ROD (64 FR 61615) of November 2, 1999, the recently released supplement analysis (73 FR 55824) of September 26, 2008.

sites in the U.S. (Fernald, Rocky Flats, and Savannah River Site), the Site's Industrial-Exclusive Area will be controlled for the foreseeable future.

5.3.2 Groundwater Beneficial Use

CERCLA and the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) establish separate requirements for a groundwater remedy: (1) to be protective of HHE, and (2) to meet ARARs. This is a concept of central importance to the development of the groundwater remedy for the 200-UP-1 Groundwater OU. These separate requirements are further clarified in a memorandum (Fields, 1997).

The requirement to achieve threshold protectiveness and ARAR-based requirements is established by the NCP. The NCP also establishes the requirement to return useable groundwater to beneficial use within a reasonable timeframe. EPA generally defers to state agency definitions of useable groundwater provided under the various comprehensive state groundwater protection programs, administered by the states across the U.S. and a state's determination of groundwater usability at CERCLA sites (EPA/540/G-88/003). The State of Washington defines groundwater as potable in WAC 173-340-720(2), unless the exclusion criteria in WAC 173-340-720(2)(a) through (c) can be demonstrated (insufficient yield, natural constituents that make it unsuitable as a drinking water source). The groundwater beneath the Central Plateau does not meet the exclusion criteria; therefore, it is classified as potable and must be restored to beneficial use wherever practicable, and within a timeframe that is reasonably consistent with the NCP requirements. The State of Washington has further determined that the highest beneficial use for potable groundwater at most of the cleanup sites within the state, including the Site, is as a potential source of domestic drinking water (WAC 173-340-720[1][a]).

Groundwater beneath the Central Plateau is currently contaminated, and withdrawal is prohibited as a result of ICs placed on it by DOE. Under current Site use conditions, no complete human or ecological exposure pathways to groundwater are assumed to exist. Further, regardless of land use designations for soils, groundwater within this OU is not anticipated to become a future source of drinking water until cleanup criteria are met and groundwater is restored to its highest beneficial use. However, groundwater in this risk analysis is evaluated for drinking water use to support the determination of the basis for action and to support the development of preliminary remediation goals (PRGs) for evaluating remedial alternatives in the FS.

5.3.3 200-UP-1 Groundwater Operable Unit Exposure Area

The 200-UP-1 Groundwater OU is the southernmost of two groundwater OUs in the 200 West Area of the Site. The northern groundwater OU is the 200-ZP-1 OU. A detailed discussion of the geology and hydrogeology of the 200 West aggregate area is presented in DOE/RL-92-16, with more recent analyses found in PNNL-13858.

The primary objective for evaluating the 200-UP-1 Groundwater OU is to provide information necessary to determine the need for remedial action and use this information to select the best remedy. These objectives are achieved by performing the following steps: (1) exposure point concentrations (EPCs) for each COPC are compared to contaminant-specific ARARs for the purpose of understanding the potential for exposure to groundwater contaminants and the associated health risks, and (2) specific locations are identified within the exposure area for the purpose of evaluating remedial alternatives in the FS. The known or suspected sources are described as follows. Appendix A shows the locations of each monitoring well included in the 200-UP-1 Groundwater OU.

Waste sites grouped around the four major facilities are the primary contributors to groundwater contamination in the 200-UP-1 Groundwater OU: S Plant (REDOX); U Plant; S-SX Tank Farm; and U Tank Farm. Several RCRA TSD units are located in the 200-UP-1 Groundwater OU and include the S-10 Pond; S-SX WMA (Tank Farm); and the U Plant WMA (Tank Farm). Table 5-3 lists the monitoring wells that were used to evaluate exposure.

Table 5-3. Summary of 200-UP-1 Groundwater Monitoring Wells

299-W14-71	299-W19-42	299-W22-81	699-33-74
299-W15-37	299-W19-43	299-W22-82	699-33-75
299-W18-15	299-W19-44	299-W22-83	699-33-76
299-W18-21	299-W19-45	299-W22-84	699-34-72
299-W18-22	299-W19-46	299-W22-85	699-35-66A
299-W18-30	299-W19-47	299-W22-86	699-35-70
299-W18-31	299-W19-48	299-W22-87	699-35-78A
299-W18-33	299-W19-50	299-W22-88	699-36-61A
299-W18-40	299-W19-9	299-W22-9	699-36-66B
299-W19-101	299-W21-2	299-W23-10	699-36-67
299-W19-104	299-W22-10	299-W23-14	699-36-70A
299-W19-105	299-W22-20	299-W23-15	699-36-70B
299-W19-107	299-W22-26	299-W23-19	699-37-66
299-W19-12	299-W22-44	299-W23-20	699-37-68
299-W19-18	299-W22-45	299-W23-21	699-38-65
299-W19-34A	299-W22-46	299-W23-4	699-38-68A
299-W19-34B	299-W22-47	299-W23-9	699-38-70
299-W19-35	299-W22-48	299-W26-13	699-38-70B
299-W19-36	299-W22-49	299-W26-14	699-38-70C
299-W19-37	299-W22-50	299-W27-2	699-40-62
299-W19-39	299-W22-69	699-30-66	699-40-65
299-W19-4	299-W22-72	699-32-62	
299-W19-40	299-W22-79	699-32-72A	
299-W19-41	299-W22-80	699-32-76	

5.3.4 Conceptual Exposure Model for Human Health and the Environment

This section describes the potential exposure pathways resulting from Site contaminants, based on currently available Site information. The CEM is formulated according to EPA guidance, and information on contaminant sources, release mechanisms, routes of migration, potential exposure points, potential routes of exposure, and potential receptor groups associated within the 200-UP-1 Groundwater OU.

An exposure pathway can be described as the physical course that a COPC takes from the point of release to a receptor. The route of exposure is the means by which a COPC enters a receptor. For an exposure pathway to be complete, all of the following components must be present:

- A source
- A mechanism of chemical release
- An environmental transport mechanism
- An exposure point
- An exposure route
- A receptor or exposed population

In the absence of any one of these components, an exposure pathway is considered incomplete and, therefore, creates no risk or hazard. Figure 5-61 schematically presents the exposure pathway analysis in the form of a human and ecological CEM.

5.3.4.1 Contaminant Sources

The primary sources of contaminants that are known or suspected to have contributed to contamination in the 200-UP-1 Groundwater OU include liquid process wastes and wastewater generated during historical operations of S Plant (REDOX) Plant; U Plant; S-SX Tank Farm; and U Tank Farm. Sanitary wastewater generated at these same process facilities, and discharged to septic tanks and sanitary leach fields may have also contributed to observed groundwater contamination. The observed groundwater contamination within the 200-UP-1 Groundwater OU is believed to have resulted from historical discharge of large volumes of liquid wastes and wastewater to the ground. These wastes were discharged in sufficiently large volumes that the discharged volume exceeded the porosity of the soil beneath the waste site(s) and resulted in downward migration of associated contaminants into underlying groundwater. In some cases, the resulting groundwater contaminants concentrations in the immediate vicinity of the release point, and adjacent groundwater downgradient of the release point, substantially exceed cleanup target concentrations. In some cases, these conditions have been recognized as secondary groundwater contaminant sources and have been addressed through implementation of IRAs. These interim actions have included P&T actions located to extract highly concentrated groundwater contaminants from localized areas.

Continued contribution of contaminants to groundwater from downward migration of residual contaminants within the vadose zone soil column is specifically excluded from consideration in the groundwater OU. Migration of contaminants within these vadose zone secondary sources will be addressed by the overlying source OUs. The source OUs will evaluate the potential for, and magnitude of, continued contribution of contaminants to the groundwater. As shown in Figure 5-61, assessment of the groundwater immediately beneath a source area and impacted by the overlying waste site(s) is the responsibility of the source waste site.

Solid waste materials disposed to ground (to dumps, pits or burial grounds) are generally not considered to have impacted groundwater at this time. Those waste materials were not disposed, along with large volumes of water or wastewater, and are not expected to affect groundwater in the immediate future, if ever.

5.3.4.2 Release Mechanisms and Environmental Transport Medium

The contaminants observed in groundwater within the 200-UP-1 Groundwater OU all resulted from release of process liquid wastes and wastewater to the soil via discharge to engineered structures (cribs, trenches, ditches, ponds, leach fields, or injection wells) in the case of intentional releases. Unintentional, or unplanned, releases typically resulted from inadvertent releases of the same, or similar, waste materials from tanks, pipelines, or other waste storage or conveyance components. Most of the liquid waste and wastewater that contributed to observed groundwater contamination entered the soil column directly and migrated downward through the soil column by gravity to reach the underlying groundwater. In some instances, this downward migration through the vadose zone is continuing; in other cases, it appears that the vadose zone has drained its readily drainable waste and continued contributions are no longer apparent.

Upon entering the groundwater at the water table, contaminants migrate in a downgradient direction away from the point of entry. Groundwater flow directions within 200-UP-1 groundwater OU have varied substantially over the period of historical Hanford operations. During the first years of operation, groundwater flow direction was generally west to east. As discharge of large volumes of wastewater to surface infiltration ponds within the 200 West Area continued, substantial groundwater mounds developed; groundwater then flowed radially away from these mounds in all directions. When these large volume discharges were stopped in the 1990s, the mounds began to dissipate and flow directions began to return to a more natural condition (generally west to east). The groundwater flow system has not yet returned to a natural state, however, there is little evidence of the historical radial flow associated with the groundwater mounds within the 200-UP-1 Groundwater OU. Section 5.1 and Section 5.2 provide additional descriptions of the processes that affect contaminant migration within the affected aquifer.

5.3.4.3 Potentially Complete Exposure Pathways and Receptors

There are currently no actual exposures of either human or ecological receptors to groundwater within the 200-UP-1 Groundwater OU. It is anticipated that groundwater contamination in this exposure area will not disperse beyond the boundaries of the 200-UP-1 Groundwater OU at concentrations exceeding the risk screening concentrations established for this RI. No discharge of groundwater originating from within the 200-UP-1 Groundwater OU to surface water is anticipated; thus, only exposure to human receptors is considered in this BRA. Based on this understanding, hypothetical adult and child receptors could potentially use the groundwater within this exposure area for drinking water and other domestic purposes.

Potential routes of exposure to groundwater contaminants include the following:

- Ingestion of contaminated water by drinking or in food preparation
- Inhalation of contaminant vapors during showering or other household activities
- Dermal contact exposure to contaminants in groundwater
- External radiation exposure from radioactive contaminants in groundwater

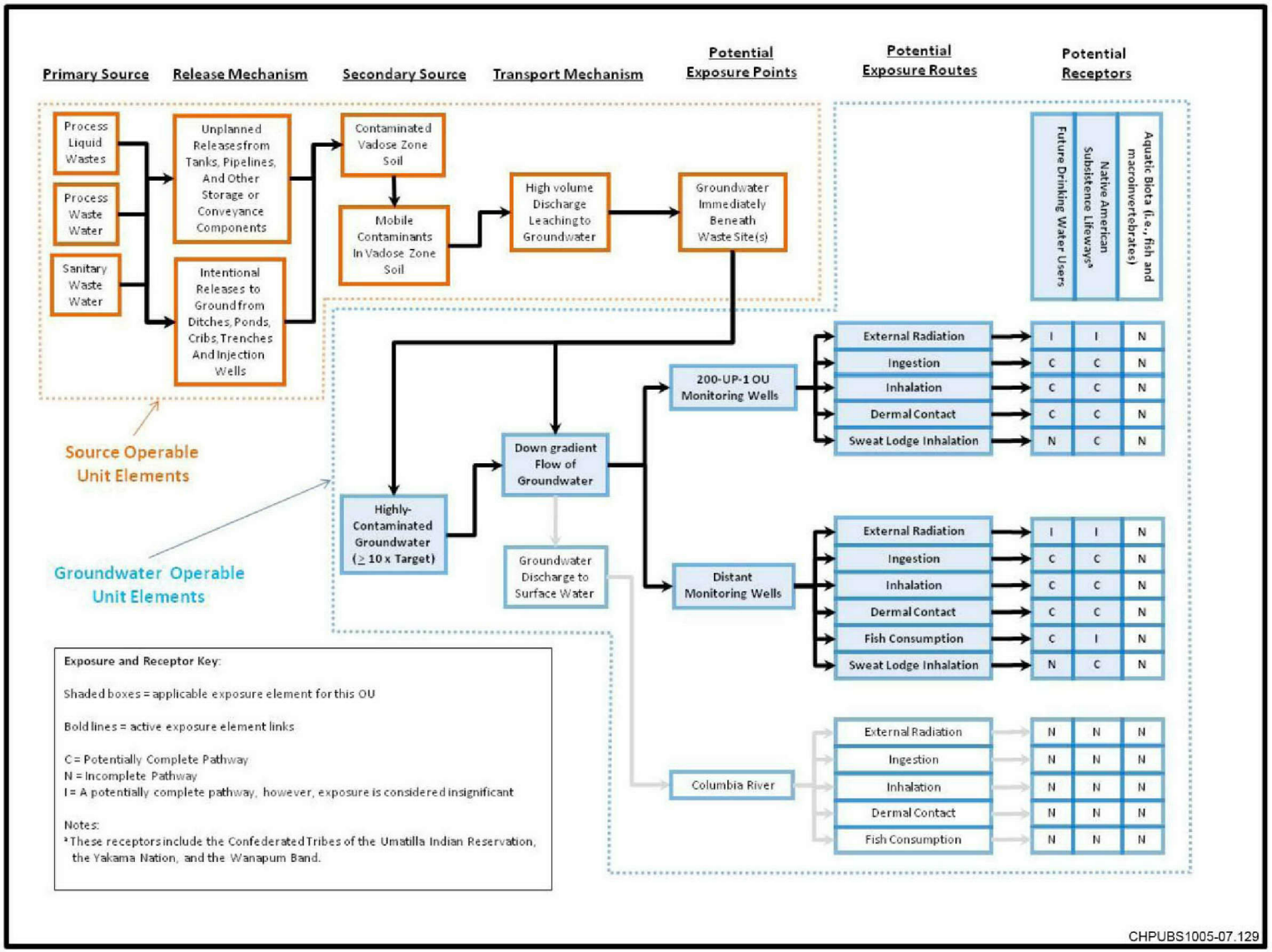

Figure 5-61. Conceptual Exposure Model for Potential Human Health and Ecological Receptors

Although dermal contact is a potential route of exposure, the chemical-specific ARARs selected for this exposure area consider ingestion and inhalation of vapors as complete and significant pathways for exposure. The dermal contact pathway is considered a complete but insignificant pathway of exposure for the contaminants detected in groundwater at the 200-UP-1 Groundwater OU and generally does not require quantitative evaluation but is discussed qualitatively as described in WAC 173-340-720(4)(iii)(A) and (B). External radiation exposure is also assumed to be an insignificant exposure pathway as a result of water's shielding effects.

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6 Baseline Risk Assessment

> *The baseline risk assessment is an analysis of the potential adverse health effects (current or future) caused by hazardous substance releases from a site in the absence of any actions to control or mitigate these releases (i.e., under an assumption of no action). The baseline risk assessment contributes to the site characterization and subsequent development, evaluation, and selection of appropriate response alternatives.* (EPA/540/1-89/002).

EPA guidance provided in Woolford and Redder, 2009 (page 4), clarifies EPA's policies for determining whether a groundwater remedial action is warranted under CERCLA. In discussing the role of the BRA, the EPA memorandum (Woolford and Redder, 2009) quotes the preamble to the NCP:

> *The results of the baseline risk assessment are used to determine whether remediation is necessary, to help provide justification for performing remedial action, and to assist in determining what exposure pathways need to be remediated.*

The memorandum (Woolford and Redder, 2009) then continues to clarify when a CERCLA remedial action is appropriate (page 5):

> *A CERCLA remedial action generally is appropriate in various circumstances, including: a regulatory standard that helps define protectiveness (a federal or state MCL or nonzero maximum contaminant level goal (MCLG) for current or potential drinking water aquifers) is exceeded; when the estimated risk calculated in a risk assessment exceeds a non-carcinogenic level for an adverse health effect or the upper end of the NCP risk range for "cumulative carcinogenic site risk to an individual based on reasonable maximum exposure for both current and future land use; the non-carcinogenic hazard index is greater than one (using reasonable maximum exposure assumptions for either the current or reasonably anticipated future land use); or the site contaminants cause adverse environmental impacts.*[1,2,3] *It is important to note that all conditions do not need to be present for action and the conditions may be independent of each other.*

EPA guidance provided in OSWER Directive 9355.0-30 (Clay, 1991) describes how to use the BRA to make risk management decisions, such as determining whether remedial action under CERCLA Section 104 or Section 106 is necessary. The directive also describes the following conditions when a CERCLA action is generally warranted:

- The BRA indicates that a cumulative site risk to an individual using reasonable maximum exposure (RME) assumptions for either current or future land use exceeds the 10^{-4} excess lifetime cancer risk (ELCR) end of the risk range.
- For groundwater actions, MCLs and non-zero MCLGs will generally be used to gauge whether remedial action is warranted.
- Chemical-specific standards that define acceptable risk levels also may be used to determine whether an exposure is associated with an unacceptable risk to HHE and if remedial action is warranted.

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[1] EPA 540-R-97-013.
[2] Clay, 1991.
[3] EPA 540-R-97-013.

Protectiveness of human health is determined by comparing groundwater concentrations to existing federal or state MCLs or nonzero MCLGs. Groundwater concentrations are compared to the WAC 173-340-720 to determine whether EPCs exceed a hazard index (HI) greater than 1. The concentrations also are compared to the upper end of the NCP risk range for cumulative carcinogenic site risk to an individual based on RME for both current and future land use.

EPA guidance provided in OSWER No. 9200.4-23 (Fields, 1997) clarifies the relationship between the two key remedy selection mandates of CERCLA: (1) the requirement to protect HHE, and (2) the requirement to attain or waive ARARs, if justified, based on site-specific circumstances. This guidance explains that it remains EPA's policy that ARARs will generally be considered protective absent multiple pathways or contaminants, where application of the ARAR would not be protective of HHE.

A BRA was performed for the 200-UP-1 Groundwater OU. Results of this risk assessment indicate that concentrations of contaminants in the 200-UP-1 Groundwater OU exceed action levels, and warrant investigation in an FS to address groundwater contamination within the OU. The 200-UP-1 Groundwater OU BRA strategy outline follows:

- Evaluate current data to identify contaminants present in groundwater. In the previous 5 years, analytical measurement data were collected to identify detected contaminants.
- Identify action levels for detected contaminants, using ARARs to establish a basis for screening COPCs.
- Compare the detected contaminant concentrations to ARARs in order to identify preliminary COPCs within the entire 200-UP-1 Groundwater OU.
- Further evaluate the initial COPCs to identify and refine a final set of COPCs.
- Conduct the risk characterization step on the final set of COPCs, including a determination that ARARs have been exceeded.

The final COPCs represent contaminants that will be evaluated in the FS to select remedial alternatives. The CEM shows that exposure to groundwater contaminants is through direct contact, while other exposure pathways are considered incomplete. The risk assessment identifies multiple contaminants within the 200-UP-1 Groundwater OU that exceed chemical-specific ARARs. WAC 173-340-708(5)(a) and WAC 173-340-708(6)(b) require that cleanup levels be adjusted downward to take into account exposure to multiple hazardous substances or multiple pathways of exposure. This adjustment needs to be made only if, without this adjustment, the HI would exceed 1, or the total ELCR would exceed 1 in 100,000 (1×10^{-5}). As a result, the risk assessment does not identify the need to develop cleanup levels that are more protective than ARARs.

Additionally, several local and regional Tribes have ancestral ties to the Hanford Reach of the Columbia River and surrounding lands. DOE has requested that each Tribe provide an exposure scenario that reflects their traditional activities. At this time, the CTUIR (Harris and Harper, 1997) and the Yakama Nation (Ridolfi, 2007) have provided scenarios. A quantitative risk evaluation is included for both Tribal use scenarios to evaluate each of the potentially complete groundwater exposure pathways. The results for the Native American Risk Assessment are provided in ECF-200UP1-10-0250.

6.1 Selection of Contaminants of Potential Concern

The first step in a BRA is an evaluation of the data to select the COPCs for protection of HHE. A detailed description of the methodology used to select COPCs and the results of the process are provided in ECF-200UP1-10-2031.

Identification of groundwater COPCs for the 200-UP-1 Groundwater OU is a two-phase process. The first step of the process identifies an initial set of COPCs that will be carried forward into the final COPC identification process. The process used to select the initial set of COPCs is described in Section 6.1.3. The second step of the process identifies the final COPCs. The process used to select the final set of COPCs is described in Section 6.14. As described in Section 5.3, the 200-UP-1 Groundwater OU is evaluated as a single exposure area. The process used to calculate EPCs for COPCs is described in Section 6.1.4. Finally, the risk characterization step is described in Section 6.4. The primary objective for evaluating groundwater within the OU is to provide information necessary to justify and select the best remedial action.

6.1.1 Data Used to Select Contaminants of Potential Concern

The last 5 years of data were determined to be representative of current groundwater conditions (samples collected between January 12, 2004, and April 28, 2009); data prior to 2004 were excluded. The initial COPC selection process included sampling and analysis data collected from 93 200-UP-1 Groundwater OU monitoring wells that are screened in the unconfined aquifer. Unconfined aquifer wells are used because they are the most applicable for the depth that a groundwater supply well might be screened. In addition, the wells are screened where the groundwater contamination is present.

The analytical data set for the 200-UP-1 OU evaluation is extracted from HEIS. After extraction from HEIS, the analytical data are processed to obtain a single set of results per sampling location and time of collection. Figure 6-1 depicts the data processing steps, number of records, and number of analytes associated with each step. Implementation details and results of the data processing step are presented in ECF-200UP1-10-0231.

Both filtered (dissolved) and unfiltered (total) analysis results are available in the HEIS database for some metals in the groundwater data set. Only unfiltered results are used for selecting COPCs. Use of filtered sampling results may underestimate chemical and radiological concentrations in water from an unfiltered tap and are not used for the COPC selection process. Generally, there are more filtered metal results available than unfiltered results; however, exclusion of filtered results does not result in the elimination of metals from the COPC process or underestimate EPCs.

6.1.2 Identification of Action Levels

Action levels are derived from readily available sources of chemical-specific ARARs. The source of the chemical-specific ARARs from federal regulations is identified as follows:

- MCLs, secondary MCLs, and non-zero MCLGs established under the *Safe Drinking Water Act of 1974* (SDWA)

The chemical-specific ARARs from Washington State regulations were identified from the following sources:

- WAC 173-340-720
- WAC 246-290-310

ECF-200-UP1-10-0231 identifies all sources of action levels (chemical-specific ARARs) for each of the 237 analytes reported.

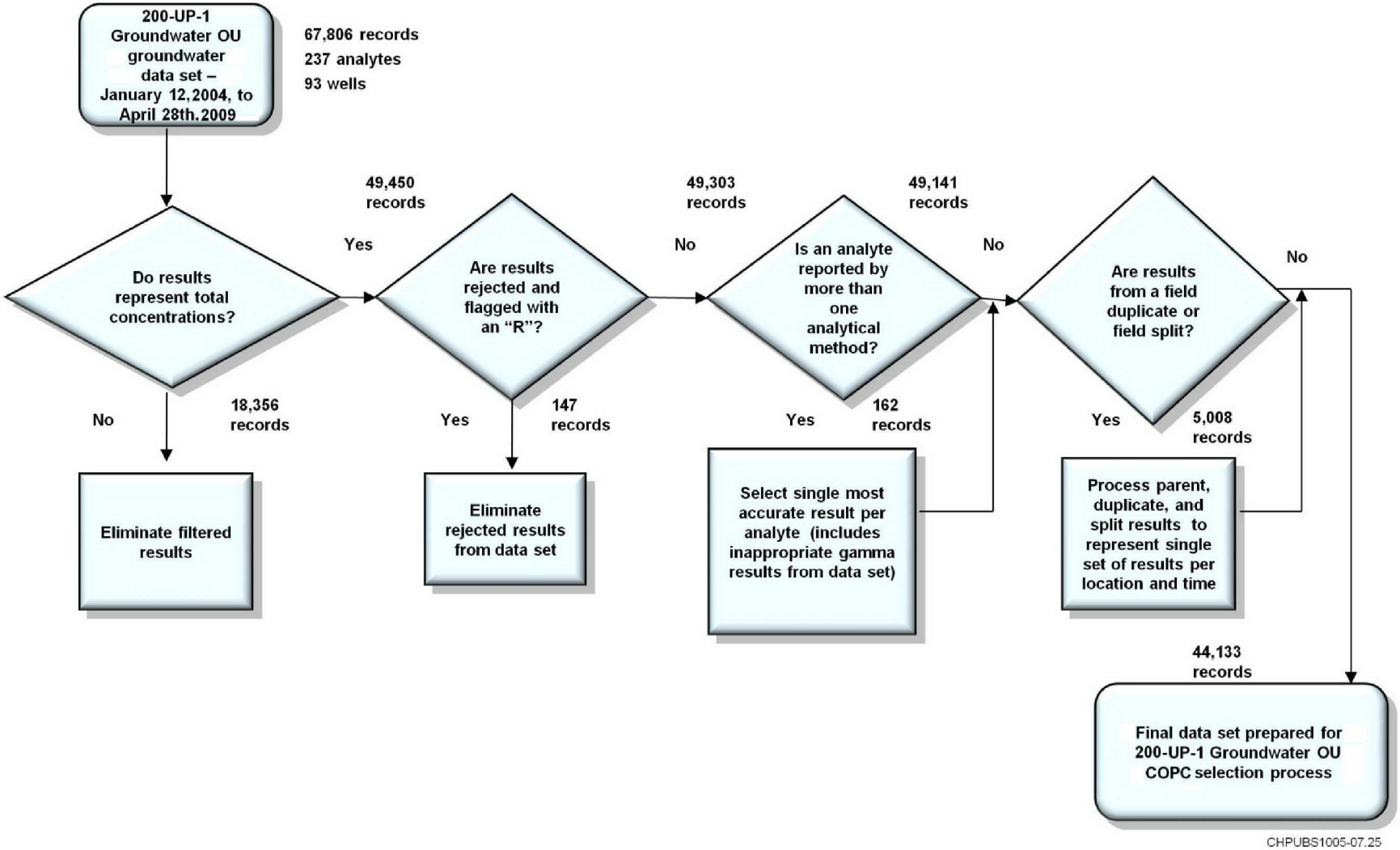


Figure 6-1. Analytical Data Processing for COPC Selection Process

The action level selected for the initial and final COPC selection process represents the lowest of the available chemical-specific ARARs protective of human health, if more than one chemical-specific ARAR exists for a certain analyte. Groundwater within the 200-UP-1 Groundwater OU is not likely to move outside the boundaries within the 1,000-year F&T simulation period, thereby limiting the potential to a future drinking water source only. A detailed description of the derivation of action levels is provided in ECF-200PO1-09-2026.

6.1.3 Process Used to Select Initial Contaminants of Potential Concern

The initial COPC selection process is used to identify those analytes that will be carried forward into the final COPC identification process. This step of the process used sampling and analytical data collected from 93 200-UP-1 Groundwater OU monitoring wells screened in the unconfined aquifer. The purpose of grouping all sampling and analytical data together is to identify those analytes with detected concentrations above the lowest available action level before an EPC is calculated. A detailed description of the initial screening process is provided in ECF-200UP1-10-0231. The COPC screening process steps, number of records, and number of analytes associated with each step are depicted in Figure 6-2 and listed as follows:

- Apply exclusion criteria.
- Identify nondetected analytes.
- Identify analytes with maximum detected concentrations less than action levels.

The results of the initial COPC selection process identified a total of 37 analytes to be carried into the final COPC identification process. Table 6-1 lists the 37 initial COPCs.

Table 6-1. Initial COPCs for the 200-UP-1 Groundwater OU

Metals	Volatile Organic Compounds	Radionuclides
Aluminum Antimony Arsenic Beryllium Cadmium Chromium Cobalt Hexavalent Chromium Iron Lead Manganese Molybdenum Nickel Thallium Uranium	1,1,2-Trichloroethane 1,2-Dichloroethane 1,4-Dioxane Acrolein Benzene Bromodichloromethane Carbon Tetrachloride Chloroform Methylene Chloride Tetrachloroethene Trichloroethene	Gross Alpha Iodine-129 Strontium-90 Technetium-99 Tritium
	Semivolatile Organic Compounds	**Anions**
	Bis(2-ethylhexyl) phthalate	Chloride Fluoride Nitrate Nitrite Nitrogen in Nitrite and Nitrate

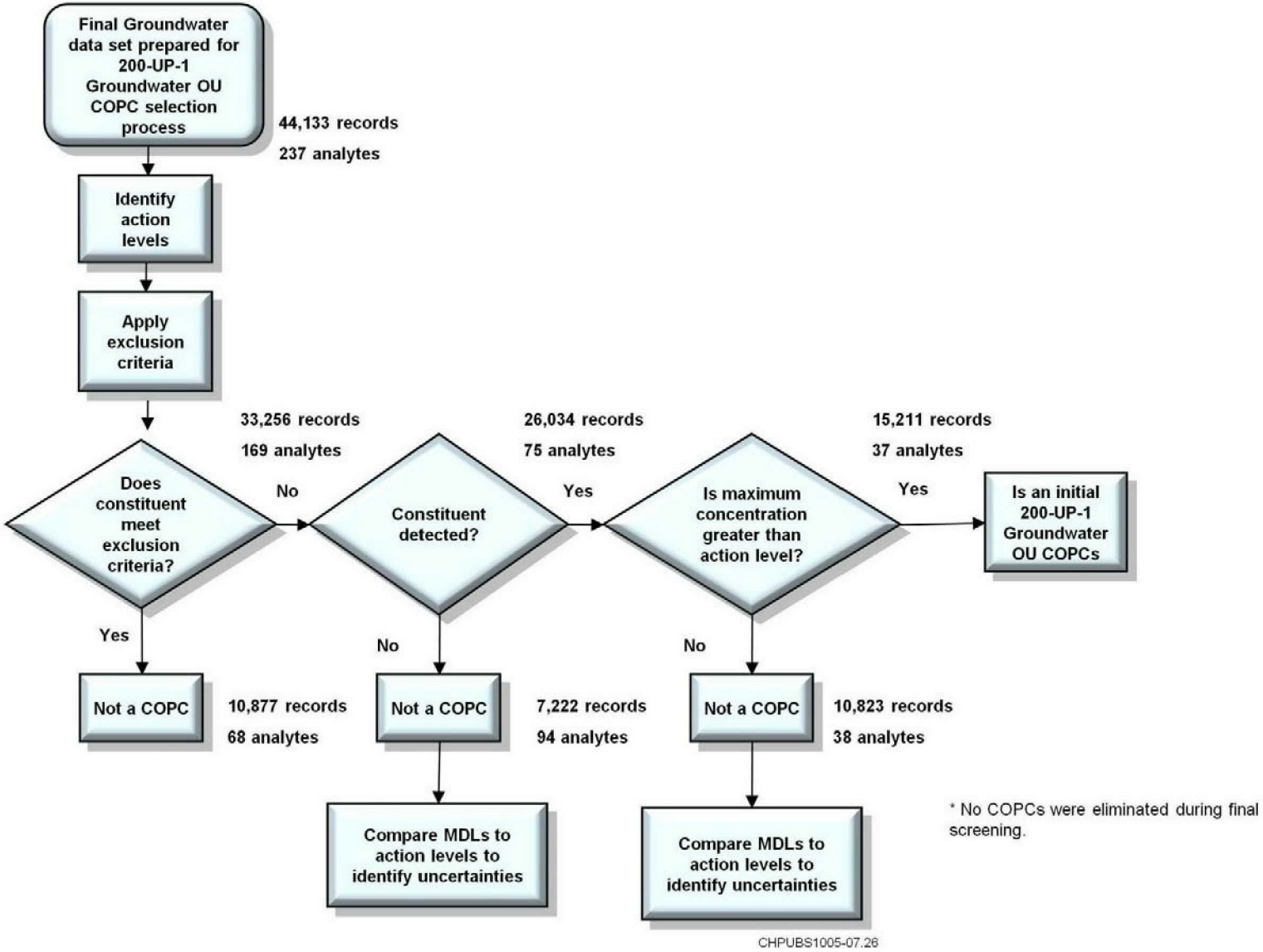


Figure 6-2. COPC Selection—A Multi-Step Process

6.1.4 Process Used to Select Final Contaminants of Potential Concern

Analytes with maximum detected concentrations greater than the action level are carried forward to the final COPC selection process. The final COPC selection process identifies those analytes that will be evaluated in the BRA. Final COPCs are identified by comparing EPCs to their respective action levels, which is different from the process used to identify initial COPCs. As described previously, the action level represents the lowest of the available chemical-specific ARARs. Groundwater within the 200-UP-1 Groundwater OU is expected to move outside the OU boundaries within the 1,000-year F&T simulation period and comingle with the 200-PO-1 plumes. Figure 6-3 depicts the final COPC screening process steps. The sequential steps in the final COPC selection process are as follows:

- Identify nondetected and detected COPCs.
- Calculate 90th percentile value as the EPC for each COPC detected.
- Identify COPCs with EPCs less than action levels.
- Identify COPCs with EPCs greater than action levels.

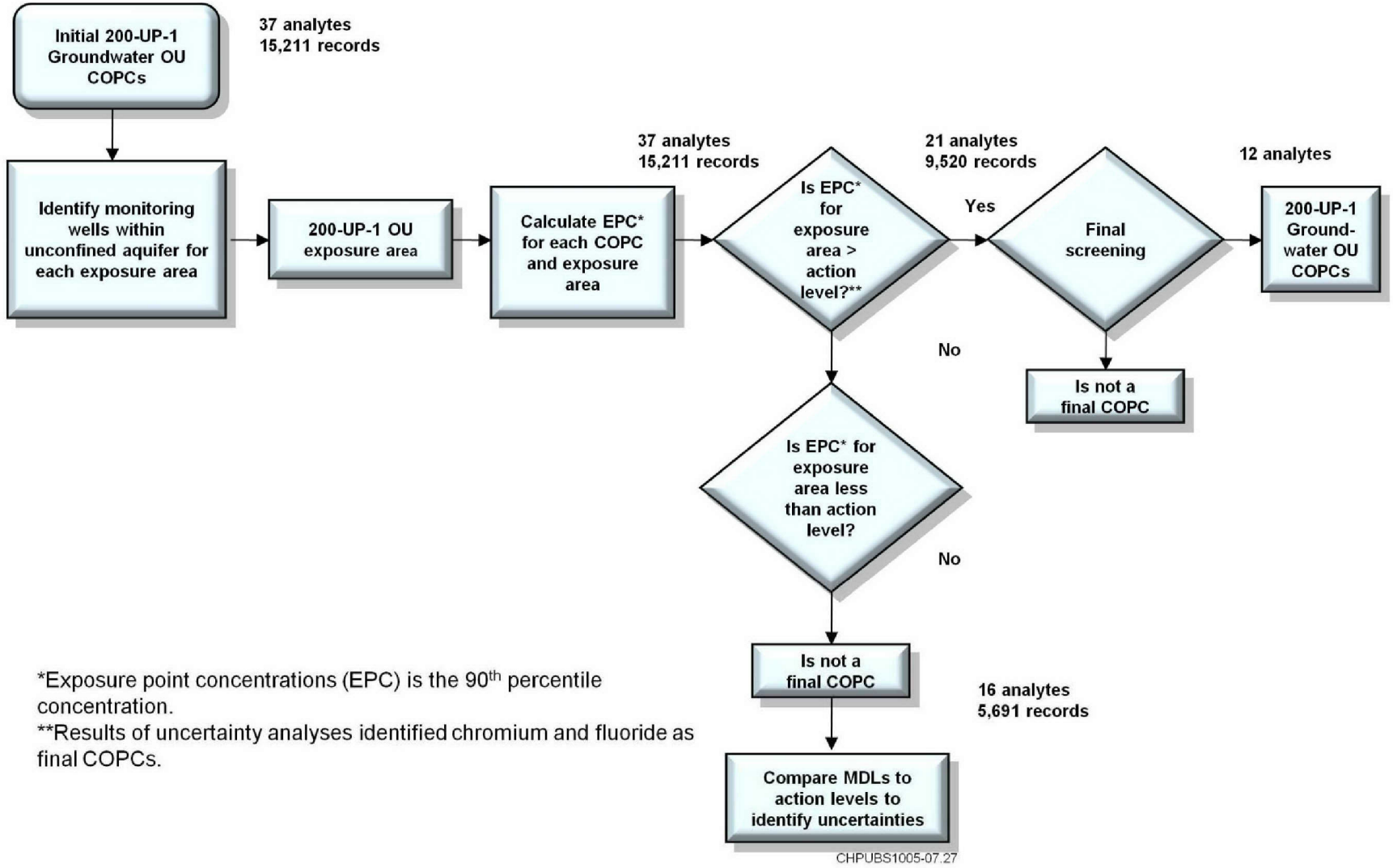
An analyte-specific evaluation is conducted after identifying COPCs with EPCs less than action levels and greater than action levels. These analyte-specific evaluations are performed to ensure that the 90th percentile value is a reasonable estimate of the groundwater exposure area, given the uncertainties associated with the potential for small localized plumes and continuing contributions from vadose sources. Figure 6-4 depicts the steps of the analyte-specific evaluation.

6.1.4.1 Exposure Point Concentrations

Final COPCs are identified by comparing statistical EPC estimates to action levels for each detected COPC. EPCs are calculated as the 90th percentile value for each COPC from the existing groundwater data set (the last 5 years). The method detection limit is used as the concentration for nondetect results in the percentile calculations. The 90th percentile exposure is identified in EPA risk assessment guidance for describing and characterizing health risks, and produces risk estimates that correspond to an RME. A description of the methodology used to calculate the 90th percentile values and the presentation of the 90th percentile values is provided in ECF-200UP1-10-0229.

In general, EPA guidance in OSWER Directive 9285.6-10 recommends using an average 95 percent upper confidence limit (UCL) for estimating EPCs. However, experience at the Site indicates that averages and UCLs cannot be reliably calculated for groundwater data sets. The 200-UP-1 Groundwater OU exhibits an aquifer setting where multiple groundwater contaminants are present in overlapping plumes, and the highest concentrations have different locations within the plumes. The 90th percentile value as an estimate of the reasonable maximum concentration of contamination is a different approach from OSWER 9285.6-10 guidance for estimating EPCs in risk assessments. ECF-200UP1-10-0229 documents the calculation of 95 percent UCLs for each final COPC using EPA's ProUCL 4.0 statistical software package. This calculation also documents the warning statements and comments associated with the use of the recommended 95 UCL value produced from this software package. These warning statements and comments support the conclusion that averages and UCLs cannot be reliably calculated for Site groundwater sets.

The RME represents an exposure scenario within the realistic range of exposure, since the goal of the Superfund program is to protect against high-end, not average, exposures (EPA/100/B-04/001). A high-end exposure is defined as that part of the exposure distribution that is above the 90th percentile, but below the 99.9th percentile. The approach is consistent with EPA/600/Z-92/001. Groundwater concentrations directly reflect potential exposures and risks, so a 90th percentile concentration reflects an RME scenario.



*Exposure point concentrations (EPC) is the 90th percentile concentration.
**Results of uncertainty analyses identified chromium and fluoride as final COPCs.

Figure 6-3. COPC Identification—A Multi-Step Process

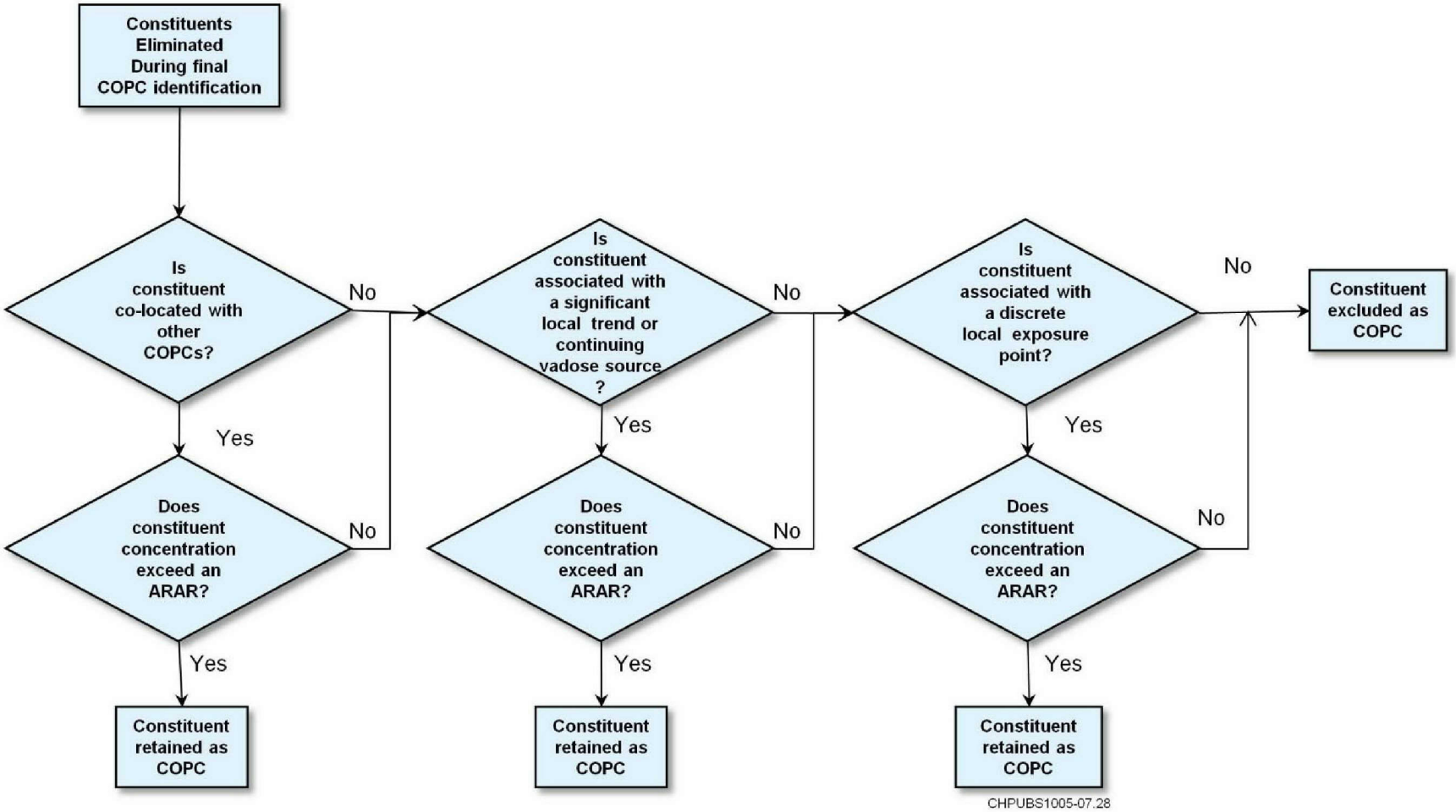


Figure 6-4. Analysis-Specific Evaluation

6.1.5 Summary of Final Groundwater COPCs

The evaluation and selection of the final COPCs for the 200-UP-1 Groundwater OU is presented in ECF-200UP1-10-0231. The final COPCs selected for the 200-UP-1 Groundwater OU are listed in Table 6-2. This list of final COPCs represents the analytes most likely to contribute to overall risk within the 200-UP-1 Groundwater OU.

1,4-Dioxane and Sr-90 are identified as final COPCs with an uncertain status. The 90th percentile value for 1,4-dioxane is 6 µg/L, which is greater than the action level of 4 µg/L. 1,4-Dioxane was detected once at Well 299-W22-20, which is located downgradient of the 216-S-20 Crib at a concentration of 120 µg/L based on the current data set (2004 and 2009). Upon further investigation, 1,4-dioxane was also measured at Well 299-W22-20 between 2002 and 2003 at concentrations ranging between 110 µg/L and 160 µg/L. 1,4-Dioxane was not measured at any other location in the 200-UP-1 Groundwater OU between 1999 and 2009.

The 90th percentile value for Sr-90 is 0.66 pCi/L, which is below the action level of 8 pCi/L. Sr-90 was detected at concentrations ranging between 27 and 76 pCi/L between 2000 and 2005 at Well 299-W22-10, which is located downgradient of the 216-S-1 and 216-S-2 Cribs, no other samples were collected from this location after 2005. Sr-90 was not detected above the action level of 8 pCi/L at any other location in the 200-UP-1 Groundwater OU between 1999 and 2009.

Table 6-2. Final Groundwater COPCs for the 200-UP-1 Groundwater OU

Metals	Volatile Organic Compounds	Radionuclides
Chromium Hexavalent Chromium Uranium	1,4-Dioxane Carbon Tetrachloride Chloroform Tetrachloroethene Trichloroethene	Iodine-129 Strontium-90 Technetium-99 Tritium
		Anions
		Fluoride Nitrate

6.2 Exposure Assessment

The exposure assessment component of the risk assessment typically identifies the populations that may be exposed, the routes by which these receptors may become exposed, and the magnitude, frequency, and duration of potential exposures.

The 200-UP-1 Groundwater OU is evaluated as a single exposure area. The primary objective for evaluating the 200-UP-1 Groundwater OU as a single exposure area is to provide information necessary to determine the need for remedial action and to use the information to select the best remedy. Evaluating the 200-UP-1 Groundwater OU as a single exposure area captures the highest contaminant concentrations from the four primary sources of contamination. If an active secondary source control action is required as part of the selected remedy process, it would likely be applied to groundwater downgradient from one of these sources. Section 5.3 provides a complete description of the 200-UP-1 Groundwater OU including the geographic boundary, sources of contamination, and the list of wells used to evaluate exposure.

The chemical-specific ARARs for use as a drinking water source consider ingestion as a complete and significant pathway for exposure. Washington State procedures assume that inhalation of vapors for VOCs is also a complete and significant exposure pathway. Washington State procedures do not include the dermal contact exposure route in the equations for calculation of potable groundwater cleanup levels. Omission of the dermal contact exposure route from chemical-specific ARARs may result in an underestimation of the cleanup level; uncertainties associated with exclusion of this exposure route are addressed in Section 6.5.

6.3 Toxicity Assessment

The toxicity assessment component evaluates the relationship between the magnitude of exposure to an analyte and the likelihood of adverse health effects to potentially exposed populations. Similar to the exposure assessment, the comparison to chemical-specific ARARs takes into consideration the likelihood of an adverse health effect to occur to the potentially exposed population. The risk-based concentrations, such as the WAC 173-340-720, are developed using toxicological information published at EPA's Integrated Risk Information System (IRIS) Web site available at: http://www.epa.gov/iris/ and EPA's hierarchy of toxicity values described in Section 6.3. The assignment of chemical-specific ARARs to COPCs is described in Section 6.1.

6.3.1 State and Federal MCLs for Non-Radionuclides

The MCLG is the maximum level of a contaminant in drinking water at which no known or anticipated adverse health effects occur, allowing for an adequate margin of safety. MCLGs are non-enforceable health goals. EPA establishes the MCL based on the MCLG. The MCL is the maximum permissible level of a contaminant in water that is delivered to any user of a public water system. Prior to the 1996 Amendments to the SDWA, the MCL was set as close to the MCLG as was feasible. The 1996 SDWA Amendments permit consideration of costs and benefits in establishing an MCL. MCLs are enforceable standards.

A description of how MCLGs are derived is provided in EPA 822-R-03-008. MCLGs are developed using an oral reference dose (RfD) for contaminants that exhibit a threshold toxic effect. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious non-cancer effects during a lifetime. EPA generally assumes that the relative source contribution from drinking water is 20 percent of the RfD, unless other exposure data for the chemical are available. This allows 80 percent of the total exposure to come from sources other than drinking water, such as exposure from food, inhalation, or dermal contact.

EPA has also used several different systems for classifying the contaminants' carcinogenicity (EPA 822-R-03-008). For drinking water contaminants regulated prior to the 1996 SDWA Amendments, the Office of Water followed a three-category, regulatory cancer classification system (Categories I, II, or III). These categories specify decisions as to the degree of concern for an agent's carcinogenic potential as a contaminant of drinking water, and define to some extent the approach to risk management that is taken for establishing MCLGs. EPA also used the six alphanumeric categories (A, B1, B2, C, D, E) of the 1986 cancer guidelines in EPA/630/P-03/001F for establishing the MCLG. The six-group classification system is often equated to the three-category system in the national primary drinking water regulations (NPDWRs) Federal Register announcements. If a chemical is a known or a probable human carcinogen (Category I, generally Group A or B), the MCLG is generally set at zero. This is because it is assumed that in the absence of other data, there is no known threshold for carcinogenicity. If a chemical falls in Group C, a RfD approach, along with an additional safety factor is used in deriving the MCLG.

Through consultations with stakeholders representing a broad range of interest groups, and internal EPA deliberations, EPA 815-R-03-002 was developed based on NDWAC, 2000. The document outlines how to review and identify NPDWRs that warrant revision to maintain, or provide for greater, public health protection. The key elements of the review process are health effects, analytical and treatment technology, other regulatory revisions (monitoring and reporting requirements), occurrence and exposure analysis and, as appropriate, economic considerations. A 6-year review cycle is performed for the health effects component of the review process. The purpose of the health effects component is to identify, within the limitations of the Agency's available resources, new health risk assessments that indicate possible change to the MCLG and possibly the MCL. The last review was conducted in 2003 and reported in EPA 822-R-03-008.

6.3.2 Maximum Contaminant Levels for Radionuclides in Drinking Water

Current MCLs for radionuclides are set at a 4 mrem/yr dose basis for the sum of the doses from beta particle and photon emitters, 15 pCi/L for gross alpha emitter activity concentration (including Radium-226 [Ra-226], but excluding uranium and radon), and 5 pCi/L combined activity concentration for Ra-226 and Radium-228 (Ra-228). A mass concentration MCL has been established for uranium as 30 µg/L. The current MCLs for beta emitters specify that MCLs are to be calculated based on an annual dose equivalent of 4 mrem to the total body or any internal organ. It is further specified that the calculation is performed on the basis of a 2 L/day (0.5 gal/day) drinking water intake, using the 168-hour data listed in National Bureau of Standards (NBS) Handbook 69.

6.3.3 Washington State Regulations

Toxicological parameter values are obtained from the Cleanup Levels and Risk Calculations (CLARC) Web-based compendium of technical information related to the calculation of cleanup levels under the MTCA cleanup procedures, WAC 173-340, available at: https://fortress.wa.gov/ecy/clarc/CLARCOverview.aspx. The sources for the oral cancer potency values and oral reference doses are provided in the CLARC database. The sources for identifying reference doses and carcinogenic potency factors are defined in WAC 173-340-708(7) and WAC 173-340-708(8), respectively.

In general, the sources of toxicity values defined by WAC 173-340-708(7) and (8) differ from the recommended hierarchy for sources as described in OSWER Directive 9285.7-53 (Cook, 2003). As a result of this difference, toxicity values were determined using the following recommended reference hierarchy (Cook, 2003):

- Tier 1—The EPA IRIS
- Tier 2—The EPA Provision Peer Reviewed Toxicity Values (PPRTVs)
- Tier 3—Other Toxicity Values

Tier 3 toxicity values include additional EPA and non-EPA sources of toxicity information, including: the California EPA Toxicity Criteria Database, the Agency for Toxic Substances and Disease Registry Minimal Risk Levels for Hazard Substances, and toxicity values in EPA/540/R-97-036. Each of the Tier 3 toxicity values can be found in EPA, 2009.

When Tier 1, Tier 2, or Tier 3 toxicity values were not available for a chemical, the toxicity values from the National Center for Environmental Assessment (NCEA) were used. NCEA values can be found in the Oak Ridge National Laboratory *Risk Assessment Information System* (RAIS) database available at: http://rais.ornl.gov/.

Toxic equivalence factors were used to calculate toxicity values for dioxins, furans, and carcinogenic polynuclear aromatic hydrocarbons, as described in WAC-173-340-708(8)(d)(iii)(A).

The toxicity value published in the CLARC Web site was selected for final COPCs when Cook (2003) recommended a different source of information. The alternative toxicity values published by the States of New Jersey and California, described as follows, were not used for the purposes of calculating groundwater cleanup levels. The toxicity values currently have an uncertain status because the science is still emerging and EPA's NCEA has not evaluated these values. Therefore, the values currently recommended in the CLARC Web site were selected for calculating groundwater cleanup levels. The differences in toxicity values for final COPCs are summarized as follows.

- The oral cancer potency factor of 0.089 $(mg/kg\text{-}day)^{-1}$ for TCE published by the Health Effects Assessment Summary Tables (HEAST) is the value published on Ecology's CLARC Web site and is used to develop the WAC 173-340-720 groundwater cleanup level. HEAST has not been updated since 1997 and, therefore, does not reflect the most current source of information for the oral cancer potency factor. The source of this toxicity value is consistent with the hierarchy of toxicity values recommended in Cook, 2003. However, the oral slope factor (SF_O) currently implemented by EPA for TCE in the Regional Screening Levels Web site is established by the California Environmental Protection Agency (CalEPA) Office of Environmental Health Hazard Assessment (OEHHA). The SF_O derived by OEHHA is 0.0059 $(mg/kg\text{-}day)^{-1}$, as presented in OEHHA, 2009. If the CalEPA values were used to calculate the WAC 173-340-720 groundwater cleanup level, the groundwater concentration would increase from 0.49 µg/L to 7.4 µg/L. While the CalEPA toxicity value may be more current, the existing value published by Ecology provides a more conservative cleanup level in groundwater.

- The RfD of 0.06 mg/kg-day for fluoride is the value published on Ecology's CLARC Web site and is used to develop the WAC 173-340-720 groundwater cleanup level. The RfD originally was published on IRIS, but the value provided by Ecology has not been updated since 1989, and the RfD does not reflect the most current source of information. The RfD currently implemented by EPA for fluoride is established by the CalEPA OEHHA and documented in OEHHA, 2009. The source of this toxicity value is consistent with the hierarchy of toxicity values recommended in Cook, 2003. If the CalEPA RfD was used to calculate the WAC 173-340-720 groundwater cleanup level, the groundwater concentration would decrease from 480 µg/L to 320 µg/L.

- The RfD of 0.003 mg/kg-day that is published by IRIS is used to develop the WAC 173-340-720 groundwater cleanup level for hexavalent chromium. An oral carcinogenic potency factor has recently been published by the New Jersey Department of Environmental Protection (NJDEP). The oral carcinogenic potency factor derived by NJDEP is 0.5 $(mg/kg\text{-}day)^{-1}$, as presented in Stern, 2009. If the NJDEP value was used to calculate the WAC 173-340-720 groundwater cleanup level, the groundwater concentration would decrease from 48 µg/L to 0.18 µg/L.

- The RfD of 0.2 mg/kg-day that is published by the PPRTV is used to develop the WAC 173-340-720 groundwater cleanup level for 1,1-dichloroethane. An oral carcinogenic potency factor has recently been published by the CalEPA OEHHA. The oral carcinogenic potency factor derived by OEHHA is 0.0057 $(mg/kg\text{-}day)^{-1}$, as presented in OEHHA, 2003. If the value published by CalEPA was used to calculate the WAC 173-340-720 groundwater cleanup level, the groundwater concentration would decrease from 1,600 µg/L to 7.7 µg/L.

6.4 Risk Characterization

Risk characterization is the summarizing step of a risk assessment. The risk characterization step is completed through the comparison of the EPC to the chemical-specific ARAR. As described earlier in this chapter, the comparison to chemical-specific ARARs determines whether existing groundwater concentrations are protective of HHE. It is also used to determine if current groundwater concentrations have the potential to exceed an HI greater than 1, or the upper end of the NCP risk range for cumulative carcinogenic site risk to an individual based on reasonable maximum exposure for both current and future land use.

6.4.1 Protectiveness Evaluation

Protectiveness of human health is determined by the comparison of 90th percentile groundwater concentrations to existing federal or state MCLs or nonzero MCLGs.

6.4.2 Risk Evaluation

This risk characterization step is included to address the presence of multiple exposure pathways or the potential for exposure to multiple contaminants. The presence of either one of these conditions may render ARARs not to be adequately protective. This step is also included to address the requirements of WAC 173-340-708(5)(a) and WAC 173-340-708(6)(b). These procedures require that cleanup levels be adjusted downward to take into account exposure to multiple hazardous substances or multiple pathways of exposure. This adjustment needs to be made only if, without this adjustment, the HI would exceed one (1) or the total ELCR would exceed one in 1000,000 (1×10^{-5}).

For the potential to exceed an HI greater than 1, or the upper end of the NCP risk range for cumulative carcinogenic site risk to an individual based on RME for both current and future land use, the following standard is used.

- WAC 173-340-720

For the purposes of this evaluation, the potential for unacceptable human health risk is identified using the following risk thresholds based on Clay, 1991:

- ELCR values are compared to the point of departure range of 10^{-6} to 10^{-4} that is generally used by regulatory agencies. The WAC 173-340 states that cancer risks resulting from multiple hazardous substances should not exceed 1×10^{-5} for unrestricted land use. ELCR values within or exceeding this range require a risk management decision that includes evaluating site-specific characteristics and exposure scenario factors to assess whether remedial action is warranted.

- An HI (the ratio of chemical intake to the RfD for all constituents) greater than 1 indicates that there is some potential for adverse non-cancer health effects associated with exposure to the COPCs.

Although this risk assessment produces numerical estimates of risk, it should be recognized that these numbers might not predict actual health outcomes because they are based largely on hypothetical assumptions. Their purpose is to provide a frame of reference for risk management decision making. Interpretation of the risk estimates provided should consider the nature and weight of evidence supporting these estimates, as well as the magnitude of uncertainty surrounding them.

Protectiveness of humans from exposure to radionuclides is determined by an annual dose equivalent to the body or any internal organ; therefore, a risk evaluation is not conducted for final COPCs that are radionuclides.

6.4.2.1 Cancer Risk Estimation Method

The potential for cancer effects is evaluated by estimating the ELCRs. This risk is an incremental increase in the probability of developing cancer during one's lifetime in addition to the background probability of developing cancer (if no exposure to site chemicals occurs). For example, a 2×10^{-6} ELCR means that, for every 1 million people exposed to the carcinogen throughout their lifetimes, the average incidence of cancer may increase by two cases of cancer. As previously mentioned, cancer slope factors developed by EPA represent upper bound estimates. Therefore, any cancer risks generated in this assessment should be regarded as an upper bound on the potential cancer risks rather than accurate representations of true cancer risk. The true cancer risk is likely to be less than that predicted (EPA/540/1-89/002).

Although synergistic or antagonistic interactions might occur between cancer-causing chemicals and other chemicals, information is generally lacking in the toxicological literature to predict quantitatively the effects of these potential interactions. Therefore, cancer risks are treated as additive within an exposure route in this assessment. This is consistent with the EPA guidelines on chemical mixtures (EPA/630/R-00/002). To estimate the cancer risks from exposure to an individual carcinogen from all exposure routes considered, the following equation is used:

$$Risk_I = \frac{EPC_{water}}{CUL_{carcinogen}} \times TR$$

Where:

$Risk_I$ = Excess lifetime cancer risk for individual chemical

EPC_{water} = 90th percentile concentration in groundwater (µg/L)

$CUL_{carcinogen}$ = Groundwater cleanup level based on carcinogenic effect (µg/L)

TR = Target excess lifetime cancer risk for individual hazardous substance for unrestricted land use (10^{-6})

To estimate the cancer risks from exposure to multiple carcinogens from all exposure routes considered, the following equation is used:

$$Risk_T = \sum_{i}^{N} \frac{EPC_{water}}{CUL_{carcinogen}} \times TR$$

Where:

$Risk_T$ = Total ELCR for all chemicals

EPC_{water} = 90th percentile concentration in groundwater (µg/L)

$CUL_{carcinogen}$ = Groundwater cleanup level based on carcinogenic effect (µg/L)

TR = Target excess lifetime cancer risk for individual hazardous substance for unrestricted land use (10^{-6})

6.4.2.2 Non-Cancer Risk Estimation Method

For non-cancer effects, the likelihood that a receptor will develop an adverse effect is estimated by comparing the predicted level of exposure for a particular chemical with the highest level of exposure that is considered protective (that is, its RfD). The ratio of the chronic daily intake (CDI) divided by RfD is termed the hazard quotient (HQ).

When the HQ for a chemical exceeds 1 (exposure exceeds RfD), there is a concern for potential non-cancer health effects. To assess the potential for non-cancer effects posed by exposure to multiple chemicals, an HI approach was used according to EPA/540/1-89/002. This approach assumes that the non-cancer hazard associated with exposure to more than one chemical is additive; therefore, synergistic or antagonistic interactions between chemicals are not accounted for. The HI may exceed 1, even if all the individual HQs are less than 1. In this case, the chemicals may be segregated by similar mechanisms of toxicity and toxicological effects. Separate HIs may then be derived based on mechanism and effect. To estimate the HQ from all exposure routes considered for an individual hazardous substance the following equation is used:

$$HQ = \frac{EPC_{water}}{CUL_{noncarcinogen}}$$

Where:

HQ	=	HQ for individual chemical
EPC_{water}	=	90th percentile concentration in groundwater (µg/L)
$CUL_{noncarcinogen}$	=	Groundwater cleanup level based on noncarcinogenic effects (µg/L)

To estimate the HI from all exposure routes considered for multiple hazardous substances the following equation is used:

$$HI_T = \sum_i^N \frac{EPC_{water}}{CUL_{noncarcinogen}}$$

Where:

HI_T	=	Total HI for all chemicals
EPC_{water}	=	90th percentile concentration in groundwater (µg/L)
$CUL_{noncarcinogen}$	=	Groundwater cleanup level based on noncarcinogenic effects (µg/L)
I	=	The sum of the ratios for the ith chemical

6.4.2.3 Estimating the Sum of Fractions and 4 mrem/yr Dose Equivalent

An annual cumulative dose equivalent of less than 4 mrem to the total body or any internal organ is considered protective of human health. The sum of fractions is used to determine whether the contribution of each radioisotope is equal to, or greater than, the cumulative annual dose equivalent of 4 mrem. The following equation is used to determine if the 4 mrem standard is exceeded when there is a mixture of radioisotopes present:

$$Sum\ of\ Fractions = \left(\frac{A\left(\frac{pCi}{L}\right)}{MCL_A\left(\frac{pCi}{L}\right)} + \frac{B\left(\frac{pCi}{L}\right)}{MCL_B\left(\frac{pCi}{L}\right)} + .\bullet\bullet\bullet \right)$$

The 4 mrem standard is not exceeded if the sum of fractions is less than or equal to one. Each fraction is converted to a dose equivalent by multiplying the fraction by 4.

6.4.3 Results of the Chemical Specific ARAR Analysis

This section presents the evaluation of the final COPCs as to whether the 90th percentile groundwater concentrations are considered protective and if the concentrations result in an exceedance of risk threshold standards.

A comprehensive set of chemical-specific ARARs that are considered protective of HHE were used to identify final COPCs. The lowest of the available chemical-specific ARARs was selected for comparison if more than one chemical-specific ARAR exists for a certain analyte. With the exception of the analytes listed in Table 6-3, the 90th percentile groundwater concentrations for all COPCs were less than the lowest available chemical-specific ARAR.

Table 6-3 provides a summary of the final COPCs, the 90th percentile groundwater concentration, federal and state MCLs, and the WAC 173-340-720 groundwater cleanup standards for carcinogenic and noncarcinogenic effects. Federal and state MCLs and WAC 173-340-720 groundwater cleanup levels represent the chemical-specific ARARs that were exceeded.

Table 6-3. Summary of Current Conditions 90th Percentile Groundwater Concentrations, Federal and State MCLs and WAC 173-340-720 Groundwater Cleanup Levels

					WAC 173-340-720 Cleanup Levels		
Final COPCs	**Units**	**90th Percentile Value**	**Federal MCL**	**State MCL**	**Non-Carcinogens**	**Carcinogens at 10^{-6} Risk Level**	**Carcinogens at 10^{-5} Risk Level**
Iodine-129	pCi/L	3.5	1	--	--	--	--
Strontium-90	pCi/L	0.66	8	--	--	--	--
Technetium-99	pCi/L	4,150	900	--	--	--	--
Tritium	pCi/L	51,150	20,000	--	--	--	--
Carbon Tetrachloride	µg/L	189	5	5	5.6	0.34	3.37
Chloroform	µg/L	7.2	80	--	--	1.4	14
1,4-Dioxane	µg/L	6.0	--	--	800	4.0	40
Tetrachloroethene	µg/L	1.0	5	5	80	0.081	0.81
Trichloroethene	µg/L	3.3	5	5	2.4	0.49	4.9
Chromium	µg/L	99	100	100	24,000	--	--
Fluoride	µg/L	470	2,000	4,000	480	--	--

Table 6-3. Summary of Current Conditions 90th Percentile Groundwater Concentrations, Federal and State MCLs and WAC 173-340-720 Groundwater Cleanup Levels

Final COPCs	Units	90th Percentile Value	Federal MCL	State MCL	WAC 173-340-720 Cleanup Levels		
					Non-Carcinogens	Carcinogens at 10^{-6} Risk Level	Carcinogens at 10^{-5} Risk Level
Hexavalent Chromium	µg/L	52	--	--	48	--	--
Nitrate	µg/L	133,000	45,000	45,000	25,600	--	--
Uranium	µg/L	206	30	--	48	--	--

COPC = contaminant of potential concern
MCL = maximum contaminant level

6.4.3.1 Protectiveness Evaluation

The protectiveness evaluation is performed to help determine if a CERCLA remedial action is appropriate. EPA 540-R-97-013 states that a remedial action is generally appropriate when a regulatory standard that helps define protectiveness (a federal or state MCL or nonzero MCLG for current or potential drinking water aquifers) is exceeded. The 90th percentile groundwater concentration for I-129, Tc-99, and tritium are greater than their respective federal MCLs. As Table 6-4 shows, potential exposure to groundwater as a drinking water source would result in a dose greater than 4 mrem per year from each of these three isotopes. The 90th percentile groundwater concentrations are not considered protective of human health, thus indicating the need to evaluate potential remedial technologies for I-129, Tc-99, and tritium. Of the 93 wells, 18 monitoring wells were reported with I-129 concentrations greater than the MCL of 1 pCi/L, 24 monitoring wells were reported with Tc-99 concentrations greater than the MCL of 900 pCi/L, and 22 wells were reported with tritium concentrations greater than the MCL of 20,000 pCi/L.

Table 6-4. Summary of 90th Percentile Current Groundwater Concentrations and Associated Sum of Fractions

Final COPC	Units	90th Percentile Value	Federal or State MCL	Individual Fraction
Iodine-129	pCi/L	3.5	1	3.5
Strontium-90	pCi/L	0.66	8	0.08
Technetium-99	pCi/L	4,150	900	4.6
Tritium	pCi/L	51,150	20,000	2.6
Sum of Fractions				**10.8**
Cumulative Annual Dose (mrem)				**42.8**

Notes: MCL; Derived single-nuclide MCL-equivalent activity concentration
COPC = contaminant of potential concern
MCL = maximum contaminant level

The 90th percentile groundwater concentration of Sr-90 is less than the federal MCL and is a minimal contribution to overall dose. Sr-90 has only been detected in Well 299-W22-10 at concentrations above the MCL, indicating its presence is localized downgradient of the 216-S-1 and 216-S-2 Cribs. The 90th percentile is considered protective of human health, however its presence warrants design considerations for any engineered controls or remedial actions performed in this OU.

The 90th percentile groundwater concentration for chromium is approximately equal to the federal and state MCL of 100 μg/L. This indicates that potential exposure to groundwater as a drinking water source would result in adverse health effects. The 90th percentile groundwater concentration is not considered protective of human health. Of the 93 monitoring wells, five monitoring wells were reported with concentrations of chromium above 100 μg/L.

A federal DWS is not available for hexavalent chromium, therefore the protectiveness evaluation was not performed.

The 90th percentile groundwater concentration for uranium is greater than the federal MCL value of 30 μg/L. This indicates that potential exposure to groundwater as a drinking water source may result in adverse health effects. The 90th percentile groundwater concentration is not considered protective of human health. Of the 93 monitoring wells, 15 monitoring wells were reported with concentrations of uranium above 30 μg/L.

The 90th percentile groundwater concentration for carbon tetrachloride is greater than the federal MCL value of 5 μg/L. This indicates that potential exposure to groundwater as a drinking water source may result in adverse health effects. The 90th percentile groundwater concentration is not considered protective of human health. Of the 93 monitoring wells, 56 monitoring wells were reported with concentrations of carbon tetrachloride above 5 μg/L. Carbon tetrachloride is being addressed by the 200-ZP-1 final remedial action.

The 90th percentile groundwater concentrations for chloroform, PCE, and TCE are less than their respective federal MCL. It should be noted that the applicable MCL for chloroform is not chemical-specific, but is the limit for total trihalomethanes. The need to evaluate remedial technologies for these VOCs is not established based on the comparison of the 90th percentile value to the MCL.

The 90th percentile groundwater concentration for nitrate (NO_3) concentration is greater than the federal and state MCL of 45,000 μg/L and 25,600 ug/L in WAC 173-340-720. This indicates that potential exposure to groundwater as a drinking water source may result in adverse health effects. The 90th percentile groundwater concentration is not considered protective of human health. Of the 93 wells, 82 monitoring wells were reported with concentrations of nitrate above the state and federal MCL (as well as WAC) of 45,000 μg/L.

6.4.3.2 Risk Evaluation

The risk evaluation is also performed to help determine whether a CERCLA remedial action is appropriate. EPA 540-R-97-013 states that a remedial action is generally appropriate when the estimated risk calculated in a risk assessment exceeds a non-carcinogenic level for an adverse health effect or the upper end of the NCP risk range for "cumulative carcinogenic site risk" to an individual based on RME for both current and future land use. The potential cumulative ELCR from all nonradiological carcinogenic COPCs is 5.8×10^{-4}, which is greater than the WAC 173-340-780 risk threshold of 1×10^{-5} for multiple hazardous substances and the upper NCP threshold of 1×10^{-4}. Table 6-5 shows the contributors to risk include carbon tetrachloride (5.6×10^{-4}, 95.6 percent contribution); chloroform ($5.1 \times 10^{-6,}$ 0.9 percent contribution); 1,4-dioxane ($1.5 \times 10^{-6,}$ 0.3 percent contribution); PCE (1.2×10^{-5}, 2.1 percent contribution); and TCE (6.7×10^{-6}, 1.2 percent contribution).

Although the 90th percentile groundwater concentration of 1,4-dioxane is greater than the groundwater cleanup level, it is a minimal contribution to total risk. 1,4-Dioxane has only been detected in well 299-W22-20 at concentrations above the groundwater cleanup level, indicating its presence is localized downgradient of the 216-S-20 Crib. Because of the localized presence of 1,4-dioxane, its presence warrants design considerations for any engineered controls performed in this OU.

Table 6-5. Summary of 90th Percentile Current Groundwater Concentrations and Associated Cancer Risk and Non-Cancer Hazard Index

Final COPC	Units	90th Percentile Value	WAC 173-340-720 Cleanup Levels			
			Non Carcinogens	HQ/HI	Carcinogens at 10^{-6} Risk Level	ELCR
Carbon Tetrachloride	µg/L	189	5.6	34	0.34	5.6 × 10-04
Chloroform	µg/L	7.2	80	0.09	1.4	5.1 × 10-06
1,4-Dioxane	µg/L	6.0	800	<0.01	4.0	1.5 × 10-06
Tetrachloroethene	µg/L	1.0	80	0.01	0.081	1.2 × 10-05
Trichloroethene	µg/L	3.3	--	--	0.49	6.7 × 10-06
Total ELCR					**--**	**5.8 × 10-04**
Chromium	µg/L	99	24,000	<0.01	--	--
Fluoride	µg/L	470	480	0.98	--	--
Hexavalent Chromium	µg/L	52	48	1.1	--	--
Nitrate	µg/L	133,000	25,600	5.2	--	--
Uranium	µg/L	206	48	4.3	--	- -
Hazard Index				**45**		

COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index
HQ = hazard quotient

The HI for the 200-UP-1 Groundwater OU is 45, which is greater than the EPA and WAC 173-340 target HI of 1. The primary contributors to the non-cancer HI are carbon tetrachloride (HQ = 34, 74 percent contribution); nitrate (HQ = 5.2, 11 percent contribution); uranium (HQ = 4.3, 9.4 percent contribution); and hexavalent chromium (HQ = 1.1, 2.4 percent contribution). The primary non-cancer health effects associated with exposure to the primary contributors to the HI are as follows:

- Carbon tetrachloride—liver toxicity
- Nitrate—methemaglobenemia
- Uranium—kidney toxicity
- Hexavalent chromium—nasal septum atrophy

It is appropriate to segregate the individual HQs because of the differences in toxicological effects and target organs.

6.4.3.3 Estimated Future Risk Conditions

Future risk conditions are estimated for the 200-UP-1 Groundwater OU. The purpose of estimating future risk conditions in groundwater is to estimate what changes in COPC concentrations may occur within the aquifer system over the period of time selected to indicate the practical duration of administrative control over the Site. Future groundwater concentrations are calculated to 1,000 years, to identify the timeframe when each groundwater COPC meets chemical-specific ARARs. The methodology used to estimate future groundwater concentrations within the 1,000-year F&T simulation period is described in Chapter 5 of this report. The methodology used to represent the exposure area spatially and chemically for the purpose of estimating future groundwater risk conditions is described as follows.

Step 1—Identify Final COPCs in Exposure Area. Table 6-6 lists the final COPCs for the 200-UP-1 Groundwater OU. Future groundwater concentrations are estimated for each of the final COPCs that currently report a 90th percentile concentration greater than the MCL or when the WAC 173-340-708 cumulative risk threshold is greater than 1×10^{-5} for multiple hazardous substances.

Future groundwater conditions are not estimated for carbon tetrachloride measured in the 200-UP-1 Groundwater OU. This is because the source of carbon tetrachloride originates from the 200-ZP-1 Groundwater OU and is actively being treated as part of the remedial design for this OU. The feasibility study for the 200-UP-1 Groundwater OU will not address the presence of carbon tetrachloride. In addition, future groundwater conditions are not estimated for 1,4-dioxane and Sr-90. The presence of 1,4-dioxane and Sr-90 is localized and measured in one well (299-W22-20 and 299-W22-10, respectively), therefore these final COPCs were not carried forward into the analysis of future risk conditions.

Step 2—Identify Monitoring Well Locations within the OU. Monitoring well locations reported with concentrations of final COPCs greater than the action levels are identified. Table 7-6 of ECF-200UP1-10-0231 lists the monitoring wells from each exposure area that report concentrations of final COPCs greater than their respective action levels. Of the 93 wells in the 200-UP-1 Groundwater OU, 90 wells were reported with concentrations of 1 or more final COPCs above the action level. A subset of 23 wells was selected to provide spatial and chemical representation of contamination within the OU (Table 6-6).

Step 3—Calculate Future Groundwater Concentrations. Table 6-6 lists the future groundwater concentrations calculated for each of the final COPCs at each of the monitoring well locations. To determine the approximate timeframe for when cleanup levels are attained, future groundwater concentrations are selected at 25-year intervals for up to 200 years and at 100-year intervals thereafter for each location and each final COPC.

Step 4—Calculate 90th Percentile Groundwater Concentrations. A 90th percentile groundwater concentration is calculated for each final COPC within the OU at each 25-year and 100-year time interval. The methodology, inputs, and equations used to calculate the future 90th percentile groundwater concentrations are documented in ECF-200UP1-10-0230. The 90th percentile groundwater concentrations are then compared to the federal and state MCLs and the WAC 173-340-720 groundwater cleanup levels. The year when the 90th percentile value has achieved the MCL or the WAC 173-340-720 groundwater cleanup levels is identified.

Table 6-6. 200-UP-1 Groundwater OU Monitoring Wells Selected for Calculating Future Groundwater Concentrations

Final COPC and Action Level											
Well Name	**I-129 (1 pCi/L)**	**Tc-99 (900 pCi/L)**	**Tritium (20,000 pCi/L)**	**Chromium (100 µg/L)**	**Fluoride (480 µg/L)**	**Hexavalent Chromium (48 µg/L)**	**Nitrate (25,600 µg/L)**	**Uranium (30 µg/L)**	**Chloroform (1.4 µg/L)**	**PCE (0.081 µg/L)**	**TCE (0.49 µg/L)**
299-W14-71					x				x	x	x
299-W18-15							x	x	x		
299-W18-21							x	x			
299-W18-30		x		x	x		x		x		x
299-W19-101		x			x		x	x	x		x
299-W19-35		x					x	x	x	x	x
299-W19-36		x			x		x	x	x	x	x
299-W19-40	x				x		x	x			
299-W19-48	x	x			x		x	x	x	x	x
299-W22-44		x		x			x				
299-W22-47		x	x	x	x		x		x		x
299-W22-72	x		x		x						
299-W22-83		x		x		x	x		x		
299-W22-86		x			x	x	x		x		
299-W23-19		x	x		x		x				
299-W23-4			x					x	x	x	x
699-30-66						x			x		
699-33-74	x	x							x		
699-34-72	x		x				x		x		x

Table 6-6. 200-UP-1 Groundwater OU Monitoring Wells Selected for Calculating Future Groundwater Concentrations

Final COPC and Action Level											
Well Name	**I-129 (1 pCi/L)**	**Tc-99 (900 pCi/L)**	**Tritium (20,000 pCi/L)**	**Chromium (100 µg/L)**	**Fluoride (480 µg/L)**	**Hexavalent Chromium (48 µg/L)**	**Nitrate (25,600 µg/L)**	**Uranium (30 µg/L)**	**Chloroform (1.4 µg/L)**	**PCE (0.081 µg/L)**	**TCE (0.49 µg/L)**
699-36-66B	x						x				
699-36-70B	x					x	x		x		
699-37-68	x						x		x	x	
699-38-70	x						x	x	x	x	x

COPC = contaminant of potential concert
PCE = tetrachloroethene
TCE = trichloroethene

A summary of the 90th percentile groundwater concentrations and maximum projected concentration for each of the 25-year time intervals up to 200 years and every 100 years up to the 1,000-year F&T simulation period (Table 6-7). These tables also list the federal and state MCLs, and the WAC 173-340-720 groundwater cleanup standards for carcinogenic and non-carcinogenic effects, which represent the chemical-specific ARARs that were exceeded in the exposure areas.

With the exception of I-129, nitrate, tritium, and uranium, the 90th percentile groundwater concentrations for each of the final COPCs attenuate to concentrations below their target action level within 25 years (Year 2034). The 90th percentile concentration for nitrate attenuates below the WAC 173-340-720 groundwater cleanup level within 125 years (2134). The 90th percentile concentration for tritium attenuates below the MCL within 50 years (2059), I-129 attenuates below the MCL within 400 years (2409), and uranium attenuates below the MCL within 600 years (2609).

Maximum projected concentrations attenuate to concentrations below their target action level within 25 years for chloroform, fluoride, and PCE (Year 2034), within 50 years for tritium (Year 2059), within 75 years for Tc-99 (2084), within 175 years for chromium (Year 2184), within 300 years for hexavalent chromium (Year 2309), within 400 years for nitrate (Year 2409), and within 1,000 years for I-129. Uranium and TCE do not attenuate below their target action level within the 1,000-year F&T simulation period. The maximum projected concentration for TCE is limited to approximately one-half the MCL value (2.5 μg/L). This is because the amount of information available limits the projected F&T model to define the extent of contamination to one-half the MCL.

Step 5—Calculate Total Risk and Total Dose. The total risk and total dose are calculated to determine when the timeframe is adequate for achieving groundwater cleanup levels. An annual cumulative dose equivalent of less than 4 mrem to the total body or any internal organ is considered protective of human health. WAC 173-340 states that cancer risks resulting from multiple hazardous substances should not exceed 1×10^{-5} and should not exceed an HI of 1 for non-cancer health effects.

Table 6-8 shows the maximum projected concentrations for each of the final radiological COPCs in the 200-UP-1 Groundwater OU. Table 6-9 shows the maximum projected groundwater concentrations for each of the final non-radiological COPCs in the 200-UP-1 Groundwater OU. In addition, the total risk and non-cancer HI are evaluated using the equations shown in Section 6.2.

The concentrations of Tc-99 and tritium are well below their respective MCLs within 125 years of the F&T simulation period (Table 6-8). The sum of fractions associated with these two COPCs is 0.50, resulting in 2.0 mrem/yr annual dose. The concentration of I-129 does not reach the MCL of 1 pCi/L at any point during the 1,000-year F&T simulation period. The concentration of I-129 at Year 3009 is 1.3 pCi/L, resulting in a cumulative annual dose rate of 5.2 mrem.

Table 6-7. Summary of 90th Percentile and Maximum Projected Future Groundwater Concentrations, Federal and State Maximum Contaminant Levels, and WAC 173-340-720 Groundwater Cleanup Levels

COPC	Units	Maximum Projected Concentration	90th Percentile Value	Year	Federal or State MCL	WAC 173-340-720 Cleanup Levels		
						Non-Carcinogens	Carcinogens at 10^{-6} Risk Level	Carcinogens at 10^{-5} Risk Level
Iodine-129	pCi/L	39	3.5	2009	1	—	—	—
		27	6.7	2034				
		23	6.9	2059				
		19	6.6	2084				
		16	6.1	2109				
		14	5.2	2134				
		14	4.2	2159				
		13	3.4	2184				
		12	2.8	2209				
		11	1.5	2309				
		9.7	0.6	2409				
		8.0	0.1	2509				
		5.9	<0.1	2609				
		4.7	<0.1	2709				
		3.4	<0.1	2809				
		2.2	<0.1	2909				
		1.3	<0.1	3009				
Technetium-99	pCi/L	137,000	4,150	2009	900	—	—	—
		1,438	688	2034				
		919	485	2059				
		655	336	2084				
		515	264	2109				
		442	155	2134				
Tritium	pCi/L	1,020,000	51,150	2009	20,000	—	—	—
		96,027	21,557	2034				
		19,313	3,684	2059				
		3,991	695	2084				
		889	138	2109				
		205	24	2134				

Table 6-7. Summary of 90th Percentile and Maximum Projected Future Groundwater Concentrations, Federal and State Maximum Contaminant Levels, and WAC 173-340-720 Groundwater Cleanup Levels

COPC	Units	Maximum Projected Concentration	90th Percentile Value	Year	Federal or State MCL	WAC 173-340-720 Cleanup Levels		
						Non-Carcinogens	Carcinogens at 10^{-6} Risk Level	Carcinogens at 10^{-5} Risk Level
Chloroform	µg/L	35	7.2	2009	80	80	1.4	14
		5.1	<0.001	2034				
		2.1	<0.001	2059				
		1.0	<0.001	2084				
		0.4	<0.001	2109				
		0.2	<0.001	2134				
Tetrachloroethene	µg/L	3.8	1.0	2009	5	80	0.081	0.81
		0.011	<0.081	2034				
		0.007	<0.081	2059				
		0.005	<0.081	2084				
		0.004	<0.081	2109				
		0.003	<0.081	2134				
Trichloroethene	µg/L (*not modeled to end-point*)	13	3.3	2009	5	—	0.49	4.9
		4.9	0.03	2034				
		3.9	0.003	2059				
		3.0	0.001	2084				
		3.0	<0.001	2109				
		2.0	<0.001	2134				
		1.0 (est)	<0.081	2159				
Chromium	µg/L	846	99	2009	100	24,000	—	—
		145	38	2034				
		138	8.4	2059				
		129	2.8	2084				
		125	2.3	2109				
		118	1.8	2134				
		105	1.8	2159				
		87	1.8	2184				
		69	1.5	2209				
		23	0.2	2309				

Table 6-7. Summary of 90th Percentile and Maximum Projected Future Groundwater Concentrations, Federal and State Maximum Contaminant Levels, and WAC 173-340-720 Groundwater Cleanup Levels

COPC	Units	Maximum Projected Concentration	90th Percentile Value	Year	Federal or State MCL	WAC 173-340-720 Cleanup Levels		
						Non-Carcinogens	Carcinogens at 10^{-6} Risk Level	Carcinogens at 10^{-5} Risk Level
Fluoride	µg/L	790	470	2009	4,000	480	—	—
		31	<1	2034				
		11	<1	2059				
		6.0	<1	2084				
		4.0	<1	2109				
		3.0	<1	2134				
Hexavalent Chromium	µg/L	236	52	2009	—	48	—	—
		145	38	2034				
		138	8.4	2059				
		129	2.8	2084				
		125	2.3	2109				
		118	1.8	2134				
		105	1.8	2159				
		87	1.8	2184				
		69	1.5	2209				
		23	0.2	2309				
		7	0.02	2409				
		6	<0.02	2509				
		6	<0.02	2609				
		6	<0.02	2709				
		5	<0.02	2809				
		5	<0.02	2909				
		5	<0.02	3009				
Nitrate	µg/L	1,740,000	133,000	2009	45,000	25,600	—	—
		174,490	76,439	2034				
		125,920	51,952	2059				
		102,060	37,363	2084				
		83,578	30,263	2109				
		66,966	21,504	2134				
		53,543	16,290	2159				
		43,481	15,239	2184				
		35,023	13,083	2209				
		28,107	1,523	2309				

Table 6-7. Summary of 90th Percentile and Maximum Projected Future Groundwater Concentrations, Federal and State Maximum Contaminant Levels, and WAC 173-340-720 Groundwater Cleanup Levels

COPC	Units	Maximum Projected Concentration	90th Percentile Value	Year	Federal or State MCL	WAC 173-340-720 Cleanup Levels		
						Non-Carcinogens	Carcinogens at 10^{-6} Risk Level	Carcinogens at 10^{-5} Risk Level
Nitrate cont.		21,177	108	2409				
		16,091	4	2509				
		12,602	0.2	2609				
		10,110	0.2	2709				
		8,366	0.1	2809				
		6,942	0.1	2909				
		5,981	0.1	3009				
Uranium	µg/L	613	206	2009	30	48	—	—
		479	383	2034				
		362	307	2059				
		325	302	2084				
		280	279	2109				
		261	249	2134				
		235	216	2159				
		216	185	2184				
		199	156	2209				
		160	114	2309				
		128	82	2409				
		99	49	2509				
		75	25	2609				
		58	12	2709				
		53	4.9	2809				
		49	2.1	2909				
		43	1.0	3009				

Notes: Highlighted cells indicate the maximum and 90th percentile projected groundwater concentrations and the year(s) at which the target action level is achieved.

COPC = contaminant of potential concert

MCL = maximum contaminant level

TCE = trichloroethene

Table 6-8. Summary of Maximum Projected Future Groundwater Concentrations and Associated Sum of Fractions

COPC	Units	Maximum Projected Concentration	Year	Federal or State MCL	Individual Fraction
Iodine-129	pCi/L	1.3	3009	1	1.3
Technetium-99	pCi/L	442	2134	900	0.49
Tritium	pCi/L	205	2134	20,000	0.010
Sum of Fractions					**1.8**
Cumulative Annual Dose (mrem)					**7.2**

COPC = contaminant of potential concern
MCL = maximum contaminant level

Table 6-9. Summary of Maximum Projected Future Groundwater Concentrations Associated Cancer Risk and Non-Cancer Hazard Index

COPC	Units	Maximum Projected Concentration	Year	Federal or State MCL	WAC 173-340-720 Cleanup Levels			
					Non Carcinogens	HQ	Carcinogens at 10^{-6} Risk Level	ELCR
Chloroform	µg/L	0.20	2134	80	80	<0.01	1.4	1.4×10^{-7}
Tetrachloroethene	µg/L	0.003	2134	5	80	<0.01	0.081	3.7×10^{-8}
Trichloroethene	µg/L	2.0	2134	5	—	—	0.49	4.1×10^{-6}
Total Risk							**4.3×10^{-6}**	
Chromium	µg/L	87	2184	100	24,000	<0.01	—	—
Fluoride	µg/L	3.0	2134	4,000	480	<0.01	—	—
Hexavalent Chromium	µg/L	23	2309	—	48	0.48	—	—
Nitrate	µg/L	21,177	2409	45,000	26,500	0.80	—	—
Uranium	µg/L	43	0809	30	48	0.90	—	—
Total HI							**2.2**	

COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index
HQ = hazard quotient
MCL = maximum contaminant level

Based on the maximum projected concentrations shown in Table 6-9, the potential cumulative ELCR from all nonradiological carcinogenic COPCs after the 1,000-year F&T period is 4.3×10^{-6}, which is less than the WAC 173-340-780 risk threshold of 1×10^{-5} for multiple hazardous substances and less than the upper NCP threshold of 1×10^{-4} (Table 6-9). The primary contributor to risk includes TCE (4.1×10^{-6}, 96 percent contribution). The total cancer risk reduced from 5.8×10^{-4} based on current groundwater concentrations to 4.3×10^{-6} based on future projected concentrations and the absence of carbon tetrachloride.

The HI for the 200-UP-1 Groundwater OU is 2.2, which is greater than the EPA and WAC 173-340 target HI of 1. The primary contributors to the non-cancer HI are hexavalent chromium (HQ = 0.48, 22 percent contribution); nitrate (HQ = 0.80, 37 percent contribution); and uranium (HQ = 0.90, 41 percent contribution). The primary non-cancer health effects associated with exposure to the primary contributors to the HI are as follows:

- Nitrate—methemoglobenemia
- Uranium—kidney toxicity
- Hexavalent chromium—nasal septum atrophy

It is appropriate to segregate the individual HQs because of the differences in toxicological effects and target organs.

6.5 Uncertainties in Risk Assessment

The purpose of this risk assessment is to determine whether a groundwater remedial action is warranted under CERCLA. Estimating and evaluating health risk from exposure to environmental contaminants is a complex process with inherent uncertainties. Uncertainty reflects limitations in knowledge, and simplifying assumptions must be made to quantify health risks.

In this assessment, uncertainties relate to the selection of COPCs and the development of media concentrations to which receptors may be exposed, the assumptions about exposure and toxicity, and the characterization of health risks. Uncertainties exist regarding the quantification of health risks in terms of several assumptions about exposure and toxicity, including site-specific and general uncertainties. Based on the anticipation of uncertainty when quantifying exposure and toxicity, the health risks and hazards presented in this risk assessment are more likely to overestimate risk.

6.5.1 Uncertainties Associated with Sampling and Analysis Data

Current baseline conditions are represented by groundwater data collected over the last 5 years from 93 monitoring wells within the 200-UP-1 Groundwater OU. The groundwater data set for the COPCs consists of more than 1,000 samples available from more than 93 wells that have been routinely sampled over many years. Therefore, the groundwater data set is considered adequate for risk assessment.

New wells are generally sampled quarterly the first year after installation, semi-annually the second year after installation, and annually thereafter. Biennial sampling is used for existing perimeter wells that have shown stable concentrations for several years. If irregular, decreasing, or increasing trends appear, the sampling frequencies are adjusted accordingly.

Sampling and analysis results from these programs comprehensively define the suite of contaminants associated with existing source area plumes. However, differences in sampling frequencies (annually or tri-annually) may create uncertainties associated with the temporal representative qualities of the data set. However, the differences in sampling frequencies are not anticipated to influence the overall concentrations of COPCs in groundwater.

Differences in method detection limits for the same sample and between samples create uncertainties associated with confirmation of the presence or absence of COPCs at or below the action level. Method detection limits vary as a result of changes that have occurred between laboratory contracts.

Both filtered (dissolved) and unfiltered (total) analysis results are available for some metals in the groundwater data set. However, only unfiltered results are used for selecting COPCs. Use of filtered sampling results may underestimate chemical and radiological concentrations in water from an unfiltered tap and are not used for the COPC selection process. Generally, there are more filtered metal results available than unfiltered results, however exclusion of filtered results does not result in the elimination of metals from the COPC process or underestimate EPCs.

6.5.2 Uncertainties Associated with Exposure Point Concentrations

The EPCs for groundwater are calculated as the 90th percentile concentration. The protectiveness and risk evaluation methodology uses an RME concentration for each COPC with an exposure area rather than performing the evaluation on a specific well or location. In general, EPA Superfund guidance recommends using a 95 percent UCL on the average for estimating EPCs. However, experience at the Site indicates that averages and UCLs cannot be reliably calculated for groundwater data sets using this approach. The 200-UP-1 Groundwater OU exhibits an aquifer setting where multiple groundwater contaminants are present in overlapping plumes and the highest concentrations have different locations within the plumes. The 90th percentile from a distribution of groundwater concentration data as an EPC is a different approach from Superfund guidance for estimating EPCs in risk assessments (OSWER 9285.6-10). However, as shown in the following description, the 90th percentile exposure is identified in EPA risk assessment guidance for describing and characterizing health risks, and produces risk estimates that correspond to an RME.

Table 6-10 provides additional information on possible ranges of concentrations in groundwater EPCs for the COPCs. Table 6-10 provides the percentile concentrations used for the protectiveness and risk evaluations, as well as the maximum, average, and 95 percent UCL concentrations using all of the data within an exposure area. For the final COPCs listed in Table 5-5, the 90th percentile concentrations are greater than the 95 percent UCL values for all COPCs.

Table 6-10. Percentile Concentrations and Summary Statistics

COPC	Units	Number of Measurements	90th Percentile	Maximum	Mean	95% UCL
Carbon Tetrachloride	µg/L	628	189	1,600	95	126.6
Chloroform	µg/L	614	7.2	35	3.7	3.359
Chromium	µg/L	280	99	846	80	91.82
Hexavalent Chromium	µg/L	74	52	236	25	31.61
Iodine-129	pCi/L	452	3.5	39	7.3	2.951
Nitrate	µg/L	1,044	133,000	1.74E+6	76,922	98,692
Technetium-99	pCi/L	1,094	4,150	13,700	2,730	4,110
Tetrachloroethene	µg/L	605	1	3.8	0.78	0.163
Trichloroethene	µg/L	631	3.3	13	2.3	1.163

Table 6-10. Percentile Concentrations and Summary Statistics

COPC	Units	Number of Measurements	90th Percentile	Maximum	Mean	95% UCL
Tritium	pCi/L	451	51,150	1.02E+6	30,661	43,718
Uranium	µg/L	743	206	613	56	80.53

COPC = contaminant of potential concern
UCL = upper confidence limit

The groundwater data set is considered robust when the 90th percentile value is greater than the 95 percent UCL value. Generally, when data sets are large, the 95 percent UCL will approach the mean concentration. For nitrate, the 95 percent UCL is 98,692 µg/L and the mean is 76,922 µg/L; in contrast, the 90th percentile is 133,000 µg/L. Therefore, 90th percentile values are reasonable upper bounds of concentrations for the purposes of the risk assessment. However, if a well was drilled at the location of the maximum concentration, risks would be significantly underestimated for the COPCs where the maximum concentration is considerably larger than the 90th percentile value (true for three of the COPCs where the maximum concentration is more than an order of magnitude larger than the 90th percentile). The percentage of results greater than the 90th percentile value for I-129 is 10.6 percent, and for nitrate and tritium 10 percent of the results were greater than the 90th percentile values. Because only 10 percent of the data exceed the 90th percentile values, these very high concentrations are few and represent a very limited areal extent.

6.5.3 Uncertainties Associated with Exposure Assumptions

The exposure assumptions used to develop the chemical-specific ARARs represent an RME. For estimating the RME, 95 percent UCL values (or upper-bound estimates of national averages) are generally used for exposure assumptions, and exposed populations and exposure scenarios are also selected to represent upper-bound exposures. The intent of the RME, as discussed by the EPA Deputy Administrator and the Risk Assessment Council (Habicht, 1992), is to present risks as a range from central tendency to high-end risk (above the 90th percentile of the population distribution). This descriptor is intended to estimate the risks that are expected to occur in small but definable “high-end” segments of the subject population (Habicht, 1992). EPA distinguishes between those scenarios that are possible but highly improbable and those that are conservative but more likely to occur within a population, with the latter being favored in risk assessment. In general, these assumptions are intended to be conservative and yield an overestimate of the true risk or hazard.

6.5.4 Uncertainties Associated with Dermal Contact Exposure

The chemical-specific ARARs for use as a drinking water source consider ingestion and inhalation of vapors as complete and significant pathways for exposure. For the chemical-specific ARARs, the dermal contact pathway is considered a complete but insignificant pathway of exposure for the contaminants detected in groundwater. The exclusion of the dermal contact exposure route from the chemical-specific ARARs may have the potential to underestimate the actual cleanup level.

EPA considers the dermal contact route to be significant if it contributes at least 10 percent of the exposure derived from the oral pathway. These results are based on comparing two main household daily uses of water: as a source for drinking and for showering or bathing (EPA/540/R/99/005). Exhibit B-3 and Exhibit B-4 of EPA/540/R/99/005 provide a screening tool to focus the dermal risk assessment on those chemicals that are more likely to make a contribution to the overall risk. Exhibit B-3 indicates that dermal exposure exceeds 10 percent of drinking water for chromium, hexavalent chromium, carbon tetrachloride, PCE, and TCE. The ratio of the dermal absorbed dose (DAD) from dermal to oral is 40 percent for chromium, 42 percent for hexavalent chromium, 27 percent for carbon tetrachloride, 60 percent for PCE, and 17 percent for TCE. Based on this comparison, the chemical-specific ARARs concentrations may have the potential to underestimate exposure to these final COPCs.

6.5.5 Uncertainties Associated with Toxicity Assessment

The toxicological database was also a source of uncertainty. EPA has outlined some of the sources of uncertainty as defined in the risk assessment guidance (RAG) (EPA/540/1-89/002) and in Cook, 2003. These sources may include or result from the extrapolation from high to low doses and from animals to humans. This is contingent on the species, gender, age, and strain differences in the uptake, metabolism, organ distribution, and target site susceptibility of a toxin. The human population's variability with respect to diet, environment, activity patterns, and cultural factors are also sources of uncertainty.

Traditionally, EPA has developed toxicity criteria for carcinogens by assuming that all carcinogens are non-threshold contaminants. However, EPA has recently published revised cancer guidelines (EPA/630/P-03/001F) where they have modified their former position of assuming non-threshold action for all carcinogens. This new guidance emphasizes establishing the specific toxicokinetic mode of action that leads to development of cancer. In the future, toxicity criteria for carcinogens in the United States will be developed assuming no threshold for contaminants that exhibit genotoxic modes of action, or where the mode of action is not known. However, currently available EPA toxicity criteria for carcinogens were all derived assuming a non-threshold model.

In most of the world, non-threshold toxicity criteria are developed only for those carcinogens that appear to cause cancer through a genotoxic mechanism (Health Canada, Netherlands). Specifically, for genotoxic contaminants, the cancer dose-response model is based on high- to low-dose extrapolation and assumes there is no lower threshold for the initiation of toxic effects. Cancer effects observed at high doses are found in laboratory animals or are extrapolated from occupational or epidemiological studies. Cancer effects observed at low doses are commonly found in environmental exposures. These models are essentially linear at low doses, so no dose is without some risk of cancer.

6.5.5.1 Slope Factors for Trichloroethene

The oral cancer potency factor of 0.089 $(mg/kg\text{-}day)^{-1}$ is used to develop the WAC 173-340-720 groundwater cleanup level and is obtained from HEAST (January 1, 1991). HEAST has not been updated since 1997 and in this case the oral cancer potency factor does not reflect the most current source of information.

The oral slope factor currently recommended by EPA for TCE is established by the CalEPA Office of Environmental OEHHA. The source of this toxicity value is consistent with the hierarchy of toxicity values recommended in Cook, 2003. The oral slope factor is 0.013 $(mg/kg\text{-}day)^{-1}$ (OEHHA,1999).

The OEHHA value is lower than the value of 0.089 $(mg/kg\text{-}day)^{-1}$ for oral exposures published in the 1991 HEAST.

If the CalEPA value was used to calculate the WAC 173-340-720 groundwater cleanup level, the groundwater concentration would increase from 0.49 µg/L to 3.4 µg/L. The groundwater risks at the 90th percentile would decrease from 6.7×10^{-6} to 9.7×10^{-7} in groundwater. However, the cumulative risk would remain above 1×10^{-5}. Use of the oral cancer potency factor from HEAST results in an overestimation of risks when compared to the oral slope factor established by CalEPA.

6.5.6 Uncertainties Associated with Risk Characterization

In the risk characterization, the assumption was made that the total risk of developing cancer from exposure to site contaminants is the sum of the risk attributed to each individual contaminant. Likewise, the potential for the development of non-cancer adverse effects is the sum of the HQs estimated for exposure to each individual contaminant. This approach, in accordance with EPA guidance, did not account for the possibility that constituents act synergistically or antagonistically.

As discussed in Section 6.2, MCLs for radionuclides are set at 4 mrem/yr for the sum of the doses from beta particle and photon emitters, 15 pCi/L for gross alpha emitter activity (including Ra-226, but excluding uranium and radon), and 5 pCi/L combined for Ra-226 and Ra-228. A mass concentration MCL has been established for uranium as 30 µg/L. At this time, no additional federal or state standards are associated with evaluating the effects of exposure to radionuclides. Risks were estimated for radioisotopes identified as final COPCs using inputs and equation 720-2 from WAC 173-340-720(4)(iii)(B) and radionuclide slope factors from HEAST. The MCL concentrations reported for each of the final radionuclide COPCs do not individually exceed the 10^{-4} ELCR end of the NCP risk range (Table 6-11).

Table 6-11. Summary of 90th Percentile Current Groundwater Concentrations, Associated Cancer Risk and Associated Sum of Fractions for Radioactive COPCs

Final COPC	90th Percentile Value (pCi/L)	Federal or State MCL (pCi/L)	ELCR at Federal or State MCL	Individual Fraction	Individual ELCR
Iodine-129	3.5	1	2.8×10^{-6}	3.5	9.80×10^{-6}
Strontium-90	0.66	8	8.5×10^{-6}	0.08	6.80×10^{-7}
Technetium-99	4,150	900	4.7×10^{-5}	4.6	2.16×10^{-4}
Tritium	51,150	20,000	1.9×10^{-5}*	2.6	4.94×10^{-5}
Sum of Fractions				**10.8**	**-**
Cumulative Annual Dose (mrem)				**42.8**	**-**
Cumulative ELCR for Radioactive COPCs				**-**	**2.76×10^{-4}**

* An excess lifetime cancer risk for tritium which includes the ingestion and inhalation exposure routes would be 1.3×10^{-4}. The ELCR for tritium would be 1.9×10^{-5} for the ingestion exposure route only.

MCL = Derived single-nuclide MCL-equivalent activity concentration

COPC = Contaminant of potential concern

MCL = Maximum contaminant level

6.6 Ecological Risk

An ecological risk assessment was not performed for the 200-UP-1 Groundwater OU because there are no potentially complete exposure pathways to aquatic receptors. Section 3.8 presents a description of the unique features, habitats, and threatened and endangered species of the area that could be affected later in the project if engineered remedies are required to address groundwater regulatory exceedances.

6.7 Summary of the Native American Risk Assessments

Several local and regional Tribes have ancestral ties to the Hanford Reach of the Columbia River and surrounding lands. DOE has requested that each Tribe provide an exposure scenario that reflects their traditional activities. At this time, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* (Harris and Harper, 2004) and *Application of the CTUIR Traditional Lifeways Exposure Scenario in Hanford Risk Assessments* (Harris, 2008) have been provided by the CTUIR, and *Yakama Nation Exposure Scenario for Hanford Site Risk Assessment* (Ridolfi, 2007) has been provided by the Yakama Nation.

The CTUIR and Yakama Nation scenarios reflect exposure conditions that assume groundwater from the 200-UP-1 Groundwater OU is restored to its highest beneficial use and is used as a drinking water source and to generate steam in a sweat lodge. Use of groundwater to irrigate crops and water livestock is not evaluated in this risk evaluation because those exposure pathways, although potentially complete, are considered insignificant and secondary to the drinking water and sweat lodge exposure pathways. Food chain pathways are generally evaluated quantitatively in the source area OUs because the RESRAD model (ANL, 2009) estimates exposure from these pathways. Contact with contaminated drill cuttings is not addressed because this assessment includes only groundwater pathway exposures.

Potentially complete exposure routes for adult and child Tribal members associated with use of groundwater as a drinking water source are as follows:

- Ingestion of drinking water
- Inhalation of volatiles when showering and other domestic purposes
- Dermal contact with skin while showering and using groundwater for other domestic purposes (such as, washing dishes)

Potentially complete exposure routes for adult Tribal members associated with the use of groundwater to generate steam in a sweat lodge are as follows:

- Inhalation of tritium, volatiles, and semivolatiles as vapors while in a sweat lodge
- Inhalation of aerosolized nonvolatiles while spending time in a sweat lodge
- Dermal contact with vapors from volatile and semivolatile compounds while in a sweat lodge
- Dermal contact with vapor and aqueous condensate while in a sweat lodge

A complete description of each of the Tribal use exposure scenarios is provided in ECF-200UP1-10-0250. This calculation describes the methodology, assumptions, and inputs, and the calculation of risks and hazards, and discusses the results of the risk assessment for each of the Native American scenarios.

6.8 Summary of the CTUIR Risk Assessment

This section summarizes the results for each of the exposures associated with use of groundwater as a drinking water source and use of groundwater to generate steam in a sweat lodge.

6.8.1 Use of Groundwater as a Potential Drinking Water Source

Potential exposure to groundwater as a drinking water source is evaluated under this scenario. Potential routes of exposure to groundwater include ingestion, dermal contact,[4] and inhalation of volatiles during household activities. Table 6-12 provides a summary of the risk estimates by exposure route for the 200-UP-1 Groundwater OU. Additional detail including COPC-specific risk contributions is provided in ECF-200UP1-10-0250.

Table 6-12. Confederated Tribes of the Umatilla Indian Reservation Exposure Scenario—Summary of Risk Estimates from Use of Groundwater as a Potential Drinking Water Source

Exposure Route	ELCR	HI
Nonradionuclide COPCs		
Ingestion	2.1×10^{-3}	33
Dermal	2.2×10^{-4}	2.4
Inhalation	3.9×10^{-5}	0.86
Total	**2.3×10^{-3}**	**36**
Radionuclide COPCs		
Ingestion	1.4×10^{-3}	--
Inhalation	2.3×10^{-5}	--
Total	**1.4×10^{-3}**	**--**
Total ELCR*	**3.7×10^{-3}**	**--**

* Sum of total ELCR values for nonradionuclides and radionuclides.

-- = HI is not applicable
COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index

The cumulative ELCR is 2.3×10^{-3} for nonradiological COPCs and 1.4×10^{-3} for radiological COPCs, which is greater than the WAC 173-340-708 cumulative risk threshold of 1×10^{-5} for multiple hazardous substances and greater than the EPA upper target risk threshold of 1×10^{-4}. The individual ELCR values for carbon tetrachloride, tritium, and Tc-99 are greater than the EPA regulatory target risk threshold of 1×10^{-4}. Individual ELCRs associated with chloroform, I-129, Sr-90, PCE, and TCE are within the EPA range of 1×10^{-4} to 1×10^{-6}. The cumulative risk for carbon tetrachloride, chloroform, PCE, and TCE is greater than the WAC 173-340 cumulative risk threshold of 1×10^{-5}. The HI is 36, which is greater than the EPA and WAC 173-340 target HI of 1.0. The primary contributors to the non-cancer HI is carbon tetrachloride (HQ of 17.5, 48.6 percent contribution); nitrate (HQ = 4.8, 13 percent contribution); and uranium (HQ = 3.9, 11 percent contribution).

[4] The dermal contact exposure route is only evaluated for nonradionuclide COPCs.

Although the individual ELCR value associated with arsenic is greater than EPA's regulatory target risk threshold of 10^{-4} and the HQ is greater than 1, the 90th percentile value of 6.6 µg/L is considered to be within the range of naturally occurring concentrations. Therefore, arsenic is not considered a contributor to risk or HI.

1,1,2-Trichloroethane, 1,2-dichloroethane, 1,4-dioxane, benzene, bis(2-ethylhexyl) phthalate, and bromodichloromethane are not considered contributors to the ELCR. 1,1,2-Trichloroethane and benzene were detected at very low frequencies (<1 percent) at a small number of locations and are not considered to be associated with a trend or local exposure point. 1,2-Dichloroethane and 1,4-dioxane are considered uncertainties at Well 299-W22-20 because they were detected once over the past 5 years at this location only and have also been detected at this location between the years 2000 and 2004. Bis(2-ethylhexyl) phthalate was detected in 4 of 75 water samples and its presence is considered to be the result of laboratory contamination. The EPC for bromodichloroethane is considered an overestimation of the actual concentration in groundwater. The 90th percentile value for bromodichloromethane reflects the presence of elevated method detection limits rather than the presence of the COPC.

Acrolein and antimony are not considered contributors to the HI. Acrolein was detected in 1 of 122 water samples and is not considered to be associated with a trend or local exposure point. The analytical method used to measure antimony is not considered reliable because detected concentrations are reported to be false positives and method detection limits are generally above the federal MCL. Arsenic concentrations, as mentioned, are considered to be naturally occurring.

6.8.2 Use of Groundwater to Generate Steam for Sweat Lodge Use

Potential exposure to groundwater as steam in a sweat lodge is evaluated under this scenario. Potential routes of exposure to steam generated from groundwater include inhalation of vaporized volatiles and semivolatiles and aerosolized nonvolatiles and dermal contact with vaporized volatiles, semivolatiles, and nonvolatiles and condensed liquid while spending time in a sweat lodge. Table 6-13 provides a summary of the risk estimates by exposure route and exposure area. Additional detail including COPC-specific risk contributions is provided in the calculation spreadsheets presented in ECF-200UP1-10-0250.

Table 6-13. CTUIR Exposure Scenario—Summary of Risk Estimates from Use of Groundwater in a Sweat Lodge

Exposure Route	ELCR	HI
Nonradionuclide COPCs		
Inhalation in Sweat Lodge		
Volatile and Semivolatile (vapor)	1.6×10^{-4}	3.5
Nonvolatile (aerosol)	3.6×10^{-2}	26
Total	**3.6×10^{-2}**	**29.5**
Dermal Exposure in Sweat Lodge		
Volatile and Semivolatile (vapor only)	1.0×10^{-7}	<0.01
Nonvolatile (vapor and aqueous condensate)	2.5×10^{-6}	0.59
Total	**2.5×10^{-6}**	**0.59**
Total Nonradionuclide COPCs	**3.6×10^{-2}**	**30**

Table 6-13. CTUIR Exposure Scenario—Summary of Risk Estimates from Use of Groundwater in a Sweat Lodge

Exposure Route	ELCR	HI
Radionuclide COPCs		
Inhalation in Sweat Lodge		
Volatile and Semivolatile (vapor)	7.1×10^{-5}	--
Nonvolatile (aerosol)	2.5×10^{-4}	--
Total Radionuclide COPCs	**3.2×10^{-4}**	--
Total ELCR*	**3.6×10^{-2}**	**30**

* Sum of total ELCR values for nonradionuclide and radionuclide COPCs.
-- = HI is not applicable
COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index

The cumulative ELCR for the 200-UP-1 Groundwater OU is 3.6×10^{-2} for nonradiological COPCs and 3.2×10^{-4} for radiological COPCs, which is greater than the WAC 173-340-708 cumulative risk threshold of 1×10^{-5} for multiple hazardous substances and greater than the EPA upper target risk threshold of 1×10^{-4}. The individual ELCR values for carbon tetrachloride, cobalt, hexavalent chromium, and Tc-99 are greater than the EPA upper target risk threshold of 1×10^{-4}. Individual ELCRs associated with beryllium, cadmium, chloroform, nickel, TCE, and tritium are within the EPA range of 1×10^{-4} to 1×10^{-6}. The HI for the 200-UP-1 Groundwater OU is 30, which is greater than the EPA and WAC 173-340 target HI of 1.0. The primary contributors to the non-cancer HI are cadmium, cobalt, hexavalent chromium, nickel, and uranium, which have HQs greater than 1.0.

Although the individual ELCR value associated with arsenic is greater than EPA's regulatory target risk threshold of 10^{-4} and the HQ is greater than 1, the 90th percentile value of 6.6 µg/L is considered to be within the range of naturally occurring concentrations. Therefore, arsenic is not considered a contributor to risk or HI.

1,1,2-Trichloroethane, 1,2-dichloroethane, 1,4-dioxane, benzene, bis(2-ethylhexyl) phthalate, and bromodichloromethane are not considered contributors to the ELCR. 1,1,2-Trichloroethane and benzene were detected at very low frequencies (<1 percent) at a small number of locations and are not considered to be associated with a trend or local exposure point. 1,2-Dichloroethane and 1,4-dioxane are considered uncertainties at Well 299-W22-20 because they were detected once over the past 5 years at this location only and have also been detected at this location between the years 2000 and 2004. Bis(2-ethylhexyl) phthalate was detected in 4 of 75 water samples and its presence is considered to be the result of laboratory contamination. The EPC for bromodichloroethane is considered an overestimation of the actual concentration in groundwater. The 90th percentile value for bromodichloromethane reflects the presence of elevated method detection limits rather than the presence of the COPC.

Acrolein and antimony are not considered contributors to the HI. Acrolein was detected in 1 of 122 water samples and is not considered to be associated with a trend or local exposure point. The analytical method used to measure antimony is not considered reliable because detected concentrations are reported to be false positives and method detection limits are generally above the federal MCL. Arsenic concentrations, as mentioned, are considered to be naturally occurring.

Although the individual HQ associated with manganese is greater than 1.0, manganese is not considered to be a contributor to the HI because the 90th percentile value of 18 µg/L is below the secondary MCL of 50 µg/L and the secondary MCL is based on aesthetic qualities and is not federally enforceable.

6.9 Summary of the Yakama Nation Risk Assessment

This section summarizes the results for each of the exposures associated with use of groundwater as a drinking water source and use of groundwater to generate steam in a sweat lodge.

6.9.1 Use of Groundwater as a Potential Drinking Water Source

Potential exposure to groundwater as a drinking water source is evaluated under this scenario. Potential routes of exposure to groundwater include ingestion, dermal contact,[5] and inhalation of volatiles during household activities. Table 6-14 provides a summary of the risk estimates by exposure route for the 200-UP-1 Groundwater OU. Additional detail including COPC-specific risk contributions is provided in the calculation spreadsheets presented in ECF-200UP1-10-0250.

Table 6-14. Yakama Nation Exposure Scenario—Summary of Risk Estimates from Use of Groundwater as a Potential Drinking Water Source

Exposure Route	ELCR	HI
Nonradionuclide COPCs		
Ingestion	2.3×10^{-3}	33
Dermal	2.2×10^{-4}	2.4
Inhalation	3.9×10^{-5}	0.86
Total	**2.5×10^{-3}**	**36**
Radionuclide COPCs		
Ingestion	1.4×10^{-3}	--
Inhalation	2.4×10^{-5}	--
Total	**1.5×10^{-3}**	**--**
Total ELCR*	**4.0×10^{-3}**	**--**

* Sum of total ELCR values for nonradionuclides and radionuclides.
-- = HI is not applicable
COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index

The cumulative ELCR is 2.5×10^{-3} for nonradiological COPCs and 1.5×10^{-3} for radiological COPCs, which is greater than the WAC 173-340-708 cumulative risk threshold of 1×10^{-5} for multiple hazardous substances and greater than the EPA upper target risk threshold of 1×10^{-4}. The individual ELCR values for carbon tetrachloride, tritium, and Tc-99 are greater than the EPA regulatory target risk threshold of 1×10^{-4}. Individual ELCRs associated with I-129, Sr-90, chloroform, PCE, and TCE are within the EPA range of 1×10^{-4} to 1×10^{-6}. The cumulative risk for carbon tetrachloride, chloroform, PCE, and TCE is greater than the WAC 173-340 cumulative risk threshold of 1×10^{-5}. The HI is 36, which is greater than the EPA and WAC 173-340 target HI of 1.0. The primary contributors to the non-cancer HI is carbon

[5] The dermal contact exposure route is only evaluated for nonradionuclide COPCs

tetrachloride (HQ of 17.5, 48.5 percent contribution); nitrate (HQ = 4.8, 13 percent contribution); and uranium (HQ = 3.9, 11 percent contribution).

Although the individual ELCR value associated with arsenic is greater than EPA's regulatory target risk threshold of 10^{-4} and the HQ is greater than 1, the 90th percentile value of 6.6 µg/L is considered to be within the range of naturally occurring concentrations. Therefore, arsenic is not considered a contributor to risk or HI.

1,1,2-Trichloroethane, 1,2-dichloroethane, 1,4-dioxane, benzene, bis(2-ethylhexyl) phthalate, and bromodichloromethane are not considered contributors to the ELCR. 1,1,2-Trichloroethane and benzene were detected at very low frequencies (<1 percent) at a small number of locations and are not considered to be associated with a trend or local exposure point. 1,2-Dichloroethane and 1,4-dioxane are considered uncertainties at Well 299-W22-20 because they were detected once over the past 5 years at this location only and have also been detected at this location between the years 2000 and 2004. Bis(2-ethylhexyl) phthalate was detected in 4 of 75 water samples and its presence is considered to be the result of laboratory contamination. The EPC for bromodichloroethane is considered an overestimation of the actual concentration in groundwater. The 90th percentile value for bromodichloromethane reflects the presence of elevated method detection limits rather than the presence of the COPC.

Acrolein and antimony are not considered contributors to the HI. Acrolein was detected in 1 of 122 water samples and is not considered to be associated with a trend or local exposure point. The analytical method used to measure antimony is not considered reliable because detected concentrations are reported to be false positives and method detection limits are generally above the federal MCL. Arsenic concentrations, as discussed, are considered to be naturally occurring.

6.9.2 Use of Groundwater to Generate Steam for Sweat Lodge Use

Potential exposure to groundwater as steam in a sweat lodge is evaluated under this scenario. Potential routes of exposure to steam generated from groundwater include inhalation of vaporized volatiles and semivolatiles and aerosolized nonvolatiles and dermal contact with vaporized volatiles, semivolatiles, and nonvolatiles and condensed liquid while spending time in a sweat lodge. Table 6-15 provides a summary of the risk estimates by exposure route and exposure area. Additional detail including COPC-specific risk contributions is provided in the calculation spreadsheets presented in ECF-200UP1-10-0250.

Table 6-15. Yakama Nation Exposure Scenario—Summary of Risk Estimates from Use of Groundwater in a Sweat Lodge

Exposure Route	ELCR	HI
Nonradionuclide COPCs		
Inhalation in Sweat Lodge		
Volatile and Semivolatile (vapor)	3.3×10^{-4}	7.4
Nonvolatile (aerosol)	7.4×10^{-2}	54
Total	**7.4×10^{-2}**	**61**
Dermal Exposure in Sweat Lodge		
Volatile and Semivolatile (vapor only)	2.0×10^{-7}	<0.01
Nonvolatile (vapor and aqueous condensate)	5.0×10^{-6}	1.2
Total	**5.2×10^{-6}**	**1.2**
Total Nonradionuclide COPCs	**7.4×10^{-2}**	**62**

Table 6-15. Yakama Nation Exposure Scenario—Summary of Risk Estimates from Use of Groundwater in a Sweat Lodge

Exposure Route	ELCR	HI
Radionuclide COPCs		
Inhalation in Sweat Lodge		
Volatile and Semivolatile (vapor)	1.5×10^{-4}	--
Nonvolatile (aerosol)	5.2×10^{-4}	--
Total Radionuclide COPCs	**6.7×10^{-4}**	**--**
Total ELCR*	**7.5×10^{-2}**	**--**

* Sum of total ELCR values for nonradionuclide and radionuclide COPCs.
-- = HI is not applicable
COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index

The cumulative ELCR for the 200-UP-1 Groundwater OU is 7.4×10^{-2} for nonradiological COPCs and 6.7×10^{-4} for radiological COPCs, which is greater than the WAC 173-340-708 cumulative risk threshold of 1×10^{-5} for multiple hazardous substances and greater than the EPA upper target risk threshold of 1×10^{-4}. The individual ELCR values for carbon tetrachloride, cobalt, hexavalent chromium, Tc-99, and tritium are greater than the EPA upper target risk threshold of 1×10^{-4}. Individual ELCRs associated with beryllium, cadmium, chloroform, I-129, nickel, and TCE are within the EPA range of 1×10^{-4} to 1×10^{-6}. The HI for the 200-UP-1 Groundwater OU is 62, which is greater than the EPA and WAC 173-340 target HI of 1.0. The primary contributors to the non-cancer HI are beryllium, cadmium, cobalt, hexavalent chromium, nickel, and uranium, which have HQs greater than 1.0.

Although the individual ELCR value associated with arsenic is greater than EPA's regulatory target risk threshold of 10^{-4} and the HQ is greater than 1, the 90th percentile value of 6.6 µg/L is considered to be within the range of naturally occurring concentrations. Therefore, arsenic is not considered a contributor to risk or HI.

1,1,2-Trichloroethane, 1,2-dichloroethane, 1,4-dioxane, benzene, bis(2-ethylhexyl) phthalate, and bromodichloromethane are not considered contributors to the ELCR. 1,1,2-Trichloroethane and benzene were detected at very low frequencies (<1 percent) at a small number of locations and are not considered to be associated with a trend or local exposure point. 1,2-Dichloroethane and 1,4-dioxane are considered uncertainties at Well 299-W22-20 because they were detected once over the past 5 years at this location only and have also been detected at this location between the years 2000 and 2004. Bis(2-ethylhexyl) phthalate was detected in 4 of 75 water samples and its presence is considered to be the result of laboratory contamination. The EPC for bromodichloroethane is considered an overestimation of the actual concentration in groundwater. The 90th percentile value for bromodichloromethane reflects the presence of elevated method detection limits rather than the presence of the COPC.

Acrolein and antimony are not considered contributors to the HI. Acrolein was detected in 1 of 122 water samples and is not considered to be associated with a trend or local exposure point. The analytical method used to measure antimony is not considered reliable because detected concentrations are reported to be false positives and method detection limits are generally above the federal MCL. Arsenic concentrations, as mentioned, are considered to be naturally occurring.

Although the individual HQ associated with manganese is greater than 1.0, manganese is not considered to be a contributor to the HI because the 90th percentile value of 18 µg/L is below the secondary MCL of 50 µg/L and the secondary MCL is based on aesthetic qualities and is not federally enforceable.

6.10 Summary of the EPA Tap Water Equations

This section summarizes the results for each of the exposures associated with use of groundwater as a drinking water source. The intake equations and exposure assumptions were obtained from the Oak Ridge Operations Office Risk Assessment Information system Web site, which is available at: http://rais.ornl.gov/tools/rais_chemical_risk_guide.html. The EPA tap water ELCR and HIs are included in this section for comparison purposes.

6.10.1 Use of Groundwater as a Potential Drinking Water Source

Potential exposure to groundwater as a drinking water source is evaluated under this scenario. Potential routes of exposure to groundwater include ingestion, dermal contact, and inhalation of volatiles during household activities. Table 6-16 provides a summary of the risk estimates by exposure route for the 200-UP-1 Groundwater OU.

Table 6-16. Summary of Risk Estimates from Use of Groundwater as a Potential Drinking Water Source Using EPA Tap Water Equations

Exposure Route	ELCR	HI
Nonradionuclide COPCs		
Ingestion	5.3×10^{-4}	6.7
Dermal	1.0×10^{-4}	0.99
Inhalation	1.6×10^{-5}	0.35
Total	**6.5×10^{-4}**	**8.1**
Radionuclide COPCs		
Ingestion	2.8×10^{-4}	--
Inhalation	7.5×10^{-6}	--
Total	**2.8×10^{-4}**	**--**
Total ELCR*	**1.6×10^{-3}**	**--**

* Sum of total ELCR values for nonradionuclides and radionuclides.

-- = HI is not applicable
COPC = contaminant of potential concern
ELCR = excess lifetime cancer risk
HI = hazard index

The cumulative ELCR is 6.5×10^{-4} for nonradiological COPCs and 2.8×10^{-4} for radiological COPCs, which is greater than the WAC 173-340-708 cumulative risk threshold of 1×10^{-5} for multiple hazardous substances and greater than the EPA upper target risk threshold of 1×10^{-4}. The individual ELCR values for carbon tetrachloride and Tc-99 are greater than the EPA regulatory target risk threshold of 1×10^{-4}. Individual ELCRs associated with I-129, chloroform, PCE, and TCE are within the EPA range of 1×10^{-4} to 1×10^{-6}. The cumulative risk for carbon tetrachloride, chloroform, PCE, and TCE is greater than the

WAC 173-340 cumulative risk threshold of 1×10^{-5}. The HI is 8.1, which is greater than the EPA and WAC 173-340 target HI of 1.0. The primary contributor to the non-cancer HI is carbon tetrachloride with a HQ of 4.

Although the individual ELCR value associated with arsenic is greater than EPA's regulatory target risk threshold of 10^{-4} and the HQ is greater than 1, the 90th percentile value of 6.6 µg/L is considered to be within the range of naturally occurring concentrations. Therefore, arsenic is not considered a contributor to risk or HI.

1,1,2-Trichloroethane, 1,2-dichloroethane, 1,4-dioxane, benzene, bis(2-ethylhexyl) phthalate, and bromodichloromethane are not considered contributors to the ELCR. 1,1,2-Trichloroethane and benzene were detected at very low frequencies (<1 percent) at a small number of locations and are not considered to be associated with a trend or local exposure point. 1,2-Dichloroethane and 1,4-dioxane are considered uncertainties at Well 299-W22-20 because they were detected once over the past 5 years at this location only and have also been detected at this location between the years 2000 and 2004. Bis(2-ethylhexyl) phthalate was detected in 4 of 75 water samples and its presence is considered to be the result of laboratory contamination. The EPC for bromodichloroethane is considered an overestimation of the actual concentration in groundwater. The 90th percentile value for bromodichloromethane reflects the presence of elevated method detection limits rather than the presence of the COPC.

Acrolein and antimony are not considered contributors to the HI. Acrolein was detected in 1 of 122 water samples and is not considered to be associated with a trend or local exposure point. The analytical method used to measure antimony is not considered reliable because detected concentrations are reported to be false positives and method detection limits are generally above the federal MCL. Arsenic concentrations, as mentioned, are considered to be naturally occurring.

6.11 Comparison of Native American and EPA Tap Water Results Risk Estimates

Table 6-17 provides a summary of the risk estimates and hazard indices for each of the Native American Scenarios and the EPA tap water scenario. Results are ingestion, dermal contact, and inhalation of volatiles during household activities.

Exposure parameters for the Native American exposure scenarios and the EPA tap water scenario differ in exposure frequency (Native American 365 day/yr; EPA tap water 350 day/yr); exposure duration (Native American 70 years; EPA tap water 30 years); drinking water ingestion rate (Native American 4 L/day [1 gal/day]; EPA tap water 2 L/day [0.5 gal/day]); and inhalation rate (CTUIR 25 m^3/day [883 ft^3/day], Yakama Nation 26 m^3/day [918 ft^3/day]; EPA tap water 20 m^3/day [706 ft^3/day]). As a result, the EPA tap water scenario has a lower total ELCR and HI than the Native American exposure scenarios.

The total ELCRs for the CTUIR and Yakama Nation exposure scenarios are 3.8×10^{-3} and 4.0×10^{-3} respectively. The total ELCR for the EPA tap water equations is 9.3×10^{-4}. The primary contributors to risk for the Native American exposure scenarios are carbon tetrachloride, chloroform, I-129, tritium, Sr-90, PCE, TCE, and Tc-99. Tritium is not a primary contributor to the EPA tap water scenario. The total HI is 36 for both the CTUIR and Yakama Nation exposure scenarios. The HI for the EPA tap water equations is 8.1. Carbon tetrachloride, nitrate, and uranium are the primary contributors to the non-cancer HI for the Native American scenario and carbon tetrachloride is the primary contributor to the EPA tap water exposure scenario.

Table 6-17. Comparison of Risk Estimates and Hazard Indices for the CTUIR, Yakama Nation, and EPA Tap Water Equations

Exposure Scenario	COPC Type	Drinking Water Ingestion		Inhalation of Volatiles		Dermal Contact with Water		Total			
		ELCR	Hazard Index	ELCR	Hazard Index	ELCR	Hazard Index	ELCR	Primary Contributors to Risk	Hazard Index	Primary Contributors to Hazard Index
CTUIR	Nonradiological	2.1×10^{-3}	33	3.9×10^{-5}	0.86	2.2×10^{-4}	2.4	2.4×10^{-3}	**Carbon Tetrachloride**, Chloroform, I-129, Sr-90, **H3**, PCE,TCE, **Tc-99**	**36**	**Carbon Tetrachloride, Nitrate, Uranium**
	Radiological	1.4×10^{-3}	--	2.3×10^{-5}	--	--	--	1.4×10^{-3}		**--**	
	Total	3.5×10^{-3}	33	6.2×10^{-5}	0.86	2.2×10^{-4}	2.4	3.8×10^{-3}		**36**	
Yakama Nation	Nonradiological	2.3×10^{-3}	33	3.9×10^{-5}	0.86	2.2×10^{-4}	2.4	2.5×10^{-3}	**Carbon Tetrachloride**, Chloroform, I-129, **H3**, Sr-90, PCE, TCE, **Tc-99**	**36**	**Carbon Tetrachloride, Nitrate, Uranium**
	Radiological	1.4×10^{-3}	--	2.4×10^{-5}	--	--	--	1.5×10^{-3}		**--**	
	Total	3.7×10^{-3}	33	6.3×10^{-5}	0.86	2.4×10^{-4}	2.4	4.0×10^{-3}		**36**	
EPA Tap Water	Nonradiological	5.3×10^{-4}	6.7	1.6×10^{-5}	0.35	1.0×10^{-4}	0.99	6.5×10^{-4}	**Carbon Tetrachloride**, Chloroform, I-129, Sr-90, H3, PCE, TCE, **Tc-99**	**8.0**	**Carbon Tetrachloride**
	Radiological	2.8×10^{-4}	--	7.5×10^{-6}	--	--	--	2.9×10^{-4}		**--**	
	Total	8.1×10^{-4}	6.7	2.4×10^{-5}	0.35	1.0×10^{-4}	0.99	9.3×10^{-4}		**8.0**	

Notes: Bolded COPCs indicate that the individual ELCR is greater than 1×10^{-4} or has a hazard quotient greater than 1.

COPC = contaminant of potential concern
CTUIR = Confederated Tribes of the Umatilla Indian Reservation
ELCR = excess lifetime cancer risk
EPA = U.S. Environmental Protection Agency
H_3 = tritium
PCE = tetrachloroethene
TCE = trichloroethene

7 Identification and Screening of Technologies

The primary objective of the FS is to ensure that appropriate remedial alternatives are developed and evaluated such that relevant information concerning the RA options can be presented to the public and an appropriate remedy selected. This chapter presents the RAOs designed to address the specific threats posed by the COCs present in 200-UP-1 OU groundwater. GRAs for achieving the RAOs are then identified and the remedial technologies and associated process options are screened. The screening process is used to develop a list of viable technologies for assembly into an array of RA alternatives in Chapter 8.

7.1 Remedial Action Objectives

RAOs are descriptions of what the RA is expected to accomplish (medium-specific or site-specific goals for protecting HHE). RAOs generally include statements, which are defined as specifically as possible, to address the following:

- Media of interest (contaminated soil or groundwater)
- Types of contaminants (radionuclides and chemical constituents)
- Potential receptors (humans and ecological)
- Exposure pathways (external radiation, dermal contact, ingestion, or inhalation)
- Contaminant concentrations that may remain in the environmental media once the RA is complete

The RAOs provide the basis for evaluating the ability of a technology or remedial alternative to achieve a specific cleanup level or level of risk for protecting HHE. RAOs for the 200-UP-1 Groundwater OU are presented in Section 7.1.4. Background information used in developing the RAOs is presented in Sections 7.1.1 through 7.1.3.

7.1.1 Contaminants of Concern

The following were identified in Table 6-2 as the final COPCs for 200-UP-1 OU groundwater: carbon tetrachloride, chloroform, PCE, TCE, 1,4-dioxane, chromium, hexavalent chromium, uranium, nitrate, fluoride, I-129, Tc-99, Sr-90, and tritium.

As part of the RAO development process, the list of COPCs from the BRA was evaluated further to develop a list of COCs to guide the remedial technology screening and alternative development process. Based on the results of this evaluation, which is presented in Section 7.1.3, the list of COCs includes: uranium, nitrate, Tc-99, I-129, and tritium. Except for uranium, this list of COCs is a subset of that presented in the 200-ZP-1 Groundwater OU ROD.

7.1.2 Applicable or Relevant and Appropriate Requirements

As part of the process for determining cleanup levels for a CERCLA site, ARARs are reviewed to identify well-known federal and state standards that will (or may) affect the development and selection of a final RA alternative. The ARARs identification process presented in this section is based on CERCLA (EPA/540/G-89/006) and RI/FS guidance (EPA/540/G-89/004).

7.1.2.1 Definition and Determination of ARARs

RAs under CERCLA, as amended under Title 42, Chapter 103, must attain levels of cleanup for hazardous substances released into the environment, and control further release, to ensure overall protection of HHE. The *Superfund Amendments and Reauthorization Act of 1986* specifies that a selected

RA must achieve a level of control that at least attains requirements that are legally applicable to the hazardous substances of concern, or relevant and appropriate under the circumstances of the release or threatened release.

The identification of ARARs is a two-step process. First, it must be determined if the law or regulation is applicable. If not applicable, it must be determined if the law or regulation is both relevant and appropriate. The terms "applicable" and "relevant and appropriate" are defined in 40 CFR 300.5 as follows.

- "Applicable" means those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility citing laws that specifically address a hazardous substance, pollutant, contaminant, RA, location, or other circumstance found at a CERCLA site. Only those state standards that are identified by the state in a timely manner, and that are more stringent than federal requirements, may be applicable.
- "Relevant and appropriate requirements" means those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that, although not "applicable" to a hazardous substance, pollutant, contaminant, RA, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well-suited to the particular site. Only those state standards that are identified in a timely manner and are more stringent than federal requirements may be relevant and appropriate.

In evaluating the relevance and appropriateness of a requirement, the following eight comparison factors described in 40 CFR 300.400(g)(2) are considered:

1. The purpose of the requirement and the purpose of the CERCLA action
2. The medium regulated or affected by the requirement and the medium contaminated or affected at the CERCLA site
3. The substances regulated by the requirement and the substances found at the CERCLA site
4. The actions or activities regulated by the requirement and the remedial action contemplated at the CERCLA site
5. Any variances, waivers, or exemptions of the requirement and their availability for the circumstances at the CERCLA site
6. The type of place regulated and the type of place affected by the release or CERCLA action
7. The type and size of structure or facility regulated and the type and size of structure or facility affected by the release or contemplated by the CERCLA action
8. Any consideration of use or potential use of affected resources in the requirement and the use or potential use of the affected resource at the CERCLA site

To be considered (TBC) information represents another category of non-promulgated advisories or guidance issued by federal or state governments that are not legally binding and do not have the status of ARARs. In some circumstances, TBC information will be evaluated, along with ARARs, in determining the RA necessary to protect HHE. TBC information complements ARARs in determining protectiveness at a CERCLA site or in assessing implementation of certain actions. For example, because cleanup

standards do not exist for all contaminants, health advisories, which would be TBC information, may be helpful in defining cleanup levels.

ARARs are divided into three categories: chemical-specific, location-specific, and action-specific as follows:

- Chemical-specific requirements are usually health- or risk-based numerical values or methodologies used to derive numerical values. When applied to site-specific conditions, these requirements result in the establishment of public and worker protection levels and site cleanup levels.
- Location-specific requirements are restrictions placed on the concentration of hazardous substances or the conduct of activities solely because they occur in special geographic areas.
- Action-specific requirements are usually technology- or activity-based requirements or limitations triggered by the RAs performed at the site.

A distinction and clarification related to ARARs involves onsite and offsite actions. Onsite actions are defined to be "the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action" (400 CFR 300). Onsite actions must comply with ARARs, but need only comply with the substantive parts of those requirements. Offsite actions must comply with both the substantive and administrative requirements. For onsite activities, a requirement under federal and state environmental laws may be either applicable or relevant and appropriate, but not both.

In summary, a requirement is applicable if the specific terms or jurisdictional prerequisites of the law or regulations directly address the circumstances at a site. If not applicable, a requirement may nevertheless be relevant and appropriate if: (1) circumstances at the site are sufficiently similar to the problems or situations regulated by the requirement, and (2) the requirement utilizes the site productively. Only the substantive requirements associated with ARARs apply to CERCLA onsite activities. The ARARs associated with administrative requirements, such as permitting, are not applicable to CERCLA onsite activities (CERCLA, Section 121[e] [1]). It is expected that the CERCLA onsite permitting exemption will be extended to all CERCLA remedial and RCRA corrective action activities conducted at the 200-UP-1 Groundwater OU. Tables 7-1 and 7-2 (respectively) list the preliminary federal and state ARARs that have been identified as potentially applicable to 200-UP-1 GRAs.

Because 200-UP-1 OU groundwater will be remediated under a CERCLA decision document, RAs are required to meet ARARs. Final ARARs for remediation of 200-UP-1 OU groundwater are consistent with those previously established in the 200-ZP-1 Groundwater OU ROD.

7.1.2.2 Potential Chemical-Specific ARARs

The chemical-specific requirements that are most likely to be applicable or relevant and appropriate to remediation of the 200-UP-1 Groundwater OU are elements of the federal and state regulations that implement the DWSs (40 CFR 141, WAC 173-340-720[4][b][iii][A] and [B]) and health protection (WAC 173-340-720[7][b]).

Since the federal DWSs and specific groundwater cleanup sections of the Washington State MTCA are considered ARARs, the RA alternatives assembled in Chapter 8 will be developed to achieve ARARs for each identified COC such that groundwater present in the 200-UP-1 Groundwater OU can be used as a future drinking water source.

Table 7-1. Identification of Potential Federal ARARs

ARAR Citation	ARAR*	Requirement	Rationale for Use
"National Primary Drinking Water Regulations," 40 CFR 141			
"Maximum Contaminant Levels for Organic Contaminants," 40 CFR 141.61	ARAR	Establishes MCLs for drinking water that are designed to protect human health from the potential adverse effects of organic contaminants in drinking water.	The groundwater in the 200-UP-1 Groundwater OU is not currently used for drinking water. However, Central Plateau groundwater may be considered a potential drinking water source and, because the groundwater discharges to the Columbia River (which is used for drinking water), the substantive requirements in 40 CFR 141.61 for organic constituents are applicable. This is a chemical-specific requirement.
"Maximum Contaminant Levels for Inorganic Contaminants," 40 CFR 141.62	ARAR	Establishes MCLs for drinking water that are designed to protect human health from the potential adverse effects of inorganic contaminants in drinking water.	The groundwater in the 200-UP-1 Groundwater OU is not currently used for drinking water. However, Central Plateau groundwater may be considered a potential drinking water source and, because the groundwater discharges to the Columbia River (which is used for drinking water), the substantive requirements in 40 CFR 141.62 for inorganic constituents are applicable. This is a chemical-specific requirement.
"Maximum Contaminant Levels for Radionuclides," 40 CFR 141.66	ARAR	Establishes MCLs for drinking water that are designed to protect human health from the potential adverse effects of radionuclides in drinking water.	The groundwater in the 200-UP-1 Groundwater OU is not currently used for drinking water. However, Central Plateau groundwater may be considered a potential drinking water source and because the groundwater discharges to the Columbia River (which is used for drinking water), the substantive requirements in 40 CFR 141.66 for radionuclides are applicable. This is a chemical-specific requirement.
Other Federal ARARs			
Archeological and Historic Preservation Act, 16 USC 469 a-1 through 2(d)	ARAR	Requires that RAs at the 200-UP-1 Groundwater OU do not cause the loss of any archaeological or historic data. This act mandates preservation of the data and does not require protection of the actual historical sites.	Archeological and historic sites have been identified within the 200 Area; therefore, the substantive requirements of this act are applicable to actions that might disturb these sites. This is an action-specific requirement.

Table 7-1. Identification of Potential Federal ARARs

ARAR Citation	ARAR*	Requirement	Rationale for Use
National Historic Preservation Act of 1966, 16 USC 470, Section 106, et seq.	ARAR	Requires federal agencies to consider the impacts of their undertaking on cultural properties through identification, evaluation, and mitigation processes.	Cultural and historic sites have been identified within the 200 Area; therefore, the substantive requirements of this act are applicable to actions that might disturb these types of sites. This is a location-specific requirement.
Native American Graves Protection and Repatriation Act of 1990, 25 USC 3001, et seq.	ARAR	Establishes federal agency responsibility for discovery of human remains, associated and unassociated funerary objects, sacred objects, and items of cultural patrimony.	Substantive requirements of this act are applicable if remains and sacred objects are found during remediation. This is a location-specific requirement.
Endangered Species Act of 1973, 16 USC 1531, et seq., subsection 16 USC 1536(c)	ARAR	Establishes requirements for actions by federal agencies that are likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of critical habitat. If remediation is within critical habitat or buffer zones surrounding threatened or endangered species, mitigation measures must be taken to protect the resource.	Substantive requirements of this act are applicable if threatened or endangered species are identified in areas where RAs will occur. This is a location-specific requirement.
Interim Control of Hazardous Waste Injection 42 USC 6939b sec. 3020(b)	ARAR	Establishes requirements to allow injection of groundwater that contains hazardous waste back into the aquifer during implementation of the CERCLA remedy.	Substantive requirements of the section are applicable to the injection of contaminated groundwater to the aquifer. This is an action-specific requirement.

Note: Regulations pursuant to the *Resource Conservation and Recovery Act of 1976* are implemented through WAC 173-303 (see Table B-2).

* The final ARARs classification (applicable, relevant, and appropriate, or TBC) will be determined in the 200-UP-1 Groundwater OU decision document. Therefore, at this time, all potential regulations are identified as ARARs.

ARAR = applicable or relevant and appropriate requirement
CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR = Code of Federal Regulations
MCL = maximum contaminant level
OU = operable unit
RA = remedial action
TBC = to be considered
USC = United States Code
WAC = Washington Administrative Code

Table 7-2. Identification of Potential State ARARs

ARAR Citation	ARAR*	Requirement	Rationale for Use
"Model Toxics Control Act," WAC 173-340			
"Standard Method B Potable Ground Water Cleanup Levels," WAC 173-340-720(4)(b)(iii)(A) and (B)	ARAR	Use of Method B equations 720-1 and 720-2 to calculate groundwater cleanup levels for noncarcinogens and carcinogens, respectively.	The groundwater in the 200-UP-1 Groundwater OU is not currently used for drinking water. However, the ARAR requires that the groundwater cleanup levels shall be based on the highest beneficial use, both current and potential future site use. The Central Plateau and the 200-UP-1 OU groundwater is considered potable under WAC 173-340-720. The substantive requirements are WAC 173-340-720(4)(b)(iii)(A) and (B). This is a chemical-specific requirement.
"Adjustments to Cleanup Levels," WAC 173-340-720(7)(b)	ARAR	Requires an adjustment downward of Method B groundwater cleanup levels based on an existing state or federal cleanup standard so that the total excess cancer risk does not exceed 1×10^{-5} and the hazard index does not exceed 1.	The groundwater in the 200-UP-1 Groundwater OU is not currently used for drinking water. However, the ARAR requires that the groundwater cleanup levels shall be based on the highest beneficial use, both current and potential future site use. The Central Plateau and the 200-UP-1 OU groundwater is considered potable under WAC 173-340-720. The substantive requirement is WAC 173-340-720(7)(b). This is a chemical-specific requirement.
"Dangerous Waste Regulations," WAC 173-303			
"Identifying Solid Waste," WAC 173-303-016	ARAR	Identifies those materials that are and are not solid wastes.	Substantive requirements of these regulations are applicable because they define how to determine which materials are subject to the designation regulations. Specifically, materials that are generated during the RA would, if a solid waste, be subject to the requirements for solid wastes. This is an action-specific requirement.
"Recycling Processes Involving Solid Waste," WAC 173-303-017	ARAR	Identifies materials that are and are not solid wastes when recycled.	Substantive requirements of these regulations are applicable because they define how to determine which materials are subject to the designation regulations. Specifically, materials that are generated during the RA would, if a solid waste, be subject to the requirements for solid wastes. This is an action-specific requirement.

Table 7-2. Identification of Potential State ARARs

ARAR Citation	ARAR*	Requirement	Rationale for Use
"Designation of Dangerous Waste," WAC 173-303-070(3)	ARAR	Establishes whether a solid waste is, or is not, a dangerous waste or an extremely hazardous waste.	Substantive requirements of these regulations are applicable to materials generated during the RA. Specifically, solid waste that is generated during this RA would, if a dangerous waste, be subject to the dangerous waste regulations. This is an action-specific requirement.
"Excluded Categories of Waste," WAC 173-303-071	ARAR	Describes those categories of wastes that are excluded from the requirements of WAC 173-303 (excluding WAC 173-303-050).	This regulation is applicable to RAs in the 200-UP-1 Groundwater OU, should wastes identified in WAC 173-303-071 be generated. This is an action-specific requirement.
"Conditional Exclusion of Special Wastes," WAC 173-303-073	ARAR	Establishes the conditional exclusion and the management requirements of special wastes, as defined in WAC 173-303-040.	Substantive requirements of these regulations are applicable to special wastes generated during the RA. Specifically, the substantive standards for management of special waste are relevant and appropriate to the management of special waste that will be generated during the RA. This is an action-specific requirement.
"Requirements for Universal Waste," WAC 173-303-077	ARAR	Identifies those wastes exempted from regulation under WAC 173-303-140 and WAC 173-303-170 through 173-303-9906 (excluding WAC 173-303-960). These wastes are subject to regulation under WAC 173-303-573.	Substantive requirements of these regulations are applicable to universal waste generated during the RA. Specifically, the substantive standards for management of universal waste are relevant and appropriate to the management of universal waste that will be generated during the RA. This is an action-specific requirement.
"Recycled, Reclaimed, and Recovered Wastes," WAC 173-303-120 Specific subsections: WAC 173-303-120(3) WAC 173-303-120(5)	ARAR	These regulations define the requirements for recycling materials that are solid and dangerous waste. Specifically, WAC 173-303-120(3) provides for the management of certain recyclable materials, including spent refrigerants, antifreeze, and lead-acid batteries. WAC 173-303-120(5) provides for the recycling of used oil.	Substantive requirements of these regulations are applicable to certain materials that might be generated during the RA. Eligible recyclable materials can be recycled and/or conditionally excluded from certain dangerous waste requirements. This is an action-specific requirement.

Table 7-2. Identification of Potential State ARARs

ARAR Citation	ARAR*	Requirement	Rationale for Use
"Land Disposal Restrictions," WAC 173-303-140(4)	ARAR	This regulation establishes state standards for land disposal of dangerous waste and incorporates, by reference, federal LDRs of 40 CFR 268 that are relevant and appropriate to solid waste that is designated as dangerous or mixed waste in accordance with WAC 173-303-070(3).	The substantive requirements of this regulation are applicable to materials generated during the RA. Specifically, dangerous/mixed waste that is generated during the RA would be subject to the relevant and appropriate substantive LDRs. The offsite treatment, disposal, or management of such waste would be subject to all applicable substantive and procedural laws and regulations, including LDR requirements. This is an action-specific requirement.
"Requirements for Generators of Dangerous Waste," WAC 173-303-170	ARAR	Establishes the requirements for dangerous waste generators.	Substantive requirements of these regulations are applicable to materials generated during the RA. Specifically, the substantive standards for management of dangerous/mixed waste are relevant and appropriate to the management of dangerous waste that will be generated during the RA. For purposes of this RA, WAC 173-303-170(3) includes the substantive provisions of WAC 173-303-200 by reference. WAC 173-303-200 further includes certain substantive standards from WAC 173-303-630 and -640 by reference. This is an action-specific requirement.
"Corrective Action Dangerous Waste Regulation Requirements," WAC 173-303-64620(4)	ARAR	Requires Corrective Action to be "consistent with" specified section in WAC 173-340.	The substantive portions of this regulation establish minimum requirements for HWMA corrective action.
"Solid Waste Handling Standards," WAC 173-350			
"On-Site Storage, Collection and Transportation Standards," WAC 173-350-300	ARAR	Establishes the requirements for the temporary storage of solid waste in a container onsite and the collecting and transporting of the solid waste.	The substantive requirements of this newly promulgated rule are applicable to the onsite collection and temporary storage of solid wastes for the 200-UP-1 Groundwater OU remediation activities. Compliance with this regulation is being implemented in phases for existing facilities. These requirements are location-specific.

Table 7-2. Identification of Potential State ARARs

ARAR Citation	ARAR*	Requirement	Rationale for Use
"Minimum Standards for Construction and Maintenance of Wells," WAC 173-160			
WAC 173-160-161	ARAR	Identifies well planning and construction requirements.	The substantive requirements of these regulations are ARAR to actions that include construction of wells used for groundwater extraction, monitoring, or injection of treated groundwater or wastes. The substantive requirements of WAC 173-160-161, 173-160-171, 173-160-181, 173-160-400, 173-160-420, 173-303-430, 173-160-440, 173-160-450, and 173-160-460 are relevant and appropriate to groundwater well construction, monitoring, or injection of treated groundwater or wastes in the 200-UP-1 Groundwater OU. These requirements are action-specific.
WAC 173-160-171	ARAR	Identifies the requirements for locating a well.	
WAC 173-160-181	ARAR	Identifies the requirements for preserving natural barriers to groundwater movement between aquifers.	
WAC 173-160-400	ARAR	Identifies the minimum standards for resource protection wells and geotechnical soil borings.	
WAC 173-160-420	ARAR	Identifies the general construction requirements for resource protection wells.	
WAC 173-160-430	ARAR	Identifies the minimum casing standards.	
WAC 173-160-440	ARAR	Identifies the equipment cleaning standards.	
WAC 173-160-450	ARAR	Identifies the well sealing requirements.	
WAC 173-160-460	ARAR	Identifies the decommissioning process for resource protection wells.	
"Underground Injection Control," WAC 173-218			
WAC 173-218-040	ARAR	Identifies what an injection well is and types of prohibited wells.	The substantive requirements of these regulations are ARAR to actions that discharge liquid effluents to injection wells. WAC 173-218-040(4) allows for injection of treated groundwater into the same formation from where it was drawn as part of a removal or RA approved by EPA in accordance with CERCLA. This is an action-specific requirement.
WAC 173-218-120	ARAR	Identifies the requirements for decommissioning a UIC well.	Periodically, injection wells may need to be removed from service and decommissioned. In the event of injection well decommissioning, WAC 173-218-120 is ARAR. This is an action-specific requirement.

Table 7-2. Identification of Potential State ARARs

ARAR Citation	ARAR*	Requirement	Rationale for Use
"General Regulations for Air Pollution Sources," WAC 173-400			
"General Standards for Maximum Emissions," WAC 173-400-040 WAC 173-400-113	ARAR	Requires all sources of air contaminants to meet emission standards for visible, particulate, fugitive, odors, and hazardous air emissions. Requires use of reasonably available control technology. This state regulation is as (or more) stringent than the equivalent federal program requirement.	Substantive requirements of these standards are ARAR to this RA because there may be visible, particulate, fugitive, and hazardous air emissions and odors resulting from remedial activities. As a result, standards established for the control and prevention of air pollution are relevant and appropriate. This is an action-specific requirement.
"Controls for New Sources of Toxic Air Pollutants," WAC 173-460			
"Controls for New Sources of Toxic Air Pollutants," WAC 173-460 Specific subsections: WAC 173-460-030 WAC 173-460-060	ARAR	Requires that new sources of air emissions meet emission requirements identified in this regulation. This state regulation is as (or more) stringent than the equivalent federal program requirement.	Substantive requirements of these standards are ARAR to this RA because there is the potential for toxic air pollutants to become airborne as a result of remedial activities. As a result, standards established for the control of toxic air contaminants are relevant and appropriate. This is an action-specific requirement.
"Ambient Impact Requirement," WAC 173-460-070	ARAR	The owner/operator of a new toxic air pollutant source that is likely to increase toxic air pollutant emissions shall demonstrate that emissions from the source are sufficiently low to protect human health and safety from potential carcinogenic and/or other toxic effects. This state regulation is as (or more) stringent than the equivalent federal program requirement.	The substantive requirements of this standard are ARAR to RAs in the 200-UP-1 Groundwater OU, should the RA result in the treatment of the soil or debris that contains COC identified in the regulation as a toxic air pollutant. This is an action-specific requirement.
"Ambient Air Quality Standards and Emission Limits for Radionuclides," WAC 173-480			
"General Standards for Maximum Permissible Emissions," WAC 173-480-050(1)	ARAR	Determine compliance with the public dose standard by calculating exposure at the point of maximum annual air concentration in an unrestricted area where any member of the public may be. This state regulation is as (or more) stringent than the equivalent federal program requirement.	Substantive requirements are ARAR when fugitive and diffuse emissions resulting from excavation occur and related activities will require assessment and reporting. This is an action-specific requirement.

Table 7-2. Identification of Potential State ARARs

ARAR Citation	ARAR*	Requirement	Rationale for Use
"Compliance," WAC 173-480-070(2)	ARAR	Requires that radionuclide emissions compliance shall be determined by calculating the dose to members of the public at the point of maximum annual air concentration in an unrestricted area where any member of the public may be. This state regulation is as (or more) stringent than the equivalent federal program requirement.	The substantive requirements of this standard are ARAR to RAs involving disturbance or ventilation of radioactively contaminated areas or structures, because airborne radionuclides may be emitted to unrestricted areas where any member of the public may be. This is an action-specific requirement.
"Radiation Protection Air Emissions," WAC 246-247			
"National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities," WAC 246-247-035(1)(a)(ii)	ARAR	This regulation incorporates requirements of 40 CFR 61, Subpart H by reference. Radionuclide airborne emissions from the facility shall be controlled so as not to exceed amounts that would cause an exposure to any member of the public of greater than 10 mrem/yr effective dose equivalent. This state regulation is as (or more) stringent than the equivalent federal program requirement.	Substantive requirements of this standard are ARAR because this RA may provide airborne emissions of radioactive particulates to unrestricted areas. As a result, requirements limiting emissions apply. This is a risk-based standard for the purposes of protecting human health and the environment. This is an action-specific requirement.
"General Standards," WAC 246-247-040(3), WAC 246-247-040(4)	ARAR	Emissions shall be controlled to ensure that emission standards are not exceeded. Actions creating new sources or significantly modified sources shall apply best available controls. All other actions shall apply reasonably achievable controls. This state regulation is as (or more) stringent than the equivalent federal program requirement.	Substantive requirements of this standard are ARAR because fugitive, diffuse, and point source emissions of radionuclides to the ambient air may result from remedial activities, such as excavation of contaminated soils and operation of exhauster and vacuums, performed during the RA. This standard exists to ensure compliance with emission standards. This is an action-specific requirement.
"Monitoring, Testing, and Quality Assurance," WAC 246-247-075(1), (2), (3), and (4)	ARAR	Emissions from non-point and fugitive sources of airborne radioactive material shall be measured. Measurement techniques may include, but are not limited to, sampling, calculation, smears, or other reasonable method for identifying emissions as determined by the lead agency. This state regulation is as (or more) stringent than the equivalent federal program requirement.	Substantive requirements of this standard are ARAR when fugitive and non-point source emissions of radionuclides to the ambient air may result from activities, such as operation of exhauster and vacuums, performed during a RA. This standard exists to ensure compliance with emission standards. This is an action-specific requirement.

Table 7-2. Identification of Potential State ARARs

ARAR Citation	ARAR*	Requirement	Rationale for Use
"Monitoring, Testing, and Quality Assurance," WAC 246-247-075(8)	ARAR	Facility (site) emissions resulting from non-point and fugitive sources of airborne radioactive material shall be measured. Measurement techniques may include ambient air measurements, or in-line radiation detector or withdrawal of representative samples from the effluent stream, or other methods as determined by the lead agency. This state regulation is as (or more) stringent than the equivalent federal program requirement.	Substantive requirements are ARAR when fugitive and diffuse emissions of airborne radioactive material due to excavation and related activities occur and will require measurement. This is an action-specific requirement.

* The final ARARs classification (applicable, relevant and appropriate, or TBC) will be determined in the 200-UP-1 Groundwater OU decision document. Therefore, at this time, all potential regulations are identified as ARARs.

ARAR	=	applicable or relevant and appropriate requirement	LDR	=	land disposal restrictions
CERCLA	=	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*	OU	=	operable unit
CFR	=	Code of Federal Regulations	RA	=	remedial action
COC	=	contaminant of concern	TBC	=	to be considered
EPA	=	U.S. Environmental Protection Agency	UIC	=	Underground Injection Control (Program)
HWMA	=	*Washington State Hazardous Waste Management Act of 1976*	WAC	=	Washington Administrative Code

7.1.2.3 Potential Location-Specific ARARs

Potential location-specific ARARs identified for the 200-UP-1 Groundwater OU include those that protect cultural, historic, and Native American sites and artifacts, as well as those that protect critical habitats of federally endangered and threatened species.

7.1.2.4 Potential Action-Specific ARARs

Potential action-specific ARARs that could be pertinent to remediation are the state solid and dangerous waste regulations (for management and characterization of remediation wastes). A variety of waste streams may be generated under the proposed RA alternatives that are described in Chapter 8 of this FS. It is anticipated that most of the waste will be designated as dangerous or mixed waste. Washington State air emission standards also identify air emission limits and control requirements for any RAs that produce air emissions.

The identification, storage, treatment, and disposal of hazardous waste and the hazardous component of mixed waste generated during the RA would be subject to the substantive provisions of RCRA. In the State of Washington, RCRA is implemented through WAC 173-303, the state dangerous waste program. The substantive portions of the dangerous waste standards for generation and storage would apply to the management of any dangerous or mixed waste generated during a 200-UP-1 Groundwater OU RA. Treatment standards for dangerous or mixed waste that is subject to RCRA land-disposal restrictions are specified in WAC 173-303-140, which incorporates 40 CFR 268 by reference.

Low-level waste that meets ERDF waste acceptance criteria is assumed to be disposed at ERDF, which is engineered to meet appropriate performance standards of 10 CFR 61. In addition, waste designated as dangerous or mixed waste would be treated as appropriate to meet land disposal restrictions (LDRs) and ERDF acceptance criteria. The ERDF is engineered to meet minimum technical requirements for landfills under WAC 173-303-665. Applicable packaging and pre-transportation requirements for dangerous or mixed waste generated at the 200-UP-1 Groundwater OU would be identified and implemented before any waste was moved. Alternate disposal locations may be considered when the RA occurs if a suitable and cost-effective location is identified. Any potential alternate disposal location will be evaluated for appropriate performance standards to ensure that it is adequately protective of HHE.

Waste designated as transuranic waste will be stored at the Central Waste Complex, with eventual disposal at a geologic repository (Waste Isolation Pilot Plant).

CERCLA states that where two or more noncontiguous facilities are reasonably related on the basis of geography, or a threat or potential threat to the public health or welfare or the environment, the facilities can be treated as one for purposes of CERCLA response actions. Consistent with this, the 200-UP-1 Groundwater OU, ERDF, and the 200 Area ETF would be considered onsite facilities for purposes of Section 104 of CERCLA, and waste may be transferred between the 200-UP-1 Groundwater OU and these facilities without a permit. Liquid effluent discharged to the ground after treatment under any remedial alternative must comply with the requirements of WAC 173-216. In the event that the treated effluent is injected into the aquifer, it may be necessary to comply with WAC 173-218.

200-UP-1 Groundwater OU RAs implemented under a CERCLA decision document will be performed in compliance with dangerous and mixed waste requirements. Waste streams will be evaluated, designated, and managed in compliance with the ARARs. Before disposal, waste will be managed in a protective manner to prevent releases to the environment or unnecessary personnel exposure.

The proposed RA alternatives presented in Chapter 8 of this FS have the potential to generate airborne emissions of both radioactive and criteria/toxic pollutants. The *Revised Code of Washington* (RCW) 70.94 regulates radioactive air pollutants. The state implementing regulation, WAC 173-480, sets standards that are as stringent, or more so, than the federal standards under the *Clean Air Act of 1990* and the implementing regulation (40 CFR 61, Subpart H). The Washington State standards protect the public by establishing conservative exposure standards applicable to the maximally exposed public individual, be that individual real or hypothetical. The standards address any member of the public, at the point of maximum annual air concentration in an unrestricted area where any member of the public may be present. Radionuclide airborne emissions from a potential construction activity or treatment facility shall not exceed amounts of exposure to the public greater than a 10 mrem/yr effective dose equivalent. The Washington State implementing regulation, WAC 246-247 (which adopts the WAC 173-480 standards), and 40 CFR 61, Subpart H, require verification of compliance with the 10 mrem/yr standard and would be applicable to the RA.

WAC 246-247 further addresses sources emitting radioactive airborne emissions by requiring monitoring of such sources. Such monitoring requires physical measurement of the effluent or ambient air. The substantive provisions of WAC 246-247 that require monitoring of radioactive airborne emissions would be applicable to the RA.

The implementing regulations listed previously further address control of radioactive airborne emissions where economically and technologically feasible (WAC 246-247-040[3] and -040[4] and associated definitions). To address the substantive aspect of these requirements, best or reasonably achieved control technology will be addressed by ensuring that applicable emission control technologies (those successfully operated in similar applications) will be used when economically and technologically feasible (based on cost benefit). If it is determined that there are substantive aspects of the requirement for control of radioactive airborne emissions, then controls will be administered as appropriate using reasonable and effective methods.

7.1.2.5 Waivers from Applicable or Relevant and Appropriate Requirements

The NCP allows selection of a RA (40 CFR 300.430[f][1][ii][C]) that does not attain ARARs. Section 121 of the *Superfund Amendments and Reauthorization Act of 1986* identifies six circumstances in which EPA may waive ARARs for onsite RAs.

- The remedial action selected is only a part of a total remedial action (an interim action), and the final remedy will attain the ARAR upon its completion.
- Compliance with the ARAR will result in a greater risk to HHE than alternative options.
- Compliance with the ARAR is technically impracticable from an engineering perspective.
- An alternative remedial action will attain an equivalent standard of performance through the use of another method or approach.
- The ARAR is a state requirement that the state has not consistently applied (or demonstrated the intent to apply consistently) in similar circumstances.
- In the case of Section 104 (Superfund-financed remedial actions), compliance with the ARAR will not provide a balance between protecting HHE and the availability of Superfund money for response at other facilities.

After remedy implementation (post-ROD), if performance-monitoring data indicate that attainment of ARARs is technically impracticable from an engineering perspective, then an evaluation may be conducted to assess whether a technical impracticability waiver from one or more chemical-specific ARARs is warranted. Technical impracticability waivers only apply to that portion of the groundwater contaminant plume for which restoration to ARARs is determined to be technically impracticable.

7.1.2.6 200-UP-1 Operable Unit Groundwater Beneficial Use

The NCP establishes an expectation to "return useable ground waters to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site" (40 CFR 300.430[a][1][iii][F]). EPA generally defers to state definitions of groundwater classification provided under EPA-endorsed Comprehensive State Groundwater Protection Programs (EPA/540/G-88/003).

Based on anticipated yield and natural water quality, the State of Washington has determined that the aquifer setting for the 200-UP-1 Groundwater OU meets the WAC 173-340-720 definition for potable groundwater, which is the highest recognized beneficial use. Under EPA's groundwater classification program, 200-UP-1 OU groundwater would be designated Class IIB, groundwater that is not a current source of drinking water, but is a potential future source.

Large portions of the 200-UP-1 Groundwater OU lie within the Central Plateau's Inner Area where the groundwater quality will be returned to unrestricted use where possible, groundwater use restricted where necessary, and treatment technologies and source removal applied to enable future use (DOE/RL-2009-81). Consistent with the beneficial-use determinations of the state and EPA, and DOE's Central Plateau Cleanup Completion Strategy, 200-UP-1 OU groundwater will be remediated to a level that supports its use as a future drinking water source.

7.1.3 Cleanup Levels

Cleanup levels represent a core component of the overall technology screening and remedial alternative development process in the FS. Cleanup levels are numerical values expressed as concentrations for a chemical or radionuclide in an environmental media. A RA's achievement of cleanup levels results in residual contamination that is protective of HHE (40 CFR 300.430[e][2][i]). Cleanup levels are also used to identify the area and volume of environmental media that must be addressed; therefore, cleanup levels are determined prior to the development of the remedial alternatives. Numerical cleanup levels are generally not required or applicable for groundwater alternatives that employ containment technologies (DOE/EH-413/9711).

The cleanup levels (Table 7-3) for the 200-UP-1 Groundwater OU are the same as those specified in the 200-ZP-1 Groundwater OU ROD except for uranium, which is a COC for the 200-UP-1 Groundwater OU only.

Table 7-3. 200-UP-1 Groundwater OU Cleanup Levels

Contaminant	Units	90th Percentile Concen-tration	Dose (mrem/yr) Based on 90th Percentile Concen-tration	ELCR Based on 90th Percentile Concen-tration	HI Based on 90th Percentile Concen-tration	Drinking Water Standard	Model Toxics Control Act Method B Cleanup Levels		200-UP-1 Groundwater OU Cleanup Level[a]
							Non-Carcinogens at HQ = 1	Carcinogens at 1×10^{-5} Risk Level	
COCs - for Remedial Technology Screening and Alternative Development									
Iodine-129	pCi/L	3.5	14	9.80×10^{-6}	-	1	–	–	1[e]
Technetium-99	pCi/L	4,150	18	2.16×10^{-4}	-	900	–	–	900
Tritium	pCi/L	51,150	10	4.94×10^{-5}	-	20,000	–	–	20,000
Uranium	µg/L	206	-	-	4.3	30	–	–	30
Nitrate[b, d]	µg/L	133,000	-	-	5.2	45,000	25,600	–	45,000
COPCs - Not Carried Forward									
Chloroform	µg/L	7.2	-	5.1×10^{-6}	0.09	80	80	14	–
Tetrachloroethene	µg/L	1	-	1.2×10^{-5}	0.01	5	80	0.81	–
Trichloroethene	µg/L	3.3	-	6.7×10^{-6}	-	5	–	4.9	–
1,4-Dioxane	µg/L	6	-	1.5×10^{-6}	<0.01	–	800	40	–
Chromium (total)	µg/L	99	-	-	<0.01	100	24,000	–	–
Hexavalent Chromium	µg/L	52	-	-	1.1	N/A[c]	48	–	–
Fluoride	µg/L	470	-	-	0.98	2,000	480	–	–
Strontium-90	pCi/L	0.66	-	6.80×10^{-7}	0.33	8	–	–	–

Table 7-3. 200-UP-1 Groundwater OU Cleanup Levels

Contaminant	Units	90th Percentile Concen-tration	Dose (mrem/yr) Based on 90th Percentile Concen-tration	ELCR Based on 90th Percentile Concen-tration	HI Based on 90th Percentile Concen-tration	Drinking Water Standard	Model Toxics Control Act Method B Cleanup Levels		200-UP-1 Groundwater OU Cleanup Level[a]
							Non-Carcinogens at HQ = 1	Carcinogens at 1×10^{-5} Risk Level	

Notes: DWSs from 40 CFR 141 with I-129 and Tc-99 values from EPA 816-F-00-002.

a. The final cleanup levels achieved at the conclusion of the RA will correspond to an ELCR less than 1×10^{-6} and HI of less than 1.

b. Nitrate may be expressed as nitrate (NO_3) or as nitrate-nitrogen (NO_3-N). The DWS for nitrate as NO_3 is 45,000 µg/L. The concentration expressed as NO_3-N is 10,000 µg/L.

c. There is no DWS specific to hexavalent chromium.

d. Nitrate is a COC that will be addressed when co-extracted with other COCs.

e. Current technology may not enable this level of treatment to be achieved. Feasibility of treatment levels will be determined though a technology evaluation.

CFR = Code of Federal Regulations
COC = contaminant of concern
COPC = contaminant of potential concern
DWS = drinking water standard
ELCR = excess lifetime cancer risk
EPA = U.S. Environmental Protection Agency
HI = hazard index
N/A = not applicable
OU = operable unit
RA = remedial action

The list of COCs presented in Table 7-3 was determined by comparing the 90th percentile groundwater concentration to the DWS or the WAC 173-340-720 groundwater cleanup levels corresponding to a 1×10^{-5} acceptable target risk level for carcinogens or a hazard quotient of 1 for non-carcinogens. Contaminants with 90th percentile concentrations greater than the DWS or WAC 173-340-720 groundwater cleanup level were retained as COCs. Those with 90th percentile concentrations less than the DWS or WAC 173-340-720 groundwater cleanup levels were not carried forward as COCs. Based on the results of this evaluation, the list of COCs includes: uranium, nitrate, Tc-99, tritium, and I-129. With the exception of uranium, the COCs identified for the 200-UP-1 Groundwater OU are a subset of the COCs identified in the 200-ZP-1 Groundwater OU ROD. Nitrate, which has a hazard quotient greater than 1, was retained as a COC. However, due to its broad distribution in groundwater at the Site, and potential for re-contamination from offsite sources, the alternative development process assumes nitrate will be actively treated when co-extracted with other COCs, but will not be targeted specifically for active RA. F&T modeling (Figure 5-16 and Table 6-7) shows that the 200-UP-1 Groundwater OU nitrate plume naturally attenuates within 175 years without active RA.

Carbon tetrachloride was not addressed as a COC in the alternative development process because carbon tetrachloride originates from a source in the 200-ZP-1 Groundwater OU. A remedy for the carbon tetrachloride plume was selected in the 200-ZP-1 Groundwater OU ROD. Chloroform, 1,4-dioxane, tetrachloroethene, trichloroethene, chromium, and hexavalent chromium were not retained as COCs because the 90th percentile groundwater concentration is less than the DWS or the WAC 173 340-720 groundwater cleanup level corresponding to a 1×10^{-5} acceptable target risk level for carcinogens or a hazard quotient of 1 for non-carcinogens. The COPCs that were not carried forward as COCs are not being eliminated from the RA process; rather they will be addressed, as necessary, through RAs that address COCs. This will be demonstrated by including COPCs within the scope of RA process control and groundwater performance monitoring where such is warranted.

7.1.4 Remedial Action Objectives

Under CERCLA and the NCP, a groundwater remedy must (1) be protective of HHE, and (2) meet ARARs (or satisfy criteria for an ARAR to be waived). Based on these requirements and NCP expectations for groundwater restoration, the RAOs for the 200-UP-1 Groundwater OU include:

- RAO 1: Return the 200-UP-1 OU groundwater to beneficial use by achieving the cleanup levels presented in Table 7-3.
- RAO 2: Apply ICs to prevent groundwater use until the cleanup levels presented in Table 7-3 are achieved.
- RAO 3: Protect the Columbia River and its ecological resources from degradation and unacceptable impact caused by contaminants originating from the 200-UP-1 Groundwater OU.

To achieve RAO 1, COC concentrations in 200-UP-1 OU groundwater will be reduced to levels corresponding to DWS or WAC 173-340-720 groundwater cleanup levels. RAO 2 will be achieved by restricting groundwater use as described in DOE/RL-2001-41 until RAO 1 is achieved. DOE will report on the effectiveness of the groundwater use restrictions in the annual reports required by DOE/RL-2001-41. To achieve RAO 3, contaminant migration from the 200-UP-1 Groundwater OU will be monitored to ensure that contaminants do not reach the Columbia River at concentrations that could adversely affect ecological resources or surface water beneficial use.

7.1.4.1 Principal and Low-Level Threat-Waste

The NCP establishes an expectation that EPA will use treatment to address the principal threats posed by a site wherever practicable (NCP CFR 300.430[a][l][iii][A]). Identifying principal threat wastes combines concepts of both hazard and risk. The manner in which principal threats are addressed generally determines whether the statutory preference for treatment as a principal element of the remedial alternative is satisfied.

Principal threat wastes are those source materials considered to be highly toxic or highly mobile that generally cannot be reliably contained, or would present a significant risk to public health or the environment should exposure occur. The decision to treat these wastes is made on a site-specific basis through a detailed analysis of remedial alternatives, using the nine remedy selection criteria specified in the NCP. This analysis provides the basis for making a statutory finding that the selected remedy uses a proven treatment technology as a principal element.

Contaminated groundwater is not considered a principal threat waste because it is not source material (EPA, 1991).

7.1.4.2 Area and Volume of Groundwater Exceeding Cleanup Levels

The area of attainment defines the portion of the aquifer where cleanup levels will be achieved in groundwater. Figure 7-1 and Table 7-4 present the estimated area and volume of the COC plumes present in the 200-UP-1 Groundwater OU. The area of the individual plumes ranges from approximately 32 ha (80 ac) for Tc-99 to 809 ha (2,000 ac) for tritium. The areas and volumes are based on COC distribution measured in CY 2008 and average plume thickness depicted in the figures presented in Chapter 4. This approach overestimates the volume of contaminated groundwater associated with each COC plume, but provides a conservative value for the purposes of remedial technology screening and alternative development and evaluation. Contaminant plume pore volume estimates are provided for uranium, nitrate, Tc-99, tritium, and I-129. Mass estimates were also developed by multiplying the plume pore volume by the 90th percentile COC concentration presented in Chapter 6; Table 7-4 summarizes this information.

7.1.4.3 Restoration Timeframe

The restoration timeframe is defined as the period of time required to achieve the groundwater ARARs at all locations within the area of attainment. A 150-year restoration timeframe was established in the ROD for the adjacent 200-ZP-1 Groundwater OU. Because the nitrate and I-129 contaminant plumes in the 200-UP-1 Groundwater OU are comparable to the 200-ZP-1 Groundwater OU carbon tetrachloride plume, a similar restoration timeframe is anticipated. For technology screening and remedial alternative development and evaluation purposes, a restoration timeframe of 150 years is established for the 200-UP-1 Groundwater OU.

7.2 General Response Actions

GRAs are remedial technologies and associated process options that are applicable to the RAOs established in Section 7.1 for the 200-UP-1 Groundwater OU. For contaminated groundwater, the GRAs include:

- No Action
- Institutional/Engineering Controls
- Natural Attenuation
- Containment

- Active Restoration
- Passive Restoration

Additional information on the GRAs described previously and their associated remedial technologies and process options is presented in the following subsections.

7.2.1 General Description of Remedial Technologies and Process Options

This section describes the remedial technology and process options for each GRA identified previously that are applicable to the 200-UP-1 Groundwater OU. The groundwater technologies and process options were identified using EPA guidance, technology information Web sites (http://clu-in.org/vendor/vendorinfo/ and http://www.frtr.gov), and PNNL-15954. Literature surveys and technology reviews for nitrate, I-129, and uranium (SGW-37783 and PNNL-16761) were also reviewed and relevant information incorporated into this technology evaluation.

The following remedial technologies and process options identified from the references cited previously are considered technically viable for addressing the COCs present in the 200-UP-1 Groundwater OU.

7.2.1.1 No Action

The No Action Alternative is required as a baseline case for comparison against other technologies and remedial alternatives as specified under the NCP (40 CFR 300.430[e][6]). Under this GRA, no further action is taken at a site. If interim actions have been completed or are underway at the time of final remedy selection, they would terminate under no action.

For the 200-UP-1 Groundwater OU, an existing P&T IRA at U Plant, and an IRA at the S-SX Tank Farm would continue to operate until the ROD Amendment[1] is signed.

7.2.1.2 Institutional and Engineering Controls

ICs are administrative controls and legal restrictions imposed on land and groundwater use to protect against exposure to hazardous constituents and/or protect the integrity of a remedy. They are intended to act as administrative barriers to separate the public from levels of contamination that exceed ARARs. ICs may include land use restrictions, natural resource use restrictions, groundwater use restriction or management areas, deed restrictions, deed notices, declaration of environmental restrictions, access controls (digging/drilling permits), surveillance, information posting or distribution, restrictive covenants, and federal/state/county/local registries.

Engineering controls generally include fences and security to protect against inadvertent exposure to contaminated groundwater (seeps/springs) until ARARs are achieved, or an alternate water supply is obtained for users when contaminated groundwater is used as a current drinking water source. ICs and engineering controls have already been implemented at the Site, including the 200-UP-1 Groundwater OU, through DOE/RL-2001-41. The Site ICs program requires annual reporting to ensure that ICs are maintained and enforced.

[1] The remedy selection for the 200-UP-1 Groundwater OU will be performed by issuing an amendment to the 200-ZP-1 Groundwater OU Record of Decision.

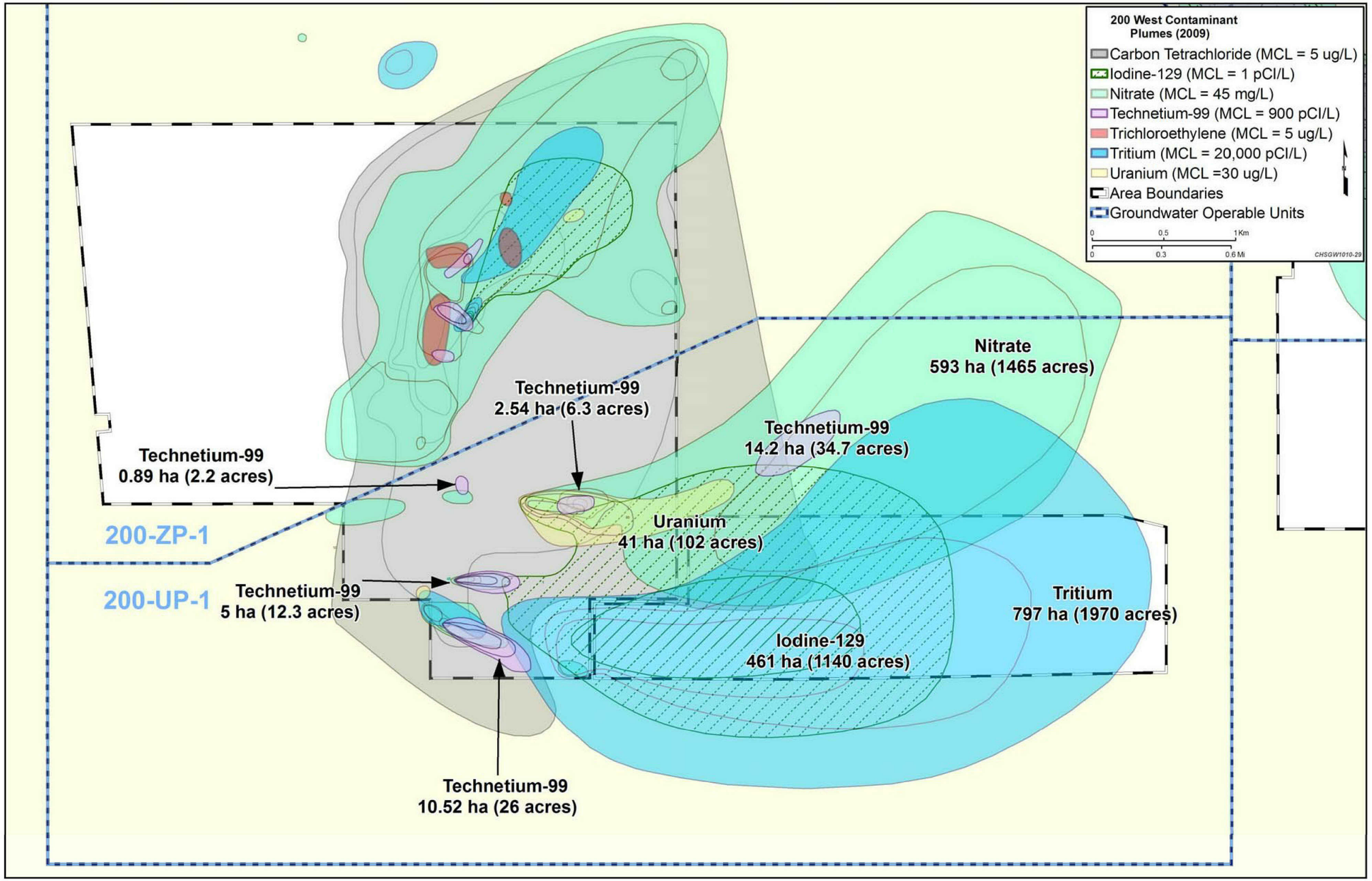


Figure 7-1. 200-UP-1 Groundwater OU Map

Table 7-4. 200-UP-1 Groundwater OU COC Pore Volume and Mass Estimates

COC	Cleanup Level (µg/L or pCi/L)	Porosity[a]	Plume Area[b] (acres)	Estimated Plume Thickness[c] (ft)	Plume Pore Volume (gallons)	90th Percentile Concen-tration (µg/L or pCi/L)	COC Mass
Uranium	30	0.2	102	50	330 million	206	570 lbs (260 kg)
Nitrate	45,000	0.2	1,465	80	7.6 billion	133,000	8,500,000 lbs (3,800,000 kg)
Tritium	20,000	0.2	1,970	100	12. 8 billion	51,150	2,500 Ci
Tc-99	900		82	65	347 million	4,150	5.5 Ci
I-129	1	0.2	1,141	100	7.4 billion	3.5	0.1 Ci

a. Porosity of 0.2 from DOE/RL-2007-28, Table D-58.

b. Plume areas above cleanup level estimated by digitizing the boundaries presented in DOE/RL-2008-66.

c. Average plume thickness estimated from plume cross-section depictions shown in Chapter 4.

COC = contaminant of concern

OU = operable unit

7.2.1.3 Natural Attenuation

Natural attenuation is "…the reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a timeframe that is reasonable compared to that offered by other more active methods. The natural attenuation processes that are at work in such a remediation approach include a variety of physical, chemical, or biological processes. Under favorable conditions, these processes act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These in situ processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants." (EPA/540/R-99/009).

Although physical, chemical, and biological processes are included in this definition, the OSWER Directive states a preference for processes that permanently degrade or destroy contaminants. Natural attenuation is not a no action approach, and requires a thorough understanding of site-specific and contaminant-specific attenuation mechanisms. In addition, a rigorous performance monitoring program is required to demonstrate that natural attenuation is occurring in accordance with expectations. Because monitoring is an important component of natural attenuation, MNA is generally used to describe this GRA.

MNA is best applied at sites where contaminant plumes are stable or shrinking, or attenuating processes are confirmed to be in effect, and where natural attenuation processes can achieve ARARs in a timeframe that is comparable with other alternatives. Natural attenuation is rarely appropriate as a sole remedy without other active remedial measures (source control) and/or ICs (EPA/540/R-99/009). In a recent study (WSRC-TR-2003-00328), MNA was selected for use at 54 percent of the sites where source control measures were also implemented. MNA is an important component of the overall remedy for the 200-ZP-1 Groundwater OU.

7.2.1.4 Containment

Containment is used to prevent horizontal and vertical contaminant migration in groundwater, and can be achieved by physical barriers or through hydraulic controls. Physical containment consists of constructing a barrier that encloses a zone of groundwater contamination to isolate it from the remaining portions of the aquifer. Barriers generally span the entire depth of the aquifer and are typically constructed to extend into the first few meters of a basal confining layer to prevent flow beneath the barrier. In aquifer settings where the contaminant plumes do not extend to the base of the aquifer, a hanging-wall-type barrier may be constructed. Physical barriers include slurry walls, grout curtains, and sheet pile walls.

A slurry wall is a non-structural underground barrier generally constructed by placing a cement-bentonite slurry into a trench excavated to the desired depth. For deep applications, the slurry can be injected through a series of wells. The slurry composition can be varied to achieve the desired permeability, durability, and compatibility with subsurface soils and contaminants. Grout curtains are formed by injecting grout, under pressure, directly into the soil matrix (permeation grouting) or in conjunction with drilling (jet grouting) at regularly spaced intervals to form a continuous low-permeability wall. If the grout is injected vertically, like the slurry wall, it forms a continuous low-permeability barrier to the horizontal movement of contaminants. Sheet pile walls are interlocking metal piles that are driven to the desired depth.

Hydraulic containment is achieved by controlling groundwater flow and contaminant migration through strategically placed extraction and/or injection wells. Extraction wells are generally placed at the leading edge of the plume, pumping the wells at the minimum rate needed to hydraulically capture the plume(s), treating the water to remove contaminants, and re-injecting the water at an upgradient, cross-gradient, or downgradient location. Hydraulic containment via injection is achieved by placing injection wells along the leading edge of the plume and injecting water to block plume migration. Containment via injection can be particularly advantageous because there is no flow stream to treat. When injection wells are used for long-term plume containment, it may be necessary to add additional injection wells if the plume begins to migrate around the ends of the injection well field. Extraction and injection wells may also be coupled to increase the overall effectiveness of hydraulic containment by using injection wells to divert the plume toward extraction points. Aquifer settings where containment may be appropriate include:

- Where the groundwater is naturally unsuitable for consumption (Class III aquifers).
- Low-mobility contaminants are present.
- Low aquifer transmissivity.
- Low contaminant concentrations.
- Low potential for exposure.
- Low projected demand for future use of the groundwater.
- Sites where contaminant sources cannot be removed or treated (deep vadose zone sources).
- Sites where the technology for treatment of a specific contaminant does not exist.

7.2.1.5 Active Restoration

Groundwater P&T for aquifer restoration generally combines hydraulic containment with a more aggressive (higher pumping rates) pumping strategy to attain cleanup goals during a finite time period.

Active restoration of contaminated groundwater in a deep aquifer setting, such as that present at the 200-UP-1 Groundwater OU, would include an array of vertical pumping wells, a treatment system to remove contaminants from pumped groundwater, and a monitoring program to assess overall remedy performance.

P&T, as an aquifer restoration measure, is best applied at sites where contaminant source control measures have been implemented, and where contaminants are relatively mobile in groundwater. Contaminant mobility affects a P&T system's ability to remove contaminants from the aquifer. Contaminants with high mobility will readily flow with groundwater toward extraction wells for removal. Contaminants with slight mobility adhere to the aquifer sediments and are not readily removed by groundwater extraction.

Treatment of extracted groundwater is accomplished using a variety of methods that are specific to the contaminant type or contaminants with similar physical/chemical characteristics. If the final remedy selected for the 200-UP-1 Groundwater OU includes groundwater extraction, it is expected that 200-UP-1 OU groundwater treatment could be performed at the 200 West Area groundwater treatment facility scheduled to begin operation before December 31, 2011. Additional information on the treatment processes used in the 200 West Area groundwater treatment facility and other potential treatment technologies for contaminated groundwater are discussed in the following subsections.

Above Ground Treatment for Volatile Organic Compounds

Above ground treatment for VOCs, such as PCE and TCE that may be co-extracted with 200-UP-1 Groundwater OU COCs, typically includes air stripping and GAC. Packed tower air stripping is used for carbon tetrachloride removal from 200-ZP-1 OU groundwater in the 200 West Area groundwater treatment facility.

Air Stripping. Air stripping is a widely applied technology in which VOCs are transferred from groundwater to air by passing large volumes of air through the contaminated water. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration. Packed towers and tray aeration represent the most common methods used in P&T systems. Air strippers can be operated continuously or in a batch mode where the air stripper is intermittently fed from a collection tank. The batch mode ensures consistent air stripper performance and greater energy efficiency than continuously operated units, because mixing in the collection tank reduces VOC concentrations in the feed water composition.

Granular Activated Carbon. GAC is also a widely applied technology for VOC removal in P&T systems in which VOC-contaminated groundwater is pumped through two or more vessels containing the GAC media. As the groundwater flows through the GAC, VOCs are removed by sorption onto the individual carbon particles. GAC can also remove some inorganic contaminants. GAC vessels are often operated in a series configuration with the first vessel acting as the lead unit, where a majority of the VOC removal occurs, and the second vessel as a lag or polishing unit. When the contaminant concentration in the lead vessel effluent exceeds a specified level, the spent GAC is replaced with fresh media and the flow control valves adjusted such that the lag vessel becomes the lead unit. Spent GAC is regenerated at an offsite facility, or disposed at an approved facility such as ERDF.

Modification of the activated carbon (silver-impregnated activated carbon) can make the GAC vessels more resistant to biological fouling. Recent laboratory studies (WSRC-TR-2002-00435) have also shown that silver-impregnated GAC can remove I-129 from groundwater.

Aboveground Treatment for Metals, Radionuclides and Nitrate

Several treatment technologies are used for metals and radionuclide removal from aqueous waste streams. The IX process and precipitation/coagulation/flocculation are the most widely used. The IX process is used in the 200 West Area groundwater treatment facility for uranium and Tc-99 removal from 200-ZP-1 OU groundwater.

Ion Exchange – Uranium and Tc-99. The IX process removes soluble ions from the aqueous phase by exchanging benign cations or anions attached to the exchange media for the ions present in the groundwater. The exchange media consists of a spherical resin made from synthetic organic materials that contain cation/anion functional groups attached to the individual resin beads. Once the resin capacity is exhausted, the resin is regenerated onsite or offsite for reuse using a strong acid/base wash, or disposed at an approved facility. As part of the final design for the 200 West Area groundwater treatment facility, tests are being conducted to select the optimum resin for removal of these three constituents from groundwater.

Ion Exchange and Silver-Impregnated Granular Activated Carbon – I-129. The RD for the 200-ZP-1 Groundwater OU P&T system included an assessment (382519-TMEM-049) on the effectiveness of I-129 water treatment technologies. This evaluation reviewed several published studies and vendor claims on I-129 removal capabilities. The IX process, silver chloride-impregnated granular activated carbon (AgCl-GAC), and silver bromide-impregnated activated carbon (AgBr-GAC) were the primary treatment technologies evaluated.

The IX process, using a strong-base anion exchange resin SIR-1200, has been shown to remove I-129 to below the laboratory detection limit (WSRC-TR-2002-00435). However, current information does not provide a strong technical basis that consistent treatment of I-129 to concentrations of 1 pCi/L or less can be achieved with the IX process. Therefore, pilot testing would be a required component of any alternative employing the IX process for I-129 removal to evaluate the feasibility of treatment.

AgCl-GAC was also shown to remove I-129, but the process generates an aqueous silver byproduct that may require treatment to control toxicity in downstream biological treatment processes or to comply with re-injection ARARs.

The 200-ZP-1 Groundwater OU I-129 treatment evaluation concluded:

- No known IX resins have sufficient selectivity for iodine to reduce the concentration to 1 pCi/L or less.
- There are no known suppliers of AgCl-GAC. AgCl-GAC would have to be manufactured by treating silver-impregnated granular activated carbon (Ag-GAC) with hydrochloric acid.
- AgBr-GAC would not generate the aqueous silver byproduct, but I-129 treatment to less than 1 pCi/L would require further refinements. There are no known suppliers of AgBr-GAC, therefore, it would need to be manufactured by treating Ag-GAC with hydrobromic acid.

Electrodialysis and Reverse Osmosis – I-129 Treatment. Electrodialysis and RO are membrane filtration technologies typically used in desalination plants and ultrapure water applications. Water is pumped through a membrane to remove the target constituents. In electrodialysis, an electric potential gradient is used to move the ions through the membrane. In RO, hydraulic pressure is used to push water though the membrane for ion removal. Both technologies generate a concentrated brine solution that simply moves the problem to a smaller, harder-to-treat waste stream while leaving the I-129 in the aqueous phase. Consequently, it is not a solution to I-129 removal because the resultant concentrated liquid stream must be stabilized prior to onsite disposal (if ERDF waste acceptance criteria are met) or shipped offsite for treatment/disposal. These technologies are not selective, and often remove other ions from solution as well.

Precipitation/Coagulation/Flocculation – Chromium. Any COC remedial technology involving groundwater extraction would likely co-extract chromium. If treatment is necessary, precipitation can be used to convert dissolved ionic species (dissolved metals and radionuclides) into solid-phase particulates that can be removed by coagulation-settling or filtration. The process often uses pH adjustment, addition of a flocculent aid (polymer), and clarification. Metals typically precipitate from the solution as hydroxides, sulfides, or carbonates. The solubility of the specific metal contaminants and the required treatment standards will determine the process used.

Precipitation of metals has been a primary method of treating metal-laden industrial wastewaters. As a result of its success in industrial applications, this technology has been growing in use for groundwater and surface water runoff remediation at CERCLA mining sites. Depending on the process design, sludges generated from the coagulation-settling or filtration process may be amenable to metal recovery; however, most sludge is dewatered and disposed at an approved facility.

Biological Treatment – Chromium and Nitrate. Biological treatment includes aerobic or anaerobic treatment performed in open (aerobic) or closed (anaerobic) vessels, or within a constructed wetland. Contaminants are degraded by micro-organisms that use the contaminants in oxidation-reduction reactions to support cellular metabolism and growth. In constructed wetlands, contaminants may be removed through bio-filtration or through uptake in plant root systems. Several removal mechanisms have been identified for biological treatment of nitrate, such as decomposition, nitrification/denitrification, settling, volatilization, adsorption, and nutrient uptake. Fluidized bed bioreactors are used in industry and are very effective in reducing nitrate concentrations such as those present in the 200-ZP-1 and 200-UP-1 OU groundwater plumes. A fluidized bed bioreactor (anaerobic biological treatment) is used in the 200 West Area groundwater treatment facility for chromium and nitrate removal from 200-ZP-1 OU groundwater.

A bioreactor for groundwater treatment would generally consist of a fixed or suspended media with a large surface area maintained in a vessel to support micro-organism growth. Typically, the groundwater being treated does not provide an adequate food or nutrient source or optimal conditions to sustain and promote biological treatment; therefore, supplemental substrate and nutrients are added to the influent groundwater to provide a carbon source for cellular metabolism and growth. For example, to create an anaerobic bioreactor for treatment of aerobic groundwater, a soluble carbon source (acetic add, methanol, or ethanol) is added to the influent groundwater to stimulate aerobic biodegradation/dissolved oxygen depletion processes to create reducing-anaerobic conditions.

Constructed wetlands are engineered systems that act as biofilters for removing soluble and particulate contaminants. A constructed wetland provides several contaminant removal mechanisms, such as decomposition, nitrification/denitrification, settling, volatilization, adsorption, and vegetative uptake. A constructed wetland often requires a large area and longer hydraulic retention time compared to a bioreactor, but it typically would not require substrate and nutrient addition or extensive operational oversight. A constructed wetland for 200-UP-1 OU groundwater could be problematic as the result of the presence of residual radionuclides, which could become airborne or pose other environmental hazards during the wetland treatment step.

Treated Water Discharge

Four general discharge options are typically used with P&T actions:

1. Reinjection: Treated water is injected to the subsurface through wells or horizontal infiltration galleries. Discharge may be either upgradient of the contamination, pushing contamination toward an extraction well network; downgradient of the contamination, so the migration of contaminants is

slowed or hydraulically controlled (flow control); cross-gradient to push contamination toward a recovery point); or a combination of all three methods.

2. Retention ponds/infiltration: Treated or untreated water is collected in a pond/basin and allowed to infiltrate back into the soil. These ponds must be located in areas where vadose zone contamination is absent.

3. Reuse: Treated water is reused for irrigation or potable water supply. Reuse of treated water reduces or eliminates the need for a facility to use water from other sources, thereby conserving water as a natural resource.

4. River water: Under the National Pollutant Discharge Elimination System (NPDES), treated water may be discharged to a surface water body such as the Columbia River.

7.2.1.6 Passive Restoration

Passive restoration includes in situ technologies that treat contaminants in the subsurface. In situ treatment generally includes biological or physical/chemical methods that immobilize contaminants or transform contaminants to less-toxic compounds.

In situ Bioremediation

In situ bioremediation is a process where indigenous or introduced micro-organisms transform (metabolize) organic contaminants into other compounds or facilitate the conversion of inorganic compounds into a lower oxidation state. Enhanced in situ bioremediation accelerates the natural biodegradation process by providing key nutrients, electron acceptors, and/or acclimated microorganisms that may otherwise be limiting in the subsurface.

In situ bioremediation is generally applied to organic contaminants such as fuel hydrocarbons (aerobic bioremediation) and chlorinated solvents (anaerobic bioremediation). Anaerobic biodegradation conditions have been used successfully to facilitate the conversion of hexavalent chromium to trivalent chromium, and hexavalent uranium to trivalent uranium.

The stimulation of aerobic bioremediation process occurs by adding oxygen to the groundwater using air sparge wells or hydrogen peroxide. Solid-phase peroxide products (oxygen-releasing compounds) can also be used for oxygen enhancement and to increase the rate of aerobic biodegradation. The stimulation of anaerobic bioremediation generally consists of injecting an organic substrate into the subsurface where biodegradation of the substrate consumes the available dissolved oxygen, which in turn creates anaerobic conditions. Solubilized nitrate has also been circulated through groundwater contamination zones to provide an alternative electron acceptor to enhance the rate of anaerobic biodegradation of organic contaminants. Development of nitrate enhancement is still at the pilot scale and not widely applied because un-reacted nitrate may create a secondary source of contamination.

In situ bioremediation is generally applied in small, well-defined source zones or in aquifer settings where high concentrations of mobile contaminants can be transported by natural or induced groundwater flow patterns into a constructed treatment zone.

In situ Chemical and Physical Treatment

Several processes are available to chemically destroy contaminants or alter their physical-chemical state to render them immobile or less toxic.

In situ chemical oxidation (ISCO) – destroys contaminants with a strong oxidant such as hydrogen peroxide, permanganate, persulfate, percarbonate, or ozone. ISCO requires contact between the oxidant and the contaminant, resulting in conversion to carbon dioxide and water. The oxidant is typically

injected into the subsurface using an array of vertically staggered injection points, or could be introduced into a constructed treatment zone such as a permeable reactive barrier (PRB). ISCO is applied at sites where the primary contaminants are organics (petroleum hydrocarbons and chlorinated solvents) in well-defined source or hot-spot areas. ISCO is not applicable for treatment of large-diffuse plumes with low concentrations.

Solidification/stabilization (S/S) – reduces contaminant mobility by immobilizing the contaminant(s) within a low-leachability host medium (solidification), or by altering the geochemical environment within a constructed treatment zone to convert contaminants into a less-mobile or less-toxic form (stabilization). Solidification agents are mixed with contaminated material using large augers, or jet injection. Stabilization agents are generally introduced in a liquid form, using injection wells, to react with the target contaminants within a defined treatment zone. Stabilization technology is currently being used in the 100-N Area to immobilize Sr-90 by injecting two separate chemicals (calcium citrate and phosphate) into an array of vertical injection wells to create a PRB. The two chemicals combine in the subsurface to form apatite, which immobilizes Sr-90 through a sequestering process. The 100-N Area apatite barrier, when fully constructed, will be 900 m (2,500 ft) long and extend to depths of about 10 m (30 to 35 ft).

This technology can be used in a wide variety of settings to immobilize many different types of contaminants. Extensive treatability testing is required to identify the most effective S/S agent, and to determine the optimum dose and delivery method. Solidification is best applied in contaminant source areas (soil) where the treatment zone is relatively small and well defined. Stabilization is best applied in source zones or at sites where natural or induced groundwater flow patterns can mobilize the contaminants into a treatment zone such as a PRB.

7.3 Identification and Screening of Technology Types and Process Options

The remedial technology and process options described in Section 7.2 are evaluated in this section to determine which technologies are best capable of achieving RAOs for the subsurface conditions present in the 200-UP-1 Groundwater OU. Table 7-5 summarizes the technology screening results and Table 7-6 presents the list of retained technologies and process options. The retained technologies will be assembled into an array of remedial alternatives in Chapter 8.

The evaluation focused on three criteria: effectiveness, implementability, and relative cost. Effectiveness considers the (1) ability of each remedial technology to handle the large volumes of contaminated groundwater present in the 200-UP-1 Groundwater OU, (2) ability of each remedial technology to achieve RAOs and cleanup levels, (3) potential impacts to HHE associated with construction and implementation of the technology, and (4) how proven and reliable the technology is with respect to treatment of the COCs. Implementability focused on both the technical and administrative feasibility of implementing the technology. Costs were evaluated on a relative scale (low, moderate, or high) only.

7.3.1 No Action

Formulation of a No Action Alternative is required by the NCP (40 CFR 300.430[e][6]). The No Action Alternative serves as a baseline for evaluating other RA alternatives and is generally retained throughout the FS process. As described in Section 7.2, no action implies that no remediation is implemented to address existing Site conditions.

7.3.1.1 Evaluation

Effectiveness: Under the No Action Alternative, the interim groundwater P&T actions underway in the U Plant area and a planned interim groundwater P&T action in the WMA S-SX area would be shutdown and no further action taken within the 200-ZP-1 Groundwater OU.

No action will result in potential long-term impacts to human health if groundwater is developed for drinking water purposes. No action will also result in long-term impacts to the environment until COC concentrations are reduced in groundwater through natural processes. No adverse effects to DOE workers or the public are anticipated, as groundwater is not currently used nor is there potential for exposure.

Implementability: No technical challenges are associated with implementing no action, however, no action may not be implementable from an administrative standpoint because it does not protect HHE, and, therefore, could not be selected in accordance with the CERCLA remedy selection requirements.

Cost: No costs are associated with no action.

Screening Result: No action is retained as a baseline for comparison to other RA alternatives per NCP requirements.

7.3.2 Institutional and Engineering Controls

ICs are implemented at the Site, including the 200-UP-1 Groundwater OU, through DOE/RL-2001-41. ICs are used to protect human health against inadvertent exposure and to protect the environment by monitoring and controlling land and groundwater use in areas where groundwater COC concentrations exceed cleanup levels. ICs and engineering controls may also be a component of other alternatives to protect the integrity of ongoing or completed RAs. At the Site, these controls include an array of administrative measures and access restrictions as described in the following subsections. It is expected that the ICs for the 200-UP-1 Groundwater OU RA would be accomplished by extending those specified in the 200-ZP-1 Groundwater OU ROD.

7.3.2.1 Administrative Measures

A number of administrative measures are used at the Site to protect against inadvertent intrusion into contaminated soil and groundwater, and to prevent land and groundwater development for purposes other than its designated uses. These measures include the *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (DOE/EIS-0222-F and DOE/EIS-0222-SA-01), public notices, DOE Directives, environmental checklists, work control processes, a Waste Information Data System (WIDS) database, excavation permits, and groundwater use management.

The *Final Hanford Comprehensive and Land-Use Plan Environmental Impact Statement* (DOE/EIS-0222-F and DOE/EIS-0222-SA-01): This document provides a comprehensive listing of all areas at the Site that have ICs for protection of HHE. The minimum required information includes the location of the area, the objectives for the restrictions, and the tools and procedures that will be applied to implement the restrictions or controls. The information in the Hanford Comprehensive Land-Use Plan Environmental Impact Statement (HCP EIS) is reviewed annually to ensure that it is current, effective, and sufficient for each site. The HCP EIS also tracks or includes, by reference, any permitting changes, renovation work on structures, well placement and drilling, construction, or other activities that could occur on institutionally controlled Hanford CERCLA sites. The CERCLA module of the HCP EIS is available on the Internet at: www.hanford.gov/doe/eis/hraeis/maintoc.htm. Those portions of the HCP EIS that contain specific information considered sensitive for security reasons are currently available for official use only by DOE or its subcontractors at the Site.

Table 7-5. Summary of Technology Screening Results

General Response Action	Technology Type	Process Option	Target Contaminants	Evaluation			Results
				Effectiveness	Implementability	Relative Cost	
No Action	No Action	None	All COCs	Low. Current and planned interim actions will slow or arrest uranium and Tc-99 plume migration until they are terminated, but are not expected to establish hydraulic control or remove significant amounts of mass from the nitrate, tritium, or I-129 plumes.	Good. From a technical perspective but may not be administratively implementable.	Low.	Retained as baseline
Institutional Controls	Entry Restrictions	Procedural requirements for access Excavation/drilling permits	All COCs	Good. Reduces or eliminates the potential for direct contact with contaminated groundwater when well implemented and maintained for the duration of elevated risk period. Protects integrity of active remedies.	Very Good. Readily implemented, requires periodic surveillance and maintenance.	Low.	Retained
	Land Use Management	Land use and real property controls (proprietary controls including easements and covenants)	All COCs	Good. Reduces or eliminates the potential for direct contact with contaminated groundwater when well implemented and maintained for the duration of elevated risk period. Ensures compatible land use.	Very Good. Readily implemented, must identify and comply with all necessary legal requirements.	Low.	Retained
	Groundwater Use Management	Groundwater controls	All COCs	Good. Ensures no improper use of groundwater.	Very Good. Readily implemented, but will likely require ongoing oversight and coordination with state water resource managers.	Low.	Retained
	Waste Site Information Management	Administrative	All COCs	Good. Ensures access to information on the location and nature of contamination.	Very Good. Readily implemented, but requires maintenance of the information management system.	Low.	Retained
Engineering Controls	Access/Entry Restrictions and Notification	Fencing Signs	All COCs	Good. Required in areas where contaminated groundwater appears at surface through seeps, springs, or treatment system handling. Effective in preventing or reducing the potential for direct contact with contaminated groundwater if well implemented and maintained for duration of elevated risk period.	Very Good. Readily implemented, requires periodic inspection and maintenance.	Low.	Retained
	Alternate Water Supply	Pump water from clean surface water or groundwater source to point of use	All COCs	Good. Not required at this time because 200-UP-1 OU groundwater not being used.	Moderate. Could be implemented if necessary, alternate water sources are available.	Low.	Rejected Groundwater not currently needed for drinking purposes.
Monitored Natural Attenuation	Groundwater Monitoring	Groundwater sampling Laboratory analysis Data evaluation and reporting	All COCs	Good for the several COCs (tritium and nitrate) with concentrations reduced to cleanup levels in timeframes estimated at less than 175 years. Less effective for uranium and I-129, which require much longer timeframes (800 to 1,000 years based on maximum projected concentrations).	Moderate. Readily implemented technically; may be less implementable administratively due to the long timeframes required for achieving cleanup levels, especially for uranium and I-129.	Moderate depending on the number of monitoring locations and sampling frequency.	Retained

Table 7-5. Summary of Technology Screening Results

General Response Action	Technology Type	Process Option	Target Contaminants	Evaluation			Results
				Effectiveness	Implementability	Relative Cost	
Containment	Vertical Barriers	• Slurry walls • Grout curtain • Sheet piling	Uranium, Tc-99, I-129	Poor to very good, depending on integrity of the installation process. Ringold Upper Mud would provide a confining layer for keying the barrier. Slurry walls used at other CERCLA sites primarily for containment of non-aqueous phase liquids acting as a long-term contaminant source to groundwater. Not widely used for dissolved phase plume containment.	Very difficult. The large size of the uranium and I-129 plumes would require barriers totaling several miles in length. Installation depths of to 91 to 137 m (300 to 450 ft) exceed the range of trenching equipment, and therefore, would require an extensive array of jet grouting points. Sheet piling could not be advanced to the required depths due to the cobbly nature of subsurface material.	Very high.	Rejected Due to technical implementability (depth and size of plumes) and high cost.
	Hydraulic Control	Vertical extraction or injection wells	Uranium, Tc-99, I-129	Good. Extraction and injection wells are used for flow-path control as a component of the 200-ZP-1 Groundwater OU final remedy. Requires long-term operation due to size and longevity of the I-129 plume.	Good. Readily implemented using conventional drilling and well installation methods, and standard construction practices.	Low to moderate capital costs, moderate O&M costs depending on degree and frequency of well maintenance activities.	Retained The NCP indicates a preference for containment (40 CFR 300.430[a][1][iii][b]) for waste that poses a relatively low long-term threat or where treatment is impracticable.
		Monitor wells	All COCs	Excellent. An array of monitor wells is required to evaluate hydraulic containment system performance. Usually comprises existing wells and new wells as necessary.	Good. Monitor wells are easily installed.	Low-Moderate. Cost depends on the number and depth of monitor wells.	Retained
		Groundwater Treatment – Use 200 West Area groundwater treatment facility • Capacity available within existing treatment Trains 1 and 2 • Add I-129 pretreatment and third treatment train if necessary	All COCs and other contaminants if co-extracted I-129	Excellent. This facility has at least 350 gpm of available capacity for treating 200-UP-1 OU groundwater.	Excellent. Readily implemented. Some piping modifications required to integrate flow. May require pre-treatment for I-129 removal if extraction wells used for containment. No treatment required for injection well containment approach.	Low, if 200 West Area groundwater treatment facility used.	Retained
Active Restoration	Groundwater Extraction	Vertical extraction wells	Uranium, Tc-99, I-129	Good for removing slight to highly mobile contaminants from aquifer; may be less effective for uranium, which is less mobile than other 200-UP-1 Groundwater OU COCs.	Good. Readily implemented. Vertical extraction wells used at a number of locations on the Site.	Moderate, depends on the total number of extraction wells required.	Retained
		Horizontal extraction wells	Uranium, Tc-99, I-129	Good for removing slight to highly mobile contaminants from aquifer; may be less effective for uranium, which is less mobile than other 200-UP-1 Groundwater OU COCs.	Poor. Very difficult. Depth of contaminant plumes 91 to 137 m (300 to 450 ft) may be beyond the capability of conventional horizontal drilling technology.	High.	Rejected Due to technical implementability and cost.
		Monitor wells	All COCs	Good. An array of monitor wells is also required to evaluate groundwater extraction system performance. Usually comprises existing wells and new wells as necessary.	Good. Monitor wells are easily installed.	Low-Moderate. Depends on the number and depth of monitor wells.	Retained

Table 7-5. Summary of Technology Screening Results

General Response Action	Technology Type	Process Option	Target Contaminants	Evaluation			Results
				Effectiveness	Implementability	Relative Cost	
	Above Ground Treatment	Existing 200 West Area groundwater treatment facility • Use existing available capacity • Construct third treatment train designed per 200-UP-1 Groundwater OU needs • Add new radionuclide pretreatment	All COCs and other contaminants if co-extracted I-129	Good. Treatment processes for all COCs (except I-129) are available within existing treatment trains. If flow rates are greater than several hundred gallons per minute, may require construction of a third treatment train. Space and infrastructure already available if this is deemed necessary. Some I-129 treatment may occur within uranium and Tc-99 IX vessels. Ability of IX to remove I-129 to 1 pCi/L or less not demonstrated. Treatability testing required.	Good. Readily implemented. If pretreatment for I-129 removal is required, may require installation of an additional IX treatment train.	Low to moderate depending on whether a third treatment train has to be constructed. Cost for developing and implementing I-129 pretreatment using IX, AgCl-GAC, or AgBr-GAC could be high.	Retained
		New treatment facility Use similar processes or others (RO) as needed	All COCs	Good. Treatment technologies have already been developed for all COCs as part of 200-ZP-1 Groundwater OU RD. Ability of IX to remove I-129 to 1 pCi/L or less not demonstrated. Treatability testing required. No information available on electrodialysis and RO effectiveness for I-129.	Good but likely redundant with 200 West Area groundwater treatment facility, which already has some hydraulic capacity set aside for 200-UP-1 OU groundwater, and space available for a third treatment train if necessary.	High to very high. The cost for constructing a new treatment facility of a scale proportionate to 200 West Area groundwater treatment facility based on hydraulic and contaminant-loading requirements is high. Additionally, a separate treatment facility would likely require an independent team of O&M personnel, which would further add to the cost.	Rejected Expansion was accounted for in the 200 West Area groundwater treatment facility design. Expansion of existing treatment facility is possible.
Treated Water Discharge	Reinjection		All COCs	Good. Reinjection used successfully at a number of locations on the Site. Can increase remedy effectiveness by providing more aggressive flushing of high-concentration areas and by providing supplemental recharge, should water-limiting conditions develop.	Good. Readily implemented.	Low to moderate depending on the number of wells required.	Retained
	Infiltration basins			Good if subsurface soil characteristics are favorable. May require infiltration tests to assess feasibility. Not an option if vadose zone contamination is present. Not used elsewhere on the Site for CERCLA RAs.	Moderate.	Moderate.	Rejected Presence of vadose zone contamination and limited use for CERCLA response actions at Site.
	Re-use			Poor. No re-use opportunities identified at this time. Not used elsewhere on the Site for CERCLA RAs.	Poor. May not be administratively implementable.	Low to high depending on location of re-use point.	Rejected No re-use opportunities identified.
	River water discharge			Good. River water discharge used in the 100 Area during reactor operation period.	Poor. May not be administratively implementable and would likely require more rigorous monitoring of effluent discharge.	Moderate to high, given proximity of river to 200-UP-1 Groundwater OU site.	Rejected Administrative implementability

Table 7-5. Summary of Technology Screening Results

General Response Action	Technology Type	Process Option	Target Contaminants	Evaluation			Results
				Effectiveness	Implementability	Relative Cost	
Passive Restoration (in situ)	In situ Chemical Oxidation	Direct Injection	All COCs	Poor for most inorganics including 200-UP-1 Groundwater OU COCs.	Poor. Technically very difficult due to depth and large size of COC plumes.	Very high. Cost of chemicals alone would be prohibitive.	Rejected
	Stabilization – Permeable Reactive Barrier	Anaerobic	Nitrate	Moderate.	Poor. Technically very difficult due to plume size and depth.	Very high.	Rejected Requires additional field demonstrations. Depth and size of treatment area expected to make cost prohibitive.
		Polyphosphate/Apatite	Uranium	Good. Will likely require field demonstration trials prior to full-scale implementation similar to 100-NR-2 apatite barrier low- and high-concentration treatability testing. Would require long-term controls to protect against inadvertent intrusion into the reactive zone.	Poor. Difficult due to depth of uranium plume (91 to 137 m [300 to 450 ft]) and lower permeability of Ringold Fm in this area. Site-specific treatability studies required to determine optimum additive concentrations and potential effects of co-contaminants.	Moderate to high.	Rejected Requires additional field demonstrations. Depth and size of treatment area expected to make cost prohibitive.
		Zero-valent iron	Nitrate	Moderate. This technology has been employed at a number of CERCLA sites but not widely applied for nitrate or other 200-UP-1 Groundwater OU COCs. Treatability testing required to assess effects on other COCs.	Very difficult to depth and broad distribution of COC plumes.	Very high.	Rejected Requires additional field demonstrations. Depth and size of treatment area expected to make cost prohibitive.
		Redox manipulation	Nitrate,Tc-99, uranium, and I-129	Good. This technology has been demonstrated at a number of CERCLA sites and in the 100 Area for hexavalent chromium treatment. Treatability testing will be required to assess effects on other co-contaminants. Would require long-term controls to protect against inadvertent intrusion into the reactive zone.	Very difficult due to depth and broad distribution of COC plumes.	Very high.	Rejected
		Univalent copper precipitation	I-129	Moderate. Expected to be good. Will require treatability testing to confirm effectiveness and assess effects on other COCs. Would require long-term controls to protect against inadvertent intrusion into the reactive zone.	Very difficult due to depth and broad distribution of I-129 plume.	Very high.	Rejected

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR = Code of Federal Regulations
COC = contaminant of concern
IX = ion exchange
NCP = National Oil and Hazardous Substances Pollution Contingency Plan
O&M = operation & maintenance
OU = operable unit
RA = remedial action
RO = reverse osmosis

Table 7-6. Remedial Technologies Retained for Remedial Alternatives Development

General Response Action	Technology Type	Process Options	Target Contaminants
No Action	No Action	No Action	All COCs
Institutional Controls	Entry Restrictions	Procedural Requirements for Access, Excavation/Drilling Permits	
	Land and Groundwater Use Management	Deed Restrictions/Notices, Declaration of Environmental Restrictions, Information Distribution, Restrictive Covenants, federal/state/ county/local registries	All COCs
	Waste Site Information Management	Administrative	
Engineering Controls	Access Controls	Signs/Fences/Security Guards	All COCs
Monitored Natural Attenuation	Groundwater Monitoring	Sampling, laboratory analysis, data evaluation, and reporting	All COCs
Containment	Hydraulic Controls/Treatment	Vertical extraction and/or injection wells, treatment at 200 West Area groundwater treatment facility	Uranium, Tc-99, and I-129
	Treated Water Discharge	Injection wells	
Active Restoration	Groundwater Extraction	Vertical extraction wells	Uranium, Tc-99, and I-129
	Above Ground Treatment	200 West Area groundwater treatment facility in current configuration or expanded to include third treatment train and I-129 pre-treatment facility	
	Treated Water Discharge	Injection wells	

COC = contaminant of concern

Public Notices: Public notice is provided as needed to inform stakeholders of IC changes. For land use changes and property leasing or transfers, stakeholders and news media are contacted and provided with the appropriate information, in accordance with the *Hanford Site Tri-Party Agreement Public Involvement Community Relations Plan* (Ecology et al., 2002).

DOE Directives: DOE directives include policies, orders, notices, manuals, and guides intended to direct, guide, inform, and instruct Tri-Party and contractor employees, and the public. DOE directives are legally binding on DOE and its contractors by inclusion into their contracts. Future directives and guidance concerning restrictions on groundwater use and access are being considered for the Site as part of the evaluation of controls to protect HHE. These may include additional well drilling restrictions or easements for monitoring, restrictive covenants, or land withdrawal documentation that would be deemed necessary to further protect the public and the environment if land use or ownership changes.

Activities involving drilling new wells and maintaining existing wells are subject to regulatory review processes that occur under CERCLA planning and decision documents, or environmental impact analysis under NEPA.

DOE Environmental Checklist: In accordance with the June 1994 "National Environmental Policy Act Policy Statement" (O'Leary, 1994), DOE relies on the CERCLA planning and decision documents to incorporate NEPA values, to the extent practicable. This information is made available to the public in accordance with CERCLA public participation requirements.

The process for a proposed action and identification of potential impacts is typically initiated with a DOE environmental checklist prepared for review and approval. Information provided in the environmental checklist includes detailed information concerning the environmental aspects and potential sources of impact, including information on potential disturbance of a contaminated site. During the environmental checklist technical review, an appropriate specialist evaluates the information. The environmental checklist review and approval process ensures that applicable environmental requirements associated with the project have been identified and that the project will comply with all requirements.

An environmental checklist is developed for all proposed activities. Environmental evaluation requirements apply to activities conducted on behalf of DOE/RL at the Site by the maintenance and operations contractor, subcontractors, lessees, or any government entity (the U.S. Geological Survey [USGS]). The environmental checklist evaluation would assess the proposed activity to identify any restrictions on disturbance of environmental media, well drilling, or management of waste or subsequent water-use restrictions related to aquifer contamination.

Work Control Process: All work at the Site is controlled through the *Integrated Environment, Safety and Health Management System* (ISMS) *Description* (HNF-MP-003), which establishes a single, defined environment, safety, and health (ES&H) management system that integrates requirements into the work planning and execution processes to effectively protect workers, the public, and the environment. The ISMS identifies a set of requirements that reflects DOE's commitment to a standards-based safety program and the safety concepts reflected by these requirements. The ISMS provides the mechanisms for increasing worker involvement in work planning including hazard identification and impact identification, analysis, and control; work execution; and feedback/improvement processes. Effective implementation of ISMS incorporates the best practices and supports the accomplishment of the Voluntary Protection Program, Enhanced Work Planning/Hanford Occupational Health Process, Responsible Care program of self-regulation, and other ES&H performance improvement initiatives.

Institutionally controlled CERCLA sites with potential radiological exposures require written authorization for entry and to work within radiological areas in accordance with "Occupational Radiation Protection" (10 CFR 835.501[d]). Records of these authorizations are mandated in accordance with 10 CFR 835.701(a) to assist DOE's operating entities to comply with the requirements of 10 CFR 835 and DOE G 441.1-12, Radiation Safety Training Guide. This series of guidelines is structured to help radiation protection professionals develop the documented radiation protection program required by 10 CFR 835.101 and the supporting site- and facility-specific policies, programs, and procedures necessary to ensure compliance with related regulatory requirements. A DOE standard (DOE-STD-1098-99) supplements DOE G 441.1-1B and serves as a secondary source or guidance for complying with 10 CFR 835.101.

Waste Information Data System: DOE maintains a tracking mechanism that identifies all waste site land areas that are under restriction or control in accordance with the IC requirement of CERCLA decision documents and as described in applicable work plans. The WIDS database, in combination with this plan and the Administrative Record, will initially be used to meet this requirement. In the future,

a database that serves the stewardship needs of non-DOE entities by focusing on key stewardship data elements (IC information) may be made available to entities having jurisdiction.

Information on the location and nature of waste sites is contained in the WIDS database. WIDS identifies waste management units on the Site, their location, waste type, and current status. Other descriptive information contained in WIDS includes size, extent, and appearance, testing or sampling efforts, regulatory information, bibliographic references, images, change history, and data validation. The system is maintained by DOE in accordance with the WIDS change control system, which documents and traces additions, deletions, and/or other changes dealing with the status of WMUs. The long-term preservation of waste site information is addressed by RL-TPA-90-0001, and it will be a key part of the Long-Term Stewardship Program for the Site.

The Administrative Record, which holds documents and information that are considered or relied on to arrive at a final decision for RA or hazardous waste management at a particular OU, is publicly available on the Internet at: http://www.hanford.gov/arpir/. The documents in the Administrative Record include, but are not limited to, proposed plans for IRAs, RD reports, and RODs.

Excavation Permits: Excavation permits are used by the Site to control access for subsurface work. The objectives of the excavation permitting process are as follows:

- Avoid unplanned disturbance or infiltration.
- Inform and protect workers regarding potential exposure to hazardous materials.
- Avoid the creation of potential pathways for the migration of hazardous materials.

The Site has a sitewide excavation permit that contractors are required to obtain before performing any excavation work, including well drilling. The work control process requires an excavation permit as part of the working-planning process. The excavation permit process is defined in the contract or procedures and contains the following features.

- Excavation permits generally follow the RCW.
- A review of the WIDS database is required to identify the proximity of existing waste sites.
- Cultural and biological resource surveys are required to comply with Section 106 of the *National Historic Preservation Act of 1966* and the *Endangered Species Act of 1973*.
- NEPA documentation requirements must be identified.
- The presence of any underground objects (utilities) must be identified.
- Excavation work is required to follow applicable health and safety requirements.

In addition to obtaining an excavation permit, wells must be registered with Ecology. Each prime contractor is responsible for ensuring that excavations are performed in accordance with excavation permit requirements. The following steps are required for excavation:

1. The excavation permit originator requests an excavation permit using the Site excavation permit process.
2. Radiological screening of the proposed work site is required.

3. The necessary reviews are performed. These include reviews of the information in WIDS, the cultural and biological resources that may be present, applicable resource management plans, and applicable NEPA documents.
4. The permit then must be logged and issued.
5. No less than 2 days, and not more than 10 work days before excavation begins, the organization conducting the excavation must call the Emergency Notification Center for Excavation (1-800-424-5555) to allow outside electric, gas, sewer, telephone, and water companies to locate and explain any potential underground interferences.
6. Notification to the excavation coordinator is made when excavation work is completed.

Groundwater Use Management: DOE restricts well drilling and groundwater use in accordance with the IC requirements of CERCLA decision documents and as described in applicable work plans. Groundwater use on the Site is restricted, as approved by EPA or Ecology, or as authorized in EPA-approved documents. Groundwater use also is controlled through excavation permits and the land use process.

Groundwater protection strategies include source control, remediation, and monitoring. An annual report is prepared and published each year documenting the results of groundwater monitoring for the previous year. The report summarizes groundwater monitoring results and provides an assessment of the effects of remediation or interim measures conducted under CERCLA. The report, along with OU-specific summaries, fulfills the reporting requirements of DOE Orders and the *Washington Administrative Code*.

Ongoing groundwater performance assessments and remediation are also reviewed and reported annually to identify any trends regarding the condition of the groundwater and the potential implication of those trends to ICs (prohibition of groundwater use). The data from the report are considered in evaluating both the effectiveness of the ICs and the need for any changes to the controls.

In the event DOE transfers property with groundwater use restrictions to another entity, the appropriate use restriction will be attached to the real estate transaction to ensure that specific ICs will remain in place.

7.3.2.2 Engineering Controls

Engineering controls restrict access or visually notify authorized personnel and public of the presence of contamination. At the Site, these controls include: security, fences, surveillance, barriers, permanent markers, and warning signs. Warning signs are the predominant method of access control at the Site. They identify the location of CERCLA sites to any persons who may intentionally or inadvertently enter or disturb a site. Warning signs are posted in accordance with 10 CFR 835 at sites where residual contamination may pose a current or future risk to HHE if excavated or otherwise disturbed. DOE generally uses two types of warning signs that, while not specifically designed as CERCLA notification signs, can serve the same purpose:

- No trespassing signs
- Notification signs for hazardous (including radiological control) and sensitive areas

A third type of sign may be used to identify Superfund sites (NPL sites), if necessary. Warning signs provide, as a minimum, information on the principal hazard(s) at the site, the media of concern, a point-of-contact with phone number, and a warning to not disturb the area unless authorized. The potential hazard(s) information is generalized (organics, inorganic, radionuclides, PCBs, asbestos, or

ordnances) without identifying specific chemicals or radionuclides. The format of the signs is consistent throughout the Site. Guidance on signage content and placement is provided in DOE/RL-2001-41.

7.3.2.3 Evaluation

Effectiveness: ICs and engineering controls can assist in meeting RAOs by protecting human health from inadvertent exposure, and protecting the environment by controlling land and groundwater use, until COC concentrations decline to cleanup levels through natural or active remediation processes. Given the large size of the COC plumes in the 200-UP-1 Groundwater OU, these controls will span a very large area and need to be maintained for timeframes of up to 1,000 years if no active remedial measures are taken. Although there are no examples where ICs and engineering controls have been maintained for such a long period of time, the Site is well known, and DOE has developed an array of overlapping measures that are expected to be very effective. Potential impacts to HHE associated with implementation of ICs and engineering controls are low.

Implementability: The technical and administrative feasibility of ICs and engineering controls is very good because many of the controls have already been implemented or can be readily modified to address the specific needs of the 200-UP-1 Groundwater OU.

Cost: Capital and O&M costs are expected to be low relative to other technologies.

Screening Result: ICs and engineering controls are retained.

7.3.3 Monitored Natural Attenuation

MNA is a remediation process that achieves contaminant toxicity, volume, concentration, mobility, volume, and/or bioavailability reduction through natural physical, chemical, or biological processes that occur without human intervention. MNA is evaluated in this section using the process described in DOE, 1999. This DOE guidance document describes the functional requirements for application of MNA as a remedial alternative and identifies a rigorous screening process to evaluate site-specific conditions against those requirements.

For the COCs present in the 200-UP-1 Groundwater OU, the primary natural attenuation processes (Table 7-7) include: sorption (uranium and I-129), radioactive decay (tritium), biodegradation (nitrate), and dispersion/diffusion (all COCs).

Table 7-7. Key Natural Attenuation Processes for Primary 200-UP-1 Groundwater OU COCs

Natural Attenuation Process	COCs	Key Factors
Sorption	Uranium	K_d = 0.4 ml/g
	I-129	K_d = 0.1 ml/g
Radioactive Decay	Tritium	Half-life = 12.3 years
Biodegradation	Nitrate	F&T modeling indicates 175 years for concentrations to reach cleanup levels.
Oxidation-Reduction-Precipitation	Uranium	Uranium present in the +6 oxidation state may be reduced to the less-mobile +4 oxidation state under anaerobic (reducing) conditions.

Table 7-7. Key Natural Attenuation Processes for Primary 200-UP-1 Groundwater OU COCs

Natural Attenuation Process	COCs	Key Factors
Dispersion/Diffusion	All COCs	Longitudinal dispersion = 50 m Lateral dispersion = 10 m Vertical dispersion = 0 m Diffusion: negligible

Notes: DOE/RL-2007-28.

COC = contaminant of concern
F&T = fate & transport
K_d = soil – water distribution coefficient
OU = operable unit

MNA may be applied as an appropriate remedial technology when site conditions can be defined as otherwise protective of HHE. The following four functional requirements are identified for MNA to be retained as a remedial technology for 200-UP-1 OU groundwater:

1. The contamination condition does not currently present an actual risk to human or ecological receptors. There must be an expectation that exposure mitigation can and will be maintained throughout the MNA period.

2. The source of the observed groundwater contamination is no longer contributing to the plume. The source may have been previously controlled through an engineered remedy or naturally ceased to contribute to the problem. In some cases, a source control element (e.g., localized P&T or selected in situ remedy) may be combined with the MNA alternative to ensure adequate control of secondary sources (e.g., residual mobile contamination in the vadose zone, or high-concentration plume segments in groundwater).

3. The target plume is static, retreating, decreasing in concentration, or existing monitoring data confirm that attenuating processes are present and operating at the Site.

4. Effective monitoring either exists currently, or can be implemented, that will provide confirmation that the attenuation is proceeding as expected and that cleanup levels are achieved. MNA alternatives may also include contingent response options in the event monitoring indicates that attenuating processes are not sufficiently effective at plume control.

DOE guidance identifies a three-tiered approach to screening MNA alternatives (SAND99-0464), with requirements for favorable conditions to allow the screening to continue and, ultimately, for MNA to be developed or included in the scope of a remedial alternative. The three assessment tiers include:

1. Scoping/Planning Phase (Tier I). In this phase, the functional requirements for MNA as applicable to a specific site, plume, or condition, are identified and evaluated. Figure 7-2 presents a logic diagram for the Tier I assessment of MNA.

2. Alternative Evaluation/Selection Technical Analysis (Tier II). In Tier II analysis, the timeframe for remediation by MNA is evaluated for compatibility with future land and groundwater use.

3. Alternative Evaluation/Selection Comparative Analysis (Tier III). In Tier III analysis, the MNA timeframe for restoration is compared to other alternatives for reasonableness.

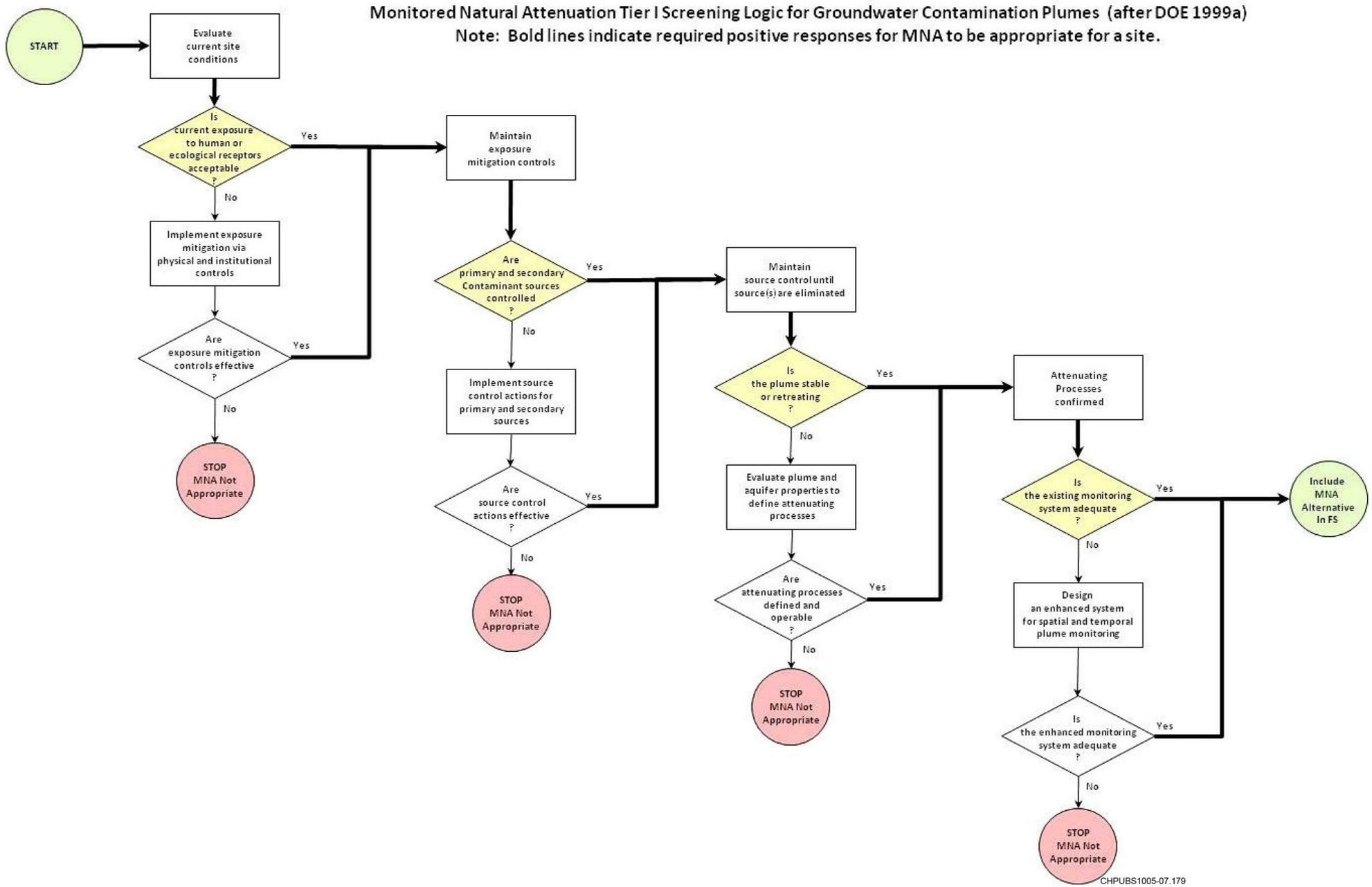


Figure 7-2. MNA Tier 1 Screening

Evaluation of, and ultimate selection of MNA as part of a final remedy for groundwater contamination in the 200-UP-1 Groundwater OU, requires rigorous analysis and thorough understanding of site-specific conditions.

7.3.3.1 Tier 1 Screening

The Tier I screening for MNA of a specific contaminant plume requires the most rigorous analysis and should, to the extent possible, be based on site-specific knowledge, understanding of site conditions, and evaluation of site-specific measurements and observations over some preceding time period. The following discussion provides a basis for analysis of groundwater plume conditions with respect to the four functional requirements for successful MNA.

Assess Current Exposures to Human and Ecological Receptors

Exposure mitigation is a primary requirement of any successful CERCLA response to environmental contamination. MNA implementation requires that there be no unacceptable actual exposure of human or ecological receptors to Site contaminants for the duration of the MNA remedy. In the Central Plateau, this means that plumes are well-defined and that no actual exposures to contaminants in excess of risk-based action levels are occurring to groundwater users or ecological receptors (aquatic organisms in the Columbia River in groundwater discharge areas). For the 200-UP-1 Groundwater OU, the groundwater contaminant plumes are generally well defined and the ICs (prohibitions against use of groundwater for a source of drinking water) prevent current exposure to human receptors. The 200-UP-1 Groundwater OU plumes are also presently contained within the fine-textured unconfined aquifer beneath, and east of, the 200 West Area. These plumes do not extend to the groundwater discharge areas along the Columbia River to the east so that no ecological receptors are currently exposed to 200-UP-1 Groundwater OU contaminants. Estimates of groundwater travel times indicate that the current level of ICs should remain effective at preventing exposure to human and ecological receptors for the foreseeable future. No additional actions to mitigate exposures are indicated for the plumes in the 200-UP-1 Groundwater OU.

Control Source Contributions to the Groundwater Plumes

The second most important requirement for consideration of MNA is that continuing contribution of contaminants to the groundwater plume(s) is controlled. In the case of the 200-UP-1 Groundwater OU, all known, non-permitted, primary source discharges (i.e., releases of process-related and sanitary wastes that were either intentionally or inadvertently released to the ground at, or near, the ground surface) have stopped. Numerous historical liquid waste and waste water releases within the 200 West Area impacted groundwater directly during their discharge periods. These same releases frequently resulted in secondary sources consisting of residual mobile contaminants within the underlying vadose zone that may continue to migrate downward. In situations where sufficient soil moisture remains in the vadose zone, residual vadose soil contaminants continue to drain through the soil column to impact the underlying groundwater. In addition to drainage of anthropogenic water in the vadose zone, some fraction of natural precipitation falling on the ground surface over the course of the year may enter the aquifer over time as recharge. In some areas, continuing vadose drainage is also associated with high-concentration local groundwater plumes, presenting both vadose and groundwater localized secondary sources.

Control of vadose zone sources of groundwater contamination in the Hanford Central Plateau is being addressed through the CERCLA RI/FS process currently underway for the overlying source OUs. Protection of groundwater is one of the three primary objectives for source OUs (the other two are protection of human and ecological receptors). Residual vadose zone secondary sources are recognized, but not addressed in the groundwater OU. Figure 7-3 illustrates the logic for integration of secondary vadose sources into the source OU(s). For the analysis of the 200-UP-1 Groundwater OU, groundwater plume segments with contaminant concentrations equal to, or greater than, 10 times the cleanup level are considered to be secondary sources.

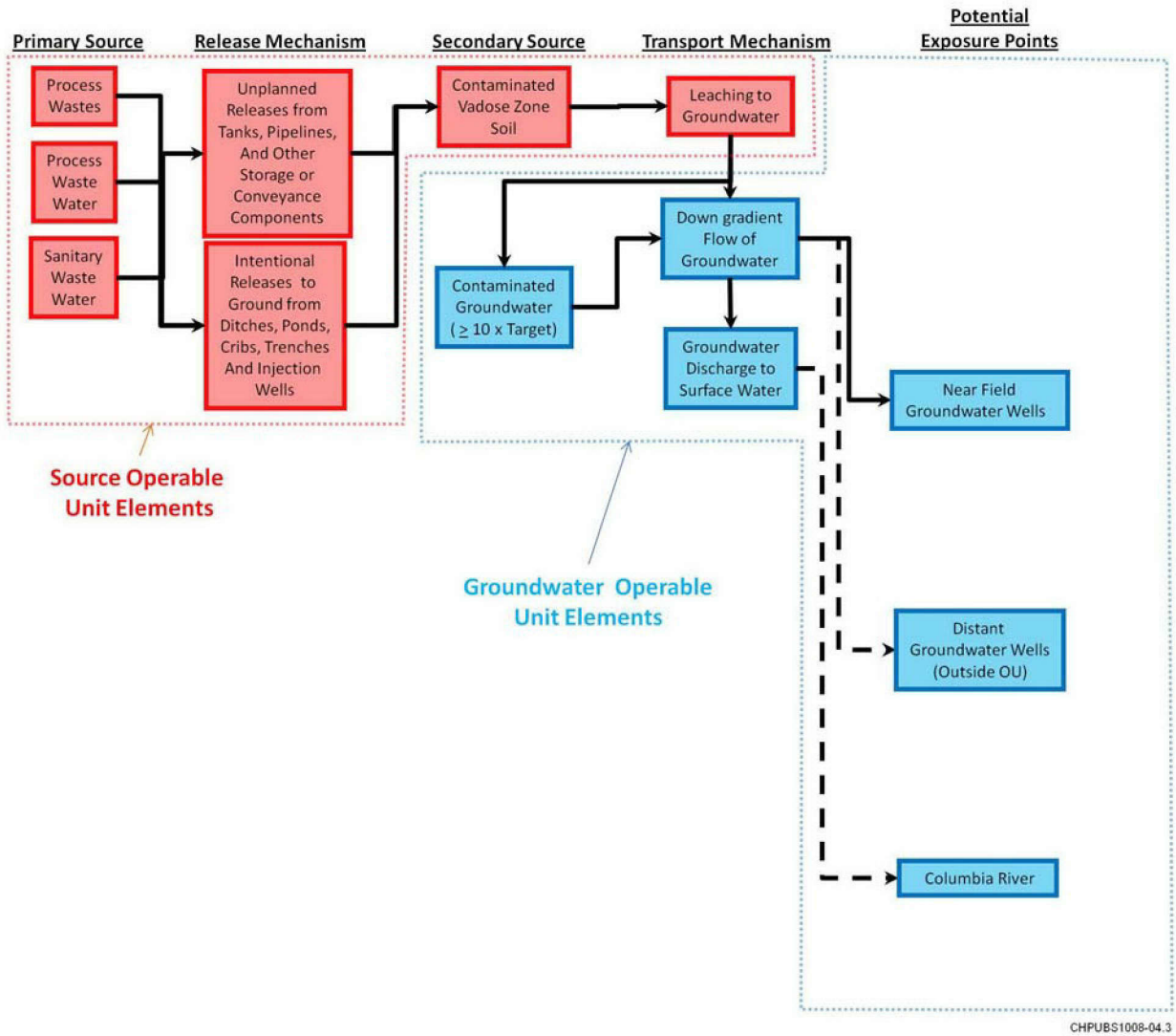


Figure 7-3. Integration of Secondary Vadose Sources

Conditions within the 200-UP-1 Groundwater OU exhibit varying degrees of source control at this time. Some contaminant plumes (e.g., the complex plumes immediately downgradient of WMA S-SX and WMA U) continue to receive contributions from vadose zone secondary sources. The plumes at WMA S-SX are the subject of IRA P&T systems to capture the high-concentration plumes in the general vicinity of the apparent release area. These localized P&T actions will remain in service until they are replaced/modified by a final remedy. The developing plume at WMA U lies within the expected capture zone of the final remedy P&T system for the 200-ZP-1 Groundwater OU. The uranium and Tc-99 plumes located in the vicinity of U Plant include high-concentration plume segments that are the subject of a current IRA to address these groundwater secondary sources.

A group of relatively large and dispersed contaminant plumes (nitrate, tritium, and I-129) are located to the east of the REDOX Plant area. These plumes exhibit their highest concentrations at locations downgradient from their apparent source areas (the REDOX cribs, U Plant cribs); this condition indicates that source contributions to these plumes (i.e., from primary source and secondary vadose sources) have diminished. Some of these plumes, however, also exhibit relatively high groundwater concentrations

(e.g., in excess of 10 times the cleanup level concentrations), and may, therefore, be considered secondary sources that should be addressed through source control actions as part of an MNA RA alternative.

Demonstrate that Attenuating Processes are Active

The presence and activity of attenuating processes within the affected aquifer system can be demonstrated by either of two methods: (1) monitoring history of the plume indicates that the plume is stable or diminishing in size or maximum concentration, which indicate that source contributions are diminished and/or attenuating processes are working within the plume, or (2) if the plume is not stable or is shrinking, then empirical measurements and observations of aquifer/plume conditions confirm that attenuating processes are present and operable within the aquifer. Within the 200-UP-1 Groundwater OU, a combination of observations and measurements demonstrate the activity of attenuating processes. In some instances, plumes and contaminant concentrations are diminishing based on the monitoring history. In other instances, observations and measurements of aquifer conditions (e.g., measurement of contaminant K_d) indicate that attenuating processes are at work within the system. Multiple attenuating processes may be effective on any one COC. The following processes are identified as functional within the 200-UP-1 Groundwater OU.

1. Radioactive decay is confirmed for radioactive COCs. Tritium has a sufficiently short radioactive half-life (i.e., 12.3 years) to support radioactive decay as a major attenuating element of an MNA alternative. Other radioactive COCs (I-129, Tc-99, and uranium) exhibit long half-lives and decay is not a major attenuating factor for those constituents.

2. Sorption of constituents to the aquifer matrix reduces the relative groundwater concentration of contaminants that interact substantially with the matrix. The tendency of a constituent to sorb or bind to the aquifer matrix is generally described by its relative K_d. Constituents with higher K_d exhibit a stronger tendency to bind to the aquifer solid matrix and reduce the relative groundwater concentration. Alternatively, constituents that exhibit lower K_d exhibit reduced tendency to bind to aquifer solids and, therefore, do not exhibit concentration reduction through sorption to the aquifer matrix. Some constituents exhibit no tendency to sorb to aquifer solids and, therefore, sorption does not provide any meaningful attenuation for those constituents. COCs for 200-UP-1 Groundwater OU that exhibit meaningful attenuation due to sorption effects include uranium and I-129. This effect produces both reduced migration velocity and reduced dissolved concentration within the aquifer. 200-UP-1 Groundwater OU contaminants that do not exhibit substantial sorption effects include tritium, Tc-99, and nitrate.

3. Diffusion and dispersion within the aquifer are physical processes that reduce contaminant concentrations in groundwater over time and distance. Diffusion is a concentration-driven physical process that results in movement of dissolved constituents from areas of high concentration to adjacent areas of relatively low concentrations. Dispersion is a physical process that results in mixing dissolved constituents within the aquifer water due to variations in groundwater flow velocity along varying flow paths within the aquifer. This mixing results in reduction in contaminant concentrations over distance. Because the 200-UP-1 Groundwater OU covers a relatively large area, and a large physical area of separation exists between the current plumes within the OU and locations of actual exposure to potential receptors, diffusion and dispersion can play a significant role as attenuating processes in an MNA alternative. Contaminant plumes migrating across the OU in the direction of groundwater flow (i.e., generally west to east) will be expected to exhibit substantial reduction in maximum concentration as distance from the point of origin increases.

Maintain Effective Monitoring

For application of MNA to groundwater contamination, effective monitoring must be maintained throughout the MNA period. Effective monitoring must provide representative three-dimensional spatial measurement and observation of aquifer conditions, as well as a representation of changes in aquifer conditions over time. Effective monitoring must be capable of demonstrating the desired change in contaminant concentration, continued activity of the attenuating process(s) (if appropriate), and the continued required mitigation of exposures. Monitoring for MNA remedial alternatives should include monitoring at appropriate points of compliance and also include defined contingent responses in the event that contaminant action level concentrations are exceeded at the compliance point(s).

The monitoring system for the 200-UP-1 Groundwater OU would be designed and constructed as part of the MNA remedial alternative and would utilize existing monitor wells in the 200-ZP-1 and 200-UP-1 Groundwater OUs where appropriate. In general, the existing monitor well network within the 200-UP-1 Groundwater OU is not adequate for monitoring an MNA alternative for all affected plume areas. Additional monitor wells will be needed to monitor the full thickness of the shallow unconfined aquifer (to evaluate the expected vertical dispersion of contaminant plumes) and to establish clearly defined points of performance measurement in the downgradient direction. No unusual or unique requirements are indicated to monitor the applicable attenuating processes for COCs in the 200-UP-1 Groundwater OU. Trigger conditions for points of performance measurement and associated contingent responses would need to be defined and implemented as part of a MNA alternative.

7.3.3.2 Evaluation

Effectiveness: MNA can reduce contaminant concentrations to cleanup levels through sorption, radioactive decay (tritium), and dispersion, and is well suited for addressing the large COC plumes present in the 200-UP-1 Groundwater OU, as demonstrated by the Tier 1 screening (Table 7-8) and the F&T modeling presented in Chapter 5 of this FS. Potential impacts to human health are low because there is very limited exposure to COCs except during installation and sampling of monitor wells. Impacts to the environment will persist for extended periods of time, but given the remote location of the 200-UP-1 Groundwater OU, these effects are not likely to be adverse. Many of the natural attenuation processes (sorption, radioactive decay, and dispersion) are reliable and unaffected by external factors.

Implementability: The methods for sampling and evaluating MNA data are well understood, so no technical challenges are associated with implementing MNA, however, administrative challenges may exist as the result of the long timeframes required before cleanup levels are achieved.

Cost: The cost for implementing MNA is expected to be moderate, relative to other alternatives, as a result of the long timeframes involved.

Screening Result: MNA is retained for use as a component of a larger remedial alternative, and as a sole remedy for addressing COCs with attenuation timeframes of less than 150 years.

7.3.4 Containment

The two primary forms of containment are vertical-physical barriers (slurry walls, grout curtain, and sheet piling) and hydraulic barriers.

Table 7-8. Monitored Natural Attenuation Analysis Summary for 200-UP-1 Groundwater OU COC Plumes

Plume/Plume Segment	COC	Exposure Control in Place?	Source Control in Place?	Attenuating Processes?	Effective Monitoring In Place?	Comments
WMA U Vicinity	Tc-99	Yes[a]	No[b]	Yes[f]	Yes[i]	
	Nitrate	Yes[a]	No[b]	Yes[f]	Yes[i]	
WMA S-SX Vicinity	Tc-99	Yes[a]	Yes[c]	Yes[f]	Yes[i]	
	Nitrate	Yes[a]	Yes[c]	Yes[f]	Yes[i]	
U Plant Vicinity	Uranium	Yes[a]	Yes[d]	Yes[f,g]	Yes[i]	
	Tc-99	Yes[a]	Yes[d]	Yes[f]	Yes[i]	
	I-129	Yes[a]	Yes[d]	Yes[f,g]	Yes[i]	
	Nitrate	Yes[a]	Yes[d]	Yes[f]	Yes[i]	
East of REDOX Vicinity	I-129	Yes[a]	Yes[e]	Yes[f,g]	Yes[i]	
	Nitrate	Yes[a]	Yes[e]	Yes[f]	Yes[i]	
	Tritium	Yes[a]	Yes[e]	Yes[h]	Yes[i]	

Table 7-8. Monitored Natural Attenuation Analysis Summary for 200-UP-1 Groundwater OU COC Plumes

Plume/Plume Segment	COC	Exposure Control in Place?	Source Control in Place?	Attenuating Processes?	Effective Monitoring In Place?	Comments

a. Hanford Site-wide ICs prevent access to, and consumption of, contaminated groundwater within the 200-UP-1 Groundwater OU.

b. Location-specific vadose source control not in place at all sources. Vadose zone secondary source falls within WMA U purview. Observed groundwater concentrations do not constitute a secondary source in groundwater.

c. Location-specific vadose source control not in place at all sources. Vadose zone source falls within WMA S-SX purview. Observed groundwater concentrations constitute a secondary source in groundwater (greater than 10 times the RAG). High-concentration groundwater plume areas are subject to IRA P&T system.

d. Location-specific source control not defined at this time. Vadose zone source falls within Central Plateau Inner Area and/or U Plant purview. Observed groundwater concentrations constitute a secondary source in groundwater (greater than 10 times the RAG for nitrate, uranium, and Tc-99). High-concentration groundwater plume areas are subject of IRA P&T system.

e. The dispersed plumes in the area east of the REDOX Plant exhibit apparent disconnection from release points. This indicates vadose sources have effectively stopped contributing to the plumes and the plumes continue to migrate downgradient. Residual vadose zone secondary sources fall under the purview of the overlying source sites within the Central Plateau Inner Area. COC concentrations in some locations continue to exceed RAG concentrations and constitute secondary sources in groundwater. Specifically, I-129 and tritium exceed 10 times the RAG.

f. Diffusion and dispersion contribute to attenuating processes.

g. Sorption to aquifer matrix (medium to high K_d) contributes to attenuating processes.

h. Radioactive decay (short half-life) contributes to attenuating processes.

i. Existing groundwater monitoring system generally provides adequate three-dimensional monitoring for most plumes but there are gaps in the network that can be improved with installation of additional monitor wells.

COC = contaminant of concern

IRA = interim remedial action

OU = operable unit

P&T = pump-and-treat

REDOX = Reduction-Oxidation (Plant)

WMA = waste management area

7.3.4.1 Vertical – Physical Barriers

Vertical barriers would consist of installing slurry walls or jet-grout curtains that fully or partially enclose the 200-UP-1 Groundwater OU contaminant plume(s). A fully enclosing vertical barrier would imprison the plume(s) to prevent further migration. Natural attenuation processes within the barrier would reduce concentrations over time. A partially enclosing barrier would lengthen groundwater flow patterns to increase contaminant transport times. This would provide additional time for natural attenuation processes to reduce concentrations.

Evaluation

Effectiveness: A fully enclosing barrier could be very effective, depending on the continuity/integrity of the barrier. A poorly constructed barrier, or barrier installed under challenging technical conditions, would be ineffective.

Implementability: Very difficult. Because the depth of construction is upward of 137 m [450 ft]), the barrier must be constructed using jet-grouting methods. Jet grouting has not been performed successfully to depths of greater than about 50 m (160 ft) at the scale required.

Cost: Very high.

Screening Result: Vertical barriers are rejected for all COCs as a result of the technical difficulty associated with their construction within the subsurface conditions present at the 200-UP-1 Groundwater OU, and the very high cost arising from the depth of installation and long barrier lengths required to partially or fully enclose the dissolved plumes or plume hot spot areas.

7.3.4.2 Hydraulic Containment

Hydraulic containment would consist of installing a network of groundwater extraction and/or injection wells along the leading edge of the largest and most persistent COC (uranium and I-129) plumes and pumping/injecting water at the minimum rate needed to prevent further migration. Containment can also be achieved by coupling extraction and injection wells to provide flow path control. This strategy is being used in the 200-ZP-1 Groundwater OU to achieve hydraulic containment of the carbon tetrachloride plume. Because of its short radioactive half-life, the tritium plume would not be specifically addressed with hydraulic containment, although large portions would be captured/blocked using hydraulic containment.

Because the extraction or injection wells would be placed along the plume's leading edge, COC concentrations would initially be low in an extraction scheme but could increase over time. Extracted groundwater would require treatment, which could be performed at the existing 200 West Area groundwater treatment facility or a newly constructed treatment train, if additional treatment capacity is required. Treated groundwater would be returned to the aquifer through an array of injection wells. If an injection-only containment system was used, treatment would not be required.

Evaluation

Effectiveness: Hydraulic containment using groundwater extraction and/or injection wells is a well-developed technology and would be very effective in controlling plume mobility. This technology is well suited to the large volume of contaminated groundwater present in the 200-UP-1 Groundwater OU. COC treatment processes developed for the 200-ZP-1 groundwater P&T remedy are directly applicable to the 200-UP-1 Groundwater OU COCs, and designed to reduce concentrations to the cleanup levels specified in the 200-ZP-1 Groundwater OU ROD. Treatment of the I-129 present in 200-UP-1 OU groundwater to a level of 1 pCi/L or less has not been demonstrated, so technology evaluation and treatability testing would be required during RD to determine what level of treatment can be achieved if

containment via groundwater extraction was used, whereas hydraulic containment accomplished using injection wells would not require an above ground treatment component. Potential impacts to HHE associated with hydraulic containment would be low but would likely continue for an extended period of time. The NCP indicates a preference for containment (40 CFR 300.430[a][1][iii][b]) for waste that poses a relatively low long-term threat or where treatment is impracticable.

Implementability: Hydraulic containment using groundwater extraction and/or injection well technology is readily implemented using available equipment and resources. Extraction and injection well technology is used elsewhere at the Site under conditions comparable to those present in the 200-UP-1 Groundwater OU. While no immediate technical or administrative challenges are associated with this technology, a hydraulic containment system would need to operate for an extended period of time. Therefore, an O&M plan would need to account for this requirement using durable materials of construction.

Cost: Moderate, depending on the final design and complexity of the system, O&M requirements, and overall operating lifetime.

Screening Result: Hydraulic containment is retained because of the large volumes of contaminated groundwater present in the 200-UP-1 Groundwater OU and because there is a preference in the NCP for containment of waste that poses a low long-term threat, or where treatment is impracticable. Hydraulic containment using injection wells is preferred over extraction wells because there is no need for above ground treatment.

7.3.5 Active Restoration

Active restoration by P&T uses many of the same elements as hydraulic containment but employs a more aggressive pumping strategy to reduce COC concentrations throughout the plume to cleanup levels within a desired timeframe. More aggressive pumping is achieved with closely spaced wells pumping at higher rates. This, in turn, requires treatment systems with greater hydraulic capacity. Pumping is generally performed on a continuous schedule during the earlier and intermediate phases of the project. As the plume contracts and perimeter extraction wells are turned off, pumping may transition into a pulsed schedule if mass removal rates become desorption, diffusion, or solubility limited.

Active restoration using P&T within the 200-UP-1 Groundwater OU would include an array of extraction wells placed within the footprint of the most persistent COC (uranium and Tc-99) plumes. Extracted groundwater would be pumped to the existing 200 West Area groundwater treatment facility, where it would be blended with 200-ZP-1 OU groundwater to remove uranium, Tc-99, and nitrate, and COPCs that may be co-extracted (namely chromium, PCE, TCE, carbon tetrachloride, and chloroform). Treatment would be performed using the existing Train 1/Train 2, or a new Train 3 would be installed within the available space if additional mass loading or hydraulic capacity is required.

Active restoration requires that sufficient groundwater be flushed through the contaminated zone to remove dissolved contaminants and those that will desorb from porous media, dissolve from precipitates, and/or diffuse from low-permeability zones. Assuming linear, reversible, and instantaneous sorption/desorption, no active source(s), and no organic non-aqueous phase liquids or solid phase contaminants, the theoretical amount of groundwater that must be removed to flush a contaminant from a homogeneous aquifer can be approximated from the contaminant-specific retardation factor, and the initial and final required contaminant concentrations. Based on information specific to the COC plumes in the 200-UP-1 Groundwater OU, the number of pore volume flushes (Table 7-9) required to reduce COC concentrations to their corresponding cleanup levels is estimated to range from 1.5 (Tc-99) to 11.7 (uranium).

Table 7-9. Estimated COC 200-UP-1 Groundwater OU Pore Volume Flushing Estimates

Contaminant	K_d[a] (mL/g)	Mobility	Pore Volume[b] (billion gals)	Retardation Factor[c]	C_i or 90th Percentile[b] (µg/L or pCi/L)	C_f or Cleanup Level[b] (µg/L or pCi/L)	No. of Pore Volume Flushes[d]
Tritium	0	High	12.8	0	51,150	20,000	1
Iodine-129	0.1	Slight	7.4	1.9	3.5	1	2.4
Technetium-99	0	High	0.35	1.0	4,150	900	1
Uranium	0.4	Slight	0.33	4.6	206	30	8.9
Nitrate	0	High	6.6	0	133,000	45,000	1

a. Assumes linear, instantaneous, and reversible sorption, and no solid phase precipitate. PNNL-18564, Table 6.9, Sandy Gravel sediment type.

b. From Table 7-4.

c. The retardation factor R is estimated from: $R = 1 + [(p_b * K_d)/ n]$. Where p_b (bulk density) is 1.8 g/cm^3 (PNNL-18564 Table 6.2) and n (porosity) is 0.2 (DOE/RL-2007-28).

d. Number of Pore Volume Flushes (PV) is: $PV = -R \ln (C_f / C_i)$ per EPA/540/S-97/504.

COC = contaminant of concern

K_d = distribution coefficient

7.3.5.1 Evaluation

Effectiveness: Active restoration using groundwater P&T is a conventional technology and would be effective in controlling plume migration, removing contaminant mass, and reducing COC concentrations. This technology is well suited to the large volumes and depth of the contaminated groundwater present in the 200-UP-1 Groundwater OU. COC treatment processes developed for the 200-ZP-1 groundwater P&T remedy are reliable and will reduce concentrations to the proposed cleanup levels. Potential impacts to HHE would be slightly higher than for hydraulic containment, but could be effectively managed using existing Hanford Site procedures.

Implementability: Active restoration using P&T technology can be implemented using readily available equipment and resources. Because of the large size of the COC plumes, a large number of extraction wells (approximately 8 to 12) are expected to be required, along with extensive infrastructure (piping and transfer buildings) to convey the water from the 200-UP-1 Groundwater OU to the 200 West Area groundwater treatment facility. While no immediate technical or administrative challenges are associated with this technology, due to the large size of the COC plumes, the P&T system would likely need to operate for an extended period of time. Therefore, design and O&M plans would need to account for this requirement using durable materials of construction.

Cost: The overall cost for active restoration will be high depending on the final number of extraction and injection wells required, whether buildout of a third treatment train in the 200 West Area groundwater treatment facility is required, and the estimated timeframe required for pumping.

Screening Result: Active restoration for Tc-99 and uranium is retained because of its flexibility and ability to address the volumes of contaminated groundwater present in the 200-UP-1 Groundwater OU.

7.3.6 Passive Restoration Using Permeable Reactive Barriers

Passive restoration consists of actions that treat groundwater COCs in situ. Methods for in situ treatment of 200-UP-1 Groundwater OU COCs include physical/chemical stabilization. Solidification is not applicable because the 200-UP-1 Groundwater OU does not include source waste sites. Because of the large size of the COC plumes in the 200-UP-1 Groundwater OU, passive treatment would be performed in a PRB. The treatment performed within the reactive portion of the PRB would be specific to each COC or group of COCs with similar requirements.

7.3.6.1 Permeable Reactive Barriers

The PRB technology is an interception technology designed to immobilize or treat contaminants as they enter a constructed-subsurface treatment zone. In general, contaminants are transported into the treatment (reactive) zone by the natural groundwater flow gradient and transformed into non-toxic compounds (biological or direct mineralization reactions), by adsorption of the contaminant onto the PRB media, or by immobilizing the contaminant through a chemical reaction. The PRB technology may be implemented as a funnel-and-gate-type system or an interception wall. Groundwater pumping wells may be placed downgradient of the PRB to help draw the contaminant plume through the reactive zone, which, in turn, may decrease its required length.

The funnel-and-gate-type PRB uses impermeable (bentonite slurry) walls placed on either side to direct contaminated groundwater through a smaller permeable treatment zone (gate). An interception PRB wall is a continuous treatment zone that spans the full width of the contaminant plume's leading edge. The groundwater flow velocity controls the duration of the remediation effort and the design of the PRB. The PRB must be designed with a suitable thickness (or multiple walls in series) to provide enough residence time for reaction (destruction), adsorption, or precipitation of the contaminant to, at, or below the cleanup level.

Several different media can be used for the PRB's treatment zone including chemical oxidants, zero-valent iron, biological media, chemical additions to control groundwater redox conditions, apatite, polyphosphate, and copper. To treat areas with overlapping COC plumes, it may be necessary to use a PRB with multiple treatment zones, or to place a series of PRBs, each designed to address a specific COC, within different areas of the plume(s).

7.3.6.2 Evaluation

Effectiveness: PRBs are generally most effective for organic and conventional inorganic contaminants present in shallow water-bearing zones, There has been very little PRB technology research and pilot testing for the 200-UP-1 Groundwater OU COCs, therefore, there is uncertainty on how effective this technology would be. Additionally, the use of PRB technology for long-lived radionuclides may require long-term management of the PRB site until radioactive decay or other processes reduce concentrations to cleanup levels.

Implementability: The PRB technology would be very difficult to implement in most portions of the 200-UP-1 Groundwater OU as the result of the depth of the COC plumes.

Cost: The overall cost for the PRB technology is expected to be high as the result of the depth of the construction and the required length.

Screening Result: The PRB technology is rejected for the COCs present in the 200-UP-1 Groundwater OU as the result of the depth of construction and uncertainty on the nature of the reactive media required.

7.3.6.3 ISCO – Nitrate

ISCO would consist of injecting a chemical oxidant into the treatment zone to oxidize contaminants as they enter and pass through the PRB. The injections would occur on a periodic basis and would be timed to coincide with a predetermined redox or other measureable in situ parameter. The injections would continue until all COCs exceeding cleanup levels have passed through the PRB.

Evaluation

Effectiveness: ISCO has a demonstrated effectiveness for destroying organic contaminants, but information on its application and effectiveness for inorganics and radionuclides is very limited. Therefore, it is assumed this technology is not effective for treatment of the latter. Additionally, ISCO is a direct-contact technology; the oxidant must come into contact with the contaminants for the treatment to occur. This requirement generally requires overlapping and multiple treatment applications to ensure that the surface area of all affected media comes into contact with the oxidant.

Implementability: While implementation of the ISCO technology is relatively straightforward, its use in a PRB application at depths of 91.4 m to 137.2 m (300 ft to 450 ft) would pose significant technical implementation challenges relative to construction of the PRB treatment zone and the PRB impermeable wings. Additionally, PRBs may need to be constructed at multiple locations to shorten the overall restoration timeframe.

Cost: Very high, as the result of the depth and required lengths of the PRBs.

Screening Result: The ISCO technology is not retained because its effectiveness in treating nitrate, metals (uranium), and radionuclides is unknown.

7.3.6.4 Stabilization

Chemical stabilization involves injection of compounds that immobilize contaminants. Based on current information, chemical stabilization could be used to treat uranium, Tc-99, I-129, and potentially nitrate. Stabilization would not be applicable to tritium.

Polyphosphate – Uranium

The polyphosphate technology injects liquid polyphosphate to stabilize uranium. The polyphosphate is injected into groundwater at a slow, controlled rate. The presence of phosphate in groundwater, even in minor concentrations (10^{-8} M), promotes the formation of autunite-group minerals, which in turn immobilize uranium. The use of a soluble long-chain polyphosphate reagent delays precipitation of the autunite, thereby mitigating plugging of the injection well and the aquifer in the vicinity of the injection point. By tailoring the polyphosphate chain, the hydrolysis reaction that releases the phosphate into the water can be engineered and the uranium stabilization rate controlled. Because autunite sequesters uranium in the oxidized form (U^{6+}), rather than forcing reduction to U^{4+}, the possibility of re-oxidation and subsequent re-mobilization is minimized. Extensive laboratory testing demonstrates very low solubility of autunite. In addition to autunite, excess phosphorous may result in apatite mineral formation, providing a secondary, long-term source for uranium immobilization. The polyphosphate technology may be deployed to treat uranium in groundwater and at the capillary fringe. The liquid form of the reagent facilitates application to and transport within the contaminated groundwater plume. Uranium transport studies in columns packed with contaminated sediment from the 300 Area indicate that a polyphosphate solution reduces the concentration of uranium in water to the 30 μg/L DWS. Polyphosphate injection would be considered an innovative treatment option.

Apatite – Uranium

Hydroxyapatite [$Ca_5(PO_4)_3OH$] has been found to be very effective in sequestering dissolved metals, including strontium and uranium. Injected or naturally occurring divalent metals react with dissolved phosphate to form a precipitate, which in turn immobilizes strontium and uranium. Apatite-forming minerals are injected using calcium citrate and phosphate solutions. The complexation of calcium and citrate delays the interaction of calcium and phosphate and subsequent formation of apatite until the citrate is degraded by microorganisms in the subsurface. Thus, apatite formation can occur over a greater radial distance from the injection well depending on the subsurface hydrology and the microbial citrate degradation rate. This technology is currently being deployed to immobilize Sr-90 in the 100-N Area. Injectable apatite would be considered an innovative treatment option.

Immobilization – Uranium and I-129

DOE's Savannah River National Laboratory (SRNL) recently initiated studies under DOE's Office of Environmental Management (EM) to identify methods for increasing sustainability of remediation addressing metal- and radionuclide-contaminated groundwater. One SRNL study area is a 1 km^2 ($.39^2$ mi) metals/radionuclides waste site where a modified funnel-and-gate barrier system has operated since 2005 to treat groundwater containing Sr-90, uranium isotopes, I-129, Tc-99, and tritium. The groundwater is acidic (pH 3.2 to 4.0), a primary factor facilitating mobility of certain contaminants and associated risk drivers. In the current treatment strategy, alkaline solutions of pH 10 are injected periodically into the gates to neutralize groundwater and reduce mobility of some contaminants. The injection frequency is determined by monitoring pH in wells downgradient from the injection wells; when a trigger of pH 5.5 is reached, alkaline solution is reinjected. In the 3 years of operation, injections were required approximately each 12 months at one gate and 18 months at the second gate. The alkaline-enhanced funnel-and-gate system treats all contaminants by mixing the stratified plume at the barrier wall as well as pH-sensitive contaminants such as Sr-90 and uranium isotopes. Early analytical data from downgradient wells indicate the system effectively reduces Sr-90, uranium isotopes, and tritium concentrations to below DWS.

Injection of reagents into the aquifer can cause iodide salts to precipitate, removing I-129 from groundwater. Addition of univalent copper [Cu(I)] could be effective in precipitation of copper iodide (WSRC-TR-2002-00571). The fact that iodide forms insoluble salts with some metals suggests that precipitation may be a viable remediation strategy for I-129 at the 200-UP-1 Groundwater OU. Univalent copper is the most promising metal for precipitation of I-129. Three of the four metals that could be used for this purpose have significant problems. Gold iodide is insoluble ($K_{sp} = 1.5 \times 10^{-14}$), but the cost of using gold would be prohibitive. Silver and mercury iodides are also insoluble ($K_{sp} = 8.1 \times 10^{-17}$ [AgI]) and 2.3×10^{-29} [HgI_2]), but both are considered hazardous metals and would not be appropriate for injection into an aquifer. Thus, univalent copper is the most promising counter ion for precipitation of iodide (3.5×10^{-12} [Cu(I)]).

Redox Manipulation – Nitrate and Uranium

Redox manipulation requires that an appropriate substrate and the necessary bacteria be present. Nitrate and uranium can be reduced under anaerobic conditions and converted to non-hazardous products (nitrate to nitrogen gas) or to insoluble chemical forms (and uranium). The biomass that grows during anaerobic bioremediation may also increase the adsorption of other contaminants such as I-129, potentially enhanced through reduction of the iodine (Muramatsu et al., 2004).

In situ anaerobic bioremediation could be implemented by distributing a long-duration substrate such as vegetable oil into the aquifer. Because the substrate is less accessible to the bacteria, it is not consumed as it is distributed and can provide a long-term food source once in place. The key property with this technology is the hydraulic conductivity of the aquifer. The radius of the treatment zone depends on how

well the substrate can be injected into and distributed through the aquifer formation. A secondary property of interest is the length of time that the substrate lasts, which impacts the frequency of "regenerating" the treatment zone. The radius of influence for long-duration substrate injection will be less than that for a soluble substrate.

Evaluation

Effectiveness: Many of the stabilization technologies described previously have been evaluated primarily at the bench or field-scale only, so their effectiveness would need to be demonstrated under the conditions present in the 200-UP-1 Groundwater OU. This introduces a significant amount of uncertainty at this time as to whether this technology can achieve the cleanup levels for all of the COCs. Additionally, physical/chemical stabilization of uranium and long-lived radionuclides such as Tc-99 and I-129 would require long-term management of the reactive zone to prevent inadvertent intrusion.

Implementability: While implementation of the stabilization technology is relatively straightforward, its use in a PRB application at depths of 91.4 m to 137.2 m (300 ft to 450 ft) would pose significant technical implementation challenges relative to construction of the PRB treatment zone and the PRB impermeable wings. Additionally, PRBs may have to be constructed at multiple locations to shorten the overall restoration timeframe.

Cost: Very high as the result of the depth and required lengths of the PRBs.

Screening Result: The PRB-stabilization technology is not retained because of uncertainty associated with overall treatment effectiveness, long-term management of treatment residuals in situ, and the high cost associated with installing PRBs in the 200-UP-1 Groundwater OU.

1

8 Development and Screening of Remedial Alternatives

The primary objective of the FS is to ensure that appropriate remedial alternatives are developed and evaluated such that relevant information concerning the RA can be presented to the public and risk managers, and an appropriate RA selected. The purpose of this FS and the overall remedy development process, is to develop and evaluate remedial alternatives that eliminate, reduce, or control risks to HHE (40 CFR 300.430[a][1]).

The remedial alternatives developed in this chapter combine the remedial technologies and process options retained from the screening performed in Section 7.3 into a range of viable remedial alternatives. The remedial alternatives were developed to achieve the RAOs identified in Section 7.1 by considering the CERCLA Program Goals and Expectations identified in the NCP. The remedial alternatives presented in Section 8.2 are screened against the CERCLA evaluation criteria of effectiveness, implementability, and cost prior to being carried forward for detailed and comparative evaluation in Chapter 9.

8.1 CERCLA Program Goals and Expectations

As described in the NCP, the CERCLA program expects to select remedies that are: protective of HHE, maintain protection over time, and minimize untreated waste. The NCP (40 CFR 300.430[a][1][i]) defines expectations for developing remedial alternatives to achieve these goals. The following were considered in developing the remedial alternatives for the 200-UP-1 Groundwater OU:

- Treatment should be used to address the principal threats posed by source materials at a site wherever practical. Principal threats for which treatment is most likely to be appropriate include liquids, areas contaminated with high concentrations of toxic compounds, and highly mobile materials. Contaminated groundwater plumes are generally not considered to be source material (EPA 540-R-97-013).
- Engineering controls (containment) should be used for waste that poses a relatively low long-term threat or where treatment is impractical.
- A combination of methods, as appropriate, should be used to achieve protection of HHE. In appropriate situations, treatment of principal threats should be combined with engineering and ICs for treatment of residuals and untreated waste.
- ICs (restrictions on water use, security, fencing, and deed restrictions) should be used to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances or contaminated environmental media. The use of ICs should not substitute for active response measures as the sole remedy unless such active measures are determined to not be practical.
- Innovative (non-demonstrated) technologies should be considered when such technologies offer the potential for comparable or superior treatment performance or implementability, fewer or lesser adverse impacts than other available approaches, or lower costs for similar levels of performance than demonstrated technologies.
- Useable groundwater should be returned to beneficial use, wherever practical, within a timeframe that is reasonable given the particular circumstances of the site. When restoration of groundwater to beneficial uses is not practical, EPA expects to prevent further migration of the plume, prevent exposure to the contaminated groundwater, and evaluate further risk reduction.

- For groundwater response actions, a limited number of remedial alternatives should be developed to achieve site-specific remediation levels within different restoration time periods using one or more different technologies. Where the contaminated groundwater is not currently used, or an alternate water source is readily available, and there is no near-term future need for the resource, it will likely be appropriate to consider a longer timeframe for achieving restoration cleanup levels (EPA 540-R-97-013).

- The No Action Alternative (no further action if some removal or RA has already occurred at a site) shall also be developed.

In addition to these criteria, the remedial alternatives were developed to achieve the RAOs within the areas of attainment identified in Section 7.1.

8.2 Development of Remedial Alternatives

This section describes the remedial alternatives developed for the 200-UP-1 Groundwater OU.

8.2.1 Description of Remedial Alternatives

The remedial technologies and process options retained from the screening performed in Section 7.3 were combined to develop a range of viable remedial alternatives for the 200-UP-1 Groundwater OU. Preliminary technical and functional requirements for the components of each alternative were identified based on RAOs and ARARs, as well as other considerations. Each of the remedial alternatives was developed around the core elements of hydraulic containment and P&T because these groundwater remediation technologies are robust and proven for the conditions present at the Hanford Site.

The remedial alternatives range from no action to active treatment using P&T with treatment performed at the 200 West Area groundwater treatment facility. The alternatives encompass a range of possible options, considering the RAOs and CERCLA expectations for groundwater presented in Section 8.1, as follows:

- **No Action Alternative.** The NCP (40 CFR 300.430[e][6]) requires consideration of a No Action Alternative. This alternative would take no further action and would terminate the ICs and IRAs underway for this OU.

- **Alternative 1—Monitored Natural Attenuation and Institutional Controls.** This alternative relies on natural attenuation processes (e.g., radioactive decay, sorption, and dispersion) to achieve the RAOs in approximately 1,000 years. Periodic groundwater monitoring and ICs are used to prevent exposure and groundwater use until cleanup levels are achieved. This alternative also continues operation of the S-SX IRA P&T system with MNA to restore the Tc-99 plume to its cleanup level within 30 years.

- **Alternative 2—Restoration of Tc-99 (30 years) and Uranium (150 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected.** This alternative uses P&T and MNA to restore the uranium and Tc-99 plumes to cleanup levels within 30 years and 150 years, respectively. The I-129 plume is hydraulically contained using injection wells until a final remedy is selected.

- **Alternative 3—Restoration of Tc-99 (30 years) and Uranium (80 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected.** This alternative uses P&T and MNA to restore the uranium and Tc-99 plumes to cleanup levels within 30 years and 80 years, respectively. The I-129 plume is hydraulically contained using injection wells until a final remedy is selected.

- **Alternative 4—Restoration of Tc-99 (25 years) and Uranium (28 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected.** This alternative uses P&T to restore the Tc-99 and uranium plumes to cleanup levels within 25 years and 28 years, respectively, without reliance on MNA. The I-129 plume is hydraulically contained using injection wells until a final remedy is selected.

Each of the alternatives employing P&T require treatment of the extracted groundwater to comply with ARARs. Treatment will be performed at the 200 West Area groundwater treatment facility. Depending on the pumping rates employed under each alternative, modifications to the 200 West Area groundwater treatment facility may be required.

Table 8-1 provides the rationale for the individual components included in each alternative. Table 8-2 summarizes the components and the technology type/process options contained within each alternative.

Many of the alternatives contain common elements. The common elements are described first in Section 8.2.2, while Section 8.2.3 provides a detailed description of each alternative.

8.2.2 Common Elements

Many of the RA alternatives developed for the 200-UP-1 Groundwater OU contain elements that are common to one or more of the alternatives. To limit redundancy in the detailed description of alternatives presented in Section 8.2.3, the common elements are described in the following subsections.

8.2.2.1 Institutional Controls

The 200-UP-1 Groundwater OU interim ROD (EPA/ROD/R10-97/048), as amended by 09-AMCP-0082, requires ICs during the interim action. DOE is responsible for implementing, maintaining, reporting on, and enforcing the ICs until the lead regulatory agency authorizes their removal.

ICs are instruments (administrative and/or legal restrictions) designed to control or eliminate specific pathways of exposure to contaminants. For groundwater within most portions of the Central Plateau, ICs are in place prohibiting the installation and use of groundwater for purposes other than monitoring, characterization, and cleanup. An existing source of potable water is provided to facilities on the Central Plateau and will continue to be available; so currently there is no demand for groundwater. The ICs proposed under all of the remedial alternatives, except the No Action Alternative, would maintain the existing ICs restricting groundwater use until cleanup levels are achieved. DOE/RL-2001-41 and Section 7.3 identify the ICs that have been implemented at the Site, and describe how ICs are to be maintained for the future.

The current ICs provide a foundation from which to identify the long-term controls needed to prevent exposure during the 150-year restoration timeframe. DOE/RL-2001-41 was updated to include the following ICs as part of the IRAs selected in the 200-UP-1 Groundwater OU Interim Action ROD, as amended by Ecology, 2009b.

1. DOE shall control access to 200-UP-1 OU groundwater to prevent unacceptable exposure of humans to contaminants, except as otherwise authorized in regulator-approved documents.
2. Visitors entering any site areas of the 200-UP-1 Groundwater OU will be required to be badged and escorted at all times.
3. No intrusive work shall be allowed in the 200-UP-1 Groundwater OU unless the lead regulatory agency has approved the plan for such work and that plan is followed.

4. DOE shall prohibit well drilling in the 200-UP-1 Groundwater OU, except for monitoring, characterization, or remediation wells authorized in regulator-approved documents.
5. Groundwater use in the 200-UP-1 Groundwater OU is prohibited, except for limited research purposes, monitoring, and treatment authorized in regulator-approved documents.
6. DOE shall post and maintain warning signs along pipelines conveying untreated groundwater that caution site visitors and workers of potential hazards from the 200-UP-1 OU groundwater.
7. In the event of any unauthorized access (trespassing), DOE shall report such incidents to the Benton County Sheriff's Office for investigation and evaluation of possible prosecution.
8. Activities that would disrupt or lessen the performance of the P&T component of the remedy are to be prohibited.
9. DOE shall prohibit activities that would damage the remedy components (extraction wells, piping, treatment plant, and monitor wells).
10. DOE will prevent the development and use of property above the 200-UP-1 Groundwater OU for residential housing, elementary and secondary schools, childcare facilities, and playgrounds.
11. DOE shall report on the effectiveness of ICs for the 200-UP-1 Groundwater OU interim remedy in an annual report, or on an alternative reporting frequency specified by the lead regulatory agency. Such reporting may be for the 200-UP-1 Groundwater OU alone or may be part of the Hanford Sitewide report.
12. Measures that are necessary to ensure continuation of ICs shall be taken before any lease or transfer of any land above the 200-UP-1 Groundwater OU. DOE will provide notice to Ecology and EPA at least 6 months prior to any transfer or sale of 200-UP-1 Groundwater OU or any land above the 200-UP-1 Groundwater OU so that the lead regulatory agency can be involved in discussions to ensure that appropriate provisions are included in the transfer terms or conveyance documents to maintain effective ICs. If it is not possible for DOE to notify Ecology and EPA at least 6 months prior to any transfer or sale, DOE will notify Ecology and EPA as soon as possible, but no later than 60 days prior to the transfer or sale of any property subject to ICs. In addition to the land transfer notice and discussion provisions stated previously, DOE further agrees to provide Ecology and EPA with similar notice, within the same timeframes, as to federal-to-federal transfer of property. DOE shall provide a copy of the executed deed or transfer assembly to Ecology and EPA.

8.2.2.2 Monitored Natural Attenuation

The MNA common element uses natural processes within the 200-UP-1 Groundwater OU aquifer to achieve reductions in the toxicity, mobility, volume, concentration, and/or bioavailability of COCs. These natural processes include physical, chemical, and biological transformations that occur without human intervention. MNA requires information to show that attenuation is occurring, an understanding of site-specific and contaminant-specific attenuation mechanisms, and monitoring to demonstrate that natural attenuation is occurring as anticipated. MNA is considered appropriate for sites where RAOs can be achieved in a reasonable timeframe compared to more active remedial alternatives.

MNA is a viable component for 200-UP-1 Groundwater OU remedial alternatives, especially for addressing: small contaminant plumes, plumes that occur at concentrations near cleanup levels, and plumes that decay in a relatively short timeframe. MNA is especially applicable for tritium because of its short radioactive half-life (12.3 years) and because there is no groundwater treatment technology for this constituent. MNA is also an important component for P&T alternatives as a follow-on step to address low-level COC concentrations when P&T becomes less efficient.

Table 8-1. Alternative Development Rationale

Alternative	Alternative Component	Remedial Action Objective Addressed			Other Objective	Rationale for Inclusion in Remedial Alternatives
		RAO No. 1	RAO No. 2	RAO No. 3		
		Restore 200-UP-1 Groundwater to Beneficial Use	Prevent Use of Groundwater Until Cleanup Levels Met	Protect Columbia River from Impact		
No Action	No Action				X	Required by 40 CFR 300.430(e)(6).
Alternative 1: Institutional Controls and Monitored Natural Attenuation	ICs		X			ICs limit groundwater use within the 200-UP-1 Groundwater OU (RAO 2) until cleanup levels are met. The development and selection of an ICs-based alternative as the sole remedy is allowable under 40 CFR 300.430(a)(ii)(D) when active measures are determined to not be practicable based on the balancing of trade-offs among all alternatives.
	MNA	X		X		Natural attenuation includes reduction of toxicity, mobility, volume, concentration, and/or bioavailability through natural physical, chemical, or biological processes that occur without human intervention. These processes will assist in achieving RAOs 1 and 3. The monitoring component verifies that the natural attenuation is occurring as anticipated and serves as a basis for determining whether objectives have been met, or additional measures are needed. MNA is especially applicable for tritium.
	P&T – Extraction (Tc-99)	X		X		Operation of the Tc-99 P&T system will contribute to achieving RAOs 1 and 3. P&T actions are already underway to address the WMA S-SX Area Tc-99 and U Plant plumes. Operation and optimization of this system will be incorporated into the final remedy. Estimated total system pumping rates are 300 L/min (80 gpm) with treatment at the 200 West Area groundwater treatment facility.
	P&T – Treatment	X		X		Groundwater treatment addresses RAOs 1 and 3 as a necessary component of groundwater extraction, which will require treatment to cleanup levels prior to injection back into the aquifer. Alternative 1 assumes treatment of 200-UP-1 OU groundwater will be accomplished at the 200 West Area groundwater treatment facility.
Alternative 2: Restoration of Tc-99 (30 years) and Uranium (150 years), and Hydraulic Containment of I-129 Plume Until a Final Remedy is Selected	ICs		X			Same as Alternative 1.
	MNA	X		X		Same as Alternative 1. Duration for each COC varies based on time to achieve cleanup levels. Complements P&T component.
	P&T – Extraction (Tc-99 and Uranium)	X		X		The P&T component restores the Tc-99 and uranium plumes to cleanup levels. The Tc-99 P&T component is the same as described for Alternative 1. P&T of uranium plume will continue for a period of 25 years, at which point an additional 125 years is required for natural attenuation to reduce concentrations to the cleanup level. The U Plant IRA P&T system will be replaced by the final remedy in this alternative.
	Hydraulic Containment (I-129)			X		This component hydraulically contains the I-129 plume until a final remedy is selected. Hydraulic containment as an engineering control is described in the NCP under 40 CFR 300.430.(1)(1)(iii)(B). Hydraulic containment is intended to contain portions of the plume where concentrations exceed cleanup levels and to prevent further plume migration to reduce potential future groundwater impacts to the Columbia River in support of RAO 3.
	P&T – Treatment (Tc-99 and Uranium)	X		X		Groundwater treatment addresses RAOs 1 and 3 as a necessary component of groundwater extraction, which will require treatment to cleanup levels prior to injection back into the aquifer. Under Alternative 2, all treatment is performed at the 200 West Area groundwater treatment facility (no expansion required).

Table 8-1. Alternative Development Rationale

Alternative	Alternative Component	Remedial Action Objective Addressed			Other Objective	Rationale for Inclusion in Remedial Alternatives
		RAO No. 1	RAO No. 2	RAO No. 3		
		Restore 200-UP-1 Groundwater to Beneficial Use	Prevent Use of Groundwater Until Cleanup Levels Met	Protect Columbia River from Impact		
Alternative 3: Restoration of Tc-99 (30 years) and Uranium (80 years), and Hydraulic Containment of I-129 Plume Until a Final Remedy is Selected	ICs		X			Same as Alternative 1.
	MNA	X		X		Same as Alternative 1. Duration for each COC varies based on time to achieve cleanup levels. Complements P&T component.
	P&T – Extraction (Tc-99 and Uranium)	X		X		The P&T component restores the Tc-99 and uranium plumes to cleanup levels. The Tc-99 P&T component is the same as Alternative 1. P&T of the uranium plume will continue for a period of 25 years, at which point an additional 55 years is required for natural attenuation to reduce concentrations to the cleanup level. The U Plant IRA P&T system will be replaced by the final remedy in this alternative.
	Hydraulic Containment (I-129)			X		Same as Alternative 2.
	P&T – Treatment	X		X		Groundwater treatment addresses RAOs 1 and 3 as a necessary component of groundwater extraction, which will require treatment to cleanup levels prior to injection back into the aquifer. Under Alternative 3, treatment is performed at the 200 West Area groundwater treatment facility. A third parallel treatment train would be installed in the treatment building within the reserve floor space.
Alternative 4: Restoration of Tc-99 (25 years) and Uranium (28 years), and Hydraulic Containment of I-129 Plume Until a Final Remedy is Selected	ICs		X			Same as Alternative 1.
	MNA	X		X		Similar to Alternative 1 but no MNA required for Tc-99 and uranium. MNA duration for tritium and nitrate expected to be comparable to Alternative 1.
	P&T – Extraction (Tc.-99 and Uranium)	X		X		The P&T component restores the Tc-99 and uranium plumes to cleanup levels without relying on MNA. The U plant IRA P&T system will be replaced by the final remedy in this alternative.
	Hydraulic Containment (I-129)			X		Same as Alternative 2.
	P&T – Treatment	X		X		Same as Alternative 3.

CFR = *Code of Federal Regulations*
COC = contaminant of concern
IC = institutional control
IRA = interim remedial action
MNA = monitored natural attenuation
NCP = National Oil and Hazardous Substances Pollution Contingency Plan
OU = operable unit
P&T = pump-and-treat
RAO = remedial action objective
WMA = waste management area

Table 8-2. 200-UP-1 Groundwater OU Remedial Alternatives Summary[c]

Remedial Alternative Elements	COCs Addressed	Alternative 1— Monitored Natural Attenuation + Institutional Controls	Alternative 2—Restoration of Tc-99 (30 years) and Uranium (150 years), and Hydraulic Containment of I-129 Until a Final Remedy is Selected	Alternative 3—Restoration of Tc-99 (30 years) and Uranium (80 years), and Hydraulic Containment of I-129 Until a Final Remedy is Selected	Alternative 4— Restoration of Tc-99 (25 years) and Uranium (28 years), and Hydraulic Containment of I-129 Until a Final Remedy is Selected
			Treatment—200 West Area Groundwater Treatment Facility with Train 1/Train 2	Treatment—200 West Area Groundwater Treatment Facility with Third Train	Treatment—200 West Area Groundwater Treatment Facility with Third Train
Estimated Groundwater Extraction and Injection Wells and Flow Rates					
Extraction/Injection for Restoration to Cleanup Levels	Tc-99 (S-SX Area)	2 extraction wells at 110 L/min (30 gpm) each and 1 extraction well at 76 L/min (20 gpm) for 25 years	Same as Alternative 1	Same as Alternative 1	5 extraction wells at 110 L/min (30 gpm) each for 25 years
	Uranium		2 extraction wells and 2 injection wells at 380 L/min (100 gpm) each for 25 years	3 extraction wells and 3 injection wells @ 380 L/min (100 gpm) each for 25 years	4 extraction wells and 4 injection wells at 380 L/min (100 gpm) each for 28 years
Hydraulic Containment	I-129		3 injection wells at 190 L/min (50 gpm) each, 570 L/min (150 gpm) total	Same as Alternative 2	Same as Alternative 2
Estimated Time to Reach Cleanup Levels					
Time to Cleanup Levels (MNA)[a]	Tc-99	30 years (25 years pumping, then 5 years MNA)	30 years (25 years pumping, then 5 years MNA)	30 years (25 years pumping, then 5 years MNA)	25 years (MNA not required)
	Uranium	>1,000 years	150 years (25 years pumping, then 125 years MNA)	80 years (25 years pumping, then 55 years MNA)	28 years (MNA not required)
	I-129	>1,000 years	To be determined pending Final Remedy Selection	To be determined pending Final Remedy Selection	To be determined pending Final Remedy Selection
	Nitrate	175 years	150 years[b]	150 years[b]	150 years[b]
	Tritium	50 years	50 years	50 years	50 years
Groundwater Treatment					
Total Extraction Rate (nominal)		300 L/min (80 gpm)	1,060 L/min (280 gpm)	1,440 L/min (380 gpm)	2,080 L/min (550 gpm)
Extraction/Injection Pumping Duration		25 years (Tc-99)	25 years (Tc-99, uranium, and 1-129)	25 years (Tc-99, I-129, and uranium)	25 years (Tc-99) and 28 years (uranium)
Physical Treatment – Air Stripping	Volatile organics (if present)	200 West Area groundwater treatment facility (existing Train 1/Train 2)		200 West Area groundwater treatment facility with addition of Train 3 in reserve floor space	
Ion Exchange	Uranium, Tc-99				
Blending	Tritium				
Chemical Treatment	pH adjustment				
Biological Treatment	Nitrate, volatile organics, and chromium (if present)				

a. The time to reach cleanup levels includes the duration of monitored natural attenuation. The duration of ICs established by the 200-ZP-1 Groundwater OU ROD is 150 years. 200-UP-1 OU will use the same duration for ICs.

b. Alternatives 2, 3, and 4 will employ Remedial Process Optimization (RPO) to accelerate achievement of the nitrate cleanup level within the 150-year RAO timeframe established in the 200-ZP-1 Groundwater OU ROD. RPO activities may include increased pumping rates in the uranium plume to capture more nitrate-contaminated groundwater, installation of additional extraction wells or other enhancements to be determined following five-year reviews.

c. All pumping rates and remedial action durations are estimated. Actual pumping rates and durations may vary.

COC = contaminant of concern IC = institutional control MNA = monitored natural attenuation OU = operable unit

8.2.2.3 Interim Remedial Actions

All of the 200-UP-1 groundwater OU remedial alternatives assume that the IRAs will be incorporated into or replaced by the final RA as necessary to achieve RAOs. These IRAs include an existing P&T system in the vicinity of U Plant and a planned P&T system in the vicinity of the WMA S-SX Area.

Since 1994, DOE has operated an IRA P&T system to remove Tc-99 and uranium from the groundwater in the vicinity of U Plant with groundwater treatment at the ETF. The effort successfully reduced contaminant concentrations to below RAGs. DOE shut down the system in January 2005 to conduct a rebound study. At the time of the rebound study, the interim RAG for uranium was 480 µg/L or 10 times the WAC 173-340 standard of 48 µg/L. An ESD issued in February 2009 lowered the interim RAG for uranium to 300 µg/L, based on a revised DWS of 30 µg/L.

Uranium concentrations at the 12 wells surrounding the initial uranium plume did not exceed the previous 480 µg/L RAG during CY 2009; however, Wells 299-W19-18 and 299-W19-43 exceeded the revised interim RAG of 300 µg/L. DOE/RL-2010-11, *Hanford Site Groundwater Monitoring and Performance Report for 2009* reports that through CY 2009, a total of 219 kg (489 lb) of uranium; 126.5 g (4.46 oz) of Tc-99; 40.2 kg (87 lb) of carbon tetrachloride; and 47,300 kg (102,366 lb) of nitrate have been removed. The IRA P&T in the vicinity of U Plant will be replaced by the components of the selected remedial alternative that address uranium.

Batch pumping (3,800 L [1,000 gal]) of Well 299-W23-19 (in the vicinity of S-SX) is performed following each quarterly sampling event. Under the interim action ROD, batch pumping will continue until Tc-99 concentrations in the well are less than or equal to 10 times the DWS (less than or equal to 9,000 pCi/L) for four consecutive quarters (Ecology, 2009b). A three well, 300 L/min (80 gpm) P&T system is planned for the Tc-99 plume located in the vicinity of the WMA S-SX Area. Extracted groundwater will be pumped through a new pipeline to the new 200 West Area groundwater treatment facility. Figure 8-1 shows the conceptual extraction well layout and capture zone for this system. Details of the interim action are outlined in DOE/RL-97-36, Rev. 3.

Treatment at the 200 West Area groundwater treatment facility includes IX to remove Tc-99 and uranium, biological treatment for nitrate and chromium, and air stripping for VOCs. Following treatment, the water is returned to the aquifer through injection wells located in the 200-ZP-1 Groundwater OU.The S-SX P&T system is assumed, for the purposes of this FS, to operate at 300 L/min (80 gpm) for approximately 3 to 4 years until it is incorporated into the final remedy to aid in achieving RAOs and, if necessary, to provide source control for existing WMA Tank Farm vadose zone Tc-99 sources for up to 25 years. The 25-year assumption provides a reasonable timeframe for additional characterization and implementation of CERCLA or RCRA remedial measures to address the vadose zone sources.

8.2.2.4 Groundwater Pump-and-Treat

Each of the 200-UP-1 Groundwater OU alternatives, with the exception of the No Action Alternative, includes a groundwater P&T system. This system consists of a groundwater extraction well network, transfer piping (with transfer pump stations), and above ground treatment facilities.

Extraction wells are designed to remove contaminants from the aquifer and to reduce or prevent further plume migration (hydraulic containment). Injection wells are used to inject treated water back into the aquifer. The placement of injection wells near the plume margins or downgradient of the plume is used to provide flow path (gradient) control to prevent migration and slow COC travel times, thus allowing more time for MNA. The above ground treatment system for all 200-UP-1 remedial alternatives is the 200 West Area groundwater treatment facility, which includes various chemical, physical, and biological treatment technologies designed specifically to treat the COCs that are being addressed.

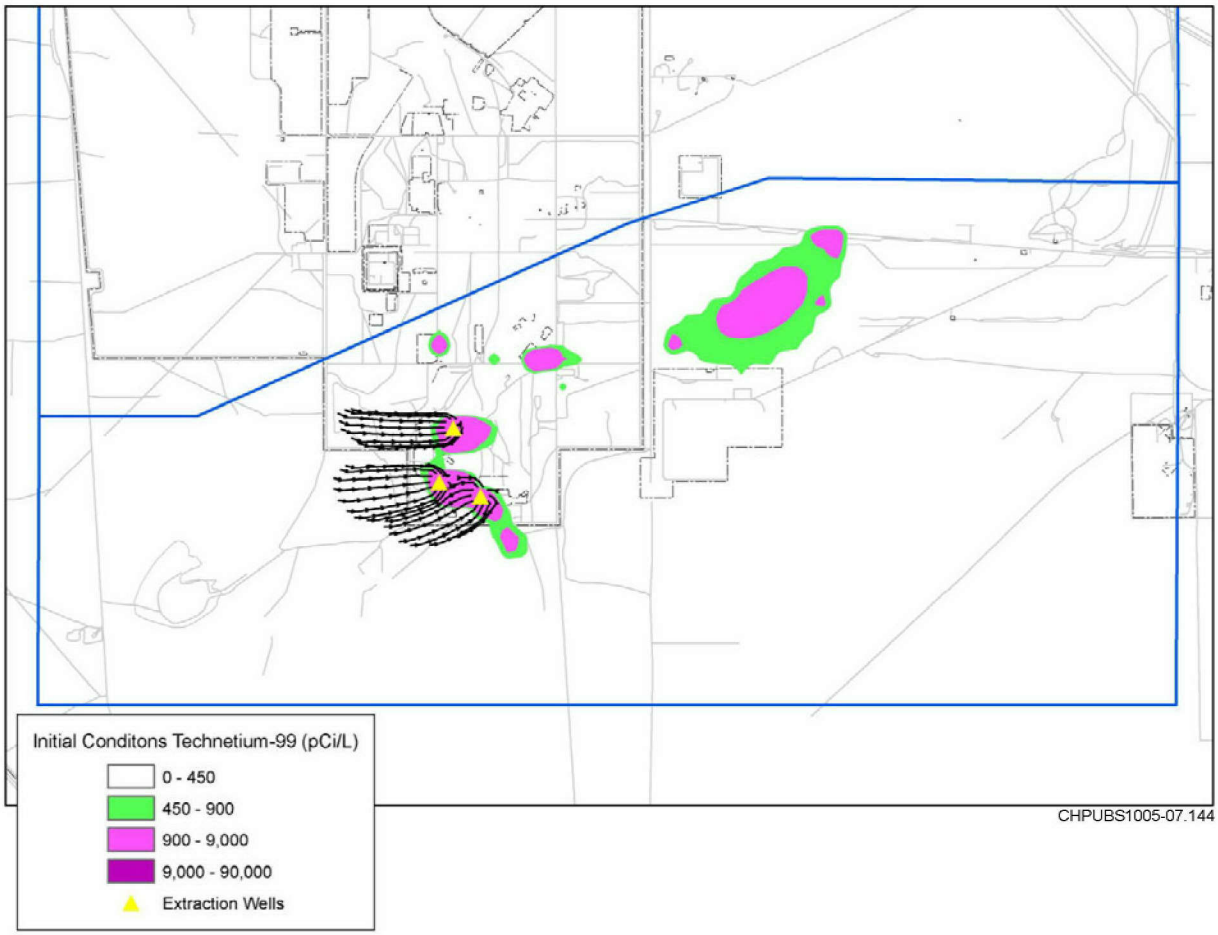


Figure 8-1. Conceptual Layout of Tc-99 Extraction Wells in the WMA S-SX Vicinity

Extraction well design must consider site-specific factors, such as the vertical contaminant distribution encountered within the aquifer during drilling, anticipated well yield, and the grain-size of the aquifer sediments. Based on the vertical contaminant distribution discussed in Section 4.2, the highest concentration of most contaminants occurs within the upper 20 to 30 m (66 to 98 ft) of the unconfined aquifer. Based on the current understanding of the N&E of contamination, it is anticipated that the extraction wells will be screened in the upper part of the aquifer with screen lengths up to 30 m (98 ft). The extraction wells are assumed to be nominally 25 cm (10 in.) diameter.

Although injection well designs are also specific to their function (inject treated water to the aquifer or provide hydraulic flow control), for the purpose of FS alternative development, the injection well design is assumed to be similar to the extraction well design. Injection wells for hydraulic containment of the I-129 plume would be extended to the base of the unconfined aquifer.

Groundwater extracted by P&T systems must be treated to appropriate standards prior to injection back into the aquifer. The 200 West Area groundwater treatment facility is designed to treat the 200-ZP-1 Groundwater OU COCs (carbon tetrachloride, chromium [total and hexavalent], nitrate, TCE, and Tc-99) (DOE/RL-2010-13). Tritium is also present in the 200-ZP-1 Groundwater OU, but it will not be actively treated. Although uranium is not a COC in the 200-ZP-1 Groundwater OU, the treatment system design includes IX treatment of uranium that may be captured by the extraction wells (DOE/RL-2008-78). Capacity is also being designed into the system to treat uranium from a 200-UP-1 Groundwater OU final

remedy. The 200 West Area groundwater treatment facility design (Figure 8-2) has reserved approximately 1,320 L/min (350 gpm) of maximum[1] flow capacity for treatment of groundwater extracted from the 200-UP-1 Groundwater OU.

The 200 West Area groundwater treatment facility process design includes the following steps:

- Filtration to remove suspended solids
- IX to remove Tc-99 and uranium with partial removal of I-129
- A fluidized bed bioreactor (FBR) for nitrate, chromium, and carbon tetrachloride treatment
- An aeration tank and membrane filtration to remove residual carbon substrate, total suspended solids, and biomass associated with the FBR operations
- An air stripper to remove the remaining carbon tetrachloride and other VOCs

The 200 West Area groundwater treatment facility design also allows for expansion of the system to include additional treatment capabilities as needed to optimize remedy performance (DOE/RL-2010-13). The design and construction of the 200 West Area groundwater treatment facility will initially include the capability for treating up to 9,460 L/min (2,500 gpm) of extracted groundwater in two parallel treatment trains. A third parallel treatment train has been designed (including available floor space), but will not be installed initially for 200-ZP-1 Groundwater OU operations. The treated effluent will be returned to the aquifer through injection wells located within the 200-ZP-1 Groundwater OU, with additional injection wells being installed as needed in the 200-UP-1 Groundwater OU.

The FS alternatives are based on the assumption that flow rates up to 120 percent of the 1,320 L/min (350 gpm) flow capacity set aside for the 200-UP-1 Groundwater OU could be accommodated at the 200 West Area groundwater treatment facility without modification. Flows in excess of 120 percent of this amount will require installation of a third treatment train in the reserve space of the 200 West Area groundwater treatment facility. Design of the third treatment train is included in DOE/RL-2010-13, however, the third treatment train equipment will not be installed during the initial construction effort for the 200 West Area groundwater treatment facility. The remedial alternatives included in this FS are based on the assumption that the third treatment train will be constructed using the design presented in DOE/RL-2010-13. Addition of the third train, as designed, will increase the capacity of the 200 West Area groundwater treatment facility to a peak flow of 14,200 L/min (3,750 gpm).

The groundwater extraction flow rates under Alternatives 1 and 2 fall within the capacity set aside for the 200-UP-1 Groundwater OU, and therefore, do not require any modifications to the 200 West Area groundwater treatment facility. The increased flow rates specified under Alternatives 3 and 4 exceed the available treatment capacity, and therefore, will require expansion to include an additional treatment train.

[1] Treatment system throughput rates are presented as nominal rates and/or maximum rates. The maximum rate is the nominal rate divided by 0.8 to account for an assumed 80 percent uptime for the 200 West Area groundwater treatment facility.

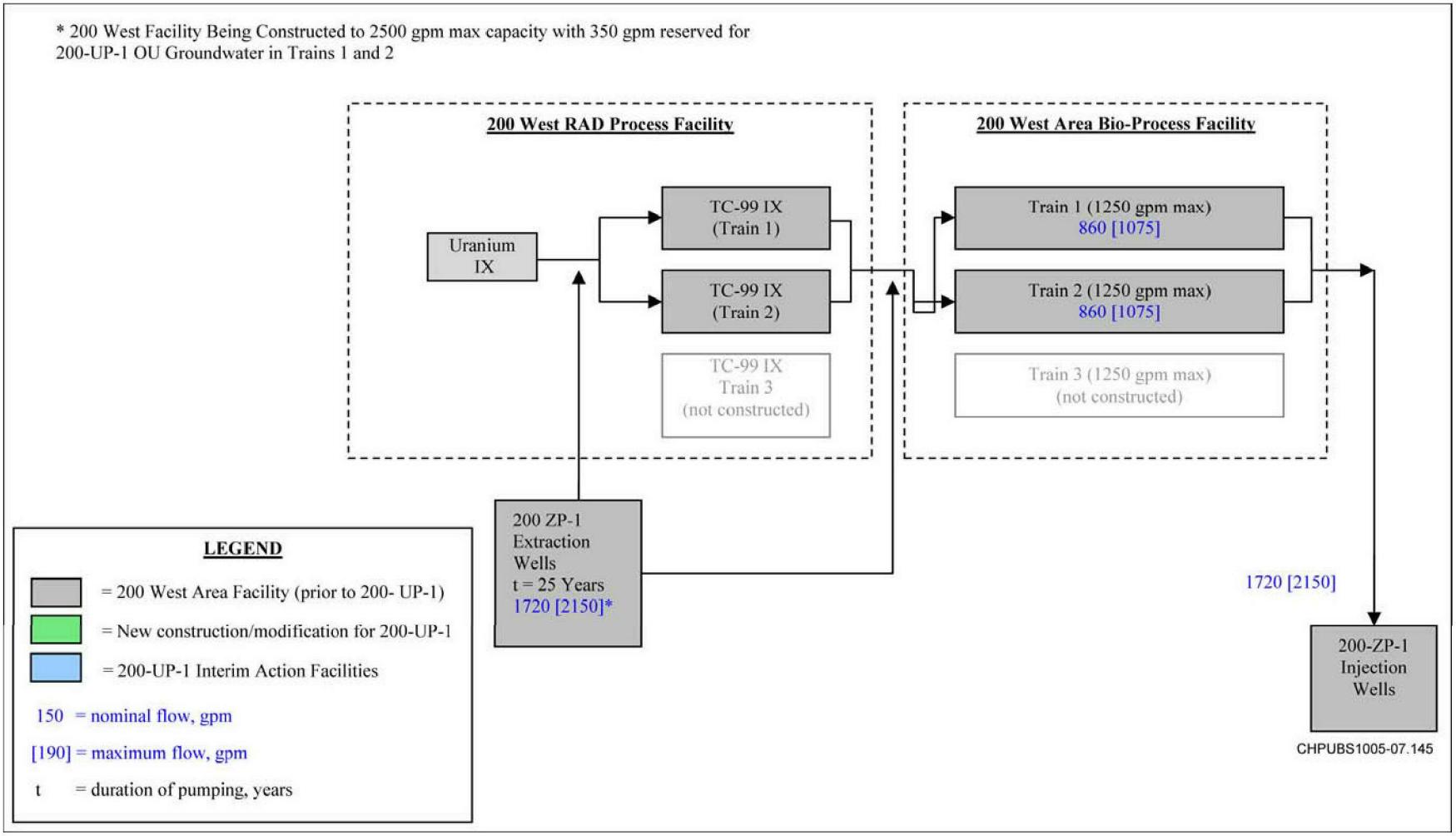


Figure 8-2. 200 West Area Groundwater Treatment Facility Block Flow Diagram

8.2.2.5 Hydraulic Containment for I-129

Hydraulic containment of the I-129 plume using a network of injection wells is a common element for Alternatives 2, 3, and 4. Hydraulic containment will be performed using a network of three injection wells placed near the leading edge of the I-129 plume in the vicinity of the 1 pCi/L concentration isopach. Treated water from the 200 West Area groundwater treatment facility will be injected into each of the three wells at estimated flow rates of 190 L/min (50 gpm). The total injection system flow rate is estimated at 570 L/min (150 gpm).

8.2.2.6 I-129 Technology Evaluation

As described in Section 7.2, there currently is no available treatment technology that can remove I-129 from groundwater to a concentration of 1 pCi/L or less. Therefore, additional technology evaluation beyond that performed for this FS is needed. This common element, which is included in Alternatives 2, 3, and 4, consists of a technology evaluation to identify I-129 remedy options. Detailed information on the overall approach and schedule for the I-129 technology evaluation will be presented in the 200-UP-1 Groundwater OU RD/RA work plan.

8.2.2.7 Remedy Performance Monitoring

Performance monitoring is conducted to evaluate the overall effectiveness of the selected remedy to attain the cleanup levels identified in the 200-UP-1 Groundwater OU decision document. The monitoring program included within the scope of each alternative (except the No Action Alternative) will address each of the components associated with the selected remedy. Detailed information on the performance monitoring program will be developed during the RD and included in an Operation and Maintenance Plan (OMP). Remedy performance monitoring applies to natural attenuation actions as well as active engineered remedies.

Performance monitoring of a P&T groundwater extraction well network would include sampling and flow measurements to evaluate contaminant mass removal from the 200-UP-1 Groundwater OU aquifer. The design would include both hydraulic and monitoring of the extraction wells. Hydraulic monitoring would consist of measuring flow rates, total flow, and water levels for each extraction well. The injection well network would also be monitored for hydraulic performance. Water-level measurements would be used to evaluate whether extraction and injection wells are operating within their design criteria. Monitoring would consist of analysis of extraction well discharge samples for COCs, and COPCs (if warranted).

Performance monitoring of the treatment system would include influent and effluent sampling to evaluate COC removal and treatment efficiency, and to compare effluent concentrations with cleanup levels. The design would include both hydraulic and monitoring of the treatment system. Hydraulic monitoring would consist of measuring flow rates and total flow at the treatment system influent. This monitoring, along with the contaminant concentrations of the influent and effluent water, would be used to determine the contaminant mass reduction from the treatment system. Monitoring would consist of treatment system influent and effluent sampling for COCs.

The performance monitoring well network would be used to evaluate remedy performance in the aquifer. The monitor well network developed for OU characterization activities includes 95 wells. Approximately 50 of these wells would form the basis for the performance monitoring network. However, characterization wells installed with the objective of defining the N&E of contamination may not be sufficient to evaluate the selected remedy. For FS remedial alternative development purposes, it is assumed that 10 to 15 new monitor wells may be needed for the performance monitoring network. The frequency of remedy performance monitoring is anticipated to vary depending on the phase of remediation. For alternatives where active remediation is occurring (P&T), the frequency of monitoring is

assumed to be semi-annual. During long-term monitoring to assess natural attenuation, after an initial period of semi-annual monitoring, the frequency of monitoring will be reduced to every 5 years corresponding to CERCLA Five-Year Reviews.

The performance monitor well network is expected to include areas near vadose zone sources, contaminated groundwater zones of highest concentration and mobility, areas immediately downgradient of active waste sites, plume fringes or distal areas exhibiting low contaminant concentrations, and plume boundaries or other compliance boundaries. The design would include both hydraulic monitoring and groundwater sampling of the well network. Hydraulic monitoring would consist of measuring water levels at each monitor well to assess groundwater flow directions and evaluate groundwater capture by extraction wells and/or flow path control by injection wells. Groundwater sampling would consist of sampling monitor wells for COCs and COPCs. In addition to these parameters, site-specific parameters may be identified to better understand the ability of natural attenuation processes, given the aquifer conditions in the 200-UP-1 Groundwater OU.

8.2.2.8 Operations and Maintenance

O&M of each remedial alternative (except the No Action Alternative) is required to ensure that the remedy achieves RAOs. O&M requirements are typically developed and presented in the OMP, which summarizes the activities necessary to operate and maintain the remedy from completion of construction through D&D of the remedy, after RAOs have been attained.

The nature and scope of O&M activities varies by alternative. For example, O&M activities for the MNA remedy component primarily include inspection, maintenance, and periodic replacement of monitor wells, whereas P&T components include routine and preventative maintenance programs as well as replacement of P&T system components at the end of their design life (typically 25 years). Alternatives with longer durations include multiple replacements of system components on a 25-year frequency.

Another component of O&M includes RPO. RPO generally includes activities to improve a remedy's technical and/or cost effectiveness, or to make modifications to ensure RAOs are achieved. Typical RPO activities for P&T remedies may include the following:

- Optimizing extraction and injection well placement and operation through observation or modeling
- Reducing flow rates at low-concentration wells so that flow rates at higher concentration wells can be increased
- Cycling extraction well flows to optimize or balance hydraulic and contaminant mass loading rate to the treatment system

Specific optimization steps for 200 West Area groundwater treatment facility operation will be determined after startup, once experience with the P&T system has been gained, and aquifer and plume response to pumping established.

8.2.3 Remedial Alternative—Detailed Descriptions

The technologies retained in Chapter 7, and the common components described in Table 8-1, provide the basis for development of each remedial alternative. The following subsections provide further discussion of the purpose, rationale, and scope of each alternative.

8.2.3.1 No Action Alternative

The NCP (40 CFR 300.430[e][6]) requires consideration of a No Action Alternative. The No Action Alternative serves as a baseline for evaluating other RA alternatives and is generally retained throughout

the FS process. No action means that no further remediation would be implemented to alter the existing groundwater conditions. As defined in EPA CERCLA guidance (EPA/540/G-89/004), no action may include environmental monitoring; however, actions taken to reduce exposure (fencing or deed restrictions) are not included as a component of the No Action Alternative. The No Action Alternative for the 200-UP-1 Groundwater consists of:

- No further actions
- Termination of existing ICs
- Termination of the IRAs

8.2.3.2 Alternative 1—Monitored Natural Attenuation and Institutional Controls

Alternative 1 relies on natural attenuation processes and periodic groundwater monitoring to achieve RAOs while relying on ICs to prevent exposure and groundwater use until cleanup levels are achieved. The groundwater F&T modeling analysis presented in Chapter 5 predicts that the maximum-projected uranium and I-129 concentrations will require more than 1,000 years to fall below cleanup levels through natural attenuation alone. Tc-99 and tritium are estimated to attenuate to cleanup levels within 75 years, and nitrate within 175 years. Incorporation of the IRA Tc-99 P&T into the final remedy will reduce that timeframe to 5 years of MNA after 25 years of P&T operations. Based on this analysis, uranium and I-129 concentrations control the required duration of MNA and ICs.

Alternative 1 includes the following common elements implemented over the durations noted:

- ICs (1,000 years)
- MNA for all COCs (up to 1,000 years)
- Tc-99 P&T operation in the S-SX area (Figure 8-1 [25 years])
- Groundwater treatment for Tc-99 (25 years)
- Remedy O&M and performance monitoring (25 years for Tc-99 P&T and 1,000 years for MNA)

Table 8-3 provides a summary of the proposed activities included for Alternative 1 and Figure 8-3 shows a block flow diagram for this alternative.

8.2.3.3 Alternative 2—Restoration of Tc-99 (30 years) and Uranium (150 years), and Hydraulic Containment of I-129 Until a Final Remedy is Selected

Alternative 2 employs P&T at an estimated extraction rate of 1,060 L/min (280 gpm) to restore the Tc-99 and uranium plumes to cleanup levels, and hydraulic containment of the I-129 plume at an estimated injection rate of 570 L/min (150 gpm) until a final remedy is selected. MNA complements P&T to achieve Tc-99 and uranium cleanup levels after P&T operations end, and to address the other Tc-99 plumes that lie outside the S-SX area. ICs prevent exposure and groundwater use until cleanup levels are achieved.

Table 8-3. Alternative 1 Summary

Alternative Description	Alternative Component Summary
Alternative 1: Institutional Controls and Monitored Natural Attenuation	1. ICs (1,000 years) a. Extend ICs within the 200-UP-1 Groundwater OU as described under the interim action ROD. b. Use access restrictions. c. Groundwater use restrictions (restrict installation of new wells in designated areas except for characterization or remediation). 2. P&T of Tc-99 plume at S-SX Area (25 years) a. Three extraction wells operating at an estimated total pumping rate of 300 L/min (80 gpm). b. Tc-99 wells, transfer station, and conveyance piping to the 200 West Area groundwater treatment facility installed under the IRA that will subsequently be incorporated into the final remedy. 3. MNA (1,000 years) a. Natural attenuation monitoring will continue until cleanup levels are met. I-129 and uranium are the most persistent COCs that control MNA duration at an estimated timeframe of 1,000 years. b. Prepare DQO and SAP and supporting documentation (HSP, Hanford-specific documentation). c. Install 10 new monitor wells for long-term groundwater monitoring. The number, location, and depth of each well will be determined in a site-specific DQO and SAP. d. Groundwater sampling during well installation to include five groundwater samples at various depths to determine vertical profile of contamination, and one soil sample at the water table to determine soil type. e. Sampling of 60 monitor wells (50 existing and 10 new) to assess natural attenuation semi-annually for 25 years (during P&T operations), and every 5 years thereafter (corresponding to Five-Year Reviews). f. Document groundwater monitoring and MNA progress in achieving RAOs in Five-Year Reviews. 4. O&M Activities (1,000 years) a. Visual inspection of monitor wells. b. Replace monitor wells at end of design life for duration of natural attenuation monitoring. Assume 30-year lifespan for monitor wells and 60 wells (two wells replaced per year for duration of MNA period). Additional vertical profile sampling will occur during replacement monitor well installation (one groundwater sample and one soil sample). c. Replace monitor well sampling pumps. Assume all sampling pumps (60 monitor wells) will be replaced every 5 years. 5. Site Closeout (Year 1,000) a. Abandon 60 monitor wells at end of MNA duration.

Table 8-3. Alternative 1 Summary

Alternative Description	Alternative Component Summary
COC = contaminant of concern	O&M = operations and maintenance
DQO = data quality objective	OU = operable unit
HSP = Health and Safety Plan	P&T = pump-and-treat
IC = institutional control	RAO = remedial action objective
IRA = interim remedial action	ROD = record of decision
MNA = monitored natural attenuation	SAP = sampling and analysis plan

* 200 West Groundwater Treatment Facility Being Constructed to 2500 gpm max capacity with 350 gpm reserved for 200-UP-1 OU groundwater in Trains 1 and 2. Flow from 200-ZP-1 Groundwater OU extraction wells assumed to be no more than 1,720 gpm nominal/ 2150 gpm maximum.

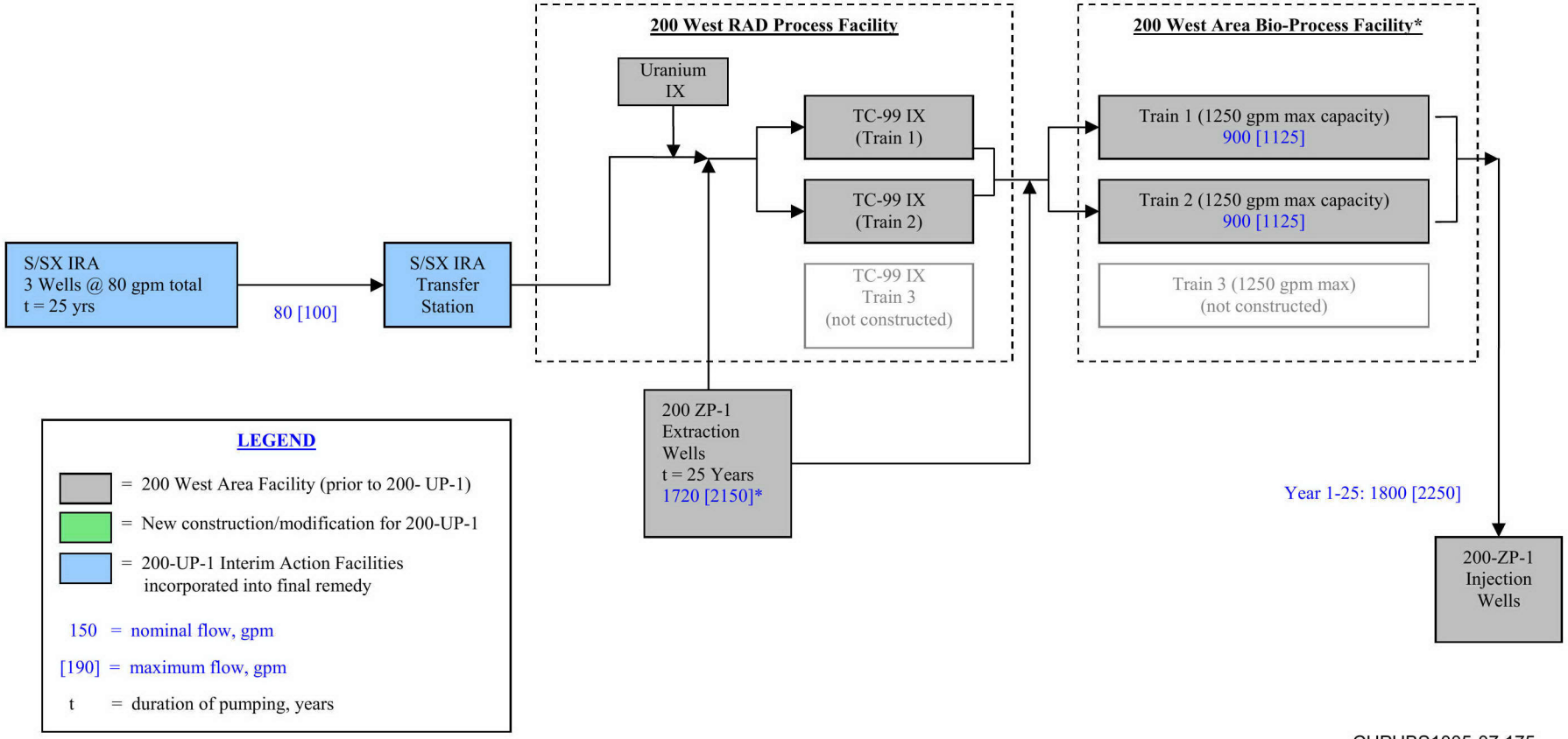


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Figure 8-3. Alternative 1—Groundwater Extraction, Treatment, and Injection Block Flow Diagram

Alternative 2 includes the following common elements and their estimated flow rates and durations:

- ICs (150 years).
- MNA (150 years).
- Groundwater P&T for Tc-99 (three extraction wells, 300 L/min [80 gpm], 25 years).
- Groundwater P&T for uranium (two extraction wells/two injection wells, 760 L/min [200 gpm], 25 years).
- Hydraulic containment of I-129 plume (three injection wells, 570 L/min [150 gpm] until a final remedy is selected. The timeframe for selection of a final remedy for I-129 is unknown. For alternative development and cost estimating purposes, a hydraulic containment period of 25-years is assumed.
- Groundwater treatment (25 years).
- Performance monitoring (25 years for P&T and hydraulic containment, 150 years for MNA).
- Remedy O&M (25 years P&T and hydraulic containment, 150 years for MNA).
- Technology evaluation for I-129 (assumed to occur over a period of up to 10 years).

Table 8-4 summarizes the proposed activities included in Alternative 2. Figure 8-1 shows the well layout for the Tc-99 extraction wells in the S-SX Area. Figures 8-4 and 8-5 illustrate the extraction and injection system capture zones for the uranium and I-129 plumes, respectively.

Figure 8-6 presents a block diagram showing the treatment approach for Alternative 2. Based on the projected I-129 concentrations in the Tc-99 and uranium extraction wells, I-129 concentrations in extracted groundwater are projected to be below 1 pCi/L (Figure 8-7), therefore, no treatment for I-129 is included in this alternative.

8.2.3.4 Alternative 3—Restoration of Tc-99 (30 years) and Uranium (80 years), and Hydraulic Containment of I-129 Until a Final Remedy is Selected

This alternative assumes extraction of groundwater targeting the Tc-99 and uranium plumes with a P&T duration of 25 years, and hydraulic containment of the I-129 plume until a final remedy is selected. After P&T operations cease, natural attenuation reduces COC concentrations below cleanup levels (except I-129). ICs are used to prevent exposure and groundwater use until cleanup levels are achieved.

Table 8-4. Alternative 2 Summary

Alternative Description	Alternative Component Summary
Alternative 2: Restoration of Tc-99 (30 years) and Uranium (150 years), and Hydraulic Containment of I-129 Until a Final Remedy is Selected	1. ICs (150 years) a. Same as Alternative 1. 2. P&T of Tc-99 Plume at S-SX Area (25 years) and Uranium Plume (25 years) a. Tc-99 P&T components of this alternative are the same as presented for Alternative 1. b. Install two uranium extraction wells pumping at 380 L/min (100 gpm) each at a total system pumping rate of 760 L/min (200 gpm). Install two injection wells with capacity to inject 760 L/min (200 gpm). Pumping duration is estimated at 25 years followed by 125 years of MNA to reach the cleanup level. c. Install uranium conveyance system (including piping to/from extraction and injection wells, transfer pump stations, and conveyance piping to/from the 200 West Area groundwater treatment facility). 3. Hydraulic Containment of I-129 Plume until a final remedy is selected (25 years) a. Install three injection wells operating at 190 L/min (50 gpm) each or 570 L/min [150 gpm] total. This alternative assumes containment is required for up to 25 years until a final remedy is selected for I-129. b. Install conveyance system (including piping to/from injection wells, transfer pump stations, and conveyance piping from the 200 West Area groundwater treatment facility). 4. MNA (150 years) a. Same as Alternative 1 except install 15 (instead of 10) new monitor wells for long-term groundwater monitoring. The five additional wells are required to provide additional monitoring for hydraulic containment of the I-129 plume. 5. Groundwater Treatment (25 years) a. Alternative 2 assumes treatment of 200-UP-1 OU groundwater at a flow rate of 1,060 L/min nominal/1,320 L/min maximum (280 gpm nominal/350 gpm maximum) at the 200 West Area groundwater treatment facility.

Table 8-4. Alternative 2 Summary

Alternative Description	Alternative Component Summary
	6. Remedy Performance Monitoring (25 years for P&T and Hydraulic Containment) a. Prepare DQO and SAP and supporting documentation (HSP, Hanford-specific documentation). b. Semi-annual sampling of 65 monitor wells (50 existing and 15 new) for all COCs during P&T and hydraulic containment pumping operation. c. Document P&T and hydraulic containment performance in CERCLA Five-Year Reviews. 7. O&M Activities (25 years for P&T and Hydraulic Containment, 150 years for MNA) a. O&M of extraction, treatment, and injection facilities (routine and preventative maintenance, waste management, and treatment media change out). b. Visual inspection and maintenance of monitor wells for duration of remedy performance monitoring (25 years) and natural attenuation monitoring (150 years). c. Replace monitor wells and sampling pumps for duration of remedy performance monitoring (25 years) and natural attenuation monitoring (150 years). Assume well design life of 30 years (replace two wells per year for duration of monitoring). Additional vertical profile sampling will occur during replacement monitor well installation (one groundwater sample and one soil sample). Assume sampling pumps will be replaced every 5 years. d. Replace extraction wells and extraction well pumps at end of design life (assume at 20 years for extraction wells). e. Rehabilitate extraction wells (back flush well, swab, jet out, pump, and disinfect) every 10 years for 25-year duration of hydraulic containment (does not occur on years when wells are replaced). f. Replace injection wells every 10 years for 25-year duration of P&T and hydraulic containment period. g. Rehabilitate uranium injection wells every 2 years for 25-year duration of pumping (does not occur on years when wells are replaced). Quarterly rehabilitation required for I-129 injection wells due to tendency for biofouling. 8. Site Closeout (Year 25 for P&T and Hydraulic Containment and Year 150 for MNA) a. Abandon 65 monitor wells at end of performance monitoring period for MNA. b. D&D groundwater extraction, conveyance, treatment, and injection facilities at end of active pumping period for hydraulic containment (occurs at year 25).

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
COC = contaminant of concern
D&D = decontamination and decommissioning
DQO = data quality objective
HSP = health and safety plan
IC = institutional control
MNA = monitored natural attenuation
O&M = operations and maintenance
OU = operable unit
P&T = pump-and-treat
SAP = sampling and analysis plan

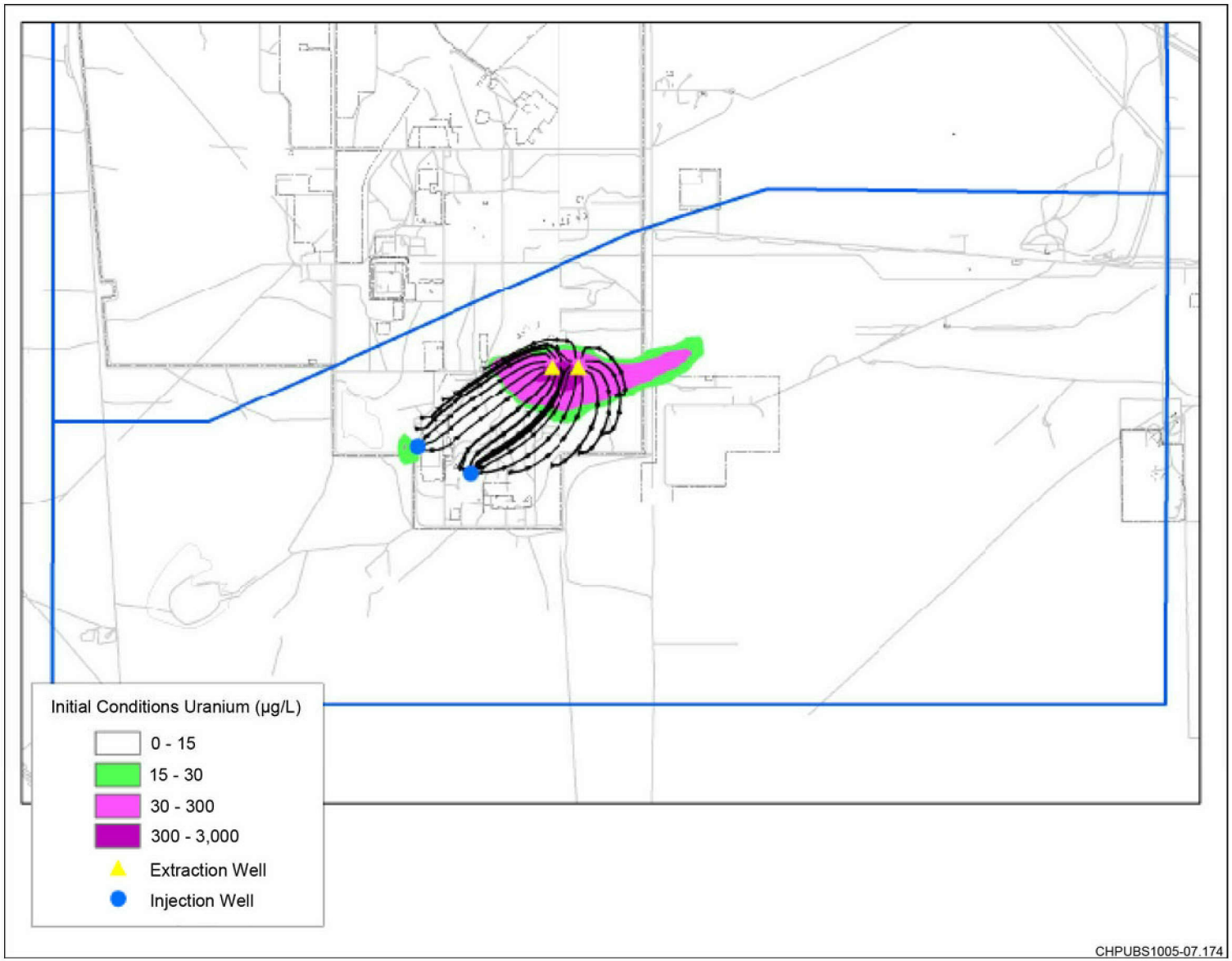

Figure 8-4. Alternative 2—Uranium Extraction and Injection Well Layout and Plume Capture Flowlines

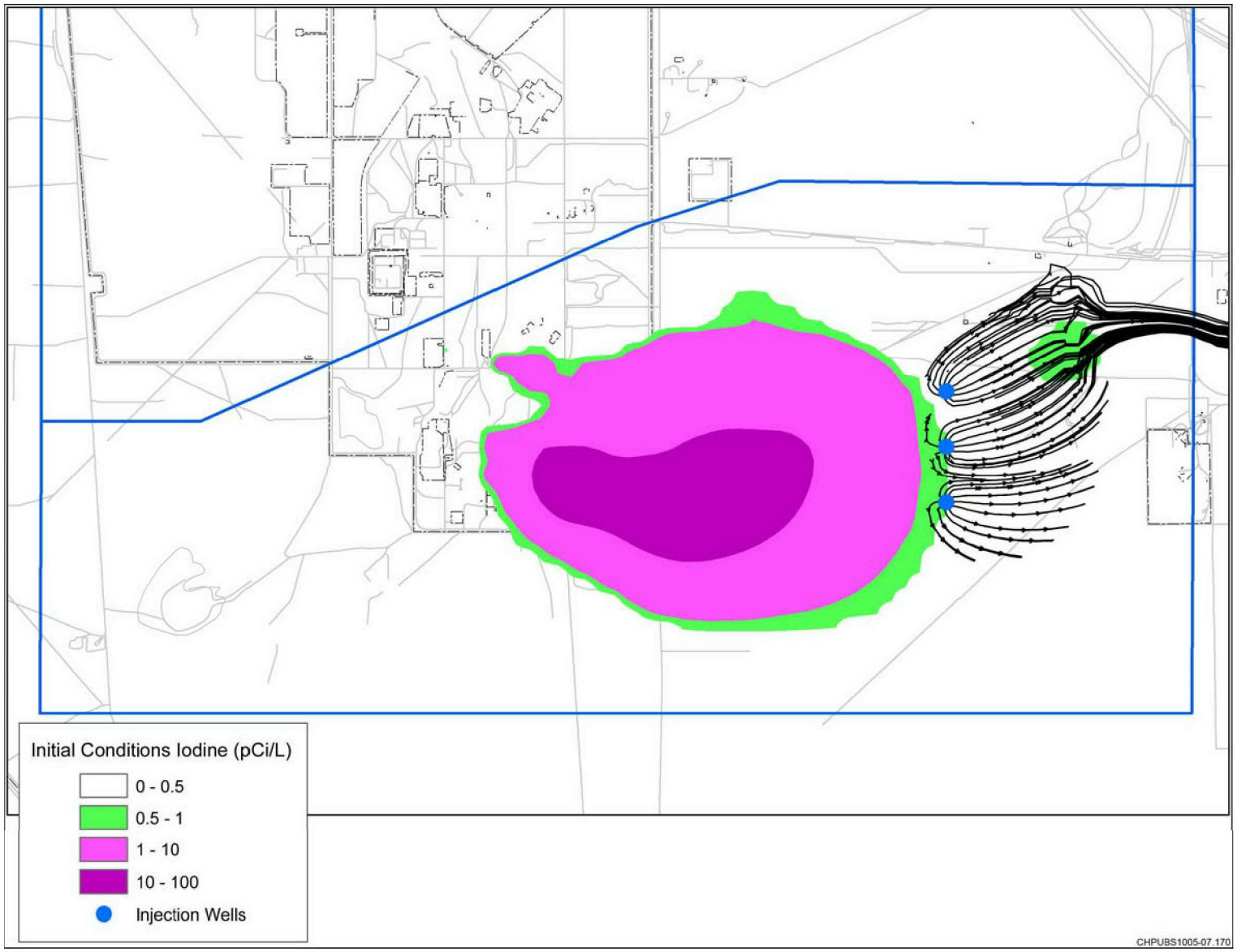

Figure 8-5. Alternative 2—I-129 Hydraulic Containment Injection Well Layout and Containment Flowlines

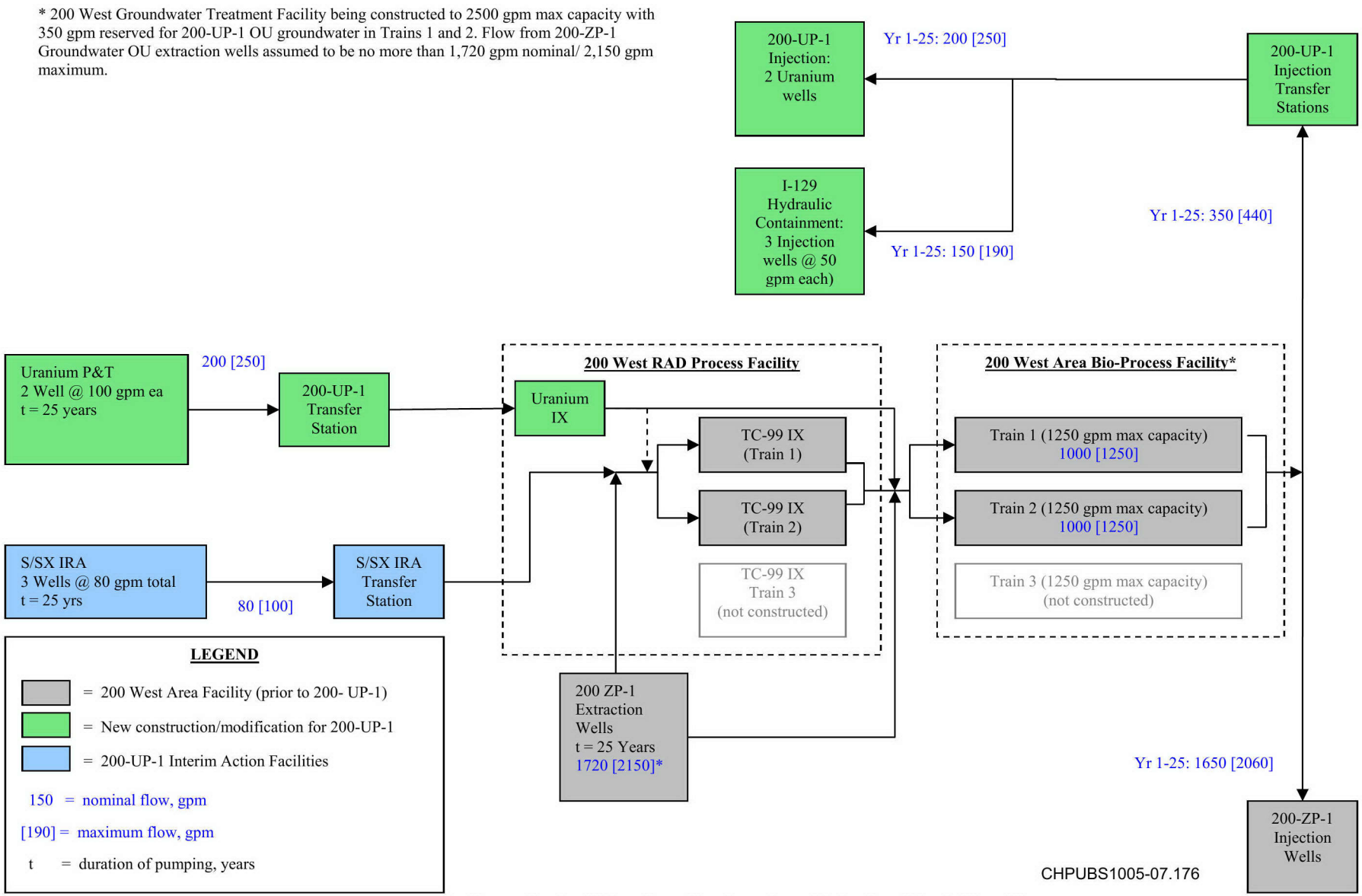

Figure 8-6. Alternative 2—Groundwater Extraction, Treatment, and Injection Block Flow Diagram

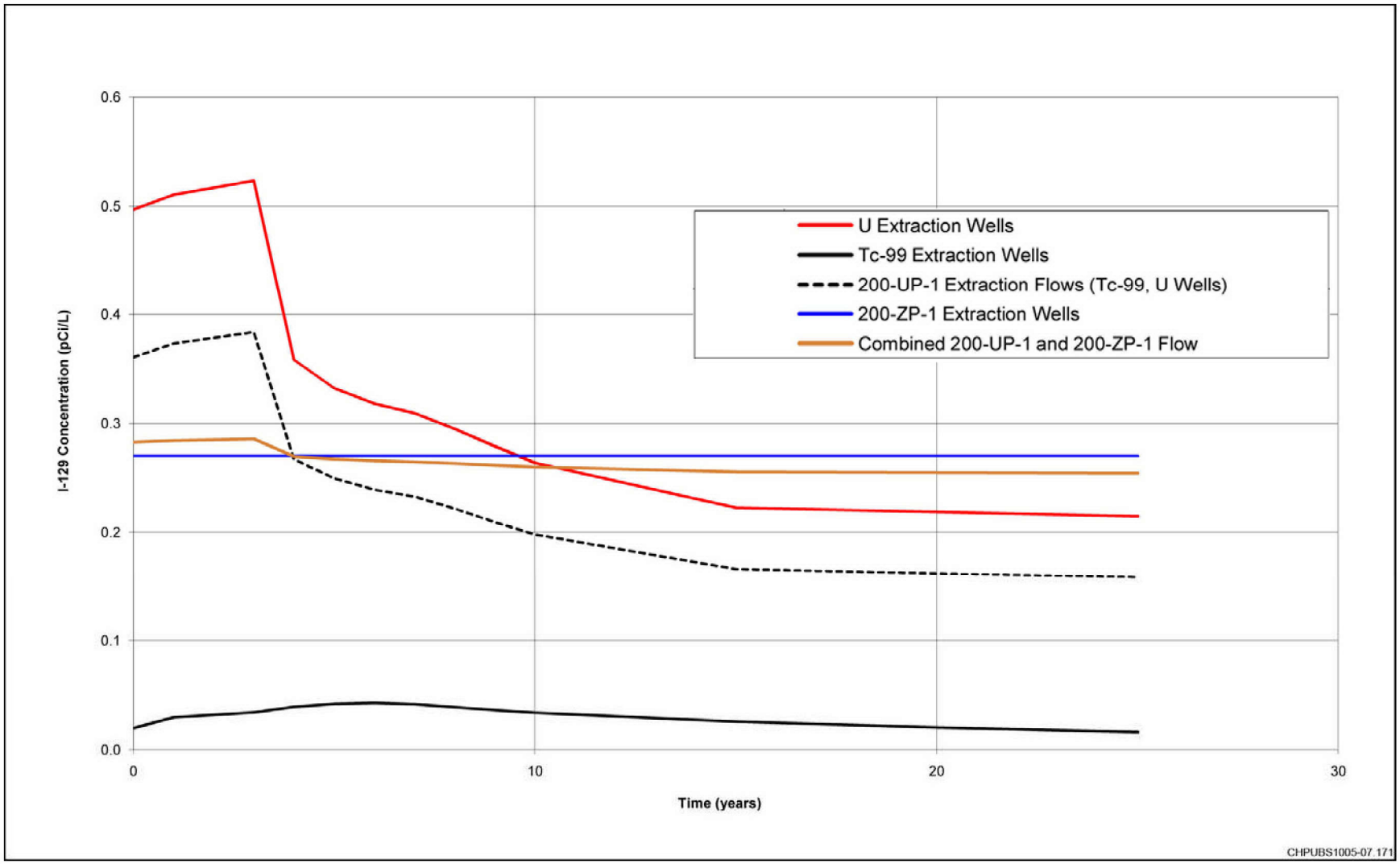

Figure 8-7. Alternative 2—Future I-129 Concentration Projections for Extraction Well Pumping

Alternative 3 includes the following components with the durations noted (flow rates and durations are estimated):

- ICs (150 years)
- MNA (150 years)
- Groundwater P&T for Tc-99 (three extraction wells, 300 L/min [80 gpm], 25 years)
- Groundwater P&T for uranium (three extraction wells/three injection wells, 1,140 L/min [300 gpm], 25 years)
- Hydraulic containment of I-129 plume (three injection wells, 570 L/min [150 gpm]) until a final remedy is selected; hydraulic containment for up to 25 years is assumed
- Groundwater treatment (25 years)
- Performance monitoring (25 years P&T and hydraulic containment, 150 years for MNA)
- Remedy O&M (25 years P&T and hydraulic containment, 150 years for MNA)
- Technology evaluation for I-129 (assumed to occur over a period of up to 10 years)

Table 8-5 provides a summary of the proposed activities included for Alternative 3.

Alternative 3 utilizes the P&T scenario for Tc-99 presented for Alternative 1 (Figure 8-1), the I-129 hydraulic containment scenario utilizing injection presented for Alternative 2 (Figure 8-5), and a P&T scenario for uranium presented in Figure 8-8. Alternative 3 uses the 200 West Area groundwater treatment facility with modifications to handle the increased flow rate (Figure 8-9). This alternative assumes that the additional flows and COC concentrations from 200-UP-1 OU groundwater can be accommodated at the 200 West Area groundwater treatment facility with the addition of the third treatment train. This addition is considered optional, since the 200-UP-1 flow is only about 380 L/min (100 gpm) above the design capacity of the first two treatment trains. Since this is above the 120 percent threshold assumed for FS alternatives, as described previously, the third treatment train has been included in this alternative for FS evaluation and cost estimation purposes.

Figure 8-10 provides an estimated projection of I-129 concentrations in the extraction wells and following blending with 200-ZP-1 extraction well flows. Based on these projections the estimated influent I-129 concentration to the 200 West Area groundwater treatment facility will be less than 1 pCi/L; therefore no treatment is required.

8.2.3.5 Alternative 4—Restoration of Tc-99 (25 years) and Uranium (28 years), and Hydraulic Containment of I-129 Until a Final Remedy is Selected

Alternative 4 uses P&T to extract up to 2,080 L/min (550 gpm) of contaminated groundwater to achieve cleanup levels for Tc-99 and uranium in 25 years and 28 years, respectively, without reliance on MNA. Alternative 4 hydraulically contains the I-129 plume for up to 25 years until a final remedy is selected. ICs prevent exposure and groundwater use until cleanup levels are achieved.

Table 8-5. Alternative 3 Summary

Alternative Description	Alternative Component Summary
Alternative 3: Restoration of Tc-99 (30 years) and Uranium (80 years), and Hydraulic Containment of I-129 Until a Final Remedy is Selected	1. ICs (150 years) a. IC components are the same as described for Alternative 1. 2. P&T of Tc-99 and Uranium Plumes (25 years) a. Tc-99 P&T components of this alternative are the same as presented for Alternative 1. b. Install three uranium extraction wells pumping at 380 L/min (100 gpm) each (1,140 L/min [300 gpm] total). Install three injection wells with capacity to inject 1,140 L/min (300 gpm). c. Install uranium conveyance system (including piping to/from extraction and injection wells, transfer pump stations, and conveyance piping to/from the 200 West Area groundwater treatment facility). 3. Hydraulic Containment of the I-129 plume until a final remedy is selected (25 years) a. Same as Alternative 2. 4. MNA (150 years) a. Same as Alternative 2. 5. Groundwater Treatment (25 years) a. 200-UP-1 OU groundwater, at a flow rate of 1,440 L/min nominal/1,800 L/min maximum (380 gpm nominal/475 gpm maximum), will be treated within the existing layout and unit processes of the 200 West Area groundwater treatment facility for the first 25 years. b. A third treatment train at the 200 West Area groundwater treatment facility may be required to treat 200-UP-1 OU groundwater, due to increased flow rate and COC concentrations. The third treatment train will be housed within the reserve floor space available at the 200 West Area groundwater treatment facility. 6. Remedy Performance Monitoring (25 years for P&T and Hydraulic Containment, 150 years for MNA) a. Remedy performance monitoring components for this alternative are the same as described for Alternative 2. 7. O&M Activities (25 years for P&T and Hydraulic Containment, 150 years for MNA) a. O&M components for this alternative are the same as described for Alternative 2. 8. Site Closeout (year 25 for P&T, year 150 for MNA) a. Abandon 65 monitor wells at end of performance monitoring period for MNA (occurs at year 150). b. D&D groundwater extraction, conveyance, treatment, and injection facilities at end of active pumping period for hydraulic containment (occurs at year 25).

COC = contaminant of concern
D&D = decontamination and decommissioning
IC = institutional control
MNA = monitored natural attenuation
OU = operable unit
O&M = operations and maintenance
P&T = pump-and-treat

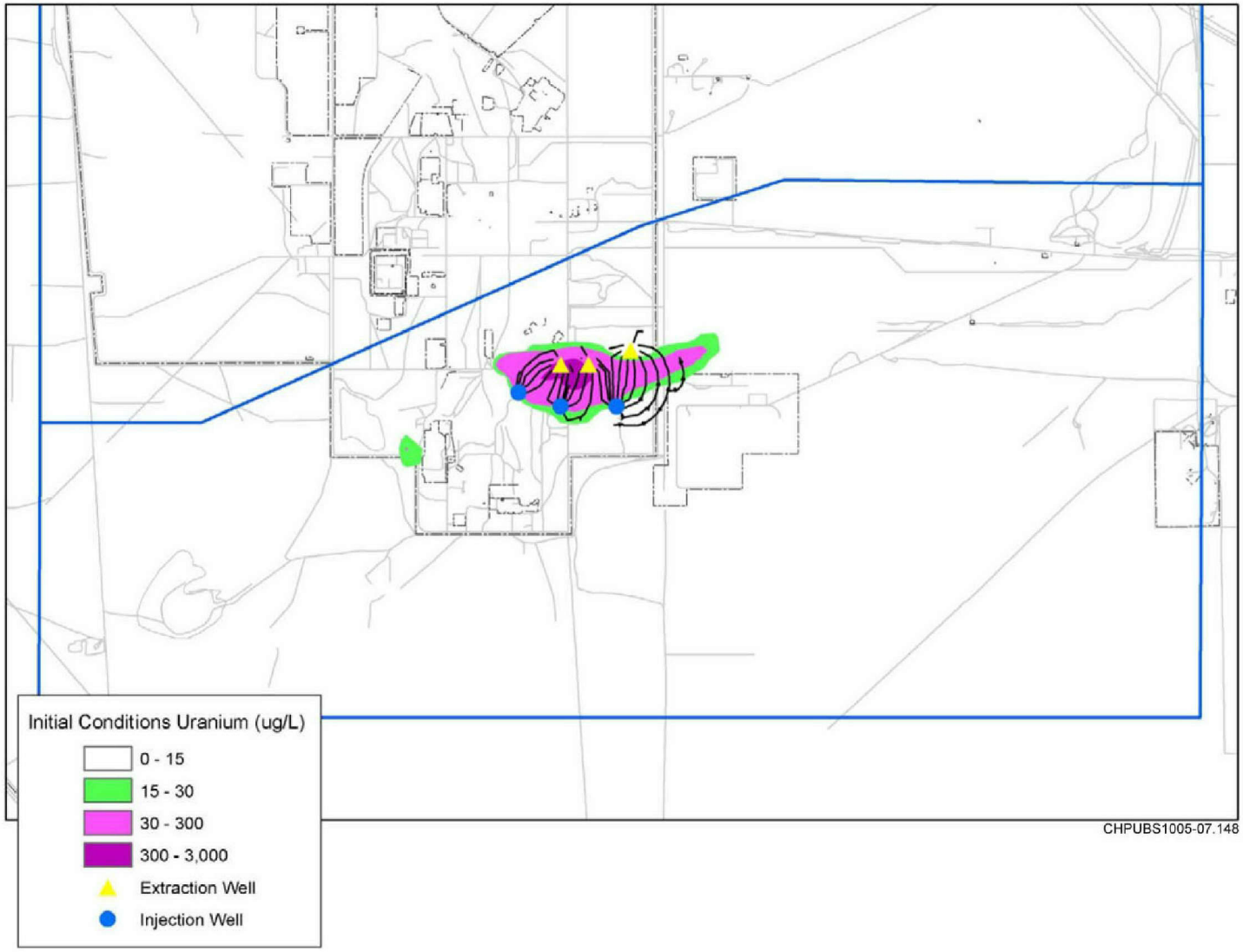

Figure 8-8. Alternative 3—Uranium Extraction and Injection Well Layout and Plume Capture Flowlines

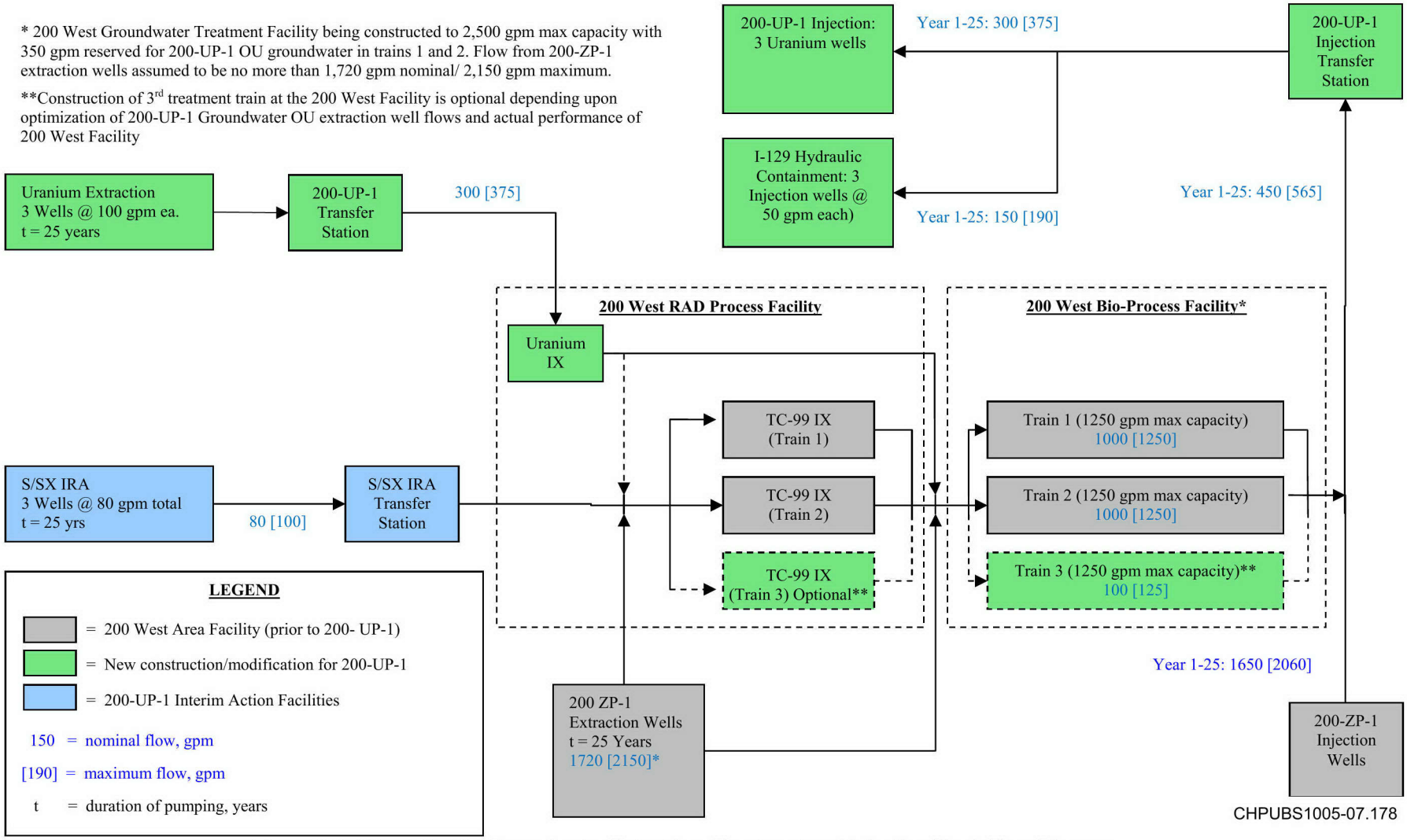

Figure 8-9. Alternative 3—Groundwater Extraction, Treatment and Injection Block Flow Diagram

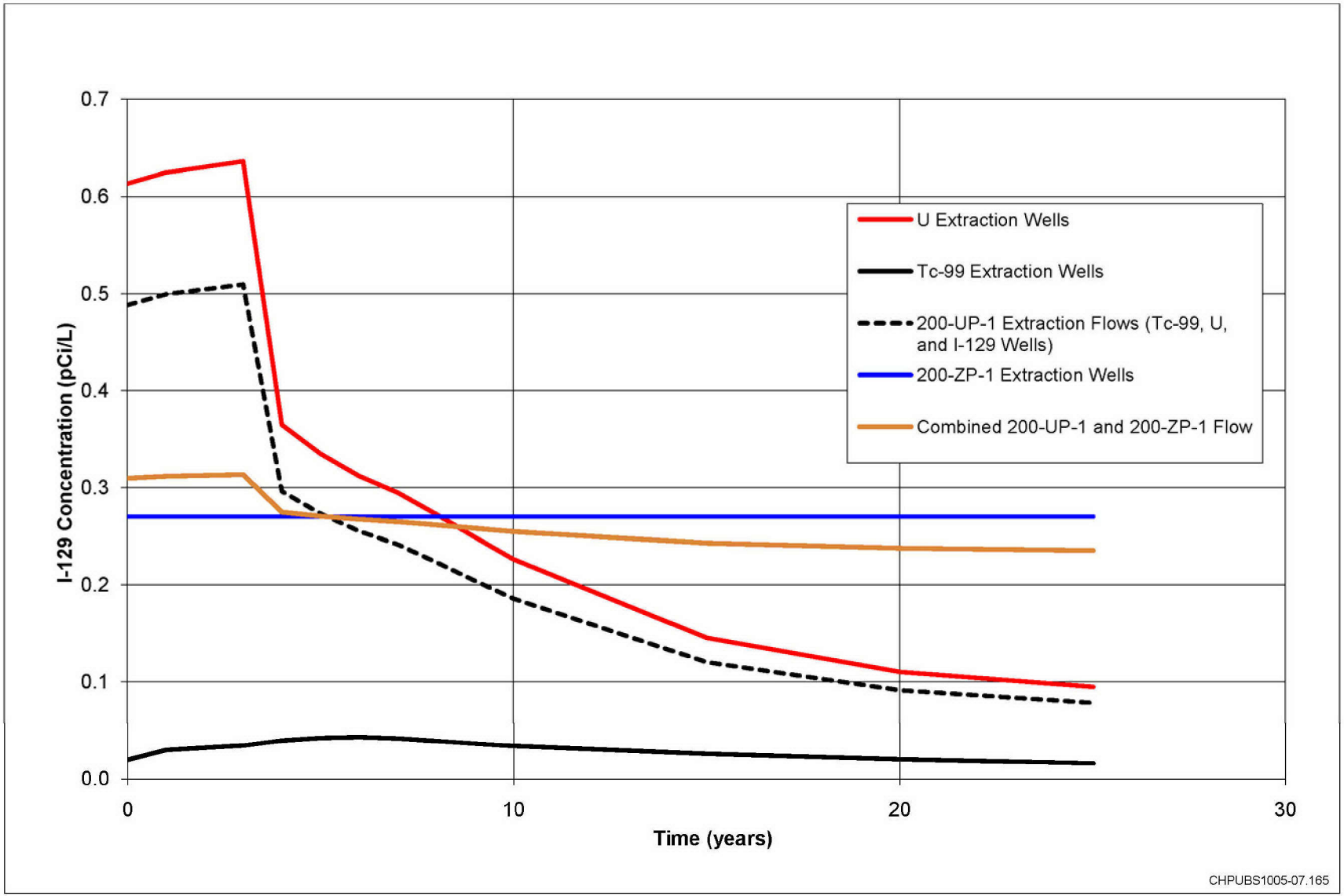

Figure 8-10. Alternative 3—Future I-129 Concentration Projections for Groundwater Extraction Well Flows

Alternative 4 includes the following components (flow rates and durations are approximate):

- ICs (150 years)
- MNA (150 years)
- Groundwater P&T for Tc-99 (five extraction wells, 570 L/min [150 gpm], 25 years)
- Groundwater P&T for uranium (four extraction wells/four injection wells, 1,510 L/min [400 gpm], 28 years)
- Hydraulic containment of I-129 plume (three injection wells, 570 L/min [150 gpm]) until a final remedy is selected; hydraulic containment for a period up to 25 years is assumed
- Groundwater treatment (28 years)
- Performance monitoring (28 years for P&T and 25 years for hydraulic containment, 150 years for MNA)
- Remedy O&M (28 years for P&T, 25 years hydraulic containment, 150 years for MNA)
- Technology evaluation for I-129 (assumed to occur over a period of up to 10 years)

Table 8-6 provides a summary of the proposed activities included for Alternative 4. Figures 8-11 and 8-12 provide the layout of extraction and injection wells for P&T of the Tc-99 and uranium plumes, respectively. Figure 8-13 provides a block diagram for Alternative 4.

Figure 8-14 provides an estimated projection of I-129 concentrations in the extraction wells and following blending with flows from the 200-ZP-1 extraction wells. Based on these projections, I-129 concentrations will be less than 1 pCi/L, and therefore, treatment is not required.

Alternative 4 assumes installation of the third parallel treatment train that has been designed for the 200 West Area groundwater treatment facility. The maximum flow rate of 2,600 L/min (690 gpm) for Alternative 4 exceeds the 1,320 L/min (350 gpm) treatment capacity reserved for 200-UP-1 OU groundwater in the first two treatment trains and requires 1,290 L/min (340 gpm) capacity from the third treatment train. Further evaluation of extraction well influent concentrations, COC loading and flow rates during RD for the 200-UP-1 Groundwater OU will be used to determine the optimum treatment system configuration.

8.3 Remedial Alternatives Screening Evaluation

Each of the remedial alternatives developed in Section 8.2 were screened based on the CERCLA criteria of effectiveness, implementability, and cost prior to being carried forward for detailed and comparative evaluation (Chapter 9).

Effectiveness considers the ability of each RA to achieve RAOs and cleanup levels, implementability focuses on both the technical and administrative feasibility of implementing the alternative, and costs were evaluated in terms of NPV and non-discounted costs.

8.3.1 Effectiveness Screening Results

The groundwater F&T modeling predicts the effectiveness of each alternative in achieving cleanup levels and the timeframe necessary to do so. Based on these results, each of the alternatives has been designed to achieve RAOs within a reasonable timeframe, with the exception of alternatives that rely on MNA only (Alternative 1).

Table 8-6. Alternative 4 Summary

Alternative Description	Alternative Component Summary
Alternative 4: Restoration of Tc-99 (25 years) and Uranium (28 years), and Hydraulic Containment of I-129 Until a Final Remedy is Selected	1. ICs (150 years) a. IC components are the same as presented for Alternative 1. 2. P&T for Tc-99 and Uranium plumes a. Install five Tc-99 extraction wells operating at 110 L/min (30 gpm) each/ 570 L/min (150 gpm) total for restoration of the Tc-99 plumes at the S-SX Area to the cleanup level. Pumping is assumed for 25 years. Three of theTc-99 wells, transfer station, and conveyance piping to the 200 West Area groundwater treatment facility are installed under the IRA that is incorporated into the final remedy. b. Install four uranium extraction wells pumping at 380 L/min (100 gpm) each/1,510 L/min (400 gpm) total. Install four injection wells with capacity to inject 1,510 L/min (400 gpm). Pumping duration is estimated at 28 years to reach the cleanup level. c. Install conveyance system (including piping to/from extraction and injection wells, transfer pump stations, and conveyance piping to/from the 200 West Area groundwater treatment facility). 3. Hydraulic Containment of I-129 plume until a final remedy is selected (25 years) a. Same as listed for Alternative 2. 4. MNA (150 years) a. MNA components are the same as listed for Alternative 2. 5. Groundwater Treatment (28 years) a. 200-UP-1 OU groundwater at a flow rate of 2,080 L/min nominal/2,600 L/min maximum (550 gpm nominal/690 gpm maximum) will be treated at the 200 West Area groundwater treatment facility. b. A third treatment train at the 200 West Area groundwater treatment facility will be constructed to treat 200-UP-1 OU groundwater due to increased flow rate and COC mass loading. The third treatment train will be housed within the reserve floor space available at the 200 West Area groundwater treatment facility. 6. Remedy Performance Monitoring (28 years for P&T and 25 years for Hydraulic Containment) a. Remedy performance monitoring components are the same as listed for Alternative 2. 7. O&M Activities (28 years for P&T, 25 years for Hydraulic Containment, 150 years for MNA) a. O&M components for this alternative are the same as listed for Alternative 2, except as noted. b. Replacement of equipment and renovation of facilities at end of 25-year design life (occurs in year 25).

Table 8-6. Alternative 4 Summary

Alternative Description	Alternative Component Summary
	8. Site Closeout (year 28 for P&T, year 150 for MNA) a. Abandon 65 monitor wells at end of performance monitoring period for MNA (occurs at year 150). b. D&D groundwater extraction, conveyance, treatment and injection facilities at end of active pumping period for P&T (occurs at year 28).

COC	=	contaminant of concern	IRA	=	interim remedial action	O&M	=	operations and maintenance
D&D	=	decontamination and decommissioning	MNA	=	monitored natural attenuation	P&T	=	pump-and-treat
IC	=	institutional control	OU	=	operable unit			

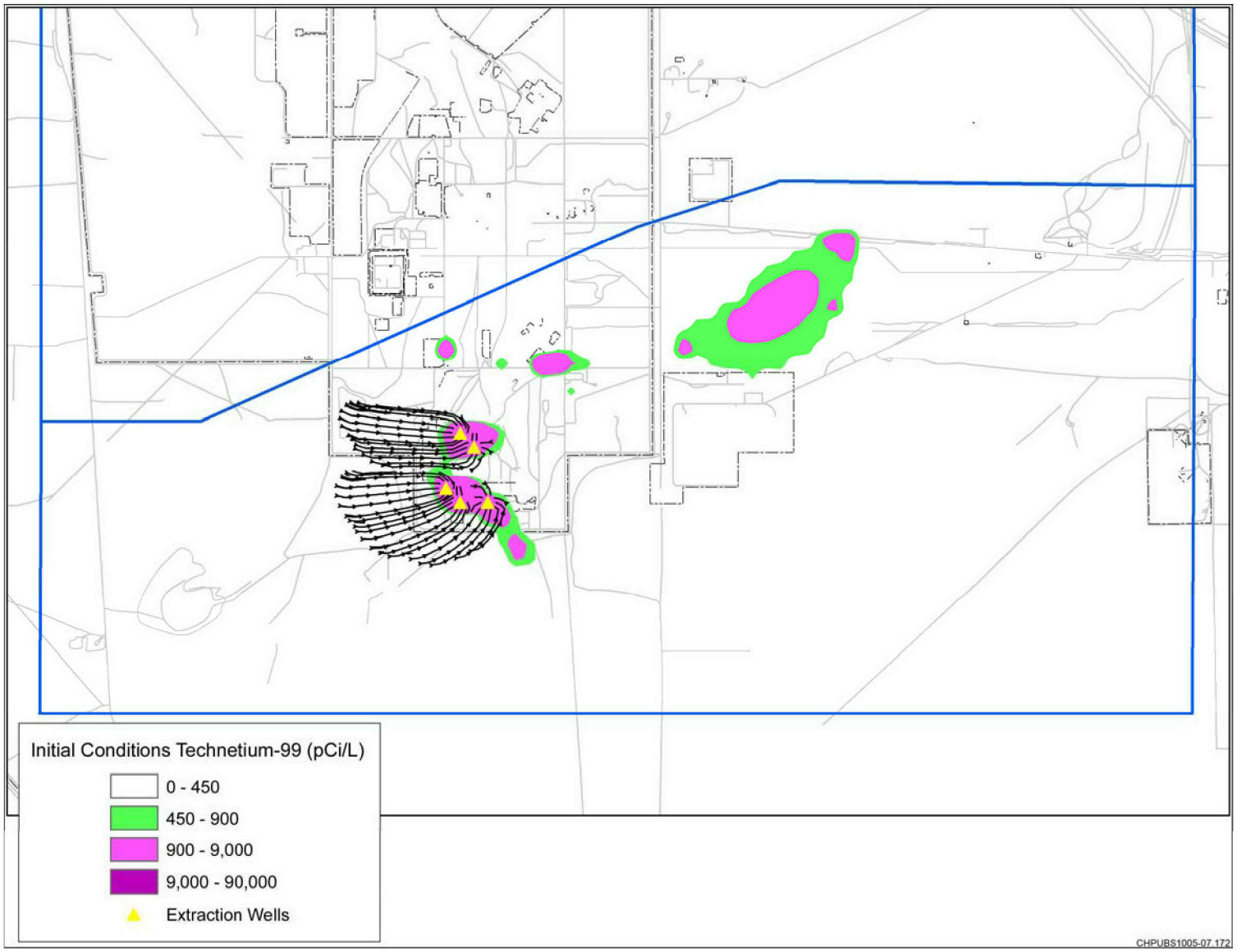

Figure 8-11. Alternative 4—Tc-99 Extraction Well Layout and Plume Capture Flowlines

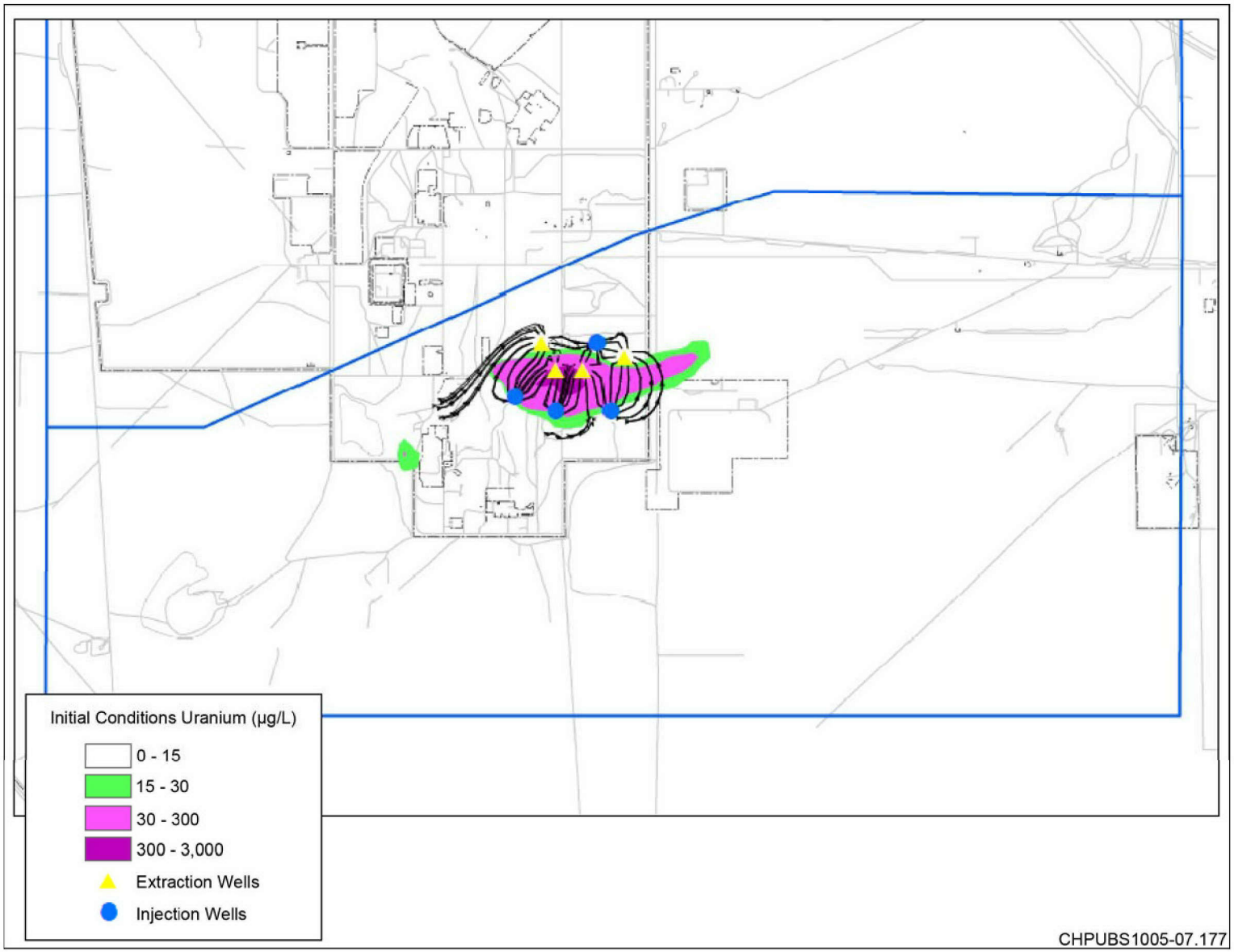

Figure 8-12. Alternative 4—Uranium Extraction and Injection Well Layout and Plume Capture Flowlines

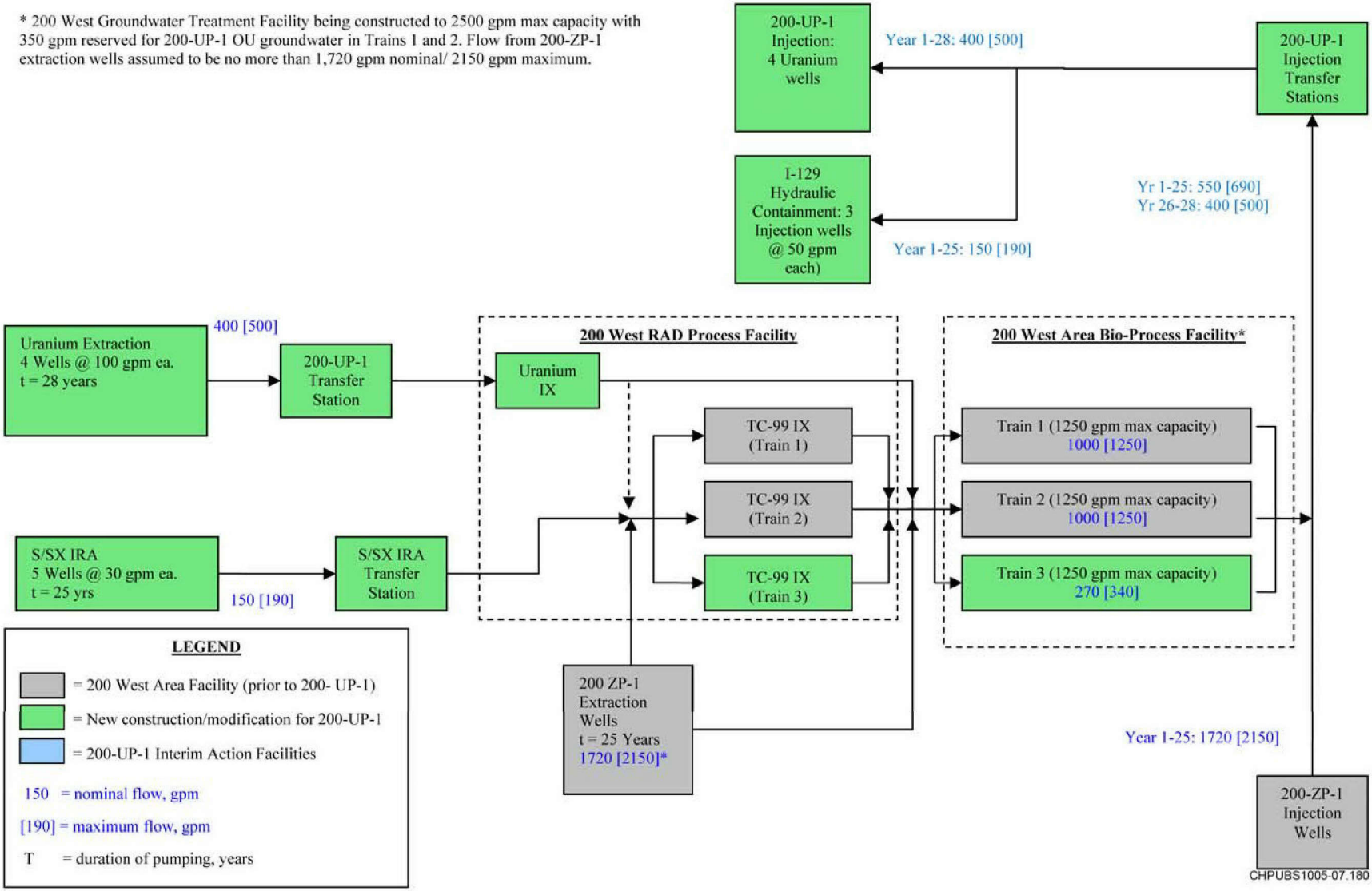

Figure 8-13. Alternative 4—Groundwater Extraction, Treatment and Injection Block Flow Diagram

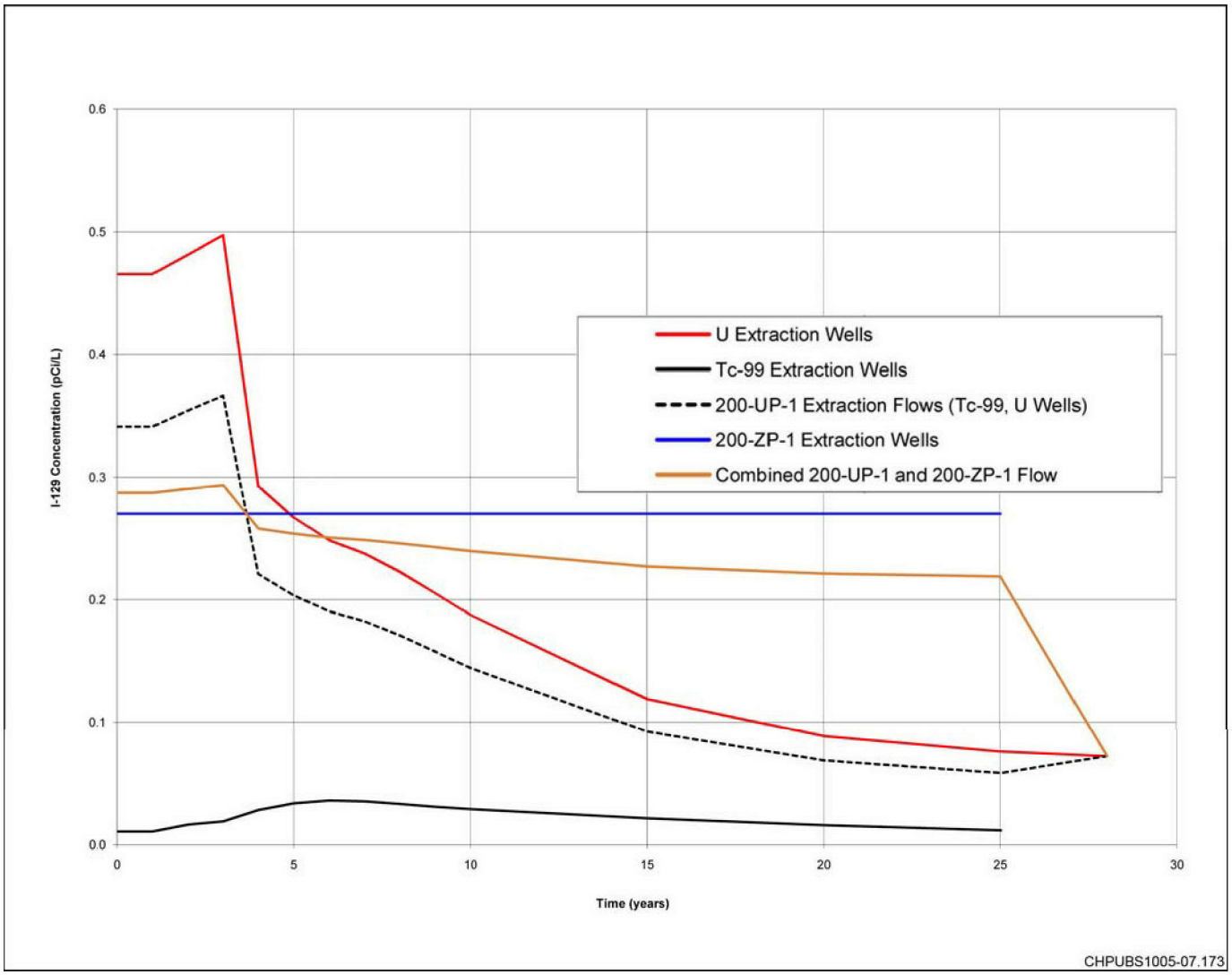

Figure 8-14. Alternative 4—Future I-129 Concentration Projections for Groundwater Extraction Well Flows

The modeling results are expected to be conservative, with actual remedy performance anticipated to result in either less time than predicted to reach cleanup goals, or to require lower flow extraction flow rates than estimated by the model. Another element of conservatism is added because no RPO benefits that may be identified during the RD or RA are incorporated into the assessment. The alternatives are assumed to pump continuously at fixed rates for the entire active pumping period. No credit is taken for enhanced extraction operations that can be achieved through varying the pumping rates over time (to mobilize contaminants out of stagnant hydraulic spots). The effect is that the required pumping durations and expected future concentrations may be lower than the model predicts.

Alternative 1 relies on natural attenuation for all COCs, except Tc-99, where the S-SX IRA will be incorporated into the final remedy. Alternative 1 requires more than 1,000 years to achieve cleanup levels for uranium and I-129. Alternatives 2, 3, and 4 rely on hydraulic containment of the I-129 plume until a final remedy is selected for I-129. As such, these alternatives primarily vary in their effectiveness at reaching cleanup levels for Tc-99 and uranium. Alternatives 2, 3, and 4 achieve cleanup levels within 150 years for all COCs.

Based on the anticipated effectiveness and duration for each alternative to achieve RAOs, and in light of the conservatism built into the modeling, each of the alternatives has been determined to be sufficiently effective to warrant consideration for detailed and comparative analysis, with the exception of Alternative 1, which requires more than 1,000 years to achieve cleanup levels for uranium and I-129.

8.3.2 Implementability Screening

The remedial action alternatives were developed around robust and proven technologies such as hydraulic containment and groundwater P&T. Alternatives employing these technologies do not pose any technical or administrative challenges based on the hydrogeologic conditions and COCs present in the 200-UP-1 Groundwater OU. The primary issue related to the implementability of these alternatives is the treatment of I-129. Currently, effective treatment technologies capable of treating I-129 to the 1 pCi/L DWS are not available

Two scenarios have been included to address this uncertainty. Alternative 1 provides a scenario that allows I-129 to naturally attenuate to the cleanup level. Alternatives 2, 3, and 4 provide a scenario where the I-129 plume is hydraulically contained until the results of the technology evaluation can be used to select a final remedy.

No significant technical issues have been identified for implementation of Alternatives 1, 2, 3, or 4. However, the long RA duration associated with Alternative 1 may make this alternative less implementable from an administrative standpoint (regulatory agency and public acceptance).

8.3.3 Cost Screening

The estimated NPV and non-discounted cost for the five alternatives are as follows:

- No Action: this alternative has a NPV and non-discounted cost of $0.
- Alternative 1: NPV cost estimated at $65 million and non-discounted cost at $1.42 billion.
- Alternative 2: NPV cost estimated at $137 million and non-discounted cost at $367 million.
- Alternative 3: NPV cost estimated at $225 million and non-discounted cost at $485 million.
- Alternative 4: NPV cost estimated at $316 million and non-discounted cost at $641 million.

Exclusive of the No Action Alternative, Alternative 1 represents the lowest NPV cost, but its non-discounted cost is twice that of any other alternative. This is the result of the high O&M costs associated with its 1,000-year duration. The NPV cost range for the remaining alternatives (2, 3, and 4) spans a broad range between $137 million and $316 million.

8.3.4 Remedial Alternative Screening Summary

Based on the preliminary screening of remedial alternatives performed on the basis of effectiveness, implementability, and cost Alternatives 2, 3, and 4 will be carried forward for detailed and comparative evaluation in Chapter 9 of this FS.

Alternative 1 is likely to be effective in achieving cleanup levels, however, it is estimated to take in excess of 1,000 years at a NPV cost of $65 million and a non-discounted cost of $1.42 billion. Alternative 1 is not retained because it is not effective in achieving RAOs within a reasonable timeframe and the cost implications related to the duration of the alternative.

Alternative 2 is predicted to be effective in achieving the cleanup levels for Tc-99 and uranium within approximately 30 years and 150 years, respectively, through P&T and MNA, with I-129 hydraulically contained for 25 years until a final remedy is selected. Cleanup levels for tritium and nitrate are achieved within 150 years using MNA. The NPV present value for Alternative 2 is $137 million. Alternative 2 is retained for detailed and comparative analysis.

Alternative 3 is predicted to be effective in achieving the cleanup levels for Tc-99 and uranium within approximately 30 years and 80 years, respectively, through P&T and MNA. I-129 is hydraulically contained for up to 25 years until a final remedy is selected. Cleanup levels for tritium and nitrate are achieved within 150 years using MNA. The NPV cost for Alternative 3 is $225 million. Alternative 3 is retained as an alternative that restores all COCs to cleanup levels in a reasonable timeframe.

Alternative 4 is predicted to be effective in reducing Tc-99 concentrations below the cleanup level within 25 years, and uranium concentrations below the cleanup level within 28 years through P&T, without relying on MNA. Alternative 4 hydraulically contains the I-129 plume for up to 25 years until a final remedy is selected. Cleanup levels for tritium and nitrate are achieved within 150 years using MNA. At a NPV cost of $316 million Alternative 4 is retained as an alternative that achieves cleanup levels within the shortest timeframe.

9 Detailed Analysis of Alternatives

The remedial alternatives defined in Chapter 8 are evaluated in this chapter using seven of the nine CERCLA criteria described in 40 CFR 300.430(e)(9). The CERCLA evaluation criteria are presented in Section 9.1, and each of the remedial alternatives is evaluated individually and comparatively against the CERCLA criteria in Sections 9.2 and 9.3, respectively. The two remaining criteria, state and community acceptance, are not addressed in this FS and will be evaluated during preparation of the Proposed Plan and in the responsiveness summary contained in the 200-UP-1 Groundwater OU decision document.

The purpose of the detailed and comparative analysis is to develop the information necessary to recommend a preferred alternative in a Proposed Plan.

9.1 Description of CERCLA Evaluation Criteria

This section describes the nine CERCLA evaluation criteria upon which the detailed and comparative evaluation is based. The nine criteria are designed to enable the analysis of each alternative to be performed to address the statutory, technical, and policy considerations necessary to allow for selecting a final remedial alternative. These evaluation criteria (Table 9-1) provide the framework for conducting the detailed analysis of alternatives and selecting an appropriate RA.

The evaluation criteria are divided into three categories (threshold, balancing, and modifying) based on the function of each category in the remedy selection process. The two threshold criteria (overall protection of HHE and compliance with ARARs) represent the statutory requirements that each alternative must satisfy to be eligible for selection. The five balancing criteria (long-term effectiveness and permanence; reduction of toxicity, mobility, and volume [TMV] through treatment; short-term effectiveness; implementability; and cost) represent technical criteria upon which the detailed analysis is primarily based. The third category (state acceptance and community acceptance) represent modifying criteria that are formally assessed during preparation of the Proposed Plan (state acceptance) and following review of public and stakeholder comments (community acceptance) on the Proposed Plan.

Table 9-1. Summary of CERCLA Criteria

Threshold Criteria	
Overall Protection of HHE	Comparison of baseline human health risk estimates with residual risk estimates Comparison of ecological risk estimates with regulatory risk criteria Evaluation of exposure pathways for human and ecological receptors following implementation of the remedial alternative. Draws on assessments conducted under other criteria, especially long-term effectiveness, short-term effectiveness, and ARARs
Compliance with ARARs	Chemical-specific ARARs Action-specific ARARs Location-specific ARARs

Table 9-1. Summary of CERCLA Criteria

Balancing Criteria	
Long-Term Effectiveness and Permanence	Magnitude of residual risk Adequacy and reliability of controls
Reduction of Toxicity, Mobility, and Volume Through Treatment	Treatment processes used and materials treated Volume of material destroyed or treated Degree of expected reduction in TMV Degree to which treatment is irreversible Type and quantity of residuals remaining after treatment
Short-Term Effectiveness	Protection of community during RAs Protection of workers during RAs Environmental impacts Time until RAOs are achieved
Implementability	Ability to construct, operate, and monitor the technology Reliability of the technology Ease of undertaking additional RA, if necessary Ability to monitor the remedy's effectiveness Ability to coordinate and obtain approvals from other agencies Availability of equipment, specialists, technologies, offsite treatment, storage or disposal services, and capacity
Cost	Capital costs Annual O&M costs Periodic costs Total net present value (NPV) of all capital, annual O&M, and periodic costs Total non-discounted cost of all capital, annual O&M, and periodic costs
Modifying Criteria	
State Acceptance	Indicates whether the state concurs with, opposes, or has no comment on the preferred alternative.
Community Acceptance	Assesses the public response to the preferred alternative. Although public comment is an important part of the decision-making process, EPA is required by law to balance community concerns with the above criteria.

ARAR = applicable or relevant and appropriate requirement
CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
EPA = U.S. Environmental Protection Agency
HHE = human health and environment
O&M = operations and maintenance
RA = remedial action
RAO = remedial action objective
TMV = toxicity, mobility, volume

9.1.1 Overall Protection of Human Health and the Environment

Alternatives are assessed to determine whether they can adequately protect HHE, in both the short and long term, from unacceptable risks posed by contaminants. Alternatives are protective by eliminating, reducing, or controlling exposures (40 CFR 300.430[e][2][i]). Overall protection of HHE draws on the assessments of the other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

9.1.2 Applicable or Relevant and Appropriate Requirements

Alternatives are assessed to determine whether they meet ARARs and other requirements, or if a basis exists for invoking one of the waivers cited in 40 CFR 300.430(f)(l)(ii)(C). An ARARs waiver may be granted under the following circumstances.

1. The alternative is an interim measure and will become part of a total RA that will attain ARARs at the completion of the RA.
2. Compliance with the requirement will result in greater risk to HHE than other alternatives.
3. Compliance with the requirement is technically impracticable from an engineering perspective.
4. The alternative will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, or limitation through use of another method or approach.
5. With respect to a state requirement, the state has not consistently applied, or demonstrated the intention to consistently apply, the promulgated requirement in similar circumstances at other sites within the state.

9.1.3 Long-Term Effectiveness and Permanence

Long-term effectiveness and permanence are criteria that evaluate the anticipated ability of an alternative to maintain reliable protection of HHE for the duration of time the risk is above allowable levels. Alternatives are assessed for the long-term effectiveness and permanence that they afford, along with the degree of certainty that the alternative will prove successful in meeting the RAOs. The following factors may be considered in this assessment:

- The magnitude of residual risk from untreated waste or treatment residuals remaining at the conclusion of the RA, including the TMV (final risk assessment).
- The adequacy and reliability of controls such as containment systems and ICs necessary to manage treatment residuals and untreated wastes (for example, this factor addresses uncertainties associated with land disposal for providing long-term protection from treatment residuals; the assessment of the potential need to replace technical components of the alternative such as a treatment system; and the potential exposure pathways and risks posed if the RA needs to be replaced).

9.1.4 Reduction of Toxicity, Mobility, and Volume Through Treatment

The degree to which the alternative employs treatment or recycling that reduces TMV will be assessed, including how the treatment is used to address the principal threats posed by the Site.

The following factors, as appropriate, are considered:

- Treatment or recycling processes that the alternatives employ and the materials that they will treat
- The amount of hazardous substances, pollutants, or contaminants that will be destroyed or recycled

- The degree of expected reduction in TMV of the waste because of the treatment or recycling and the discussion of which reductions are occurring, specifically:
  - The degree to which the treatment is irreversible
  - The type and quantity of residuals that will remain following treatment, taking into consideration the persistence, toxicity, mobility, and propensity of hazardous substances and their constituents to bio-accumulate
  - The degree to which treatment reduces the inherent hazards posed by the principal threats at the Site

9.1.5 Short-Term Effectiveness

Short-term effects during implementation of the RA will be assessed, including the following:

- Short-term risks that might be posed to the community during RA
- Potential risks or hazards to workers, and the effectiveness and reliability of protective measures
- Potential environmental effects and the effectiveness and reliability of mitigating measures
- Time until RAOs are achieved

9.1.6 Implementability

The ease or difficulty of implementing the alternative is assessed by considering the following types of factors, as appropriate:

- Technical feasibility, including the technical difficulties and unknowns associated with constructing and operating the technology, the reliability of the technology, the ease of undertaking additional RAs, and the ability to monitor the effectiveness of the remedy
- Administrative feasibility, including activities required to coordinate with other agencies, and the ability and time needed to obtain from other agencies any necessary approvals and permits for offsite actions
- Availability of required services, personnel, and materials necessary to construct and operate the alternative

9.1.7 Cost

Cost plays an important role in the detailed evaluation of RA alternatives because there is a CERCLA statutory requirement that the remedial alternative selected in a ROD be cost-effective. A RA alternative is cost-effective if its "costs are proportional to its overall effectiveness" (40 CFR 300.430[f][1][ii][D]). The overall effectiveness of a RA alternative is determined by evaluating the following three of the five balancing criteria: long-term effectiveness and permanence; reduction in TMV through treatment; and short-term effectiveness. The Proposed Plan presents the overall effectiveness evaluation.

The cost estimates for each remedial alternative presented in the 200-UP-1 Groundwater OU FS include allowances for capital costs, operation and maintenance (O&M) costs, and periodic costs. Capital costs consist primarily of expenditures incurred to construct the RA (e.g., construction of a groundwater treatment system and related site work). Capital costs also include all labor, equipment, and material costs, including contractor markups such as overhead and profit, associated with mobilization/ demobilization; site work; installation of extraction, containment, or treatment systems; and disposal.

Capital costs also include expenditures for professional/technical services that are necessary to support design and construction of the remedial alternative.

O&M costs are those post-construction costs necessary to support the RA until RAOs are achieved. These costs are estimated mostly on an annual basis. Annual O&M costs include all labor, equipment, and material costs, including contractor markups such as overhead and profit, associated with activities such as monitoring; operating and maintaining extraction, injection, and treatment systems; and waste disposal. Annual O&M costs also include expenditures for professional/technical services necessary to support O&M activities.

Periodic costs are those costs that occur only once every few years (e.g., five-year reviews, equipment replacement, and well rehabilitation and replacement) or expenditures that occur only once during the entire remedial timeframe (decommissioning costs).

The cost estimate for the 200 UP-1 Groundwater OU FS was developed in accordance with EPA/540/R-00/002 and PRC-PRO-EP-40282. The Remedial Action Cost Estimate Requirement (RACER)™ cost estimating software (http://www.fecpractice.com/?p=RACER) was used in conjunction with Microsoft Excel (MS Excel)™ software to develop the cost estimate for each of the RA alternatives.

The cost estimates are based on unit costs derived from RACER and actual pricing information derived from historical experience and standard commercial databases, such as RS Means (Means, 2010a; 2010b; 2010c). The unit costs associated with each one of the quantity estimates may have been factored/adjusted by the estimator and/or FS project team, as appropriate.

The cost estimates contain a breakdown of capital, O&M, and periodic costs, while also providing a total NPV and total non-discounted cost. These latter two cost categories facilitate comparisons between alternatives with different RA timeframes. The NPV cost represents the dollars that would need to be set aside today, at the defined interest rate, to ensure that funds would be available in the future as they are needed to perform the remedial alternative.

NPV costs were estimated using the real discount rate published in Appendix C of the Office of Management and Budget (OMB) Circular No. A-94, effective through January 2010. Programs with durations longer than 30 years use the 30-year interest rate of 2.7 percent. The NPV for all future O&M costs, and periodic costs, is based on the overall RA timeframe and the timeframe when the cost is incurred. NPV costs were calculated by RACER™ 2010, version 10.3 and manually entered into the Microsoft Excel NPV workbook template described further in ECF-200UP1-10-0375.

The cost estimates are for comparison purposes and were prepared to meet the -30 to +50 percent range of accuracy recommended in EPA (EPA/540/G-89/004) CERCLA guidance. The cost estimate details, uncertainties, and supporting information are included in ECE-200UP1-10-00005.

™ Remedial Action Cost Estimate Requirement (RACER)™ is a trademark of AECOM.

™ Microsoft Excel (MS Excel) is a trademark of Microsoft Corporation.

9.1.8 Sustainable Remedial Alternative Evaluation Factors

Although not called out as a specific CERCLA evaluation criterion, there is an increasing emphasis to consider the complete life-cycle impacts of a remedial alternate during the development and detailed evaluation phase. These considerations may include one or more of the following evaluation factors:

- Minimize total energy use and maximize use of renewable energy sources
- Minimize air pollutants and green house gas emissions
- Minimize water use and adverse impacts to water resources
- Reduce, reuse, and recycle material and waste
- Protect land and ecosystems

The sustainable elements of each remedial alternative are discussed in the comparative evaluation of alternatives in Section 9.3.

9.2 Individual Analysis of Alternatives

This section evaluates each of the RA alternatives retained from the screening performed in Chapter 8 against the threshold and balancing CERCLA criteria described in Section 9.1. The modifying criteria will be formally addressed during the Proposed Plan and following receipt of public comments on the Proposed Plan.

The four RA alternatives retained from Chapter 8 include:

- No Action Alternative
- Alternative 2—Restoration of Tc-99 (30 years) and Uranium (150 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected
- Alternative 3—Restoration of Tc-99 (30 years) and Uranium (80 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected
- Alternative 4—Restoration of Tc-99 (25 years) and Uranium (28 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected

Each alternative is analyzed based on current groundwater concentrations and mass inventory.

Another consideration that benefits each of the RA alternatives is the 200-ZP-1 Groundwater OU remedy, which is scheduled to become operational before September 30, 2011. The 200-ZP-1 Groundwater OU remedy includes: 25 years of P&T to reduce carbon tetrachloride concentrations in groundwater to less than 100 μg/L; MNA for an additional 100 years to reduce carbon tetrachloride concentrations from 100 μg/L to the cleanup level of 3.4 μg/L; flow-path controls consisting of treated water injection to prevent contaminant migration; and maintenance of ICs to control land and groundwater use until all cleanup levels are achieved. P&T and MNA of the carbon tetrachloride plume also addresses the other COCs present in the 200-ZP-1 Groundwater OU. Because the 200-ZP-1 Groundwater OU remedy is designed to address carbon tetrachloride throughout the 200 West Area, the detailed evaluation of alternatives presented in this section does not describe how each alternative will perform relative to carbon tetrachloride. The detailed evaluation of alternatives is summarized in Table 9-2 and discussed further in the following subsections.

Table 9-2. Detailed Analysis of Alternatives Summary for the 200-UP-1 Groundwater OU

Alternative	Threshold Criteria		Balancing Criteria				
	1. Overall Protection of Human Health and the Environment?	2. Compliance with ARARs?	1. Long-Term Effectiveness and Permanence	2. Reduction of Toxicity, Mobility, and Volume Through Treatment	3. Short-Term Effectiveness	4. Implementability	5. NPV Cost
No Action Alternative	No. Although this alternative is currently protective of human health, because groundwater is not being used, this alternative does not protect future HHE because it contains no measures to eliminate, reduce, or control exposure or to restore groundwater for future beneficial use.	No. Chemical-specific ARARs not achieved for more than 1,000 years. Compliance with action- and location-specific ARARs achieved because there is no active/intrusive activity.	Poor. Radioactive decay and other natural processes reduce risk over time but at the end of the 1,000-year evaluation period, the maximum uranium (43 µg/L) and I-129 (1.3 pCi/L) still exceed cleanup levels. No controls established to prevent exposure.	Poor. Some toxicity and volume reduction occur through decay of short-lived radionuclides such as tritium. Uranium and long-lived radionuclides such as I-129 persist for more than 1,000 years.	Poor. No short-term effects to community or workers because there is no activity that would allow exposure to occur. Does not pose an implementation risk to workers because no RA construction activities occur. Timeframe to achieve RAOs for all COCs is greater than 1,000 years.	Poor. Easily implemented from a technical standpoint but may not be accepted by the state and community.	$0
Alternative 2—Restoration of Tc-99 (30 years) and Uranium (150 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected	Yes. ICs are maintained until P&T and MNA reduce Tc-99 and uranium concentrations to cleanup levels. Nitrate and tritium are addressed primarily though MNA, while I-129 is hydraulically contained until a final remedy is selected. The environment is protected by preventing expansion of the long-lived COC (Tc-99, uranium, and I-129) plumes and restoring groundwater beneficial use.	Yes. I-129 compliance achieved following selection of final remedy. Depending on the scope of the final remedy for I-129, a waiver for tritium may be required to comply with re-injection standards. Action- and location-specific ARARs are achieved by complying with existing Site processes.	Moderate. Some levels of residual risk may occur because there is a greater reliance on MNA to address uranium once pumping ceases. ICs protect against inadvertent exposure until MNA processes reduce COC concentrations to cleanup levels. Treatment residuals transported to secure facility for long-term management.	Moderate. P&T and MNA reduce TMV for Tc-99 and uranium. Tritium and nitrate toxicity reduction occurs through MNA. I-129 mobility reduced through hydraulic containment until final remedy selected when toxicity and volume reduction will occur. Immobilized treatment residuals transported to secure facility for permanent disposal.	Moderate. Nominal short-term risks to workers during extraction and injection well installation, during routine 200 West Area groundwater treatment facility O&M, and during periodic groundwater sampling events. Risks minimized through HSP and PPE. No adverse risks to community, due to the Site's remote location. Timeframe to achieve RAOs is estimated at 150 years.	Good. Readily implemented with standard construction equipment and methods.	$136,267,000
Alternative 3—Restoration of Tc-99 (30 years) and Uranium (80 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected	Yes. ICs are maintained until P&T and MNA reduce Tc-99 and uranium concentrations to cleanup levels. Nitrate and tritium are addressed primarily though MNA, while I-129 is hydraulically contained until a final remedy is selected. The environment is protected by preventing expansion of the long-lived COC (Tc-99, uranium, and I-129) plumes and restoring groundwater beneficial use.	Yes. I-129 compliance achieved following selection of final remedy. Depending on the scope of the final remedy for I-129, a waiver for tritium may be required to comply with re-injection standards. Action- and location-specific ARARs are achieved by complying with existing Site processes.	Moderate-Good. Greater reliance on P&T and less reliance on MNA to reduce COC concentrations to cleanup levels. ICs protect against inadvertent exposure until cleanup levels are achieved. Treatment residuals transported to secure facility for long-term management.	Moderate-Good. P&T and MNA reduce TMV for Tc-99 and uranium. Less reliance on MNA for TMV reduction. Tritium and nitrate toxicity reduction occur through MNA. I-129 mobility reduced through hydraulic containment until final remedy selected. Immobilized treatment residuals transported to secure facility for permanent disposal.	Moderate. Nominal short-term risks to workers during extraction and injection well construction, during routine 200 West Area groundwater treatment facility system O&M, and periodic groundwater sampling events. Risks minimized through HSP and PPE. No adverse risks to community, due to the Site's remote location. Timeframe to achieve RAOs is estimated at 150 years.	Moderate - Good. Readily implemented with standard construction equipment and methods. May require expansion of 200 West groundwater treatment system.	$225,078,000
Alternative 4—Restoration of Tc-99 (25 years) and Uranium (28 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected	Yes. ICs are maintained until P&T reduces Tc-99 and uranium concentrations to cleanup levels. Nitrate and tritium are addressed primarily though MNA, while I-129 is hydraulically contained until a final remedy is selected. The environment is protected by preventing expansion of the long-lived COC (Tc-99, uranium, and I-129) plumes and restoring groundwater beneficial use.	Yes. I-129 compliance achieved following selection of final remedy. Depending on the scope of the final remedy for I-129, a waiver for tritium may be required to comply with re-injection standards. Action- and location-specific ARARs are achieved by complying with existing Site processes.	Good. No reliance on MNA to achieve Tc-99 and uranium cleanup levels following cessation of P&T. MNA used to address three low-level Tc-99 plumes, nitrate, and tritium. Treatment residuals transported to secure facility for long-term management.	Good. P&T reduces TMV for Tc-99 and uranium. No reliance on MNA for TMV reduction. Tritium and nitrate toxicity reduction occurs through MNA. I-129 mobility reduced through hydraulic containment until a final remedy selected. Immobilized treatment residuals transported to secure facility for permanent disposal.	Moderate. Nominal short-term risks to workers during extraction well and conveyance piping construction, during routine 200 West Area groundwater treatment facility system O&M, and during periodic groundwater sampling events. Risks minimized through HSP and PPE. No adverse risks to community, due to the Site's remote location. Timeframe to achieve RAOs is estimated at 150 years.	Moderate. Readily implemented with standard construction equipment and methods. Requires expansion of 200 West groundwater treatment system.	$316,363,000

Table 9-2. Detailed Analysis of Alternatives Summary for the 200-UP-1 Groundwater OU

Alternative	Threshold Criteria		Balancing Criteria				
	1. Overall Protection of Human Health and the Environment?	2. Compliance with ARARs?	1. Long-Term Effectiveness and Permanence	2. Reduction of Toxicity, Mobility, and Volume Through Treatment	3. Short-Term Effectiveness	4. Implementability	5. NPV Cost

ARAR = applicable or relevant and appropriate requirement
COC = contaminant of concern
HHE = human health and the environment
HSP = health and safety plan
IC = institutional control
MNA = monitored natural attenuation
NPV = net present value
O&M = operations and maintenance
OU = operable unit
P&T = pump-and-treat
PPE = personal protective equipment
RA = remedial action
RAO = remedial action objective
TMV = toxicity, mobility, volume

9.2.1 No Action Alternative

Under 40 CFR 340.430(e)(6), a No Action Alternative is included in the FS to provide a baseline for comparison against the other alternatives. Under this alternative, no further (additional) action would be taken for the 200-UP-1 Groundwater OU. The existing P&T IRA at U Plant, and a planned P&T IRA at the S-SX Tank Farm would continue to operate until the ROD Amendment[1] is signed. The costs for termination and decommissioning of the P&T systems would be borne by the IRA project.

The 200-UP-1 Groundwater OU interim action ROD required DOE to implement an array of ICs to limit land use in the 200 Areas to industrial, implement administrative measures to restrict drilling and groundwater use, and implement controls (security, badges, fences, signs, excavation permits, and WIDS) to prevent inadvertent exposure. These ICs would be lifted under the No Action Alternative. Radioactive decay and other natural processes would reduce COC concentrations in groundwater over time.

9.2.1.1 Overall Protection of Human Health and the Environment

Because 200-UP-1 OU groundwater is not being used, the No Action Alternative is currently protective of human health. However, the No Action Alternative is not protective of future HHE, because uranium and I-129 concentrations will exceed their respective cleanup levels for more than 1,000 years. Maximum projected Tc-99 concentrations drop below their 900 pCi/L cleanup level in approximately 75 years. The concentrations for the remaining COCs decline below their respective cleanup levels within 50 years for tritium and 175 years for nitrate (Table 9-3).

Table 9-3. Future Projected COC Concentrations and Cleanup Timeframe for No Action Alternative

COC	Drinking Water Standard (µg/L or pCi/L)	Current 90th Percentile Concentration (µg/L or pCi/L)	200-UP-1 Ground-water OU Cleanup Level	Concentration (µg/L or pCi/L) and Year When Future Projected Concentration Declines Below Cleanup Level			
				90th Percentile	Year	Maximum	Year
I-129	1	3.5	1	0.6	2409	1.3	3009
Uranium	30	206	30	25	2609	43	3009
Nitrate	45,000	133,000	45,000	37,363	2084	43,481	2184
Tc-99	900	4,150	900	688	2034	655	2084
Tritium	20,000	51,150	20,000	3,684	2059	19,313	2059

COC = contaminant of concern
OU = operable unit

9.2.1.2 Compliance with ARARs

Chemical-specific ARARs. The No Action Alternative does not comply with chemical-specific (DWS) ARARs for all COCs for protection of HHE for more than 1,000 years based on the maximum projected concentrations.

Location-specific ARARs. There is no activity within the scope of this alternative that would disturb the ground surface within the 200-UP-1 Groundwater OU boundary. Therefore, the No Action

[1] The remedy decision for the 200-UP-1 Groundwater OU will be performed by issuing an amendment to the 200-ZP-1 Groundwater OU ROD.

Alternative complies with location-specific ARARs associated with preservation of archaeological or historical data, protection of historic properties, and protection of Native American and archaeological sites.

Action-specific ARARs. The No Action Alternative complies with action-specific ARARs because there is no activity within the scope of this alternative.

9.2.1.3 Long-Term Effectiveness and Permanence

This criterion relates to the health risks that remain at the Site from untreated waste or treatment residuals at the conclusion of remedial activities, the certainty that the alternative will prove successful, and the adequacy and reliability of controls required to manage treatment residuals and untreated groundwater.

Magnitude of Residual Risk. Under the No Action Alternative, no active measures are taken to control exposure pathways or to reduce COC concentrations in groundwater. However, radioactive decay and other natural processes reduce COC concentrations in situ, and given adequate time (more than 1,000 years), this alternative reduces concentrations to levels that are protective of HHE. At the end of the 1,000-year simulation period, the maximum projected I-129 concentration is 1.3 pCi/L and the maximum projected uranium concentration is 43 μg/L. The concentrations for the remaining COCs decline below cleanup levels with 175 years.

Adequacy and Reliability of Controls. The No Action Alternative contains no provisions for controls to prevent exposure. Therefore, this analysis factor does not apply.

9.2.1.4 Reduction of Toxicity, Mobility, and Volume Through Treatment

The No Action Alternative does not employ active treatment technology. However, some toxicity and volume reduction occur through radioactive decay, a well-understood process that is based on the known half-lives for each individual radionuclide. Radioactive decay is an important toxicity and volume reduction process for tritium (12.3 years), but due to the long half-life for I-129 (15.3 million years) and Tc-99 (211,000 years), radioactive decay is an insignificant process for these two constituents. Other naturally occurring processes within the 200-UP-1 Groundwater OU reduce the toxicity and volume of nitrate-contaminated groundwater within about 175 years, and uranium in about 1,000 years.

The No Action Alternative provides no reduction in mobility for any of the COCs and they will continue to migrate under the influence of the natural groundwater flow gradient to the east-northeast toward the 200-PO-1 Groundwater OU.

9.2.1.5 Short-Term Effectiveness

This criterion addresses the effects of the alternative to the community, RA workers, and the environment during the construction and implementation phase, and the timeframe required before RAOs are met. Because there is no activity associated with the No Action Alternative, there are no short-term effects to the community or to RA workers. RAOs will not be achieved for more than 1,000 years.

9.2.1.6 Implementability

This criterion addresses the technical and administrative feasibility of implementing the RA alternative, and the availability of various services and materials required during its implementation. Because the No Action Alternative does not include implementation of any remedial activities at the Site, the technical feasibility of this criterion is not applicable. From an administrative feasibility perspective, this alternative may not be implementable from a regulatory agency standpoint.

9.2.1.7 Cost

There are no costs associated with the No Action Alternative.

9.2.2 Alternative 2—Restoration of Tc-99 (30 years) and Uranium (150 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected

The primary components of this alternative include:

- P&T and MNA restoration of the Tc-99 plumes. Three groundwater extraction wells installed under the IRA within the two S-SX plumes would continue to be pumped at estimated rates of 114 L/min (30 gpm) each, while the third well is pumped at an estimated rate of 76 L/min (20 gpm). The total nominal pumping rate for all three wells is estimated at 303 L/min (80 gpm). The pumping duration is estimated at 25 years. Approximately 5 years of MNA would be required following termination of P&T operations before the Tc-99 cleanup level of 900 pCi/L is achieved within the S-SX plumes. MNA is used to address the three other Tc-99 plumes present in the 200-UP-1 Groundwater OU.
- P&T and MNA restoration of the uranium plume. Two groundwater extraction wells would be installed and pumped at estimated rates of 380 L/min (100 gpm) each for 25 years. The total nominal pumping rate for the two wells is estimated at 760 L/min (200 gpm). Approximately 125 years of MNA are necessary following termination of P&T operations before the uranium cleanup level of 30 μg/L is achieved. Pumping from the uranium plume also co-extracts a high-concentration portion of the nitrate plume.
- Hydraulic containment of the I-129 plume. Three injection wells would be placed near the leading edge of the I-129 plume and treated water from the 200 West Area groundwater treatment facility injected at estimated rates of 190 L/min (50 gpm) each. The total injection rate is estimated at 570 L/min (150 gpm). Hydraulic containment would continue until a final remedy for I-129 is selected.
- MNA restoration of the nitrate and tritium plumes. Periodic groundwater monitoring would be performed at 50 existing and 15 new monitor well locations for up to 150 years to confirm that concentrations are declining in accordance with expectations. The monitoring and data evaluation results would be documented in periodic progress reports.
- Maintenance of ICs to control land and groundwater use until RAOs are achieved.

Groundwater from the five extraction wells would be pumped to a transfer building and then to the 200 West Area groundwater treatment facility for treatment in the existing Train 1/Train 2 systems.

9.2.2.1 Overall Protection of Human Health and the Environment

Alternative 2 protects human health by maintaining ICs to prevent exposure to contaminated groundwater until cleanup levels are achieved. Alternative 2 protects the environment by reducing Tc-99 and uranium concentrations to cleanup levels, preventing expansion of the I-129 plume until a final remedy is selected, and relying on MNA to reduce nitrate and tritium concentrations; thus restoring groundwater beneficial use within the 200-UP-1 Groundwater OU unconfined aquifer.

9.2.2.2 Compliance with ARARs

Chemical-specific ARARs. Alternative 2 achieves cleanup levels within the aquifer for each COC. Treatment of extracted groundwater ensures compliance with re-injection ARARs. Compliance with the I-129 1 pCi/L ARAR occurs following selection of a final remedy. Depending on the scope of the I-129 final remedy, an ARARs waiver for re-injection of tritium-contaminated groundwater may be necessary because there is no recognized treatment technology for this constituent. The Tc-99 and uranium

extraction wells are located outside the footprint of the tritium plume (as defined by the 20,000 pCi/L DWS), so this waiver is not necessary until the scope of the final I-129 remedy is known.

Location-specific ARARs. All new monitor and extraction well installations and periodic groundwater monitoring activities would be conducted so as to minimize disturbance of the ground surface within the 200-UP-1 Groundwater OU boundary in accordance with cultural resource survey findings. All groundwater treatment would be performed using the 200 West Area groundwater treatment facility. Therefore, this alternative complies with location-specific ARARs associated with preservation of archaeological or historical data, protection of historic properties, and protection of Native American and archaeological sites.

Action-specific ARARs. Alternative 2 complies with action-specific ARARs through worker protection programs, adherence to existing remediation waste management programs, and air emission requirements. Alternative 2 would comply with well decommissioning regulations during periodic well replacement events and at the conclusion of the RA when all wells would be decommissioned in accordance with WAC standards. All new treatment facility operation, waste management, and decommissioning practices under Alternative 2 would be performed in accordance with action-specific ARARs.

9.2.2.3 Long-Term Effectiveness and Permanence

This criterion relates to the health risks that remain from untreated waste or treatment residuals at the conclusion of remedial activities, and the adequacy and reliability of controls required to manage treatment residuals and untreated groundwater.

Magnitude of Residual Risk. Under Alternative 2, cleanup levels are achieved for each COC, therefore, the magnitude of residual risk present in the aquifer at the completion of the RA will fall within the CERCLA risk range and meet the MTCA acceptable risk level. Under this alternative, all treatment residuals are disposed at ERDF. Because EDRF has been specifically designed to provide for long-term management of hazardous materials, treatment residuals should not pose a risk to HHE in the future. The ICs implemented under this alternative will prevent exposure to contaminated groundwater until cleanup levels are achieved.

Adequacy and Reliability of Controls. Under Alternative 2, existing ICs are used to protect against inadvertent exposure until cleanup levels are achieved. The adequacy and reliability of ICs is expected to be very good at the Hanford Site because the measures are comprehensive, with enough redundancy to ensure that protectiveness is maintained even if one measure fails. Placement of groundwater treatment residuals within ERDF provides a high level of assurance that treatment residuals are safely managed long-term.

9.2.2.4 Reduction of Toxicity, Mobility, and Volume Through Treatment

Alternative 2 achieves TMV reduction for Tc-99 and uranium within the aquifer through above ground treatment and MNA, while preventing expansion (mobility) of the I-129 plume until a final remedy is selected. A reduction in the toxicity and volume of the nitrate and tritium plumes occurs through MNA. All above ground treatment is performed in the 200 West Area groundwater treatment facility.

9.2.2.5 Short-Term Effectiveness

This criterion addresses the effects of the alternative to the community, RA workers, and the environment during the construction and implementation phase, and the timeframe required before RAOs are met. Under Alternative 2, some short-term risks to RA construction workers may arise during well installation, transfer building construction, and treatment system O&M activities. However, this work would be

performed by experienced workers using well-established Hanford Site work and safety processes. The timeframe until RAOs are achieved is estimated at 150 years.

9.2.2.6 Implementability

Alternative 2 is readily implemented and would not pose significant technical or administrative difficulties. Because Alternative 2 utilizes existing capacity within the 200 West Area groundwater treatment facility, no expansion of this facility is required. This attribute improves the implementability of Alternative 2. Many of the activities contained within this alternative, such as groundwater monitoring and data evaluation, and maintenance of ICs, are already being performed on a routine basis at the Hanford Site. Additionally, many of the work processes used for design, construction, and operation of the 200-UP-1 Groundwater OU IRAs and final design of the 200-ZP-1 Groundwater OU remedy would be used to implement Alternative 2.

9.2.2.7 Cost

The total estimated present value cost for Alternative 2 is $137,267,000. This cost includes a capital cost of $23,424,000. The total non-discounted cost for Alternative 2, which includes all capital, O&M, and periodic costs, is estimated at $366,856,000.

9.2.3 Alternative 3—Restoration of Tc-99 (30 years) and Uranium (80 years) to Cleanup Levels and Hydraulic Containment of I-129 until a Final Remedy is Selected

The primary components of this alternative include:

- P&T and MNA restoration of the Tc-99 plumes. Three groundwater extraction wells installed under the IRA within the two S-SX plumes would continue to be pumped at estimated rates of 114 L/min (30 gpm) each and the third at an estimated rate of 76 L/min (20 gpm). The total nominal pumping rate is estimated at 303 L/min (80 gpm). The pumping duration is estimated at 25 years. Approximately 5 years of MNA would be required following cessation of P&T operations before the 900 pCi/L cleanup level is achieved within the S-SX plumes. MNA is used to address the three other Tc-99 plumes present in the 200-UP-1 Groundwater OU.

- P&T and MNA restoration of the uranium plume. Three groundwater extraction wells would be installed and pumped at estimated rates of 380 L/min (100 gpm) each for 25 years. The total nominal pumping rate for all three wells is estimated as 1,140 L/min (300 gpm). Approximately 55 years of MNA are required following termination of P&T operations before the uranium cleanup level of 30 μg/L is achieved. Pumping from the uranium plume also co-extracts a high-concentration portion of the nitrate plume.

- Hydraulic containment of the I-129 plume. Three injection wells would be placed near the leading edge of the I-129 plume and treated water from the 200 West Area groundwater treatment facility will be injected at estimated rates of 190 L/min (50 gpm) each. The total injection rate is estimated at 570 L/min (150 gpm). Hydraulic containment would continue until a final remedy for I-129 is selected.

- MNA restoration of the nitrate and tritium plumes. Periodic groundwater monitoring would be performed at 50 existing and 15 new monitor well locations for up to 150 years to confirm that concentrations are declining in accordance with expectations. The monitoring and data evaluation results would be documented in periodic progress reports.

- Maintenance of ICs to control land and groundwater use until RAOs are achieved.

Groundwater from the six extraction wells would be pumped to a transfer building and then to the 200 West Area groundwater treatment facility for treatment in the existing Train 1/Train 2 system, or in a new Train 3 system. The need for the new Train 3 system will be determined during RD when more detailed information on actual/projected groundwater extraction well flow rates is known.

9.2.3.1 Overall Protection of Human Health and the Environment

Alternative 3 protects human health by maintaining ICs to prevent exposure to contaminated groundwater until cleanup levels are achieved. Alternative 3 protects the environment by reducing Tc-99 and uranium concentrations to cleanup levels, preventing expansion of the I-129 plume until a final remedy is selected, and relying on MNA to reduce nitrate and tritium concentrations; thus restoring groundwater beneficial use within the 200-UP-1 Groundwater OU unconfined aquifer.

9.2.3.2 Compliance with ARARs

Chemical-specific ARARs. Alternative 3 achieves cleanup levels for each COC within the aquifer. Treatment of extracted groundwater ensures compliance with re-injection ARARs. Compliance with the I-129 1 pCi/L ARAR occurs following selection of the final remedy. Depending on the scope of the I-129 final remedy, an ARARs waiver for re-injection of tritium-contaminated groundwater may be necessary because there is no recognized treatment technology for this constituent. The Tc-99 and uranium extraction wells are located outside the footprint of the tritium plume (as defined by the 20,000 pCi/L DWS), so this waiver is not necessary until the scope of the final I-129 remedy is known.

Location-specific ARARs. All new monitor and extraction well installations and periodic groundwater monitoring activities would be conducted so as to minimize disturbance of the ground surface within the 200-UP-1 Groundwater OU boundary. All groundwater treatment would be performed using the 200 West Area groundwater treatment facility. Therefore, this alternative complies with location-specific ARARs associated with preservation of archaeological or historical data, protection of historic properties, and protection of Native American and archaeological sites.

Action-specific ARARs. Alternative 3 complies with action-specific ARARs through worker protection programs, adherence to existing remediation waste management programs, and compliance with air emission regulations. This alternative would comply with well decommissioning regulations during periodic replacement and at the conclusion of the RA when the wells would be decommissioned in accordance with WAC standards. All groundwater treatment would be performed in accordance with action-specific ARARs as described in DOE/RL-2009-122.

9.2.3.3 Long-Term Effectiveness and Permanence

This criterion relates to the health risks that remain from untreated waste or treatment residuals at the conclusion of remedial activities, and the adequacy and reliability of controls required to manage treatment residuals and untreated groundwater.

Magnitude of Residual Risk. Under Alternative 3, cleanup levels are achieved for each COC, therefore, the magnitude of residual risk present in the aquifer at the completion of the RA will fall within the CERCLA risk range and meet the MTCA acceptable risk level. Under this alternative, all treatment residuals are disposed at ERDF. Because EDRF has been specifically designed to provide for long-term management of hazardous materials, treatment residuals should not pose a risk to HHE in the future. The ICs implemented under this alternative will prevent exposure to contaminated groundwater until cleanup levels are achieved.

P&T plays a greater role in achieving cleanup levels for Tc-99 and uranium which, in turn, lessens reliance on MNA. Therefore, under this alternative, there is greater certainty that at the conclusion of the RA, acceptable risk levels will be achieved for these two COCs.

Adequacy and Reliability of Controls. Under Alternative 3, existing ICs are used to protect against exposure until COC concentrations are reduced to cleanup levels. The adequacy and reliability of ICs is expected to be very good at the Hanford Site because the measures are comprehensive, with enough redundancy to ensure that protectiveness is maintained even if one measure fails. Placement of groundwater treatment residuals within ERDF provides a high level of assurance that treatment residuals are safely managed long-term.

9.2.3.4 Reduction of Toxicity, Mobility, and Volume Through Treatment

Alternative 3 achieves TMV reduction for Tc-99 and uranium within the aquifer through above ground treatment of extracted groundwater and MNA while preventing expansion (mobility) of the I-129 plume until a final remedy is selected. A reduction in the toxicity and volume of the nitrate and tritium plumes occurs through MNA. All above ground treatment is performed in the 200 West Area groundwater treatment facility, Because Alternative 3 employs a higher pumping rate for the uranium plume, a larger portion of the TMV reduction occurs through active treatment.

9.2.3.5 Short-Term Effectiveness

This criterion addresses the effects of the alternative to the community, RA workers, and the environment during the construction and implementation phase, and the timeframe required before RAOs are met. Under Alternative 3, some short-term risks to RA construction workers may arise during well installation, transfer building construction, and treatment system O&M activities. However, this work would be performed by experienced workers using well-established Hanford Site work and safety processes. The timeframe until RAOs are achieved is estimated at 150 years.

9.2.3.6 Implementability

Alternative 3 is readily implemented and would not pose significant technical or administrative difficulties. However, this alternative may require expansion of the 200 West Area groundwater treatment facility, which could make this alternative more difficult to implement. Many of the activities contained within this alternative, such as groundwater monitoring and data evaluation, and maintenance of ICs, are already being performed on a routine basis at the Hanford Site. Additionally, many of the work processes used for design, construction, and operation of the 200-UP-1 Groundwater OU IRAs and final design of the 200-ZP-1 Groundwater OU remedy would be used to implement Alternative 3.

9.2.3.7 Cost

The total estimated NPV cost for Alternative 3 is $225,078,000. This includes a capital cost of $81,450,000. The total non-discounted cost for Alternative 3, which includes all capital, O&M, and periodic costs is estimated at $484,709,000.

9.2.4 Alternative 4—Restoration of Tc-99 (25 years), Uranium (28 years), and Hydraulic Containment of I-129 until a final remedy is Selected

The primary components of this alternative include:

- P&T restoration of the Tc-99 plumes. Two additional groundwater extraction wells would be installed to complement the three wells installed under the IRA to address the two S-SX plumes. All five wells would be pumped at estimated rates of 114 L/min (30 gpm) each for 25 years until the 900 pCi/L cleanup level is achieved. The total nominal pumping rate is estimated 570 L/min (150 gpm). No MNA following cessation of P&T operations is required under this alternative for the S-SX plumes.

However, MNA is used to address the three other Tc-99 plumes present in the 200-UP-1 Groundwater OU.

- P&T restoration of the uranium plume. Four groundwater extraction wells would be installed and pumped at rates of 380 L/min (100 gpm) each for 28 years. The total nominal pumping rate for all four wells is 1,520 L/min (400 gpm). No MNA is required following termination of P&T operations. Pumping from the uranium plume also co-extracts a high-concentration portion of the nitrate plume.
- Hydraulic containment of the I-129 plume. Three injection wells would be placed near the leading edge of the I-129 plume and treated water from the 200 West Area groundwater treatment facility injected at rates of 190 L/min (50 gpm) each until a final remedy is selected. The total injection rate is 570 L/min (150 gpm).
- MNA restoration of the nitrate and tritium plumes. Periodic groundwater monitoring would be performed at 50 existing and 15 new monitor well locations for up to 150 years to confirm that COC concentrations are declining in accordance with expectations. The monitoring and data evaluation results would be documented in periodic progress reports.
- Maintenance of ICs to control land and groundwater use until RAOs are achieved.

Groundwater from all nine extraction wells would be pumped to a transfer building and then to a new Train 3 system installed within the existing 200 West Area groundwater treatment facility building.

9.2.4.1 Overall Protection of Human Health and the Environment

Alternative 4 protects human health by maintaining ICs to prevent exposure to contaminated groundwater until cleanup levels are achieved. Alternative 4 protects the environment by reducing Tc-99 and uranium concentrations to cleanup levels, preventing expansion of the I-129 plume until a final remedy is selected, and relying on MNA to reduce nitrate and tritium concentrations; thus restoring groundwater beneficial use within the 200-UP-1 Groundwater OU unconfined aquifer.

9.2.4.2 Compliance with ARARs

Chemical-specific ARARs. Alternative 4 achieves cleanup levels within the aquifer for each COC. Treatment of extracted groundwater ensures compliance with re-injection ARARs. Compliance with the I-129 1 pCi/L ARAR occurs following selection of a final remedy. Depending on the scope of the I-129 final remedy, an ARARs waiver for re-injection of tritium-contaminated groundwater may be necessary because there is no recognized treatment technology for this constituent. The Tc-99 and uranium extraction wells are located outside the footprint of the tritium plume (as defined by the 20,000 pCi/L DWS), so this waiver is not necessary until the scope of the final I-129 remedy is known.

Location-specific ARARs. All new monitor and extraction well installations and periodic groundwater monitoring activities would be conducted so as to minimize disturbance of the ground surface within the 200-UP-1 Groundwater OU boundary. All construction of new treatment facilities under Alternative 4 would be performed within the footprint of the existing facilities. Therefore, this alternative complies with location-specific ARARs associated with preservation of archaeological or historical data, protection of historic properties, and protection of Native American and archaeological sites.

Action-specific ARARs. Alternative 4 complies with action-specific ARARs through worker protection programs, adherence to existing IDW and remediation waste management processes, and compliance with air emission regulations. Alternative 4 complies with well decommissioning regulations during periodic well replacement events and at the conclusion of the RA when all wells would be decommissioned in accordance with WAC standards. All new treatment facility operation, waste management, and

decommissioning practices under this alternative would be performed in accordance with the action-specific ARARs as described in DOE/RL-2009-122.

9.2.4.3 Long-Term Effectiveness and Permanence

This criterion relates to the health risks that remain at the Site once RAOs are met, and the adequacy and reliability of controls required to manage treatment residuals and untreated groundwater.

Magnitude of Residual Risk. Under Alternative 4, cleanup levels are achieved for each COC, therefore, the magnitude of residual risk present in the aquifer at the completion of the RA will fall within the CERCLA risk range and meet the MTCA acceptable risk level. Under this alternative, all treatment residuals are disposed at ERDF. Because EDRF has been specifically designed to provide for long-term management of hazardous materials, treatment residuals should not pose a risk to HHE in the future. The ICs implemented under this alternative will prevent exposure to contaminated groundwater until cleanup levels are achieved.

P&T is used to achieve cleanup levels for Tc-99 and uranium. Therefore, under this alternative, there is greater certainty that at the conclusion of the RA, acceptable risk levels will be achieved for these two COCs.

Adequacy and Reliability of Controls. Under Alternative 4, existing ICs are used to protect against exposure until COC concentrations are reduced to cleanup levels. The adequacy and reliability of ICs is expected to be very good at the Hanford Site because the measures are comprehensive, with enough redundancy to ensure that protectiveness is maintained even if one measure fails. Placement of groundwater treatment residuals within ERDF provides a high level of assurance that treatment residuals are safely managed long-term.

9.2.4.4 Reduction of Toxicity, Mobility, and Volume Through Treatment

Alternative 4 reduces TMV by aggressively pumping the Tc-99 and uranium plumes and removing any co-extracted COCs (except tritium) from extracted groundwater in an above ground treatment system. The higher pumping rates employed for Tc-99 and uranium shift all TMV reduction to P&T with no reliance on MNA. TMV reduction for the nitrate and tritium plumes occurs through MNA. Mobility reduction for I-129 occurs through hydraulic containment, with toxicity and volume reduction occurring following selection of a final remedy.

9.2.4.5 Short-Term Effectiveness

This criterion addresses the effects of the alternative to the community, RA workers, and the environment during the construction and implementation phase, and the timeframe required before RAOs are met. Under Alternative 4, some short-term risk to remedial action construction workers may arise during well installation, treatment system expansion, and treatment system O&M activities. Short-term risks to RA workers may also arise during treatment system media changeout and residuals handling, and other necessary maintenance and repair activities. However, this work would be performed by experienced personnel using well-established Hanford Site work and safety processes. The timeframe until RAOs are achieved is estimated at 150 years.

9.2.4.6 Implementability

Alternative 4 is readily implementable using a similar array of technical and administrative procedures as employed for the 200-UP-1 Groundwater OU IRA and the 200-ZP-1 Groundwater OU RD. However, this alternative will require expansion of the 200 West Area groundwater treatment facility to accommodate the increased groundwater pumping rates, which make this alternative more difficult to implement. Site personnel have previous experience with P&T remedies, which will increase the reliability of long-term

operations. Many of the other activities contained within this alternative, such as groundwater monitoring and data evaluation, and maintenance of ICs, are already being performed on a routine basis at the Site.

9.2.4.7 Cost

The total estimated NPV cost for Alternative 4 is $316,363,000. This includes a capital cost of $93,587,000. The total non-discounted cost for Alternative 4, which includes all capital, O&M, and periodic costs, is estimated at $641,209,000.

9.3 Comparative Analysis of Remedial Alternatives

The 200-UP-1 Groundwater OU remedial alternatives analyzed in Section 9.2 are compared in this section. The comparative analysis identifies the relative advantages and disadvantages of each alternative in the context of the CERCLA evaluation criteria so the key trade-offs may be identified and balanced. The comparative analysis provides a measure of the relative performance of the alternatives against each evaluation criterion. Table 9-4 summarizes the relative performance and ranking of each remedial alternative for each evaluation criterion.

Table 9-4. Comparative Evaluation of Alternatives for 200-UP-1 Groundwater OU

CERCLA Criteria	Remedial Alternatives			
	No Action	**2**	**3**	**4**
Threshold Criteria				
Protection of human health/environment	No	Yes	Yes	Yes
Compliance with ARARs	No	Yes*	Yes*	Yes*
Balancing Criteria				
Long-term effectiveness and permanence	●	◐	◐	○
Reduction of toxicity, mobility, or volume through treatment	●	◐	◐	○
Short-term effectiveness and Time to Achieve RAOs	●	◐	◐	◐
Implementability	●	○	◐	◐
NPV Cost (million $)	$0	$137	$225	$316
Modifying Criteria				
State acceptance	To be determined			
Community acceptance	To be determined			
Other Evaluation Factors				
Sustainable Elements	○	○	◐	◐

Notes:

○ = Performs very well against the criterion with no apparent disadvantages or uncertainty

◐ = Performs moderately well against the criterion but with some disadvantages or uncertainty

● = Performs less well against the criterion and may have disadvantages or uncertainty

Table 9-4. Comparative Evaluation of Alternatives for 200-UP-1 Groundwater OU

CERCLA Criteria	Remedial Alternatives			
	No Action	2	3	4
Alternatives				
1—Not retained.				
2—Restoration of Tc-99 (30 years) and Uranium (150 years), and Hydraulic Containment of I-129 until a Final remedy is Selected.				
3—Restoration of Tc-99 (30 years) and Uranium (80 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected.				
4—Restoration of Tc-99 (25 years) and Uranium (28 years), and Hydraulic Containment of I-129 until a Final Remedy is Selected.				
* Alternative may require an ARAR waiver for tritium in the future following selection of a final remedy for I-129.				
ARAR = applicable or relevant and appropriate requirement				
CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*				
NPV = net present value				
OU = operable unit				
RAO = remedial action objective				

9.3.1.1 Overall Protection of Human Health and the Environment

All of the alternatives, except the No Action Alternative, protect current and future human health by preventing exposure to contaminated groundwater through the use of ICs until RAOs are achieved.

Alternative 4 is expected to provide a higher level of protection for the environment because a majority of the Tc-99 and uranium are removed from the aquifer using aggressive P&T with less reliance on MNA. Alternatives 3 and 2 also provide a high level of protection for the environment, however, under these two alternatives MNA plays a greater role in achieving Tc-99 and uranium cleanup levels. Under all three alternatives, nitrate and tritium are addressed through MNA; although pumping of the uranium plume results in some co-extraction of nitrate-contaminated groundwater. The I-129 plume is hydraulically contained until a final remedy is selected.

9.3.1.2 Compliance with ARARs

All of the alternatives, except the No Action Alternative, comply with chemical-specific ARARs in the defined aquifer attainment areas within about 150 years. Alternatives 2, 3, and 4 may require a re-injection ARARs waiver for tritium if the I-129 final remedy employs P&T technology because a large portion of the tritium plume lies within the I-129 plume.

Each of the alternatives would comply with action- and location-specific ARARs if RA activities are conducted in accordance with existing Hanford Site work processes.

9.3.1.3 Long-Term Effectiveness and Permanence

Although Alternatives 2, 3 and 4 all achieve RAOs in a similar timeframe, Alternative 4 provides a higher degree of long-term effectiveness and permanence because a majority of the Tc-99 and uranium treatment is performed using an above ground treatment system with very little reliance on MNA. Alternatives 3 and 2 provide less long-term effectiveness and permanence because MNA plays a greater role in achieving cleanup levels for Tc-99 and uranium. All three alternatives provide comparable levels of

long-term effectiveness and permanence for I-129, nitrate, and tritium because the remedial alternative components addressing these COCs are the same.

The No Action Alternative provides the lowest degree of long-term effectiveness and permanence because uranium and I-129 will persist at concentrations above cleanup levels for extended periods of time.

9.3.1.4 Reduction of Toxicity, Mobility, and Volume Through Treatment

Alternative 4 provides the highest degree of Tc-99 and uranium TMV reduction because a majority of the COC mass is removed from the aquifer using above ground treatment and the treatment residuals immobilized and disposed at a secure long-term management facility (ERDF). Alternatives 3 and 2 have less Tc-99 and uranium TMV reduction because MNA plays a greater role in achieving cleanup levels. MNA reduces toxicity and volume but is less effective for mobility reduction. All three alternatives have comparable levels of TMV reduction for I-129, nitrate, and tritium because the approach for addressing these three COCs is the same.

The No Action Alternative provides the lowest degree of toxicity and volume reduction because natural attenuation is the only form of treatment that occurs. There is no mobility reduction under the No Action Alternative.

9.3.1.5 Short-Term Effectiveness

Alternatives 2, 3, and 4 provide similar levels of short-term effectiveness because the work required under these alternatives can be performed safely with minimal risk to workers and the environment by conducting the work per existing Site work processes. However, as the scope of a remedial alternative grows, the potential for worker risk increases. Therefore, Alternative 2 would pose the least short-term risk to workers followed by Alternative 3 and Alternative 4, respectively. Because of the remote location of the 200-UP-1 Groundwater OU, there is no risk to the community associated with implementation of this group of alternatives. At 150 years, the timeframe required to achieve RAOs is comparable amongst the three alternatives.

The No Action Alternative poses no apparent risk to workers and the community during implementation. However, because the timeframe required to achieve RAOs is much greater, this alternative is ranked lowest.

9.3.1.6 Implementability

Alternatives 2, 3, and 4 are readily implemented using existing Site work procedures. However, as the scope of an alternative increases, the degree of difficulty associated with its implementation also grows. Because Alternative 2 does not require expansion of the 200 West Area groundwater treatment facility, whereas Alternative 3 and Alternative 4 do, Alternative 2 would be more implementable from a technical standpoint followed by Alternative 3 and Alternative 4, respectively.

The No Action Alternative is not expected to be implementable based on regulatory agency acceptance.

9.3.1.7 Cost – Net Present Value

At $0, the No Action Alternative has the lowest NPV cost followed by Alternative 2 at a NPV cost (Table 9-5) of $137,267,000, Alternative 3 at a NPV cost of $225,078,000, and Alternative 4 with a NPV cost of $316,363,000. The NPV costs for Alternatives 2, 3, and 4 do not include an allowance for implementation of the final remedy for I-129.

Table 9-5. Comparison of Remedial Alternative Costs [a] for the 200-UP-1 Groundwater OU

Site: Site **Base Year:** 2010
Location: Hanford, WA **Date:** 9/17/2010
Phase: FS, etc

Item Description	No Action	Alternative 2 Restoration of Tc-99 (30 years) and Uranium (150 years), and Hydraulic Containment of I-129 Until a Final Remedy Selected	Alternative 3 Restoration of Tc-99 (30 years) and Uranium (80 years), and Hydraulic Containment of I-129 Until a Final Remedy Selected	Alternative 4 Restoration of Tc-99 (25 years) and Uranium (28 years), and Hydraulic Containment of I-129 Until a Final Remedy Selected
Common Elements				
MNA and ICs		X	X	X
Treatment				
200 West Area Groundwater Treatment Facility		X	X	X
200 West Area Groundwater Treatment Facility with Train 3 Expansion			X[b]	X
Nominal Extraction Flow Rate L/min (gpm)	0	1,060 (280)	1,440 (380)	2,080 (550)
Nominal Injection Flow Rate L/min (gpm)	0	1,630 (430)	2,000 (530)	2,650 (700)
Total Pumping Duration (years)	0	25 (Tc-99 and uranium)	25 (Tc-99 and uranium)	25 (Tc-99), 28 (uranium)
MNA Duration all COCs (years)	0	5 (Tc-99), 125 (uranium), 150 (nitrate), 50 (tritium), TBD (I-129)	5 (Tc-99), 55 (uranium), 150 (nitrate), 50 (tritium), TBD (I-129)	150 (nitrate), 50 (tritium), TBD (I-129)
Total Project Duration (years)	0	150	150	150
Capital Cost	$0	$23,424,000	$81,450,000	$93,587,000
Total O&M Cost	$0	$243,746,000	$275,513,000	$368,047,000
Average Annual O&M Cost (overall duration)	$0	$1,392,834	$1,574,360	$2,103,126
Total Periodic Cost	$0	$99,686,000	$127,747,000	$179,576,000
Non-Discounted	$0	$366,856,000	$484,709,000	$641,209,000
Total NPV (Discounted)	**$0**	**$137,267,000**	**$225,078,000**	**$316,363,000**

Notes: Present Value discount percent used is 2.7%.
Range of accuracy is expected to be +50%/-30%.
a. The total net present value cost, capital cost, O&M cost, and periodic costs do not include design, construction and O&M allowances for the I-129 final remedy.
b. A determination on the need for Train 3 will be made during remedial design. For cost estimating purposes, it is assumed Train 3 installation would be required.
COC = contaminant of concern
IC = institutional control
MNA = monitored natural attenuation
NPV = net present value
O&M = operations and maintenance
OU = operable unit
TBD = to be determined

9.3.2 Sustainable Evaluation Factors

All of the alternatives, except the No Action Alternative require hydroelectric-generated power to operate groundwater extraction and treatment system equipment, and fossil fuels to provide transportation for construction, O&M, and D&D activities. Although the remedial alternatives developed for evaluation in this FS do not have specific provisions for sustainable remediation, these values can be incorporated during the RD phase.

9.4 NEPA Values

This section discusses the incorporation of the *National Environmental Policy Act of 1969* values into CERCLA documents. This is consistent with DOE Order 451.1B, Chg. 1 that requires CERCLA actions to address and incorporate NEPA values such as socioeconomic, ecological, offsite, and cumulative impacts in CERCLA documents to the extent practicable.

Alternatives to address the release or threatened release of hazardous substances have been identified and analyzed in this RI/FS (Section 9). The No Action Alternative would not mitigate the environmental impacts from the hazardous substances. All other alternatives could mitigate the impacts associated with the release or threatened release, as well as provide for the remediation of the hazardous substances. Specifically, the application of the substantive environmental protection standards identified as ARARs would reduce impacts of the hazardous substances on air, surface waters, soil, groundwater, plants, and animals to levels that have been identified by regulation.

NEPA values associated with remediation are based on the detailed information presented in this RI/FS including the area and Site characteristics (Chapters 1, 2, and 3), COC identification (Chapters 6 and 7), and the development and analysis of RA alternatives (Chapters 8 and 9). Applying a "sliding scale" of NEPA analysis to the 200-UP-1 Groundwater OU using DOE's NEPA guidance (DOE, 2004), and considering the ARARs presented in Chapter 7, the principle resource areas of concern include: contaminated groundwater, liquid and solid radioactive and hazardous waste treatment residuals, air emissions, potential adverse effects to historic and cultural resources, ecological resources, socioeconomics (including environmental justice concerns), and transportation associated with implementation of the RA.

For purposes of implementing the RA alternatives described in Chapters 8 and 9 of this document, when groundwater in the 200-UP-1 Groundwater OU is found to be contaminated with hazardous substances in concentrations presenting unacceptable risk to HHE, that threat will be mitigated by meeting the applicable ARAR standards as well as following current DOE policy and guidance. The net anticipated effect could be an overall positive contribution to cumulative environmental effects at the Site through TMV reductions of COC concentrations and transfer of all above ground treatment residuals into a facility that has been designed and legally authorized to safely contain such contaminants. DOE expects that ERDF will be the primary facility to receive treatment residuals. NEPA values specifically associated with ERDF were addressed in DOE/RL-94-41.

Table 9-6 describes the NEPA values (resource area and relevant NEPA considerations) most relevant to and potentially affected by the actions occurring under this RA.

The alternatives presented in this FS are within the scope of DOE/EIS-0391. DOE expects that the final action for the 200-UP-1 Groundwater OU will support the eventual final Tank Farm and Waste Management Environmental Impact Statement preferred alternative.

Table 9-6. NEPA Values Evaluation

NEPA Values	Description	Evaluation (Includes the Evaluation for Each Alternative)
Transportation	Considers impacts of the proposed action on local traffic (traffic at the Site) and traffic in the surrounding region.	Implementation of Alternatives 2 to 4 would be expected to produce short-term impacts on local traffic. A majority of the impact is associated with increased truck traffic associated with the aforementioned alternatives; which would involve transport of construction materials, in addition to conveyance of extracted groundwater to the 200 West Area groundwater treatment facility and treatment residuals to ERDF. Transportation impacts were considered in the ERDF RI/FS, DOE/RL-93-99, as part of the evaluation of short-term effectiveness and implementability. NEPA values specifically associated with ERDF were addressed in DOE/RL-94-41. Transportation impacts associated with the No Action Alternative are negligible and considerably less than for the other alternatives.
Air Quality	Considers potential air quality concerns associated with emissions generated during the proposed action.	Airborne releases associated with Alternatives 2 to 4 would be expected to be minor with the use of appropriate work and treatment controls (dust suppressants during construction and air treatment provisions where required). Any potential of airborne release of contaminants during the RAs would be controlled in accordance with DOE radiation control and air pollution control standards, to minimize emissions of air pollutants at the Site, and protect all communities outside the Site boundaries. Operation of trucks and other diesel-powered equipment for these alternatives would be expected, in the short term, to introduce quantities of sulfur dioxide, nitrogen dioxide, particulates, and other pollutants to the atmosphere, typical of similar-sized construction projects. These releases would not be expected to cause any air quality standards to be exceeded and (as needed) dust generated during remedial activities would be minimized by watering or other dust-control measures. Vehicular and equipment emissions would be controlled and mitigated in compliance with the substantive standards for air quality protection that apply to the Site.

Table 9-6. NEPA Values Evaluation

NEPA Values	Description	Evaluation (Includes the Evaluation for Each Alternative)
Natural, Cultural, and Historical Resources	Considers impacts of the proposed action on wildlife, wildlife habitat, archeological sites and artifacts, and historically significant properties.	Impacts on ecological resources in the vicinity of the RAs would be mitigated in accordance with DOE/RL-96-32 and DOE/RL-96-88, and with the applicable standards of all relevant biological species protection regulations. Because a majority of the 200-UP-1 Groundwater OU has already been evaluated or disturbed, implementation of DOE/RL-98-10 and consultation with area Tribes would help ensure appropriate mitigation to avoid or minimize any adverse cultural or historical resource effects and address any relevant concerns. Impacts to other cultural values will be minimized through implementation of DOE/RL-98-10, DOE/RL-2005-27, and consultation with area Tribes as needed. This will help ensure appropriate mitigation to avoid or minimize any adverse effects to natural and cultural resources and address any other relevant concerns. Potential impacts to cultural and historical resources that may be encountered during the short-term construction activities associated with implementing the action would be mitigated through compliance with the appropriate substantive requirements of the *National Historic Preservation Act of 1966* and other ARARs related to cultural preservation.
Socioeconomic Impacts	Considers impacts pertaining to employment, income, other services (water and power utilities), and the effect of implementation of the proposed action on the availability of services and materials.	The proposed alternatives are within the scope of current RL environmental restoration activities and would have minimal impact on the current availability of services and materials. This work would be expected to be accomplished largely using employees from the existing contractor workforce. Even if remedial activities create additional service sector jobs, the total expected increase in employment would be expected to be less than 1 percent of the current employment levels. The socioeconomic impact of the project would contribute to the continuing overall positive employment and economic impacts on eastern Washington communities from Site cleanup operations.
Environmental Justice	Considers whether the proposed response actions would have inappropriately or disproportionately high and adverse HHE effects on minority or low-income populations.	Per Executive Order 12898, DOE seeks to ensure that no group of people bears a disproportionate share of negative environmental consequences resulting from proposed federal actions. No impacts are associated with proposed activities associated with the 200-UP-1 Groundwater OU that could reasonably be determined to affect any member of the public; therefore, they would not have the potential for high and disproportional adverse impacts on minority or low-income groups.

Table 9-6. NEPA Values Evaluation

NEPA Values	Description	Evaluation (Includes the Evaluation for Each Alternative)
Cumulative Impacts (Direct and Indirect)	Considers whether the proposed action could have cumulative impacts on HHE when considered together with other activities locally, at the Site, or in the region.	The environmental concern for the 200-UP-1 Groundwater OU is associated directly with the targeted attainment areas. Because of the temporary nature of the activities and their remote location, cumulative impacts on air quality or noise with other Site or regional construction and cleanup projects would be minimal. When groundwater in this OU is found to be contaminated with hazardous substances in concentrations presenting a material threat to HHE, that threat would be mitigated. The net anticipated effect could be a positive contribution to cumulative environmental effects at the Site through TMV reduction and transfer of all treatment residuals into a facility that has been designed and legally authorized to safely contain such contaminants (i.e., the ERDF). Treatment residuals generated under any alternative would meet the ERDF waste acceptable criteria as described in WCH-191. Wastes generated during implementation of the proposed alternatives would be manageable within the capacities of existing facilities. For perspective, ERDF received more than 700,000 tons of waste in CY 2008 and more than 430,000 tons in CY 2007.
Mitigation	Considers whether or not if adverse impacts cannot be avoided, response action planning should minimize them to the extent practicable. This value identifies required mitigation activities.	Compliance with the substantive requirements of the ARARs would mitigate potential environmental impacts on the natural environment, including migratory birds and endangered species. DOE has also established policies and procedures for the management of ecological and cultural resources when actions might affect such resources (DOE/RL-96-32, DOE/RL-96-88, and DOE/RL-98-10). Cultural resource and biological species reviews/surveys are undertaken that also provide suggested mitigation activities to ensure that adverse effects associated with implementing the actions are minimized or avoided. Health and safety procedures, documented in the HSP, established by Site contractors, would mitigate risks to workers from the remedial activities.
Irreversible and Irretrievable Commitment of Resources	Considers the use of nonrenewable resources for the proposed response actions and the effects that resource consumption would have on future generations. (When a resource [energy minerals, water, wetland] is used or destroyed and cannot be replaced within a reasonable amount of time, its use is considered irreversible.)	Alternatives 2 to 4 would require long-term use of hydroelectric power to operate conveyance P&T equipment. Non-renewable fossil fuels will also be irreversibly used by O&M personnel. Restoration of formerly disturbed areas at the completion of the RA would be expected to result in a net benefit to the ecological and visual resources within the region.

Table 9-6. NEPA Values Evaluation

NEPA Values	Description	Evaluation (Includes the Evaluation for Each Alternative)
ARAR	= applicable or relevant and appropriate requirement	
CY	= calendar year	
DOE	= U.S. Department of Energy	
ERDF	= Environmental Restoration Disposal Facility	
HHE	= human health and the environment	
HSP	= health and safety plan	
NEPA	= *National Environmental Policy Act of 1969*	
O&M	= operations and maintenance	
OU	= operable unit	
P&T	= pump-and-treat	
RA	= remedial action	
RI/FS	= remedial investigation/feasibility study	
TMV	= toxicity, mobility, volume	

9.5 CERCLA and RCRA Corrective Action

The HFFACO states the intent of the Parties that CERCLA remediation at the Site will also fulfill the corrective action requirements for the Site. Key language specific to past-practice unit cleanup includes the following:

- Article IV, Paragraph 17, which cites the Tri-Parties intent "to integrate DOE's CERCLA response obligations and RCRA corrective action obligations which relate to the release(s) of hazardous substances, hazardous wastes, pollutants and contaminants" covered by Ecology et al., 1989a.
- Article XIV, which applies to the performance of both CERCLA RA and RCRA corrective action.
- Article XXIII, which acknowledges the potential for overlap between CERCLA and RCRA cleanup.
- Article XXIV, which specifies the approach for regulatory oversight. Section 5.4 of Ecology et al., 1989b, which addresses the rationale and approach for past-practice cleanup.
- Two key objectives are to "ensure that only one past-practice program will be applied at each operable unit" and that the "process selected be sufficiently comprehensive to satisfy the technical requirements of both statutory authorities and the respective regulations."
- In accordance with HFFACO, Parts Three and Four, and the Action Plan, Sections 5.4, 5.6, and 7.0, past-practice cleanup (remediation) is intended to satisfy both CERCLA remedial action and RCRA corrective action requirements. In addition to fulfilling CERCLA requirements, the 200-UP-1 Groundwater OU preferred alternative (to be identified in the Proposed Plan) is intended to fulfill DOE's corrective action obligations under RCW 70.105 for the units identified herein. The Tri-Parties agree that the preferred alternative identified in the Proposed Plan, or other alternative

selected in the ROD[2] is sufficiently comprehensive to satisfy the technical requirements of both statutory authorities and the respective regulations.

DOE's corrective action obligation for work performed under CERCLA RA for this OU is addressed in the RCRA Hanford Facility Permit (WA7890008967, Condition II.Y.2.a). Specifically, Condition II.Y.2.a provides that DOE corrective action obligations are met through adherence to the TPA and the resulting ROD, subject to the reservations and requirements of Condition II.Y.a.i through Condition II.Y.2.a.iv.

[2] The 200-UP-1 Groundwater OU final remedial action will be selected in an amendment to the 200-ZP-1 Groundwater OU ROD.

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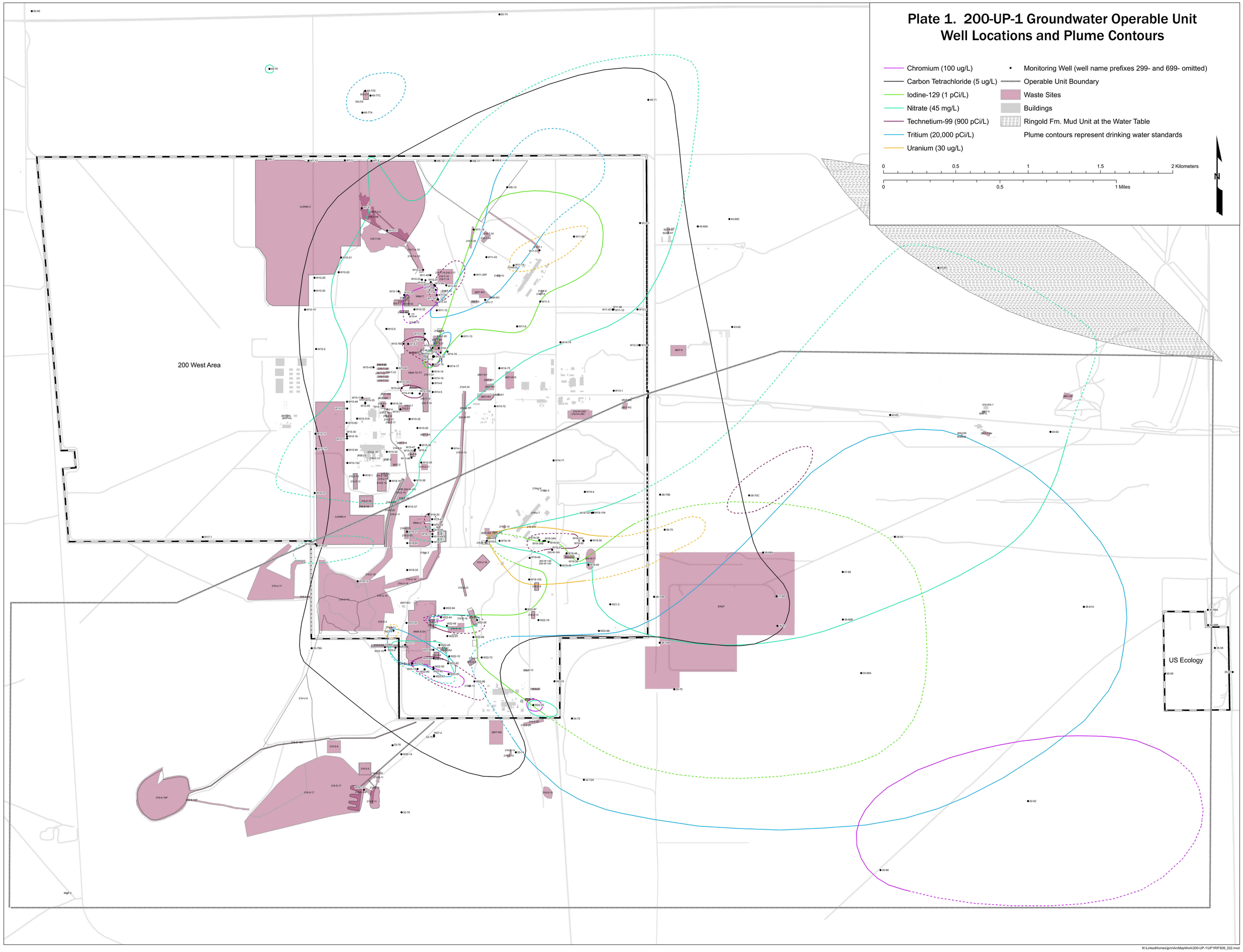
Appendix A

Plate Map

1

Plate 1. 200-UP-1 Groundwater Operable Unit Well Locations and Plume Contours



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Appendix B

Annotated Bibliography

Table B. Bibliography

Reference	Summary
CERCLA Process Activities From Source Identification to Work Plans for the LFI, LFI Results, ROD, and Remedial Design/Remedial Action Work Plan	
DOE/RL-92-16, 1993, *200 West Groundwater Aggregate Area Management Study Report, Rev. 0*	Contains an evaluation of various sources and COCs applicable to the OU. See Section 3-4 for a summary of this document.
DOE/RL-91-52, 1992, *U Plant Source Aggregate Area Management Study Report, Rev. 0*	This report presents the results of an AAMS for the U Plant aggregate area. This scoping-level study provides the basis for initiating RI/FS activities under CERCLA, as well as RFI/CMS activities under RCRA. The report provides background, environmental setting, and known contamination data. This information provides the basis for development of the preliminary conceptual model and for assessing health and environmental concerns. Preliminary ARARs and preliminary RA technologies are also developed based on the data. Data needs are developed based on data gaps determined during the development of the conceptual model, human health, environmental concerns, ARARs, and RA technologies. The U Plant aggregate area contains a large variety of waste disposal and storage facilities. Based on construction, purpose, or origin, the U Plant aggregate area WMUs fall into one of 10 subgroups. The number of units in each subgroup and the listed subgroups are as follows: • 1 waste management unit (plant, buildings, and storage areas) • 22 tanks and vaults • 12 cribs and drains • 1 reverse well • 10 ponds, ditches, and trenches • 4 septic tanks and associated drain fields • 13 transfer facilities, diversion boxes, and pipelines • 1 basin • 2 burial sites • 34 unplanned releases The final management recommendations include criteria and selection of appropriate Hanford Site past-practice strategy paths (ERA, IRM, and final remedy selection) for individual waste management units and unplanned releases in the U Plant aggregate area.
DOE/RL-91-60, 1992, *S Plant Aggregate Area Management Study Report, Rev. 0*	This report presents the results of an AAMS for the S Plant aggregate area. This scoping-level study provides the basis for initiating RI/FS activities under CERCLA, as well as RCRA RFI/CMS. The report provides background, environmental setting, and known contamination data. This information provides the basis for development of the preliminary conceptual model and for assessing health and environmental concerns. Preliminary ARARs and preliminary RA technologies are also developed based on the data. Data needs are developed based on data gaps determined during the development of the conceptual model, human health, environmental concerns, ARARs, and redial action technologies.

Table B. Bibliography

Reference	Summary
	The S Plant aggregate area contains a variety of waste disposal and storage facilities. Based on construction, purpose, or origin, the S Plant aggregate area waste management units fall into one of 10 subgroups. The number of units in each subgroup and the listed subgroups are as follows: • 4 WMUs (plants, buildings, and storage areas) • 35 tanks and vaults • 13 cribs and drains • 0 reverse well • 13 ponds, ditches, and trenches • 3 septic tanks and associated drain fields • 18 transfer facilities, diversion boxes, and pipelines • 2 basins • 2 burial sites • 45 unplanned releases The final management recommendations include criteria and selection of appropriate Hanford Site past-practice strategy paths (ERA, IRM, and final remedy selection) for individual waste management units and unplanned released in the S Plant aggregate area.
BHI-00150, 1995, *Borehole Summary Report for 200-UP-1 Operable Unit, 200 West Area, Rev. 00*	This report summarized the results of drilling and related characterization activities performed in FY94 for the 200-UP-1 Groundwater OU. The focus of the drilling program was to assess the N&E of the uranium, technetium, and nitrate plumes located beneath U Plant. This multi-contaminant plume was designated as a candidate for an IRM in the 200 West groundwater AAMSR (DOE/RL-92-16). The primary objective of this drilling program was to refine the vertical and horizontal extent of uranium, technetium, and nitrate plumes and the hydrogeology of the saturated zone in the vicinity of the plume. The program consisted of installing four wells screened at various depths, borehole geophysical logging, soil and groundwater sampling, and aquifer testing. The report contains sections describing the various characterization activities and summarizing results: • A stratigraphic interpretation of the 200-UP-1 Groundwater OU in the vicinity of the IRM plume based on existing and new borehole data • Description of the drilling, sampling, aquifer testing, geophysical logging, and construction of four monitoring wells • Drilling investigation and associated soil sampling results (groundwater sampling and results are not discussed in this report) • Radionuclide data obtained from geophysical logs for each of the new wells • Description of analysis results for hydraulic tests conducted to determine the hydraulic properties of the uppermost unconfined aquifer (Ringold unit E) and the confined aquifer (Ringold unit A)
DOE/RL-96-33, 1996, *Limited Field Investigation for the 200-UP-1 Operable Unit, Rev. 0*	Provides data required to refine the site conceptual model and conduct a risk assessment. The following high-priority contaminants were found to exceed MCLs within the 200-UP-1 Groundwater OU: 1,2-dichloroethane, carbon tetrachloride, trichloroethylene, Sr-90, Tc-99, I-129, uranium, cadmium, and chromium. See additional summary in Section 3.5.

Table B. Bibliography

Reference	Summary
DOE/RL-98-28, 1999, *200 Areas Remedial Investigation/Feasibility Study Implementation Plan – Environmental Restoration Program, Rev. 0*	This document outlines the framework for implementing assessment activities in the 200 Area to ensure consistency in documentation, level of characterization, and decision making. The Implementation Plan also consolidates background information and other typical work plan materials to serve as a single reference source for this type of information. The Implementation Plan does not provide detailed information about the assessment of individual waste sites or groups. Site-specific data needs, DQOs, data collection programs, and associated assessment tasks and schedules will be defined in subsequent group-specific (OU-specific) work plans. A common regulatory framework is established that integrates the RCRA, CERCLA, federal facility regulations, and TPA requirements into one standard approach for 200 Area cleanup activities. The Implementation Plan also streamlines work plans that are required for each waste site group by consolidating background information, providing a single referenceable source of this information. This allows the information in the group-specific work plans to focus on waste group or waste site-specific information. The background information includes an overview of the 200 Area facilities and processes, the operational history, contaminant migration concepts, and a list of COCs. It also documents and evaluates existing information to develop a Site description and conceptual model of expected Site conditions and potential exposure pathways. With this conceptual understanding, preliminary potential ARARs, preliminary RAOs, and RA alternatives are identified. The alternatives are broadly defined but represent potential alternatives that may be implemented at the Site. The identification of potential alternatives helps ensure that the data needed to fully evaluate the alternatives are collected during the RI.
	The specific type and quality of data are to be defined through the site-specific DQOs and form the basis for the data collection programs. The 200 Area strategy recognized the interrelationships between the various activities in the area and the need to integrate with other environmental restoration and Hanford Site projects/programs. The implementation plan describes the approach to interfacing with other programs and agencies, the integrated schedule of activities that addressed both RCRA and CERCLA program requirements, and the public participation process.
DOE/RL-2000-51, 2002, *Interim Action Waste Management Plan for the 200-UP-1 Operable Unit, Rev. 3*	This interim action waste management plan establishes the requirements for management and disposal of waste generated from groundwater wells used to monitor P&T interim action at the 200-UP-1 Groundwater OU. The plan addresses only waste generated from activities related to P&T performance monitoring and 200-UP-1 Groundwater OU groundwater monitoring. The wells addressed by this plan are listed in Appendix A of the document. The activities that will likely generate waste include, but are not limited to, the following: • Groundwater well installation • Groundwater well development, sampling, maintenance, and decommissioning • Maintenance activities associated with the extraction well head and associated valves and piping up to the connection with the pipeline that runs from ERDF to the ETF • Water-level and other in situ groundwater measurements • Screening/analysis of samples • Decontamination of equipment and material • Aquifer testing, geophysical logging, and treatability studies Testing, treatability studies, or other special activities not specifically identified in the applicable work plan (DOE/RL-97-36, Rev. 2, *200-UP-1 Groundwater Remedial Design/Remedial Action Work Plan*) will be evaluated with the regulatory agencies for coverage under this waste management plan.

Table B. Bibliography

Reference	Summary
RPP-7884, 2002, *Field Investigation Report for Waste Management Area S-SX, Rev. 0*	Provides detailed discussion of COCs and potential migration from the S, SX Tank Farms. See Section 3.4 for a summary of this document.
Interim Remedial Measure	
DOE/RL-95-26, 1995, *Interim Remedial Measure Proposed Plan for the 200-UP-1 Operable Unit, Hanford Washington, Rev. 0*	The IRM proposed plan describes an interim action that was proposed for the 200-UP-1 Groundwater OU. The objectives of the IRM are to contain elevated concentration of uranium and Tc-99 in the 200-UP-1 Groundwater OU and to collect data on aquifer and contaminant response to the selected remediation measure. The proposed plan was developed in accordance with the TPA (Ecology et al., 1989) and summarizes more detailed information available in other documents. The plan discusses the following: • Site background information and studies • A summary of site risks (cancer and non-cancer risk) • Contaminants of potential concern (Tc-99, uranium, and nitrate) • Need for RA • Interim RAOs • Detailed description of alternatives • Comparative analysis of alternatives (using EPA's nine evaluation criteria) • Summary of preferred alternative
	The preferred alternative was P&T. The goals of the RA are to halt the spread of the highly contaminated protection of the contaminant plume, remove contaminant mass, and collect data on aquifer and contaminant response to the remediation measures. The preferred alternative was believed to provide the best balance of trade-offs among the alternatives and will protect human health and the environment.

Table B. Bibliography

Reference	Summary
BHI-00187, 1996, *Engineering Evaluation/ Conceptual Plan for the 200-UP-1 Groundwater Operable Unit Interim Remedial Measure, Rev. 2*	This report contains an engineering evaluation and conceptual plan for the IRM to address a uranium and Tc-99 groundwater plume in the 200-UP-1 Groundwater OU. The report provides a historical summary of the type and extent of contamination and information regarding the need for an IRM and its potentially achievable objectives and goals. The report also evaluated alternatives to contain elevated concentrations of uranium and Tc-99 and to obtain information necessary to develop final RAs for the OU. Performance goals for the P&T IRM included the following: • Maintain hydraulic control and contain the high-concentration area of the plume • Prevent uranium and Tc-99 concentrations from increasing downgradient from the containment zone • Reduce uranium, Tc-99, and carbon tetrachloride to the MCLs prior to reinjection or disposal of treated groundwater • Obtain data to support the final remedy • Several specific technical criteria were to be addressed in the evaluation of the IRM following implementation: – Criterion #1 – Is the well field hydraulically containing and/or intercepting the combined uranium and Tc-99 plume? – Criterion #2 – Have contaminant concentrations within or downgradient of the contaminant zone been stabilized or reduced? – Criterion #3 – Is mass removal occurring at a rate that will remove the dissolved contamination in a reasonable period of time and at a reasonable cost? – Criterion #4 – Have data been obtained on aquifer and contaminant response to remediation measures that are sufficient to support a determination of the need for, and feasibility of, final remedial measures for the site? – Criterion #5 – Is the treatment system performance meeting the treatment goals?
EPA/541/R-97/048, 1997, *Record of Decision for the 200-UP-1 Interim Remedial Measure*	The ROD for the 200-UP-1 Groundwater OU presents a description of the selected interim remedy for uranium and Tc-99 groundwater contamination in the vicinity of U Plant. The interim RA was chosen in accordance with CERCLA, SARA, the TPA (Ecology et al., 1989), and, to the extent practicable, the NCP. The State of Washington concurred with the selected remedy. The selected remedy consists of pumping the highest concentration zone of the contaminated plume at 200-UP-1 and treatment using the existing ETF in the 200 East Area. The selected remedy is intended to reduce contaminant mass within the plume and minimize migration of uranium and Tc-99 from the 200 West Area. The high-concentration portion of the plume corresponds to that area having contaminants greater than or equal to levels 10 times greater than the MCL of uranium under WAC 173-340-720(4) (“Model Toxics Control Act--Cleanup,” “Ground Water Cleanup Standards”), and 10 times or greater than the MCL for Tc-99. The cleanup level is based solely on an assessment of uranium toxicity and not on cancer risk that it may pose.

Table B. Bibliography

Reference	Summary
	The ETF is a multi-stage facility that can remove and/or destroy a large number of contaminants, including nitrate and carbon tetrachloride, which are present in 200-UP-1 groundwater. The State of Washington has made a "contained-in" determination of carbon tetrachloride for this action to facilitate the treatment of carbon tetrachloride at the ETF. The interim action is protective of human health and the environment in the short term and is intended to provide adequate protection until a final ROD is signed. The groundwater removed will be treated to meet requirements before discharge. This interim action is only part of the total RA for 200-UP-1 and is considered cost effective.
DOE/RL-97-36, 1997, *200-UP-1 Groundwater Remedial Design/Remedial Action Work Plan, Rev. 2*	The 200-UP-1 remedial design report presents the RAOs and rationale for the design and implementation of the selected IRM for the 200-UP-1 Groundwater OU. The RAOs for this IRM are to: (1) hydraulically contain and treat the high-concentration portion of the uranium and Tc-99 groundwater plumes, and (2) provide data to support a final remediation measure. The high-concentration portions of the plume are defined as 480 µg/L for uranium (10 times the WAC 173-340-720[4] cleanup level) and 9,000 pCi/L (10 times the MCL) contour for Tc-99. The groundwater is not classified as a RCRA hazardous waste but will be managed as a RCRA hazardous waste because of the associated "F001" code. The IRM was chosen in accordance with CERCLA, as mandated by SARA, and in accordance with the TPA (Ecology et al., 1989) and the NCP. The preferred alternative (groundwater P&T using the ETF for disposal) was chosen for the following reasons: • Reduction in potential risk to HHE by removing contaminant mass and minimizing migration of the high-concentration portion of the uranium and Tc-99 plumes. • Groundwater would be treated at the state-of-the-art ETF located in the 200 East Area of the Hanford Site. Certain co-contaminants (carbon tetrachloride) will be destroyed, which minimizes waste generation. • The selected remedy would remove the COC and specific co-contaminants of nitrate and carbon tetrachloride that exist within the groundwater.
DOE/RL-96-81, 1997, *Waste Site Grouping for 200 Areas Soil Investigations, Rev. 0*	The analogous site approach concept was a key element in the development of the *200 Areas Soil Remediation Strategy – Environmental Restoration Program* (DOE/RL-96-67) because many of the 200 Area waste sites share similarities in geological conditions, functions, and types of waste received. As a result, the need to establish waste site groups for 200 Area waste sites was identified as an initial step in the implementation of DOE/RL-96-67. The purpose of this document was to identify logical waste site groups for characterization based on criteria established in DOE/RL-96-67. Specific objectives of the document included the following: • Finalize waste site groups based on the approach and preliminary groupings identified in the DOE/RL-96-67. • Prioritize the waste site groups based on criteria developed in DOE/RL-96-67. • Select representative sites that best represent typical and worst-case condition for each waste group. • Develop conceptual models for each waste group.

Table B. Bibliography

Reference	Summary
	Waste site group prioritization and representative site selection will support a more efficient and cost-effective approach to characterizing the 200 Area waste sites. Characterization efforts will be limited to representative sites, the data from which will be used for RA decisions for all waste sites within a group (consistent with the analogous site approach). Waste site group properties will be used to establish a sequence in which the representative sites are expected to be addressed. The conceptual models developed in this document provide an initial prediction of the N&E of primary COC and support the selection of representative sites and prioritization of groups.
Groundwater Management and Current Sampling	
DOE/RL-2002-68, 2003, *Hanford's Groundwater Management Plan: Accelerated Cleanup and Protection, Rev. 0*	This document lays out a plan developed by DOE, in conjunction with EPA and Ecology, to accelerate Hanford Site cleanup. The goal is to return groundwater to its highest beneficial use where practicable, which will at least prevent further degradation. The previous baseline shows remediation beginning in 2008 and extending to 2024. The new accelerated schedules illustrated in this document show that the baseline will begin in 2004 and will be completed by 2012. The document contains discussion of specific results that can be expected using the accelerated plan for cleanup. These results and expected dates of completion include the following: • Remediate high-risk wastes: 2011 • Shrink the contaminated areas: 2112 • Reduce recharge: 2012 • Remediate groundwater: 2012 • Evaluate groundwater monitoring needs: ongoing Plans to deal with waste sites in immediate proximity to the tank farms require additional work and will depend greatly on the strategy employed to close the tanks. The regions selected for completion by 2012 avoid those areas immediately adjacent to tank farms until an integrated approach to waste site remediation and tank closure can be developed. In addition to accelerated schedules for cleanup and groundwater protection, the document contains definitions and discussion of various proposed groundwater protection boundaries (core zone and outside the core zone). As part of the integrated accelerated plan, an area closure strategy is discussed. Three major areas in the 200-UP-1 Groundwater OU are identified, which include the following: • U Plant area closure • S Tank Farm area closure • REDOX area closure When cleanup is implemented on an area-by-area basis, these coordinated efforts to control sources, implement RA, and assess and monitor impact are expected to place major portions of the 200 Area plateau into a condition of long-term stewardship monitoring starting in 2006.
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*	The purpose of this DQO process was to assess the current groundwater monitoring well networks for the 200 West and 200 East Areas. This assessment was needed to address changing contaminant plume conditions (plume migration) and to ensure that monitoring activities meet the requirements for remediation performance monitoring (CERCLA monitoring), Sitewide surveillance monitoring to meet the requirements of DOE orders, and detection/assessment monitoring to meet the requirements of RCRA. This DQO summary report was prepared in support of DOE's Cleanup, Constraints, Challenges Team (C3T) process.

Table B. Bibliography

Reference	Summary
	Because of the changing shape of the groundwater contaminant plume contours over time and changing programmatic needs, the 200 West and 200 East groundwater monitoring network is required to be periodically re-evaluated. The objective of the groundwater CERCLA remediation performance monitoring program is to provide a routine assessment of the effectiveness of groundwater remediation activities within the 200-ZP-1 and 200-UP-1 Groundwater OUs. The objectives of the Sitewide surveillance monitoring program are as follows: • Determine baseline conditions of groundwater quality and quantity • Characterize and define hydrogeologic, physical, and chemical trends in the groundwater system • Identify existing and potential groundwater contamination sources • Assess existing and emerging groundwater quality problems • Evaluate existing and potential offsite impacts of groundwater contamination • Provide data on which decisions can be made concerning land disposal practices and the management and protection of groundwater resources Finally, the objective of the RCRA detection program is to identify if TSD units are impacting groundwater quality. If impacts to groundwater are detected, the objective of the RCRA assessment program is to define the rate and extent of contaminant migration. This DQO process identified the optimum number of groundwater wells to be monitored to meet these objectives and determined that a number of new groundwater wells needed to be installed. The identity of wells in the monitoring network, sampling frequency, analyses to be performed, detection limit requirements, and other analytical performance requirements (precision and accuracy) were defined in this document. The resultant groundwater monitoring network fulfilled the needs of the three major Hanford Site regulatory monitoring activities (CERCLA, RCRA, and AEA).
CP-15315, 2003, *Data Quality Objectives Summary Report Supporting the 200-UP-1 Operable Unit Remedial Investigation/ Feasibility Study Process, Rev. 0*	The purpose of this DQO process was to identify and evaluate the data needs required to support the RI/FS process for the 200-UP-1 Groundwater OU. The report defines and evaluates the data needs to support defining the N&E of contamination, risk assessment, evaluation of RA alternatives, and long-term monitoring of completed RAs. The RI/FS process for the 200-UP-1 Groundwater OU was scoped in accordance with the scoping requirements contained in 40 CFR 300.430(b), “National Oil and Hazardous Substances Pollution Contingency Plan,” “Remedial Investigation/ Feasibility Study and Selection of Remedy.” To fulfill the requirements to “identify likely response scenarios,” the FS will identify a range of alternatives that include the following: • Restoration of groundwater to its highest beneficial use everywhere within the plume boundary, within a reasonable restoration timeframe, by implementing one or more potentially applicable technologies (including MNA for individual contaminants). • If it is determined that it is not technically practicable to restore the groundwater to its highest beneficial use, then alternate action levels will be established within the plume boundary, followed by implementing one or more potentially applicable technologies. • If it is determined that it is not technically practicable to achieve alternate action levels everywhere within the plume boundary, then one or more conditional points of compliance will be established, beginning at the boundary of individual waste area groups (groupings of proximate waste sites) and going next to the plume boundary. The plume boundary for many contaminants in the 200 Areas is roughly coincident with the “core zone” of 200 Area waste sites.

Table B. Bibliography

Reference	Summary
	RA alternatives have not been fully evaluated at this time, and some refinement may be needed as alternative actions are selected. However, it is anticipated that the following remediation options will be considered in the 200-UP-1 FS: • No action • Institutional controls • Monitored natural attenuation • Groundwater P&T (using onsite treatment system that may include injection of treated water) The DQO process was applied to determine whether additional data were needed to support implementation of the RI/FS process for the 200-UP-1 Groundwater OU. It was determined through the DQO process that additional data would be necessary. This document identifies the sampling requirements, analyses to be performed, detection limit requirements, and other analytical performance requirements (precision and accuracy) for the data to be collected.
PNNL-14187, 2003, *Hanford Site Groundwater Monitoring for Fiscal Year 2002*	This report presents the results of groundwater and vadose zone monitoring and remediation for FY02 on the Site. Water-level monitoring was performed to evaluate groundwater flow directions, to track changes in water levels, and to relate such changes to evolving disposal practices. Water levels over most of the Site continued to decline between March 2001 and March 2002. The most extensive plumes are tritium, I-129, and nitrate, which all had multiple sources and are mobile in groundwater. The largest portions of these plumes are migrating from the central Site to the southeast, toward the Columbia River. Concentrations of tritium, nitrate, and some other contaminants continued to exceed DWSs in groundwater discharging to the river in FY02; however, contaminant concentrations in river water remained low and were far below standards. Carbon tetrachloride and associated organic constituents form a relatively large plume beneath the central portion of the Site. Hexavalent chromium is present in smaller plumes beneath the reactor areas along the river and beneath the central portion of the Site. Sr90 exceeds standards beneath each of the reactor areas, and Tc-99 and uranium are present in the 200 Areas. Other minor contaminant plumes are also noted. Interim groundwater remediation in the 100 and 200 Areas continued in 2002. The objective of the two interim remediation (P&T) systems in the 200-ZP-1 and 200-UP-1 Groundwater OUs in the 200 West Area is to prevent the spread of carbon tetrachloride and Tc-99/uranium plumes. This annual report presents groundwater contours and the perimeter of the carbon tetrachloride, chloroform, and trichloroethylene plumes within the 200-ZP-1 Groundwater OU, as well as groundwater contours and the perimeter of the Tc-99 and uranium plumes within the 200-UP-1 Groundwater OU. Maps are also provided showing the location of sampled groundwater wells and identifying the frequency at which wells are sampled, the depth of well screens, and so forth. A set of computer models known as the SAC (System Assessment Capability) simulates movement of contaminants from waste sites through the vadose zone and groundwater. In FY02, modelers completed an initial assessment of 10 contaminants, simulating their movement over the years 1944 through 3050. Specific modeling of plume movements in the 200 Areas and local-scale modeling of the 200 Area P&T IRMs were reported.

Table B. Bibliography

Reference	Summary
DOE/RL-2002-67, 2003, *Fiscal Year 2002 Annual/ Summary Report for the 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations, Rev. 0*	Interim RODs were issued for the 200-UP-1 and 200-ZP-1 Groundwater OUs in 1997 and 1995. The RODs require remediation of the area of highest contaminant concentrations of the baseline target plumes. The RAOs specified are the following: • Hydraulically contain the central area of the plume. • Reduce contaminant mass in the aquifer. • Protect HHE. • Gather data that will support a final remedy. • The COCs for each P&T system are as follows: – Tc-99 and uranium for the 200-UP-1 Groundwater OU (secondarily, carbon tetrachloride and nitrate). – Carbon tetrachloride for the 200-ZP-1 Groundwater OU (secondarily, chloroform and trichloroethylene). – The document summarizes performance of the groundwater P&T systems in FY02 and discusses the changes that have been observed in plume shape and concentration during the reporting period. – The two 200-UP-1 extraction wells operated at an average annual rate of 197 L/min, exceeding the ROD operational requirement of 189 L/min (50 gal/min). The amount of contaminant mass removed in FY02 was as follows: o Technetium-99: 14.5 g o Uranium: 26.4 kg o Carbon tetrachloride: 2.75 kg o Nitrate: 3,686 kg The 200-UP-1 hydraulic conditions did not change significantly in FY02. Based on field measurements and numerical modeling, hydraulic capture of the baseline plume area was maintained, meeting the RAO to prevent further migration of the baseline plume area. Water levels continued to decline at an estimated rate of 0.36 m/year, compared to 0.4 m/year in FY01. The water level decline has left the monitoring network without coverage in the south, southeast, or southwest portions of the 200-UP-1 plume. Additional monitoring wells planned for installation in future years will fill some of these monitoring gaps. Overall 200-UP-1 plume configurations for both Tc-99 and uranium are similar to those of past years, with two distinct high-concentration areas (one near each extraction well). As discussed in the IRM conceptual plan (BHI, 1996), there were four RAOs: • Maintain hydraulic control and contain the high-concentration area of the plume. • Prevent uranium and Tc-99 concentration from increasing downgradient from the containment zone. • Reduce uranium, Tc-99, and carbon tetrachloride to MCLs prior to reinjection or disposal of treated groundwater. • Obtain data to support a final remedy.

Table B. Bibliography

Reference	Summary
	Three of the four RAOs were met; however, the objective to reduce concentrations below the MCLs for Tc-99 and uranium was not achieved. It is reported that the RAO for Tc-99 may be achieved in the next 1 or 2 years, however, methods of enhancing reductions in uranium concentrations should be investigated. Other recommendations in the report included the following: • Replacing dry monitoring wells for plume tracking • Decommissioning dry monitoring wells to prevent recharge • Converting well 299-W19-43 from a monitoring well to an extraction well to reduce high-contamination concentrations
Modeling	
PNNL-14027, 2002, *An Initial Assessment of Hanford Impact Performed with the System Assessment Capability*	This document contains an explanation of the SAC framework and the results of recent runs. In 1999, DOE initiated the development of an assessment tool that will enable the users to model the movement of contaminants from all waste sites at Hanford through the vadose zone, groundwater, and the Columbia River and estimate the impact of contaminants on human health, ecology, and the local cultures and economy. An assessment was recently completed with the SAC demonstrating that it is a functional assessment capability. Future modifications to the tool will be driven by the requirements of specific assessments. Results will continue to improve as input data are refined through characterization and scientific research. The results of the first runs performed with SAC were presented to the Integration Project Expert Panel in September 2000. Analysis performed on these early results identified a number of issues that needed to be addressed before the tool could be considered useful. The major issues were addressed by replacing a simple two-dimensional groundwater model in the SAC with the three-dimensional Hanford Sitewide groundwater model, correcting the quantity of contaminant assigned to several waste sites, and obtaining more efficient hardware for performing analyses. Following the implementation of those changes, the assessment was re-run. The assessment included the following: • Modeled the movement of contaminants from more than 500 locations throughout the Site representing 890 waste sites through the vadose zone, groundwater, and Columbia River. • Incorporated data on 10 radioactive and chemical contaminants (carbon tetrachloride, Cs-137, chromium, I-129, Pu-239/240, Sr-90, Tc-99, tritium, total uranium, and U-238). • Focused on subsurface transport, the Columbia River, and risks to human and ecological health, and the economy and culture. See Section 5.3.1 of this document for an additional discussion of the anticipated use of the SAC in the 200-UP-1 Groundwater OU.

Table B. Bibliography

Reference	Summary
PNNL-11800, 1998, *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site*	A composite analysis was prepared for the Site considering only sources in the 200 Area Plateau. Estimating doses to hypothetical members of the public for the composite analysis was a multi-step process involving the estimation or simulation of inventories; waste release to the environment; migration through the vadose zone, groundwater, and atmospheric pathways; and exposure and dose. Doses were estimated for scenarios based on agriculture, residential, industrial, and recreational land uses. The radionuclides included in the vadose zone and groundwater pathway analyses of future releases were C-14, Cl-36, Se-79, Tc-99, I-129, and uranium isotopes. In addition, tritium and Sr-90 were included because they exist in groundwater plumes. Radionuclides considered in the atmospheric pathway included tritium and C-14. The analysis indicated that most of the radionuclide inventory in past-practice liquid discharge and solid waste burial sites on the 200 Area plateau was projected to be released in the first several hundred years following Site closure. The radionuclide doses for all of the exposure scenarios outside of a defined buffer zone were all <3 mrem/year, which is well below the performance objectives of 100 mrem/year or the ALARA objective of 30 mrem/year.
	Several sources of uncertainty were noted in the first iteration of the composite analysis, with the largest uncertainty associated with the inventories of key mobile radionuclides. Other sources of uncertainty in the analysis arose from the conceptual and numerical models of contaminant migration and fate in the vadose zone and assumption regarding source-term release models and end states. The composite analysis demonstrated a significant separation in time between past-practice discharges and disposals, and active and planned disposal of solid waste, environment restoration waste, and immobilized low-activity waste. The higher integrity disposal facilities and surface covers of these active and planned disposal delay releases and the releases do not superimpose on the plumes from the near-term past-practice disposals. See Section 5.3.1 of this document for an additional discussion of the anticipated use of the SAC in the 200-UP-1 Groundwater OU.

Table B. Bibliography

Reference	Summary
HNF-45099, 2010, *Development of a Geochemical Model for Uranium Transport in the Unsaturated and Saturated Sediments at the 200 West Area of the Department of Energy Hanford Site, Washington*	The document provides discussion of initial work to develop a geochemical model for transport of uranium through the unsaturated and saturated zone in the 200-UP-1 Groundwater OU. The distribution of contaminants (uranium) in the soil profile depends on the physical properties of the waste stream, which provides the transport medium (water) and the chemical properties of the contaminant. Other characteristics affecting the contaminant soil interaction include the geologic and geochemical properties of the soil column and the composition of soil moisture and soil gases. The major modeling assumptions presented in the document include the following: • The primary sorbents of uranium are Fe(III) and Al oxyhydroxides, clays, zeolites, phosphate minerals, and organic matter. Previous studies cited in the document have indicated that iron-hydroxide surface sites (FeOM) dominate UO2+2 complexation in Hanford soils. MSE assumed that the primary sorbent of uranium in soils was FeOH. • MSE chose to use a diffuse layer surface complexation model for the geochemical modeling efforts. The primary parameters of interest for the modeling included the concentration of available sorbing sites in a given volume of the soil matrix, the surface area of the sorbents exposed to the groundwater, and the thermodynamic equilibrium constants for reactions involving surface sites and aqueous components. The results of the initial geochemical model and the results from batch testing are presented in this report. The results are presented as plots of the percent of uranium adsorbed as a function of the pH under which the adsorption occurred for both the model predictions and observed data. The results indicated poor agreement between the modeled and observed values for adsorption; however, it was reported that the general shape of the of the modeled and observed sorption curves was, in most cases, promising. Additional work to resolve discrepancies between the model and batch testing is in progress.
WHC-EP-0133, 1988, *U1/U2 Uranium Plume Characterization, Remedial Action Review and Recommendation for Future Action*	This document notes the following: • The contaminant plume below the 216-U-1 and 216-U-2 Cribs is moving slowly, so delay of remediation by up to 10 years will not significantly increase time and cost of cleanup. • Pumping commenced on June 13, 1985, and continued until November 26, 1985. A total of 8 million gal of groundwater were pumped and treated to remove 687 kg of uranium via an ion-exchange column. The maximum uranium concentration was reduced from about 72,000 to 17,000 pCi/L.

Table B. Bibliography

Reference	Summary
	It is recommended that: • Additional multi-level sampling devices should be installed to characterize the horizontal and vertical extent of the plume. • Aquifer test should be performed to determine hydraulic properties of the U1 and U2 Sites. • Using the additional characterization data obtained above, three-dimensional flow and transport models should be developed to evaluate the vertical extent of contaminant migration under no action and pumping scenarios. • Before resuming groundwater pumping for cleanup, transport simulations should be performed to evaluate the effect that pumping would have on other groundwater contamination (the carbon tetrachloride contamination from the PFP). • Additional contamination may be introduced into the aquifer below the 216-U-1 and 216-U-2 Cribs by discharge of treated groundwater. The treated groundwater contains some residual contamination because the ion-column treatment system cannot be 100% efficient, and additional contamination may be transported from the unsaturated portion of the flow system to the water table. This should continue to be considered when planning for remediation. • The nitrate contamination in the groundwater below the 216-U-1 and 216-U-2 Cribs is also characterized in this document.
WHC-EP-0342, Addendum 19, 1990, *UO_3 Plant Process Condensate Stream-Specific Report*	This document notes that the proposed waste stream designation for the UO_3 Plant process condensate waste stream is that this stream is not a dangerous waste, as defined by WAC 173-303, "Dangerous Waste Regulations." A combination of process knowledge and sampling data was used to make this determination. Traces of butanol, acetone, and 2-butanone were identified as process impurities sent with uranyl nitrate hexahydrate from the PUREX Plant.
DOE/RL-2002-10, 2002, *Sampling and Analysis Plan for the 200-UP-1 Groundwater Monitoring Well Network, Rev. 0*	
DOE/RL-91-52, 1992, *U Plant Source Aggregate Area Management Study Report, Rev. 0*	The 216-U-1 and 216-U-2 Cribs are located 61 m (200 ft) north of 16th Street and 205 m (1,000 ft) east of the 207-U retention basins. Each crib is composed of a 3.6 m by 3.6 m by 1.2 m (12 ft by 12 ft by 4 ft) deep wooden structure constructed of 15 cm by 15 cm (6 in. by 6 in.) timbers on undisturbed soil at the bottom of 6.1 m (20 ft) deep backfilled excavations, with 1:1 side slopes. The cribs were backfilled with native soil. The cribs are 18 m (60 ft) apart and are connected by a 8.9 cm (3.5 in.) diameter, stainless-steel pipe. Overflow from the 216-U-1 Crib flows to the 216-U-2 Crib. All wastes flowed to the 216-U-1 and 216-U-2 Cribs from the 241-U-361 settling tank, which is 24 m (80 ft) east of the 216-U-1 Crib. Reportedly, 4,000 kg (8,900 lb) of uranium were discharged to the cribs between 1957 and 1967 (WHC-EP-0400, 1991, *200-UP-2 Operable Unit Technical Baseline Report*). The uranium reacted with the sediments to form carbonate-phosphate compounds. After 1967, other cribs (notably 216-U-12) were used to dispose this wastewater.

Table B. Bibliography

Reference	Summary
	The 216-U-4 reverse well is the only reverse well in the U Plant aggregate area and is located 5.2 m (17 ft) west and 0.6 m (2 ft) north of the west corner of the 222-U Laboratory building. This State of Washington-registered underground injection well is a 7.6 cm (3 in.) diameter steel pipe, extending 23 m (75 ft) beneath the surface. The bottom 2.4 m (8 ft) is perforated. From 1947 to 1955, the 216-U-4 reverse well received 300,000 L (80,000 gal) of decontamination waste from the 222-U Laboratory hood sinks (acidic plutonium and fission product waste). In 1955, when the 216-U-4 reverse well began to plug, it was deactivated and an overflow line was installed to the new 216-U-4A French drain. It is documented that the well was sealed off (WHC-EP-0400). The 216-U-4A French drain was installed to receive 222-U Laboratory hood sink wastes when the 215-U-4 reverse well began to plug in 1955. The drain was installed 2.4 m (8 ft) north of the well, and the 216-U-4A French drain and well were connected by an overflow line. The 216-U-4A French drain is a 130 cm (51 in.) diameter concrete pipe extending downward at least 1.2 m (4 ft), and the upper surface is 1.5 m (5 ft) below grade. The drain rests on undisturbed soil and is not gravel-filled. From 1955 to 1970, the 216-U-4A French drain received 545,000 L (144,000 gal) of acidic plutonium and fission product decontamination waste. The 216-U-8 Crib consists of three underground timber crib structures within a north/south-oriented trench that is approximately 49 m by 15.2 m (160 ft by 50 ft), backfilled with gravel. Each crib is a 4.9 m by 4.9 m by 3 m (16 ft by 16 ft by 10 ft) box, constructed of 0.15 m by 0.2 m (6 in. by 8 in.) Douglas fir timbers resting on a 0.9 m (3 ft) thick gravel bed, about 9.4 m (31 ft) below grade. The 216-U-8 Crib is located 137 m (450 ft) west of Beloit Avenue and 229 m (750 ft) south of 16th Street. Approximately 379,000 L (100,000 gal) of acidic process condensate from the 221-U and 224-U Buildings and the 291-U stack drainage system were discharged to the crib. In 1960, the surface above the 216-U-8 Crib began to subside. In response to this subsidence, the incoming line was blanked off and the waste was diverted to the 215-U-12 Crib (RHO-CD-673, 1979, *Handbook 200 Areas Waste Site*). The 216-U-8 Crib reportedly holds the largest inventory of waste uranium of any 200 West Area crib.
WHC-EP-0287, 1989, *Waste Stream Characterization Report, Vols. 2 and 3*	The principal source of waste to the S Plant wastewater is overflow of raw water from the fire protection water tank. Cooling water from REDOX and steam condensate are minor contributors. In addition, the 222-S Laboratory discharged wastewater into the 216-SS-10 Ditch on a temporary basis. Radionuclides previously detected include Sr-89/90 and Cs-137. The UO_3 Plant process condensate is obtained from plant overheads. Plant campaigns are conducted for several week intervals, several times a year, to calcine that is contained in aqueous solutions of uranyl nitrate. Since January 1988, the condensate has been collected and neutralized batch-wise prior to discharge, which has had significant impact on the pH data collected after this date. The waste stream is evaluated as two discharges: the first is associated with plant operation, and the second is generated when the plant is in standby status. Radionuclides previously detected include hydrogen-3 and uranium. The UO_3 Plant and U Plant wastewater contains process cooling water and steam condensate, aqueous makeup waste, sink and floor drain waste from the UO_3 Plant, facility cooling water and steam condensate from both plants, and yard drainage associated with nitric acid loadout activities. Aqueous makeup and nitric acid loadout activities are controlled by procedures to reduce the risk of the introduction of chemicals into this waste stream through floor drains. Seasonal variation of this waste stream is possible. Radionuclides previously detected include hydrogen-3, uranium, and Tc-99.

Table B. Bibliography

Reference	Summary
PNNL-14301, 2003, *Monitoring Plan for RCRA Groundwater Assessment at the 216-U-12 Crib*	The 216-U-12 Crib received process waste from U Plant and the 224 Building, which has impacted the unconfined aquifer. This document provides information on the monitoring well network design, monitoring constituents, sampling and analysis protocols and frequency, quality assurance, data management, site hydrogeology, a conceptual model of the RCRA facility, and an integrated CERCLA/RCRA final status post-closure monitoring plan. The document notes that the 216-U-12 Crib was built in 1960 to replace the 216-U-8 Crib when it showed signs of potential cave-in. The 216-U-12 Crib was operational until 1988, when the pipeline was cut and capped. The retired 216-U-12 Crib was replaced by the 216-U-17 Crib, which operated from 1988 to 1994. The crib is located downgradient of several other liquid waste disposal cribs in the 200 West Area. These cribs received large volumes of liquid effluent containing radioactive and hazardous waste at various times during the operational history of the U and S Plants.
PNL-6456, 1988, *Hazard Ranking System Evaluation of CERCLA Inactive Waste Sites at Hanford, Volume 1 – Evaluation Methods and Results and Volume 2 – Engineered-Facility Sites (HISS Data Base)*	Based on volume of waste disposed at each REDOX waste site, a calculation was made to determine if the volume disposed exceeded the volume necessary to cause groundwater contamination as result of its operation. At total of 13 inactive waste sites exceeded the volume criteria. Seven of the sites (216-S-3, 216-S-4, 216-S-5, 216-S-6, 216-S-16D, 216-S-16P, and 216-S-17) received steam condensate and cooling water with little or no chemical or radiological content and, therefore, are not of much concern (primarily the S-ponds and ditches). The other six sites (216-S-1 and 2, 216-S-7, 216-S-9, 216-S-11, 216-S-20, and 216-S-21) were either process condensate wastes or process wastes that would contain sufficient chemical and radionuclide contamination to cause groundwater impacts. The process condensate sites 216-S-1 and 2, 216-S-7, 216-S-9, and 216-S-21 have the greatest volume. Sites 216-S-1 and 2, 216-S-7, and 216-S-9 are REDOX process condensate sites, which means they received liquids generated due to the dissolution of nuclear fuel elements in nitric acid. The primary contaminants in these streams are nitrate, tritium, and I-129. These sources are all located in the region north of REDOX and represent the origin of the large plume of the previously mentioned contaminants. Site 216-S-21 is from 241-SX Tank Farm, which contained a number of tanks of self-boiling wastes that produced large volumes of condensate. These wastes were much less concentrated than the REDOX dissolver condensate described previously. The last two sites considered potentially significant were 216-S-20 and 216-S-11. Site 216-S-20 received process waste from the 222-S Laboratory, also a far less concentrated waste stream, and it is in a location downgradient from the previously mentioned, more significant sources that could easily mask the impact of this site. Site 216-S-11, on the other hand, only received a relatively small volume of process waste and very large volume of cooling water, leaving little chance for any measurable groundwater impact.

Table B. Bibliography

Reference		Summary
AAMS	=	Aggregate Area Management Study
AAMSR	=	Aggregate Area Management Study Report
AEA	=	*Atomic Energy Act of 1954*
ALARA	=	as low as reasonably achievable
ARAR	=	applicable or relevant and appropriate requirement
CERCLA	=	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	=	*Code of Federal Regulations*
COC	=	contaminant of concern
DOE	=	U.S. Department of Energy
DQO	=	data quality objective
DWS	=	drinking water standard
Ecology	=	Washington State Department of Ecology
EPA	=	U.S. Environmental Protection Agency
ERA	=	expedited response action
ERDF	=	Environmental Restoration Disposal Facility
ETF	=	Effluent Treatment Facility
FY	=	fiscal year
HHE	=	human health and the environment
IRM	=	interim remedial measure
LFI	=	limited field investigation
MCL	=	maximum contaminant level
MNA	=	monitored natural attenuation
MSE	=	MSE Technology Applications, Inc.
NCP	=	*National Oil and Hazardous Substances Pollution Contingency Plan*
N&E	=	nature and extent
OU	=	operable unit
P&T	=	pump-and-treat
PFP	=	Plutonium Finishing Plant
PUREX	=	Plutonium-Uranium Extraction (Plant)
RA	=	Remedial Action
RAO	=	remedial action objective
RCRA	=	*Resource Conservation and Recovery Act of 1976*
REDOX	=	Reduction-Oxidation (Plant)
RI/FS	=	remedial investigation/feasibility study
RFI/CMS	=	RCRA facility investigation/corrective measures study
ROD	=	record of decision
SAC	=	system assessment capability
SARA	=	*Superfund Amendments and Reauthorization Act of 1986*
Tri-Party Agreement	=	*Hanford Federal Facility Agreement and Consent Order* (Ecology et al., 1989)
TSD	=	treatment, storage, and disposal
WAC	=	*Washington Administrative Code*

Appendix C

Geological Cross Sections

1

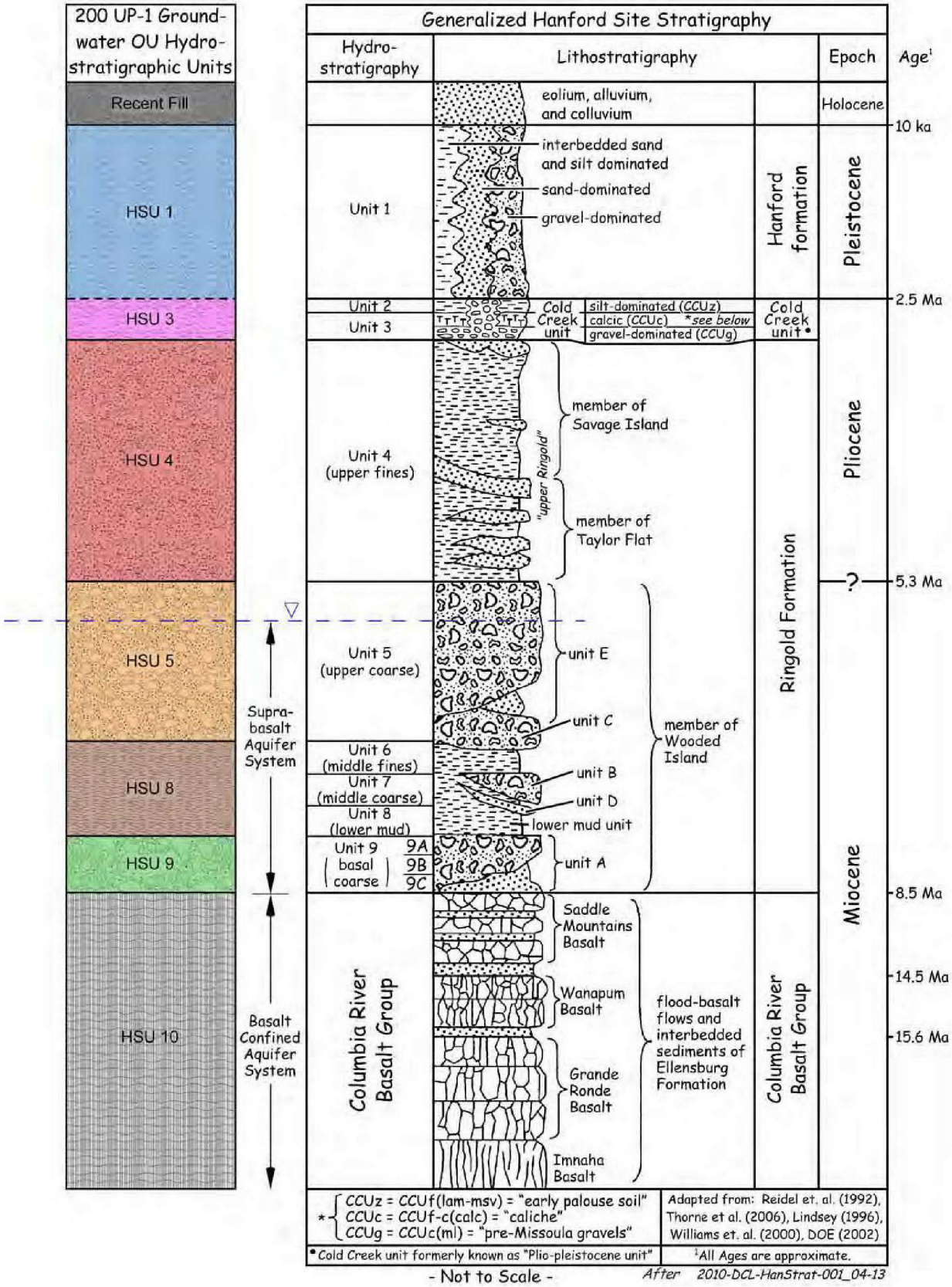

Figure C-1. Hydrogeologic Nomenclature Comparison for the 200-UP-1 Groundwater Operable Unit

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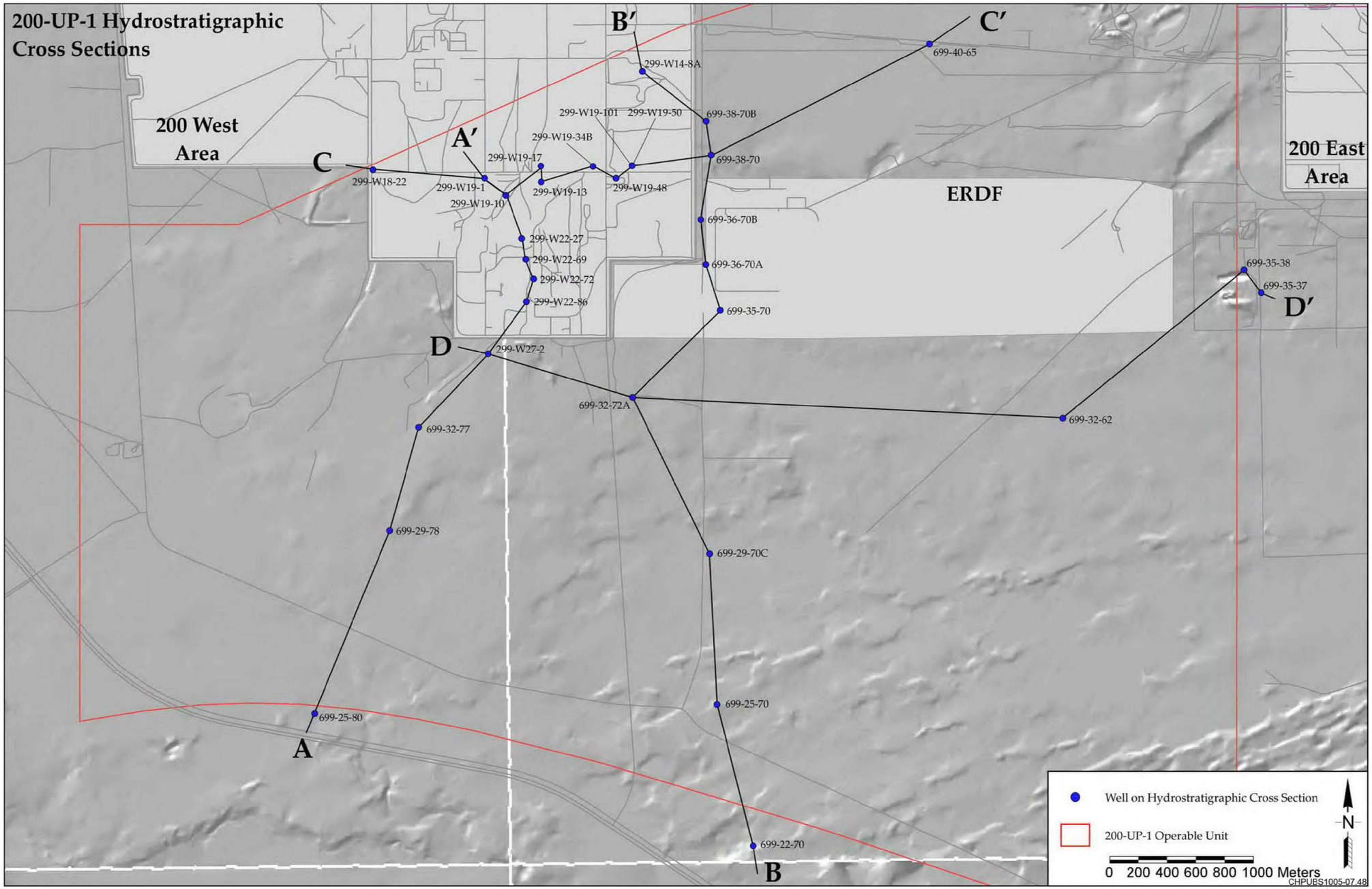

Figure C-2. 200-UP-1 Hydrostratigraphic Cross Sections

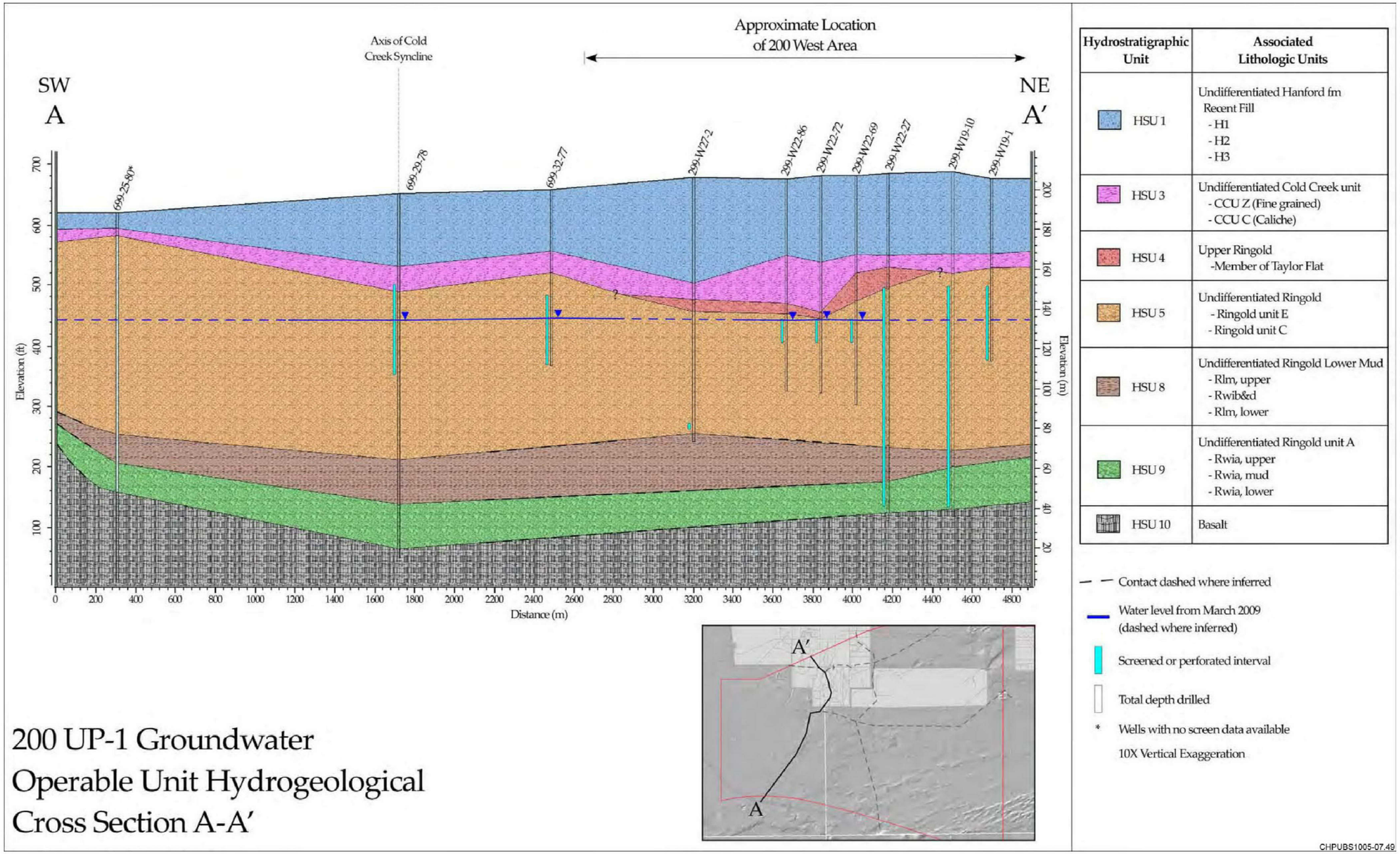

Figure C-3. 200-UP-1 Groundwater Operable Unit Hydrogeological Cross Section A-A'

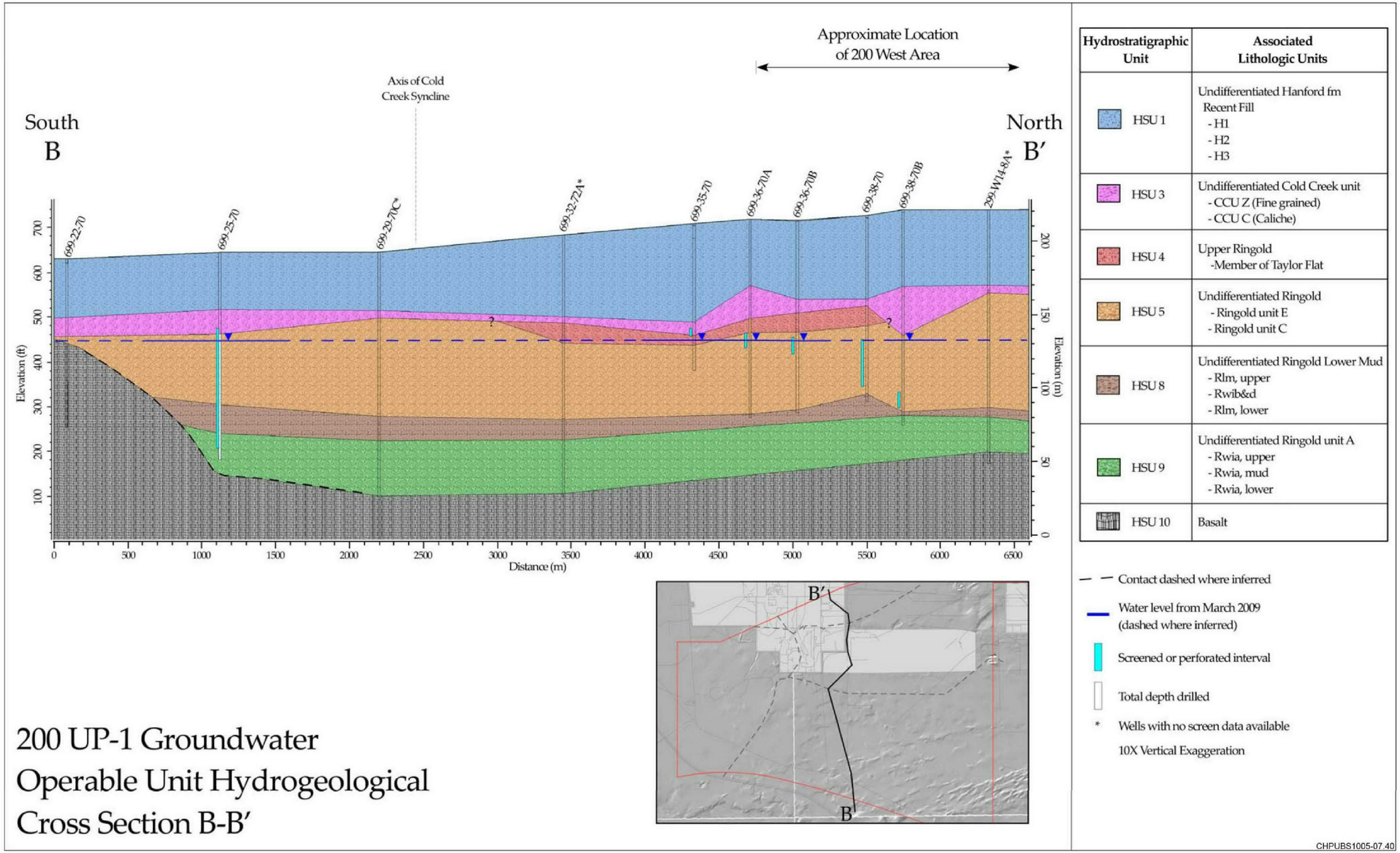

Figure C-4. 200-UP-1 Groundwater Operable Unit Hydrogeological Cross Section B-B'

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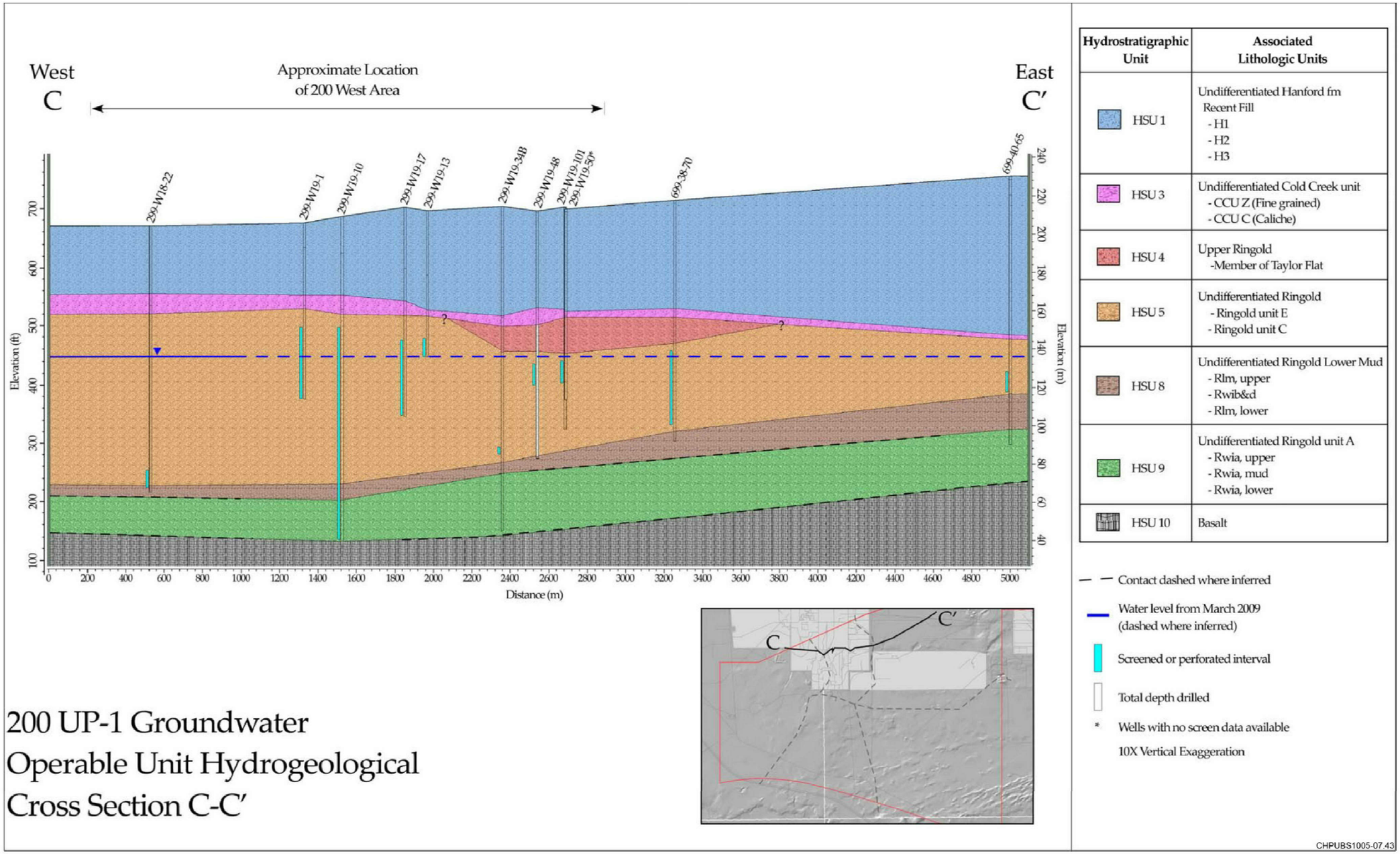

Figure C-5. 200-UP-1 Groundwater Operable Unit Hydrogeological Cross Section C-C'

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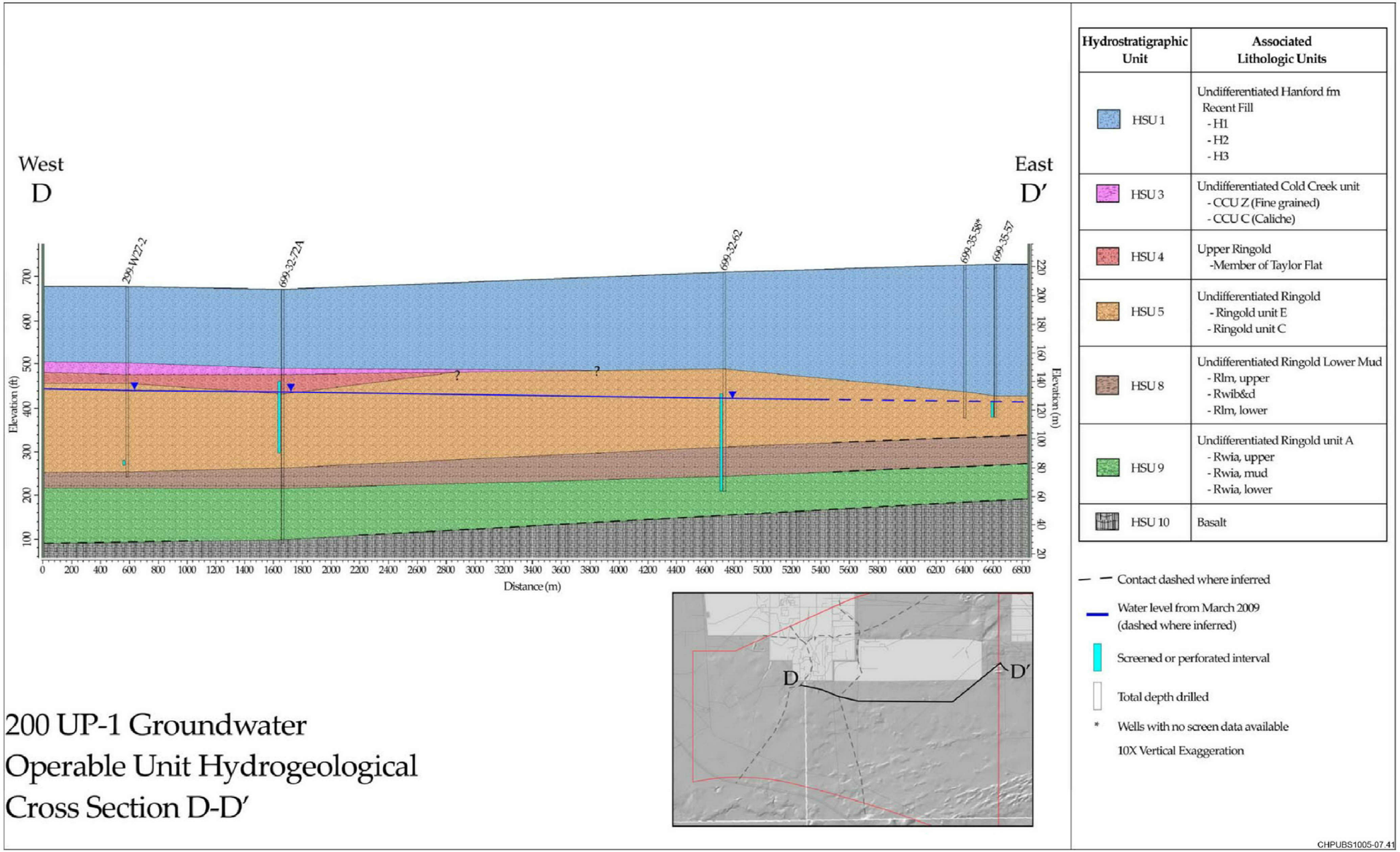

Figure C-6. 200-UP-1 Groundwater Operable Unit Hydrogeological Cross Section D-D'

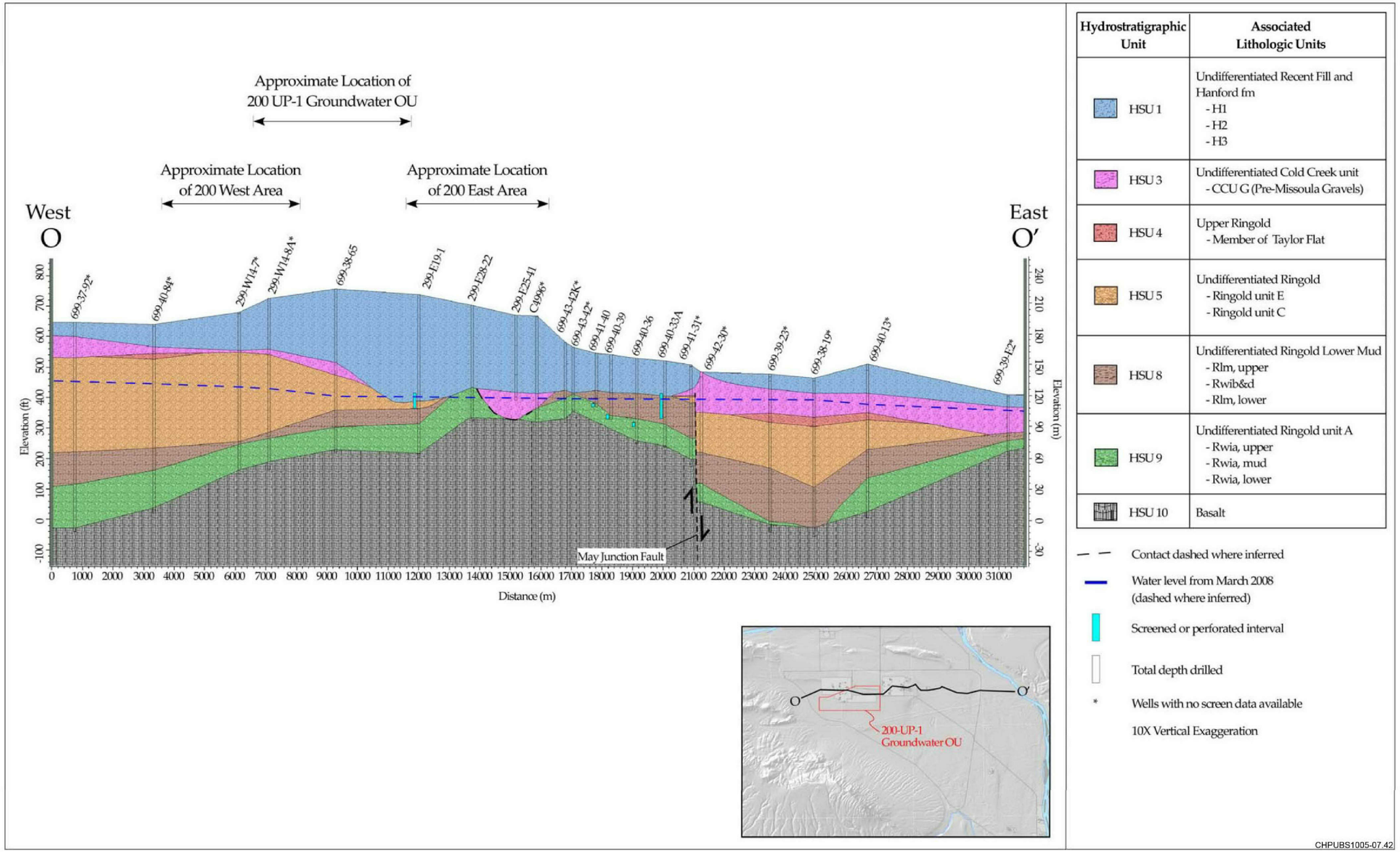

Figure C-7. 200-UP-1 Groundwater Operable Unit Hydrogeological Cross Section O-O'

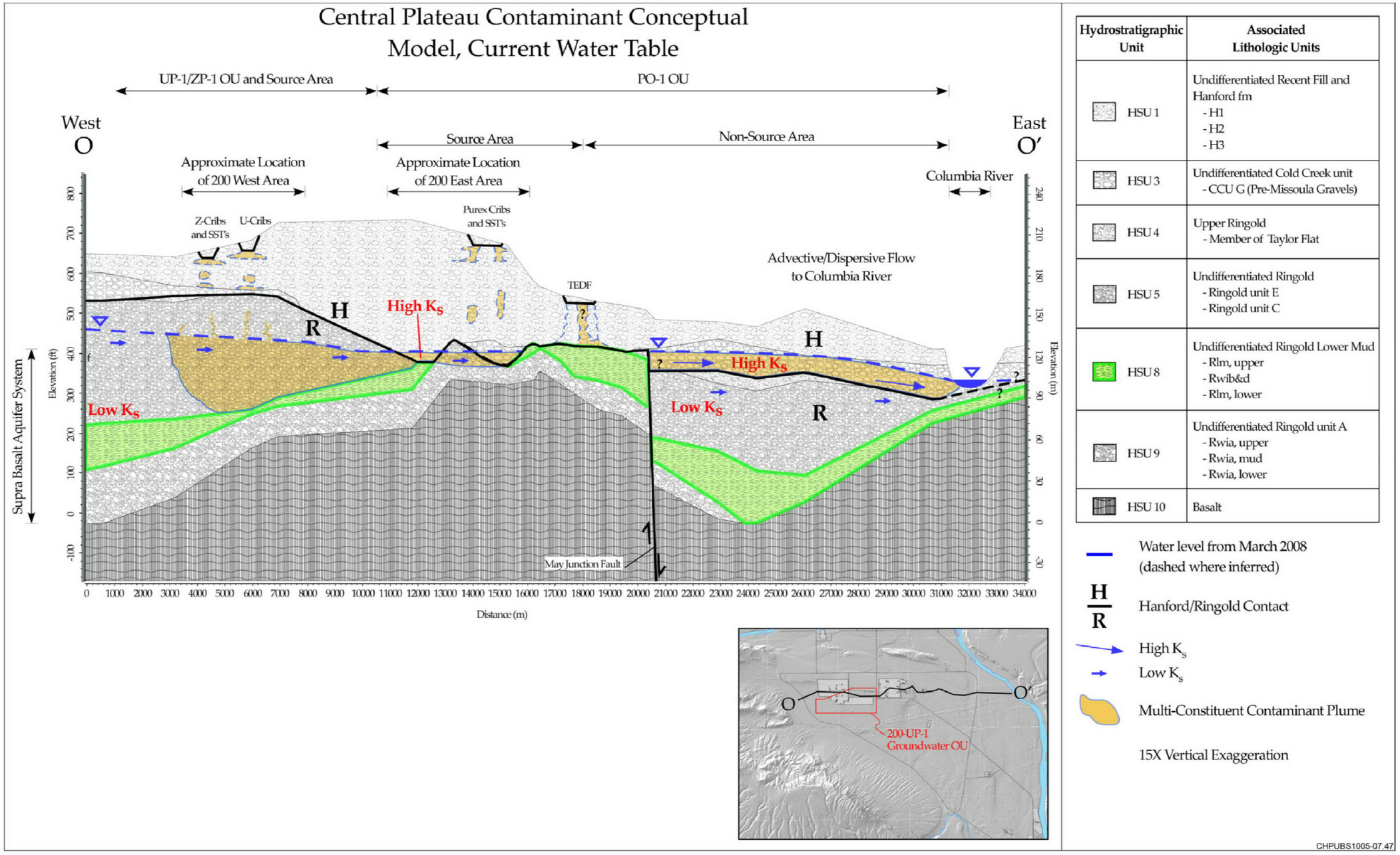

Figure C-8. Central Plateau Contaminant Conceptual Model, Current Water Table

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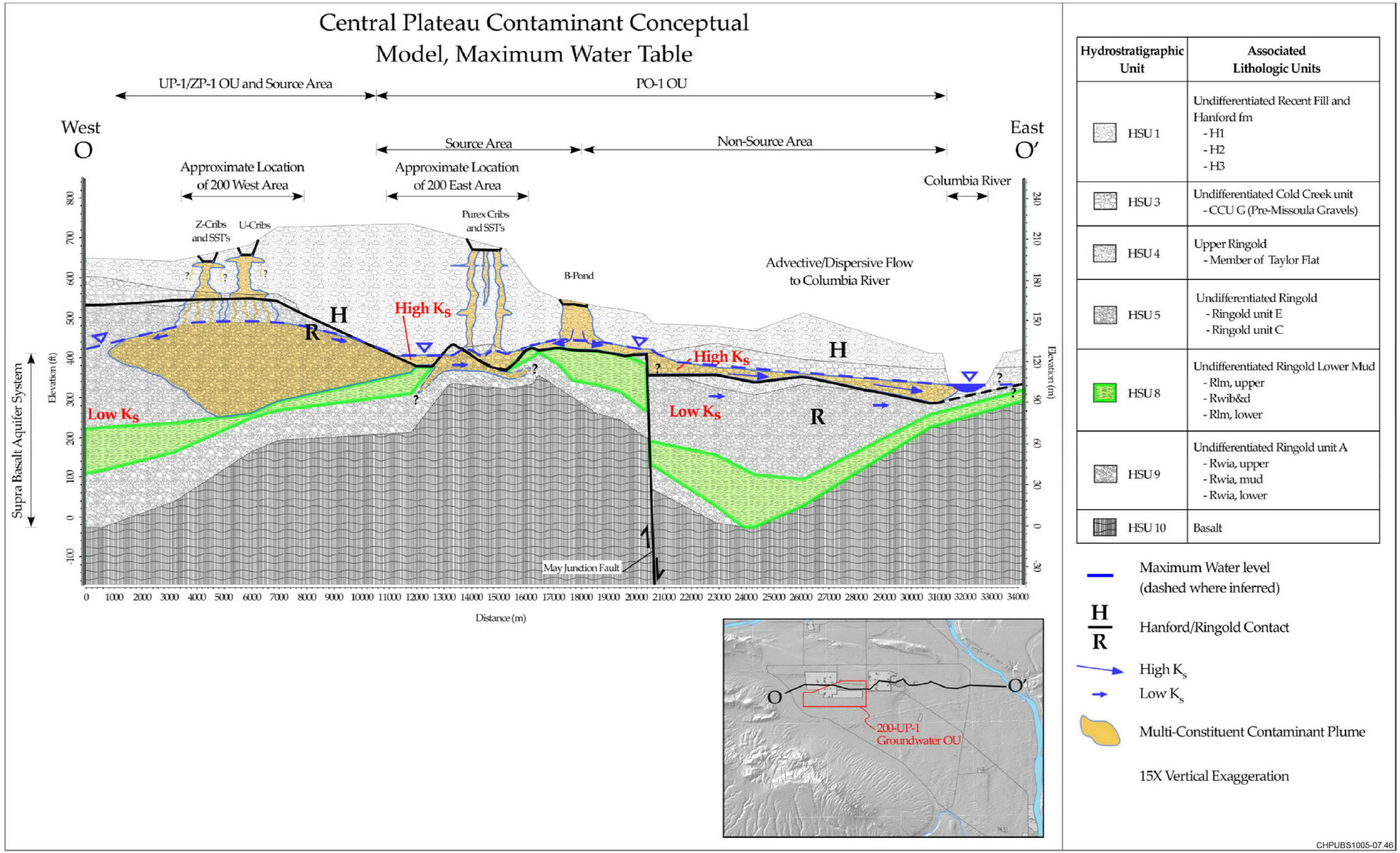

Figure C-9. Central Plateau Contaminant Conceptual Model, Maximum Water Table

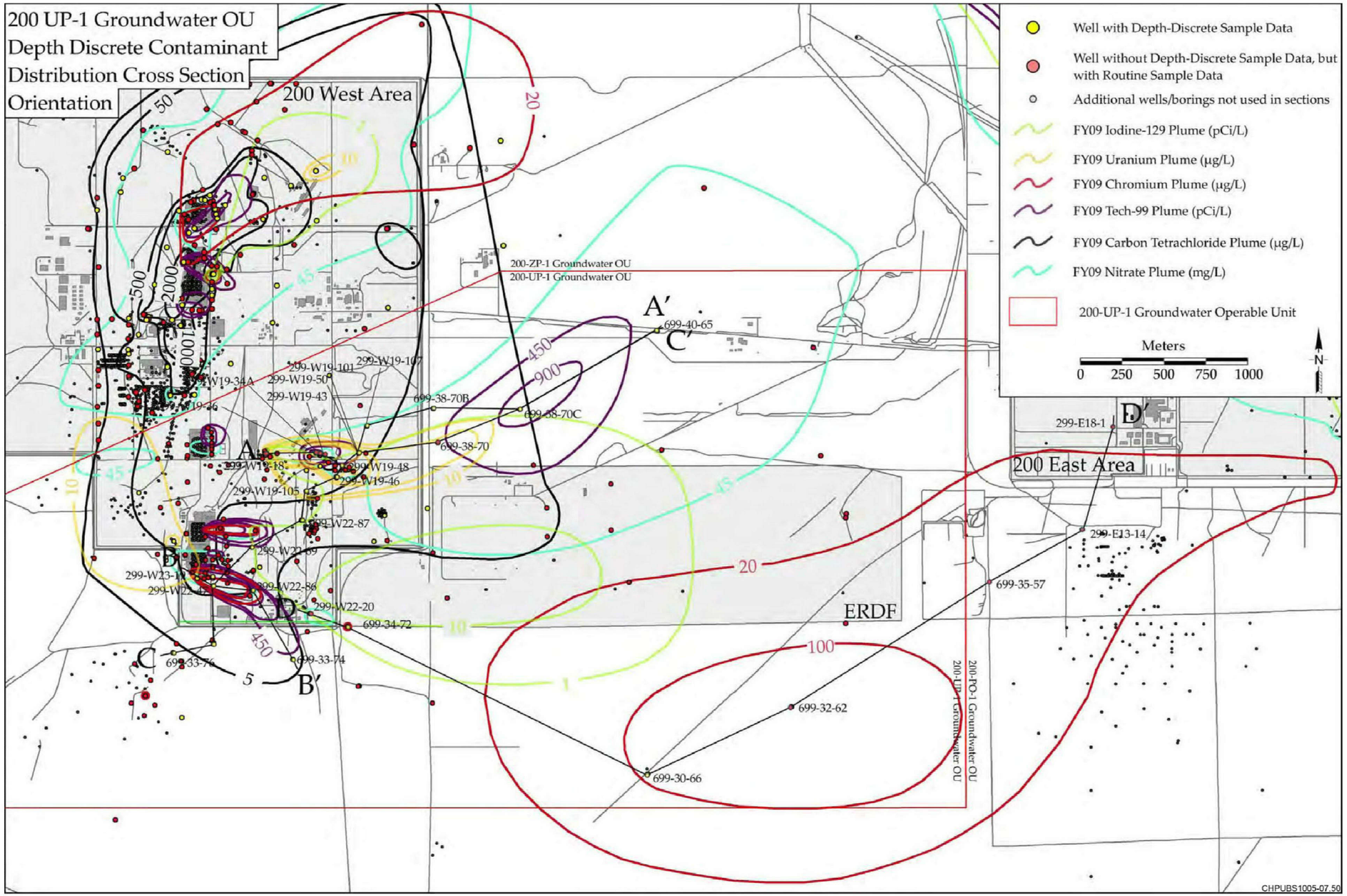

Figure C-10. 200-UP-1 Groundwater OU Depth Discrete Contaminant Distribution Cross Section Orientation

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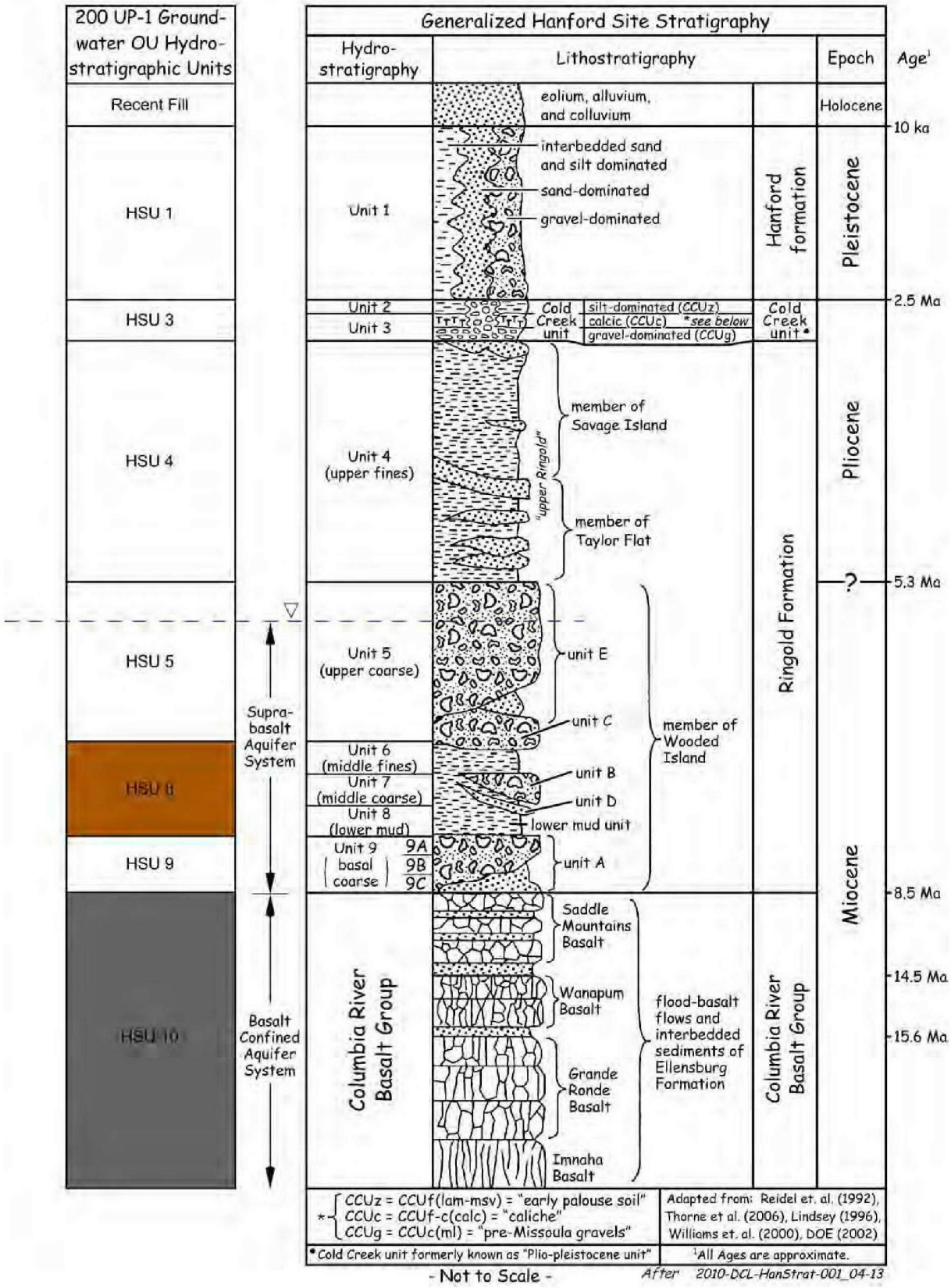

Figure C-11. 200 UP-1 Groundwater Operable Unit Hydrostratigraphic Nomenclature

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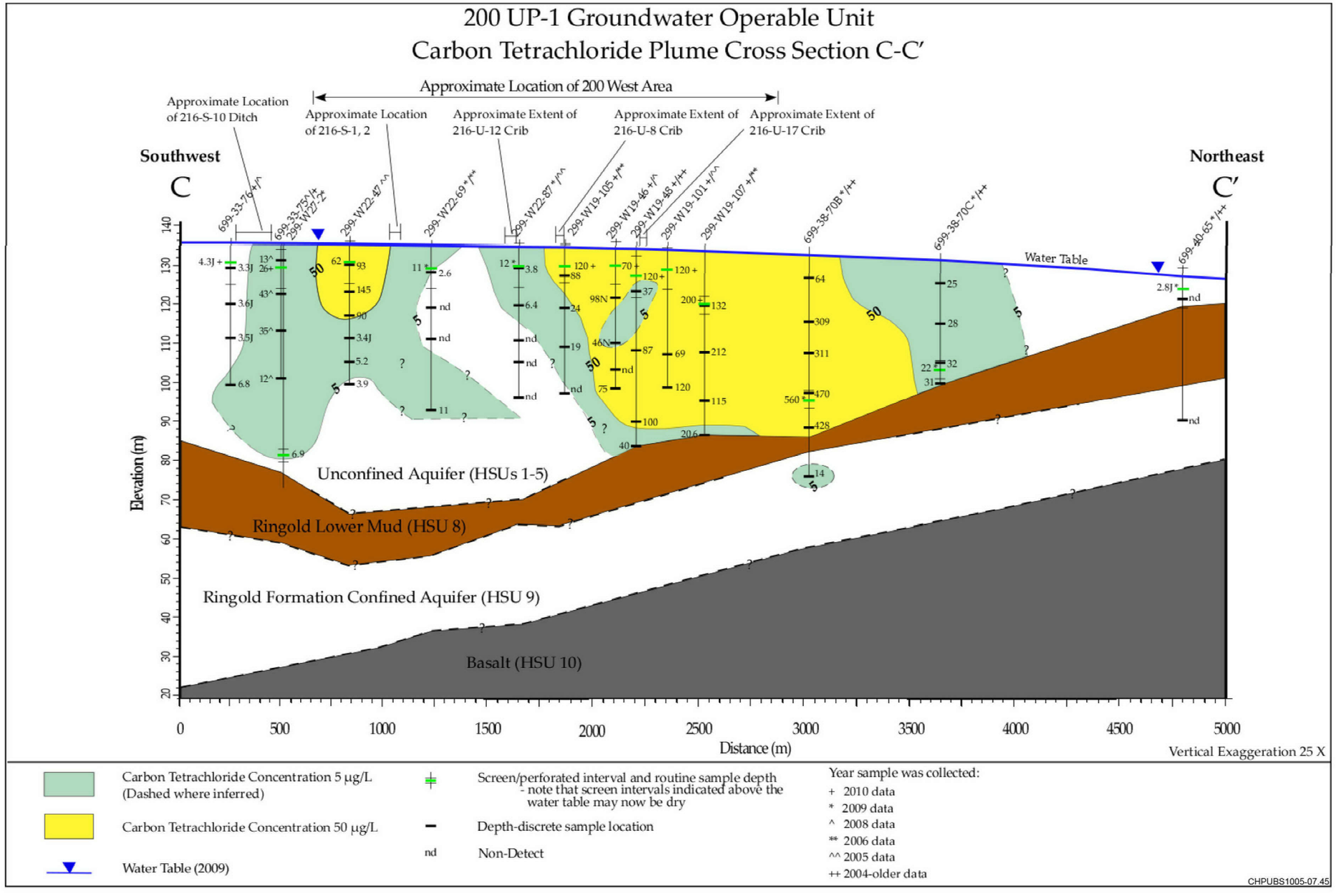

Figure C-12. 200-UP-1 Groundwater Operable Unit Carbon Tetrachloride Plume Cross Section A-A'

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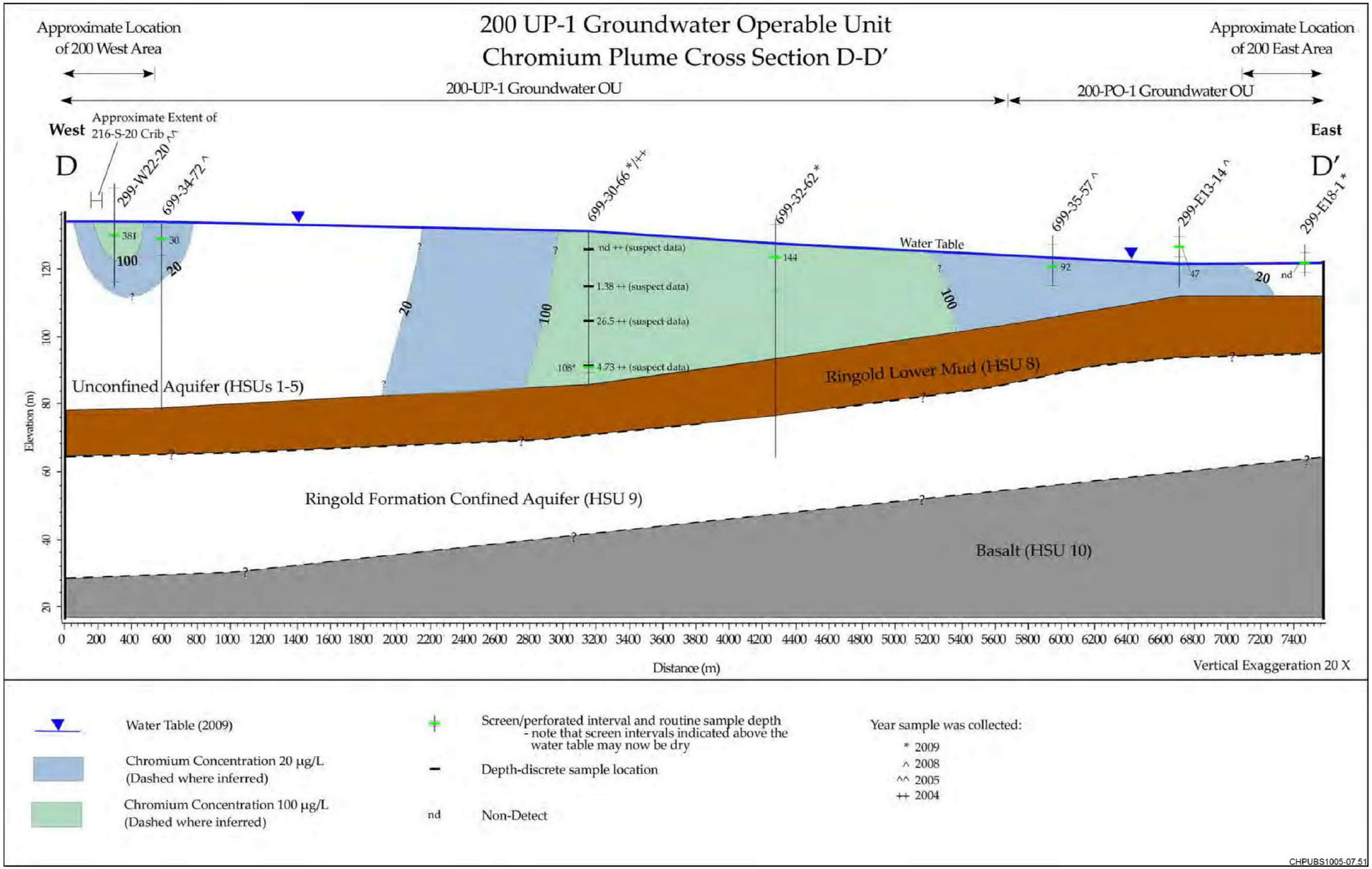

Figure C-13. 200-UP-1 Groundwater Operable Unit Chromium Plume Cross Section D-D'

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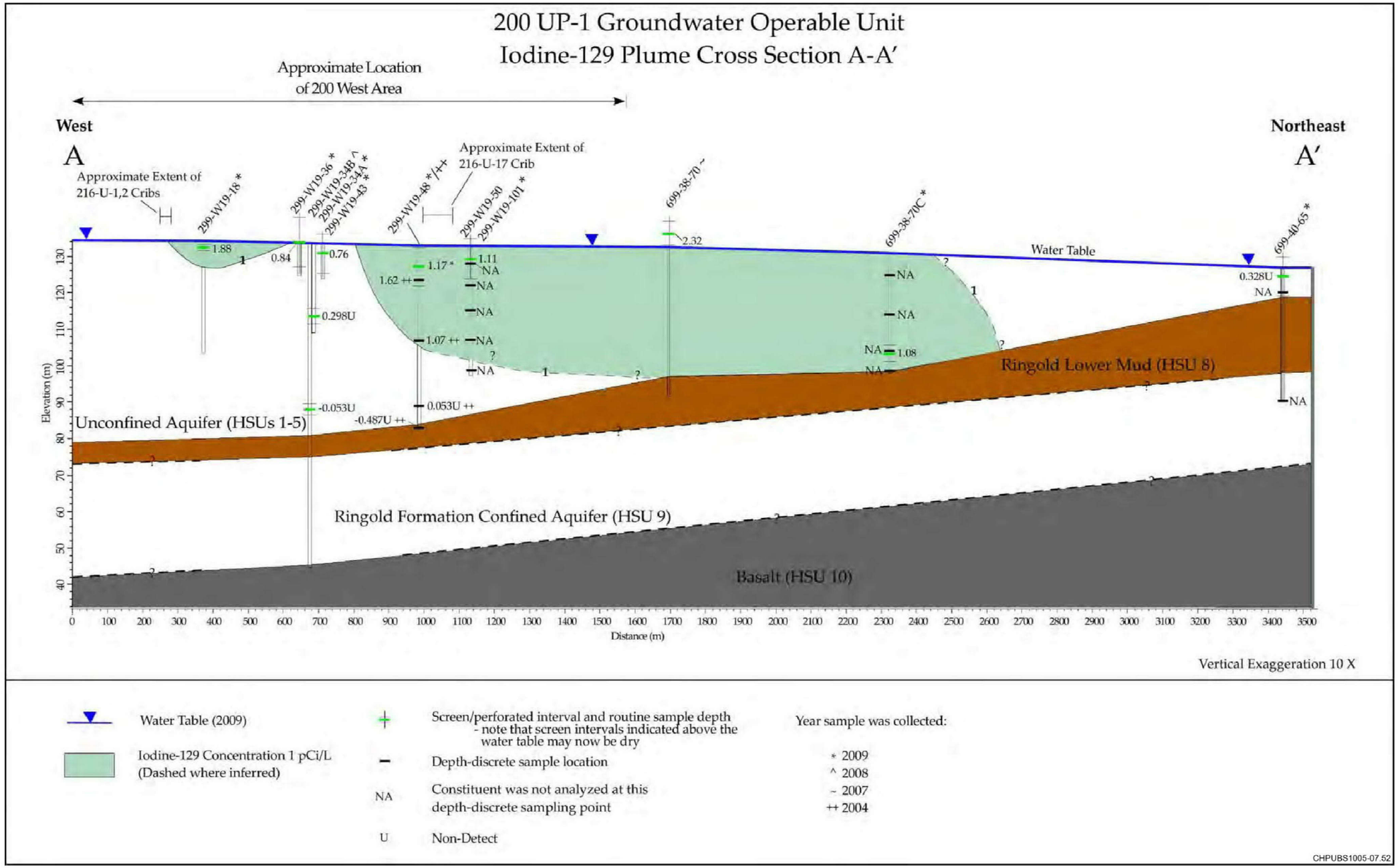

Figure C-14. 200-UP-1 Groundwater Operable Unit Iodine-129 Plume Cross Section A-A'

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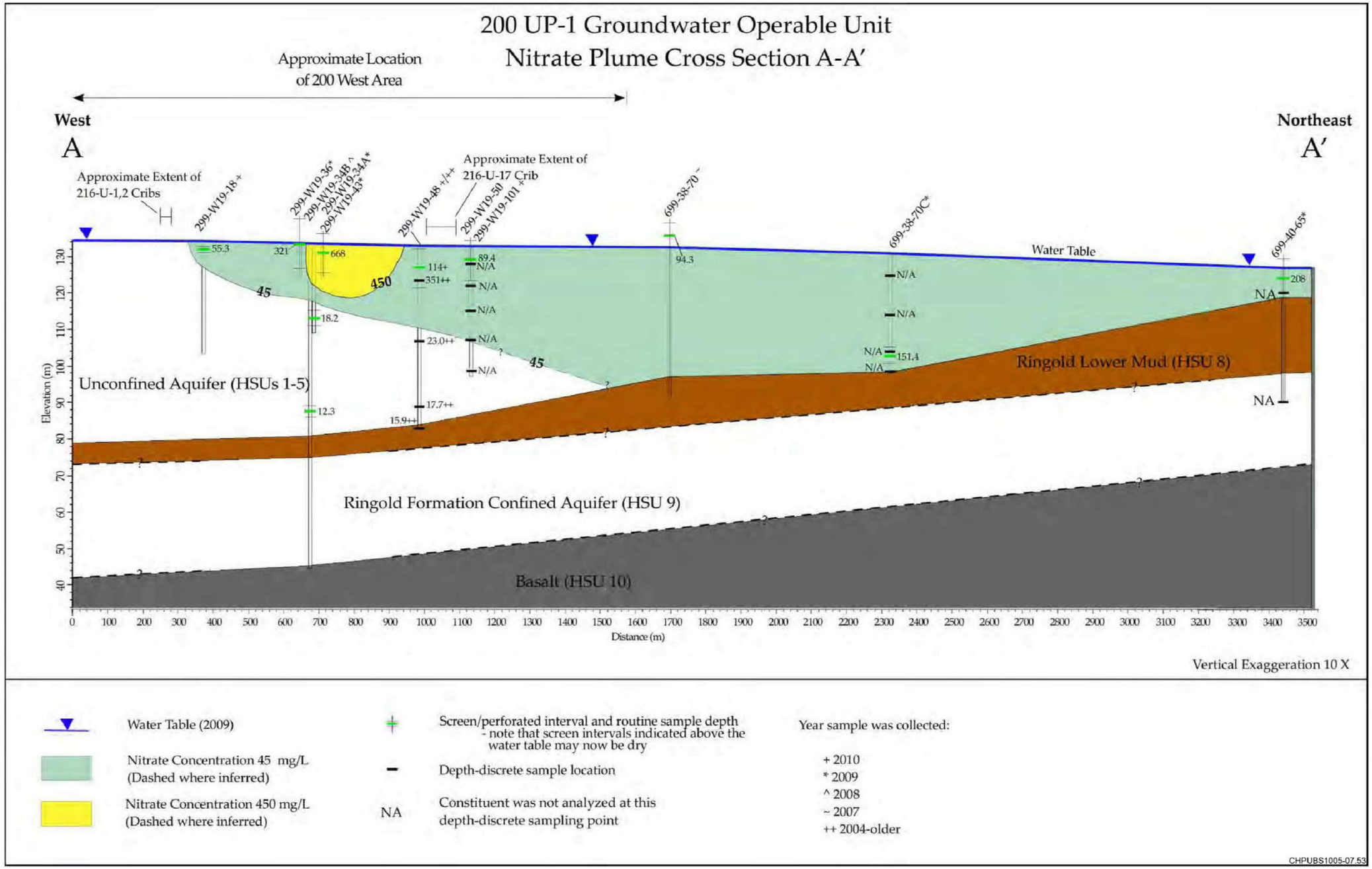

Figure C-15. 200-UP-1 Groundwater Operable Unit Nitrate Plume Cross Section A-A'

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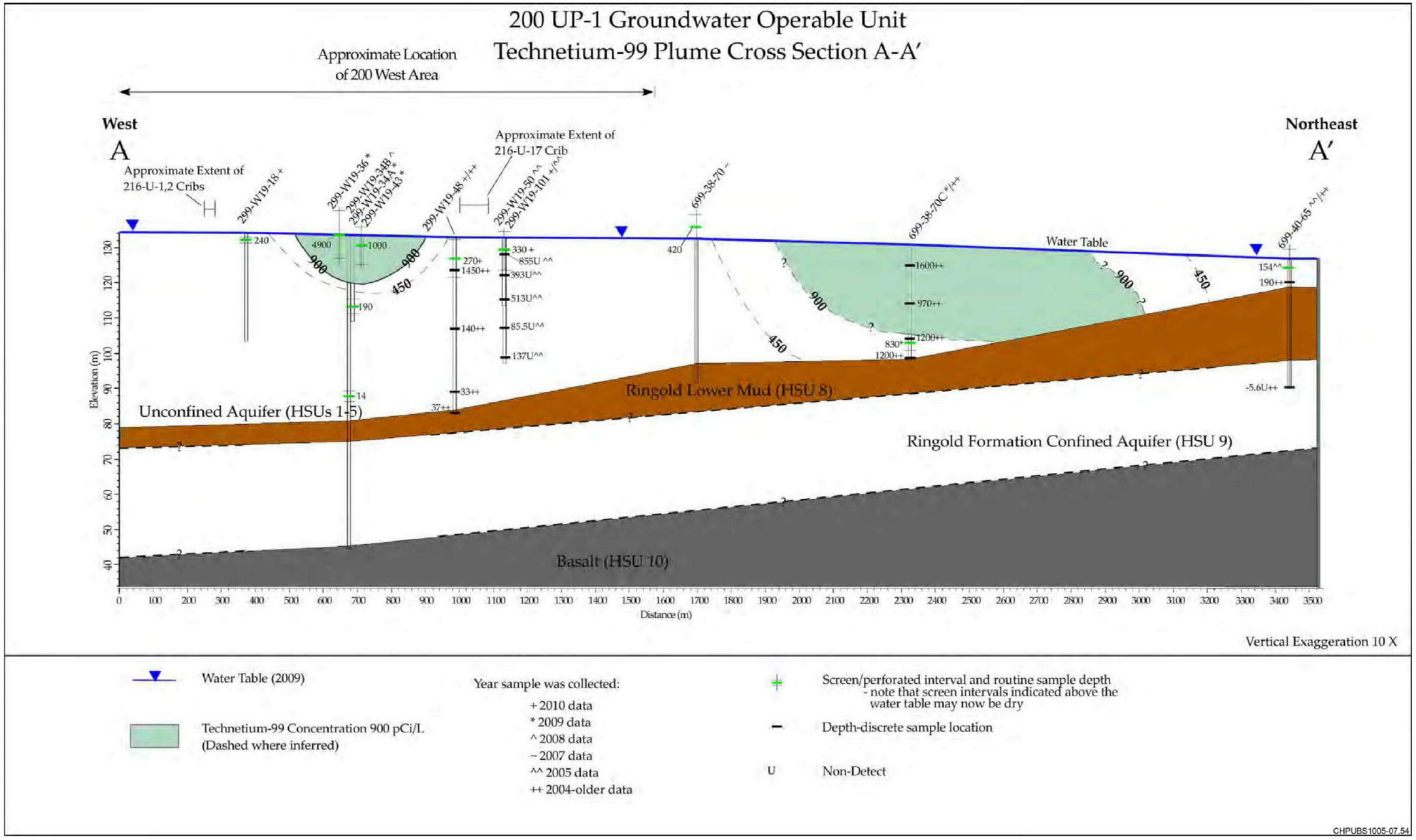

Figure C-16. 200-UP-1 Groundwater Operable Unit Technetium-99 Plume Cross Section A-A'

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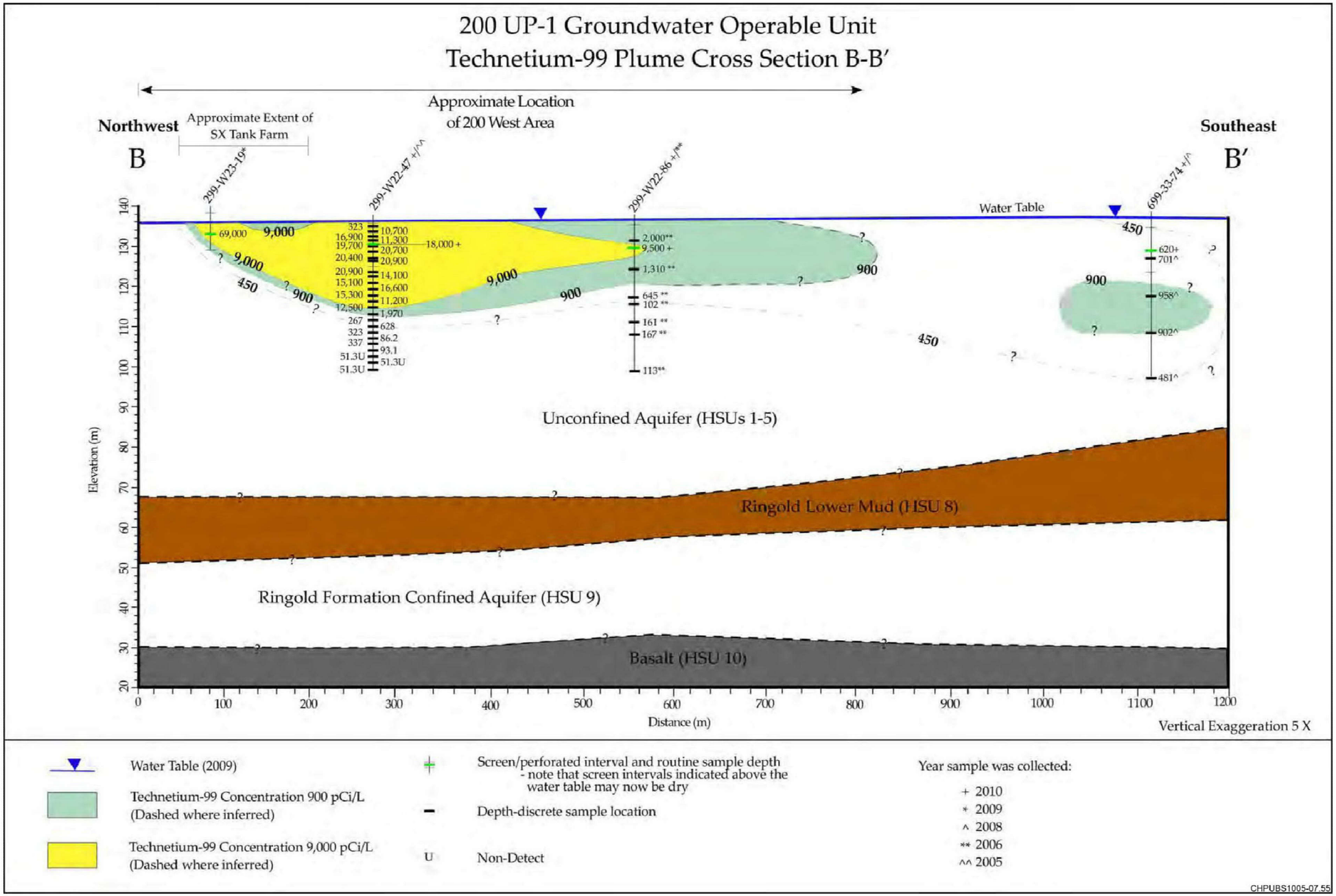

Figure C-17. 200-UP-1 Groundwater Operable Unit Technetium-99 Plume Cross Section B-B'

1

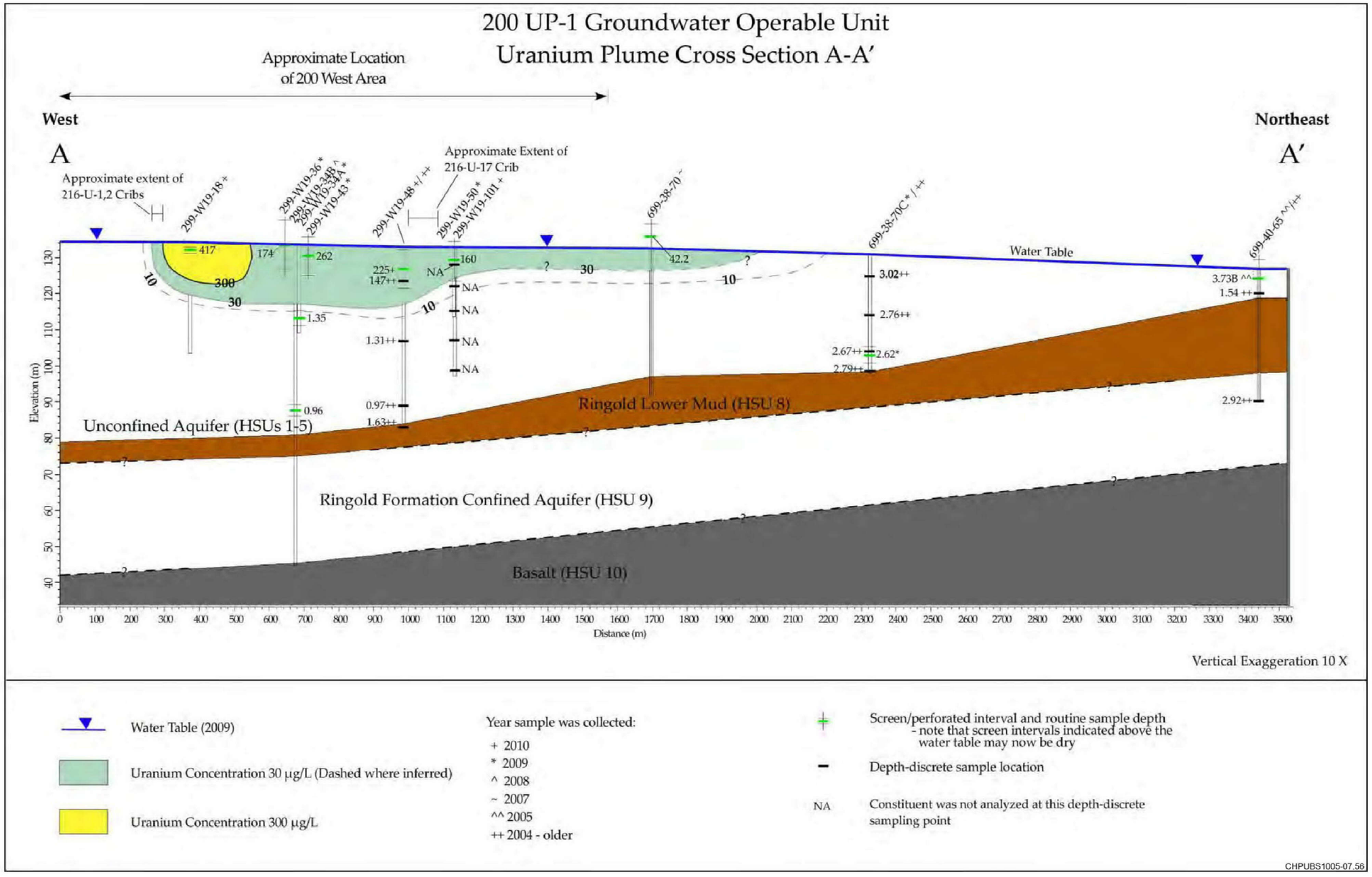

Figure C-18. 200-UP-1 Groundwater Operable Unit Uranium Plume Cross Section A-A'

1