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DRAFT B

Feasibility Study Report for the 200-ZP-1 Groundwater Operable Unit

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

United States Department of Energy
P.O. Box 550
Richland, Washington 99352

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EXECUTIVE SUMMARY

The 200-ZP-1 Groundwater Operable Unit (OU) underlies the northern portion of the 200 West Area of the Hanford Site (shown in Figure ES-1 below). Historical waste practices conducted throughout the 200 West Area contributed to contamination of the 200-ZP-1 Groundwater OU. The major groundwater contaminants include carbon tetrachloride, technetium-99, total chromium (both chromium [III] and chromium [VI] exceed the total chromium maximum contaminant level [MCL]), nitrate, trichloroethylene (TCE), iodine-129, and tritium.

The purpose of this feasibility study (FS) is to establish a basis for remedial action in the 200-ZP-1 OU, to formulate preliminary objectives for conducting the remedial action, and if action is required, to develop and evaluate alternatives for remediation of the groundwater in the 200-ZP-1 OU. The alternatives considered provide a range of potential response actions, including the following:

- No action (Alternative #0)
- Institutional controls supplemented by monitored natural attenuation (MNA) (Alternative #1)
- Full-scale pump-and-treat, institutional controls, MNA, plus flow-path controls (Alternative #2).

These actions are appropriate to address site-specific conditions. The alternatives are evaluated against seven of the nine *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) evaluation criteria defined in U.S. Environmental Protection Agency (EPA) guidance, *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA/540/G-89/004). The remaining two criteria will be evaluated following public comment on the Proposed Plan

The primary cribs and trenches that contributed contaminants to the groundwater included the 216-Z-1A, 216-Z-9, 216-Z-18, the 216-Z-19 Ditch, the 216-Z-20 Crib, and 216-U-10. Bulk liquid waste discharges contributing the majority of contamination to the subsurface occurred from 1945 to the early 1970s. Presently, state-permitted liquid waste discharges occur from the State-Approved Land Disposal Site facility and various small, permitted structures (e.g., sanitary tile fields). As effluents were discharged to these sites, more mobile contaminants were

transported to the groundwater. Less mobile contaminants (as well as residual contamination of higher mobility) remain in the vadose zone and are being addressed in the vadose zone OU remedies (e.g., 200-PW-1 OU). The technetium-99 field investigation near Waste Management Area (WMA)-T and WMA-TX/TY is underway to determine the mass and distribution of technetium-99 in the vadose zone in these areas. The results of this investigation will be considered in the final design and implementation of a remedy for 200-ZP-1 OU groundwater.

Contaminant distributions in the 200-ZP-1 OU groundwater are changing in response to multiple influences, including (1) general downgradient transport of contaminants in the direction of groundwater flow; (2) pump-and-treat operations from the 200-ZP-1 interim response measure (IRM), which are containing much of the high-concentration portion of the carbon tetrachloride plume in the upper part of the aquifer; (3) decreasing groundwater elevations from the termination of effluent releases to surrounding cribs, ponds (primarily T and U Ponds), and trenches; and (4) continued operation of the soil vapor extraction IRM in the 200-PW-1 OU. Contaminant distributions within the 200-ZP-1 OU are represented in three categories:

- A high-concentration zone exists close to the ponds, cribs, and trenches that disposed the liquid wastes. Current data does not support the presence of significant dense nonaqueous phase liquids (DNAPLs) in groundwater acting as a continuing source. However, future monitoring and characterization efforts will continue to evaluate the validity of this assessment.
- A larger dispersed or low concentration zone has migrated from the discharge locations and/or overlies the high-concentration zone. This less contaminated groundwater can occur above the high-concentration zone where large quantities of lower concentration effluent were discharged during or after the high-concentration waste discharges.
- An area of technetium-99 contamination is undergoing further investigation near WMA-T and WMA-TX/TY. Characterization efforts are focusing on refining the understanding of contamination in both the vadose zone and the groundwater at these locations. Estimates of the mass and distribution of technetium-99 at these locations are still under development. Because of its high mobility, the mass of technetium-99 in the vadose zone will be a significant consideration in the final remedial design (i.e., the

quantity of technetium-99 in the vadose zone may present a future source of groundwater contamination because of its high mobility).

The baseline risk assessment (BRA) was conducted to determine, based on current and potential future uses of the land, whether potential health risks are present if people encounter these solvent-, inorganic-, and radionuclide-impacted materials in their environment. The BRA concluded that the risks from exposure to groundwater exceeded 1×10^{-4} using an industrial exposure scenario at the 90th and 50th percentile concentrations in groundwater, due to carbon tetrachloride. The carbon tetrachloride non-cancer hazards were also risk drivers and exceeded target health goals at the 90th and 50th percentile concentrations in groundwater. Although reductions in future concentrations were not quantified for carbon tetrachloride, the contaminant concentrations will decrease over time. As a result of these findings, the risk assessment identified carbon tetrachloride as the principal threat contaminant of concern (COC).

Remedial action objectives (RAOs) were developed to provide a basis for evaluating the capability of a specific remediation alternative to achieve compliance with potential applicable or relevant and appropriate requirements (ARARs) and/or an intended level of risk protection for human health or the environment. The RAOs specific to the 200 Areas for soils, solid wastes, and groundwater were developed in the *200 Areas Remedial Investigation/Feasibility Study Implementation Plan – Environmental Restoration* (referred to as the Implementation Plan) (DOE/RL-98-28). Specific RAOs for this FS were defined based on the fate and transport of contaminant, projected land uses for the 200 Areas, and the 200-ZP-1 OU conceptual exposure model. The RAOs for this FS are as follows:

- RAO #1: Prevent or mitigate risk to human and ecological receptors associated with ingestion of, and external exposure to, contaminants (i.e., carbon tetrachloride, technetium-99, total chromium, hexavalent chromium, nitrate, TCE, iodine-129, and tritium) in groundwater at levels that exceed ARARs or an excess carcinogenic risk of 1×10^{-4} using an industrial exposure scenario, or a hazard index of 1. This RAO is meant to return the groundwater to meet drinking water standards (MCLs).
- RAO #2: Prevent or mitigate the migration of contaminants (i.e., carbon tetrachloride, technetium-99, total chromium, hexavalent chromium, nitrate, TCE, iodine-129, and tritium) in groundwater so that the contaminants do not reach levels in groundwater that

exceed ARARs and excess carcinogenic risk of 1×10^{-4} using an industrial exposure scenario, or a hazard index of 1.

- RAO #3: Prevent the migration of high-concentration areas of contaminants (i.e., carbon tetrachloride, technetium-99, total chromium, hexavalent chromium, nitrate, TCE, iodine-129, and tritium) in the 200-ZP-1 OU and reduce the contaminant mass available for migration.
- RAO #4: Prevent or mitigate occupational health risks to workers performing remedial action.
- RAO #5: Provide the appropriate monitoring and institutional controls to ensure conditions that are suitable for future land uses.

Technologies that might meet the RAOs for the 200-ZP-1 OU were identified and screened. Technologies retained in the screening process were used as a basis for assembling a range of alternatives to meet RAOs. During the alternatives formulation process, further consideration was given to technologies that provided active, reliable means of reducing contaminant mass or risk and that prevent further migration of contaminated groundwater.

The remedial action alternatives range from no action without institutional controls, to active treatment (e.g., a pump-and-treat system). The alternatives were formulated to encompass a range of possible outcomes and enhance compatibility with current operations and infrastructure. The alternatives include the following:

- Alternative #0 – No action
- Alternative #1 – Institutional controls supplemented by MNA
- Alternative #2 – Full-scale pump-and-treat, institutional controls, MNA, plus flow-path controls.

Alternative #2 includes a pump-and-treat remedy that encompasses options for final shutdown of active treatment. This full-scale, robust pump-and-treat system is intended to remove approximately 95% of the contaminant mass in the 200-ZP-1 OU groundwater. The remaining contaminant mass will undergo enhanced MNA. A flow-path control regime will be implemented to prolong the time available for natural attenuation processes to work. This alternative is specifically formulated to return 200-ZP-1 OU groundwater to beneficial use by

achieving Federal MCLs for the contaminants that are listed in Section 3.3. Active treatment will remove contaminant mass from the following:

- High-concentration portions of the COC-contaminated groundwater within 200-ZP-1 OU.
- The lower (or dispersed) concentration areas of COC-contaminated groundwater that exceed 100 μg/L.
- Areas of technetium-99 contamination in groundwater near WMA-T and WMA-TX/TY. The conceptual remedy developed for this alternative does not account for technetium-99 in the vadose zone at these locations because characterization efforts are still underway. The final remedial design will consider information from the investigation because it will impact final cleanup times, extraction network configuration, and treatment train design.

Contingency measures, as well as optimization of the preferred remedy, will be invoked in the event that a persistent source zone (e.g., DNAPL) is discovered during ongoing remedial system performance monitoring. These measures were formulated to address small, discrete areas of DNAPL or very high-concentration contamination that could potentially be found in the fine-grained, discontinuous sediments within the aquifer. In such a scenario, the areas targeted for treatment are expected to be distributed over a small area (less than 2 ha [5 ac]). Contingency measures evaluated for use in this FS include in situ treatment technologies such as electrical resistance heating or anaerobic bioremediation.

The alternatives were analyzed in detail, both individually and in comparison with each other, with respect to the CERCLA evaluation criteria listed below:

- Threshold criteria:
  1. Overall protection of human health and the environment
  2. Compliance with ARARs
- Balancing criteria:
  3. Long-term effectiveness and permanence
  4. Reduction of toxicity, mobility, or volume through treatment
  5. Short-term effectiveness
  6. Implementability
  7. Cost.

The modifying criteria, state acceptance and community acceptance, will be evaluated following the public comment period on the Proposed Plan. This allows the regulators to identify the alternatives that will mitigate unacceptable risks, meet threshold criteria, and meet balancing and modifying criteria.

The results of the detailed and comparative analysis with respect to the CERCLA evaluation are summarized below.

Overall Protection of Human Health and the Environment. All of the alternatives, including Alternative #0 will meet RAO #4 (occupation health risks) by not implementing any remedial actions or by implementing institutional controls to eliminate human health risk through site access restrictions. Alternative #2 meets all of the RAOs by implementing institutional controls and providing representative process options that treat and remove contaminant mass from the areas of concern, thus improving overall protection of human health and the environment. Alternative #0 does not meet RAOs #1, #2, #3, and #5 because it assumes that the institutional controls currently in place are no longer in effect. Loss of existing controls would allow the potential for exposure to contaminated groundwater. Alternative #1 will not meet RAOs #2 and #3 as quickly as Alternative #2 because it lacks engineered controls to prevent or mitigate the migration of contaminants in 200-ZP-1 OU groundwater. Additionally, Alternative #1 may not meet the MCLs at the industrial-exclusive land-use boundary by the year 2150.

Compliance with Applicable or Relevant and Appropriate Requirements. Alternative #0 (no action under CERCLA authority, Sections 104 and 106) applies to remedial actions only; thus, the no action alternative will not invoke ARARs. Initially, Alternative #1 would not meet drinking water standards because engineered controls are not used to treat the toxicity or volume of groundwater contamination. However, preliminary analyses indicate that MNA processes would eventually achieve cleanup goals. Alternative #2 would meet all RAOs and chemical-specific ARARs and would achieve the goal of restoring groundwater to beneficial use by achieving Federal MCLs. Alternative #2 will achieve MCLs significantly faster than Alternative #1.

Long-Term Effectiveness and Permanence. Alternatives #0 does not provide any long-term effectiveness or permanence, while Alternative #1 achieves remediation goals slowly. Alternative #2 will provide long-term effectiveness and permanence for contaminated groundwater by removing the COCs and constituents that exceed the MCLs, thereby restoring

groundwater to beneficial use in the shortest timeframe. Long-term engineering controls would be implemented that will effectively mitigate risks to prevent future exposure to human and ecological receptors. These alternatives would effectively reduce risks associated with workers by execution of institutional controls, including access restriction and administrative controls.

Reduction of Toxicity, Mobility, or Volume Through Treatment. Treatment would not be administered with Alternatives #0. In Alternative #1, reduction in contamination may occur through radioactive decay and natural attenuation processes. Alternative #2 will provide an irreversible treatment process that would reduce the mass of the contaminants in the groundwater by removing/treating 95% of the mass of the COCs, as well as the contaminants that exceed the MCLs. A reduction in toxicity for the remaining 5% of the COCs is expected to occur through natural attenuation processes.

Short-Term Effectiveness. Construction and operation of all of the alternatives can be implemented with little or no additional risk to the public, workers, or the environment. The potential for slight, temporary increases in risk to the community (and workers) due to particulate emissions during construction of pump-and-treat system would be controlled with dust-control technologies (e.g., water or foam sprays). Exposure to the groundwater contaminants can be minimized by using proper personal protective equipment, using engineering controls, and following Occupational Safety and Health Administration and U.S. Department of Energy guidelines, rules, and regulations, as applicable.

Implementability. No implementability concerns are involved with Alternatives #0 and #1. A pump-and-treat system is currently operating in the 200-ZP-1 OU as an IRM. Implementation of Alternative #2 would require the installation of new wells and treatment trains to address the COCs and the constituents that exceed the MCLs. The number and locations of the wells, and the location and design of treatment trains, will be determined during remedial design. Current contaminant distributions in groundwater will need to be refined as new data become available, and the potential of new contaminant loading from the vadose zone will need to be addressed.

Cost. The present-worth cost for Alternative #0 is $0, Alternative #1 is $3,100,000, and Alternative #2 ranges from $93,000,000 to approximately $180,000,000 (depending on the scale of the system implemented) (see Appendix C for further details). While Alternative #2 is substantially more expensive than Alternative #1, it clearly achieves the goal of restoring the groundwater to beneficial use in a timeframe compatible with overall land-use objectives. The

costs associated with these activities can substantially change because of the use of the habitat by a variety of wildlife and the potential for discovery of cultural resources. All of these issues will need to be considered during remedial design and planning.

200-ZP-1 Operable Unit	Alternative #0	Alternative #1	Alternative #2[a] ☑
CERCLA Evaluation Criteria	No Action	Institutional Controls Supplemented by MNA	Full-Scale Pump-and-Treat, Institutional Controls, MNA, Plus Groundwater Flow-Path Controls
Overall protection of human health and the environment	1	2	3
Does alternative meet ARARs?	[b]	Yes	Yes
Long-term effectiveness and permanence	1	1	3
Reduction of toxicity, mobility, or volume through treatment	1	1	3
Short-term effectiveness	1	3	2
Implementability	1	3	3
Present-worth cost	$0	$3,100,000	$93,000,000

NOTE: 1 = low ranking, 2 = medium ranking, and 3 = high ranking.
☑ = Preferred alternative.
[a] Preferred alternative.
[b] The no action alternative does not invoke applicable or relevant and appropriate requirements (ARARs).
CERCLA= *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
MNA = monitored natural attenuation

PREFERRED ALTERNATIVE

Based upon the outcome of the comparative analysis, Alternative #2 (full-scale pump-and-treat, institutional controls, MNA, plus groundwater flow-path controls) is recommended as the preferred remedy. Alternative #2 is designed to return groundwater in the 200-ZP-1 OU to beneficial use through attainment of Federal MCLs and to remove and treat the following:

- Contaminant mass in the high-concentration areas of carbon tetrachloride contamination.
- Contaminant mass from the areas of contamination that exceed 100 μg/L of carbon tetrachloride (approximately 95% of the mass for the contaminant).
- Technetium-99 contamination in the groundwater near WMA-T and WMA-TX/TY. However, the conceptual remedy developed for this alternative does not account for technetium-99 in the vadose zone at these locations, as characterization efforts are still underway. The final remedial design will consider information from this investigation

because it will impact final cleanup times, extraction network configuration, and treatment train design.

The preferred treatment remedy, augmented with a flow-control regime, includes between 14 and 27 injection wells and 14 and 27 extraction wells (Figures ES-2 and ES-3). Each extraction well is expected to pump at a rate of approximately 227 L/min (60 gallons per minute [gpm]) for a total system extraction rate of 3,180 to 6,113 L/min (840 to 1,615 gpm). The preferred remedy hydraulically captures 95% of the mass ofcarbon tetrachloride, and treats constituents above the MCL to reduce cumulative risk and return groundwater to beneficial use. The remedy relies on the operation of the pump-and-treat system to remove contaminant mass (and thereby reduce risk). Remedies based on mass removal strategies tend to remove large fractions of the mass in the early stages of the remedy with declining rates of mass removal toward the end of the remedy. Based on the experience of operating the interim remedy at 200-ZP-1, it is anticipated that removal of a large fraction of the mass and significant risk reduction will be accomplished within the first decade of operation. The time to achieve groundwater remediation will be evaluated as the system is operated and optimized, but could take from 20 to 50 years, depending on the scope of remedy implementation (Figure ES-4). The remedy relies on the operation of the pump-and-treat system to remove contaminant mass (and thereby reduce risk). After sufficient mass has been removed, the pump-and-treat system will cease operations, and natural attenuation processes will be the primary mechanism for remediation. Actual cleanup times will vary based on final design and remedy implementation; details such as well locations, well screen lengths, well screen depths; and retardation coefficients for the target compounds, and the potential for unanticipated contaminant flux from the vadose zone. Final design of the remedy will be informed by new estimates of technetium-99 mass and distribution in the vadose zone at WMA-T and WMA-TX/TY. These estimates may necessitate the addition of new RAOs, or the reformulation of existing RAOs.

Contingency measures, as well as adjustments to the preferred remedy will be invoked in the event persistent (or future) source zones are discovered, or if performance expectations are not being met. The need for continuous sampling, analysis, and modeling will occur throughout the lifetime of this remedy to assist in the performance evaluation and implementation.

Figure ES–1. Location of the Hanford Site.

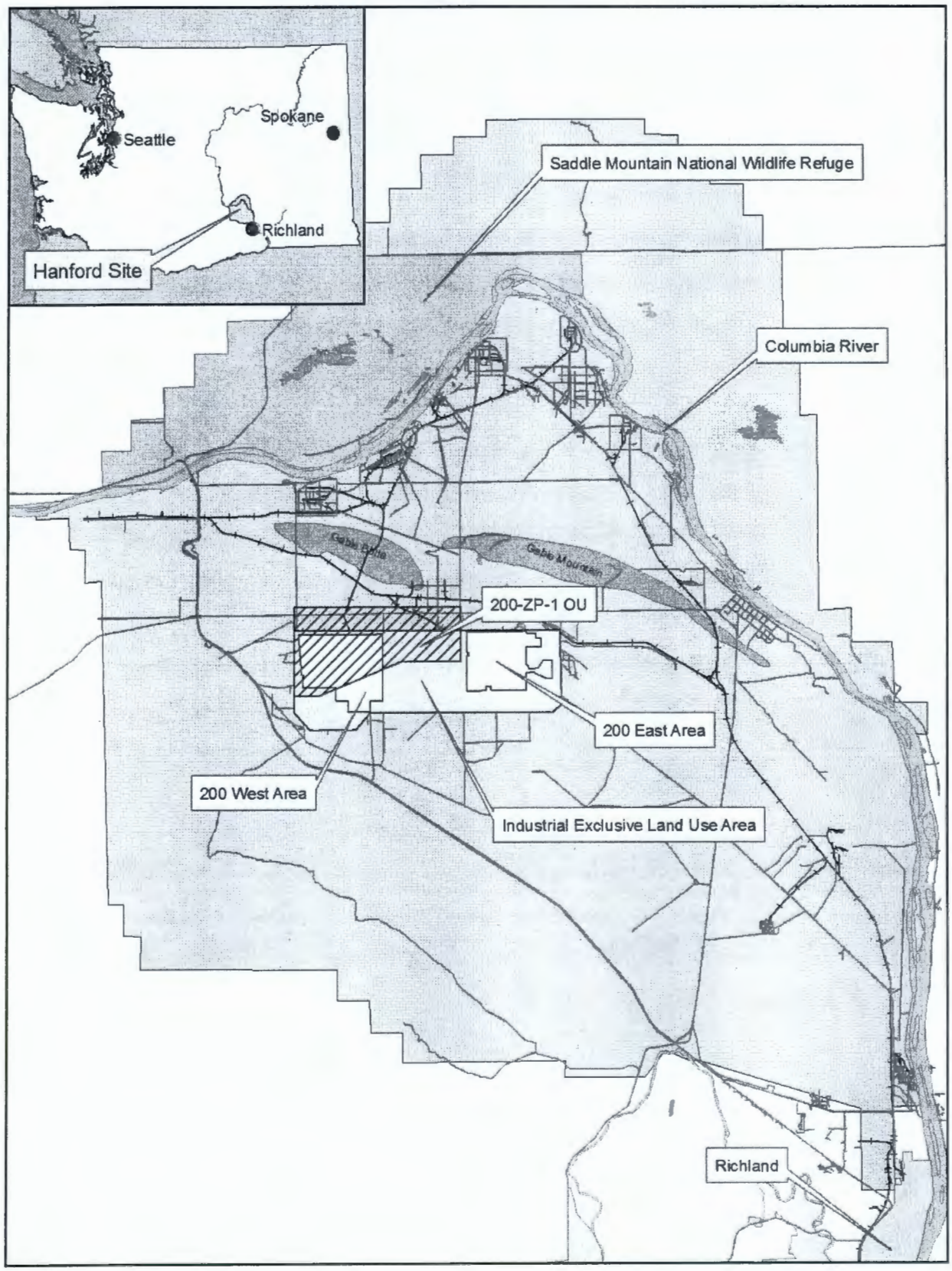


Figure ES-2. Anticipated Well Locations for the Preferred Alternative (840 gpm).

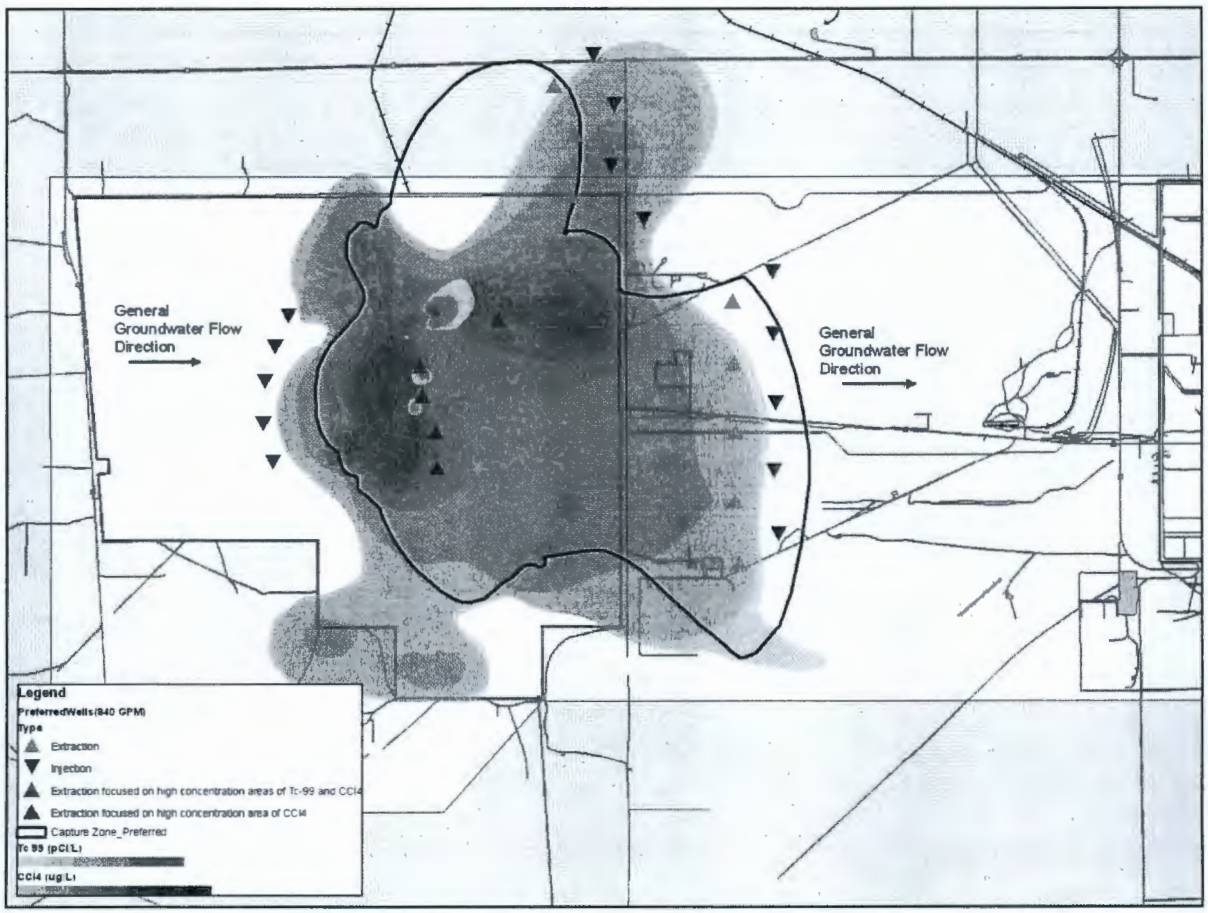


Figure ES-3. Anticipated Well Locations for the Preferred Alternative (1,615 gpm).

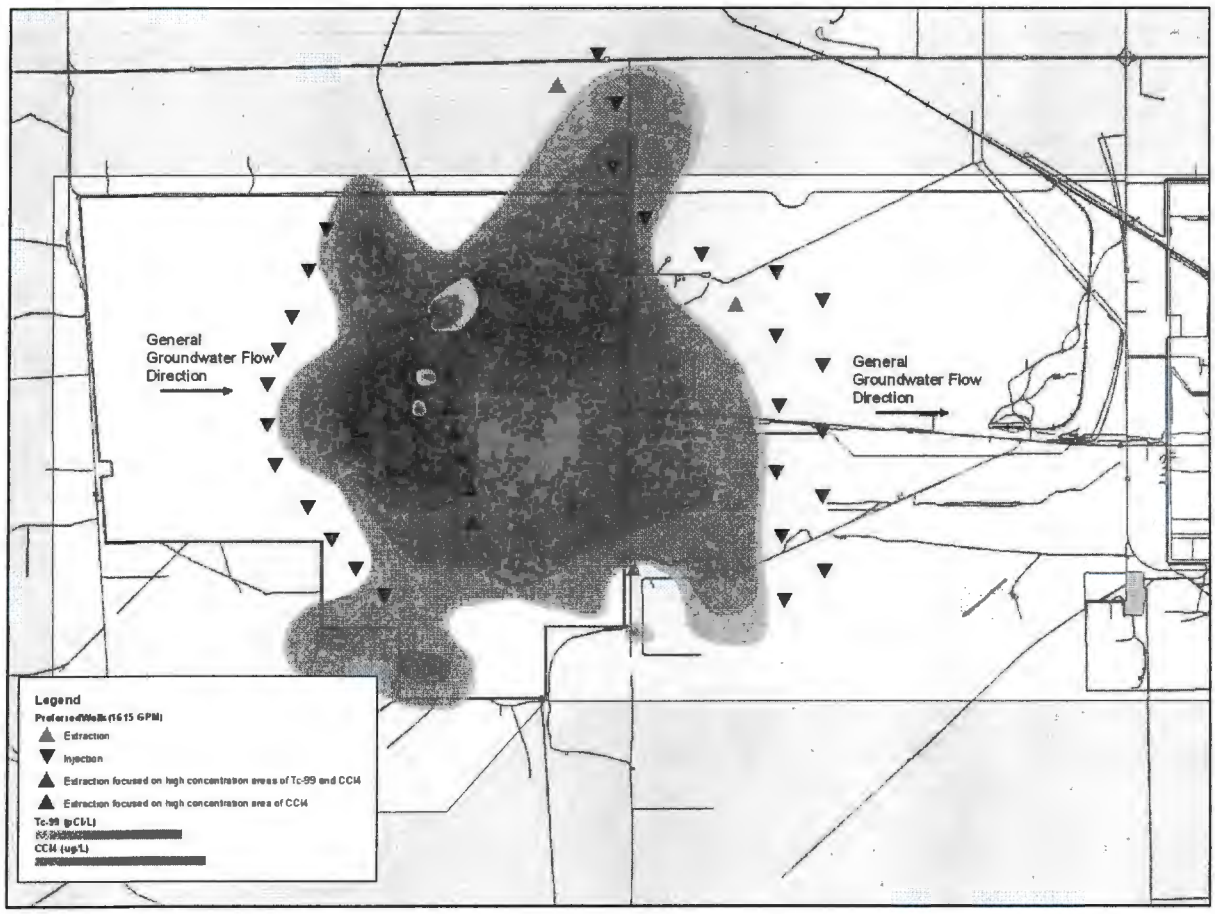
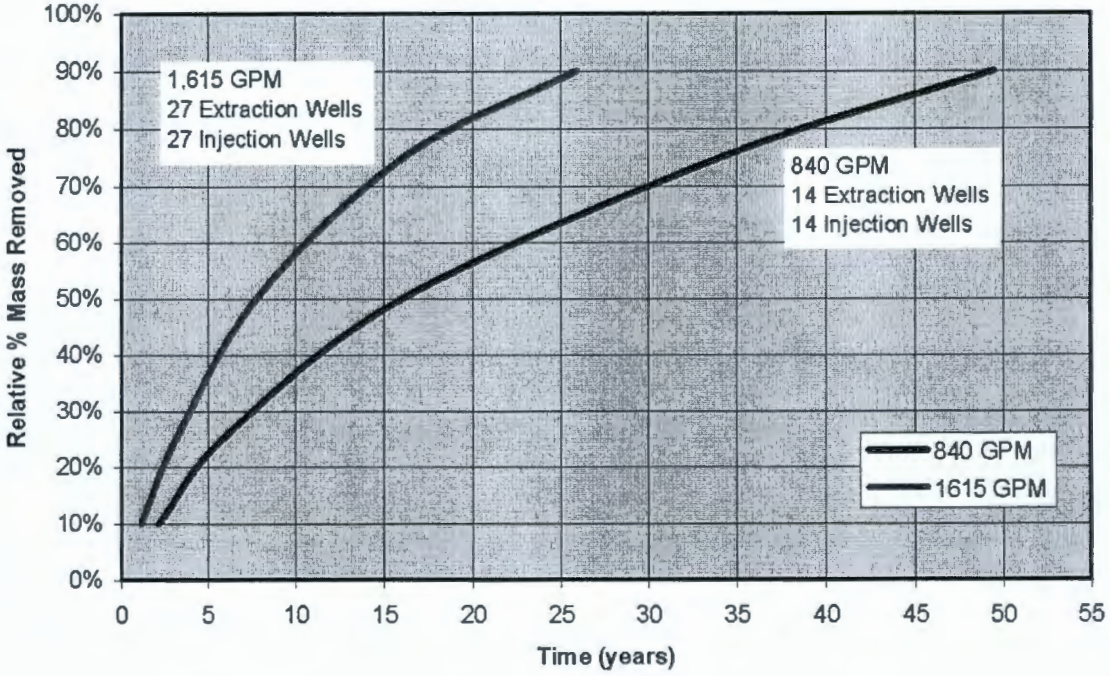


Figure ES-4. Relative Clean-Up Times for Preferred Pump-and-Treat Remedy.



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LIST OF TERMS

AEA	*Atomic Energy Act of 1954*
AEC	Atomic Energy Commission
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
BLM	U.S. Bureau of Land Management
BOR	U.S. Bureau of Reclamation
BRA	baseline risk assessment
bwt	below the water table
CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
CFR	*Code of Federal Regulations*
COC	contaminant of concern
COPC	contaminant of potential concern
CSM	conceptual site model
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
DNAPL	dense nonaqueous phase liquid
DO	dissolved oxygen
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DQO	data quality objectives
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ERDF	Environmental Restoration Disposal Facility
ERH	electrical resistance heating
ESA	*Endangered Species Act of 1973*
ES&H	environment, safety, and health
ETF	Effluent Treatment Facility
FS	feasibility study
FY	fiscal year
GAC	granular activated carbon
gpm	gallons per minute
HAB	Hanford Advisory Board
HCP EIS	*Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement*
HEIS	Hanford Environmental Information System
HHRA	human health risk assessment
HI	hazard index
HMS	Hanford Meteorological Station
Industrial	industrial-exclusive
IRIS	Integrated Risk Assessment System
IRM	interim remedial measure
ISMS	Integrated Environment, Safety, and Health Management System
IX	ion exchange
K_d	distribution coefficient

LLBG	Low-Level Burial Grounds
LLWMA	Low-Level Waste Management Area
MCL	maximum contaminant level
MNA	monitored natural attenuation
MOA	memorandum of agreement
MTCA	*Model Toxics Control Act*
NCP	National Contingency Plan
NEPA	*National Environmental Policy Act of 1969*
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
ORP	U.S. Department of Energy, Office of River Protection
OSHA	Occupational Safety and Health Administration
OSWER	U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response
OU	operable unit
PCE	tetrachloroethylene
PFP	Plutonium Finishing Plant
PNNL	Pacific Northwest National Laboratory
ppb	parts per billion
ppm	parts per million
PRF	Plutonium Reclamation Facility
PRG	preliminary remediation goal
RAO	remedial action objective
RBC	risk-based concentration
RCBRA	River Corridor baseline risk assessment
RCRA	*Resource Conservation and Recovery Act of 1976*
RCW	*Revised Code of Washington*
RECUPLEX	Recovery of Uranium and Plutonium by Extraction
RESRAD	RESidual RADioactivity (dose model)
RI	remedial investigation
RL	U.S. Department of Energy, Richland Operations Office
RME	reasonable maximum exposure
ROD	Record of Decision
SALDS	State-Approved Land Disposal Site
SST	single-shell tank
SVE	soil vapor extraction
TAL	target action level
TBC	to-be-considered
TCE	trichloroethylene
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
TSD	treatment, storage, and disposal
UCL	upper confidence limit
UIC	underground injection control
VOC	volatile organic compound
WAC	*Washington Administrative Code*
WCH	Washington Closure Hanford, LLC
WIDS	Waste Information Data System database

WMA	waste management area

METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
If You Know	*Multiply By*	*To Get*	*If You Know*	*Multiply By*	*To Get*
Length			**Length**		
inches	25.4	millimeters	millimeters	0.039	inches
inches	2.54	centimeters	centimeters	0.394	inches
feet	0.305	meters	meters	3.281	feet
yards	0.914	meters	meters	1.094	yards
miles	1.609	kilometers	kilometers	0.621	miles
Area			**Area**		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.093	sq. meters	sq. meters	10.76	sq. feet
sq. yards	0.836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.6	sq. kilometers	sq. kilometers	0.4	sq. miles
acres	0.405	hectares	hectares	2.47	acres
Mass (weight)			**Mass (weight)**		
ounces	28.35	grams	grams	0.035	ounces
pounds	0.454	kilograms	kilograms	2.205	pounds
ton	0.907	metric ton	metric ton	1.102	ton
Volume			**Volume**		
teaspoons	5	milliliters	milliliters	0.033	fluid ounces
tablespoons	15	milliliters	liters	2.1	pints
fluid ounces	30	milliliters	liters	1.057	quarts
cups	0.24	liters	liters	0.264	gallons
pints	0.47	liters	cubic meters	35.315	cubic feet
quarts	0.95	liters	cubic meters	1.308	cubic yards
gallons	3.8	liters			
cubic feet	0.028	cubic meters			
cubic yards	0.765	cubic meters			
Temperature			**Temperature**		
Fahrenheit	subtract 32, then multiply by 5/9	Celsius	Celsius	multiply by 9/5, then add 32	Fahrenheit
Radioactivity			**Radioactivity**		
picocuries	37	millibecquerel	millibecquerels	0.027	picocuries

1.0 INTRODUCTION

The Hanford Site, managed by the U.S. Department of Energy (DOE), encompasses approximately 1,517 km^2 (586 mi^2) in the Columbia Basin of south-central Washington State. In 1989, the U.S. Environmental Protection Agency (EPA) placed the 100, 200, 300, and 1100 Areas of the Hanford Site on the 40 *Code of Federal Regulations* (CFR) 300, "National Oil and Hazardous Substances Pollution Contingency Plan" (NCP) Appendix B, "National Priorities List" (NPL), pursuant to the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA). The 200 Areas NPL sites consist of the 200 West and 200 East Areas (Figure 1-1). The 200 Areas contain waste management facilities, inactive irradiated fuel reprocessing facilities, and the 200 North Area (formerly used for interim storage and staging of irradiated fuel). Several waste sites in the 600 Area, located near the 200 Areas, also are included in the 200 Areas NPL site.

The 200 Areas NPL site is in a region referred to as the "Central Plateau" and consists of approximately 700 waste sites, excluding sites assigned to the tank farm waste management areas. The 200-ZP-1 Groundwater Operable Unit (OU) consists of the groundwater located under the northern portion of the 200 West Area. Waste sources that contributed to the 200-ZP-1 OU included cribs and trenches that received liquid and/or solid waste in the past from the Z Plant and T Plant aggregate areas, Waste Management Area (WMA)-T, WMA-TX/TY, and the State-Approved Land Disposal Site (SALDS).

This feasibility study (FS) for the 200-ZP-1 Groundwater OU was prepared in accordance with the requirements of CERCLA decision documents. These decision documents are part of the Administrative Record for the selection of remedial actions for each waste site and present the selected remedial actions that are chosen in accordance with CERCLA, as amended by the *Superfund Amendments and Reauthorization Act of 1986*, and to the extent practicable, the NCP. This FS conforms to the conditions set forth in the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 2003) and amendments, signed by the Washington State Department of Ecology (Ecology), EPA, and U.S. Department of Energy (DOE), Richland Operations Office (RL). This also includes Tri-Party Agreement Milestone M-015-00C for completing all 200 Area non-tank farm OU pre-Record of Decision (ROD) documents on or before December 31, 2011. This FS supports the final remedy selection for the 200-ZP-1 OU as described in the *Remedial Investigation/ Feasibility Study Work Plan for the 200-ZP-1 Groundwater Operable Unit* (referred to as the 200-ZP-1 RI/FS work plan) (DOE/RL-2003-55), as agreed upon by RL and EPA. Tri-Party Agreement Milestone M-015-48B requires the Draft A of the 200-ZP-1 OU FS and Proposed Plan to be transmitted to EPA by September 30, 2007.

As agreed to with EPA in the *200 Area Unit Managers' Meeting Groundwater Operable Unit Status* (FH-0503130), the baseline risk assessment (BRA) was delayed from inclusion in the remedial investigation (RI) report and is completed and documented in this FS. The *Remedial Investigation Report for 200-ZP-1 Groundwater Operable Unit* (referred to as the 200-ZP-1 RI report) (DOE/RL-2006-24) included an evaluation of human health and ecological risks and hazards. The RI report identified the radiological and chemical contaminants of potential concern (COPCs) that represent the primary risks to human health and the environment. The complete risk assessment in this FS incorporates additional analytical data from the unconfined aquifer that were obtained during or after preparation of the RI report, particularly for carbon

tetrachloride and technetium-99. This FS also includes the initial results from an ongoing study of technetium-99 contamination near WMA-T, the sampling of new wells near the 216-W-LC Laundry Waste Crib and T Plant, updated Hanford vadose zone fate and transport modeling, and groundwater particle-tracking analysis.

1.1 PURPOSE

The purpose of this FS is to develop and evaluate alternatives for remediation of the groundwater in the 200-ZP-1 OU. The alternatives considered provide a range of potential response actions (i.e., no action, institutional controls with monitored natural attenuation [MNA], full-scale pump-and-treat with institutional controls, flow-path control, and MNA) that are appropriate to address site-specific conditions. The alternatives are evaluated against seven of the nine CERCLA evaluation criteria defined in *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA/540/G-89/004). The remaining two CERCLA criteria will be formally assessed during the public comment period.

The FS evaluation serves as the basis for identifying a remedy to mitigate potential risks to human health and the environment. A preferred alternative (or alternatives) will be presented to the public for review and comment in the Proposed Plan. Following public review, EPA will prepare a CERCLA ROD that identifies the remedial alternative(s) to be implemented for the groundwater in the 200-ZP-1 OU.

1.2 SCOPE

The scope of this FS includes the formulation and evaluation of remedial alternatives designed to address contamination in groundwater resulting from waste sources above the 200-ZP-1 OU. This includes groundwater contamination that was released from sources including Z Plant, T Plant, WMA-T, WMA-TX/TY, the SALDS, and various cribs and trenches that received liquid waste from these facilities (Figure 1-2).

The Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit (200-PW-1 OU) overlies the 200-ZP-1 Groundwater OU (Figure 1-2). Because three of the 200-PW-1 OU waste sites (i.e., 216-Z-1A tile field, 216-Z-9 Trench, and 216-Z-18 Crib) were the primary sources of carbon tetrachloride contamination in the 200-ZP-1 Groundwater OU, the FS reports for both the 200-PW-1 and the 200-ZP-1 OUs were prepared by an integrated project team to ensure that the BRA, FS analysis and assumptions, and remedial alternatives for these OUs were consistent. This integration consisted of a single BRA (see Appendix A) that considered the integrated risk to current and future land users from both the disposal waste sites in the vadose zone and the groundwater contamination. Based upon the BRA, appropriate and compatible remedial actions were considered in each of the independent FS documents. As shown in Figure 1-2, other waste sites also overlie the 200-ZP-1 OU, and some of these waste sites may be sources for the other contaminants found in the groundwater. These other waste sites are being addressed by the CERCLA RI/FS process for other OUs in the 200 West Area or under the *Resource Conservation and Recovery Act of 1976* (RCRA) for sites assigned to the tank farm waste management areas.

1.3 REGULATORY STATUS

1.3.1 Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement)

The characterization and remediation of waste sites on the Hanford Site are addressed in the Tri-Party Agreement. This agreement addresses the integration of cleanup programs under CERCLA and RCRA to provide a standard approach for directing cleanup activities and to ensure that applicable regulatory requirements are met. Details of this integration for the 200 Areas are presented in the Implementation Plan (DOE/RL-98-28) and the 200-ZP-1 RI/FS work plan (DOE/RL-2003-55).

The Tri-Parties (i.e., Ecology, EPA, and DOE) developed a framework to support risk assessments in the Central Plateau. This included a series of workshops completed in 2002 with representatives from Ecology, EPA, DOE, the Hanford Advisory Board (HAB), the Tribal Nations, the State of Oregon, and other interested stakeholders. The workshops focused on the different programs involved in activities on the Central Plateau and the need for a consistent application of risk assessment assumptions and goals. The results of the risk framework are documented in *Exposure Scenarios Task Force on the 200 Area* (HAB Advice #132); the Tri-Parties' response to *Consensus Advice #132: Exposure Scenarios Task Force on the 200 Area* (02-HAB-0006); and in the *Report of the Exposure Scenarios Task Force* (HAB 2002O-06). This guidance has been followed in the preparation of the 200-ZP-1 OU BRA.

The land surrounding the 200 East and 200 West Areas was designated as industrial-exclusive (industrial) land use in the *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (HCP EIS) (DOE/EIS-022--F). This area encompasses the major vadose zone waste sites that influence the 200-ZP-1 OU and, therefore, classifies groundwater use in this area as industrial use (*Remedial Investigation Report for the 200-PW-2 Uranium-Rich Process Waste Group and the 200-PW-4 General Process Condensate Group Operable Units* [DOE/RL-2004-55]; DOE/RL-2005-91).

1.3.2 Comprehensive Environmental Response, Compensation, and Liability Act of 1980 Process

Table 1-4 of the 200-ZP-1 RI report (DOE/RL-2006-24) and the 200-ZP-1 RI/FS work plan (DOE/RL-2003-55) contains a summary of the references for CERCLA and related documents and activities for the 200-ZP-1 OU. The references include descriptions of an interim remedial measure (IRM) (EPA/ROD/R10-95/114) that was undertaken for the 200-ZP-1 OU carbon tetrachloride plume. The IRM has a complete suite of documentation including a ROD (EPA/ROD/R10-95/114), remedial design report (DOE/RL-96-07), work plan (DOE/RL-2003-55), sampling requirements, and data assessment requirements. These documents were considered in the preparation of this FS.

1.3.3 Relevant Resource Conservation and Recovery Act of 1976 and State-Approval Land Disposal Sites

A number of treatment, storage, and disposal (TSD) units and non-TSD unit disposal locations are located within the 200-ZP-1 OU boundary. Possible contaminants of concern (COCs) impacting groundwater that may be originating from these TSD units have been included in this FS report because the groundwater OU will be remediated under CERCLA. The TSD

compliance issues are not considered in this FS report because these facilities are regulated under RCRA. The DOE Office of River Protection (ORP), which has authority over these RCRA units, will predict impacts to groundwater from RCRA sites in the 200-ZP-1 OU when data are available. These impacts will support the optimization of the 200-ZP-1 OU remedy. The anticipated groundwater data schedule is outlined below (from DOE/RL-2006-24):

- Single-shell tank (SST) system TSD unit WMA-T: 2028 closure date.
- SST system TSD unit WMA-TX/TY: 2028 closure date.
- Low-Level Burial Grounds (LLBG) TSD unit Low-Level Waste Management Area (LLWMA)-3 and LLWMA-4: No individual closure dates are established; however, all 200 Area non-tank farm OUs must be closed by 2024 in accordance with the Tri-Party Agreement Milestone M-016-00.
- SALDS: Although this disposal site is located outside of the 200 West Area boundaries (Figure 1-2) and it is not a TSD unit, the tritium plume resulting from discharges to this location is monitored because it could affect other plumes in the 200-ZP-1 Groundwater OU. This disposal location is active and no individual closure date has been established, other than Tri-Party Agreement Milestone M-016-00. The disposal location supports operation of the 200 Area Effluent Treatment Facility (ETF).

The 200-ZP-1 OU underlies several LLBG and SST system TSD units that are regulated by Ecology according to the requirements of RCRA for hazardous waste constituents in *Washington Administrative Code* (WAC) 173-303. These units are also regulated under the *Atomic Energy Act of 1954* (AEA) for radionuclides (e.g., source, special nuclear, and byproduct materials). This FS report incorporates available data from CERCLA monitoring, RCRA monitoring, and AEA compliance activities. The data presented in this report are not intended to replace or negate requirements for RCRA monitoring (DOE/RL-2006-24).

1.3.4 Facility Ownership

The Hanford Site land holdings consist of three different real-property classifications: (1) lands acquired in fee by DOE or its predecessor agencies, (2) U.S. Bureau of Land Management (BLM) public domain lands withdrawn from the public domain for use as part of the Hanford Site, and (3) lands that the U.S. Bureau of Reclamation (BOR) withdrew from the public domain or acquired in fee as part of the Columbia Basin Project. All lands in the Hanford area were ceded to the United States by the Treaties of 1855, and these treaties contain reserved rights for perpetuity. All Federal agencies and projects, including the BOR and BLM, have a Federal trust responsibility to protect the rights of the Indian Tribes.

The BOR agreed in a memorandum of agreement (MOA) to transfer custody, possession, and use of certain acquired and withdrawn lands situated within the control zone of the Hanford Works to the U.S. Atomic Energy Commission (AEC) on February 27, 1957. The BOR retained the right to construct, operate, and maintain the Wahluke Canal and related facilities and any necessary waste ways and drainage ways through the Wahluke Slope in connection with irrigation of lands outside of the control zone. These lands were included in the South Columbia Basin Irrigation District and the East Columbia Irrigation District at the time of district formation. In the MOA, the BOR identified a continued interest in development of irrigable lands on the Wahluke Slope as part of the Columbia Basin Project. The AEC acknowledged the interest of the BOR and reaffirmed a policy of keeping DOE land ownership and restrictions of land use on the Wahluke Slope to a minimum (DOE/EIS-0222-F).

1.4 FEASIBILITY STUDY REPORT ORGANIZATION

This FS report includes all of the required elements suggested in CERCLA guidance (EPA/540/G-89/004). The report contains nine sections and supporting appendices, as summarized below:

- Section 1.0: Presents the purpose, scope, and regulatory framework for the FS, as well as an overview of the organization of the report.
- Section 2.0: Presents a discussion of the waste sites that may have contributed contamination to the 200-ZP-1 OU, the physical setting, and a description of the natural resources near this OU. Section 2.4 describes the nature and extent of contamination posed by the COPCs identified in the 200-ZP-1 RI report (DOE/RL-2006-24). Specific attention is given to the variety of ways in which the 200-ZP-1 OU groundwater contamination has been portrayed and how the understanding of groundwater contamination has improved. Section 2.5 presents the 200-ZP-1 OU conceptual site model (CSM). Section 2.6 presents information regarding the fate and transport of the COPCs identified in the 200-ZP-1 RI report (DOE/RL-2006-24).
- Section 3.0: Discusses land-use assumptions and develops the overall cleanup objectives and media-specific goals for the waste sites. Specifically, current and future land uses, as well as the uses of groundwater, were identified. The potential applicable or relevant and appropriate requirements (ARARs) for the 200-ZP-1 OU were also identified. A summary of the risk assessment, which integrated both the 200-ZP-1 OU and 200-PW-1/200-PW-3/200-PW-6 (referred to hereinafter as 200-PW-1/3/6) OUs, is presented in Section 3.2. Using the results of the BRA, the COPCs identified in the 200-ZP-1 RI report (DOE/RL-2006-24) were evaluated to establish the contaminants to be considered in the FS. The COCs, land-use and groundwater-use objectives, and ARARs were considered in formulating remedial action objectives (RAOs) and preliminary remediation goals (PRGs).
- Section 4.0: Refines the technologies applicable to this OU by evaluating new information on existing technologies or promising and relevant emerging technologies. The technologies were broadly screened for applicability to this OU. Screening considerations include effectiveness (i.e., likelihood of meeting RAOs for the specific contaminants present at a site), implementability relative to specific site conditions, status of technology development, and relative cost. The technologies carried forward from this screening evaluation were used as process options in formulating the remedial alternatives, as described in Section 5.0.
- Section 5.0: Describes the remedial alternative development process, initially conducted as part of the Implementation Plan (DOE/RL-98-28) development, and uses that information in concert with site-specific data from the RI to refine the remedial alternatives retained for the detailed and comparative analyses. It should be noted that the level of design described for the alternatives was appropriate for the FS evaluation but is not sufficient for a final remedial design.
- Section 6.0: Presents a detailed analysis of each of the remedial alternatives formulated in Section 5.0 against the seven CERCLA evaluation criteria (overall protection of human health and the environment; regulatory compliance; long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term

effectiveness; implementability; and cost), as defined in EPA/540/G-89/004. The remaining two CERCLA evaluation criteria (state/support agency acceptance and community acceptance) will be conducted during the public comment period. This section also assesses each alternative relative to the *National Environmental Policy Act of 1969* (NEPA) values, as required by DOE policy. The detailed analysis evaluates each alternative against the CERCLA evaluation criteria independently; the results of the detailed analysis form the basis for the comparative analysis performed in Section 7.0.

- Section 7.0: Presents the comparative analysis of the remedial alternatives and identifies relative advantages and disadvantages, based on the seven CERCLA evaluation criteria. The comparative analysis evaluates the relative strengths and weaknesses of each alternative as they relate to the seven evaluation criteria and the analysis performed in Section 6.0. The results of this analysis provide a basis for selecting a remedial alternative for the 200-ZP-1 OU.
- Section 8.0: Provides a summary of the key uncertainties inherent to the FS analyses included in this FS report and discusses their impacts on the FS evaluations. Specific consideration is given to the uncertainties relating to estimating baseline risk, estimating the nature and extent of contamination (as well as the effectiveness of remedial technologies), and the costs of implementing remedial technologies. In each case, the potential impacts of the uncertainties are qualitatively described.
- Section 9.0: Summarizes the conclusions of the FS. This section also presents the preferred alternative and path forward for remediation of the 200-ZP-1 OU.
- Section 10.0: Contains the references cited for the main text of the report; each appendix contains its own reference section.
- Appendix A: Includes an integrated human health risk evaluation, including the methodology, results, and uncertainties for both the 200-ZP-1 Groundwater OU and the 200-PW-1/3/6 OU waste sites.
- Appendix B: Presents an analysis of the regulatory requirements and available guidance with respect to the 200-ZP-1 OU.
- Appendix C: Presents the basis for the comparative cost estimates.
- Appendix D: Presents supporting calculations and modeling evaluations of the groundwater in the 200-ZP-1 OU.
- Appendix E: Presents new groundwater analytical data that were not included in the 200-ZP-1 OU RI Report (DOE-RL-2006-24).
- Appendix F: Presents a report documenting a screening of various remedial thecnologies that may be appropriate for the 200-ZP-1 OU.
- Appendices G and H: Presents two reports evaluating various alternatives for treating granular activated carbon (GAC) used in the operation of 200-ZP-1 OU.
- Appendix I: Presents a test plan for evaluating a treatment technology for removing Technetium-99 from the 200-ZP-1 groundwater.
- Appendix J: Presents an additional baseline risk assessment that addresses Native American traditional lifeways.

Figure 1-1. Location of the Hanford Site.

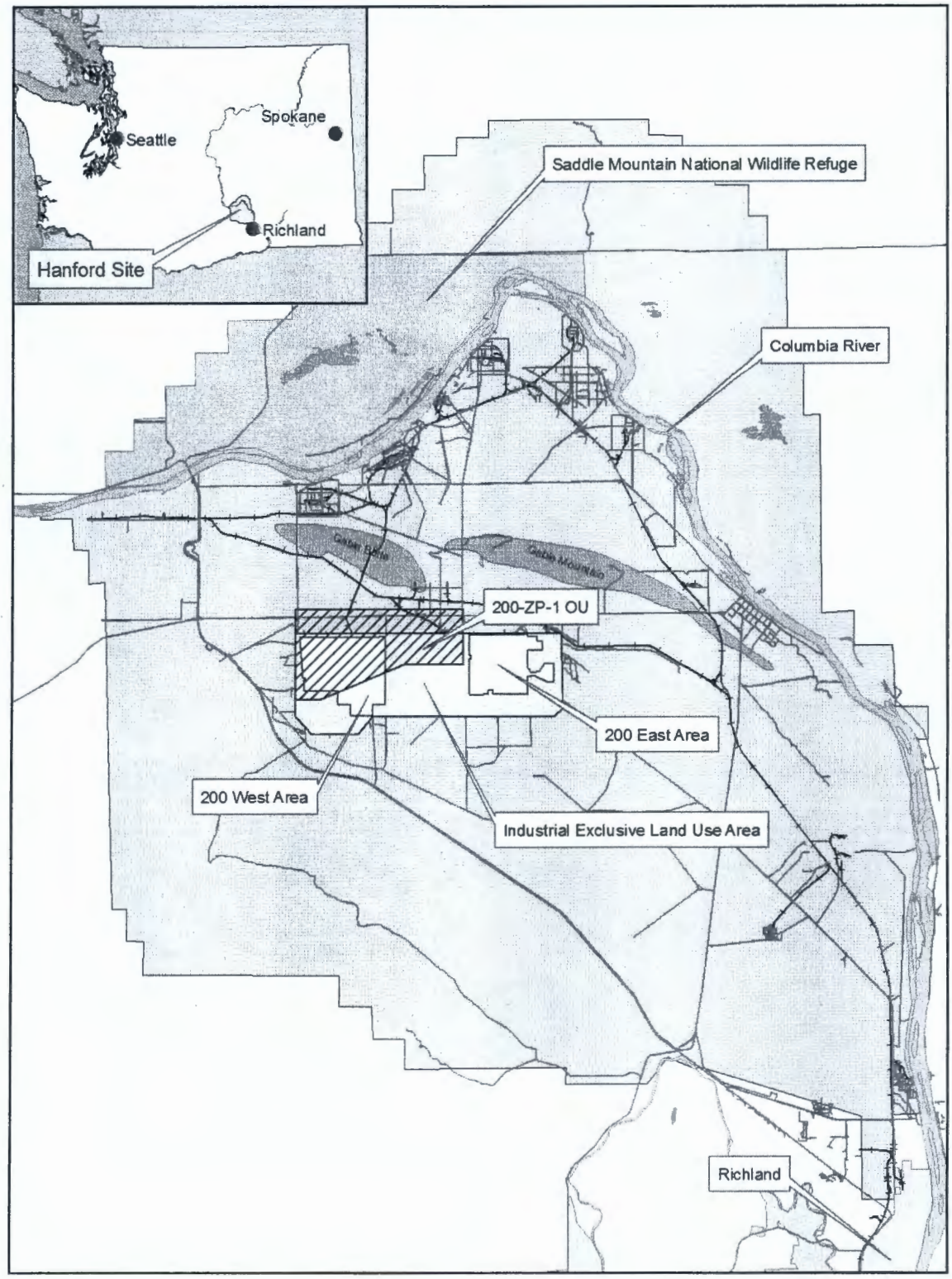
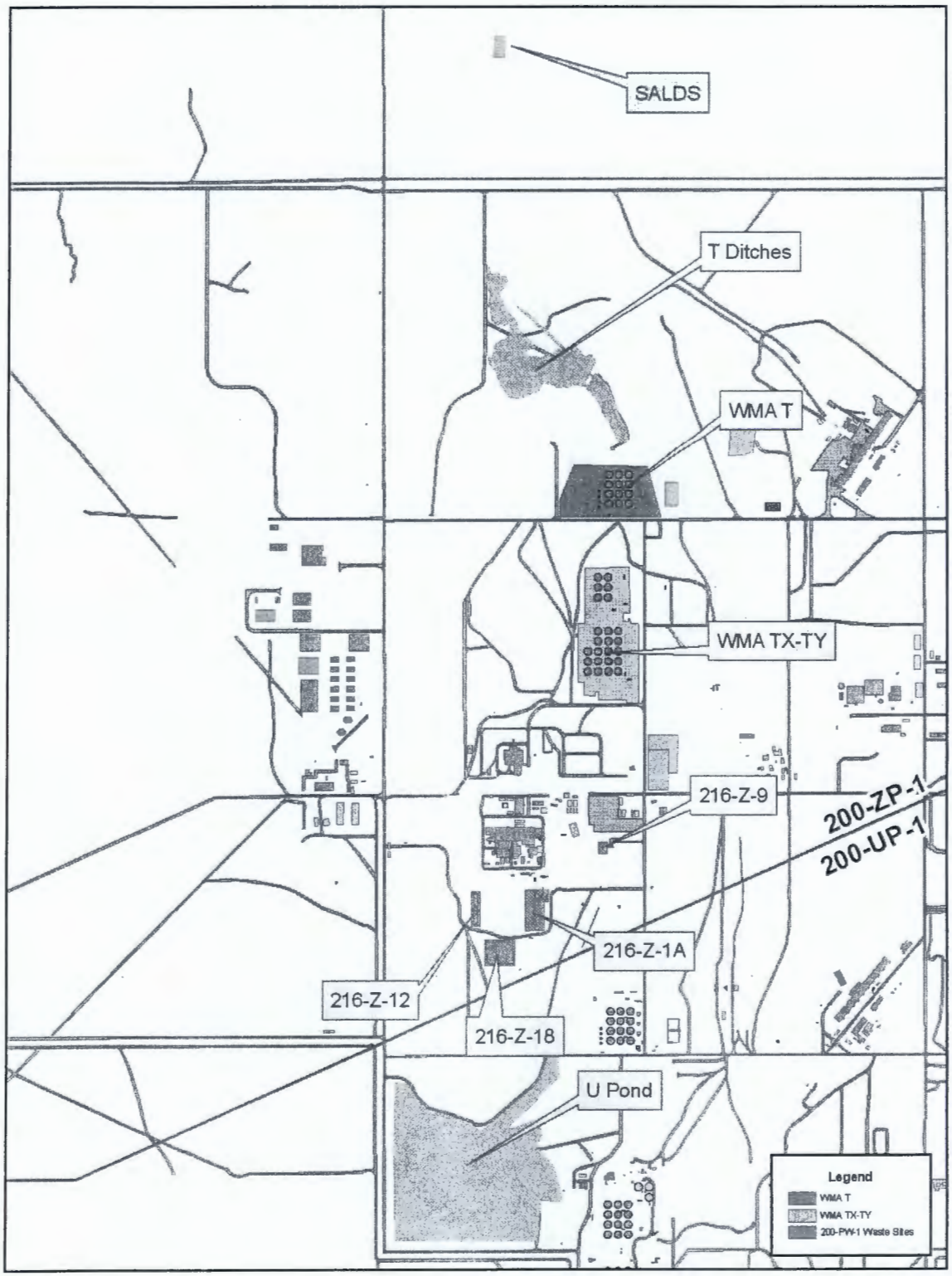


Figure 1-2. Relationship of the 200-PW-1 Operable Unit and Other Contributing Waste Sites to the Operable Unit and Other Waste Sites in the 200 West Area.



2.0 BACKGROUND INFORMATION

This section discusses the background and history of waste sources and sites overlying the 200-ZP-1 OU that may have contributed to groundwater contamination. The information includes OU background and history; physical setting; natural resources; representative waste site description, nature and extent of contamination; the CSM; and a risk assessment summary, which includes an evaluation of ecological significance.

2.1 SITE DESCRIPTION

The 200-ZP-1 OU is centered within the 200 West Area of the Hanford Site (Figure 1-1). The 200-ZP-1 Groundwater OU is one of two groundwater OUs centered within the 200 West groundwater aggregate areas of the Hanford Site. The 200-ZP-1 OU groundwater underlies the Z Plant and T Plant aggregate areas, WMA-T, WMA-TX/TY, the SALDS, and various cribs and trenches receiving liquid waste (Figure 1-2). The primary cribs and trenches include the following:

- 216-Z-1A
- 216-Z-9
- 216-U-10
- 216-Z-12
- 216-Z-18
- 216-Z-19
- 216-Z-20.

This section describes the background and history of waste sources and sites overlying the 200-ZP-1 OU to assist in evaluating alternatives for remediation of the groundwater. The information in Sections 2.1.1 and 2.1.2 was obtained from the 200-ZP-1 RI report (DOE/RL-2006-24). The information in Sections 2.1.3 and 2.1.4 was obtained from *Z Plant Source Aggregate Area Management Study Report* (DOE/RL-91-58). The information in Sections 2.1.5 through 2.1.7 was obtained from *Hanford Site Groundwater Monitoring for Fiscal Year 2005* (PNNL-15670).

The DOE has operated an interim action pump-and-treat system to prevent carbon tetrachloride from spreading since 1994. Carbon tetrachloride concentrations have decreased in the original target area. In fiscal year 2005 (FY05), the pump-and-treat system was expanded by adding additional extraction wells (PNNL-15670). Currently, the pump-and-treat system includes 10 extraction wells. Since 1994, more than 3.2 billion L (840 million gal) of groundwater have been extracted. To date, more than 10,000 kg of carbon tetrachloride have been extracted from groundwater (*Fiscal Year 2006 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations* [DOE/RL-2006-73]).

2.1.1 T Plant

The T Plant was built in 1944. The 221-T Building (also known as T Plant, or T Canyon Building) housed the first operational, full-scale bismuth-phosphate separation facility. The dilute plutonium-nitrate solution generated through this process was transferred to the 224-T Bulk Reduction Building (also known as the Concentration Building), where it was purified to reduce volume using the lanthanum-fluoride process. Plutonium-separation operations in the

221-T and 224-T Buildings ceased in 1956. Primary waste streams from the 221-T and 224-T Buildings included process waste and aqueous process waste that were discharged to tanks, cribs, and trenches. The associated analytical laboratory operated from 1944 to 1956 and produced aqueous process waste that was discharged to a crib.

2.1.2 Z Plant Aggregate Area

The Z Plant began operation in 1945 as the 231-Z Facility, which concentrated plutonium-nitrate solution produced by either of the separation facilities (T Plant or B Plant) and converted the concentrate to a plutonium-nitrate paste for shipment to Los Alamos, New Mexico for further refinement. This operation took place from 1945 to 1949. Primary waste streams from the Plutonium Isolation Facility included process waste and wastewaters that were discharged to a ditch, several cribs, and a reverse well.

In 1949, the 234-5 Facility was constructed to produce plutonium metal. The 234-5 Facility, or Z Plant Complex (also referred to as the Plutonium Finishing Plant [PFP]), operated continuously from 1949 to 1973 and then intermittently from 1985 to 1988. Discharge of organic liquids to the ground was discontinued in 1973. The Z Plant processed plutonium from the 200 East and 200 West Area separation facilities to a plutonium metal and/or plutonium oxide. Primary waste streams from the PFP included process waste and wastewaters that were discharged to cribs, tanks, ponds, ditches, and seepage basins.

Plutonium recovery facilities also operated in the Z Plant process area. These included the Recovery of Uranium and Plutonium by Extraction (RECUPLEX) Facility (234-5Z Building) that operated from 1955 to 1962, and the Plutonium Reclamation Facility (PRF) (236-Z) that operated from 1964 to 1979 and again from 1984 to 1987. These facilities recovered plutonium from the PFP liquid waste stream. The primary waste streams from the RECUPLEX Facility included aqueous process waste, organic solvent waste, and spent silica gel that were discharged to a ditch, pond, trench, and french drain. The primary waste streams from the PRF included aqueous process waste and organic process waste that were discharged to trenches, cribs, and tile fields. Key among these disposal sites for the discharge of organic (carbon tetrachloride) wastes was the 216-Z-9 Trench, 216-Z-1A tile field, and 216-Z-18 Trench. The RECUPLEX Facility was shut down after a criticality event in 1962.

A process line also operated in the 242-Z Building from 1949 to 1959, and again from 1964 to 1976, to recover americium from the PFP waste stream. The primary waste stream from the americium recovery was spent ion-exchange (IX) resin that was discharged to ditches and a pond. The americium recovery process also generated an organic waste stream (carbon tetrachloride and dibutyl butyl phosphonate). This facility was shut down after an explosion in 1976 in one of the recovery units.

Laboratory operations, which produced liquid effluent wastes at Z Plant, began with production of plutonium metal in 1949 and ceased following completion of nuclear material stabilization. Analytical services included process control for the plutonium metal product, research and development, nuclear material stabilization, and non-defense work. Waste liquids were discharged to cribs following treatment at the 241-Z TSD facility (*History and Stabilization of the Plutonium Finishing Plant* [HNF-EP-0924]).

Between 1955 and 1973, an estimated 600,000 to 900,000 kg of carbon tetrachloride were discharged to the soil column overlying the 200-ZP-1 OU (*ERA Engineering Evaluation Cost*

Analysis and Environmental Assessment for 200-W Area Carbon Tetrachloride Plume [DOE/RL-91-32]).

2.1.3 Single-Shell Tank System Waste Management Area T

The WMA-T is located in the north-central portion of the 200 West Area and consists of the T Tank Farm, pipelines, diversion boxes, and other equipment. The tank farm contains 16 tanks that were constructed between 1943 and 1944; 12 tanks have a capacity of 2 million L (528,344 gal) each, and 4 tanks have a capacity of 208,000 L (54,948 gal) each. Leaks are known or suspected at 7 of the 16 tanks (PNNL-15670).

Over its operating history, the WMA-T waste management area received both chemical and radiochemical contamination as a result of deliberate discharges and infrastructure losses of high-level tank waste. Tank waste releases to this WMA consist principally of bismuth phosphate separation process supernatants and 242-T evaporator concentrates. The concentrated evaporator wastes are a time-specific blend of the various Hanford chemical separation waste streams, thus their compositions can vary widely. A notable potential source of subsurface contamination in the WMA-T is single-shell tank 241-T-106, which lost over 115,000 L of waste in 1973. More comprehensive descriptions regarding the compositions and amounts of waste contributing to contamination in the WMA-T are provided in (*Hanford Defined Waste Model, Rev. 5*, RPP-19822, Rev. 0 [Higley 2004]) and (*Hanford Soil Inventory Rev. 1, RPP-26744, Rev. 0* [Corbin 2005]).

Groundwater is monitored in accordance with WAC 173-303, AEA, and CERCLA. The objective of RCRA groundwater monitoring is to assess the extent and migration rate of wastes that originated from WMA-T. The monitoring wells are sampled for RCRA indicators (i.e., pH and specific conductance) and site-specific parameters (i.e., alkalinity, anions, dissolved oxygen [DO], metals, oxidation-reduction potential, and turbidity), as required by 40 CFR 265.93(d) and WAC 173-303-400. WMA-T is also monitored for the AEA constituents technetium-99 and tritium. The current groundwater assessment plan is described in *RCRA Assessment Plan for Single-Shell Tank Waste Management Area T* (PNNL-15301)

2.1.4 Single-Shell Tank System Waste Management Area TX-TY

The WMA-TX/TY is located in the north-central portion of the 200 West Area and consists of the TX and TY Tank Farms and associated facilities. The tank farms contain 24 tanks (each 2.9 million L [0.77 million gal]) that were constructed between 1944 and 1952. Leaks are known or suspected at 12 of the 24 tanks (PNNL-15670).

Over its operating history, the TX/TY waste management area (WMA-TX/TY) received both chemical and radiochemical contamination as a result of deliberate discharges and infrastructure losses of high-level tank waste. Tank waste releases to this WMA consist principally of REDOX, Uranium Recovery waste, and 242-T evaporator concentrates. The concentrated evaporator wastes are a time-specific blend of the various Hanford chemical separation waste streams, thus their compositions can vary widely. Notable potential sources of subsurface contamination in the TX/TY-WMA are single-shell tanks 241-TY-105 and 241-TY-106, which lost approximately 35,000 L and 20,000 L of waste in 1957 and 1959, respectively. (Higley 2004) and (Corbin 2005) provide more comprehensive descriptions regarding the compositions and amounts of waste contributing to contamination in WMA-TX/TY.

Groundwater is monitored in accordance with WAC 173-303-400, AEA, and CERCLA. The WMA-TX/TY monitoring wells are sampled for RCRA indicators (i.e., pH and specific conductance) and site-specific parameters (i.e., alkalinity, anions, DO, metals, oxidation-reduction potential, and turbidity), as required by 40 CFR 265.93(d), and WAC 173-303-400. WMA-TX/TY is also monitored for the AEA constituents technetium-99, iodine-129, and tritium. The current groundwater assessment plan is described in *RCRA Assessment Plan for Single-Shell Tank Waste Management Area TX-TY* (PNNL-16005).

2.1.5 State Waste Discharge Permit Groundwater Monitoring for the State-Approved Land Disposal Site

The Hanford Site's 200 Area ETF processes contaminated aqueous waste. The wastewater is discharged to the 200 Area SALDS according to the requirements of State of Washington "State Waste Discharge Permit Program" (WAC 173-216). The discharge permit was approved in June 1995, and the site began operating in December 1995 (PNNL-15670).

Permit requirements for groundwater monitoring are described in the *Groundwater Monitoring and Tritium-Tracking Plan for the 200 Area State-Approved Land Disposal Site* (PNNL-13121). The discharge permit establishes enforcement limits for maximum concentrations of nine compounds (i.e., acetone, benzene, cadmium, chloroform, copper, lead, mercury, sulfate, and tetrahydrofuran) and two other parameters (i.e., pH and total dissolved solids). Groundwater is also sampled for four AEA parameters: gross alpha, gross beta, strontium-90, and tritium. Numerical flow-and-transport modeling of the SALDS is conducted as required by the permit.

The continuing wastewater discharges at SALDS have resulted in a mound in the water table under the facility. Groundwater flows outward in all directions, away from the SALDS discharge points.

2.2 PHYSICAL SETTING

The following subsections briefly describe the meteorology, topography, and hydrogeologic frameworks in the vicinity of the 200-ZP-1 OU. This discussion summarizes information provided in the 200-ZP-1 RI report (DOE/RL-2006-24), the *200 West Groundwater Aggregate Area Management Study Report* (DOE/RL-92-16), the *Hanford Site National Environmental Policy Act (NEPA) Characterization Report* (PNNL-6415), and *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-West Area and Vicinity, Hanford Site, Washington* (PNNL-13858).

2.2.1 Meteorology

The Hanford Site lies within the semi-arid shrub-steppe Pasco Basin of the Columbia Plateau in south-central Washington State. Climatological data for the Hanford 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.

The prevailing surface winds on the Central Plateau are from the northwest and occur most frequently during the winter and summer. The HMS reports that wind speeds from 1945 through 2004 at 15.2 m (50 ft) above the ground were lower during the winter months, averaging 2.7 to 3.1 m/sec (6 to 7 mph), and were faster during the spring and summer, averaging 3.6 to 4.0 m/sec (8 to 9 mph).

Based on data collected from 1946 through 2004, the average monthly temperatures at the HMS ranged from a low of -0.7°C (31°F) in January to a high of 24.7°C (76°F) in July. The record maximum temperature of 45°C (113°F) occurred at the HMS on July 13, 2002, and on August 4, 1961. The record minimum temperature of -31°C (-23°F) occurred on both February 1 and 3, 1950. The annual average relative humidity at the HMS is 55%. The annual average dew point temperature at the HMS is 1°C (34°F).

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% of all precipitation from December through February.

Concerns about severe weather usually center on hurricanes, tornadoes, and thunderstorms. Fortunately, Washington does not experience hurricanes; tornadoes are infrequent and generally small in the northwestern portion of the United States. The estimated probability of a tornado striking a point on the Hanford Site is 9.6×10^{-6}/yr. The average occurrence of thunderstorms near the HMS is 10 per year (PNNL-6415).

2.2.2 Topography and Geomorphology

The 200-ZP-1 OU underlies the 200 West Area of the Hanford Site. The 200 Areas are located on a broad, relatively flat area constituting local topographic high commonly referred to as the Central Plateau (Figure 2-1). The plateau is a giant flood bar (Cold Creek bar) formed during cataclysmic Ice Age floods from glacial Lake Missoula. The flood bar may have started forming during the earliest floods 1 to 2 million years ago. The Cold Creek Bar trends generally east-west, with elevations between 197 and 225 m (647 to 740 ft). The plateau drops off rather steeply to the north and northeast into a former flood channel running east-southeast, with elevation changes of between 15 and 30 m (50 and 100 ft). The plateau gently decreases in elevation to the south into the Cold Creek valley and to the southeast toward the Columbia River. Most of the 200 West Area and the southern half of the 200 East Area are situated on the Cold Creek bar, while the northern half of the 200 East Area lies on the edge of a former flood channel. A secondary flood channel, with surface expression, runs south from the main channel to bisect the 200 West Area (Figure 2-1). The buried former river and flood channels may provide preferential pathways for contaminant movement in the vadose zone and groundwater. More detailed information on the physical setting of the 200 Areas and vicinity is provided in Appendix F of the Implementation Plan (DOE/RL-98-28).

Waste sites in the 200 West Area are situated on a relatively flat area within the secondary flood channel bisecting the 200 West Area. Surface elevations range from approximately 201 to 217 m (660 to 712 ft).

2.2.3 Geology

Information in this subsection was obtained from *Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units* (DOE/RL-2006-51).

The 200-ZP-1 Groundwater OU is located in the Pasco Basin, one of several structural and topographic basins of the Columbia Plateau. From oldest to youngest, the major geologic units of interest are the Elephant Mountain Member of the Saddle Mountain Basalt, Columbia River

Basalt Group, the Ringold Formation, the Cold Creek unit, the Hanford formation, and surficial deposits (Figures 2-2 and 2-3).

2.2.3.1 Elephant Mountain Member. The Elephant Mountain Member of the Saddle Mountains Basalt Group is the uppermost basalt unit (i.e., bedrock) in the 200 Areas (Appendix F of DOE/RL-98-28). Except for a small area north of the 200 East Area boundary where it has been eroded away, the Elephant Mountain Member is laterally continuous throughout the 200 Areas. The field investigations for the RI did penetrate to the basalt.

2.2.3.2 Ringold Formation. The Ringold Formation consists of an interstratified fluvial-lacustrine sequence of unconsolidated to semi-consolidated clay, silt, sand, and granule-to-cobble gravel deposited by the ancestral Columbia River. These sediments consist of four major units (from oldest to youngest): the fluvial gravel and sand of Unit 9 (basal coarse); the buried soil horizons, overbank, and lake deposits of Unit 8 (lower mud); the fluvial sand and gravel of Unit 5 (upper coarse); and the fluvial sand and overbank deposits of Unit 4 (upper fines). Units 9 and 5 consist of silty-sandy gravel with secondary lenses and interbeds of gravelly sand, sand, and muddy sands to silt and clay. Unit 8 (lower mud) consists mainly of silt and clay. Unit 4 (upper fines) consists of silty over-bank deposits and fluvial sand. Units 6 and 7 are not present beneath the 200 West and 200 East Areas; Unit 4 is not present in the 200 East Area, and it is discontinuous in the 200 West Area where it is present.

2.2.3.3 Cold Creek Unit. The Cold Creek unit includes standardized name for several post-Ringold Formation and pre-Hanford formation units present beneath a portion of the 200 East and 200 West Areas. The Cold Creek unit 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. The Cold Creek unit has been divided into five lithofacies: fine-grained, laminated to massive (fluvial-overbank and/or eolian deposits, formerly the early Palouse soil); fine- to coarse-grained, calcium-carbonate cemented (calcic paleosol, formerly the caliche); coarse-grained, multi-lithic (mainstream alluvium, formerly the pre-Missoula gravels); coarse-grained, angular, basaltic (colluvium); and coarse-grained, rounded, basaltic (side-stream alluvium, formerly side-stream alluvial facies). The Cold Creek unit varies in thickness, has been locally eroded, and not all of the facies are present everywhere. There is a slight dip in Cold Creek unit sediments to the south and/or southwest, and the dip is suspected of imposing some control on downward flow.

2.2.3.4 Hanford Formation. The Hanford formation is the informal stratigraphic name used to describe the Pleistocene cataclysmic flood deposits in the Pasco Basin. The Hanford formation consists predominantly of unconsolidated sediments range from boulder-size gravel to sand, silty sand, and silt. The sorting ranges from poorly sorted to well-sorted. The Hanford formation is divided into three main facies associations: interbedded sand- to silt-dominated (formerly called the Touchet beds or slackwater facies); sand-dominated (formerly called the sand-dominated flood facies); and gravel-dominated (formerly called the Pasco gravels), which have been further subdivided into 11 textural structural lithofacies. Beneath the 200 West Area waste sites, the Hanford formation includes all three facies associations. 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 the sand. Where the sand and silt content is low in the gravel-dominated facies, an open-framework

texture is common. Clastic dikes are common in the Hanford formation but are rare in the Ringold Formation. They appear as vertical to subvertical sediment-filled structures, especially within sand- and silt-dominated units. In general, from shallowest to deepest, the Hanford formation units encountered beneath the 200 West Area included an upper fine-grained unit (HFUF), the upper gravel-dominated unit (H1), a sand-dominated unit (H2), and a lower gravel-dominated unit (H3). Not all of these units are laterally continuous beneath the Site.

The cataclysmic floodwaters depositing sediments of the Hanford formation locally reshaped the topography of the Pasco Basin. The floodwaters deposited a thick sand and gravel bar (Cold Creek bar) constituting the higher southern portion of the 200 Areas, informally known as the 200 Areas Plateau. In the waning stages of the Ice Age floods, these floodwaters also eroded a channel north of the 200 Areas in the area currently occupied by West Lake and the former Gable Mountain Pond. Both pre-Hanford formation erosion and the floodwaters removed all of the Ringold Formation from this area and deposited Hanford formation sediments directly over basalt.

2.2.3.5 Surficial Deposits. Surficial deposits include Holocene eolian sheets of sand forming a thin veneer over the Hanford formation across the Site, except in localized areas where the deposits are absent. Surficial deposits consist of very fine- to medium-grained sand to occasionally silty sand. Fill material was placed in and over some waste sites during construction and for contamination control. The fill consists of reworked Hanford formation sediments and/or surficial sand and silt.

2.2.4 Hydrostratigraphy

The hydrostratigraphic units in the 200-ZP-1 OU include Units 9, 8, 5, and 4 (Ringold Formation); Units 2 and 3 (Cold Creek unit); Unit 1 (Hanford formation); and surficial deposits. The base of the unconfined aquifer typically is the top of the Ringold Unit 8 (lower mud) in the 200 West Area. The information provided in this section was obtained from DOE/RL-2006-51.

2.2.4.1 Vadose Zone. The vadose zone is the area between the ground surface and the water table. In the 200 West Area, the vadose zone thickness ranges from 40 to 75 m (132 to 246 ft). Sediments in the vadose zone are the Ringold Formation, the Cold Creek unit, and the Hanford formation. Erosion during cataclysmic flooding removed some of the Cold Creek unit and the Ringold Formation, especially in the northern portion of the 200 West Area.

Historically, and as recently as the early 1990s, perched water has been documented above the Cold Creek unit at locations in the 200 West Area. While liquid waste disposal facilities were operating, localized areas of saturation or near saturation were created in the soil column. With the reduction of artificial recharge in the 200 Areas in 1995, downward flux of liquid in the vadose zone beneath these waste sites has been decreasing. However, moisture content in the vadose zone is expected to remain elevated above preoperational conditions for some time.

2.2.4.2 Unconfined Aquifer. The top of the unconfined aquifer in the 200 Areas occurs within the Ringold Formation, the Cold Creek unit, or the Hanford formation, depending on location. The base of the unconfined aquifer is the top of the Ringold Unit 8 (lower mud), or the top of the basalt where Unit 8 is absent at the 200 West Area, and the top of the basalt at the 200 East Area. The basalt also projects above the water table in the northern portion of the 200 East Area. Groundwater in the unconfined aquifer flows from recharge areas where the water table is higher (west of the Hanford Site) to areas where it is lower, near the Columbia River.

Groundwater beneath the 200 West Area occurs primarily in the Ringold Formation. Depth to water varies from about 40.2 m (132 ft) to greater than 75 m (246 ft). Groundwater flow is predominately to the east (Figure 2-4). The surface elevation of the water table beneath the 200 West Area currently is declining at a rate of 0.36 m/yr (1.2 ft/yr) in those areas not influenced by pump-and-treat remediation systems.

Recharge to the unconfined aquifer within the 200 Areas in the past was primarily from artificial sources and is now primarily from natural precipitation. Estimates of recharge from precipitation range from 0 to 10 cm/yr (0 to 4 in./yr) and are largely dependent on soil texture and the type and density of vegetation. *Hanford Site Groundwater Changes 1950 through 1980, Data Observation and Evaluation* (PNL-5506) reports that between 1943 and 1980, 6.33×10^{11} L (1.67×10^{11} gal) of liquid wastes were discharged to the soil column at the Hanford Site. Most sources of artificial recharge were terminated in 1995. The artificial recharge continuing largely is limited to liquid discharges from sanitary sewers, two state-approved land disposal structures (one east of the 200 East Area and one north of the 200 West Area), and 140 small-volume, uncontaminated miscellaneous liquid discharge streams.

2.3 NATURAL RESOURCES

Natural resources in the vicinity of the study area include vegetation and wildlife resources. The wildfire in 2000 did not reach the ground surface overlying the OU.

Biological and ecological information aids in evaluating impacts to the environment from contaminants in the soils, including potential effects of implementing remedial actions and identification of sensitive habitats and species. This section also considers cultural and aesthetic resources and socioeconomics associated with activities in the 200 Areas.

2.3.1 Vegetation

The *Hanford Site National Environmental Policy Act (NEPA) Characterization Report* (PNNL-6415) reports that the undisturbed portions of the 200 Areas are characterized by sagebrush/cheatgrass or sagebrush/Sandberg's bluegrass communities. The dominant plants on the 200 Areas Plateau are big sagebrush, rabbitbrush, cheatgrass, and Sandberg's bluegrass. Of the vegetation types found on the Hanford Site, adjacent to the study areas, those with a shrub component (i.e., big sagebrush, threetip sagebrush [*Artemisia tripartita*], bitterbrush [*Purshia tridentata*], gray rabbitbrush [*Ericameria nauseousa*, previously *Chrysothamnus nauseosus*], green rabbitbrush [*Chrysothamnus viscidiflorus*], black greasewood [*Sarcobatus vermiculatus*], winterfat [*Krascheninnikovia (Ceratoides) lanata*], snow buckwheat [*Eriogonum niveum*], and spiny hopsage [*Grayia (Atriplex) spinosa*]) are considered shrub-steppe. These stands typically have an understory dominated by bunchgrasses such as bluebunch wheatgrass (*Pseudoroegnaria spicata*, previously *Agropyron spicatum*), Sandberg's bluegrass (*Poa sandbergii [secunda]*), needle-and-thread grass (*Hesperostipa comata*, previously *Stipa comata*), Indian ricegrass (*Achnatherum hymenoides*, previously *Oryzopsis hymenoides*), bottlebrush squirreltail (*Elymus elymoides*, previously *Sitanion hysterix*), and prairie junegrass (*Koeleria cristata*), as well as a number of broad-leaf forbs. Heavily grazed or disturbed areas on the Hanford Site often have an understory dominated by cheatgrass.

2.3.2 Wildlife

The shrub and grassland habitat of the Hanford Site supports many groups of terrestrial wildlife. Species may include large animals such as the Rocky Mountain elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*); predators such as coyote (*Canis latrans*), bobcat (*Lynx rufus*), and badger (*Taxidea taxus)*; and herbivores including deer mice (*Peromyscus maniculatus)*, harvest mice (*Riethrodontonomys megalotis*), ground squirrels (*Spermophilus* spp.), voles (*Lagurus* spp., *Microtus* spp.), and black-tailed jackrabbits (*Lepus californicus*). The most abundant mammal on the Hanford Site is the Great Basin pocket mouse (*Perognathus parvus*). Many of the rodent species and some predators (badgers) construct burrows on the site. Other non-borrowing animals may include cottontails (*Sylvilagus nutalli*), jackrabbits, snakes, and burrowing owls (*Athene cunicularia*), which may use abandoned burrows of other animals (PNNL-6415).

The largest mammal potentially frequenting the study areas is the mule deer. Mule deer collected around the 200 Areas, away from the river, constitute a grouping named the central population. The Rattlesnake Hills herd of elk inhabiting the Hanford Site primarily occupies the Fitzner-Eberhardt Arid Lands Ecology Reserve Unit and private lands adjoining the reserve to the south and west. They are occasionally seen on the 200 Areas Plateau (PNNL-6415).

Common upland gamebird species in shrub and grassland habitat include chukar (*Alectoris chukar*), partridge (*Perdix perdix*), California quail (*Callipepla californica*), and ring-necked pheasant (*Phasianus colchicus*). Chukars are most numerous in the Rattlesnake Hills, Yakima Ridge, Umtanum Ridge, Saddle Mountain, and Gable Mountain areas of the Hanford Site. Less common species include greater sage grouse (*Centrocercus urophasianus*), and scaled quail (*Callipepla squamata*). Greater sage grouse were historically abundant on the Hanford Site; however, populations have declined since the early 1800s (PNNL-6415).

Among the more common raptor species to use shrub and grassland habitat are the ferruginous hawk (*Buteo regalis*), Swainson's hawk (*B. swainsoni*), and red-tailed hawk (*B. jamaicensis*). Northern harriers (*Circus cyaneus*), sharp-shinned hawks (*Accipiter striatus*), rough-legged hawks (*B. lagopus*), and golden eagles (*Aquila chrysaetos*) also occur in this habitat, although infrequently (PNNL-6415).

The side-blotched lizard (*Uta stansburiana*) is the most abundant reptile species occurring on the Hanford Site. Short-horned (*Phrynosoma douglassii*) and sagebrush (*Sceloporus graciosus*) lizards are also found on the Hanford Site, but occur infrequently. The most common snake species include gopher snake (*Pituophis melanoleucus*), yellow-bellied racer (*Coluber constrictor)*, and western rattlesnake (*Crotalus viridis*) (PNNL-6415).

Many species of insects occur throughout habitats on the Hanford Site. Butterflies, grasshoppers, and darkling beetles are among the most conspicuous of the about 1,500 species of insects identified from specimens collected on the Hanford Site. The actual number of insect species occurring on the Hanford Site may reach as high as 15,500 (PNNL-6415).

2.3.3 Species of Concern

The Hanford Site is home to a number of species of concern, but many of these are associated with the Columbia River and its shoreline, or steel transmission line towers. There are no Federal- or state-listed endangered or threatened mammals, reptiles, amphibians, or invertebrates on the Hanford Site, but there are 3 species of fish, 5 species of birds, and 11 species of plants listed as threatened or endangered by either the state or Federal governments outside of the land overlying the 200-ZP-1 OU (PNNL-6415).

2.3.4 Cultural Resources

Much of the 200 Areas have been altered by Hanford operations. The Hanford Cultural Resources Laboratory conducted a comprehensive archaeological resources survey of the fenced portions of the 200 Areas during 1987 and 1988. The results did not indicate evidence of cultural resources associated with the Native American cultural landscape, early settlers/farming landscape, or archaeological discoveries associated with the study areas (PNNL-6415).

The *National Historic Preservation Act of 1966* requires agencies to consult with the State Historic Preservation Officer and the Advisory Council on Historic Preservation to ensure that all potentially significant cultural resources (including structures and associated sites) were adequately identified, evaluated, and considered in planning for a proposed undertaking (e.g., remediation, renovation, or demolition) (*Draft Hanford Site Manhattan Project and Cold War Era Historic District Treatment Plan* [DOE/RL-97-56]). The land overlying the 200-ZP-1 OU contains one Manhattan Project signature facility, T Plant (Chemical Separation Building) (*Recommendations and Preservation Options for Manhattan Project Signature Facilities at Oak Ridge and Hanford Reservations* [EM-51]). No other buildings or structures are associated with the Manhattan Project and Cold War landscape or eligible for the National Register as contributing properties within the Historic District requiring individual documentation (PNNL-6415).

2.3.5 Aesthetics, Visual Resources, and Noise

PNNL-6415 reports that, with the exception of Rattlesnake Mountain, the land near the Hanford Site is generally flat with little relief. Rattlesnake Mountain, rising to 1,060 m (3,477 ft) above mean sea level, forms the western boundary of the Hanford Site. Gable Mountain and Gable Butte are the highest landforms within the Site. The Columbia River and Rattlesnake Mountain are generally considered scenic.

Studies of the propagation of noise at Hanford have been concerned primarily with occupational noise at work sites. Environmental noise levels have not been extensively evaluated because of the remoteness of most Hanford activities and isolation from receptors covered by Federal or state statutes. Most industrial facilities on the Hanford Site are located far enough away from the Site boundary that noise levels at the boundary are not measurable or are barely distinguishable from background noise levels (PNNL-6415).

2.3.6 Socioeconomic

PNNL-6415 reports that activity on the Hanford Site plays a dominant role in the socioeconomics of the Tri-Cities (i.e., the cities of Pasco, Richland, and Kennewick, Washington) and other parts of Benton and Franklin Counties. The agricultural community also has a significant effect on the local economy. Any major changes in Hanford activity would potentially affect the Tri-Cities and other areas of Benton and Franklin Counties.

Contractors to DOE compose the largest single source of employment in the Tri-Cities. During FY04, an average of 10,247 employees were employed by the ORP and its prime contractor CH2M Hill Hanford Group, Inc.; and by RL and its prime contractors Fluor Hanford, Inc.; Bechtel Hanford, Inc.; AdvanceMed Hanford; and PNNL (which is operated by Battelle for the DOE Office of Science's Pacific Northwest Site Office). The FY04 year-end employment for DOE contractors was 10,225, which was down slightly from 10,288 at the end of FY03. In addition to these totals, Bechtel National, Inc. and its subcontractors, including prime

subcontractor Washington Group International, employed 3,780 employees at the end of FY04. As of August 2005, Washington Closure Hanford, LLC (WCH) formally replaced Bechtel Hanford, Inc. WCH is a partnership consisting of Washington Group International, Inc.; Bechtel National, Inc.; and CH2M Hill, Inc. During December 2000, ORP awarded a contract directly to Bechtel National, Inc. to design, build, and start up waste treatment facilities for the glassification of liquid radioactive waste.

The Hanford Site represents 14% of the total jobs in the local economy. Total employment in the Tri-Cities metropolitan statistical area averaged 99,900 during 2004, which is up from 96,400 in 2003. Based on employee records as of February 2005, 91% of the direct employees of Hanford live in Benton and Franklin Counties. Approximately 73% of Hanford employees reside in Richland, Pasco, or Kennewick. More than 36% are Richland residents, 10% are Pasco residents, and 26% live in Kennewick. Residents of other areas of Benton and Franklin Counties (including West Richland, Benton City, and Prosser) account for approximately 17% of total Hanford Site employment.

In addition to the Hanford Site, other key employers in the area are as follows:

- Energy Northwest
- ConAgra/Lamb Weston
- Tyson Fresh Meats
- Boise Cascade Corporation Paper and Corrugated Container Divisions
- AREVA NP, Inc.
- Wal-Mart.

Tourism and government transfer payments to retirees in the form of pension benefits also are important contributes to the local economy.

An estimated total of 155,100 people lived in Benton County and 57,000 lived in Franklin County during 2004, totaling 212,100, which is an increase of almost 11% from the census count for the year 2000. According to the 2000 census, population totals for Benton and Franklin Counties were 142,475 and 49,347, respectively. Both Benton and Franklin Counties grew at a faster pace than Washington did as a whole during the 1990s. The population of Benton County grew 26.6%, up from 112,560 during 1990. The population of Franklin County grew 31.7%, up from 37,473 during 1990.

Based on the 2000 census, the 80-km (50-mi) radius area surrounding the Hanford Site had a total population of 482,300 and a minority population of 178,500. The ethnic composition of the minority population is primarily white Hispanic (24%), self-designated "other and multiple races" (63%), and Native American (6%). Asians and Pacific Islanders (4%) and African Americans (3%) make up the remainder of the population in the area. The Hispanic population resides predominantly in Franklin, Yakima, Grant, and Adams Counties. Native Americans within the 80-km (50-mi) area reside primarily on the Yakama Reservation and upstream of the Hanford Site near the town of Beverly, Washington.

2.4 NATURE AND EXTENT OF CONTAMINATION

The following subsections describe the changes in the understanding of carbon tetrachloride and technetium-99 contamination as new data have become available, as well as the current understanding of contaminant distribution in the 200-ZP-1 OU groundwater. Since issuance of the *Record of Decision for the USDOE Hanford 200-ZP-1 Operable Unit Interim Remedial*

Measure (EPA/ROD/R10-95/114) in May 1995, the understanding of contaminant distribution in 200-ZP-1 OU groundwater has been refined as additional wells have been installed and analytical techniques (e.g., lower detection limits) have improved. Additional focused investigations in both the vadose zone and groundwater have enhanced the 200-ZP-1 OU conceptual model (presented in Section 2.5). Additional information on the nature and extent of contamination can be found in the 200-ZP-1 RI report (DOE/RL-2006-24), the *Carbon Tetrachloride Dense Non-Aqueous Phase Liquid (DNAPL) Source- Term Interim Characterization Report* (DOE/RL-2006-58), and the *Carbon Tetrachloride Dense Non-Aqueous Phase Liquid (DNAPL) Source-Term Characterization Report Addendum* (DOE/RL-2007-22).

2.4.1 Variability in Portrayals of Contaminant Distribution

2.4.1.1 200-ZP-1 Operable Unit Remedial Investigation. Contours for COPCs identified during preparation of the 200-ZP-1 RI report were presented in Appendices A and C (DOE/RL-2006-24). The contours presented in Appendix A of the RI report were developed using average annual concentrations measured in groundwater during FY05 and were presented in the FY06 annual groundwater report. To further evaluate the vertical extent of carbon tetrachloride concentrations in groundwater, contours were prepared for three depth intervals and are presented in Appendix C of the RI report. The three depth intervals for which contours were prepared were shallow (0 to 18.3 m [0 to 60 ft] below the water table [bwt]), medium (18.3 to 36.6 m [60 to 120.1 ft] bwt), and deep (greater than 36.6 m [120.1 ft] bwt). The concentrations used to generate these contours were the maximum concentrations detected from each depth interval for each well for samples collected from 2002 to 2006.

2.4.1.2 Annual Pump-and-Treat Reports. Contours for carbon tetrachloride, chloroform, and trichloroethylene (TCE) have also been prepared annually for the pump-and-treat reports for the 200-ZP-1 OU IRM (PNNL-15670). These contours are generated based on extraction well and monitoring well data collected in August of each year. The contouring approach used in assessing the performance of the IRM is designed to be consistent with the method used to establish the high-concentration portion of the plume, as described in the ROD (*Record of Decision for the USDOE Hanford Environmental Restoration Disposal Facility Remedial Action* [EPA/ROD/R10-95/110]).

2.4.1.3 Fiscal Year 2005 Annual Groundwater Monitoring Report. Sitewide annual groundwater monitoring reports prepared by Pacific Northwest National Laboratory (PNNL) present contours for various COCs within the 200-ZP-1 OU. These contours are prepared based on annual average concentrations and professional judgment. Contaminants are contoured, based on average results for samples collected in the FY for each well. If no new data were collected for a well in the FY, data from previous FYs are used (PNNL-15670). The annual groundwater monitoring reports do not provide specific details on the methods and algorithms used in generations of these contours. Figures 2-5 and 2-6 depict the distribution of carbon tetrachloride contamination in the 200-ZP-1 OU, as presented in the annual groundwater reports in 1994 and 2005, respectively.

2.4.1.4 Dense Non-Aqueous Phase Liquid Source Term Characterization Report. The carbon tetrachloride dense nonaqueous phase liquid (DNAPL) interim characterization report (DOE/RL-2006-58) and associated DNAPL interim characterization report addendum (DOE/RL-2007-22) document a major DOE-RL effort to identify and locate DNAPL source

term(s). Extensive characterization of both the vadose zone and the groundwater were conducted as part of this effort. Within the vadose zone, the only region identified as having near DNAPL concentrations was a silt lens at approximately 19.8 m (65 ft) on the southern edge of the 216-Z-9 Trench. This lens is estimated to have a lateral extent of approximately 9.2m (30 ft) by 21.3m (70 ft). The carbon tetrachloride that is trapped in this silt lens is believed to be trapped by sorption and capillary forces and will not undergo any further downward migration. This carbon tetrachloride will continue to degrade and volatize and could impact the groundwater system only through vapor phase transport. This transport is currently being controlled by the operation of a Soil Vapor Extraction (SVE) system as part of the 200-PW-1 operable unit interim remedial measure (IRM).

The DNAPL investigation effort also characterized the groundwater with depth discrete sampling efforts over the majority of the high concentration portion of the carbon tetrachloride groundwater plume. Contaminant distribution maps were developed using the data set developed as part of the carbon tetrachloride dense nonaqueous phase liquid (DNAPL) interim characterization report (DOE/RL-2006-58) and the DNAPL interim characterization report addendum (DOE/RL-2007-22). This data set consisted of 48 wells in which depth-discrete data for (carbon tetrachloride) was collected. DNAPL was not identified in any samples collected as part of this data set. In addition to the depth discrete sampling, well 299-W15-6, which is the only deep well near the 216-Z-9 Trench, was connected to the pump and treat system and pumped for a duration of 4 months. The carbon tetrachloride concentrations showed a minor initial increase and then stabilized at less than 2,000 μg/L , which is less than expected if DNAPL was present at the bottom of the aquifer under the 216-Z-9 Trench.

The conceptual site models developed for the DNAPL reports support a DNAPL source term in the vadose zone at 216-Z-9 at a depth of 19.8 m (65 ft). This source term is to be addressed by the 200-PW-1 interim and final remedies. The transport mechanism for this source is vapor transport down through the vadose zone. The data obtained to date does not indicate a DNAPL groundwater source; however, given the uncertainty in the mass balances, the potential for a currently undiscovered source is carried forward as a contingency that remedial measures must address.

2.4.1.5 Pacific Northwest National Laboratory Geostatistical Evaluation. To identify areas in the 200 West Area where apparently persistent high local concentrations of carbon tetrachloride in the groundwater may indicate the presence of continuing sources, an analysis was performed by PNNL using a geostatistical approach. Several of the northern sub-areas had relatively high median concentrations with low variability, and little variation with time. This suggests that these would be sub-areas that might contain continuing sources. Sub-area 7 shows a significant decrease in median concentration over time, suggesting that concentrations in that area have substantially decreased, possibly due to the pump-and-treat remedial action taking place near that sub-area. Sub-areas 6 and 1 also show significant decreases in median concentration over time and seem unlikely to contain continuing carbon tetrachloride sources. Sub-area 8 shows an increasing median carbon tetrachloride concentration with time, but concentrations in that sub-area remains significantly lower than all of the other sub-areas, indicating that it is unlikely to contain a significant continuing source of carbon tetrachloride. As such, the results suggest that undiscovered sources may exist in the vadose zone or aquifer in some areas, and the nature and location of which would need to be verified by additional characterization (*Geostatistical Analyses of the Persistence and Inventory of Carbon*

Tetrachloride in the 200 West Area of the Hanford Site 2007 [PNNL-16509]). Figure 2-7 provides a summary of these results.

In addition, PNNL performed geostatistical analysis of the inventory of carbon tetrachloride remaining in the unconfined aquifer in the 200 West Area. One data set consisted of three-dimensional carbon tetrachloride and chloroform data from depth-discrete sampling at 192 discrete depths during drilling in 36 boreholes and is termed as the "depth-discrete data set." The depth-discrete data were sampled from 1999 to 2006. A secondary data set, termed the "packer data set," was also used. It supplemented the depth-discrete data taken while drilling, with 88 measurements taken in completed wells using packers in the screened intervals to attempt to isolate discrete vertical zones of the unconfined aquifer.

The inventory of carbon tetrachloride and chloroform were estimated within the geostatistical simulation grid using a Monte Carlo approach. The inventory reflects carbon tetrachloride and chloroform present in the groundwater and sorbed to the sediment, with the chloroform assumed to represent carbon tetrachloride that degraded early. The inventory simulations were based solely on aqueous concentration data from the two data sets, and DNAPL is not included in the inventory estimates. The Monte Carlo approach used to estimate the inventory attempted to account for uncertainty in the porosity and the sediment/water equilibrium distribution coefficient (K_d) values for carbon tetrachloride and chloroform by drawing values for those parameters from probability distributions.

Simulation and inventory calculations performed using the combined data set that included packer data, as well as the depth-discrete data, suggested inventories of carbon tetrachloride distributed in the aquifer that were 7.4% higher, with a mean inventory of approximately 108,900 kg and a 95% probability interval derived from the simulations of 70,300 to 171,700 kg. Although a standard T-test suggests that the average inventory for the combined data set is significantly higher, there is wide uncertainty in the inventory simulations, with only a slight upward shift in the distribution of simulated inventory values.

Analysis of the potential effect of hydrolysis on carbon tetrachloride present in the aquifer for the two data sets suggests that between 132,000 and 143,500 kg of carbon tetrachloride would have had to reach the aquifer to result in the current distribution of carbon tetrachloride and chloroform. This would account for about 18% to 19% of the 750,000 kg of carbon tetrachloride thought to have been originally disposed in the 200 West Area, which is almost an order of magnitude higher than previous estimates of the disposed carbon tetrachloride accounted for by the inventory in the unconfined aquifer (PNNL-16509).

2.4.1.6 200-ZP-1 Operable Unit Feasibility Study. To further define the horizontal and vertical extent of the carbon tetrachloride and other principal COPCs in groundwater, data from additional wells (not previously included in DOE/RL-2006-58 depth-discrete data set) were used for which collection depths of samples were known in the 200-ZP-1 OU FS. Groundwater monitoring wells were installed and depth-discrete samples were collected in 2006 from wells 299-W11-86, 299-W14-71, and 299-W14-72 (near the former 216-W-LC Laundry Waste Crib). Data from wells 299-W11-45, 299-W11-47, 299-W19-101, 299-W19-104, 299-W19-105, 299-W19-107, 299-W19-46, 299-W19-48, 299-W19-50, 299-W21-2, 299-W22-47, 299-W22-50, 299-W22-69, 299-W22-72, 299-W22-86, 299-W22-87, 699-30-66, and 699-36-70B were also used. Data from these wells were not available in the Hanford Environmental Information System (HEIS) database at the time that the 200-ZP-1 RI report (DOE/RL-2006-24) was prepared.

In order to better evaluate impacts to groundwater for the purposes of preparing this FS report, groundwater contours were prepared for carbon tetrachloride, TCE, and technetium-99 for the following depth intervals: 0 to 10 m (0 to 32.8 ft) bwt, 10 to 20 m (32.8 to 65.6 ft) bwt, 20 to 30 m (65.6 to 98.4 ft) bwt, 30 to 40 m (98.4 to 131.2 ft) bwt, 40 to 50 m (131.2 to 164 ft) bwt, and greater than 50 m (164 ft) bwt. Shallow groundwater (0 to 10 m [0 to 32.8 ft] bwt) sampling data were added to the data set for wells 299-W10-14, 299-W10-21, 299-W12-1, 299-W18-22, 299-W22-9, 299-W26-12, 299-W26-6, 299-W26-7, 299-W27-1, 299-W6-3, 299-W6-4, 299-W7-10, 299-W7-4, 299-W7-5, 299-W7-6, 299-W7-7, 299-W7-8, 299-W7-9, 299-W8-1, 299-W9-1, 699-35-66A, 699-35-70, 699-36-78A, 699-36-67, 699-36-70A, 699-37-68, 699-37-82A, 699-38-65, 699-39-79, 299-44-64, 699-45-69A, 699-48-71, and 699-54-75 to better define the 5 µg/L carbon tetrachloride contour. Locations of these wells are shown in Figure D-11 in Appendix D. The data for each COPC impact were contoured using a kriging approach (as described in Appendix D), using the maximum value for the COPC from each depth interval (or from each well, at the center of the screened interval, for COPCs in which multiple depth intervals are not available) for data collected since January 1, 2000. Additional details regarding COPC data contouring are provided in Appendix D.

2.4.2 Current Understanding of 200-ZP-1 Operable Unit Contaminant Distribution

Appendix D outlines the data analysis and modeling methods that were used to evaluate groundwater hydraulic conditions at the 200-ZP-1 OU to support the comparative analysis of the FS and remedy identification. The subsections below describe the current understanding of the contaminant distribution. Details describing the methods used to interpolate contaminant distributions are provided in Appendix D.

Contour intervals for specific contaminants were based on mass, human health risk, and maximum contaminant level (MCL) values. The mass of a contaminant was calculated within various contour intervals as part of the pump-and-treat modeling described in Appendix D. Specific concentrations for various human health risk levels (e.g., 1×10^{-4}, 1×10^{-5}, 1×10^{-6}, etc.) were calculated as part of the risk assessment summarized in Appendix A. The contour intervals presented in Figures 2-8 through 2-35 were based on an evaluation of the contaminant mass distribution, human health risk levels, and MCL values.

2.4.2.1 Carbon Tetrachloride. The extent of carbon tetrachloride in groundwater for each depth interval is shown in Figure 2-8 through Figure 2-13. The carbon tetrachloride contamination above the MCL (the 5 µg/L contour) extends from south of 216-U-10 (within the 200-UP-1 OU) to the northern core zone boundary, and from approximately 762 m (2,500 ft) west of PFP to approximately 609.6 m (2,000 ft) east of the former 216-W-LC Laundry Waste Crib. The extent of the 5 µg/L contour for the 0 to 10 m (0 to 32.8 ft) bwt interval is shown in Figure 2-7. The highest concentration portion of the carbon tetrachloride groundwater impacts (i.e., greater than 1,000 µg/L) are currently located north and northeast of PFP and toward the former laundry waste facility. In general, the location of the highest concentration portion of the carbon tetrachloride groundwater impacts are located further east and south with depth. This distribution generally conforms to the Hanford Site hydraulic conceptual model that during mounding of the groundwater table in the vicinity of 200-ZP-1 OU, the magnitude and extent of the increases in hydraulic head were generally less with depth. The smaller magnitude of hydraulic heads with depth resulted in a generally more easterly groundwater flow with depth, as compared to more northerly flow near the water table surface. It also appears that the

distribution of carbon tetrachloride in shallow groundwater was directly influenced by discharges to 216-U-10 Pond, 216-Z-19 Ditch, and 216-Z-20 Crib.

The results from the RI and a data set focused on identifying the presence or absence of DNAPL carbon tetrachloride deep in the unconfined aquifer (DOE/RL-2007-22) do not suggest that a DNAPL source or other high-concentration source area is present within the aquifer. However, if a DNAPL source is identified during future investigation activities, contingent actions have been included in the remedy selection process to remediate these potential source areas.

Estimates of the mass of carbon tetrachloride in the aquifer range from 70,300 to 171,700 kg (PNNL-16509, DOE/RL-2006-58).

2.4.2.2 Chloroform. The interpolated extent of chloroform in groundwater is shown in Figure 2-14. The maximum concentrations of chloroform (i.e., 1,100 µg/L) in groundwater are located in the vicinity of PFP, between the PFP and 216-Z-9 Trench. The chloroform contamination above the MCL (the 80 µg/L contour) extends from south of 216-U-10 (within the 200-UP-1 OU) to the northern core zone boundary, and from approximately 425 m (1,400 ft) west of PFP to approximately 2,743 m (9,000 ft) east of the former 216-W-LC laundry Waste Crib.

2.4.2.3 Methylene Chloride. The interpolated extent of methylene chloride in groundwater is shown in Figure 2-15. The maximum concentrations of methylene chloride in groundwater are located in the vicinity of PFP, between the PFP and 216-Z-9 Trench, and in an area near the former laundry waste site. The methylene chloride contamination above the MCL (the 5 µg/L contour) extends from south of 216-U-10 (within the 200-UP-1 OU) to the northern core zone boundary, and from approximately 1,128 m (3,700 ft) west of PFP to approximately 1,609 m (5,280 ft) east of the former 216-W-LC Laundry Waste Crib.

2.4.2.4 Trichloroethylene. Figures 2-16 through 2-21 show the interpolated concentrations of TCE for each depth interval (0 to 10 m [0 to 32.8 ft] bwt, 10 to 20 m [32.8 to 65.6 ft] bwt, 20 to 30 m [65.6 to 98.4 ft] bwt, 30 to 40 m [98.4 to 131.2 ft] bwt, 40 to 50 m [131.2 to 164 ft] bwt, and greater than 50 m [164 ft] bwt). In general, the highest concentrations of TCE in groundwater within the 200-ZP-1 OU are located east of PFP, west of the WMA-TX/TY tank farm area, and west of WMA-T. The highest reported TCE concentration is 147 µg/L. The TCE contamination above the MCL (the 5 µg/L contour) extends from PFP north to WMA-TX/TY, and from WMA-TX/TY approximately 732 m (2,400 ft) northeast.

2.4.2.5 Tetrachloroethylene. The interpolated extent of tetrachloroethylene (PCE) in groundwater is shown in Figure 2-22. Similar to chloroform and methylene chloride, the maximum concentrations of PCE in groundwater are located in the vicinity of PFP, between the PFP and 216-Z-9 Trench. The PCE contamination above the MCL (the 5 µg/L contour) is located in the vicinity of PFP, WMA-TX/TY, and near the east central portion of the core zone area.

2.4.2.6 Nitrate. Nitrate, measured on the basis of the nitrogen content of nitrate, is present in groundwater in much of the 200-ZP-1 OU above the maximum drinking water level of 10 mg/L nitrate measured as nitrogen. Elevated nitrate concentrations in the western portion of the Hanford Site are considered to be the result of offsite agricultural activities, primarily because the concentrations are persistent and high concentrations are present in areas far upgradient from

groundwater underlying the waste sites. Figure 2-23 shows the interpolated extent of nitrate in groundwater.

2.4.2.7 Chromium (Total and Hexavalent). Figures 2-24 and 2-25 show the interpolated extent of total chromium and hexavalent chromium, respectively, in groundwater. Maximum chromium concentrations in groundwater are found in the vicinity of WMA-TX/TY at concentrations above the maximum contaminant level (MCL) of 100 µg/L. The extent of the chromium groundwater impacts are uncertain due to the relatively low density of sampled monitoring wells, particularly downgradient of the WMA-TX/TY area and beneath WMA-T. Another area of chromium exceeding the MCL is found in the vicinity of the SALDS.

2.4.2.8 Technetium-99. Figure 2-26 through Figure 2-31 show the interpolated concentrations of technetium-99 for each depth interval (0 to 10 m [0 to 32.8 ft] bwt, 10 to 20 m [32.8 to 65.6 ft] bwt, 20 to 30 m [65.6 to 98.4 ft] bwt, 30 to 40 m [98.4 to 131.2 ft] bwt, 40 to 50 m [131.2 to 164 ft] bwt, and greater than 50 m [164 ft] bwt). The impacts to groundwater from technetium-99 within the 200-ZP-1 OU are located east of WMA-T and east and south of WMA-TX/TY. The locations of maximum concentrations vary with depth, indicating that there may be multiple source areas of technetium-99 to the groundwater. The maximum technetium-99 concentration from 0 to 10 m (0 to 32.8 ft) bwt was 77,010 µg/L; from 10 to 20 m (32.8 to 65.6 ft) bwt was 54,740 µg/L; from 20 to 30 m (65.6 to 98.4 ft) bwt was 42,330 µg/L; from 30 to 40 m (98.4 to 131.2 ft) bwt was 37,740 µg/L; from 40 to 50 m (131.2 to 164 ft) bwt was 30,770 µg/L; and greater than 50 m (164 ft) bwt was 782 µg/L. Additional investigation activities at the site are ongoing to further evaluate the extent of technetium-99 in groundwater and possible source areas of groundwater contamination. The new information regarding the nature and extent of technetium-99 contamination in groundwater around WMA-T and WMA-TX/TY will be considered in the development of a final remedial design. Vadose zone data from this investigation will be used to develop an understanding of the potential vadose zone sources of technetium-99 that may impact a final groundwater remedy.

2.4.2.9 Uranium. The interpolated extent of uranium in groundwater is shown in Figure 2-32. Uranium concentrations in the 200-ZP-1 OU exceeding the MCL of 30 µg/L are located north and northeast of WMA-T.

2.4.2.10 Iodine-129. Figure 2-33 shows the interpolated extent of iodine-129 within the 200-ZP-1 OU. The highest concentrations are found near WMA-T and extend northeast from this area. Another area with concentrations exceeding the MCL of 1 pCi/L is found east of WMA-TX/TY.

2.4.2.11 Tritium. Tritium at concentrations in groundwater exceeding the MCL of 20,000 pCi/L is found in two areas within the 200-ZP-1 OU (Figure 2-34). The first area extends northeast from the vicinity of WMA-T and WMA-TX/TY. The second area, near the SALDS, also exceeds the MCL.

2.5 CONCEPTUAL SITE MODEL

A CSM was developed for the 200-ZP-1 OU using data from the 200-ZP-1 RI report (DOE/RL-2006-24), as well as data that became available since issuance of the RI report (Figure 2-35). Other sources of data used for the model included results of groundwater

sampling prior to and during the RI, geologic and well logs, process history, estimates of contaminant inventories, site drawings and maps, and historical data compilations and summaries.

The primary cribs and trenches that contributed contaminants to the groundwater included 216-Z-1A, 216-Z-9, 216-Z-18, the 216-Z-19 Ditch, the 216-Z-20 Crib, and 216-U-10. Bulk liquid waste discharges that contributed the majority of contamination to the subsurface occurred from 1945 to the early 1970s. Presently, state-permitted liquid waste discharges occur from the SALDS facility and various small, permitted structures (e.g., sanitary tile fields). After effluents were discharged to these vadose zone disposal sites, more mobile contaminants were transported to the groundwater. Less mobile contaminants (as well as residual contamination of higher mobility) remain in the vadose zone and are being addressed in the vadose zone OU remedies (e.g., 200-PW-1 OU). The technetium-99 field investigation near WMA-T and WMA-TX/TY is underway to determine the mass and distribution of technetium-99 in the vadose zone in these areas. The results of this investigation will be considered in the final design and implementation of a remedy for 200-ZP-1 OU groundwater.

The top of the groundwater table within the 200-ZP-1 OU occurs within Ringold Unit E, at depths typically greater than 67 m (220 ft) below ground surface (bgs). The current direction of groundwater flow is generally easterly, with a principally horizontal component. Previously, historical groundwater mounding from past wastewater discharges caused a more northerly component to groundwater flow near suspected vadose zone source areas that contributed contamination to the groundwater.

Contaminant distributions in 200−ZP−1 OU groundwater are changing in response to multiple influences, including (1) general downgradient transport of contaminants in the direction of groundwater flow; (2) pump-and-treat operations from the 200-ZP-1 IRM, which are containing much of the high-concentration portion of the carbon tetrachloride plume in the upper part of the aquifer; (3) decreasing groundwater elevations from the termination of effluent releases to surrounding cribs, ponds (primarily T and U Ponds), and trenches; and (4) continued operation of the soil vapor extraction (SVE) IRM in the 200-PW-1 OU.

Contaminant distributions within the 200-ZP-1 OU can be represented in three categories:

- A high-concentration zone close to the ponds, cribs, and trenches that were used to dispose of the liquid wastes. At present, data do not support the presence of significant DNAPL in groundwater acting as a continuing source. However, future monitoring and characterization efforts will continue to evaluate the validity of this assessment.
- A larger, dispersed or low concentration zone that has migrated from the discharge locations, or overlies the high-concentration zone. This less-contaminated groundwater can occur above the high-concentration zone where large quantities of lower concentration effluent were discharged during or after the high-concentration waste discharges.
- An area of technetium-99 contamination that is undergoing further investigation near WMA-T and WMA-TX/TY. Characterization efforts are focusing on refining the understanding of contamination in both the vadose zone and the groundwater at these locations. Estimates of the mass and distribution of technetium-99 at these locations are still under development. Because of its high mobility, the mass of technetium-99 in the vadose zone will be a significant consideration in the final remedial design (i.e., the

quantity of technetium-99 in the vadose zone may present a future source of groundwater contamination because of its high mobility).

2.6 FATE AND TRANSPORT

Primary mechanisms of contaminant transport in groundwater include advection (movement due to bulk, large-scale movement of water), dispersion (spread of contaminant from the expected advective path), and retardation (the slowing of chemical movement due to sorption). These primary mechanisms were considered during the fate and transport modeling conducted for the COPCs (see Appendix D for a more detailed discussion). Transport of COPCs in groundwater within and downgradient of the 200-ZP-1 OU is expected to occur generally west to east at the site, in the general direction of groundwater flow. This section provides information on the key parameters that control the fate and transport processes, the environmental fate of the COPCs and their transport through groundwater. The key parameters are discussed first followed by a summary of the fate and transport analysis.

2.6.1 Key Fate and Transport Parameters.

Larger K_d values indicate a greater likelihood for sorption of the contaminant to soil particles. The solubility of the constituent in water is reported as K_{sp}. The K_d with respect to the organic fraction is reported as K_{oc}. The daughter products of radionuclide contaminants are also presented within the 1,000-year horizon required by *Radioactive Waste Management* (DOE O 435.1). The fate and transport of the COPC varies widely in the environment based on historic and current conditions and site-specific chemical factors.

2.6.1.1 Nonradionuclide Contaminants of Potential Concern. There are five organic nonradionuclide COPCs considered for the 200-ZP-1 OU, which include carbon tetrachloride, chloroform, methylene chloride, PCE, and TCE. There are four inorganic nonradionuclide COPCs considered for the 200-ZP-1 OU, which include total chromium, hexavalent chromium, nitrate, and total uranium. Values for K_d, K_{sp}, and K_{oc} for each constituent are presented in the following sections and Table 2-1. Hanford specific values are cited where available. The corresponding fate and transport within the environmental media are summarized in the following subsections.

2.6.1.2 Carbon Tetrachloride. Carbon tetrachloride is an organic constituent composed of one carbon atom and four chlorine atoms. The volatile nature of this chemical makes the vapor phase the most likely transport mechanism in the vadose zone. Carbon tetrachloride vapor is highly mobile in the vadose zone and the corresponding dense vapor plume has the potential to contaminate the groundwater at the water table interface. DNAPL carbon tetrachloride is known to be retained within the vadose zone in a thin, fine-grained silt lens at 19.8 m (65 ft) bgs adjacent to well 299-W15-46 (DOE/RL-2006-51). Desorption experiments determined that K_d ranged from 0.106 to 0.367 mL/g for contaminated aquifer sediments collected from borehole C3246 (well 299-W15-46), located in the 200 West Area adjacent to the 216-Z-9 Trench (*Carbon Tetrachloride and Chloroform Partition Coefficients Derived from Aqueous Desorption of Contaminated Hanford Sediments* [PNNL-15239]). Carbon Tetrachloride can exist as a DNAPL with a solubility limit in water of 758 mg/L (DOE/RL-91-58). However, concentrations measured in the groundwater to date are sufficiently below the DNAPL solubility limits, and DNAPL is not believed to be present in the aquifer.

Carbon tetrachloride undergoes natural attenuation processes via a variety of mechanisms depending on the geochemisty. The conditions that favor biodegradation of carbon tetrachloride are predominately anaerobic and require the presence of biodegradable organic carbon (Bouwer and McCarty, 1983; Hooker et al, 1998; Cobb and Bouwer 1991). The anaerobic breakdown path for carbon tetrachloride is presented in Figure 2-36. In aerobic conditions, carbon tetrachloride undergoes abiotic hydrolysis as presented in Figure 2-37. The hydrolysis half-life of carbon tetrachloride ranges from 36 to 290 years depending on the temperature and geochemical conditions (PNNL-13560). The best estimates range from 41 to 100 years (PNNL-15937 & PNNL-13560). Additional testing to determine the specific hydrolysis rate of carbon tetrachloride for Hanford conditions is currently ongoing. The current groundwater conditions tend to support an aerobic environment through the majority of the plume. Particular portions of the plume, especially those in the high concentration regions, may be slightly anaerobic causing the generation of chloroform. Past conditions are also believed to have been slightly anaerobic, leading to the conditions that produced the existing chloroform concentrations.

2.6.1.3 Chloroform. Chloroform is an organic compound consisting of one carbon atom, one hydrogen atom, and three chlorine atoms. Chloroform is one of the possible breakdown products of carbon tetrachloride under anaerobic conditions as presented previously. Desorption experiments determined that the chloroform K_d ranged from 0.084 to 0.432 mL/g for contaminated aquifer sediments collected from borehole C3246 (well 299-W15-46), located in the 200 West Area adjacent to the 216-Z-9 Trench (PNNL-15239). The solubility of chloroform in water is 8,200 mg/L (DOE/RL-91-58).

2.6.1.4 Chromium (Total and Hexavalent). Chromium is a metallic element with oxidation states ranging from chromium (-II) to chromium (+VI). Chromium occurs naturally in ores and is produced from anthropogenic sources. Total chromium includes all oxidation states. The solubility and K_d varies depending on the oxidation state. Chromium (III) is insoluble in groundwater and is less mobile in the environment. A literature review reported the mean chromium (III) K_d between soil and water as 3.9 mL/g, between suspended matter and water as 5.1 mL/g, and between sediment and water as 4.5 mL/g (*Partition Coefficients for Metals in Surface Water, Soil, and Waste* [Allison and Allison 2005]). Hexavalent chromium is the most soluble form of chromium, as well as the most stable. A conservative K_d for chromium (VI) has been estimated as 0 mL/g (DOE/RL-91-58), suggesting high mobility in the environment.

2.6.1.5 Methylene Chloride. Methylene chloride is an organic compound composed of one carbon atom, two hydrogen atoms, and two chlorine atoms. The volatile nature of this chemical makes the vapor phase the most likely transport mechanism. Methylene chloride is very soluble in water, with a solubility of 20,000 mg/L (DOE/RL-91-58). Methylene chloride is expected to be highly mobile in soils based on the K_{oc} of 8.8 mL/g (DOE/RL-91-58).

2.6.1.6 Nitrate. Nitrate is an inorganic compound composed of one nitrogen atom and three oxygen atoms. Nitrate is an anionic species with a net charge of -1. The K_d for nitrate is estimated to be zero, indicating high mobility in the vadose zone. Nitrate may undergo chemical and biological transformations, resulting in release to the atmosphere (as N_2) or incorporation into living organisms, depending on the soil environment (DOE/RL-91-58). Nitrate is water-soluble.

2.6.1.7 Tetrachloroethylene. PCE is an organic compound composed of two carbon atoms and four chlorine atoms. The volatile nature of this chemical makes the vapor phase the most likely transport mechanism. PCE may be transformed into vinyl chloride under some reduction-oxidation conditions. It has a water solubility of 150 mg/L (DOE/RL-91-58). The K_{oc} of PCE is 360 mL/g (DOE/RL-91-58).

2.6.1.8 Trichloroethylene. TCE is an organic compound composed of two carbon atoms, one hydrogen atom, and three chlorine atoms. The volatile nature of this chemical makes the vapor phase the most likely transport mechanism. It may be transformed into vinyl chloride under some reduction-oxidation conditions. TCE has a water solubility of 1,100 mg/L, and the K_{oc} of TCE is 130 mL/g (DOE/RL-91-58).

2.6.1.9 Uranium (Total). Uranium is a natural metallic element existing in five oxidation states (+2, +3, +4, +5, and +6). Total uranium includes all oxidation states. The K_d for uranium is zero for the +6 oxidation state, indicating high mobility (DOE/RL-91-58). A K_d value of zero is the most conservative value for the five oxidation states. Uranium is an unusual contaminant in that it is both chemically and radioactively toxic to humans and animals. Uranium exists in both soluble and insoluble forms

2.6.2 Radionuclide Contaminants of Potential Concern

There are three radionuclide (i.e., iodine-129, technetium-99, and tritium) COPCs for the 200-ZP-1 OU. The nuclear data for the COPC are presented in Table 2-2 and are described more fully in the following subsections. Water solubility is not readily available for radionuclides.

2.6.2.1 Iodine-129. Iodine-129 is a fission product. The recommended iodine K_d for the Hanford Site is less than 1 mL/g, indicating high mobility (DOE/RL-91-58). The half-life of iodine-129 is 17 million years. Based on the long half-life, daughter products are not of concern for the scope of this FS. It has a specific activity of 0.0001634 Ci/g and has negative beta-emission decay (*CRC Handbook of Chemistry and Physics* [Lide 2006]).

2.6.2.2 Technetium-99. Technetium is artificially produced and has not yet been discovered in terrestrial materials. Technetium is formed as a spontaneous fission product of uranium. The half-life of technetium-99 is 213,000 years. Based on the long half-life, daughter products are not of concern for the scope of this FS. It has a specific activity of 0.01699 Ci/g and a negative beta-emission decay mode (Lide 2006). For technetium-99, K_d has been reported in Hanford Site soils as 0 to 1 mL/g (DOE/RL-91-58), indicating high mobility through the vadose zone.

2.6.2.3 Tritium. Tritium is a fission product with high specific activity. The recommended tritium K_d for the Hanford Site is zero, indicating high mobility (DOE/RL-91-58). The half-life of tritium is 12.33 years. There are no daughter products with a half-life greater than 1 day. Tritium has a specific activity of 9,626.7 Ci/g and has negative beta-emission decay mode (Lide 2006).

2.6.3 Fate and Transport Summary.

This section summarizes the data analysis and modeling methods used to evaluate groundwater hydraulic conditions at the Hanford Site's 200-ZP-1 Operable Unit (OU) to support the comparative analysis of the 200-ZP-1 feasibility study (FS) and remedy selection. The details of the analysis can be found in Appendix D of this report. The objectives of the analysis were (1) to

compile, summarize, and analyze data to support modeling calculations; and (2) to conduct the calculations with sufficient detail to meet the requirements of the FS. The evaluation and design of a groundwater pump-and-treat (P&T) remedy and/or alternate remedies at the 200-ZP-1 OU required data and calculation methods that could approximately describe the following:

- Extent of contaminated groundwater to be actively remediated (hereinafter referred to as the "target treatment zone[s]")
- Direction(s) and rate(s) of groundwater flow
- Extent of groundwater capture developed by (1) modifying pumping rates at existing groundwater recovery wells, and/or (2) the addition of new groundwater recovery wells.
- Considering these requirements, the groundwater data analysis and modeling included evaluations of the following:
- Likely mechanisms leading to the current distribution of contaminants
- Extent of hydraulic capture of the current 200-ZP-1 OU interim remedial measure (IRM)
- Configuration of alternative groundwater P&T scenarios to be considered during the evaluation of remedial actions as part of the FS
- Possible fate of contaminants not remedied by alternate P&T scenarios.

The analyses were completed using parameters representative of the central tendency described by the summary statistics. However, the analyses considered the contrasting roles of uncertainty and variability in the evaluation of the parameters. Uncertainty refers to things that are unknown or uncertain (e.g., the date that a single event occurred). Variability refers to true diversity or heterogeneity in a variable (e.g., the range in hydraulic conductivity).

Evaluation of Contaminant Transport. The migration of contaminants dissolved in groundwater was approximated using standard and industry-accepted particle-tracking techniques. The particle tracking was used to indicate (1) the approximate horizontal historic migration pathways taken by COPCs, (2) the approximate extent of groundwater capture developed by the 200-ZP-1 IRM, (3) the approximate extent of groundwater capture developed by alternate remedy configurations of groundwater pumping and injection wells, and (4) the approximate relative timing of the arrival of COPCs at potential receptors and/or other points of calculation

In order to evaluate the approximate extent of groundwater capture developed by the 200-ZP-1 IRM, particle tracking was performed on groundwater elevation surfaces calculated by the application of steady-state calculations (see Section D6.2) within a kriging routine. These results are described in Section D6.0 of Appendix D. In order to evaluate the approximate extent of groundwater capture developed by alternate remedy configurations of groundwater pumping and injection wells, particle tracking was performed on groundwater elevation surfaces calculated using the program THEIS-GRID; these results are described in Section D7.0. In order to evaluate the approximate relative timing of the arrival of COPCs at potential receptors and/or other points of calculation, particle tracking was performed on groundwater elevation surfaces calculated by mapping measured groundwater elevations; these results are described in Section D8.0.

As discussed above, the THEIS-GRID program was used to calculate historic groundwater elevations and flow directions in response to the infiltration of large volumes of wastewater. Figure 2-38 illustrates the paths calculated for particles released from the location of the principal waste site areas (216-Z-1A, 216-Z-18, and 216-Z-9) during periods of active disposal using groundwater levels calculated using THEIS-GRID and illustrated in Figures D-21 (1945) through D-33 (2005). These particle paths were calculated assuming contaminants reached the water table soon after disposal activities commenced, and they assume the advective-dispersive transport of ideal (non-retarded, non-reactive) dissolved contaminants in groundwater.

Figure 2-38 illustrates that the path taken by particles released at the principal waste sites broadly mimics the distribution of the contaminants (i.e., the majority of the particles are distributed in the areas of high concentrations, with particles generally distributed throughout the area depicted as showing elevated concentrations of carbon tetrachloride).

Contaminants of Concern not Captured by each/any Remedial Alternatives. The approximate fate of contaminants that are not recovered by the remedial alternative (i.e., within the far field) were evaluated using two distinctly different approaches:

- Two-dimensional/three-dimensional analytical ADR transport using a popular open-source transport simulator, ATRANS (Neville, 1998).
- Particle tracking using the standard and industry-accepted RK4/RW particle-tracking techniques encompassed in the program GRID-TRACK.

Within the far field, which is mainly downgradient of the 200-ZP-1 OU to the north and east, the distribution and contrasting hydraulic properties of different aquifer units (e.g., Hanford formation and Ringold Unit E) lead to areas of differing transmissivities and hydraulic gradients, and therefore differing groundwater and contaminant transport velocities. Under the assumption that throughout the area of likely future contaminant migration (i.e., from the 200-ZP-1 OU to the Columbia River), recent historic measured groundwater levels broadly reflect future groundwater levels and, therefore, likely reflect approximate future hydraulic gradients (and, therefore, groundwater flow directions), a map was prepared of an approximate groundwater elevation surface, to be used together with particle tracking to indicate approximate directions and rates of groundwater and contaminant transport as described above. These calculations were then used to define approximate long-term average groundwater velocities for use in the analytical transport analysis using ATRANS. ATRANS simulation results for the no action alternative are presented in Figure 6-1 of the main text. A discussion of the results is presented in Section 6.3.1 of the main text. ATRANS simulation results for the preferred pump and treat scenario are shown in Figure D-58, and a discussion of the results is presented in Section 7.3.

Figure 2-1. Topographic Map of the Hanford Site.

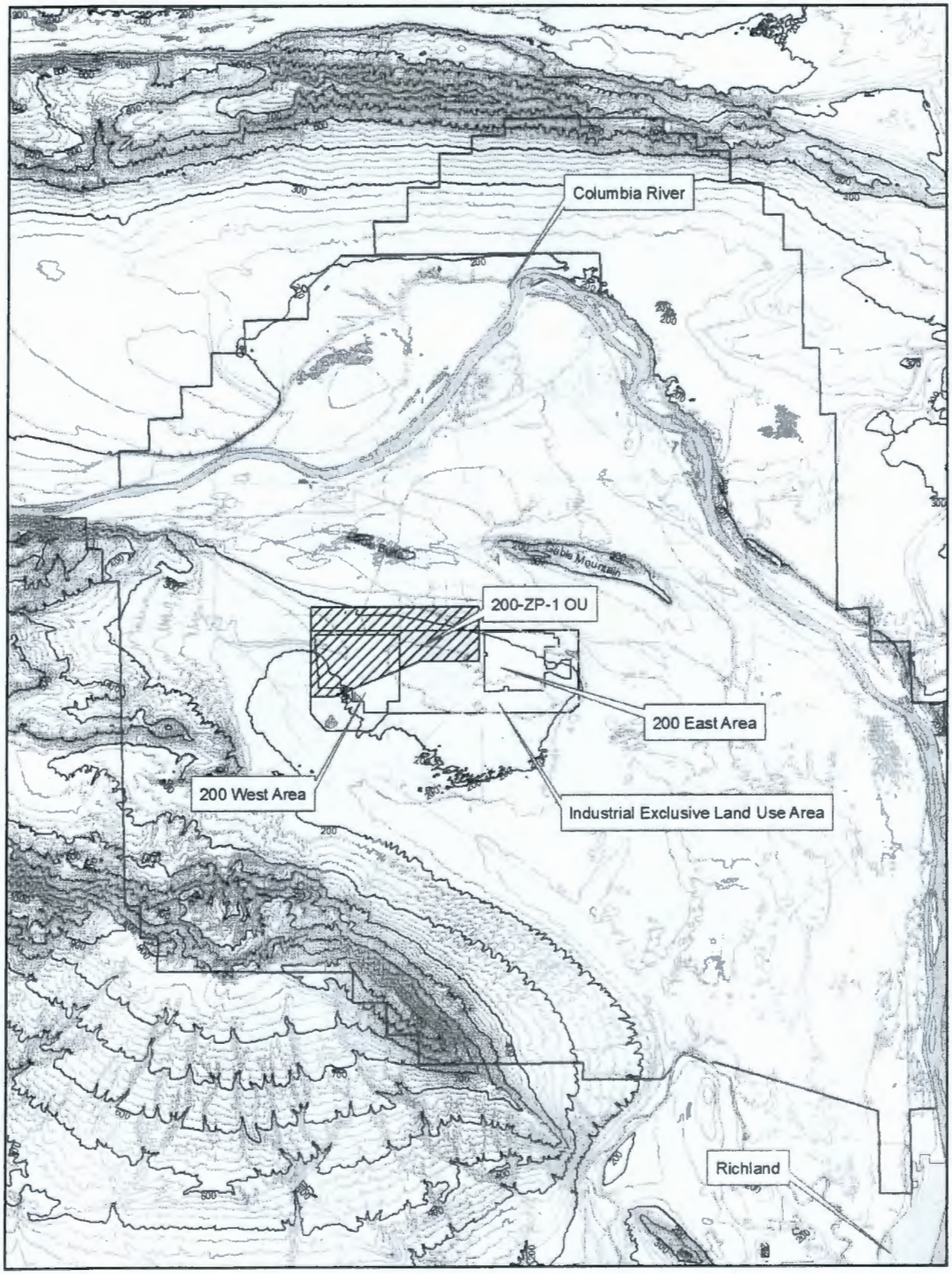
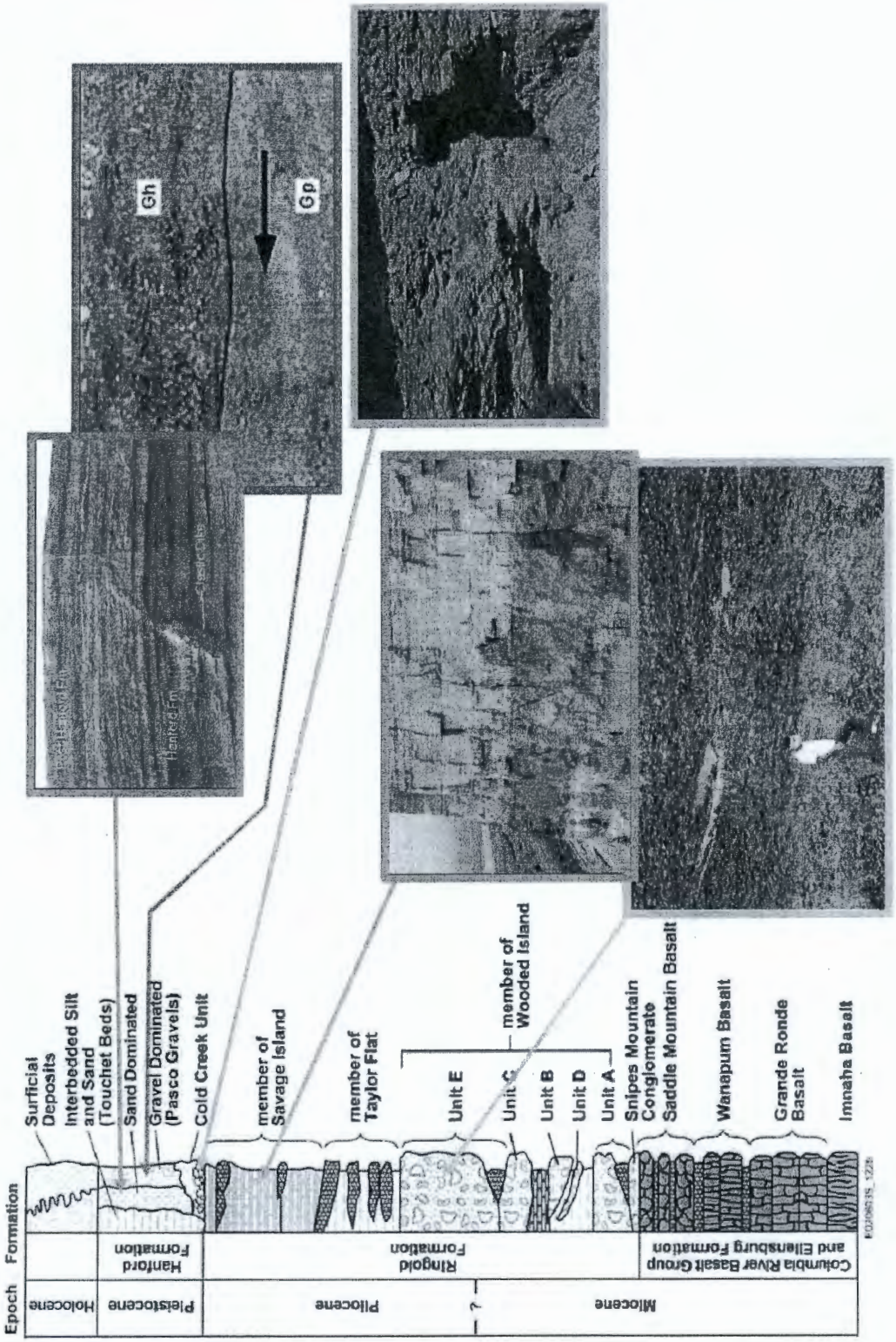
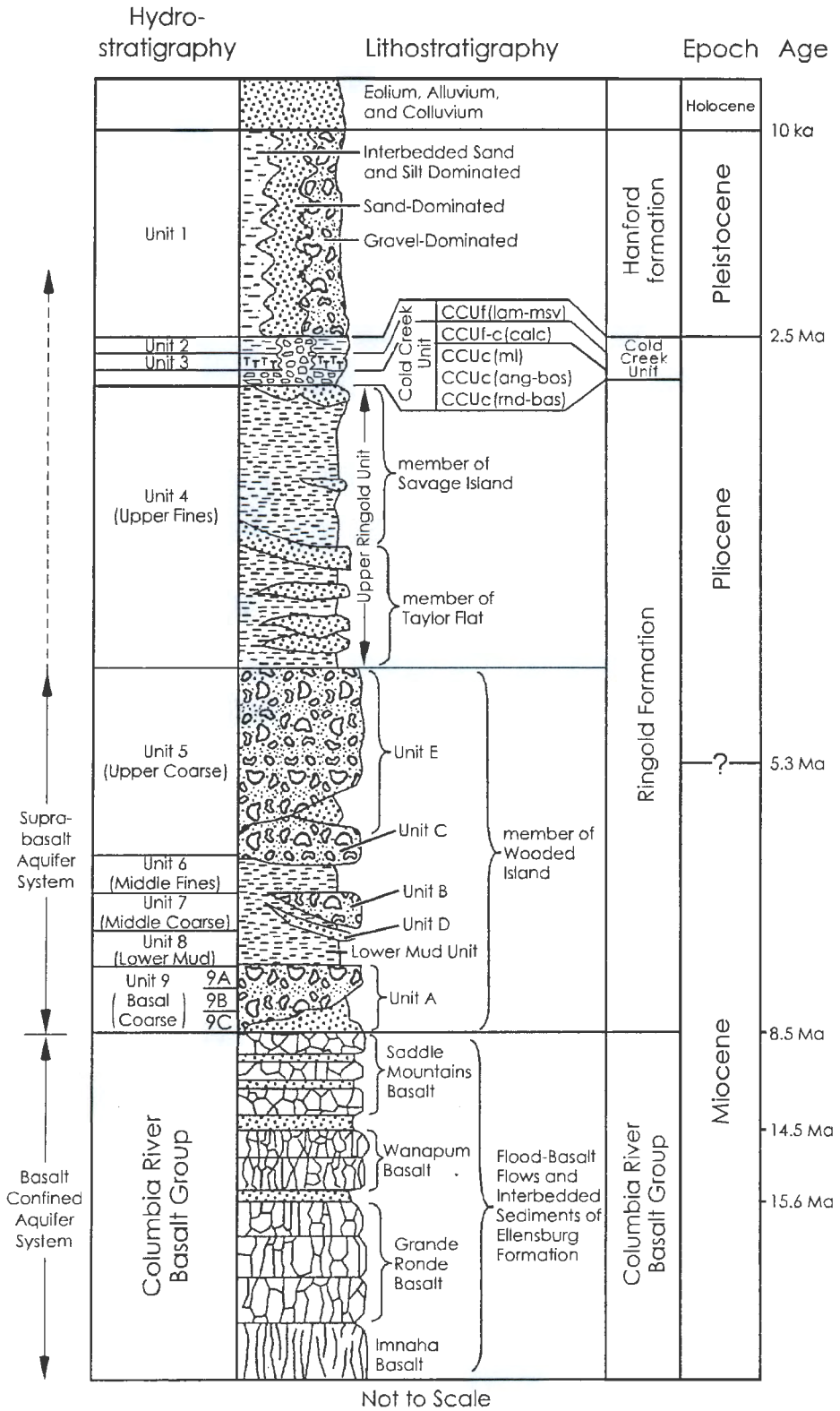


Figure 2-2. Major Geologic Units of Interest in the 200 Areas.



NOTES: Gh = horizontally bedded, Gp=foreset-bedded.
Figure from DOE/RL-2002-39.

Figure 2-3. Generalized Stratigraphic Column for the 200 Areas.



NOTE: Figure modeled after WHC-MR-0391, PNL-8971, BHI-00184, PNNL-12261, DOE/RL-2002-39.

Figure 2-4. Hanford Site Mapped Hydraulic Heads, 2005.

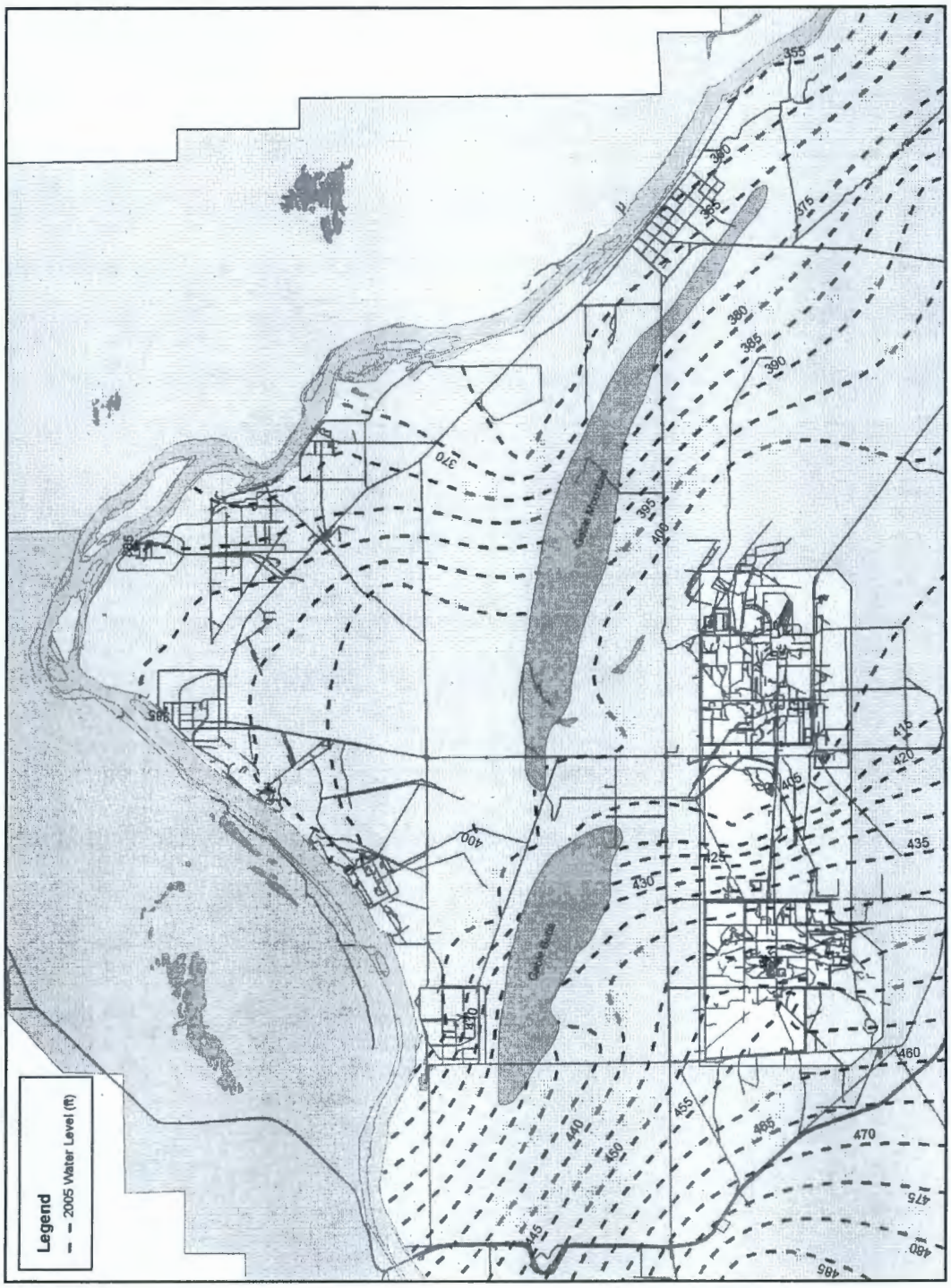


Figure 2-5. Distribution of Carbon Tetrachloride Contamination in the 200-ZP-1 Operable Unit, 1994.

Figure 2-6. Distribution of Carbon Tetrachloride Contamination in the 200-ZP-1 Operable Unit, 2005.

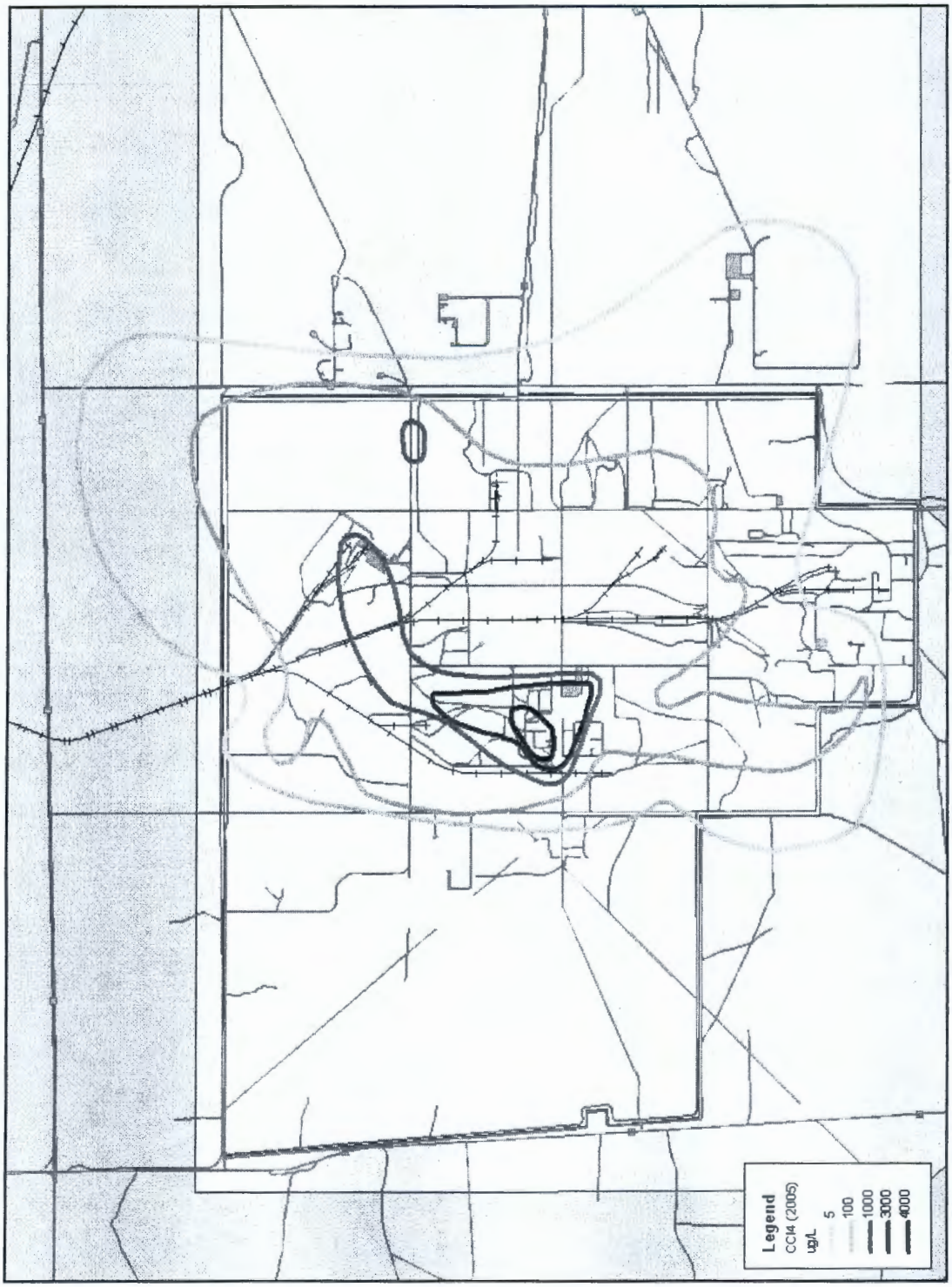
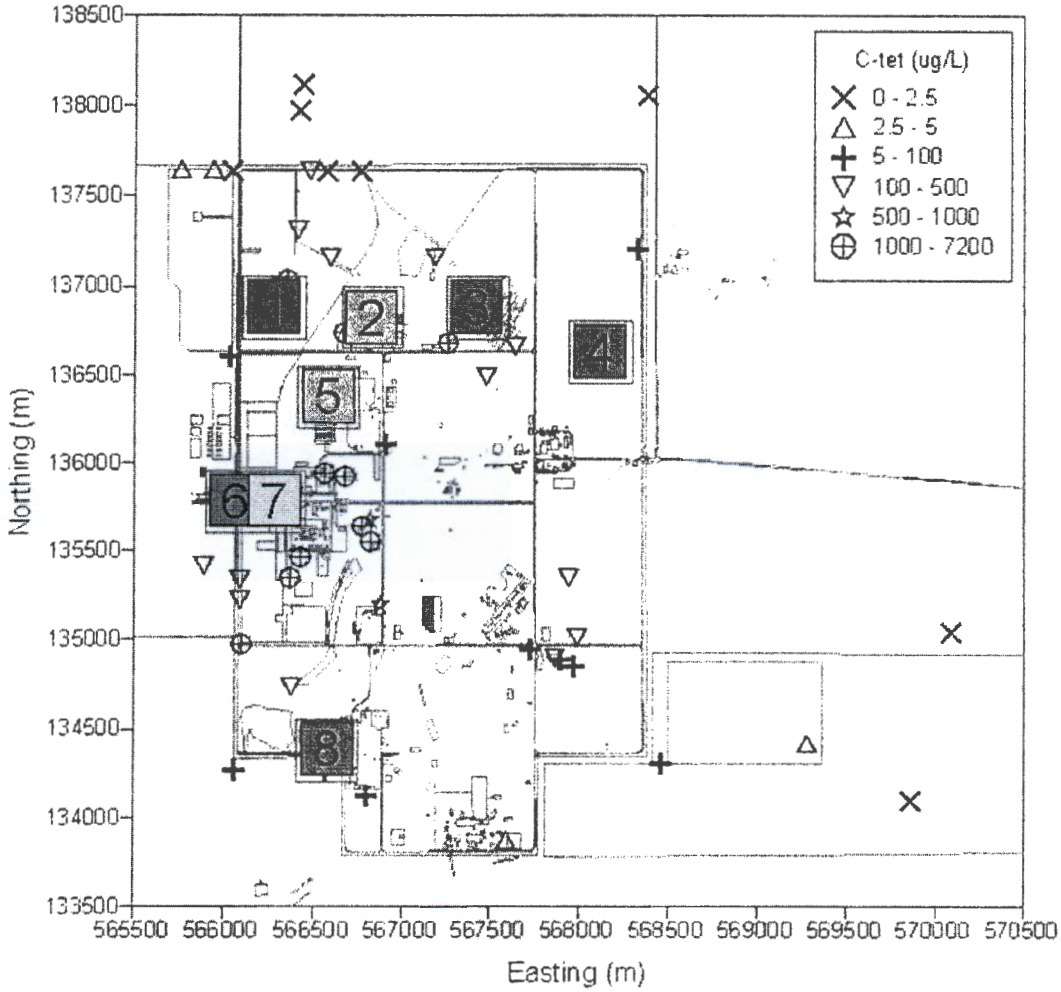


Figure 2-7. Summary Map of Classification of Sub-Areas Based on Their Likelihood of Containing Persistent Sources.



NOTE: Color scale ranges from red for high probability to blue for the lowest probability (PNNL-16509).

Figure 2-8. Interpolated Extent of Carbon Tetrachloride, 0 to 10 m Below Water Table.

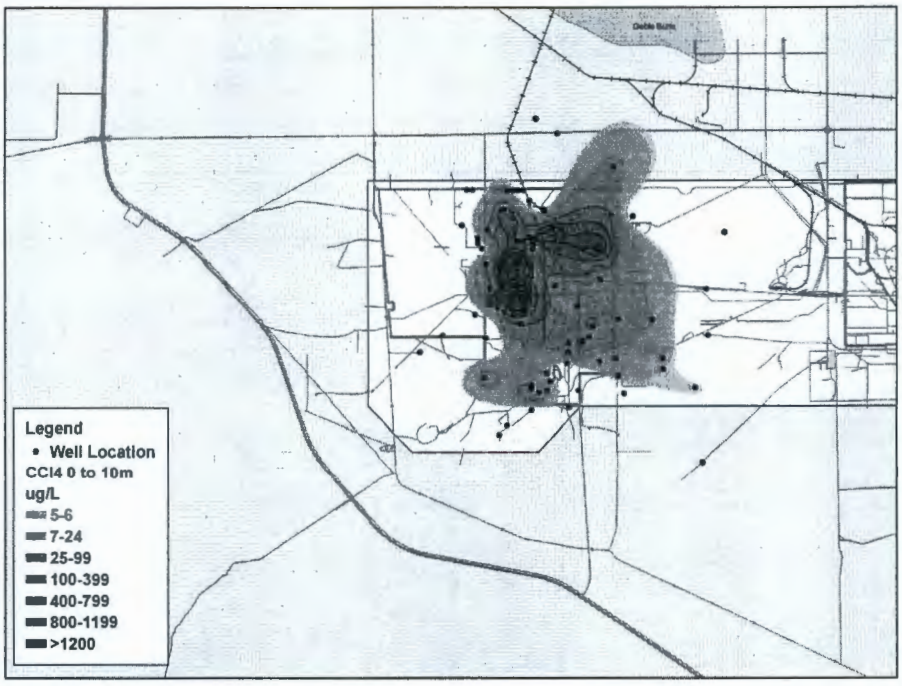


Figure 2-9. Interpolated Extent of Carbon Tetrachloride, 10 to 20 m Below Water Table.

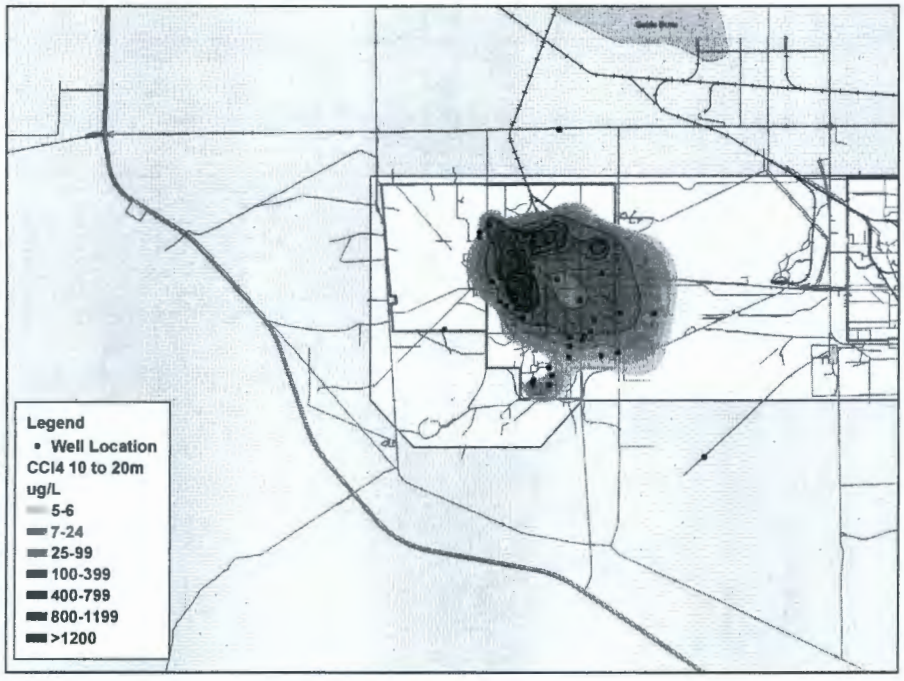


Figure 2-10. Interpolated Extent of Carbon Tetrachloride, 20 to 30 m Below Water Table.

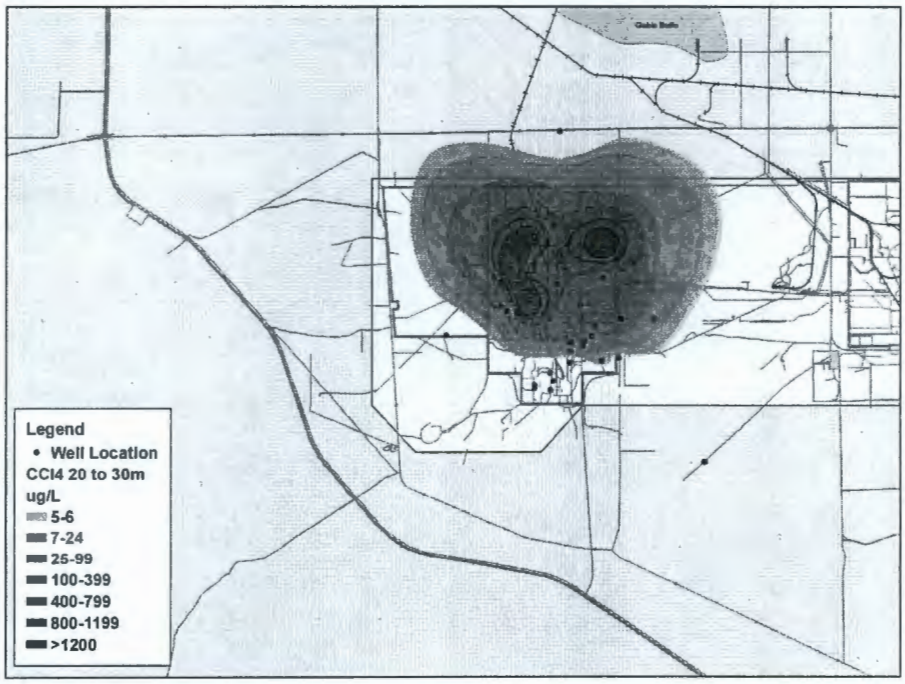


Figure 2-11. Interpolated Extent of Carbon Tetrachloride, 30 to 40 m Below Water Table.

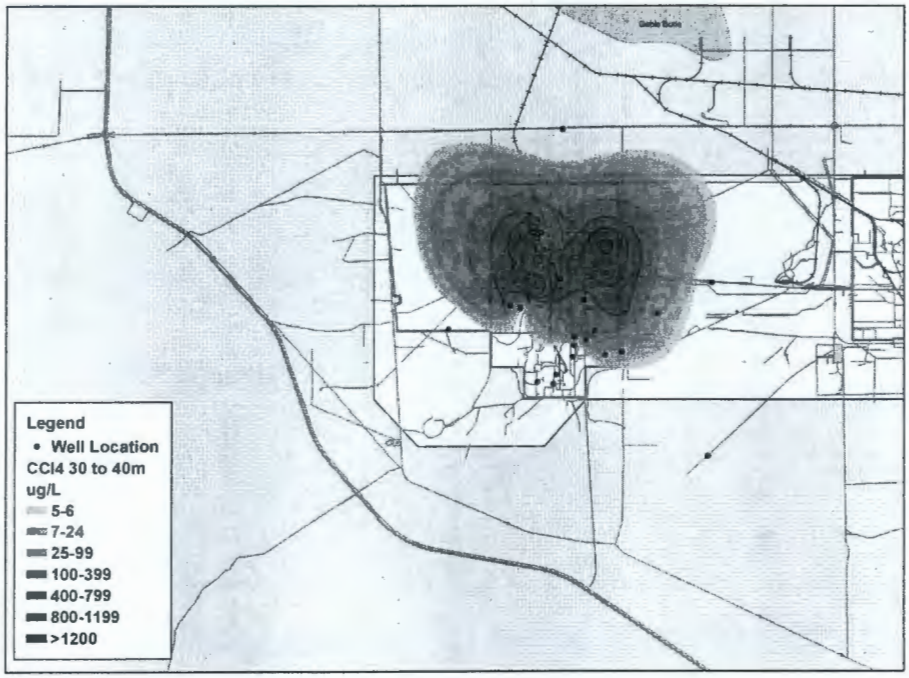


Figure 2-12. Carbon Tetrachloride Concentrations (µg/L), 40 to 50 m Below Water Table at Sampled Wells.

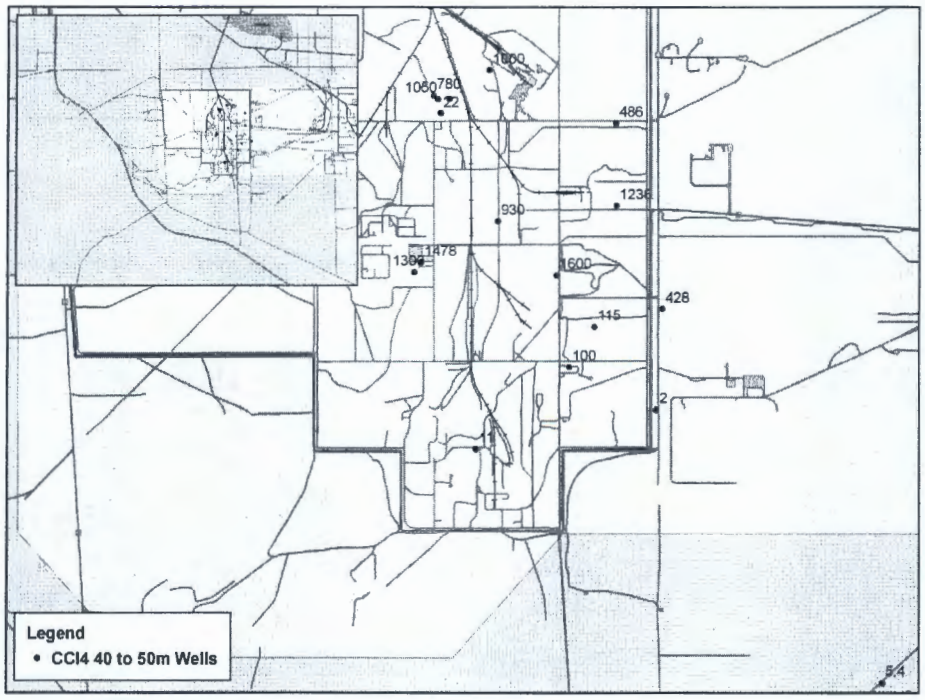


Figure 2-13. Carbon Tetrachloride Concentrations (µg/L), Greater Than 50 m Below Water Table at Sampled Wells.

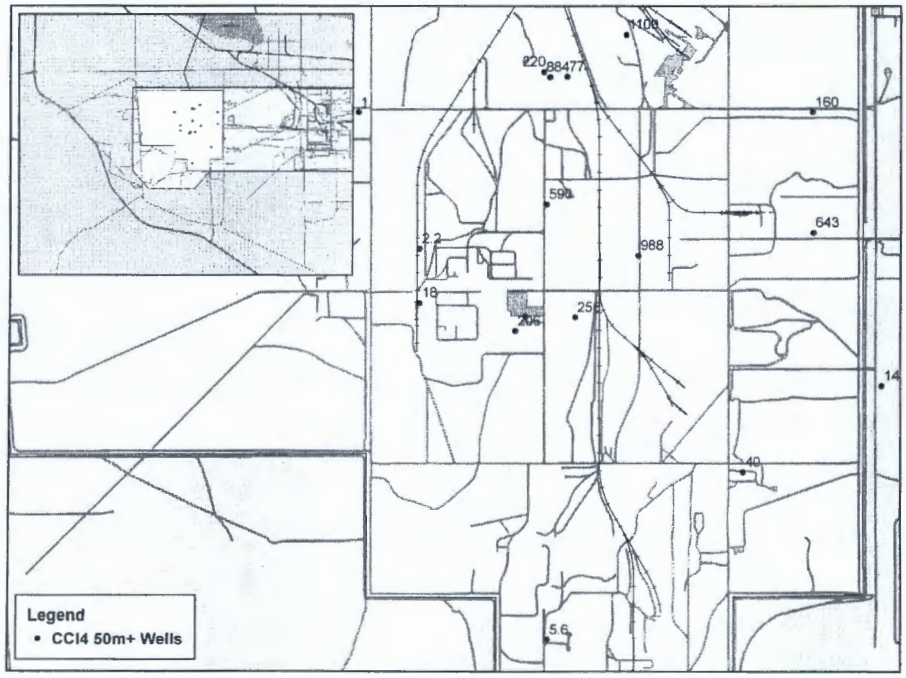


Figure 2-14. Interpolated Extent of Chloroform in Groundwater.

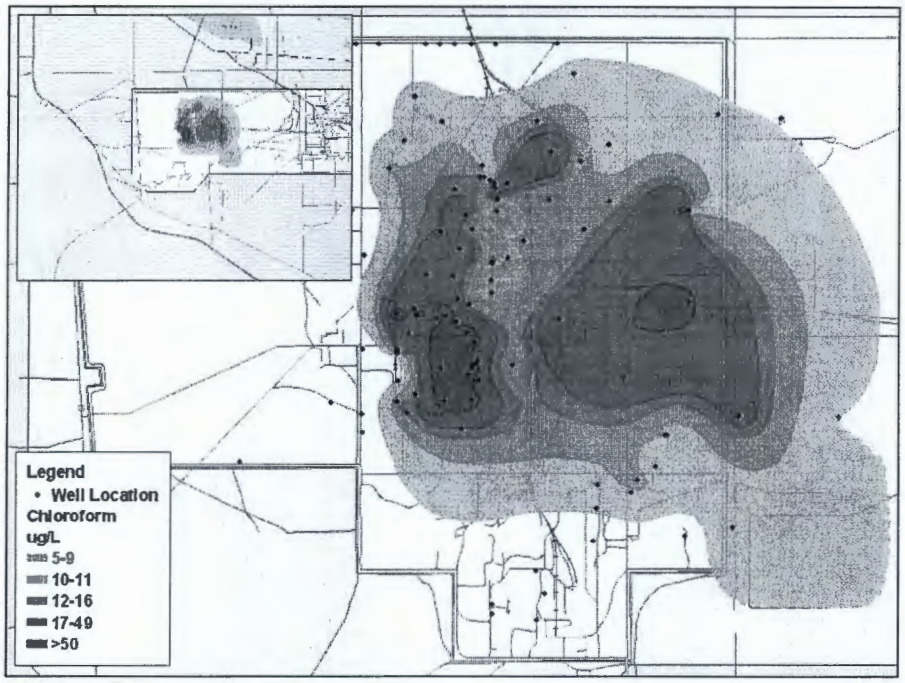


Figure 2-15. Interpolated Extent of Methylene Chloride in Groundwater.

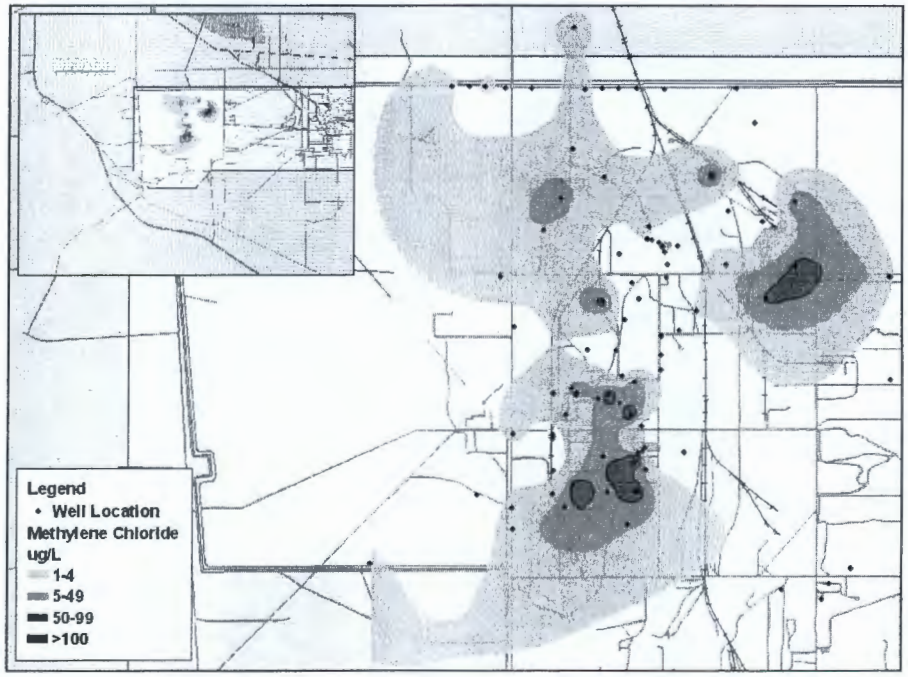


Figure 2-16. Interpolated Extent of Trichloroethylene (TCE), 0 to 10 m Below Water Table.

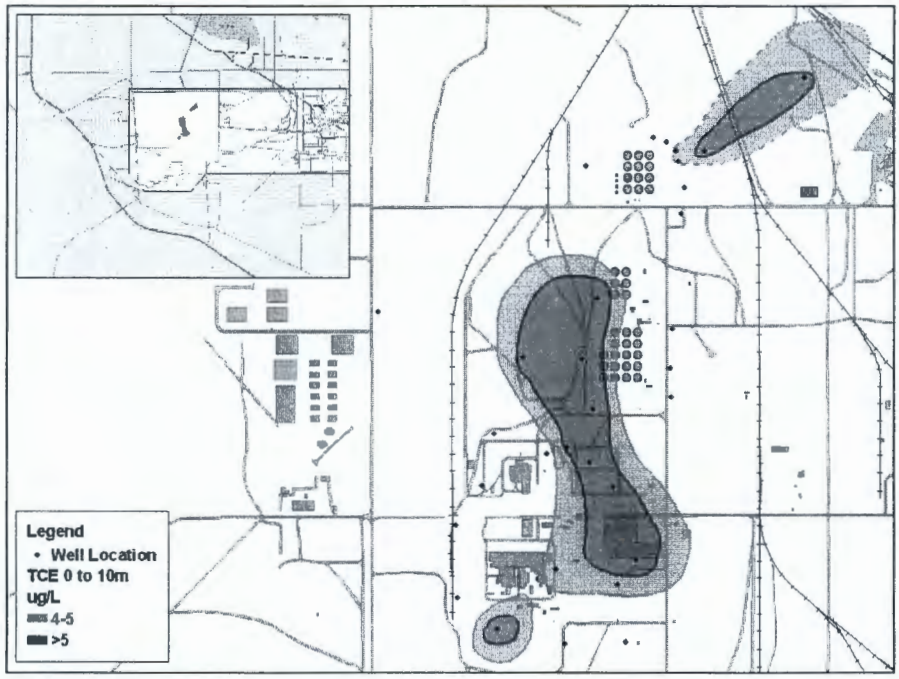


Figure 2-17. Interpolated Extent of Trichloroethylene (TCE), 10 to 20 m Below Water Table.

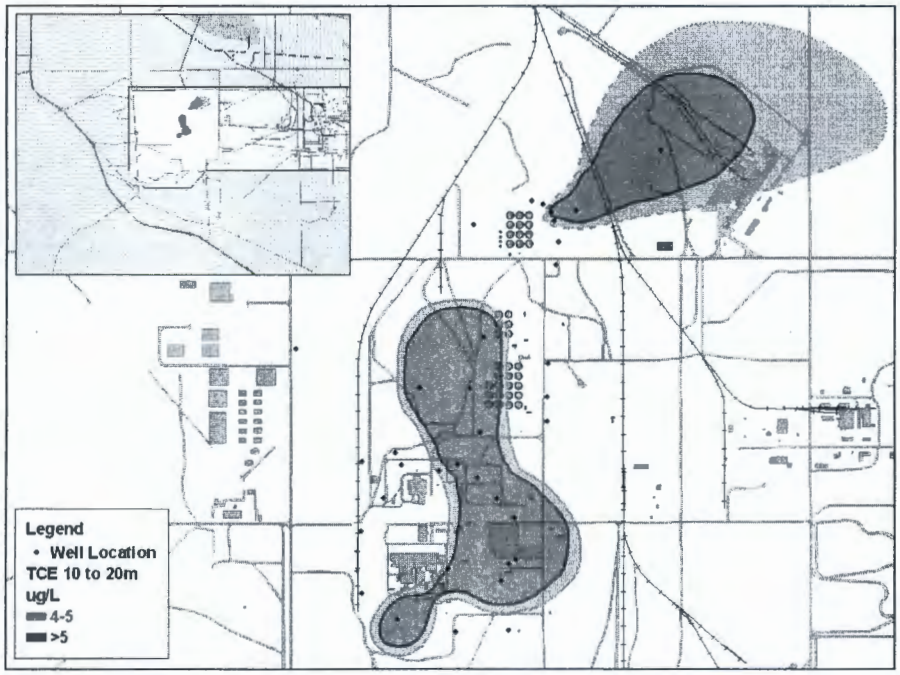


Figure 2-18. Interpolated Extent of Trichloroethylene (TCE), 20 to 30 m Below Water Table.

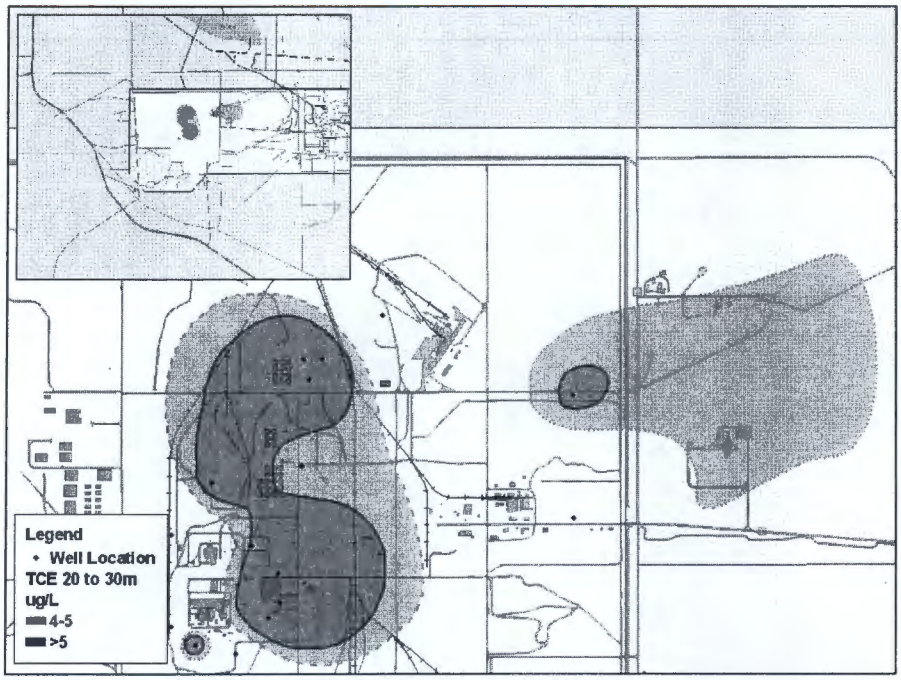


Figure 2-19. Trichloroethylene (TCE) Concentrations (µg/L), 30 to 40 m Below Water Table at Sampled Wells.

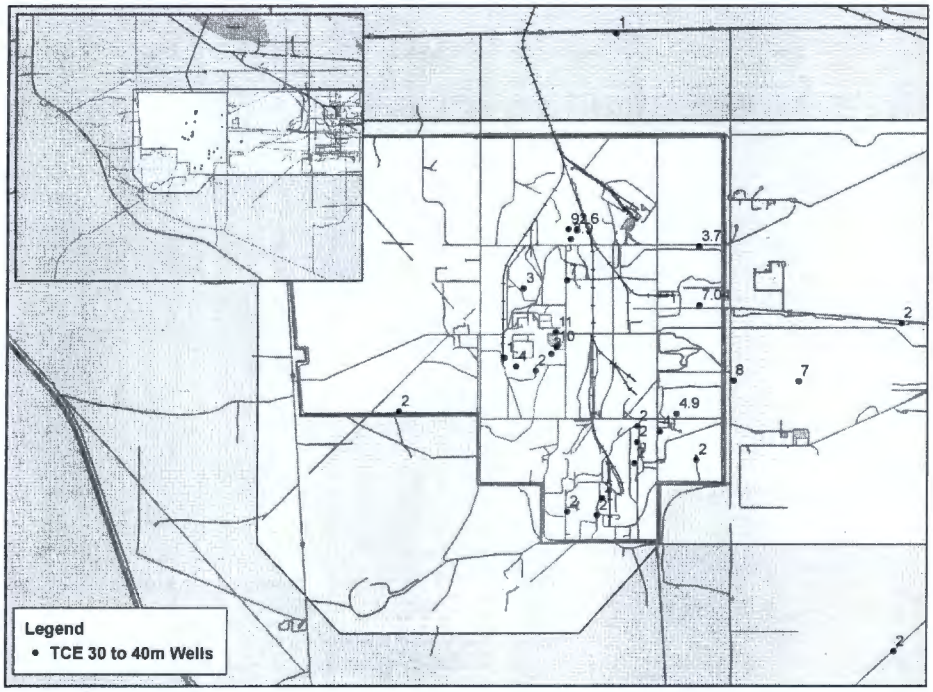


Figure 2-20. Trichloroethylene (TCE) Concentrations (µg/L), 40 to 50 m Below Water Table at Sampled Wells.

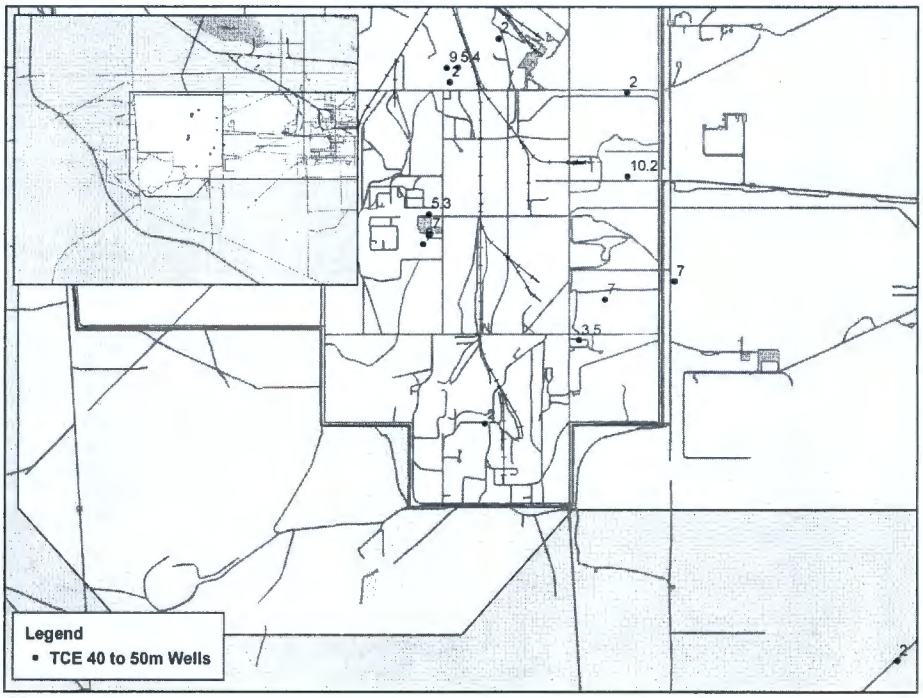


Figure 2-21. Trichloroethylene (TCE) Concentrations (µg/L), Greater Than 50 m Below Water Table at Sampled Wells.

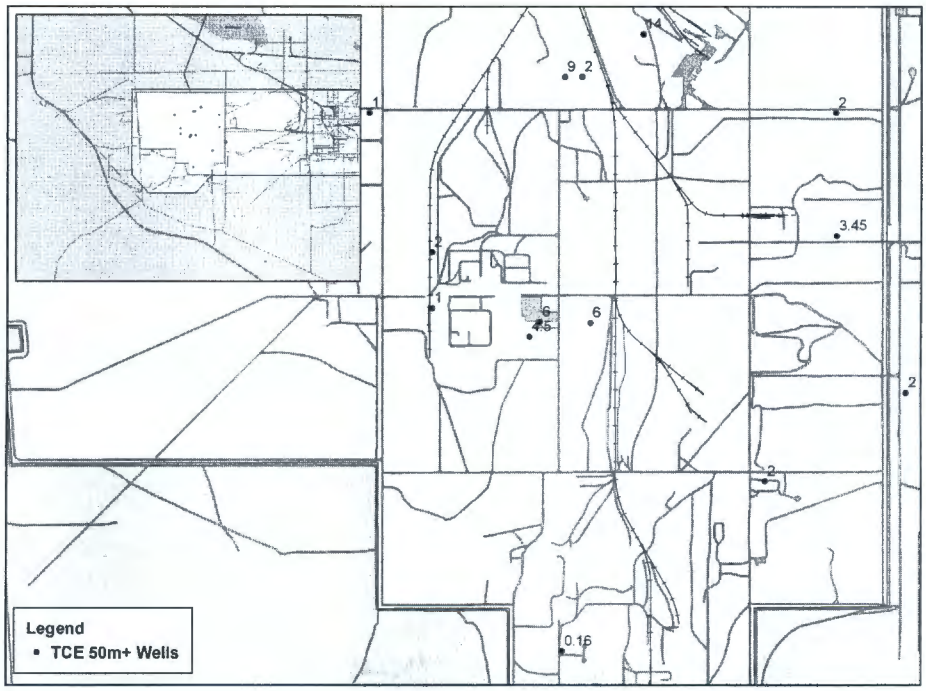


Figure 2-22. Interpolated Extent of Tetrachloroethylene in Groundwater.

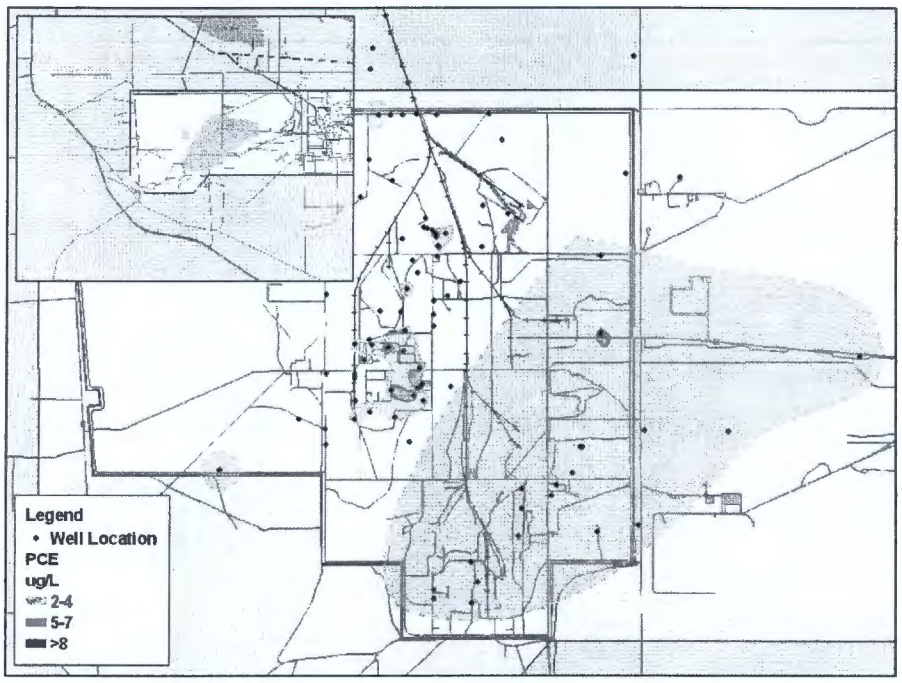


Figure 2-23. Interpolated Extent of Nitrate in Groundwater.

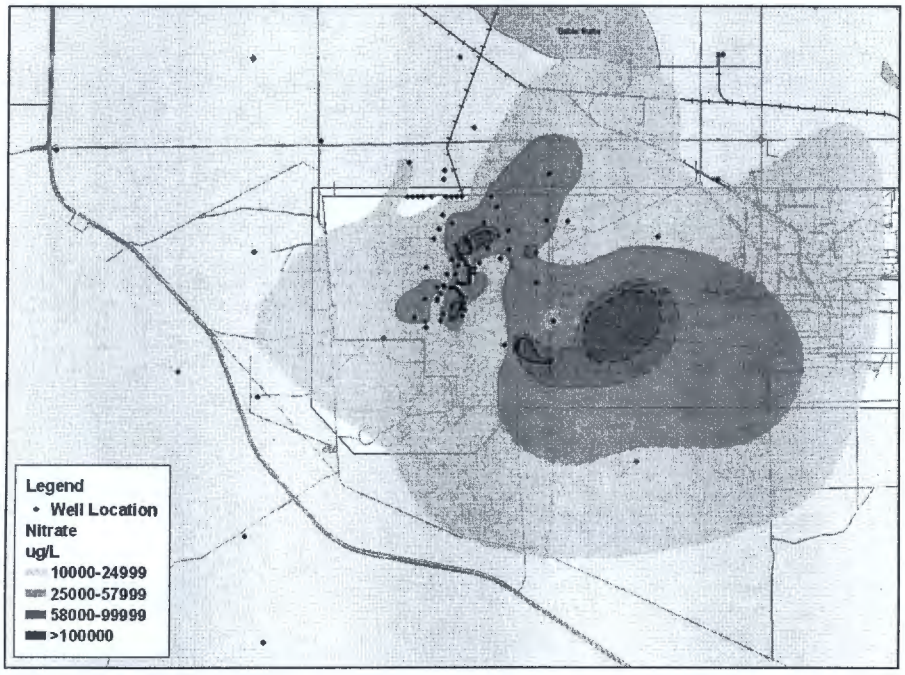


Figure 2-24. Interpolated Extent of Chromium (Total) in Groundwater.

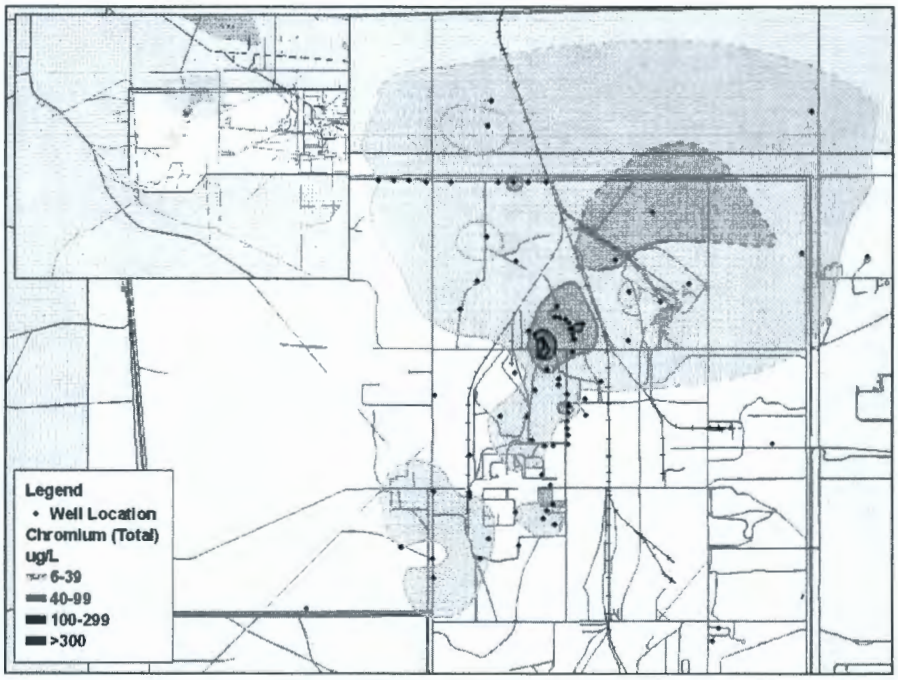


Figure 2-25. Chromium (Hexavalent) Concentrations (µg/L) at Sampled Wells.

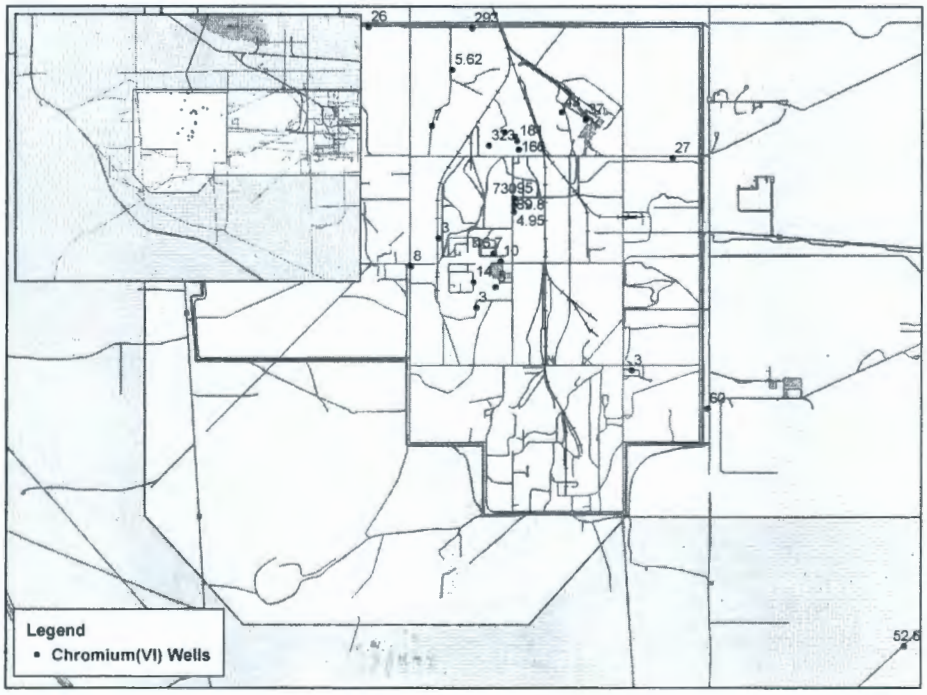


Figure 2-26. Interpolated Extent of Technetium-99, 0 to 10 m Below Water Table.

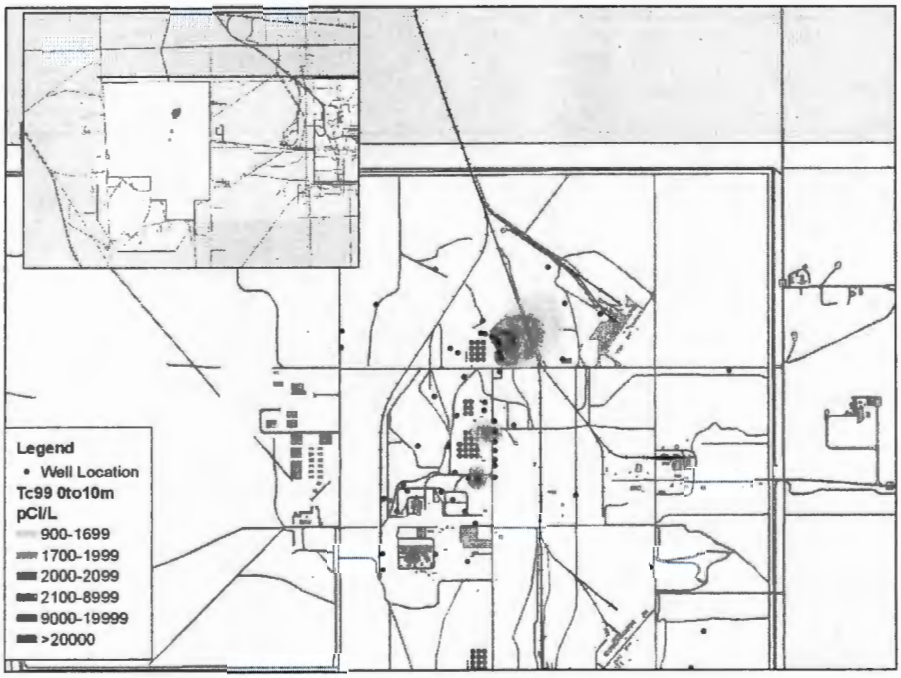


Figure 2-27. Technetium-99, 10 to 20 m Below Water Table (pCi/L).

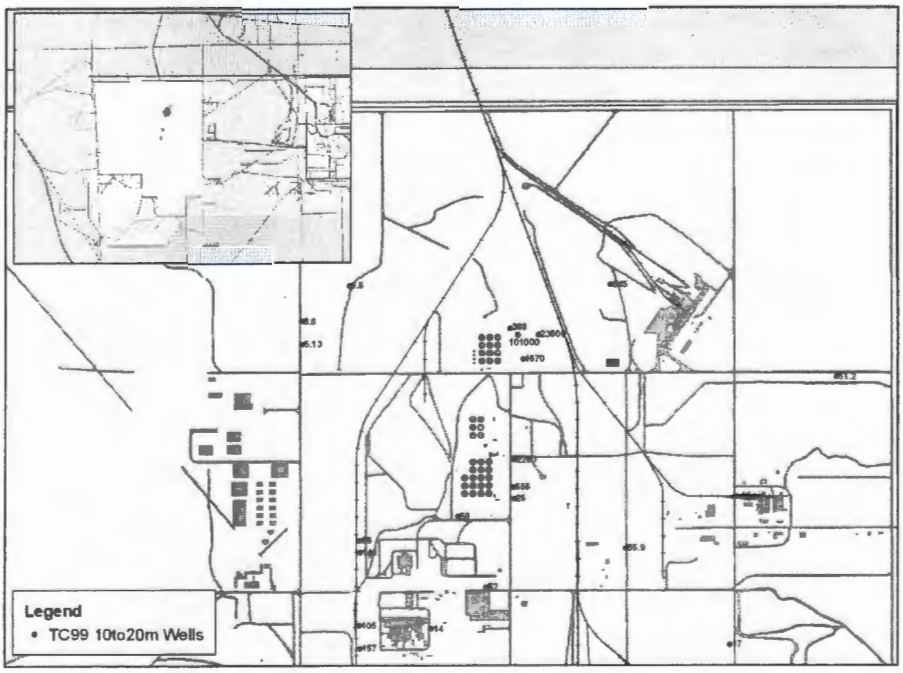


Figure 2-28. Technetium-99, 20 to 30 m Below Water Table (pCi/L).

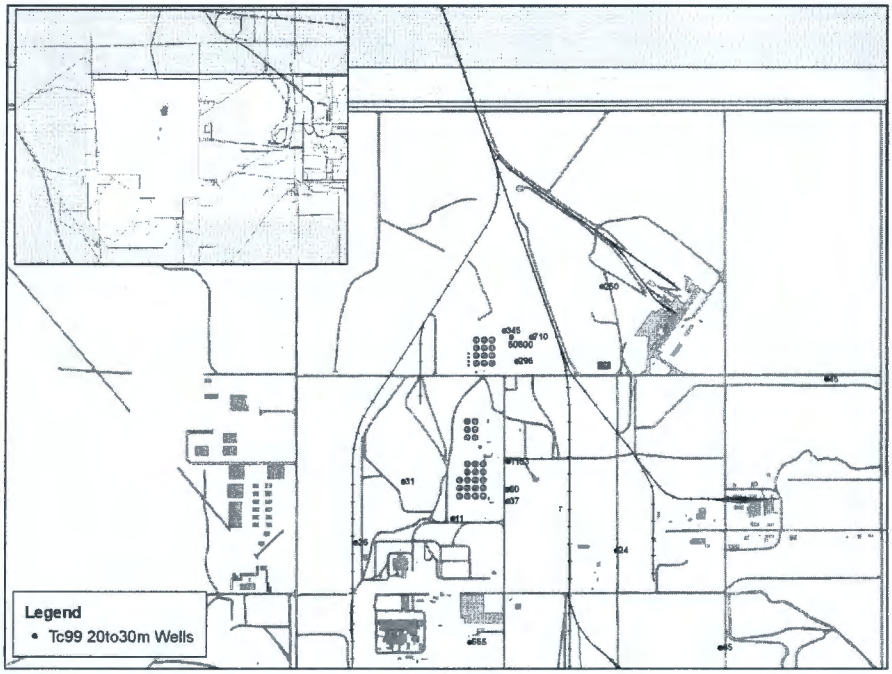


Figure 2-29. Technetium-99, 30 to 40 m Below Water Table (pCi/L).

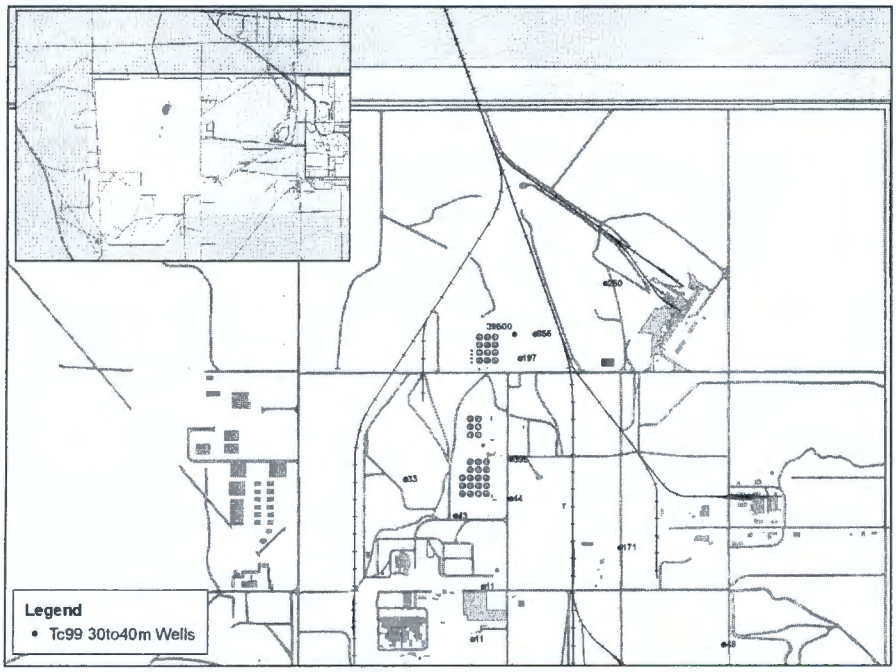


Figure 2-30. Technetium-99, 40 to 50 m Below Water Table (pCi/L).

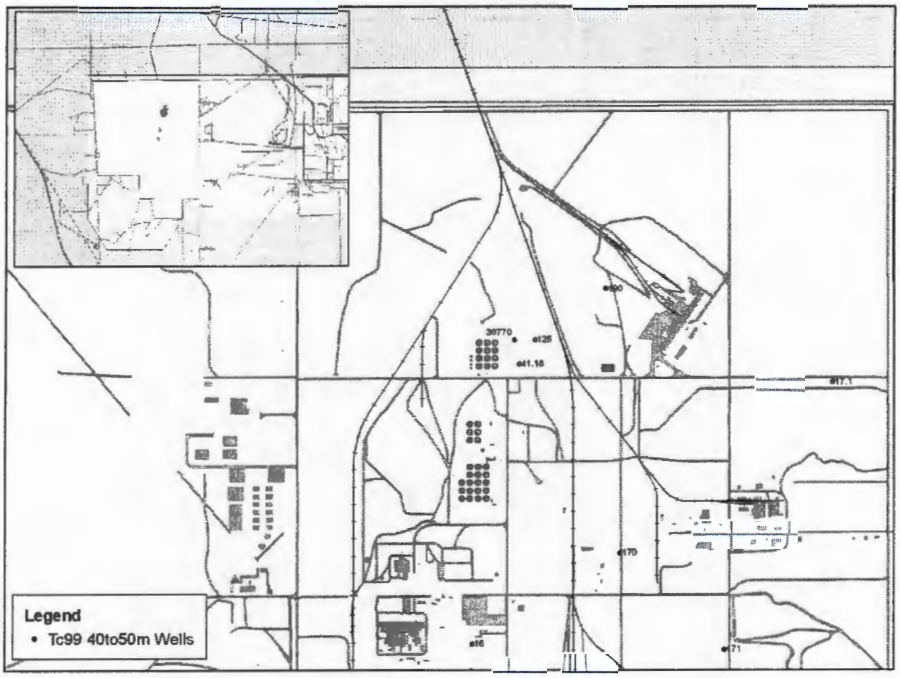


Figure 2-31. Technetium-99, Greater Than 50 m Below Water Table (pCi/L).

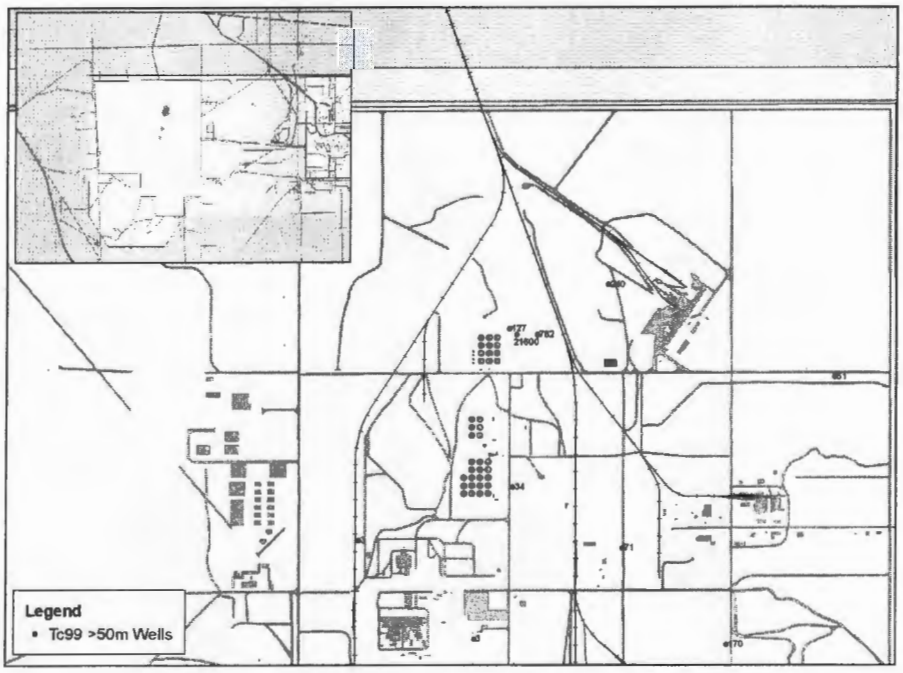


Figure 2-32. Interpolated Extent of Uranium in Groundwater.

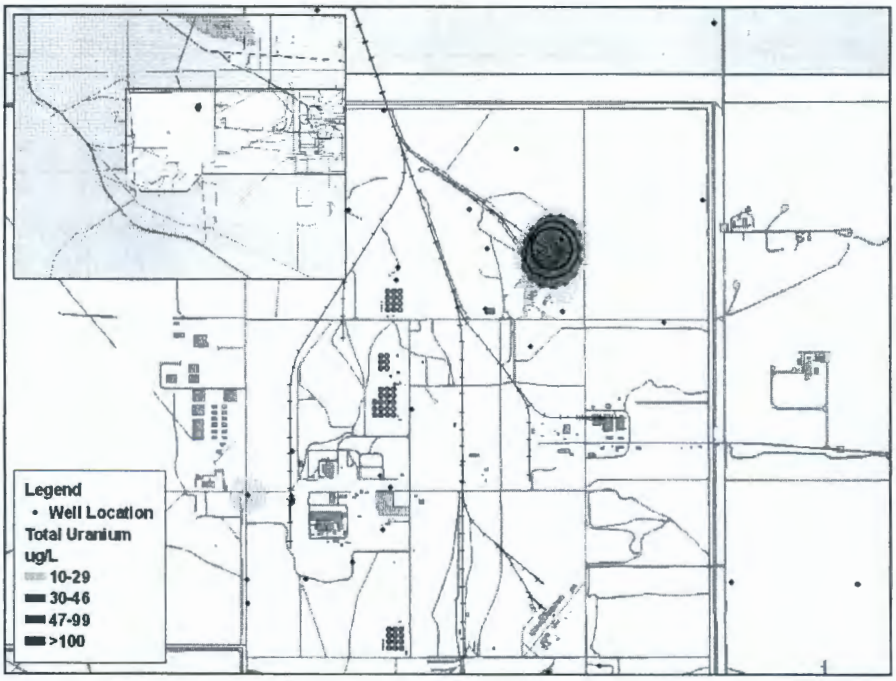


Figure 2-33. Interpolated Extent of Iodine-129 in Groundwater.

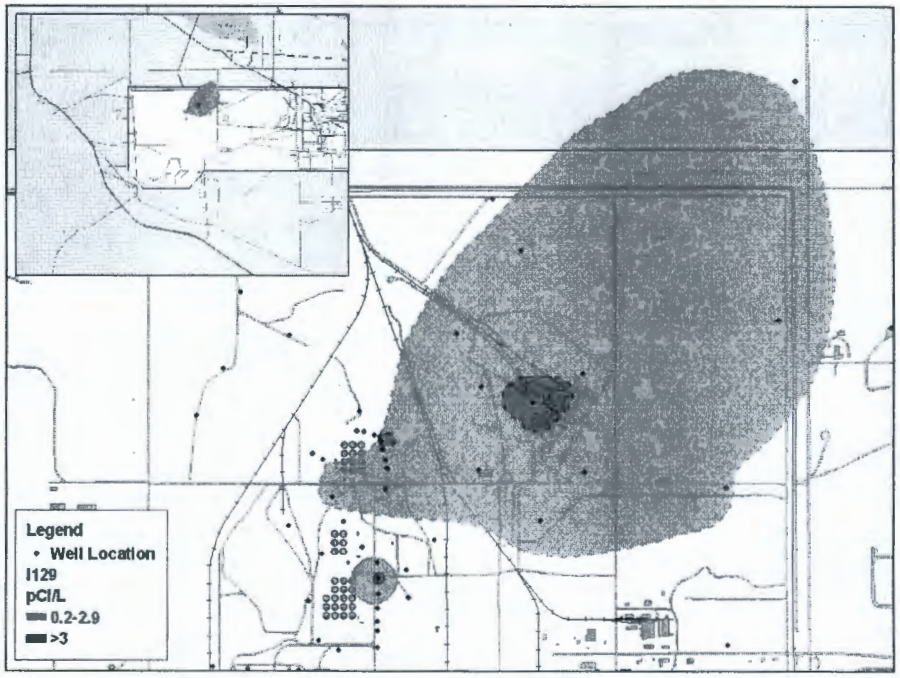


Figure 2-34. Interpolated Extent of Tritium in Groundwater.

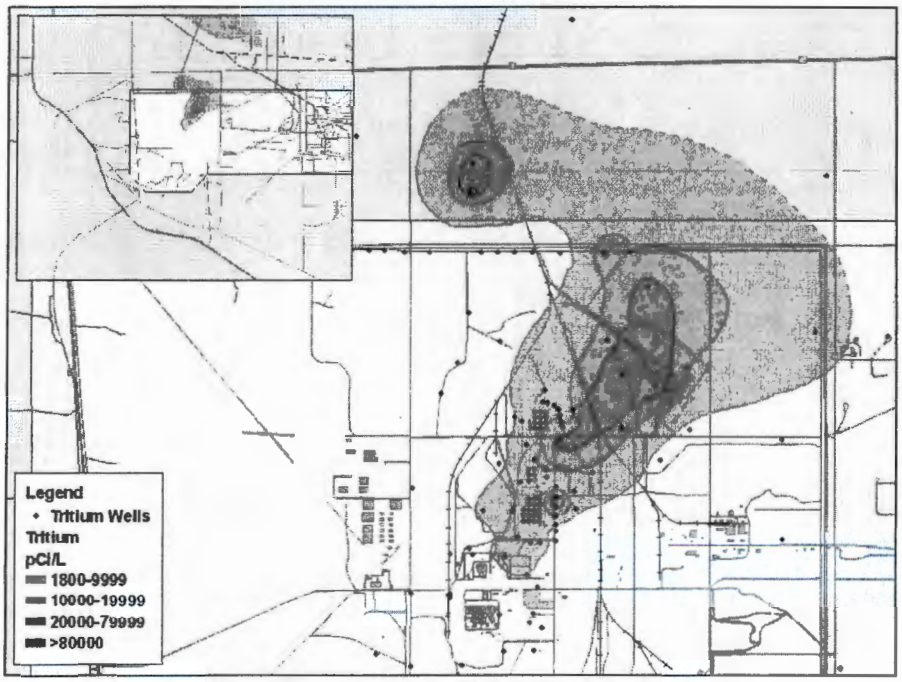


Figure 2-35. Conceptual Site Model for the 200-ZP-1 Operable Unit.

Groundwater | **Central Plateau**

200-ZP-1 Operable Unit

History

The 200-ZP-1 Groundwater Operable Unit (OU) is one of two groundwater OUs centered within the 200 West groundwater aggregate areas of the Hanford Site. The 200-ZP-1 OU groundwater underlies the Z Plant and T Plant aggregate areas; Low Level Waste Management Area (LLWMA)-3 and LLWMA-4; T-Tank Farm; TX/TY-Tank Farms; the State Approved Land Disposal Site (SALDS); as well as various cribs and trenches that received liquid waste. The primary cribs and trenches that contributed contaminants to the groundwater included 216-Z-1A, 216-Z-9, 216-Z-18, and 216-U-10.

Bulk liquid waste discharges that contributed the majority of contamination to the subsurface occurred from 1945 to the early 1970's. Presently, state-permitted liquid waste discharges occur from the SALDS facility and various small, permitted structures such as sanitary tile fields.

RI Characterization Summary

The groundwater sampling frequency for the 200-ZP-1 monitoring well network varies depending on how recently a well was installed and the results of previous sampling events. New wells (FY03 and newer) are typically sampled quarterly during the year following installation, semi-annually during the second year after installation, and annually thereafter. Wells located near a contaminant plume perimeter are sampled biennially (i.e., every 2 years), if the contaminant concentrations are stable for several years. The sampling frequency may increase in wells where contaminant concentrations are irregular or increasing.

Currently, more than 66 groundwater monitoring and extraction wells are used for routine groundwater sampling to collect data for the evaluation of contaminant trends. The annual site-wide groundwater monitoring report and the annual summary report for 200-ZP-1 pump-and-treat operations provide the sampling locations and results for individual contaminants.

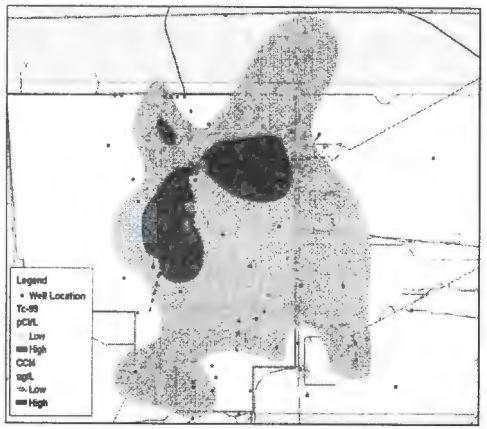
Contaminants Of Concern

A risk assessment performed as part of the 200-ZP-1 Feasibility Study (FS), identified carbon tetrachloride (CCl_4) as the principal threat Contaminant of Concern (COC), posing an unacceptable human health risk for an industrial land-use. Performance monitoring will include CCl_4 degradation products. Other contaminants that exceed the MCL at the 90th percentile concentration, but are not COCs include total chromium (both chromium III and chromium VI exceed the total chromium MCL), nitrate, TCE, ^{129}I, ^{99}Tc, and tritium.

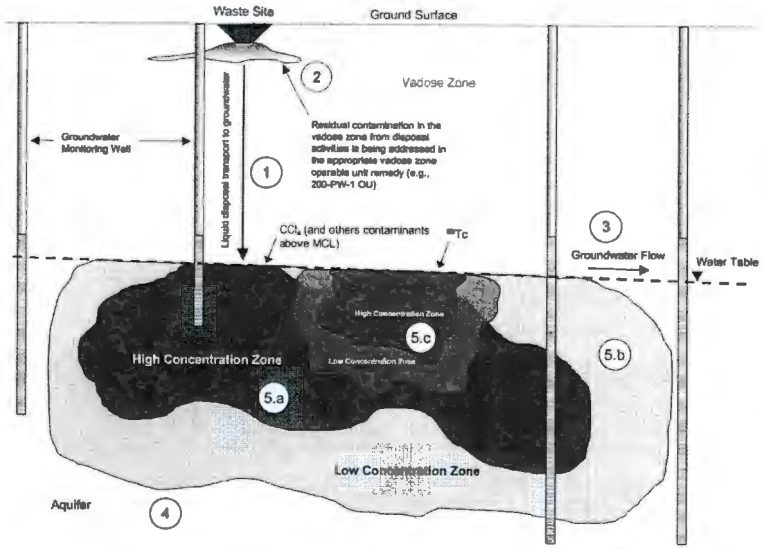
References:

PNNL-16346
DOE/RL-2006-24
DOE/RL-2006-58
DOE/RL-2002-39

Cross Section Location
(not to scale)



Contaminant Distribution Model
(not to scale)



Unconfined Aquifer Sediments

Ringold Formation Unit E sediments exposed in White Bluffs along the Columbia River (near Taylor Flats)

1. After effluents were discharged to disposal sites (such as cribs, trenches, and ponds) in the vadose zone, more mobile contaminants were transported to groundwater.
2. Less mobile contaminants (as well as residual contamination of higher mobility) remain in the vadose zone, and are being addressed in the vadose zone operable unit remedies (e.g., 200-PW-1 OU).
3. The top of the groundwater table within the 200-ZP-1 OU occurs within Ringold Formation Unit E, at depths typically greater than 220 feet below ground surface. The current direction of groundwater flow is generally easterly, with a principally horizontal component. Previously, historical groundwater mounding from past wastewater discharges caused a more northerly component to groundwater flow near suspected vadose zone source areas that contributed contamination to the groundwater.
4. Contaminant distributions in 200-ZP-1 groundwater are changing in response to multiple influences, including (1) general down-gradient transport of contaminants in the direction of groundwater flow; (2) pump-and-treat operations from the 200-ZP-1 Interim Response Measure (IRM), which are containing the high-concentration portion of the CCl_4 plume; (3) decreasing groundwater elevations from the termination of effluent releases to surrounding cribs, ponds (primarily T and U Ponds), and trenches; and (4) continued operation of the soil vapor extraction IRM in 200-PW-1 OU.
5. Contaminant distribution within the 200-ZP-1 OU can be represented in three categories:
   a) A high concentration zone close to the ponds, cribs and trenches that disposed of the liquid wastes. At present data does not support the presence of significant Dense, Non-aqueous Phase Liquids (DNAPL) in groundwater acting as a continuing source.
   b) A larger dispersed, or low concentration zone that has migrated from the discharge locations, or overlies the high concentration zone. This less contaminated groundwater can occur above the high concentration zone where large quantities of lower concentration effluent was discharged during or after the high concentration waste discharges.
   c) An area of ^{99}Tc contamination that is undergoing further investigation.

Figure 2-36. Dechlorination Reactions for CT under the Anaerobic Geochemical Setting (PNNL-15937)

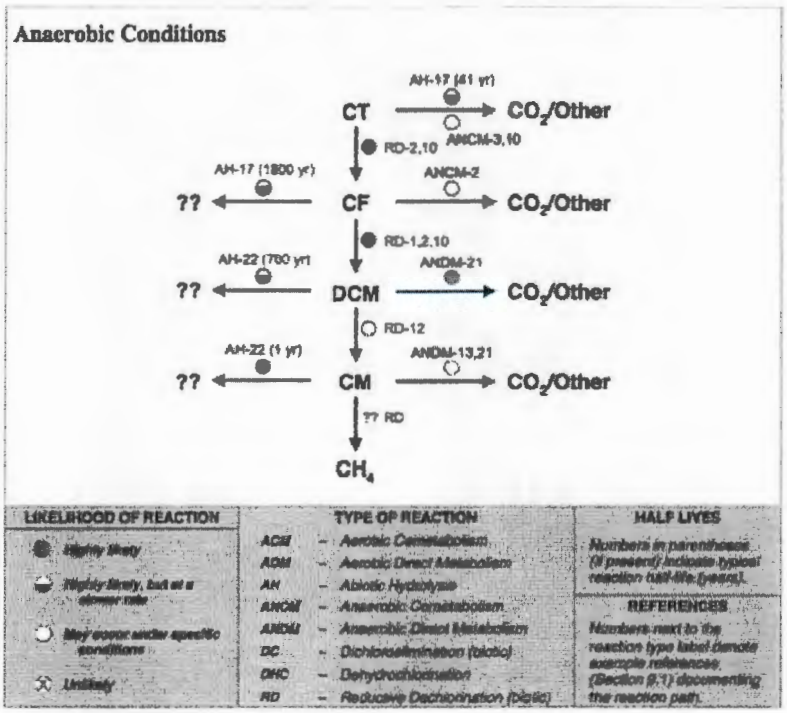


Figure 2-37. Dechlorination Reactions for CT under the Aerobic Geochemical Setting (PNNL-15937)

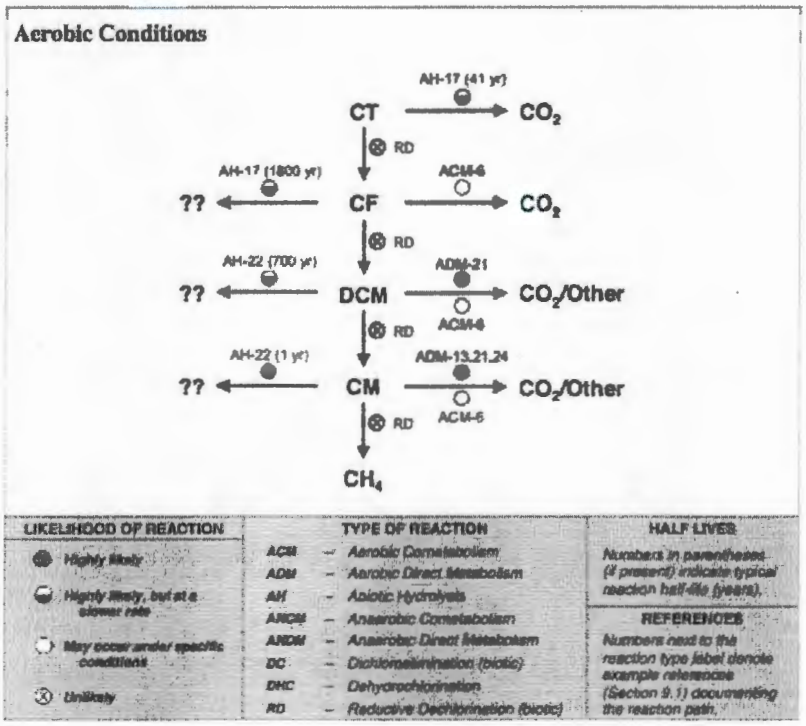


Figure 2-38. Historic Transport of Carbon Tetrachloride.

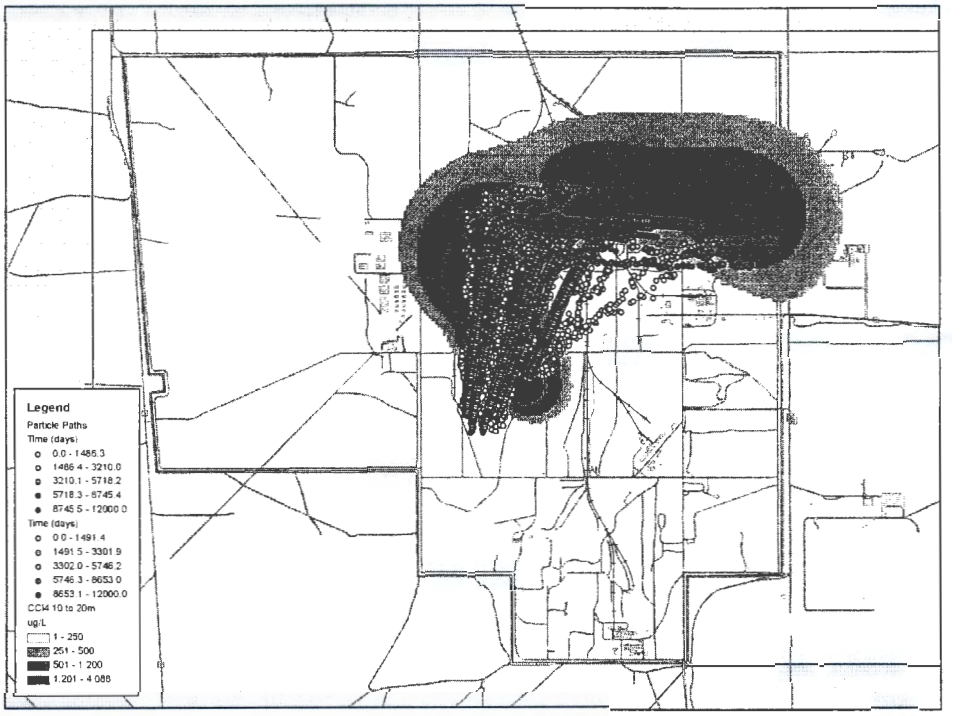


Table 2-1. Nonradionuclide Constituent Distribution Coefficient (K_d), Water Solubility (K_{sp}), and Partitioning Coefficient with Respect to Organic Fraction (K_{oc}).

Constituent	K_d (mL/g)	K_{sp} (mg/L)	K_{oc} (mL/g)
Carbon tetrachloride	0.0000131 to 0.367[a]	758[b]	110[b]
Chloroform	0.084 to 0.432[a]	8,200[b]	31[b]
Chromium, total	Variable[c]	Variable	Variable
Chromium (VI)	0[b]	Soluble	NA
Methylene chloride	NA	20,000[b]	8.8[b]
Nitrate	0[b]	Soluble	NA
Tetrachloroethylene (PCE)	NA	150[b]	360[b]
Trichloroethylene (TCE)	NA	1,100[b]	130[b]
Uranium	0.5 (±0.2)[d] 2.5 (±1.0)[d]	Insoluble	NA

NOTE: Hanford Site specific values cited where available – see Appendix D for details.

[a] From *Carbon Tetrachloride and Chloroform Partition Coefficients Derived from Aqueous Desorption of Contaminated Hanford Sediments* (PNNL-15239) and *Carbon Tetrchloride Partition Coefficients Measured by Aqueous Sorption to Hanford Sediments from Operable Units 200-UP-1 and 200-ZP-1* (PNNL-16100, Rev. 1)

[b] From *Z Plant Source Aggregate Area Management Study Report* (DOE/RL-91-58).

[c] From *Partition Coefficients for Metals in Surface Water, Soil, and Waste* (Allison and Allison 2005).

[d] From *Characterization of 200-UP-1 Aquifer Sediments and Results of Sorption-Desorption Tests Using Spiked Uncontaminated Groundwater* (PNNL-15502).

NA = published value not available

Table 2-2. Radionuclide Constituent Nuclear Data and Distribution Coefficients (K_d).

Constituent	Half-Life[a] (yr)	Decay Rate (yr^{-1})	Molecular Weight[a]	Specific Activity (Ci/g)	K_d (mL/g)
Iodine-129	17,000,000	4.0773E-08	128.9050	1.634E-04	0 (±0.05)[b]
Technetium-99	213,000	3.2542E-06	98.9063	1.699E-02	0 (±0.1)[b]
Tritium	12.33	5.6216E-02	3.0160	9.627E+03	0[c]

[a] From *CRC Handbook of Chemistry and Physics* (Lide 2006).

[b] From *Characterization of 200-UP-1 Aquifer Sediments and Results of Sorption-Desorption Tests Using Spiked Uncontaminated Groundwater* (PNNL-15502).

[c] From *Z Plant Source Aggregate Area Management Study Report* (DOE/RL-91-58).

Decay rate = ln(0.5) / half-life (yr)

Specific activity = -358,000/(((ln(0.5) / decay rate)) x molecular weight)

3.0 DEVELOPMENT OF REMEDIAL ACTION OBJECTIVES AND PRELIMINARY REMEDIATION GOALS

The RAOs for the 200-ZP-1 OU FS are developed in this section. Inputs to developing the RAOs include the conceptual exposure model, the results of the BRA, and significant chemical-specific ARARs. The resulting RAOs are work statements that specify the media, COCs, potential exposure routes, and PRGs to protect human health and the environment and to ensure that the site complies with ARARs.

The RAOs are used throughout the FS process, first to aid in identifying technologies, and later as a basis for evaluating their effectiveness. The objectives for protection of human health and the environment are achieved by reducing or eliminating exposure routes, as well as by reducing contaminant concentrations and mass. In the 200-ZP-1 OU BRA evaluation of exposure routes, three potential human receptors were noted: current site workers, hypothetical future site workers, and future residents that would locate in areas outside of the industrial land-use area. The BRA evaluated potential exposure routes primarily from contaminated groundwater for workers and for future residents.

The conceptual exposure described in Section 3.2 depicts the exposure routes of ingestion, inhalation, and dermal contact for current site workers, hypothetical future site workers, and future residents. The BRA concluded that the inhalation and dermal-contact exposure routes were insignificant contributors to risk. The water supply at the 200-ZP-1 OU is institutionally controlled, and workers are provided water from sources other than groundwater. The BRA evaluated ingestion of contaminated water by a hypothetical future resident living outside of the industrial-use area rather than a future worker (i.e., it is assumed future workers would be protected by institutional controls). This is because a resident is assumed to have a higher rate of exposure to drinking water than a worker, and the residential exposure route is more protective. Therefore, the only groundwater exposure route evaluated further in this FS is the ingestion of contaminated groundwater by a hypothetical future resident.

The ecological risk evaluation performed in the 200-ZP-1 RI report (DOE/RL-2006-24) concluded that there are no direct-exposure pathways from Central Plateau groundwater to ecological receptors. The main concern for ecological exposure occurs at the Columbia River. Ecological risks were evaluated in the RI using a simple bounding analysis that includes three exposure scenarios. The bounding analysis will not account for contributions from multiple groundwater OUs, but it is expected to demonstrate which contaminants and OUs are more likely to present ecological risks to the Columbia River.

Groundwater concentrations were compared to applicable ecological indicators that are protective of aquatic and riparian organisms. The indicator concentrations are protective of aquatic organisms and are compiled from the 100 Area and 300 Area River Corridor baseline risk assessment (RCBRA), as documented in *Data Quality Objectives Summary Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment* (BHI-01757). The undiluted comparison is the worst-case condition and will indicate if there are potential ecological effects from the OU. Two dilution scenarios were evaluated to estimate the more likely impact of groundwater in the hyporheic zone and a mass-balance dilution in the Columbia River. Each of these two dilution scenarios was compared to applicable ecological indicator concentrations for aquatic and riparian organisms.

Development of the RAOs and PRGs takes into account current and future land uses, current and future groundwater use, and the specific chemicals of concern. The appropriate ARARs also impact and guide RAO and PRG development. These are all discussed in the following sections.

3.1 LAND USE

To identify appropriate cleanup objectives, the future land use of a site must be considered. Current and future land uses of the 200 Areas and the Central Plateau are discussed below.

3.1.1 Current Land Use

All current land-use activities associated with the 200 Areas and Central Plateau are industrial in nature. The facilities located in the Central Plateau were built to process irradiated fuel from plutonium-production reactors located in the 100 Areas. Most of the facilities directly associated with fuel reprocessing are now inactive and awaiting final disposition. Several waste management facilities operate in the 200 Areas, including permanent waste disposal facilities (e.g., the Environmental Restoration Disposal Facility [ERDF]), low-level radioactive waste burial grounds, and a mixed-waste trench permitted under RCRA. Construction of a facility for vitrification of tank waste facilities in the 200 Areas began in 2002. The 200 Areas are also the planned disposal location for the vitrified low-activity tank wastes. Past-practice disposal sites in the 200 Areas are being evaluated for remediation that will include institutional controls (e.g., deed restrictions or covenants) as part of the selected remedy. Federal agencies other than DOE (e.g., the U.S. Department of the Navy) use the Hanford Site 200 Areas nuclear waste TSD facilities. A commercial, low-level radioactive waste disposal facility, operated by US Ecology, Inc., currently operates on a portion of a tract in the 200 Areas leased to the State of Washington.

The DOE-selected land use for the 200 Areas, documented in the "Hanford Comprehensive Land-Use Plan Environmental Impact Statement (CLUP EIS), Hanford Site, Richland, Washington; Record of Decision (ROD)" (referred to hereinafter as the HCP EIS ROD) (64 FR 61615), is industrial for areas located within the industrial use boundary and conservation (mining) for sites located outside of the industrial use boundary, as shown in Figure 3-1. In response to *Consensus Advice #132: Exposure Scenarios Task Force on the 200 Area* (02-HAB-0006), a slightly different boundary, currently known as the industrial use zone, was created to define the 200 Areas industrial land-use area. The cleanup criteria for these sites must be consistent with either land use or PRGs, based on HAB Advice #132.

According to the HCP EIS (DOE/EIS-0222-F), industrial land use would preserve DOE control of the continuing remediation activities and would use the existing compatible infrastructure required to support activities such as dangerous waste, radioactive waste, and mixed-waste TSD facilities. The DOE and its contractors, and the U.S. Department of Defense (DOD) and its contractors, could continue their Federal waste disposal missions; and the Northwest Interstate Compact for Low-Level Radioactive Waste Management could continue using the US Ecology, Inc., site for commercial radioactive waste. Research supporting dangerous waste, radioactive waste, and mixed-waste management facilities would also be encouraged within this land-use designation. New uses of radioactive materials (e.g., food irradiation) could be developed, and the products could be packaged for commercial distribution under this land-use designation.

The conservation (mining) land use would enable the extraction of valuable near-surface geologic resources to support implementation of remedial actions (i.e., surface barriers) at some locations on the Hanford Site after obtaining NEPA, RCRA, or CERCLA approval to protect

NEPA-sensitive resources (e.g., biologic, geologic, historic, or cultural). The Hanford Site has no proven reserve of any metallic ore bodies; therefore, heap/leach or open-pit mining methods would not be applicable. In addition, the HCP EIS (DOE/EIS-0222-F) indicates that a notice of deed restriction would be placed in those areas where vadose zone contamination remained in place, according to a CERCLA ROD or RCRA closure permit, foreclosing the mining option. The HCP EIS anticipates mining only for materials needed to build surface barriers as part of remedial actions and that mining would be precluded from contaminated areas. The conservation (mining) land use would afford protection of natural resources; however, other compatible uses (e.g., recreation or non-intrusive environmental research activities) would also be allowed, provided that these activities are consistent with the purpose of the conservation land-use designation. Conservation would require active management practices to enhance or maintain the existing resources and to minimize or eliminate undesirable or non-native species.

The HCP EIS ROD (64 FR 61615) identifies conservation (mining) as an area reserved for the management and protection of archeological, cultural, ecological, and natural resources. Limited and managed mining (e.g., quarrying for sand, gravel, basalt, and topsoil for governmental purposes only) could occur as a special use (i.e., a permit would be required) within appropriate areas. Limited public access would be consistent with resource conservation. The HCP EIS ROD also indicates that mining would be restricted from contaminated areas.

3.1.2 Anticipated Future Land Use

The reasonably anticipated future land use for the industrial use zone (shown in Figure 3-1) is continued industrial activities. Eventually, portions of this area may be used for non-DOE-related industrial uses. The DOE worked for several years with cooperating agencies and stakeholders, including the National Park Service, Tribal Nations, the states of Washington and Oregon, local county and city governments, economic and business development interests, environmental groups, and agricultural interests to define land-use goals for the Hanford Site and develop future land-use plans. The results were reported in *The Future for Hanford: Uses and Cleanup, The Final Report of the Hanford Future Site Uses Working Group* (HFSUWG 1992) and culminated in the HCP EIS (DOE/EIS-0222-F) and associated ROD (64 FR 61615) issued in 1999.

The HCP EIS was written to address the growing need for a comprehensive, long-term approach to planning and development on the Hanford Site because of DOE's separate missions of environmental restoration, waste management, and science and technology. The HCP EIS analyzes the potential environmental impacts of alternative land-use plans for the Hanford Site and considers the land-use implication of ongoing and proposed activities. In the HCP EIS, the land-use designation for sites inside the industrial area is as follows:

- Industrial-exclusive (industrial): Areas suitable and desirable for TSD of hazardous, dangerous, radioactive, and nonradioactive wastes, and related activities.

For sites outside the industrial area, the land-use designation is as follows:

- Conservation (mining): An area reserved for the management and protection of archeological, cultural, ecological, and natural resources.

Under the preferred land-use alternative selected in the ROD (64 FR 61615), the area inside the industrial boundaries of the Central Plateau was designated for industrial use. The current vision for all of the 200 Areas is continued use for management of hazardous, dangerous, radioactive, and nonradioactive wastes. The HCP EIS and ROD incorporate this vision in the selected

alternative, describe the means by which new projects will be sited, and focus on using existing infrastructure and developed areas of the Hanford Site for new projects. To support the current vision, the 200 Areas projects will maintain current facilities for continuing missions, remediate soil waste sites and groundwater as necessary to support industrial land uses, lease facilities for waste disposal (i.e., US Ecology, Inc.), and demolish facilities that have no further beneficial use. Based on the HCP EIS and associated ROD, and consistent with other Hanford Site waste management decisions, this FS assumes an industrial land use for all of the waste sites within the industrial land-use boundary. Risk assessments for the industrial land use are conducted considering a non-Hanford Site worker industrial receptor to bound the industrial land-use exposure possibilities.

Operations at the Hanford Site are expected to terminate in approximately 2050, and active institutional controls are assumed for approximately another 100 years following the termination of operations. Effective passive institutional controls will be designed to endure to provide protection for at least 500 years, which is the time period stated for the ERDF (EPA/ROD/R10-95/114). Institutional controls are expected to be maintained until the contamination is no longer hazardous to human health or the environment.

Under the preferred land-use alternative selected in the HCP EIS ROD (64 FR 61615), the area outside of the industrial area of the Central Plateau was designated for other activities. For the sites in the study area, the land use was designated as conservation (mining). This would include restrictions against intrusive human activities but would allow recreational use (e.g., hiking, biking, hunting, and bird watching, where a receptor spends only a small fraction of time in actual proximity to the contaminated areas) of the surface areas. Restricted use (e.g., recreation or waste management) means that surface use of the waste sites could occur, but subsurface activities such as excavation, well drilling, and farming would be restricted to preclude contact with or disturbance of contaminated soils. These activities could occur *around* the waste sites, but not *on* the waste sites. Based on the risk framework workshops, groundwater use outside the core zone also would be restricted until remediation efforts result in meeting groundwater cleanup standards. At that point, unrestricted groundwater use would be assumed.

To date, the conservation (mining) land use has not been represented by a specific risk assessment model. As a conservative estimate, this FS uses the industrial-exposure scenario to evaluate the conservation (mining) land use, under the assumption that a person using the area for recreation would spend less time there than a worker spending the majority of the year on a site. However, through the risk framework workshops (02-HAB-0006), RL agreed to evaluate other scenarios as a means to provide decision makers and stakeholders with additional information for comparison purposes. Both residential and recreational scenarios were evaluated and included as sensitivity discussions to the risk assessment and alternative evaluation discussions. For purposes of the remedial investigation BRA, human-health COPCs were identified employing industrial-use screening values.

3.1.3 Regional Land Use

Communities in the region of the Hanford Site consist of the incorporated cities of Richland, West Richland, Kennewick, and Pasco, as well as numerous other smaller communities within Benton and Franklin Counties. In 2000, the population of Benton County was 142,475 and the population of Franklin County was 49,347. There are no residences on the Hanford Site. The inhabited residences nearest to the 200 Areas are farmhouses on land located approximately

16 km (10 mi) north across the Columbia River. The City of Richland corporate boundary is approximately 27 km (17 mi) to the south (PNNL-6415).

3.1.4 Groundwater Use

The HCP EIS indicates that contamination in the groundwater would restrict use (DOE/EIS-0222-F). Groundwater beneath the Central Plateau is currently contaminated and is not withdrawn for beneficial uses. This FS evaluates potential future impacts of contaminated groundwater, as well as groundwater remediation in the 200-ZP-1 OU.

3.2 SUMMARY OF HUMAN HEALTH RISK ASSESSMENT

A human health risk assessment (HHRA) was conducted for chemicals and radionuclides in the 200-ZP-1 Groundwater OU under the northern portion of the 200 West Area. Previous investigations identified chlorinated solvents, inorganics, and radionuclides above regulatory criteria in groundwater at the 200-ZP-1 OU from past spills, leaks, and work practices associated with the processing of plutonium and uranium to produce nuclear weapons. This risk assessment evaluated whether potential health risks are present if people encounter these contaminants in their environment. The complete risk assessment is included as Appendix A and is summarized in this section. In Appendix A, risks from soil at the 200-PW-1/3/6 OUs and groundwater at 200-ZP-1 OU are addressed. Specifically, cumulative risks were evaluated for those populations that could have concurrent exposures to soil and groundwater (i.e., a hypothetical residential farming population 150 years in the future). However, this summary focuses on the results of the groundwater portion of the risk assessment.

The risk assessment evaluates risks under current conditions (industrial land use, assuming the existing institutional controls with adult workers as the population potentially exposed) and future conditions (unrestricted land use, if institutional controls fail in the future). Under current conditions, existing institutional controls prevent the use of groundwater until such time as concentrations are below the MCLs. The unrestricted land-use scenario assumes that land-use controls will remain in place for 150 years; after that time, there is assumed to be a failure of institutional controls so potential exposures to a residential farming population (adults and children) and a working population are hypothetically possible. Including an unrestricted land-use scenario fulfills the requirements of the NCP (40 CFR 300.430[a]) for a risk evaluation under a "no action" scenario; fulfills federal EPA requirements to address current and future conditions (EPA/540/1-89/002); assesses food chain exposures consistent with both Federal EPA and Hanford risk assessment guidance (EPA/540/1-89/002 and DOE/RL-91-45, respectively); and provides information regarding the protectiveness of various remedies during the FS process. However, cleanup concentration goals and decisions will be based on industrial land-use exposures, as consistent with the current industrial nature of the site. The site is anticipated to remain industrial with existing institutional controls for the foreseeable future.

3.2.1 Selection of Contaminants of Potential Concern

The first step in a HHRA is an evaluation of the data in order to select the COPCs for human health. The 200-ZP-1 RI report (DOE/RL-2006-24) identified 55 compounds as possibly of concern in groundwater in (CP-16151, DOE/RL-2003-55). The data quality objectives (DQO) summary report (CP-16151) and the 200-ZP-1 RI/FS work plan (DOE/RL-2003-55) went through a rigorous process of identifying potential sources of contaminants and establishing what constituents could possibly be present in groundwater due to site activities. The RI then further

evaluated these contaminants by comparing maximum concentrations to health-based screening levels. The selected screening levels were either risk-based drinking water cleanup levels from Ecology's *Model Toxic Control Act* (MTCA) Method B cleanup levels, or were MCLs from state and Federal drinking water regulations. Details of these screening levels and how they were selected (screening levels are referred to as target action levels [TALs]) are presented in Table 1-5 of the 200-ZP-1 RI report (DOE/RL-2006-24). Details of the RI screening process are discussed below.

In the RI report, the COCs selected after an initial screening of maximum concentrations against TALs were placed into one of two groups: Group A or Group B. Group A included the analytes of groundwater plumes (presented in Table 1-9 of the 200-ZP-1 RI report [DOE/RL-2006-24]), and Group B included analytes not part of a known plume. Group A, or the potential major risk drivers, had a least one result greater than two times the TAL. The other analytes of Group B were separated into two subgroups:

- Analytes with fewer than 10% of detects above a TAL and the 95% upper confidence limit (UCL) of the mean if results were above the TAL
- Analytes with greater than 10% of detects above the TAL with the 95% UCL also above the TAL.

The results of this process identified 15 contaminants that were likely to be COCs in groundwater based on data collected from 116 groundwater monitoring wells sampled between the years 1988 to 2005. Table 1-2 of the 200-ZP-1 RI report (DOE/RL-2006-24) presents the wells used in the RI evaluation. Data excluded were samples collected prior to 1988, rejected data by laboratory validators, data with "null' results, and nonradioactive data reported as "zero" without reporting limits or detection limits.

This risk assessment evaluation for the 200-ZP-1 OU used a subset of the RI data set. Specifically, the last 5 years of data were selected as being representative of current conditions (i.e., samples collected between the years 2000 to 2005), and data prior to 2000 were excluded. Therefore, the HHRA includes only the data from the past 5 years. In addition, of the 116 wells evaluated in the 200-ZP-1 RI report (DOE/RL-2006-24), 107 wells were selected for the risk assessment because their screened intervals were the most applicable for the depth that a groundwater supply well might be screened. These 107 wells also include the wells with the highest concentrations found in the groundwater. Based on this revised data set, the groundwater human health evaluation selected 12 of the 15 RI COPCs to carry through the risk assessment process:

- Carbon tetrachloride
- Chloroform
- Chromium (III)
- Chromium (VI)
- Methylene chloride
- Nitrate
- PCE
- TCE
- Uranium
- Iodine-129
- Technitium-99
- Tritium.

The three contaminants on the original RI list that do not represent a health concern and do not require evaluation in the risk assessment are 1,2-dichloroethane, antimony, and iron. The specific reasons why these contaminants do not require analysis are as follows:

- 1,2-dichloroethane: The maximum chemical concentration did not exceed target action level in the last 5 years of data.

- Antimony: The maximum concentration in the last 5 years did not exceed background levels.
- Iron: The TAL is a secondary MCL and very little of the data over the last 5 years exceeded the TAL (less than 5%). Secondary MCLs are not health-based (e.g., the iron MCL is based on objectionable color of drinking water), and the maximum concentration of iron in the last 5 years of data did not exceed an EPA Region 6 human health screening level for tap water. Thus, this chemical is not present at levels that are a health concern. [NOTE: Because EPA Region 10 does not calculate their own screening levels, Region 10 mandates the use of Region 6 screening levels for EPA projects in Region 10.]

Uranium is retained as a COPC based on its chemical toxicity, not its radioactive toxicity. The radioactive isotopes of uranium have either not been detected in recent groundwater monitoring rounds or have been detected at concentrations well below health-based levels (200-ZP-1 RI/FS work plan [DOE/RL-2003-55]); thus, only chemical toxicity is a concern for uranium. Uranium is unique in that its chemical toxicity occurs at or below levels that are a concern for radioactive toxicity.

3.2.2 Exposure Assessment

The risk assessment evaluated risks under current conditions (industrial land use, assuming the existing institutional controls with current construction workers as the population potentially exposed) and future conditions (unrestricted land use post-2150, if institutional controls fail in the future). Under current industrial land use and the existing institutional controls, there is no exposure to impacted groundwater. In the event that knowledge of the site is lost and institutional controls fail, a future unrestricted land-use scenario was evaluated where people could come into contact with groundwater and subsurface soil brought to the surface as drill cuttings from drilling a groundwater well. This scenario is assumed to occur 150 years in the future. Exposures to groundwater could occur to a future residential farming population (adults and children) in the following ways:

- Drinking the water
- Exposure to water vapors outdoors during irrigation (adults)
- Use of the water to irrigate their crops, which they ingest
- Watering their livestock, which they ingest and obtain milk from.

The livestock are assumed to drink groundwater and to eat fodder irrigated with groundwater. The unrestricted land-use post-2150 scenario also evaluates a working population (future regular workers) who might drink groundwater at their place of employment.

Native Americans currently live near the Hanford Site and could potentially also be exposed to contaminants in groundwater and subsurface soil in the 200 West Area under a future failure of institutional controls scenario, similar to a residential farming population. They have treaty fishing rights on portions of the Columbia River and have reserved the right to fish, hunt, gather roots and berries, and pasture horses and cattle on open, unclaimed land (*Hanford Site Environmental Report for Calendar Year 2005* [PNNL-15892]). With some exceptions, Native American exposures are similar in type to the residential farmer (e.g., both groups could be exposed via direct contact with contaminated materials and via the food chain), but exposures may be different in kind (e.g., more time spent outdoors and greater consumption of native plants and animals) than the typical default exposures that EPA has developed for a residential population (*Risk Assessment Guidance for Superfund: Supplemental Guidance: Standard*

Default Exposure Factors [OSWER Directive 9285.6-03]; *Exposure Factors Handbook*, Volumes I–III [EPA/600/P-95/002Fa]; *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* [Harris and Harper 2004]). For this assessment, the residential farming population has been selected to represent the future highly exposed population under the institutional controls failure scenario; however, implications on the results of the risk assessment of not quantitatively evaluating a Native American population are further discussed in Section 3.6.5. Native American scenarios will be quantified and included in the risk assessment in the next revision of this document (see Appendix J).

Figures 3-2 and 3-3 present human health CSMs depicting the populations and exposure pathways evaluated in the risk assessment under a current industrial land-use scenario and a future institutional controls scenario, respectively. Note that the detailed information regarding contaminant sources, releases to the environment, and contaminant fate and transport information required to fully characterize the site was developed and presented as part of the DQO summary report (CP-16151) and 200-ZP-1 RI report (DOE/RL-2006-24). This discussion focuses on human exposure to contaminants in the media.

Groundwater flow is generally from west to east across the Central Plateau and towards the Columbia River (some groundwater may also flow north through Gable Gap). Currently, contaminants in the 200-ZP-1 OU groundwater plume have not reached the nearest surface water body (Columbia River) but may reach the Columbia River in 75 years or more if actions are not taken (see discussions in Sections 2.4 and 2.5). Due to the uncertainties in estimating groundwater concentrations at the river boundary 75 years or more in the future, these potential future pathways are not quantified in the risk assessment but are included as an uncertainty in potentially affected media. Depending on the concentrations reaching the river, there could be a human health concern via contact with contaminants in sediment or surface water during recreational activities, or through the ingestion of impacted fish.

Impacted groundwater beneath the site is widely dispersed and consists of overlapping groundwater plumes (i.e., all the highest concentrations or the lowest concentrations for different COPCs do not occur at the same location). Therefore, a range of concentrations for each COPC were selected as exposure point concentrations (EPCs) to evaluate the "low," "medium," and "high" groundwater concentrations for the groundwater exposure routes. These EPCs are the 25th, 50th, and 90th percentile values for each COPC from the existing groundwater data set. Use of the existing data set (rather than modeling future concentrations) likely over-estimates future concentrations, particularly for tritium and the volatile organic compounds (VOCs). The effect of this over-estimation on the risk assessment findings is further discussed in Section 3.2.4.

Because a groundwater well could be drilled at any location and plume configurations for the 12 groundwater COPCs are complex, this approach was selected as providing the best information regarding the range of possible groundwater risks throughout the site. Using this approach, the EPC is independent of geographic location and provides a useful degree of conservatism. The groundwater concentrations used in the risk assessment equations for each COPC at the 25th, 50th, and 90th percentiles are summarized in Table 3-1. In addition to using the groundwater data directly to estimate health risks from drinking the water, modeling equations were used to estimate the amount of contaminant in plants, beef, and milk transferred to these media from water used for irrigation and stock watering, respectively. Modeling methodology and selected transfer factors are described in detail in Section A3.2.3 of Appendix A. Tissue concentrations (i.e., concentrations in plants and animals) used in the risk calculations, modeling

equations, and contaminant-specific transfer factors are presented in Tables A3-5 through A3-9 in Appendix A.

The formulas and exposure factors that were used together with the EPCs to quantify doses for the complete and significant pathways shown in Figures 3-2 and 3-3 are presented in Appendix A, Tables A3-11 through A3-19. The tables also indicate the sources of the factors. In general, EPA's *Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors* (OSWER Directive 9285.6-03) and *Exposure Factors Handbook* (EPA/600/P-95-002Fa) default exposure factors were used for residential and industrial exposures. Default exposure factors are discussed in Appendix A, Attachment A-4. Where site-specific factors rather than accepted defaults were proposed, the rationale for their selection is provided in Appendix A, Section A3.3.

3.2.3 Toxicity Assessment

The third step in risk assessment is an evaluation of the toxicity of the COPCs by an assessment of the relationship between the dose of a contaminant and the occurrence of toxic effects. Chemical toxicity criteria, which are based on this relationship, consider both cancer effects and effects other than cancer (non-cancer effects). The toxicity criteria are required in order to quantify the potential health risks due to the COPCs. Only cancer effects are of concern for the radionuclides (except for uranium); however, a number of the nonradionuclide COPCs are considered toxic for their potential to induce cancer and because of their non-cancer toxic effects. The toxicity criteria used in the risk calculations are presented in Appendix A, Tables A4-1 through A--3. Toxicity criteria for nonradionuclides are from EPA, preferentially EPA's Integrated Risk Information System (IRIS) database (which is an on-line database of toxicity criteria), but were obtained from other EPA sources if a value was not available in the IRIS database. Toxicity criteria for the radionuclides are from Federal Guidance Report No. 13 ("Cancer Risk Coefficients for Environmental Exposure to Radionuclides" [EPA/402-R-99-001]). Federal Guidance Report No. 13 incorporates state-of-the-art models and methods that take into account age- and gender-dependence of radionuclide intake, metabolism, dosimetry, radiogenic cancer risk, and competing risks. Additional toxicological information for the COPCs can be found in Appendix A, Attachment A-5.

3.2.4 Risk Assessment Results

Risks (for cancer) and hazards (for non-cancer effects) are calculated for a reasonable maximum exposure (RME) scenario for each pathway, a calculation that over-estimates risks for the majority of the population in order to ensure that public health is protected. Cancer risk estimates represent the potential for cancer effects by estimating the probability of developing cancer over a lifetime due to site exposures (e.g., a risk of 1×10^{-6} indicates a 1 in 1 million chance of developing cancer due to exposures at the site). Non-cancer hazards assume that there is a level of chemical intake that is not associated with an adverse health effect even in sensitive individuals. EPA's target cancer risk goal is 1×10^{-6} to 1×10^{-4}, with action usually required if risks exceed 1×10^{-4}; target health goals for non-cancer contaminants are a hazard index (HI) less than or equal to 1.

Two of the three radionuclides selected as COPCs in groundwater, technetium-99 and iodine-129, have very long half-lives (213,000 and 17,000,000 years, respectively), and future concentrations would not be different than current concentrations. However, the third radionuclide COPC, tritium, has a half-life of 12.3 years and will likely be at concentrations that

are below a health concern within 150 years, as depicted in Figure 3-4. Overall groundwater risks and hazards are summarized in Table 3-2, and details of the risk and hazards by contaminant and pathway are summarized in Tables 3-3 through 3-10. A more detailed discussion on the risk assessment results is presented in Appendix A, Section A5.0, and risk calculation spreadsheets are in Appendix A, Attachment A-6.

Risks from exposure to groundwater exceeded 1×10^{-4} at the 90th and 50th percentiles, due primarily to carbon tetrachloride, followed by technetium-99, for both residential and industrial drinking water exposures. Carbon tetrachloride's non-cancer hazards were also non-cancer risk drivers and exceeded target health goals at the 90th and 50th percentiles. Although reductions in future concentrations were not quantified for carbon tetrachloride, the chemical's concentrations will be decreasing relatively rapidly over time in comparison to technetium-99, which has a half-life of 213,000 years. Therefore, while carbon tetrachloride concentrations represent the highest current risks, in the future (post-150 years and further), technetium-99 will become the risk driver. Risks due to technetium-99 exceeded 1×10^{-4} for ingestion of produce (90th and 50th percentile concentrations) and ingestion of dairy products (90th percentile concentration).

- Future workers drinking groundwater at their place of employment exceeded a risk level of 1×10^{-4} only for carbon tetrachloride at the 90th and 50th percentile concentrations (see Table 3-3). Carbon tetrachloride was also the only chemical with a non-cancer hazard above the target goal of 1 (see Table 3-4). Note that three chemicals shown in Table 3-4 would have an HI above 1 if their toxic effects were additive (chromium [VI], nitrate, and TCE); however, because the primary toxic effects of these chemicals are not based on the same critical toxic endpoint, their cumulative hazards are not a health concern (see Sections A4.0 and A5.1 in Appendix A). Four additional COPCs (technetium-99, tritium, PCE, and chloroform) exceed a 1×10^{-6} risk level at the 90th percentile. Cancer risks and non-cancer hazards for this scenario are presented in Tables 3-3 and 3-4, respectively. This scenario, industrial use of groundwater, was used as the basis for determining which COPCs might require risk-based concentrations (RBCs), discussed in Section 3.6.6.
- Future residents (post-2150) drinking groundwater exceeded a risk level of 1×10^{-4} only for carbon tetrachloride at the 90th and 50th percentile concentrations. While below a risk level of 1×10^{-4}, chloroform and PCE both exceeded a risk level of 1×10^{-6} at the 25th, 50th, and 90th percentile concentrations, and carbon tetrachloride also exceeds 1×10^{-6} at the 25th percentile. Radionuclide risks were the highest for technetium-99 (8×10^{-5}), assuming that tritium concentrations decay to low levels in 150 years. Non-cancer hazards are significant for carbon tetrachloride at both the 90th and 50th percentile concentrations. In addition, chromium (VI), nitrate, and TCE all have non-cancer hazards above the target goal of 1 at the 90th percentile groundwater concentration. However, carbon tetrachloride's HI is two orders of magnitude higher than any other chemical's HI. Cancer risks for future residents drinking groundwater are presented in Table 3-5, and non-cancer hazards are shown in Table 3-6.

- Future residents exposed to contaminants through the food chain would have risks above 1×10^{-2} due primarily to eating produce irrigated with impacted groundwater. Carbon tetrachloride had the highest produce ingestion risks (1×10^{-2}), followed by technetium-99 (3×10^{-3}). Risks from PCE exceeded 1×10^{-6} for produce ingestion at all three groundwater concentrations evaluated. Risks from ingesting dairy products exceed 1×10^{-4}. Risks from eating beef are below 1×10^{-4}. Cancer risks and non-cancer hazards are presented in Tables 3-7 and 3-8, respectively.
- Carbon tetrachloride is the risk driver currently for all groundwater pathways (two orders of magnitude higher than most other COPCs), with the exception of the milk and meat pathways, where risks from technetium-99 are the highest. In the future (post-150 years) technetium-99 is likely to be the risk driving contaminant in groundwater due to the natural degradation of carbon tetrachloride at much faster rates than are expected for technetium-99.

Residential farmer risks were highest for ingestion of produce, followed by ingestion of groundwater, consumption of dairy products, and consumption of beef.

3.2.5 Uncertainties

Estimating and evaluating health risk from exposure to environmental contaminants is a complex process with inherent uncertainties. Uncertainty reflects limitations in knowledge, such that simplifying assumptions must be made to quantify health risks. Some key areas of uncertainty evaluated in the risk assessment are listed below. A more detailed discussion regarding uncertainties in the risk assessment process is presented in Section A6.0 of Appendix A.

- Produce ingestion: Risks and hazards are significantly above target health goals due to ingesting homegrown produce watered with impacted groundwater (risks and hazards shown on Tables 3-7 and 3-8) and also for produce grown in impacted soils (see Tables A5-6 and A5-7 in Appendix A). Calculated risks and hazards from ingestion of homegrown produce are dependent on the concentration in the plant tissue and the produce ingestion rate. Plant tissue concentrations were estimated using health-protective modeling that likely over-estimates the amount of COPC that could be in the plant. The modeling equations used were from the RESidual RADioactivity (RESRAD) Version 6 computer model (soil-to-plants) and those developed by Oak Ridge National Laboratory for calculation of PRGs (water-to-plants and water-to-cattle). The transfer factors were obtained from *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment* (Rittman 2004), which preferentially used Hanford-specific data when it was available. Modeling details and transfer factors are described in detail in Section A3.2.3 of Appendix A. Modeling necessarily simplifies complex environmental processes and, therefore, concentrations in plants cannot be absolutely determined without field data. While transfer factors are generally chosen to be conservative (i.e., concentrations of contaminants in the food chain will be over-estimated), it is possible that modeling might also under-estimate actual plant concentrations in a future garden.

  In addition to uncertainties surrounding actual concentrations of COPCs in plants, there is also uncertainty surrounding how much homegrown produce a person would eat. The risk calculations used average homegrown fruit and vegetable ingestion rates for households who farm in the western United States (EPA/600/P-95/002Fa) (see

Section A3.3.2.1 in Appendix A). These values were selected to best represent a rural farming population that would be expected to receive a significant portion of their produce from their own garden; however, actual ingestion rates could vary. A more detailed discussion regarding produce ingestion rates can be found in Section A6.2.4 of Appendix A.

- A Native American population was not quantitatively evaluated because cancer risks and non-cancer hazards are already well above target health goals for the residential farmer. A residential farming population was selected to represent the RME "bounding" scenario because this population has widely accepted exposure factors that have been used over many years at many CERCLA sites. However, based on ongoing work evaluating the differences between a Tribal scenario and a residential farmer, Native Americans likely have higher exposure to many environmental media, although, with few exceptions, Native American exposure pathways are the same as the residential farmer (e.g., both groups could be exposed via direct contact with contaminated materials and the food chain). Table 3-9 compares the exposure factors and possible risks for a residential farmer and Native Americans using exposure factors established for the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) by *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* (Harris and Harper 2004) for the exposure pathways that are the same (i.e., direct soil and water contact pathways). Because the risk assessment equations are linear for non-cancer hazards and for cancer risks up to 1×10^{-2}, an increase in exposure could result in an increase in risk of the same amount. Thus, as shown in the example risk estimations in Table 3-9, combined exposures to soil and groundwater for Native Americans could result in an estimated increase of about an order of magnitude (10 times) of the exposure of the residential farmer.

  Another area where Tribal subsistence scenarios and residential scenarios can differ, in addition to increased exposures for pathways that are the same (e.g., soil ingestion), is in the amount of food gathered or grown locally. Under the assumptions in this risk assessment, groundwater is used to irrigate a garden area, sufficient to produce a significant portion of a residential farmer's diet, but not sufficient in size to supply all of a family's dietary needs. Therefore, in this case, the homegrown produce ingestion rates (produce ingestion was a risk-driving pathway) would be similar between the two populations. However, irrigating a garden with groundwater is not limited by area. Produce ingestion risks assuming that the only source of contaminants into plants was irrigation water were also significant ($>1 \times 10^{-4}$ for carcinogens, and HIs well above one due to carbon tetrachloride exposures, at the 90th and 50th percentile groundwater concentrations). Therefore, if more food is produced from a larger garden irrigated with groundwater, risks and hazards would increase. This would be true for both a residential farming population and a Native American population. However, risks and hazards already exceed target health goals by a significant amount, so an increase in the amount of homegrown produce ingested would not change the conclusions of the risk assessment.

  Similar to produce irrigated with groundwater, if a Native American produced more of their own protein than a residential farmer did, they might ingest more of their own beef. Beef ingestion had the lowest risks and hazards for the residential farmer exposure pathways with risks of 3×10^{-5} or less and no non-cancer hazards above one. Ingestion rates of dairy products from home-raised dairy are also potentially different for Native Americans than the ingestion rates established by EPA for families who farm.

There are several exposure pathways applicable to a Native American population that are not evaluated for the residential farmer: ingestion of wild plants and wild game, and exposures to water and water vapor in a sweat lodge. Under the assumptions in this assessment, wild plants and wild game would not be significantly affected by contaminants because contaminants are confined to a residential garden and water from groundwater. While contaminants in soil might be spread by windblown dust and, if an irrigation ditch system is used, there could be minimal exposure to groundwater, in general a developed farm would not be conducive to wild plant growth and wild game habitat. Therefore, these exposure pathways are not applicable to Hanford's Central Plateau waste sites. However, a sweat lodge using groundwater would be possible, and, using the sweat lodge exposure parameters developed by Harris and Harper (2004), a sweat lodge could be a significant source of contaminants in groundwater, with risks and hazards potentially exceeding the drinking water pathway. The estimates of sweat lodge risks, as approximately an order of magnitude larger than those for drinking water shown in the example in Table 3-9, are based on a comparison of risks from vapor inhalation in a sweat lodge to risks from drinking water for the Native American sweat lodge scenario evaluated for Midnite Mine, a uranium mine in northeastern Washington State (*Midnite Mine Superfund Site Spokane Indian Reservation, Washington, Record of Decision* [EPA Region 10, 2006]). As noted above for ingestion of produce, risks and hazards already exceed target health goals by a significant amount, so an increase in the amount of exposure and risk due to addition of the sweat lodge pathway would not change the conclusions of the risk assessment.

3.2.6 Risk-Based Concentrations

Although risks were calculated under both a current and future industrial land-use scenario, as well as for a future unrestricted land-use scenario, risk-based cleanup goals and decisions will generally be based on industrial land-use exposures as consistent with the current industrial nature of the site. The site is anticipated to remain as industrial use with existing institutional controls for the foreseeable future, and groundwater will not be used as a drinking water source as long as institutional controls are functioning and concentrations remain above cleanup levels. The RBCs have been calculated based on a hypothetical future working population drinking the water at their place of employment.

The RBCs do not need to be calculated for every COPC at the site. In general, RBCs are calculated in two cases:

- The contaminant exceeds target health goals.
- The contaminant does not exceed a target health goal but contributes a significant percentage to total site risks (i.e., is a concern not necessarily alone, but contributes substantially to the site's cumulative risks).

For industrial use of groundwater post-2150, Tables 3-3 and 3-4 indicate that only one constituent, carbon tetrachloride, exceeds 1×10^{-4}, or an HI of 1, for future workers drinking the water. Therefore, RBCs were calculated for carbon tetrachloride based on both a cancer risk of 1×10^{-4} and an HI of 1. Because the RBC based on cancer of 220 µg/L is greater than the RBC based on an HI of 1 of 62 µg/L, the lower value based on the HI is selected as the industrial drinking water RBC for carbon tetrachloride.

The RBC and ARARs (see Section 3.4) are used to develop the RAOs (see Section 3.5) and PRGs (see Section 3.6).

3.3 CONTAMINANT IDENTIFICATION

This section describes the COCs identified for the 200-ZP-1 OU, the degradation products associated with the COCs, and the constituents that were identified to have exceeded a Federal MCL at the 90th percentile. Each of these contaminants will be considered in the development and subsequent analysis of alternatives, but the principal threat COC will serve as the primary contaminant when evaluating the effectiveness of the assembled alternatives. An outcome of identifying these contaminants will be RAOs developed to provide a basis for evaluating the capability of remedial alternatives to achieve compliance with ARARs and/or an intended level of risk protection for human health or the environment.

3.3.1 Contaminant of Concern

As discussed in the previous sections, the risk assessment process compares contaminant concentrations, appropriate radiological risk and dose limits, and risk-based cleanup standards through computer modeling and/or screening. Only those constituents that exceed one or more of these criteria, and were not removed by further evaluation, are retained as COCs. The EPA target cancer risk range is 1×10^{-6} to 1×10^{-4}; however, EPA generally does not recommend taking action unless the upper end of the risk range (i.e., 1×10^{-4}) is exceeded (OSWER Directive 9285.6-03). Of the COPCs, only carbon tetrachloride exceeds a 1×10^{-4} risk level and is a COC and a principal threat on that basis. In general, principal threat wastes are those source materials considered to be highly toxic or highly mobile or which generally cannot be contained in a reliable manner or would present a significant risk to human health and the environment should exposure occur (40 CFR 300.430[a]). The EPA expects to use treatment to address the principal threats posed by a site, wherever practicable (40 CFR 300.430[a][1][iii][A]). This determination is important in determining how the remedial alternatives presented in Section 5.0 are formulated. Section 2.4 provides additional detail on the nature and extent of this COC in the groundwater at the 200-ZP-1 OU.

3.3.2 Degradation Products of Carbon Tetrachloride

Degradation products of carbon tetrachloride (e.g., chloroform, methylene chloride, and chloromethane) currently do not exceed the acceptable risk range or Federal MCLs. Any performance-monitoring strategy implemented as part of a final remedy will include carbon tetrachloride degradation products. The selected remedy will be designed to remove carbon tetrachloride degradation products present in groundwater.

3.3.3 Constituents That Exceed Maximum Contaminant Levels

Other than carbon tetrachloride, six COPCs exceed applicable MCLs at the 90th percentile concentration in groundwater, including total chromium (both chromium [III] and chromium [VI] exceed the total chromium MCL), nitrate, TCE, iodine-129, technetium-99, and tritium (see Table 3-1). These constituents are also COCs and the preferred remedy will also address these COCs to achieve Federal MCLs so the groundwater may be returned to beneficial use. Some of the tritium present within the 200-ZP-1 OU groundwater is a result of the permitted discharges at the SALDS. Areas of tritium contamination related to SALDS

discharges will not be specifically addressed by the alternatives formulated in Section 5.0 or the preferred remedy.

3.4 POTENTIAL APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

The ARARs identification process is based on CERCLA guidance (*CERCLA Compliance with Other Laws Manual: Interim Final* [EPA/540/G-89/006] and *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final* [EPA/540/G-89/004]). Section 121 of CERCLA requires, in part, that any applicable or relevant and appropriate standard, requirement, criterion, or limitation promulgated under any Federal environmental law, or any more stringent state requirement promulgated pursuant to a state environmental statute, be met (or a waiver justified) for any hazardous substance, pollutant, or contaminant that will remain onsite after completion of remedial action.

"Applicable" 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 specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. Only those state standards that are identified by a 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, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, 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 eight comparison factors in 40 CFR 300.400(g)(2), "Identification of Applicable or Relevant and Appropriate Requirements," are considered:

(i) The purpose of the requirement and the purpose of the CERCLA action

(ii) The medium regulated or affected by the requirement and the medium contaminated or affected at the CERCLA site

(iii) The substances regulated by the requirement and the substances found at the CERCLA site

(iv) The actions or activities regulated by the requirement and the remedial action contemplated at the CERCLA site

(v) Any variances, waivers, or exemptions of the requirement and their availability for the circumstances at the CERCLA site

(vi) The type of place regulated and the type of place affected by the release or CERCLA action

(vii) 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

(viii) 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.

In addition, potential ARARs were evaluated to determine if they fall into one of three categories: chemical-specific, location-specific, or action-specific. These categories are defined as follows.

- Chemical-specific requirements are usually health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, result in the establishment of public and worker safety levels and site cleanup levels.
- Location-specific requirements are restrictions placed on the concentration of dangerous 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 remedial actions performed at the site.

Further details on potential ARARs for these categories are contained in Section 3.4.1 and in Appendix B.

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, based on best professional judgment, sufficiently similar to the problems or situations regulated by the requirement; and (2) the requirement's use is well suited to the site. Only the substantive requirements (e.g., use of control/containment equipment or compliance with numerical standards) associated with ARARs apply to CERCLA onsite activities. The ARARs associated with administrative requirements (e.g., permitting) are not applicable to CERCLA onsite activities (CERCLA, Section 121[e][1]). In general, this CERCLA permitting exemption will be extended to all remedial and corrective action activities conducted at the 200-ZP-1 Groundwater OU.

The to-be-considered (TBC) information is nonpromulgated advisories or guidance issued by Federal or state government that is not legally binding and does not have the status of potential ARARs. In some circumstances, TBCs will be considered along with ARARs in determining the remedial action necessary for protection of human health and the environment. The TBCs complement the ARARs in determining protectiveness at a site or implementation of certain actions. For example, because soil cleanup standards do not exist for all contaminants, health advisories, which would be TBCs, may be helpful in defining appropriate remedial action goals.

3.4.1 Potential Applicable or Relevant and Appropriate Requirements Applicable to Remedial Actions for Groundwater in the 200-ZP-1 Groundwater Operable Unit

Potential Federal and state ARARs are presented in Tables B-1 and B-2 of Appendix B, respectively. The chemical-specific ARARs likely to be most relevant to remediation of the 200-ZP-1 OU are elements of the Federal regulations that implement drinking water standards (40 CFR 141).

Action-specific ARARs that could be pertinent to remediation are state solid and dangerous waste regulations (for management of characterization and remediation of wastes). Washington State air emission standards are likely to be important in identifying air emission limits and control requirements for any remedial actions that produce air emissions.

Regarding waste management activities during remediation, a variety of waste streams may be generated under the proposed remedial action alternatives. It is anticipated that most of the waste will be designated as low-level waste. However, quantities of dangerous or mixed waste also could be generated

The identification, storage, treatment, and disposal of hazardous waste and the hazardous component of mixed waste generated during the remedial action would be subject to the substantive provisions of RCRA. In the state of Washington, RCRA is implemented through WAC 173-303, which is an EPA-authorized state RCRA 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 this remedial action. Treatment standards for dangerous or mixed waste that is subject to RCRA land-disposal restrictions are specified in WAC 173-303-140, "Land Disposal Restrictions," which incorporates 40 CFR 268, "Land Disposal Restrictions," by reference.

Waste (e.g., investigation-derived wastes) designated as 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, "Licensing Requirements for Land Disposal of Radioactive Waste." In addition, waste designated as dangerous or mixed waste would be treated as appropriate to meet land-disposal restrictions and ERDF acceptance criteria, and would be disposed at ERDF. The ERDF is engineered to meet minimum technical requirements for landfills under WAC 173-303-665, "Landfills." Applicable packaging and pre-transportation requirements for dangerous or mixed waste generated at the 200-ZP-1 Groundwater OU would be identified and implemented before any waste was moved. Alternate disposal locations may be considered when the remedial action 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 human health and the environment.

Waste designated as transuranic waste will be stored at the Central Waste Complex, with eventual disposal at a geologic repository (e.g., Waste Isolation Pilot Plant).

CERCLA states that where two or more noncontiguous facilities are reasonably related on the basis of geography, or on the basis of the 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-ZP-1 Groundwater OU, ERDF, and the 200 Area ETF would be considered to be onsite for purposes of Section 104 of CERCLA, and waste may be transferred between the facilities without requiring a permit. Liquid effluent discharged to the ground after treatment in any remedial alternative must comply with the requirements of WAC 173-216. In the event that the treated effluent is reinjected to the aquifer, it may be necessary to comply with WAC 173-218, "Underground Injection Control."

All alternative actions will be performed in compliance with the waste management ARARs. 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 exposure to personnel.

The proposed remedial action alternatives have the potential to generate airborne emissions of both radioactive and criteria/toxic pollutants.

The *Revised Code of Washington* (RCW) 70.94, "Washington Clean Air Act," requires regulation of radioactive air pollutants. The state implementing regulation WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides," sets standards that are as stringent, or more so, than the Federal standards under the Federal *Clean Air Act of 1990* and under the Federal implementing regulation (40 CFR 61, Subpart H ["National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities"]). The Washington State standards protect the public by conservatively establishing exposure standards applicable to the maximally exposed public individual, be that individual real or hypothetical. To that end, 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. Radionuclide airborne emissions from the facility are not to exceed amounts that would cause an exposure to any said member of the public of greater than 10 mrem/yr effective dose equivalent. The Washington State implementing regulation, WAC 246-247, "Radiation Protection – Air Emissions" (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 remedial action.

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 remedial action.

The above-stated implementing regulations further address control of radioactive airborne emissions where economically and technologically feasible (WAC 246-247-040[3] and -040[4], "Radiation Protection - Air Emissions," "General Standards," 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 (i.e., 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.

3.4.2 Waivers from Applicable or Relevant and Appropriate Requirements

The EPA may waive ARARs and select a remedial action that does not attain the same level of site cleanup as that identified by the ARARs. Section 121 of the *Superfund Amendments and Reauthorization Act of 1986* identifies six circumstances in which the EPA may waive ARARs for onsite remedial actions:

1. The remedial action selected is only a part of a total remedial action (e.g., an interim action), and the final remedy will attain the ARAR upon its completion.
2. Compliance with the ARAR will result in a greater risk to human health and the environment than alternative options.
3. Compliance with the ARAR is technically impracticable from an engineering perspective.
4. An alternative remedial action will attain an equivalent standard of performance through the use of another method or approach.

5. The ARAR is a state requirement that the state has not consistently applied (or demonstrated the intent to apply consistently) in similar circumstances.
6. In the case of Section 104 (Superfund-financed remedial actions), compliance with the ARAR will not provide a balance between protecting human health and the environment and the availability of Superfund money for response at other facilities.

Because the groundwater encompassed by the 200-ZP-1 Groundwater OU will be remediated under a CERCLA decision document, any remedial and corrective actions are required to meet ARARs. Appendix B identifies and evaluates potential ARARs for this groundwater remedial action. Final ARARs for remediation will be established in the ROD. In many cases, the ARARs form the basis for the PRGs to which contaminants must be remediated to protect human health and the environment. In other cases, the ARARs define or constrain how specific remedial measures can be implemented.

Since the Federal MCLs identified in Appendix B are considered as ARARs, the alternatives presented in Section 5.0 will be developed to achieve ARARs for the constituents listed in Section 3.3 and to return the groundwater in at the 200-ZP-1 OU to beneficial use. In some cases, the final restoration of groundwater to MCL-based cleanup levels may not be achieved using currently available, or new and innovative, methods and technologies.

After remedy implementation (i.e., post-ROD), if performance-monitoring data indicates that attainment of ARARs is technically impracticable from an engineering perspective, then an evaluation will be conducted to assess whether a technical impracticability waiver is required from the chemical-specific ARARs discussed in Section 3.3. Technical impracticability waivers apply only to that portion of the contaminated groundwater for which restoration to ARARs is determined to be technically impracticable. An example case for reconsidering remedial objectives would be an instance where the operating remedy has reduced contaminant levels, but contaminant recovery has dropped to the point where the remedy is no longer effective (*Technical Impracticability Decisions for Ground Water at CERCLA Response Action and RCRA Corrective Action Sites* [DOE/EH-413/9814]). The technical impracticability evaluation would include the following information:

- The specific ARARs for which the technical impracticability decision is being sought; generally these should include only ARAR- or risk-based thresholds that are used to establish cleanup standards or levels.
- A delineation on site maps and geologic cross-sections of the horizontal and vertical extent of the area that is fixed in space for which the technical impracticability determination is sought, including both area and depth in absolute or relative terms.
- A revised CSM presenting the following information: site description and history; geologic and hydrogeologic factors; contaminant sources and releases; and contaminant distribution, transport, and fate parameters. This information should be based on and supported by interpretive graphics, reduced and analyzed data, subsurface investigation logs, and other pertinent characterization information. It should provide sufficient detail to define key site conditions and mechanisms that limit restoration potential; it should not consist of mathematical or computer models.
- Demonstration that source control measures have been or will be implemented to the extent practicable. This will include an analysis of the suitability and performance of any ongoing or completed ground water remedial actions (including any enhancements),

a predictive restoration time analysis that identifies assumptions and uncertainties, and a demonstration that no other conventional or innovative technologies can attain the cleanup levels within a reasonable timeframe.

- Estimations of present worth of construction, operation, and maintenance costs, as well as costs for the continued operation of existing remedies or alternative remedial strategies. In cases where a technical impracticability waiver would update an existing ROD, estimates should identify potential cost savings of the update (gross cost savings for large sites with potentially large cost savings) or the proportion of total remedy cost, which EPA uses when establishing priorities for ROD reviews. Finally, it may be desirable to illustrate DOE cost savings relative to a remedy implementation timeline (i.e., the cost savings for technical impracticability decisions made at the design phase will be much greater than for technical impracticability decisions that occur during or following construction).

3.5 200-ZP-1 OPERABLE UNIT REMEDIAL ACTION OBJECTIVES

The RAOs are descriptions of what the remedial action is expected to accomplish (i.e., medium-specific or site-specific goals for protecting human health and the environment). They are defined as specifically as possible and address the following variables:

- Media of interest (e.g., contaminated soil or groundwater)
- Types of contaminants (e.g., radionuclides or inorganic and organic chemicals)
- Potential receptors (e.g., humans, animals, or plants)
- Possible exposure pathways (e.g., external radiation or ingestion)
- Levels of residual contaminants that may remain following remediation (i.e., contaminant levels below cleanup standards or below a range of levels for different exposure routes).

The RAOs provide a basis for evaluating the capability of a specific remediation alternative to achieve compliance with potential ARARs and/or an intended level of risk protection for human health or the environment. The RAOs specific to the 200 Areas for soils, solid wastes, and groundwater were developed in the Implementation Plan (DOE/RL-98-28). Specific RAOs for this FS were defined based on the fate and transport of contaminants, projected land uses for the 200 Areas, and the 200-ZP-1 OU conceptual exposure model. The RAOs for this FS are further discussed in the following subsections.

3.5.1 Remedial Action Objective #1

- Prevent or mitigate risk to human and ecological receptors associated with ingestion of, and external exposure to contaminants (carbon tetrachloride, technetium-99, total chromium, hexavalent chromium, nitrate, TCE, iodine-129, and tritium) in groundwater at levels that exceed ARARs or an excess carcinogenic risk of 1×10^{-4} using an industrial exposure scenario, or an HI of 1. This RAO is meant to return the groundwater to meet drinking water standards (MCLs).

To show that this RAO has been achieved, it will be necessary to show that the MCL published in "National Primary Drinking Water Regulations" (40 CFR 141) for carbon tetrachloride and the other constituents originally exceeding MCLs have been met; or that the pathways for exposure to COCs or constituents above the MCLs are mitigated.

3.5.2 Remedial Action Objective #2

- Prevent or mitigate the migration of contaminants (carbon tetrachloride, technetium-99, total chromium, hexavalent chromium, nitrate, TCE, iodine-129, and tritium) in groundwater so the contaminants do not reach levels in groundwater that exceed ARARs and excess carcinogenic risk of 1×10^{-4} using an industrial exposure scenario, or an HI of 1.

Achievement of RAO #2 will be shown when the applicable MCL for carbon tetrachloride and the constituents exceeding MCLs have been met at the industrial land-use boundary by the year 2150. The proposed remedy will select the appropriate locations within the OU and at the industrial land-use boundary where monitoring wells will be installed to assess whether ARARs (i.e., MCLs) and an excess carcinogenic risk of 1×10^{-4}, or an HI of 1, are being met using an industrial exposure scenario. Final performance monitoring locations shall be established during the remedial design.

3.5.3 Remedial Action Objective #3

- Prevent the migration of high-concentration areas of contaminants (carbon tetrachloride, technetium-99, total chromium, hexavalent chromium, nitrate, TCE, iodine-129, and tritium) in the 200-ZP-1 OU and reduce the contaminant mass available for migration.

Achievement of this RAO requires identification of the boundaries defining the high-concentration areas contaminated by principal threat COCs, and that these areas are contained (either through natural processes or hydraulic controls). Furthermore, the selected remedy must specifically reduce the mass of COC available for migration. The portion of the aquifer exceeding 100 µg/L defines the high-concentration area of carbon tetrachloride; this number represents approximately 95% of the carbon tetrachloride mass in the 200-ZP-1 OU. This level was established because contaminant mass is a critical factor in developing remedies designed to treat and contain carbon tetrachloride.

3.5.4 Remedial Action Objective #4

- Prevent or mitigate occupational health risks to workers performing remedial action.

This RAO will be achieved by meeting RAOs #1 and #2, by implementing existing Hanford Site standards for protection of industrial workers, and by continuing to implement existing institutional controls and monitoring requirements.

3.5.5 Remedial Action Objective #5

- Provide the appropriate monitoring and institutional controls to ensure conditions suitable for future land uses.

Implementing the appropriate institutional controls and monitoring requirements that are identified in the ROD and the operations and maintenance plan will achieve this RAO. The institutional controls will also be located in the *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions* (DOE/RL-2001-41).

3.6 PRELIMINARY REMEDIATION GOALS

The PRGs (i.e., cleanup levels) are numeric representations of the RAOs. Using the anticipated future land use, the conceptual exposure model, and the RAOs as a basis, PRGs are identified for

applicable contaminants and exposure pathways. The PRGs are used to define unacceptable risk posed by specific contaminants, to provide target cleanup goals for use during remedial design, and to provide guidance during remediation. The PRGs are based on acceptable levels of human health and ecological risk, ARARs, TBC guidance, and remediation timeframes. The remediation goals will be used to assess the effectiveness of the selected remedial alternatives in meeting the RAOs. Final remedial action goals are developed from the PRGs and are specified in a ROD that identifies the selected remedial alternative for the 200-ZP-1 OU.

Typically, PRGs are identified for individual hazardous substances identified as COCs. If multiple contaminants are present at a site, the suitability of using individual PRGs as final cleanup values protective of human health and the environment is evaluated based on site-specific information and the potential for contaminant interaction. Meeting these PRGs, the potential ARARs (and by extension, achieving RAOs) can be accomplished by reducing concentrations (or activities) of contaminants to remediation goal levels or by eliminating potential exposure pathways/routes.

Contaminant-specific PRGs for groundwater are presented numerically as concentrations (mg/L or μg/L) or radioactivity (pCi/L). The PRGs for groundwater COCs are developed from the more stringent of potential ARARs (e.g., MCLs [as defined in 40 CFR 141]) and published risk-based standards. Contaminants in the groundwater for the 200-ZP-1 OU are currently above MCLs; however, concentrations of contaminants migrating from the 200-ZP-1 OU near the groundwater/river interface do not present unacceptable risk to human health or the environment (DOE/RL-2006-24). Thus, PRGs are considered protective of human health and protective of potential ecological receptors at the groundwater/river interface. Federal MCLs and the risk-based cleanup level for each constituent are presented in Table 3-10. The value selected for the PRG is also presented.

Figure 3-1. Future Land Use for Industrial Use Zone.

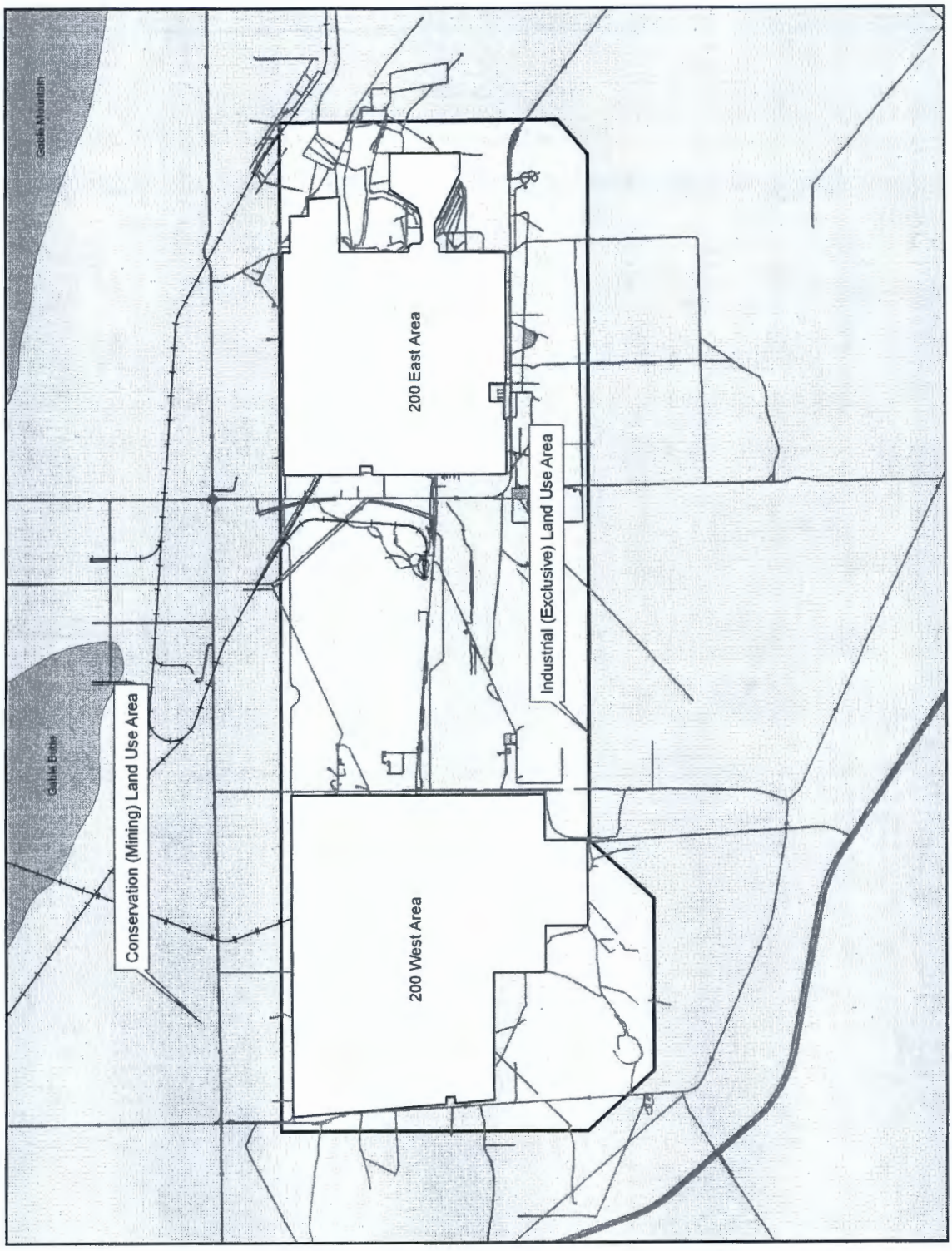


Figure 3-2. Present Human Health Conceptual Site Model Depicting the Populations and Exposure Pathways Evaluated in the Risk Assessment Under a Current Industrial Land-Use Scenario.

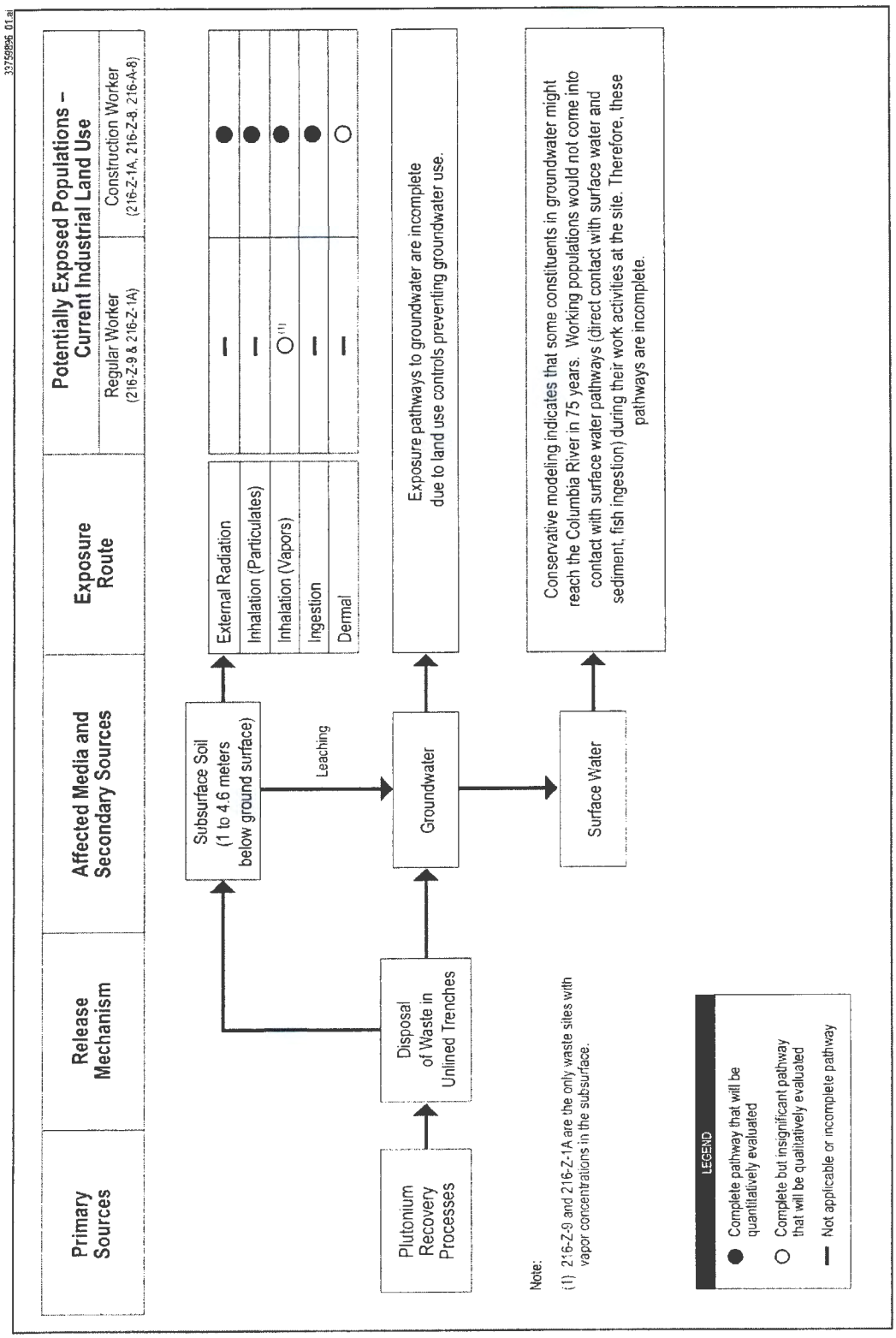


Figure 3-3. Present Human Health Conceptual Site Model depicting the Populations and Exposure Pathways Evaluated in the Risk Assessment Under a Current Industrial Land-Use Scenario.

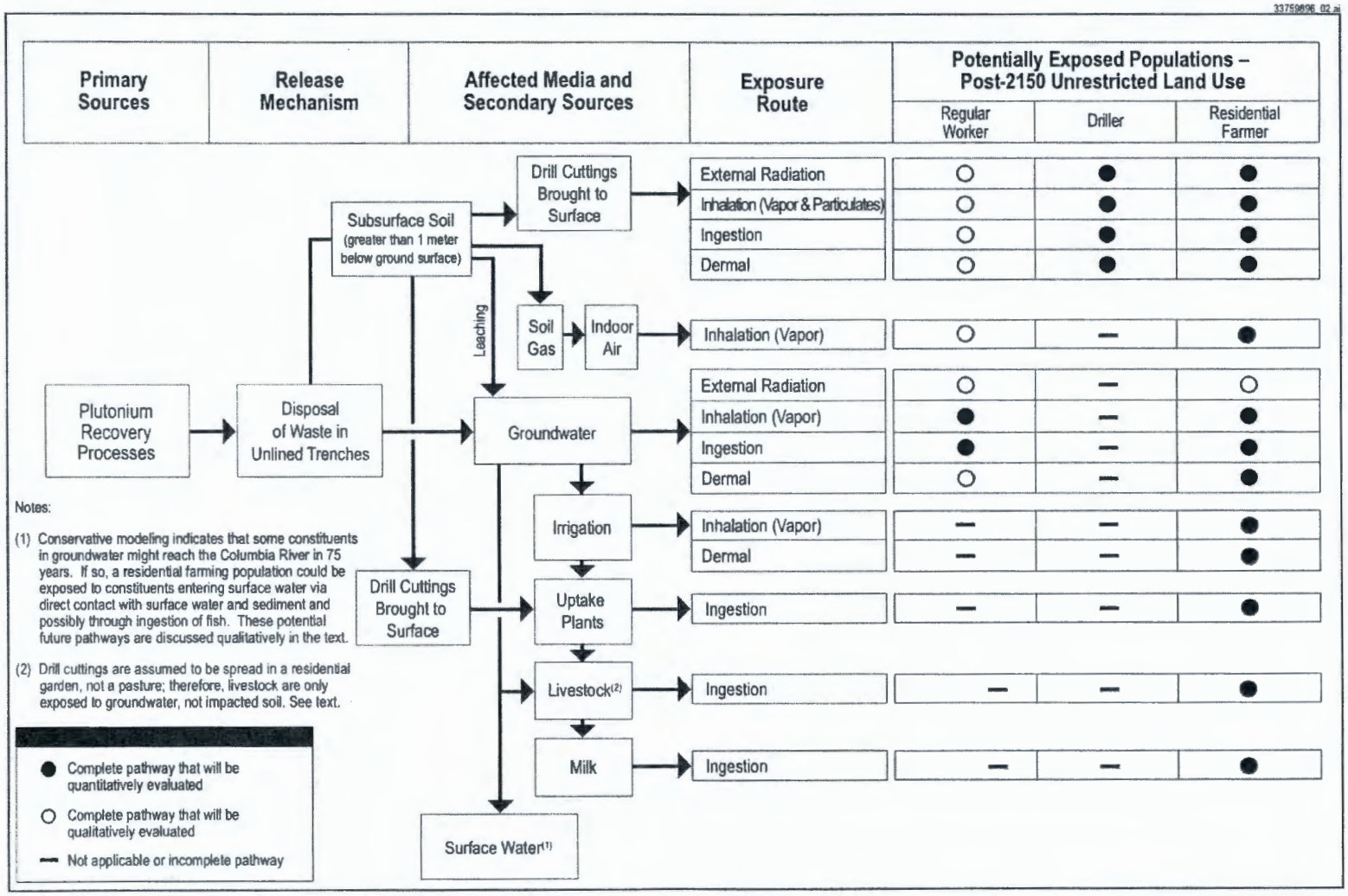


Figure 3-4. Cancer Risks from Tritium in Groundwater Over Time.

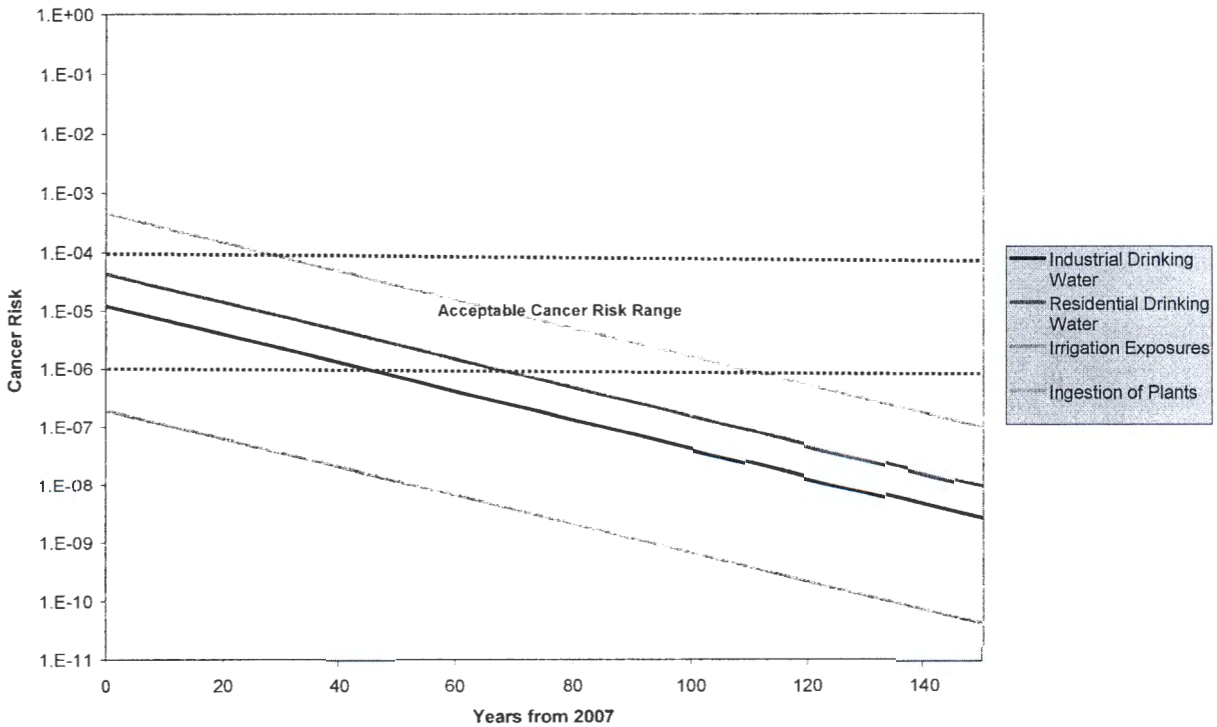


Table 3-1. Summary of Exposure Point Concentrations for Groundwater, 200-ZP-1 Operable Unit.

COPC	Percentiles			Units
	25th	50th	90th	
Carbon tetrachloride	6.53	505.00	2900.00	µg/L
Chloroform	0.58	6.40	24.00	µg/L
Total chromium	3.6	10.3	130	µg/L
Chromium (VI)	7.00	10.90	203.40	µg/L
Methylene chloride	0.12	0.185	2.734	µg/L
Nitrate as nitrogen	14000	21900	81050	µg/L
Tetrachloroethylene (PCE)	0.18	0.36	2.5	µg/L
Trichloroethylene (TCE)	0.155	1.7	10.9	µg/L
Uranium	0.74	1.17	5.06	µg/L
Iodine-129	<0.025	0.030	1.170	pCi/L
Tecnetium-99	54.1	173	1436	pCi/L
Tritium	513.75	3605	36200	pCi/L

NOTE: The "less than" symbol (<) indicates a nondetected value.
COPC = contaminant of potential concern

Table 3-2. Summary of Hazards and Risks from Groundwater, Post-2150 Unrestricted Land Use.

Exposure Pathway	Receptor Population	Receptor Age	Contaminant Group	High	Medium	Low
Total Non-Cancer Hazards						
Tap water	Industrial worker	Adult	Nonradionuclides	42	7	0.2
	Residential farmer	Child/adult	Nonradionuclides	316	55	1
Irrigation	Residential farmer	Adult	Nonradionuclides	2	0.28	0.006
Meat (beef)	Residential farmer	Child/adult	Nonradionuclides	0.34	0.02	0.01
Ingestion of produce	Residential farmer	Child/adult	Nonradionuclides	362	63	1
Milk (dairy)	Residential farmer	Child/adult	Nonradionuclides	0.09	0.02	0.0006
Total Cancer Risks						
Tap water	Industrial worker	Adult	Radionuclides	4E-05	4E-06	1E-06
			Nonradionuclides	3E-03	5E-04	7E-06
	Residential farmer	Child/adult	Radionuclides	1E-04	1E-05	4E-06
			Nonradionuclides	2E-02	3E-03	5E-05
Irrigation	Residential farmer	Adult	Radionuclides	2E-07	2E-08	3E-09
			Nonradionuclides	8E-05	1E-05	2E-07
Meat (beef)	Residential farmer	Child/adult	Radionuclides	3E-05	3E-06	8E-07
			Nonradionuclides	2E-06	3E-07	5E-09
Ingestion of produce	Residential farmer	Child/adult	Radionuclides	3E-03	4E-04	1E-04
			Nonradionuclides	1E-02	2E-03	3E-05
Ingestion of dairy products	Residential farmer	Child/adult	Radionuclides	2E-04	2E-05	6E-06
			Nonradionuclides	4E-06	6E-07	1E-08

NOTE: "High," "medium," and "low" columns are the hazards and risks from exposure to concentrations of the contaminants of potential concern at the 90th percentile, 50th percentile, and 25th percentile, respectively, for all of the 200-ZP-1 Operable Unit groundwater data from 2000 through 2005.

Yellow highlighting indicates that target health goals have been exceeded, based on a hazard index >1 and cancer risks ≤1E-4.

Table 3-3. Summary of Cancer Risks (Radionuclide and Nonradionuclide)[a].

COPCs	Tap Water		
	90th	50th	25th
Radionuclide COPCs			
Iodine-129	1E-06	3E-08	[b]
Technetium-99	2E-05	3E-06	9E-07
Tritium	1E-05	1E-06	2E-07
Totals[c]	**4E-05**	**4E-06**	**1E-06**
Nonradionuclide COPCs			
Carbon tetrachloride	3E-03	5E-04	6E-06
Chloroform	2E-05	4E-06	4E-07
Methylene chloride	1E-07	7E-09	5E-09
Tetrachloroethylene (PCE)	5E-06	7E-07	4E-07
Trichloroethylene (TCE)	6E-07	9E-08	9E-09
Totals[c]	**3E-03**	**5E-04**	**7E-06**

NOTE: Yellow highlighting indicates that target health goals have been exceeded, based on cancer risks ≤1E-4.

[a] Based on the 90th, 50th, and 25th percentile groundwater concentrations post-2150 unrestricted land use (future regular worker).

[b] Iodine-129 was not detected in the 25th percentile of the groundwater concentrations.

[c] Totals are calculated using unrounded values.

COPC = contaminant of potential concern

Table 3-4. Summary of Non-Cancer Hazards (Nonradionuclides Only).[a]

COPCs	Tap Water		
	90th	50th	25th
Carbon tetrachloride	41	7	0.1
Chloroform	0.07	0.02	0.002
Chromium (III)	0.0008	0.00007	0.00002
Chromium (VI) (groundwater)	0.7	0.04	0.02
Methylene chloride	0.0005	0.00004	0.00002
Nitrate	0.5	0.1	0.09
Tetrachloroethylene (PCE)	0.003	0.0004	0.0002
Trichloroethylene (TCE)	0.4	0.06	0.005
Uranium	0.02	0.004	0.002
Totals[b]	**42**	**7**	**0.2**

NOTE: Yellow highlighting indicates that target health goals have been exceeded, based on a hazard index of >1.

[a] Based on the 90th, 50th, and 25th percentile groundwater concentrations post-2150 unrestricted land use (future regular worker).

[b] Totals are calculated using unrounded values.

COPC = contaminant of potential concern

Table 3-5. Summary of Cancer Risks for Contaminants of Potential Concern (Radionuclide and Nonradionuclide).[a]

COPCs	Tap Water			Irrigation		
	90th	50th	25th	90th	50th	25th
Radionuclide COPCs						
Iodine-129	4E-06	9E-08	[c]	[b]	[b]	[c]
Technetium-99	8E-05	1E-05	3E-06	[b]	[b]	[b]
Tritium	4E-05	4E-06	6E-07	2E-07	2E-08	3E-09
Totals[d]	**1E-04**	**1E-05**	**4E-06**	**2E-07**	**2E-08**	**3E-09**
Nonradionuclide COPCs						
Carbon tetrachloride	2E-02	3E-03	4E-05	7E-05	1E-05	2E-07
Chloroform	1E-04	4E-05	3E-06	2E-07	5E-07	4E-08
Methylene chloride	6E-07	4E-08	3E-08	9E-10	6E-11	4E-11
Tetrachloroethylene (PCE)	3E-05	4E-06	2E-06	5E-07	7E-08	4E-08
Trichloroethylene (TCE)	3E-06	4E-07	4E-08	2E-08	3E-09	2E-10
Totals[d]	**2E-02**	**3E-03**	**5E-05**	**8E-05**	**1E-05**	**2E-07**

NOTE: Yellow highlighting indicates that target health goals have been exceeded based on cancer risks ≤1E-4.

[a] Based on the 90th, 05th, and 25th percentile groundwater concentrations post-2150 unrestricted land use (future residential farmer).

[b] Radionuclide not volatile; as inhalation of volatile is the main source of exposure during irrigation, the pathway is incomplete for these radionuclides.

[c] Iodine-129 was not detected in the 25th percentile of the groundwater concentrations.

[d] Totals are calculated using unrounded values.

COPC = contaminant of potential concern\

Table 3-6. Summary of Non-Cancer Hazards for the Contaminants of Potential Concern (Nonradionuclides Only).[a]

COPCs	Tap Water						Irrigation		
	90th		50th		25th		90th	50th	25th
	Child	Adult	Child	Adult	Child	Adult	Adult	Adult	Adult
Carbon tetrachloride	304	130	53	23	0.7	0.3	2	0.3	0.004
Chloroform	0.8	0.3	0.2	0.09	0.02	0.008	0.0007	0.001	0.0001
Chromium (III)	0.007	0.003	0.0005	0.0002	0.0002	0.00007	0.00009	0.000007	0.000003
Chromium (VI) (groundwater)	5	2	0.3	0.1	0.2	0.1	0.07	0.004	0.003
Methylene chloride	0.004	0.002	0.0003	0.0001	0.0002	0.0001	0.000004	0.0000002	0.0000002
Nitrate	3	1	0.9	0.4	0.6	0.2	[b]	[b]	[b]
Tetrachloro-ethylene (PCE)	0.03	0.01	0.004	0.002	0.002	0.001	0.0002	0.00003	0.00002
Trichloro-ethylene (TCE)	3	1	0.5	0.2	0.04	0.02	0.009	0.002	0.0001
Uranium	0.1	0.05	0.03	0.011	0.02	0.007	0.00005	0.00001	0.000007
Totals[c]	**316**	**135**	**55**	**23**	**1**	**0.6**	**2**	**0.28**	**0.006**

NOTE: Yellow highlighting indicates that target health goals have been exceeded, based on a hazard index of >1.

[a] Based on the 90th, 50th, and 25th percentile groundwater concentrations post-2150 unrestricted land use (future residential farmer).

[b] No toxicity criteria available to quantify exposures by this pathway.

[c] Totals are calculated using unrounded values.

COPC = contaminant of potential concern

Table 3-7. Summary of Cancer Risks for Contaminants of Potential Concern (Radionuclide and Nonradionuclide).[a]

COPCs	Homegrown Produce			Beef			Dairy Products		
	90th	50th	25th	90th	50th	25th	90th	50th	25th
Radionuclide COPCs									
Iodine-129	8E-06	2E-07	[b]	3E-06	7E-08	[b]	1E-05	3E-07	[b]
Technetium-99	3E-03	3E-04	1E-04	2E-05	2E-06	6E-07	1E-04	2E-05	5E-06
Tritium	5E-04	5E-05	7E-06	9E-06	9E-07	1E-07	4E-05	4E-06	5E-07
Totals	**3E-03**	**4E-04**	**1E-04**	**3E-05**	**3E-06**	**8E-07**	**2E-04**	**2E-05**	**6E-06**
Nonradionuclide COPCs									
Carbon tetrachloride	1E-02	2E-03	3E-05	2E-06	3E-07	4E-09	3E-06	6E-07	8E-09
Methylene chloride	3E-06	2E-07	1E-07	7E-12	5E-13	3E-13	1E-11	9E-13	6E-13
Tetrachloroethylene (PCE)	4E-05	6E-06	3E-06	2E-08	3E-09	1E-09	4E-08	6E-09	3E-09
Trichloroethylene (TCE)	6E-06	1E-06	9E-08	3E-10	5E-11	4E-12	6E-10	9E-11	9E-12
Totals	**1E-02**	**2E-03**	**3E-05**	**2E-06**	**3E-07**	**5E-09**	**4E-06**	**6E-07**	**1E-08**

NOTE: Yellow highlighting indicates that target health goals have been exceeded, based on cancer risks ≤1E-4.
[a] Based on the 90th, 50th, and 25th percentile groundwater concentrations post-2150 unrestricted land use (food chain pathways, future residential farmer).
[b] Iodine-129 was not detected in the 25th percentile of the groundwater concentrations.
COPC = contaminant of potential concern

Table 3-8. Summary of Non-Cancer Hazards for Nonradionuclide Contaminants of Potential Concern.[a]

COPC	Homegrown Produce			Beef			Dairy Products		
	90th	50th	25th	90th	50th	25th	90th	50th	25th
Carbon tetrachloride	354	62	0.8	0.05	0.008	0.0001	0.09	0.02	0.0002
Chloroform	0.4	0.09	0.008	0.000006	0.000002	1E-07	0.00001	0.000003	3E-07
Chromium (III)	0.005	0.0004	0.0001	0.0004	0.00003	0.00001	0.000003	2E-07	7E-08
Chromium (VI)	4	0.2	0.1	0.3	0.02	0.01	0.0020	0.0001	0.00007
Methylene chloride	0.01	0.0009	0.0006	4E-08	3E-09	2E-09	7E-08	5E-09	3E-09
Tetrachloro-ethylene (PCE)	0.02	0.003	0.001	0.000009	0.000001	6E-07	0.00002	0.000002	1E-06
Trichloro-ethylene (TCE)	4	0.6	0.05	0.0002	0.00003	3E-06	0.0004	0.00006	5E-06
Uranium	0.1	0.02	0.01	0.0002	0.00006	0.00004	0.002	0.0005	0.0003
Totals	**362**	**63**	**1**	**0.3**	**0.02**	**0.01**	**0.09**	**0.02**	**0.0006**

NOTE: Yellow highlighting indicates that target health goals have been exceeded, based on a hazard index >1.
[a] Based on the 90th, 50th, and 25th percentile groundwater concentrations post-2150 unrestricted land use (food chain pathways, future residential farmer).
COPC = contaminant of potential concern

Table 3-9. Example of Potential Increase in Health Risks for Tribal Exposures Compared to Residential Farmer.

Exposure Pathway	Residential Farmer (Soil at 216-Z-9; 90th Percentile Groundwater)		Tribal Exposures[a] (Intake Rates from Harris and Harper 2004)	
	Intake Rate	Risk	Intake Rate	Risk[c]
Drinking groundwater	2 L/day, 30 years	2E-02	4 L/day, 70 years	8E-02
Soil exposure:				
Incidental ingestion	200 mg/day (child – 6 years); 100 mg/day (adult – 24 years)	2E-02	400 mg/day (child and adult – 70 years)	2E-01
Inhalation	20 m^3/day, 30 years	2E-04	30 m^3/day, 70 years	7E-04
External radiation	30 years	1E-02	70 years	2E-02
Produce ingestion	16% to 49% homegrown[b], 30 years	1E-01	Not stated, up to 100%, 70 years	3E-01
Sweat lodge (inhalation of vapor)	Not evaluated for residential farmer		Estimated	4E-01
Total cancer risks	--	**2E-01**	--	**9E-01**

[a] Intake rates from *Exposure Scenario for CTUIR Traditional Subsistence Lifeways* (Harris and Harper 2004).

[b] Produce (fruits and vegetables) ingestion rates used in the risk assessment calculation are 16% of total per capita consumption rates for high-end consumers (95th percentile) and area 49% of total per capita average consumption rates from the U.S. Environmental Protection Agency's Integrated Risk Information System (IRIS) online database (EPA 2007).

[c] These values should be considered as screening level and may not capture every difference between a residential farmer and a Tribal risk scenario.

Table 3-10. Groundwater Preliminary Remediation Goals for the Year 2150 and Beyond.

Constituent		50th Percentile Concentration	90th Percentile Concentration	MCL	Risk-Based Cleanup Level	Selected PRG
Principal Threat COC						
Carbon tetrachloride (ppb)		505	2,900	5	62	5
Nonradiological Constituents Exceeding MCL at the 90th Percentile Concentration in Groundwater						
Total chromium (ppb)	as Cr III	10.9	203	100	-	100
	as Cr VI	10.3	130		-	
Nitrate as nitrogen (ppb)		21,900	81,050	10,000	-	10,000
Trichloroethylene (TCE) (ppb)		1.7	10.9	5	-	5
Radiological Constituents Exceeding MCL at the 90th Percentile Concentration in Groundwater						
Iodine-129 (pCi/L)		0.03	1.17	1	-	1
Technetium-99 (pCi/L)		173	1,436	900	-	900
Tritium (pCi/L)		3,605	36,200	20,000	-	20,000

MCL = maximum contaminant level
ppb = parts per billion
PRG = preliminary remediation goal

4.0 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

This section identifies, screens, and evaluates technologies and process options that may be applicable for remediation of 200-ZP-1 OU groundwater.

A primary objective of this FS is to identify remedial technologies and process options that may potentially meet 200-ZP-1 OU RAOs for contaminated groundwater and then combine them into a range of remedial alternatives. The potential remedial technologies are evaluated for implementablity, effectiveness, and relative cost in eliminating, reducing, or controlling risks to human health and the environment (i.e., ecological receptors). The criteria for identifying, screening, and evaluating potentially applicable technologies are provided in EPA guidance (EPA/540/G-89/004) and the NCP (40 CFR 300.430[e][1][I]).

CERCLA requires the development and evaluation of a range of responses, including a no action alternative, to ensure that an appropriate remedy is selected. The selected final remedy must comply with ARARs and must protect human health and the environment. The technology-screening process consists of a series of steps that include the following:

1. Identifying general response actions that may meet RAOs, either individually or in combination with other general response actions.
2. Identifying, screening, and evaluating remedial technology types for each general response action.
3. Selecting one or more representative process options for each technology type.

Following the technology screening, the representative process options are assembled into remedial alternatives (Section 5.0) for evaluation in the detailed and comparative analyses of alternatives (Sections 6.0 and 7.0, respectively). During final remedial design, a technology that is screened out in this section may be reconsidered as a remedy component in the event that the technology sufficiently advances remedy performance.

4.1 GENERAL RESPONSE ACTIONS

General response action categories for the 200-ZP-1 OU are assembled based on the nature and extent of contamination (as described in Section 2.0). Based on EPA guidance (EPA/540/G-89/004), general response actions include treatment, containment, removal, disposal, institutional controls, in situ or ex situ treatment, or a combination of these categories. The 200-ZP-1 OU is limited only to groundwater, so the list of general response actions reviewed will be limited to institutional controls, containment, monitoring (natural attenuation), removal and treatment, in-situ treatment, or a combination of these categories. The following subsections discuss each general response action and its applicability to the groundwater contamination associated with the 200-ZP-1 OU.

The DOE order, *Radioactive Waste Management* (DOE O 435.1), stipulates at least 100 years of institutional controls after closure at sites where wastes remain in place. The 200-ZP-1 OU is proposed to remain an industrial use area. Institutional controls are currently in place in accordance with the Tri-Party Agreement. These institutional controls will remain in place until at least the year 2150, or while hazards exist that preclude releasing the area for unrestricted use.

Six general response actions that may potentially satisfy the RAOs identified for groundwater are discussed in the following subsections.

4.1.1 No Action

Formulation of a no action alternative is required by the NCP (40 CFR 300.430[e][6]). The no action alterative serves as a baseline for evaluating other remedial action alternatives and is generally retained throughout the FS process. "No action" implies that no remediation would be implemented to alter the existing site conditions. As defined in EPA CERCLA guidance (EPA/540/G-89/004), no action may include environmental monitoring; however, actions taken to reduce exposure (e.g., fencing or deed restrictions) are not included as a component of the no action alternative.

4.1.2 Institutional Controls

Institutional controls are used in conjunction with the physical remedy to protect human health and the environment. They generally include non-engineered restrictions on activities and access to land, groundwater, surface water, waste sites, waste disposal areas, and other areas or media that contain hazardous substances to minimize the potential for human exposure to the substances (DOE/RL-2001-41). Institutional controls, as defined by EPA Region 10, are as follows: "Institutional controls are generally non-engineering restrictions on activities, access, or exposure to land, groundwater, surface water, waste and waste disposal areas and other areas or media. Some common examples of tools to implement ICs include restrictions on use or access, zoning, governmental permitting, public advisories, or installation master plans. Institutional controls may be temporary or permanent restrictions or requirements."

4.1.3 Monitoring

Monitoring may be used in combination with other technologies to meet RAOs. Monitoring of groundwater could include initial determination of extent of contamination above PRGs, determination of groundwater COC concentrations during remediation, post-remediation characterization to determine compliance with cleanup goals, and long-term monitoring.

4.1.4 Natural Attenuation

According to EPA guidance, *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites* (OSWER Directive 9200.4-17P), natural attenuation refers to the reliance on natural processes to achieve site-specific remedial objectives within a timeframe that is reasonable compared to other more active methods. These processes, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These in situ processes include biological degradation or stabilization, dispersion, dilution, sorption, radioactive decay and volatilization, as well as the chemical stabilization, transformation, or destruction of contaminants.

4.1.5 Pump-and-Treat Actions

Pump-and-treat systems would involve installing additional groundwater extraction wells with submersible pumps to extract affected site groundwater. There are generally two components to pump-and-treat:

- Hydraulic containment: Used to prevent migration of a constituent above a selected concentration to a receptor or potential receptor.

- Aquifer restoration: Used to remove contaminant mass, including nonaqueous liquid, if present, from an aquifer to achieve selected cleanup criteria (discussed in the following subsections). Technologies that actively restore the aquifer by removing contaminants are favored in the evaluation process). (See also Section 4.1.5.2)

A pump-and-treat system can also be designed to meet requirements for the discharged water, and possibly discharged air, depending on the system design. Identified disposal options (i.e., reinjection, infiltration, and discharge to surface water) are discussed further in Section 4.1.5.3

4.1.5.1 Hydraulic Containment by Pump-and-Treat. Groundwater pump-and-treat would involve installing groundwater extraction wells with submersible pumps to extract impacted site groundwater. An appropriate number and spacing of extraction wells would be used to ensure hydraulic containment of groundwater exceeding applicable cleanup levels. Groundwater extraction wells would not necessarily be placed or preferentially pumped in source or high-concentration areas, as long as the selected locations and groundwater extraction rate were adequate to prevent downgradient migration beyond acceptable distances. In pump-and-treat applications where hydraulic containment is the primary objective (i.e., mass removal is secondary), extraction may be targeted in lower concentration areas downgradient from certain contaminant source areas in order to minimize the concentrations of particular contaminants that may be costly to treat or that threaten the ability to meet treatment system discharge limits.

As a remedy, hydraulic containment requires treatment and discharge of extracted groundwater. Potentially applicable ex situ groundwater treatment technologies are identified and screened in Section 4.1.5.2. Potentially applicable discharge options for treated groundwater are identified in Section 4.1.5.3.

4.1.5.2 Ex Situ Treatment. Ex situ treatment of groundwater is used to reduce groundwater contaminant levels more rapidly than plume containment or MNA, and it prevents further plume migration. Ex situ treatment is accomplished through collection, treatment, and discharge of groundwater. An extraction system is used to remove contaminated groundwater from the affected aquifer using extraction wells. Pumping may be continuous or pulsed to remove contaminants after they have been given time to desorb from the aquifer material and equilibrate with groundwater. Aboveground treatment may involve physical and chemical processes (e.g., air stripping, carbon adsorption, IX, and biological treatment), depending on the physical and chemical properties of the contaminants.

4.1.5.3 Discharge. There are four discharge options considered for the use with the pump-and-treat options, which are as follows:

- Reinjection: Treated water is reinjected to the subsurface through wells, galleries, or basins. Discharge may be either upgradient of the contamination, pushing contamination towards an extraction network; downgradient of the contamination, so the migration of uncaptured contaminants is slowed, or a combination of both.
- Retention ponds/infiltration: Treated or untreated water is collected in a pond/basin and allowed to infiltrate back into the soil.
- Reuse: Treated water is reused at an active industrial facility or is used for irrigation or potable water supply.

- Surface water: Under the National Pollution Discharge Elimination System (NPDES), treated water may potentially be discharged directly to a nearby surface water body.

In addition, discharge options for extracted groundwater should be considered in the design of the pump-and-treat system to meet state regulatory standards.

4.1.6 In Situ Treatment

In situ treatment consists of actions that treat contamination in place. In situ treatment of contaminated groundwater generally includes methods to separate and remove contaminants or to degrade contaminants in place. Three process options have been selected for evaluation, which are as follows:

- In situ electrical resistance heating (ERH): In situ ERH process options are ways to desorb and mobilize contaminants in the subsurface by heating and then removing the contaminants by vapor or water extraction.
- Air sparging: This involves injecting air into the aquifer to strip or flush volatile contaminants as the air bubbles up through the groundwater and is captured by a vapor extraction system installed above the water table. Stripped or volatilized contaminants are usually removed through SVE wells, treated if necessary, and discharged directly to the atmosphere.
- In situ anaerobic bioremediation: This process involves injection of electron donor substrates and nutrients to degrade or immobilize contaminants.

4.2 SCREENING AND IDENTIFICATION OF TECHNOLOGIES

This section evaluates the available technologies applicable to groundwater contaminants and screens out those that cannot be technically implemented under site-specific conditions or for principal threat contaminants. The purpose of the screening is to evaluate technologies that can treat groundwater contamination in situ or ex situ. Although some technologies are screened out as a primary groundwater treatment technology, these technologies will be carried forward for consideration in treatment train design for treatment of removed groundwater.

Review of Pre-FS Technology Screening Results

Preliminary identification and screening of potential remediation methods was conducted by PNNL and reported in *Screening of Potential Remediation Methods for the 200-ZP-1 Operable Unit at the Hanford Site* (PNNL-15954). The report documents a screening-level evaluation of potential remediation methods for application to the major risk drivers at the 200-ZP-1 Operable Unit, as identified in the remedial investigation report (DOE-RL 2006). Each remedial method was screened with respect to effectiveness, implementability, and relative cost, in accordance with the technology screening process defined in *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final* (EPA 1988). Contaminants with similar properties, and treatable by the same technology, were addressed as a group in the screening evaluation. Also, because multiple scales of application may be useful for the overall remediation efforts, potential remediation methods are also assessed based upon scale of application. PNNL-15954, which documents the effort, is included as Appendix F.

A review of the potential remediation methods carried forward by PNNL-15954 readily identified a number that, based on current site information, clearly did not warrant more detailed

consideration. The following discussion identifies those technologies and provides technical justification for excluding them from FS-level screening.

- PNNL-15954 identifies a number of technologies as suitable for treating continuing source areas. Because no contaminant source areas have been identified within the 200-ZP-1 OU, these remedial methods are not carried forward.
- PNNL-15954 identifies a number of technologies for in situ treatment of contaminants other than CCl_4. Because only CCl_4 was identifies as a COC (Section 3.3.1), in situ technologies specifically targeting other contaminants are not carried forward.
- PNNL-15954 identified two in situ technologies that target CCl_4, but that have a relatively small radius of influence: in situ anaerobic bioremediation and in situ redox manipulation (See Appendix F for description). These remediation methods are eliminated from further consideration due to the size of the contaminated area. The portion of the aquifer that exceeds 1,000 pCi/L CCl_4 has an areal extent of more than 0.6 km^2, and has a transgradient dimension of more than 1500 m. Anaerobic bioremediation is a potentially effective technology, but it has an anticipated radius of influence of approximately 8 m. It would take more than 3,000 wells to cover a 0.6 km^2 target area and, if implemented as a permeable reaction barrier (PRB – See Appendix ## for description), would require two strings of more than 100 wells each (more than 200 wells total). In situ redox manipulation, which has an anticipated radius of influence of about 7 m, would require an even larger number of wells for effective implementation. Due to the clear impracticability of constructing such a large number of wells, neither in situ anaerobic remediation nor in situ redox manipulation appears to warrant further consideration.
- Two other in situ remediation methods identified for further consideration in PNNL 15954 have somewhat larger radii of influence. In-well air stripping and air sparging (See Appendix F for description) are in situ approaches that specifically target volatile and semivolatile organics (e.g., carbon tetrachloride). Both technologies have the potential for a radius of influence of up to 30 m. Application of either to the portion of the aquifer that exceeds 1,000 pCi/L CCl_4 would still require more than 200 new wells which, again, is neither practical nor reasonably implemented. Applying either of these technologies as a PRB would entail installing two strings of at least 25 wells each (at least 50 wells total), downgradient from the targeted area. Even this reduced number of wells is still impractical. Neither in-well air stripping or air sparging appears to warrant further consideration.

None-the-less, two of these in situ technologies, in situ anaerobic bioremediation and air sparging, were carried forward for additional evaluation to ensure balanced coverage of technologies. An addition in situ technology, electrical resistance heating (ERH), was also incorporated for evaluation.

Technology Screening

A secondary screening of the remaining retained technologies documented in the PNNL study was performed in support of this FS. The screening criteria conducted in this FS are based on the screening process defined in EPA guidance (EPA/540/G-89/004). The effectiveness evaluation is focused on (1) the potential effectiveness of process options in handling the estimated areas or volumes of media and meeting the remediation goals identified in the RAOs,

(2) the potential impacts to human health and the environment during the construction and implementation phase, and (3) how proven and reliable the process is with respect to the contaminants and conditions at the site. Implementability is focused on both the technical and administrative feasibility of implementing a technology. Cost also plays a limited role in the screening of process options. Relative capital and operation and maintenance costs, based on a general conceptual design, are analyzed.

Technology and process options judged to be potentially implementable were retained and are summarized in Table 4-1 through Table 4-5. Site-specific information, including site description and contaminant characterization, was used to eliminate technologies or process options that are not applicable or could not be effectively implemented. The preliminary screening process reduces the number of possible process options for a given remedial technology type to a more manageable set of options that are considered potentially applicable for contaminated groundwater at the 200-ZP-1 OU.

Technologies already implemented for 200-ZP-1 OU include pump-and-treat implemented under the Interim ROD (EPA/ROD/R10-95/114) and institutional controls.

4.2.1 Identification and Preliminary Screening of Remedial Technologies and Process Options

Each of the technology process options is discussed in detail in the following subsections.

4.2.1.1 No Action. Formulation of a no action alternative is required by the NCP (40 CFR 300.430[e][6]). The no action alterative serves as a baseline for evaluating other remedial action alternatives and is generally retained throughout the FS process. No action implies that no remediation will be implemented to alter the existing site conditions. As defined in EPA CERCLA guidance (EPA/540/G-89/004), no action may include environmental monitoring; however, actions taken to reduce exposure (e.g., fencing or deed restrictions) are not included as a component of the no action alternative. This general response action involves no technology and also considers the breakdown of existing institutional controls.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: No action will not assist in meeting RAOs but will aid in the protection of human health. No hazardous byproducts will be produced and no negative effects will result from implementation of no action. No action will not assist in treating targeted volume but will provide protection of human health for the construction worker implementing other remediation alternatives. No remediation would be conducted, thus no construction or operation risks would occur.
- Implementability: No action does not require any construction or operation, nor does it have any consumable usage.
- Cost: No action cost is $0 because there is no groundwater monitoring or engineered remediation implemented.

Screening Results. No action is retained as a baseline for comparison to other remedial action alternatives. See Table 4-1 for a summary of the results.

4.2.1.2 Institutional Controls. At the 200-ZP-1 OU, institutional controls are currently implemented through the Sitewide institutional controls plan (DOE/RL-2001-41). Institutional

controls are appropriate to protect human health and the environment in areas where groundwater contaminant concentrations exceed RAOs and to ensure continued effectiveness of the response action(s). Institutional controls consist of warning notices, entry restrictions, land-use management, groundwater-use management, and waste site information management.

4.2.1.2.1 Administrative Controls.

Hanford Comprehensive and Land-Use Plan. The HCP EIS (DOE/EIS-0222-F) serves as a comprehensive listing of all areas or locations of the Hanford Site that have institutional controls for protection of human health and the environment. The minimum required information includes the location of the area, the objectives if the restrictions, and the tools and procedures that will be applied to implement the restrictions or controls. The information in the HCP EIS is reviewed annually to ensure that it is current, effective, and sufficient for each site. The CERCLA module of the HCP EIS is revised annually as needed. 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 CERCLA sites Hanford. 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 Hanford Site.

Public Notices. Public notice is provided as needed to inform stakeholders of changes in the institutional controls. For land-use changes and property leasing or transfers, the stakeholders and new media are contacted and provided with the appropriate information, in accordance with the *Hanford Federal Facility Agreement and Consent Order Community Relations Plan* (hereinafter referred to as the Community Relations Plan) (EPA et al. 2001).

DOE Directives. The DOE directives include policies, orders, notices, manuals, and guides intended to direct, guide, inform, and instruct employees in the agencies, contractors, and the public. The DOE directives are legally binding on DOE and on all of its contractors by inclusion into their contracts. Future directives and guidance concerning restrictions of groundwater use and access are being considered for the Hanford Site as part of the evaluation of controls to protect human health and the environment. 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 water wells are subjected to regulatory processes, such as under CERCLA remedial investigation and remedial action monitoring, RCRA, or environmental impact analysis under NEPA.

DOE Environmental Checklist. In accordance with the June 1994 *Secretarial Policy on the National Environmental Policy Act* (DOE 1994), DOE relies on the CERCLA activity documents to incorporate NEPA values to the extent practicable and are made available to the public in accordance with the requirements of CERCLA.

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 environmental checklist technical review, an appropriate specialist

evaluates the information. The environmental check list 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 proposed activities, such as drilling new potable water supply wells or modifying such wells or water supply systems. Environmental evaluation requirements apply to activities conducted on behalf of RL at Hanford by the maintenance and operations contractor, subcontractors, lessees, or any government entity (e.g., the U.S. Geological Survey). The environmental checklist evaluation would assess the proposed activity to identify any restrictions on disturbance of environmental media, on well drilling, or on management of waste or subsequent water-use restrictions related to aquifer contamination.

Work Control Process. All work at the Hanford 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 plan identifies a set of requirements that reflects DOE's commitment to a standards-based safety program and the safety concepts reflected by these requirements. ISMS provide the mechanisms for increasing worker involvement in work planning, including hazard and environmental 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 help DOE's operating entities comply with the requirements of 10 CFR 835 and *Radiation Safety Training Guide* (DOE G 441.1-12). 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. *Radiological Control* (DOE-STD-1098-99) supplements DOE G 441.1-1B and serves as a secondary source or guidance for complying with 10 CFR 835.

Waste Site Information Management. The DOE will maintain a tracking mechanism that identifies all waste site land areas that are under restriction or control in accordance with the institutional control requirements of CERCLA decision documents and as described in applicable work plans. The Waste Information Data System (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 (e.g., institution control information) may be made available to entities having jurisdiction.

Information on the location and nature of waste sites is contained in the WIDS database. The WIDS identifies waste management units on the Hanford 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 RL in accordance with the WIDS change control system, which documents and traces additions, deletions and/or other changes dealing with the status of waste management units. The long-term preservation of waste site information is addressed by the *Tri-Party Agreement Handbook, Management Procedures* (RL-TPA-90-001) and it will be a key part of the Long-Term Stewardship Program.

The Administrative Record, which holds documents and information that is considered or relied on to arrive at a final decision for remedial action 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 interim remedial action, remedial design reports, and RODs.

Excavation Permits. Excavation permits under access controls are used by the Hanford 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 Hanford 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 contractor 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* (ESA).
- NEPA documentation requirements must be identified.
- The presence of any underground objects (e.g., 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 initiates the excavation permit process using the Hanford Site excavation permit.
2. Radiological screening of the proposed work 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. The DOE will restrict well drilling and groundwater use in accordance with the institutional control requirements of CERCLA decision documents and as described in applicable work plans. Groundwater use on the Hanford Site is restricted, except for the purposes of monitoring and treatment, as approved by the 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. The Hanford Site Groundwater Performance Assessment Remediation Project produces an annual report 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 reports, fulfills the reporting requirements of DOE orders and the WAC.

The results of the Groundwater Performance Assessment Remediation Project are reviewed and reported annually to identify any trends regarding the condition of the groundwater and the potential implication of those trends to institutional controls (e.g., prohibition of groundwater use). The data from the report are considered in evaluating both the effectiveness of the institutional controls and the need for any changes to the controls.

In the event that 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 institutional controls will remain in place.

Evaluation Criteria. The evaluation criteria are as follows:

Effectiveness: Administrative controls will not assist in meeting RAOs but will aid in the protection of human health. No hazardous byproducts will be produced and no negative impacts will result from implementation of administrative controls. Administrative controls will not assist in treating targeted volume but will provide protection of human health as long as the groundwater is not used as required by the institutional controls. No construction or operation risks would occur during implementation of administrative controls.

Implementability: Neither construction nor operation would result from administrative controls. A reasonable consumable usage can be accomplished with administrative controls.

Cost: Administrative control cost would factor in the implementation of setup, maintenance, enforcement, reporting, and the cost of failure.

Screening Results. Administrative controls are retained for further evaluation. See Table 4-2 for a summary of the results.

4.2.1.2.2 Access Restrictions.

Warning Notices. Warning notices are those institutional controls that restrict personnel access at a specific CERCLA site. Warning notices may include barriers, permanent markers, or

warning signs. Warning signs are the predominant method of access restriction at the Hanford 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 when residual contamination at the site may pose a current or future risk to human health or the environment if excavated or otherwise disturbed. The 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 (i.e., 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 (e.g., organics, inorganic, radionuclides, polychlorinated biphenyls, asbestos, or ordnance) without identifying specific chemicals or radionuclides. The format of the signs is consistent throughout the Hanford Site. Guidance on signage content and placement is provided in the Sitewide institutional controls plan (DOE/RL-2001-41).

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Access restrictions will not assist in meeting RAOs but will aid in the protection of human health. No hazardous byproducts will be produced from implementation of access restrictions. No negative effects will result from implementation of access restrictions. Access restrictions will not assist in treating targeted volume but will provide protection of human health. No construction or operation risks would occur during implementation of administrative controls; some risk might occur when posting signage.
- Implementability: Neither construction nor operation would result from access restrictions. A reasonable consumable usage can be accomplished with access restrictions.
- Cost: Access restriction costs would factor in the implementation of setup, maintenance, enforcement, reporting, and the cost of failure.

Screening Results. Access restrictions are retained for further evaluation. See Table 4-2 for a summary of the results.

4.2.1.3 Monitoring. The *Hanford Site Ground Water Protection Management Plan* (DOE/RL-89-12) describes the approach for monitoring the effectiveness of the Hanford Site groundwater management activities, which includes 200-ZP-1 OU groundwater. The plan ensures that monitoring at active waste disposal facilities complies with requirements of RCRA, AEA, DOE orders, and Washington State regulations, as well as with the requirements for operational monitoring around reactor and chemical-processing facilities and environmental surveillance monitoring. PNNL manages these monitoring efforts to assess the distribution and movement of existing groundwater contamination, to identify and characterize potential and emerging groundwater contamination problems, and to integrate the various groundwater projects to minimize redundancy.

Implementation of the groundwater monitoring requirements outlined in groundwater protection monitoring plan (DOE/RL-89-12) and the *Environmental Monitoring Plan, United States Department of Energy, Richland Operations Office* (DOE/RL-91-50) are described by the *Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project* (PNNL-11989). This plan includes a description of the monitoring well networks, constituents, sampling frequencies, and criteria used to design the monitoring program; identifies Federal and state groundwater monitoring requirements and regulations; and provides a list of wells, constituents, and sampling frequencies for groundwater monitoring conducted on the Hanford Site. Federal and state regulations include RCRA, CERCLA, and the WAC. The monitoring requirements can also be found in the 200-ZP-1 RI/FS work plan (DOE/RL-2003-55).

The 200-ZP-1 OU groundwater monitoring is incorporated and described in the Hanford integrated monitoring plan (PNNL-11989); thus, no new monitoring components are required. Any changes to the monitoring approach would be defined during the final design phase of the selected remedy.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Monitoring will not assist in meeting RAOs but will aid in the protection of human health. No hazardous byproducts will be produced from implementation of monitoring. No negative effects will result from implementation of monitoring. Monitoring will not assist in treating targeted volume but will provide protection of human health. Minimum construction or operational risks would occur during implementation of monitoring. Construction or operational risks would occur from drilling but will be controlled under the existing Occupational Safety and Health Administration (OSHA)-compliant work requirements.
- Implementability: Construction and operation would result from the drilling of monitoring wells. Consumable usage is dependent on operation and maintenance of the wells.
- Cost: Cost factors for monitoring include installation, maintenance, sampling, and replacement of monitoring wells.

Screening Results. Monitoring has been retained for further evaluation. See Table 4-3 for a summary of the results.

4.2.1.4 Monitored Natural Attenuation. The MNA process involves a reduction of contaminant toxicity, volume, concentration, mobility, and/or bioavailability through natural physical, chemical, or biological processes that occur without human intervention. Synonyms include intrinsic remediation, natural recovery, and natural assimilation. MNA is not a "no action" approach, but requires demonstration that attenuation is occurring, an understanding of site-specific and contaminant-specific attenuation mechanisms, and performance monitoring. MNA is appropriate for sites with a low potential for contaminant migration (i.e., stable plumes) and where natural attenuation processes will achieve RAOs in a reasonable period compared to treatment that is more active. MNA is rarely appropriate as a sole remedy without other active remedial measures (e.g., source control) and/or institutional controls (OSWER Directive 9200.4-17P).

MNA was determined to be feasible as a remedy at over 75% of the sites where the application of MNA was evaluated (36% sole remedy, 46% with other treatment) (WSRC-TR-2003-00328). Importantly, MNA was determined to be infeasible at about 23% of the sites.

At sites where MNA is used with an active treatment, the active treatment is still in operation at approximately 72% of those sites. The 1998 US EPA protocol (US EPA, 1998 and 1999) was most often referenced as the guideline for MNA implementation (36%). Notably, almost 29% used a site specific protocol. Other protocols used as the basis for the reported sites included: 12% state protocol, 19% other, and 5% National Research Council (NRC) MNA review (NRC, 2001).

Natural attenuation includes biological, chemical, and physical processes. Biological processes include biological degradation, transformation, and stabilization. Chemical processes include abiotic degradation, transformation, and stabilization. Physical processes include dispersion, dilution, sorption, volatilization, and radioactive decay. Although some processes apply to all contaminants and site conditions (e.g., dispersion and dilution), most have limited application to specific contaminants and site conditions. Processes that destroy or degrade contaminants are preferred (OSWER Directive 9200.4-17P).

Factors that may limit applicability and effectiveness include the following:

- Data used as input parameters for modeling
- Intermediate degradation products may be more mobile and more toxic than the original contaminant
- Natural attenuation is not appropriate where imminent site risks are present
- Contaminants may migrate before they are degraded
- Institutional controls may be required, and the site may not be available for reuse until contaminant levels are reduced
- If free product exists, it may have to be removed
- Some inorganics can be immobilized (e.g., mercury), but they will not be degraded
- Long-term monitoring and associated costs
- Longer timeframes may be required to achieve remediation objectives compared to active remediation
- The hydrologic and geochemical conditions amenable to natural attenuation are likely to change over time and could result in renewed mobility of previously stabilized contaminants and may adversely impact remedial effectiveness
- More extensive outreach efforts may be required in order to gain public acceptance of natural attenuation.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: MNA has the potential to significantly decrease contaminant concentration, as well as decrease concentrations over time as a result of sorption, dispersion, and dilution. MNA has been utilized at numerous other sites nationwide and proven to an effective remedial measure when properly applied (WSRC-TR-2003-00328). No hazardous byproducts will be produced from implementation of MNA. Other than carbon tetrachloride (which has the potential to produce hazardous byproducts, chloroform and methylene chloride, as the result of biodegradation in an anaerobic environment), no other COC is expected to produce a hazardous byproduct (PNNL-15954). No negative effects will result from implementation of MNA

(PNNL-15954). MNA will assist in treating toxicity but is independent of volume. No construction or operation risks would occur during implementation of MNA.

- Implementability: Neither construction nor operation would be problematic for MNA. The need for long-term monitoring and the potential need for a contingency remedy if natural attenuation does not limit contaminant migration, are operational risks. Consumable usage is dependent on area of treatment.
- Cost: Cost factors for MNA include initial MNA evaluation, installation, and maintenance of monitoring wells, and long-term monitoring.

Screening Results. Monitoring and MNA have been retained for further evaluation. See Table 4-3 for a summary of the results.

4.2.1.5 Pump-and-Treat Actions. Pump-and-treat systems consist of a groundwater withdrawal system (also called the "containment system") and an aboveground treatment system. Extraction wells designed to remove the contaminants from the groundwater system and to control the plume from further migration. In some cases, injection wells are used to inject treated water back into the aquifer. Aboveground treatment systems include chemical, physical, and biological treatment technologies. Subsequent sections (4.2.1.5.1 through 4.2.1.5.3) discuss these components of the pump and treat system.

The following factors may limit the applicability and effectiveness of groundwater pumping as part of the remedial process:

- The potentially long time necessary to achieve the remediation goal.
- System designs may fail to contain the contaminant as predicted, allowing the contaminant plume to migrate.
- Residual saturation of the contaminant in the soil pores cannot be removed by groundwater pumping. Contaminants may tend to be sorbed in the soil matrix. Groundwater pumping is not applicable to contaminants with high residual saturation, contaminants with high sorption capabilities, and homogeneous aquifers with hydraulic conductivity less than 10^{-5} cm/sec.
- The cost of permitting, procuring, and operating treatment systems is high. Additional costs may also be attributed to the disposal of spent carbon and other treatment residuals and wastes.
- Bio-fouling of the extraction wells and associated treatment stream is a common problem that can severely affect system performance. The potential for this problem should be evaluated prior to the installation.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Pump-and-treat is reliable to significantly decrease contaminant concentration. No hazardous byproducts will be produced from implementation of pump-and-treat technologies; however, depending on the treatment train selected a secondary waste stream may be generated and will need to be disposed of properly. No negative effects will result from implementation of pump-and-treat. Pump-and-treat will assist in treating toxicity and volume. Construction or operational risks would occur from drilling but will be controlled under the existing OSHA-compliant work requirements.

- Implementability: Pump-and-treat technologies provide highly flexibility design and can be readily installed. The need for long-term monitoring and continued maintenance would follow post installation. Consumable usage for pump-and-treat technologies is dependent upon operational efficiency and the ex situ treatment technologies selected.
- Cost: The cost of a pump-and-treat system depends upon well installation (considering site geology, aquifer thickness, extent and type of contamination) and the number of wells. Piping distances and construction and operation of the treatment facility (i.e., the periods and durations of pumping, and the electrical power requirements, and secondary waste disposal/treatment). Additional, costs would include performance and downgradient groundwater monitoring.

Screening Results. Pump-and-treat has been retained for further evaluation. See Table 4-4 for a summary of the screening results.

4.2.1.5.1 Hydraulic Containment by Pump-and-Treat. Hydraulic containment using pump-and-treat systems interrupts the exposure pathways to contaminated groundwater and prevents or reduces transport of contaminants into the surrounding environment. While containment reduces the mobility of the contaminant, it does not reduce the toxicity or volume. Containment technologies include physical treatment barriers (which have been rejected [PNNL-15954]) and groundwater withdrawal or containment systems (i.e., pump-and-treat systems) that use extraction and/or injection wells to alter the natural gradient of groundwater flow.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Hydraulic containment using pump-and-treat is reliable to significantly decrease contaminant concentration. No hazardous byproducts will be produced; however, depending on the treatment technologies selected, a secondary waste stream may be generated and will need to be disposed of properly. No negative effects will result. Hydraulic containment itself does not reduce toxicity or volume of contamination; however, the pump-and-treat technology associated with the hydraulic containment will provide treatment for toxicity and volume. Construction or operational risks would occur from drilling but will be controlled under the existing OSHA-compliant work requirements.
- Implementability: Pump-and-treat technologies provide high design flexibility and can be readily installed. The need for long-term monitoring and continued maintenance would follow post installation. Consumable usage for pump-and-treat technologies is dependent upon operational efficiency and ex situ treatment selected.
- Cost: The cost of a pump-and-treat system is dependent upon site geology, aquifer thickness, extent and type of contamination, periods and durations of pumping, and electrical power requirements. Additional wells other than the wells used for the pump-and-treat system would be needed to maintain control of contaminated groundwater. Other costs include performance and downgradient groundwater monitoring.

Screening Results. As a stand-alone technology, hydraulic containment by pump-and-treat has not been retained for further evaluation because it does not actively reduce the volume, mass, or toxicity of contaminants in the aquifer. However, it is an opportunistic technology to be incorporated in other potential pump-and-treat remedies.

4.2.1.5.2 Ex Situ Physical/Chemical Treatment Technologies. Physical/chemical treatment uses the physical properties of the contaminants or the contaminated medium to destroy (i.e., chemically convert), separate, or contain the contamination.

Ex situ treatment generally requires shorter periods of time to obtain remediation versus in situ and provides certainty about the uniformity of treatment attributable to the ability to monitor and continuously mix the groundwater. Ex situ treatment, however, requires pumping of groundwater, as described in the section above.

Physical/chemical treatment is typically cost effective and can be completed in short periods (in comparison with biological treatment). Equipment is readily available and is not engineering or energy-intensive. Treatment residuals from separation techniques will require treatment or disposal, which will add to the total project costs and may require permits. The treatment technologies evaluated in this FS are as follows: air stripping, IX, granular activated carbon (GAC), zero-valent iron, and reverse osmosis.

Air Stripping. Air stripping is a full-scale technology in which VOCs are partitioned from groundwater by greatly increasing the surface area of the contaminated water exposed to air. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

Air stripping involves the mass transfer of volatile contaminants from water to air. For groundwater remediation, this process is typically conducted in a packed tower or an aeration tank. The typical packed tower air stripper includes a spray nozzle at the top of the tower to distribute contaminated water over the packing in the column, a fan to force air countercurrent to the water flow, and a sump at the bottom of the tower to collect decontaminated water. Auxiliary equipment that can be added to the basic air stripper includes an air heater to improve removal efficiencies, automated control systems with sump level switches and safety features (e.g., differential pressure monitors, high sump level switches, and explosion-proof components), and air emission control and treatment systems (e.g., activated carbon units, catalytic oxidizers, or thermal oxidizers). Packed tower air strippers are installed either as permanent installations on concrete pads or on a skid or trailer.

Aeration tanks strip volatile compounds by bubbling air into a tank through which contaminated water flows. A forced air blower and a distribution manifold are designed to ensure air/water contact without the need for any packing materials. The baffles and multiple units ensure adequate residence time for stripping to occur. Aeration tanks are typically sold as continuously operated skid-mounted units. The advantages offered by aeration tanks are considerably lower profiles (less than 2 m [6 ft] high) than packed towers (5 to 12 m [15 to 40 ft] high) where height may be a problem, and the ability to modify performance or adapt to changing feed composition by adding or removing trays or chambers. The discharge air from aeration tanks can be treated using the same technology as for packed tower air discharge treatment.

Modifying the packing configuration may greatly increase removal efficiency. A recent innovation is the so-called "low-profile air stripper" that is offered by several commercial vendors. This unit packs a number of trays in a very small chamber to maximize air/water contact while minimizing space. Because of the significant vertical and horizontal space savings, these units are being used more frequently for groundwater treatment.

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 storage tanks eliminates any inconsistencies in feed water composition.

The eventual duration of cleanup using an air-stripping system may be tens of years and depends upon the capture of the entire plume from the groundwater.

The following factors may limit the applicability and effectiveness of the process:

- The potential exists for inorganic (e.g., iron greater than 5 parts per million [ppm], hardness greater than 800 ppm) or biological fouling of the equipment, requiring pre-treatment or periodic column cleaning.
- Effective only for contaminated water with VOC or semi-volatile concentrations with a dimensionless Henry's Law constant greater than 0.01.
- Consideration should be given to the type and amount of packing used in the tower.
- Process energy costs are high.
- Compounds with low volatility at ambient temperature may require pre-heating of the groundwater.
- Off-gases may require treatment based on mass emission rate.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Air stripping is effective on organic compounds with Henry's Law constants greater than 0.01; however, it is ineffective for inorganic containments. No hazardous byproducts will be produced; however, a secondary waste stream may be generated and will need to be disposed of properly. No negative impacts will result. Removal efficiencies are typical of greater than 98% for VOCs and greater than or equal to 80% for semi-volatile organics are possible (*Environmental Engineers' Handbook* [Liptak 1997]). Construction or operational risks arise from drilling, because contaminated groundwater is extracted to the surface for treatment. However, these risks are minimized by OSHA-compliant work practices.
- Implementability: Air stripping is a proven technology for removal of volatiles from groundwater and a packed tower air stripper is currently being implemented for removal of carbon tetrachloride from extracted groundwater at the 200-ZP-1 OU as part of the IRM.
- Cost: The capital costs of an air stripper include the costs of tower shell or aeration tank, packing, tower internals, air delivery system, electrical equipment and controls, housing, design, contingency equipment and performance sampling and monitoring. Other costs are associated with the treatment technologies utilized for the emissions of the air stripper (i.e., GAC regeneration and disposal).

Screening Results. Air stripping has been retained for further evaluation. See Table 4-4 for a summary of the results.

Granular Activated Carbon. GAC is a full-scale technology in which groundwater is pumped through one or more vessels containing activated carbon to which dissolved organic contaminants, and a limited number of inorganic contaminants, adsorb. When the concentration of contaminants in the effluent from the bed exceeds a certain level, the carbon can be regenerated in place, removed and regenerated at an offsite facility, or removed and disposed.

The two most common reactor configurations for carbon adsorption systems are the fixed bed and the pulsed (or moving) bed. The fixed-bed configuration is the most widely used for adsorption from liquids. Pre-treatment for removal of suspended solids from the influent to be treated is an important design consideration. If not removed, suspended solids in a liquid stream may accumulate in the column, causing an increase in pressure drop. When the pressure drop becomes too high, the accumulated solids must be removed, for example, by backwashing. The solids removal process necessitates adsorber downtime and may result in carbon loss and disruption of the mass transfer zone.

Modification of the GAC process (e.g., silicone-impregnated carbon) could increase removal efficiency and extend the length of operation. The GAC may also be safer to regenerate.

The operational lifetime of GAC is usually short term; however, if concentrations are low enough, the duration may be long term. The duration of operation and maintenance is dependent upon contaminant type, concentration, and volume; regulatory cleanup requirements; and metal concentrations.

The following factors may limit the applicability and effectiveness of the GAC process:

- The presence of multiple contaminants can impact process performance. Single-component isotherms may not be applicable for mixtures. Bench tests may be conducted to estimate carbon usage for mixtures.
- Influent with high suspended solids (>50 mg/L) and oil and grease (>10 mg/L) may cause fouling of the carbon and may require frequent carbon replacement maintenance. In such cases, pre-treatment is generally required.
- Costs are high if used as the primary treatment on waste streams with high contaminant concentration levels.
- Type, pore size, and quality of the carbon, as well as the operating temperature, will impact process performance. Vendor expertise should be consulted for carbon selection.
- Carbon used for explosives or metal-contaminated groundwater is not regenerated.
- Highly water-soluble compounds and small molecules are not adsorbed well.
- All spent carbon eventually needs to be properly disposed.
- Current operations of the 200-ZP-1 OU IRM have found low quantities of uranium and thorium in the GAC. This limits the locations where GAC can be sent for regeneration. Appendices G and H include two evaluations that have been conducted to identify treatment alternatives to complement or replace the use of GAC. The evaluation results will be used in developing the treatment process in the remedial design.

Evaluation Criteria. The evaluation criteria are as follows

Effectiveness: The effectiveness of GAC depends on the molecular weight, structure, and solubility of the contaminant, as well as the properties of the carbon, water temperature, and the presence of impurities (e.g., iron and manganese). No hazardous byproducts will be produced; however, a secondary waste stream may be generated and will need to be disposed of properly. No negative impacts will result. The volume treated is dependent upon the contaminant/carbon contact time and will vary among contaminants and system designs. Construction or operational risks arise from drilling, because contaminated groundwater is extracted to the surface for treatment. However, these risks are minimized by OSHA-compliant work practices.

Implementability: GAC is a commonly used groundwater treatment technology, and carbon adsorption vessels are readily available commercially and are currently being used for the removal of carbon tetrachloride from extracted groundwater at the 200-ZP-1 OU. Current issues prevent GAC from being sent offsite for regeneration at the previously used facility; however, other regeneration options are being evaluated.

Cost: The cost of a GAC system includes the cost of carbon, carbon vessels, pumps and piping, electrical equipment and controls, housing, design, and contingency equipment. The cost also depends on the flow rates, type of contaminant, concentrations, discharge requirements, carbon regeneration, and spent carbon disposal.

Screening Results. Granular activated carbon has been retained for further evaluation. See Table 4-4 for a summary of the evaluation. While a final, full-scale treatment train may rely on options other than GAC, significant operational data are available to show that GAC is effective in the removal of the COC (as well as other VOCs) from contaminated groundwater at the 200-ZP-1 OU.

Ion Exchange. The IX process removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium. The IX materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are attached. The materials may also be inorganic or natural polymeric. After the resin capacity has been exhausted, resins can be regenerated for reuse.

Factors that may affect the applicability and effectiveness of this process include the following:

- Oil and grease in the groundwater may clog the IX resin.
- Suspended solids content greater than 10 ppm may cause resin binding.
- The pH of the influent water may affect the IX resin selection.
- Oxidants in the groundwater may damage the IX resin.
- Wastewater is generated during the regeneration step and will require additional treatment and disposal.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: The IX process is a reliable and proven technology that will reduce ionic contaminants (i.e., nitrate, chromium, technetium-99, and iodine-129). No hazardous byproducts are produced, and no negative impacts will result. However, a secondary waste stream may be generated and will need to be disposed of properly. The volume treated depends on the system design and the types of contaminants in the groundwater. Construction or operational risks arise from drilling, because contaminated groundwater is extracted to the surface for treatment. However, these risks are minimized by OSHA-compliant work practices.
- The treatability test plan for using an IX resin to remove technetium-99 from the 200-ZP-1 groundwater is included in Appendix I. The results of this test will be used in developing the treatment for this contaminant in the remedial design.
- Implementability: The IX process is a commonly used treatment technology and is readily available commercially. Consumable usage is not a significant issue for IX, as resins can be regenerated and restored for reuse.

- Cost: The cost for a typical IX system includes pre-treatment requirements, discharge requirements and resin use, and the use and efficiency of the regenerant.

Screening Results. The IX process has been retained for further evaluation. See Table 4-4 for a summary of the screening results.

Reverse Osmosis. In normal osmotic processes, solvent flows across a semi-permeable membrane from a dilute solution to a more concentrated solution until equilibrium is reached. Applying high pressure to the concentrated side causes the process to reverse. Solvent flows from the concentrated solution, leaving an even higher concentration of solute. The semi-permeable membrane can be flat or tubular, and acts like a filter due to the pressure driving force. The waste stream flows through the membrane, while the solvent is pulled through the membrane's pores. The remaining solutes, such as organic or inorganic components, do not pass through but become more and more concentrated on the influent side of the membrane (Liptak 1997). Factors that may limit the applicability and effectiveness of these processes include the following:

- Semi-permeable membrane's chemical and physical properties must be compatible with the waste stream's chemical and physical characteristics.
- Some wastes will dissolve some membranes.
- Suspended solids and some organics will clog the membrane material.
- Low-solubility salts may precipitate onto the membrane surface.
- The presence of oil and grease contaminants may interfere with these processes by decreasing flow rate.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Significant uncertainty is associated with the ability to meet RAOs using reverse osmosis because it only targets dissolved inorganic compounds and small particles from process water. Reverse osmosis is primarily used as a potable water treatment technology but can be implemented in groundwater as a polishing step where water has very little suspended solids (*Cost-Effective Design of Pump-and-Treat Systems* [EPA/542-R-05/008]). No hazardous byproducts would be produced; however, treatment will result in a concentrated waste stream that will need to be disposed of properly. No negative impacts on other COCs are expected.
- Implementability: Reverse osmosis is commercially available. Consumable usage can be high if a high level of suspended solids is present in the system.
- Cost: The system usually has very high costs associated with maintenance and waste disposal if solid levels are elevated (EPA/542-R-05-008)

Screening Results. Reverse osmosis has not been retained for further evaluation. During final remedial design, reverse osmosis may be considered in the selection of a final treatment train, even though it will not be considered for inclusion during remedy formulation and the subsequent analyses. See Table 4-4 for further details.

4.2.1.5.3 Disposal Systems. Discharge options include pumping the treated groundwater back into the aquifer (i.e., reinjection), storing the treated water in a retention pond or infiltration basin and allowing the water to infiltrate into the ground, reusing the treated water for agricultural or industrial purposes, and discharging to surface water (e.g., the Columbia River).

Factors that may limit the applicability and effectiveness of this process include the following:

- The distance from the contaminated site to the nearest disposal facility with the required permit(s) will affect cost.
- Transportation through populated areas may affect community acceptability.
- Disposal options for certain waste (e.g., mixed or transuranic waste) may be limited. There is currently only one licensed disposal facility for radioactive and mixed waste in the United States.
- Contaminants can potentially migrate from confined disposal facilities from several pathways, including effluent discharge to surface water, rainfall surface run-off, leachate into groundwater, volatilization to the atmosphere, and dike uptake.

Reinjection. Treated water is returned to the aquifer system through wells, galleries, and/or basins. Reinjection can be used for assisting in hydraulic containment or flushing of a contaminant source, as well as flow-path control. When using reinjection for these purposes, it is important that well placement is considered during the extraction design. Reinjection requires that treated water meet or exceed drinking water standards. In some cases where drinking water standards cannot be met, waivers or permit leniency may be granted (EPA/542-R-05-008).

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Reinjection will likely assist treatment technologies in meeting RAOs. No hazardous byproducts are produced. Spread of contamination may occur if well placement is not carefully considered during the design phase of the extraction system. The volume of treated water would be a design consideration, but it should be consistent with the pump-and-treat system. Construction or operational risks arise from drilling; however, these risks are minimized by OSHA-compliant work practices. Risk is primarily from necessary drilling.
- Implementability: Well location and design are the most important components when implementing reinjection of treated water. Consumable usage is similar to that of pump-and-treat.
- Cost: Costs associated with reinjection are similar to that of pump-and-treat.

Screening Results. Reinjection has been retained for further evaluation. See Table 4-5 for further details.

Retention Pond or Infiltration Basin. A retention pond or infiltration basin is normally used to collect storm water. However, for this process, the retention pond or infiltration basin would be used to accept treated groundwater and infiltrate it back into the soil. This practice is believed to have high pollutant removal efficiency and can help recharge the groundwater, thus increasing base flow to stream systems. Retention ponds or infiltration basins can be challenging at many sites due to soil properties. For example, concentration of low-level waste through accumulation can lead to levels of concern and has potential to create a contamination spread problem. In

addition, some studies have shown relatively high failure rates compared with other management practices. (See the Internet http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=factsheet_results&view=specific&bmp=69 for more information.)

Although retention ponds or infiltration basins can be useful practices, they have several limitations. Retention ponds or infiltration basins are not generally aesthetic practices, particularly if they become clogged. If infiltration basins are designed and maintained so the standing water is left for no more than 3 days, mosquitoes should not be a problem. However, if an infiltration basin becomes clogged and takes 4 days or more to drain, the basin could become a source for mosquitoes. In addition, these practices are challenging to apply due to concerns over groundwater contamination and sufficient soil infiltration. Finally, maintenance of infiltration practices can be burdensome and they have a relatively high documented rate of failure in the literatures.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Retention ponds or infiltration basins will likely assist treatment technologies in meeting RAOs. No hazardous byproducts are produced. The volume of treated water received in the basin would be subjected to design considerations. Risk is primarily from trenching.
- Implementability: When designing infiltration basins, designers need to carefully consider both the restrictions on the site and the design features to improve the long-term performance of the practice. In addition, infiltration practices need to be located carefully. In particular, designers need to ensure that the soils on the site are appropriate for infiltration and that designs minimize the potential for vadose zone and groundwater contamination and long-term maintenance problems. Infiltration basins typically consume about 2% to 3% of the source draining to them, which is relatively small.
- Cost: Infiltration basins are relatively cost-effective practices because little infrastructure is needed for construction. Maintenance costs are estimated at 5% to 10% of the construction costs. One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly maintained, infiltration basins have a high failure rate; thus, it may be necessary to replace the basin after a relatively short period of time.

Screening Results. Retention ponds or infiltration basins have not been retained for further evaluation. See Table 4-5 for further details.

Reuse. Treated water that meets RAOs is reused at an active industrial facility or is used for irrigation or potable water supply. Reuse of treated water reduces or eliminates the need for a facility or organization to use water from other sources, thereby conserving water as a natural resource. Reuse may also eliminate the costs associated with discharging the water and the costs of using water from other sources. However, when reusing treated groundwater, additional testing may be required (EPA/542-R-05-008).

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Reuse will not assist the selected remedy in meeting RAOs. No hazardous byproducts are produced and no negative impacts will result. The volume of treated water would be a design consideration but it should be consistent with the pump-

and-treat system. Risk would be associated with a treatment system failure and distribution to any human or ecological receptor.

- Implementability: Reuse is easily implemented but may require many additional treatment components and testing. Consumable usage is similar to that of pump-and-treat and is dependent on the destination of the treated water
- Cost: Costs associated are facility- and site-dependent.

Screening Results. Reuse has not been retained for further evaluation. See Table 4-5 for further details.

Surface Water. Under the NPDES, treated water may potentially be discharged to a nearby surface water body. The Columbia River is the closest surface water body that could be used under this process option. Treated groundwater that meets or exceeds RAOs would be transported via pipelines to the Columbia River for discharge. However, additional analytical and environmental testing may be required to ensure that standards are met and that ecological impacts are not occurring (EPA/542-R-05-008).

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Surface discharge would not assist the selected remedy in meeting RAOs. No hazardous byproducts are produced and no negative impacts will result. The volume of treated water would be a design consideration but it should be consistent with the pump-and-treat system. Risk would arise if there was a system failure, specifically impacts of a treatment system where distribution to any human or ecological receptor occurred.
- Implementability: Surface discharge is easily implemented but may require a great deal of additional analytical and environmental testing. Consumable usage is similar to that of pump-and-treat.
- Cost: Costs associated involve piping effluent from the treatment system to a surface water body. Analytical sampling and testing of influent and effluent are needed.

Screening Results. Surface water has not been retained for further evaluation. See Table 4-6 for further details.

4.2.1.6 In Situ Technologies. In situ treatment consists of actions that treat contamination in place. In situ treatment of contaminated groundwater generally includes methods to separate and remove contaminants or to degrade contaminants in place. These methods may include in situ ERH, air sparging, and anaerobic bioremediation. The in situ ERH treatment method mobilizes contaminants in the subsurface by heating and then removing the contaminants by vapor or water extraction. Air sparging involves injecting air into the aquifer to strip or flush volatile contaminants as the air bubbles up through the groundwater and is captured by a vapor extraction system installed above the water table. Stripped or volatilized contaminants are usually removed through SVE wells, treated if necessary, and then discharged directly to the atmosphere.

Methods of in situ degradation generally involve adding agents to groundwater (via injection wells or permeable barriers) that facilitate chemical or biological destruction. The types of in situ degradation most frequently used at groundwater contamination sites are in situ biological treatment and in situ chemical treatment. Depending on the contaminant, biodegradation may require aerobic or anaerobic aquifer conditions. Aerobic in situ bioremediation of groundwater

involves pumping nutrients and/or oxygen into the aquifer to enhance biodegradation. Anaerobic in situ bioremediation involves injection of electron-donor substrates and nutrients. In situ chemical treatment involves injecting strong oxidants or reductants into the subsurface to degrade or immobilize contaminants.

4.2.1.6.1 In Situ Electric Resistance Heating. Heating is achieved by passing three-phase or six-phase electrical current between electrodes, which are in electrical contact but out of phase with each other. As electrical current passes through the aquifer materials between electrodes, the natural electrical resistance of aquifer soils results in heating. Because heating occurs within the aquifer matrix, the electrodes are not hot points in the treatment zone; instead, heating and steam generation occur relatively uniformly between electrodes. Subsurface zones with the highest electrical conductivity are heated preferentially due to a greater flow of electrical current in those zones. Advantageously, high electrical conductivity zones include low-permeability silt or clay and areas of potential DNAPL or high-concentration, aqueous-phase contamination. As a result, ERH targets those zones that are typically the most difficult to remediate by other technologies. Steam and contaminant vapors are collected by vacuum extraction wells typically co-located with each electrode well. The horizontal spacing between electrode/vapor recovery wells is usually 4.3 to 7.3 m (14 to 24 ft) (*In-Situ Thermal Remediation of DNAPL and LNAPL Using Electrical Resistance Heating* [Beyke and Fleming 2005]).

Factors that may limit the applicability and effectiveness of the process include the following:

- Soil type
- Contaminant characteristics and concentrations
- Geology and hydrogeology (which will significantly impact process effectiveness).

Evaluation Criteria. The evaluation criteria include the following:

- Effectiveness: ERH will assist in reducing contaminant concentrations in a small volume. Some issues with ERH are associated with effective extraction of the vapor-phase contaminants in a heterogeneous subsurface without spreading the contamination. No hazardous products are produced, and no negative impacts with other COCs are expected. ERH is commonly used to treat small areas of continuing source areas. Construction risks arise from necessary drilling but will be controlled under the existing OSHA-compliant work requirements. Operational risks are associated with vapor-phase treatment processes and electrical equipment.
- Implementability: ERH is easily implemented and the equipment is inexpensive, mobile, and easy to operate. ERH is applicable to both shallow- and deep-contaminated areas and provides a relatively rapid aerial coverage (Liptak 1997). Consumable usage would depend on the amount of electricity used.
- Cost: Cost estimates for this technology are strongly dependent on the treatment area rate, and range.

Screening Results. ERH has been retained for further evaluation. See Table 4-6 for further details.

4.2.1.6.2 In Situ Air Sparging. Air sparging is a physical treatment method used primarily to remove or degrade volatile contaminants from groundwater. Air is injected into a contaminated aquifer through a well screened beneath the zone of groundwater contamination. Air bubbles move upward through the aquifer and volatile compounds (e.g., carbon tetrachloride and TCE)

are transferred from the aqueous phase to the vapor phase according to Henry's Law. Air stripping may be combined with SVE to collect contaminant vapors from the vadose zone for ex situ treatment. SVE is likely required for chlorinated solvents that are not biodegraded under anaerobic conditions (*Cost and Performance Report Multi-Site In Situ Air Sparging* [TR-2260-ENV]). Collected vapors are treated using conventional methods, including GAC and thermal oxidation. A variation of air sparging known as "biosparging" is also used to provide oxygen to enhance biodegradation of semi-volatiles that respond to biological degradation under aerobic aquifer conditions (e.g., diesel).

Factors that may limit the applicability and effectiveness of the process include the following:

- Air flow through the saturated zone may not be uniform, which implies that there can be uncontrolled movement of potentially dangerous vapors.
- Depth of contaminants and specific site geology must be considered.
- Air injection wells must be designed for site-specific conditions.
- Soil heterogeneity may cause some zones to be relatively unaffected.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Effectiveness of air sparging is dependent upon heterogeneous layers within the aquifer. No hazardous products are produced, and no negative impacts with other COCs are expected. Air sparging targets VOCs and is best suited for small areas with higher concentrations. Construction risks arise from necessary drilling. Operational risk is similar to the pump-and-treat system.
- Implementability: This technology has been demonstrated at numerous sites, although only a few sites are well documented. Air sparging has demonstrated sensitivity to minute permeability changes, which can result in localized stripping between the sparge and monitoring wells. Consumable usage is similar to the pump-and-treat system.
- Cost: The primary cost affecting air sparging is the surface area of the contamination, which directly affects the quantity of air-sparge points. The second cost affecting air sparging is the depth to contamination, as it influences the drilling costs. The other cost factor for air sparging is surface area (i.e., contaminant orientation).

Screening Results. Air sparging is not retained for further evaluation for following reasons (see Table 4-6 for further details):

- Aquifer heterogeneities result in non-uniform treatment and asymmetrical treatment zones.
- Approximately half or less of the aquifer pore volume is treated due to discrete channeling of air flow.
- Relatively close well spacing would be required that would substantially add to the capital and operation and maintenance costs as compared to other alternatives.
- Implementability of air sparging is estimated to be low to moderate based on the depth of contamination.

4.2.1.6.3 In Situ Anaerobic Bioremediation. Anaerobic treatment is an effective biological method for treating organic contaminants. The microbiology involved in the process includes facultative and anaerobic microorganisms, which in the absence of oxygen, convert organic

materials into gaseous end products such as methane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas (Liptak 1997).

Factors leading to the application of in situ anaerobic bioremediation are as follows (Fetter 1999):

- The physical heterogeneity of earth materials results in flushing media, air, or water moving primarily through the most permeable parts of the earth.
- Contaminates will diffuse into regions of the earth that are inaccessible and then slowly diffuse back into the more permeable zones.
- Contaminants will sorb onto solid surfaces and then slowly desorb.
- DNAPLs pools may be present, as well as globules of DNAPLs that cannot be flushed from the aquifer by flowing water.

Sometimes contaminants may be degraded to intermediate or final products that may be less, equally, or more hazardous than the original contaminant. To avoid such problems, most bioremediation projects are conducted in situ. For example, TCE anaerobically biodegrades to the persistent and more toxic vinyl chloride. However, vinyl chloride can be quickly oxidized to ethylene, ethane, or ethanol in aerobic environments (contaminant hydrogeology). When using in situ treatment for chlorinated hydrocarbons, aquifer conductions are altered and production of an anaerobic zone (i.e., reductive dehalogenation is occurring) followed by an aerobic zone (i.e., vinyl chloride and chloromethane are consumed) can occur. Factors that may limit the applicability and effectiveness of the process include the following:

- Cleanup goals may not be attained if the soil matrix prohibits contaminant-micro-organism contact.
- Preferential colonization by microbes may occur causing clogging of nutrient and water-injection wells.
- Preferential flow paths may severely decrease contact between injected fluids and contaminants throughout the contaminated zones. The system should not be used for clay, highly layered, or heterogeneous subsurface environments because of oxygen (or other electron acceptor) transfer limitations.
- High concentrations of heavy metals, highly chlorinated organics, long-chain hydrocarbons, or inorganic salts are likely to be toxic to micro-organisms.
- Bioremediation slows at low temperatures.
- A surface treatment system (e.g., air stripping or carbon adsorption) may be required to treat extracted groundwater prior to reinjection or disposal.

Many of the above factors can be controlled with proper attention to good engineering practices. The length of time required for treatment can range from 6 months to 5 years and depends upon many site-specific factors.

Evaluation Criteria. The evaluation criteria are as follows:

- Effectiveness: Effectiveness of anaerobic bioremediation is dependent upon aquifer conditions. Where the subsurface is heterogeneous, it is very difficult to deliver the substrate throughout every portion of the contaminated zone (PNNL-15954). Higher permeability zones will be cleaned up much faster because groundwater flow rates are

greater. Reductive dechlorination of carbon tetrachloride may lead to hazardous products (PNNL-15954). Other COCs are not expected to produce hazardous products, and no negative impacts with other COCs are expected. Anaerobic bioremediation can treat large or small volumes but will require numerous wells for larger volumes due to the limited influence of substrate distribution (PNNL-15954). Construction risks arise from necessary drilling; however, these risks are minimized by OSHA-compliant work practices

- Implementability: A groundwater circulation system must be created so contaminants do not escape from zones of active biodegradation. Distribution of substrate in a long well screen can cause problems, and a large amount of wells may be necessary (PNNL-15954). Consumable usage is dependent upon the amount of substrate required.
- Cost: The primary cost affecting anaerobic bioremediation is related to well operation and maintenance, the amount of substrate required to sustain anaerobic bioremediation conditions, performance sampling and analysis as well as the longevity of the substrate.

Screening Results. In situ anaerobic bioremediation has been retained for further evaluation. See Table 4-6 for further details.

Table 4-1. Summary of No Action Technology.

General Response Action	Remedial Technology	Process Option	Description	Retained ?	Reasons	Comments
No action	No action	None	No institutional controls or treatment.	Yes	Required	Baseline for comparison.

Table 4-2. Summary of Institutional Controls. (2 sheets)

General Response Action	Remedial Technology	Process Option	Description	Retained ?	Reasons	Comments
Institutional controls	Administrative controls	HCP EIS	Tracks and reports activities that could occur on Hanford CERCLA sites with institutional controls.	Yes	1, 2, 3	Conservative approach; may benefit because site is anticipated to remain an industrial-use area.
		Public notice	Notifies stakeholders of changes in institutional controls.	Yes	1, 2, 3	Conservative approach; may benefit because site is anticipated to remain an industrial-use area.
		DOE directives	Legally binding on DOE and contractors; can include well-drilling restrictions or easements for monitoring, restrictive covenants, or land withdrawal documentation.	Yes	1, 2, 3	Conservative approach; may benefit because site is anticipated to remain an industrial-use area.
		NEPA	Requires that all Federal actions subject to NEPA receive appropriate evaluation.	Yes	1, 2, 3	Conservative approach; may benefit because site is anticipated to remain an industrial-use area.
		Work controls	Includes specific regulatory requirements for work activities.	Yes	1, 2, 3	Conservative approach; may benefit because site is anticipated to remain an industrial-use area.
		WIDS	Identifies waste management units on the Site, location, waste type, and status.	Yes	1, 2, 3	Conservative approach; may benefit because site is anticipated to remain an industrial-use area.

Table 4-2. Summary of Institutional Controls. (2 sheets)

General Response Action	Remedial Technology	Process Option	Description	Retained ?	Reasons	Comments
		Excavation permitting	Required for excavation work, including well drilling.	Yes	1, 2, 3	Conservative approach; may benefit because site is anticipated to remain an industrial-use area.
		Groundwater use management	The DOE will restrict well drilling and groundwater use in accordance with the institutional control requirements of CERCLA.	Yes	1, 2, 3	Conservative approach; may benefit because site is anticipated to remain an industrial-use area.
	Access restrictions	Warning notices	Institutional controls that restrict personnel access at specific CERCLA sites.	Yes	1, 2, 3	Conservative approach; may benefit because site is anticipated to remain an industrial-use area.

NOTES:
1 Effective
2 Implementable/technically feasible
3. Cost effective

CERCLA = *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
HCP EIS = *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement* (DOE/EIS-0222-F)
DOE = U.S. Department of Energy
NEPA = *National Environmental Policy Act of 1969*
WIDS = Waste Information Data System (database)

Table 4-3. Summary of Monitoring and Monitored Natural Attenuation.

General Response Action	Remedial Technology	Process Option	Description	Retained ?	Reasons	Comments
Monitoring	Hanford Site Ground-Water Protection Management Plan	Sampling and analysis	Includes regular monitoring of groundwater of COCs to assess the protectiveness of human health and the environment.	Yes	2, 3	Currently implemented, some reduction to COCs is expected to occur through natural attenuation or radiological decay processes.
	Natural attenuation	MNA	Reduction of contaminant toxicity, volume, concentration, mobility, and/or bioavailability through natural physical, chemical, or biological processes that occur without human intervention.	Yes	2, 3	Easy to implement, some reduction to COCs is expected to occur through natural attenuation or radiological decay processes.

NOTES:
1 Effective
2 Implementable/technically feasible
3. Cost effective
COC = contaminant of concern
MNA = monitored natural attenuation

Table 4-4. Summary of Pump-and-Treat Actions.

General Response Action	Remedial Technology	Process Option	Description	Retained ?	Reasons	Comments
Pump-and-treat actions	Groundwater withdrawal	Extraction wells (pump-and treat)	Use of wells to extract groundwater out of the aquifer for subsequent disposal with treatment	Yes	1, 2	Pump-and-treat is a baseline remedy for all COCs.
	Hydraulic containment by pump-and-treat	Extraction wells (pump-and-treat)	Wells used to extract groundwater.	No	A, B, C	Costly to implement at required depth and not expected to reduce mass, volume or toxicity of COCs.
Ex situ	Physical/ chemical	Air stripping	Transfer of volatile contaminants from extracted groundwater to an air stream. Typically effective for compounds with a high vapor pressure, low solubility, and low molecular weight.	Yes	1, 2	Currently implemented and proven successful on the 200-ZP-1 OU interim treatment system.
		GAC	GAC provides a large surface area per volume for adsorption of contaminants. Typically used for organic contaminants.	Yes	1, 2	Currently implemented and proven successful on the 200-ZP-1 OU interim treatment system.
		Ion exchange	Involves the adsorption of an ionic contaminant (typically on a resin substrate)	Yes	1, 2	Proven to be a highly effective option for remediation of groundwater.
		Reverse osmosis	Water is forced through the semi-permeable membrane under pressure where contaminant free water is allowed to pass through and contaminated water is recirculated through the system.	No	A, C	Costly to implement when compared to other technologies that are available.

NOTES:

1 Effective
2 Implementable/technically feasible
3. Cost effective

A Not effective
B Not implementable
C Not cost effective

COC = contaminant of concern
GAC = granular activated carbon
OU = operable unit

Table 4-5. Summary of Disposal Technologies.

General Response Action	Remedial Technology	Process Option	Description	Retained ?	Reasons	Comments
Disposal	Reinjection	Injection wells	Involves pumping the treated groundwater back into the aquifer using drilled wells.	Yes	1, 2	Currently implemented and proven successful on the 200-ZP-1 OUs interim treatment system.
	Retention pond/ infiltration	Basin	Groundwater would be allowed to infiltrate to the subsurface.	No	A, C	Effectiveness is limited due to infiltration, clogging and retention of contaminants. Studies show high failure rates.
	Reuse	Use of treated water	Irrigation or potable water use.	No	A, C	Effectiveness is dependent on design capacities which may or may not include treatment for all of the contaminants present in the groundwater. Cost will increase if treatment systems is designed to meet all discharge requirements for all contaminants.
	Discharge to surface water (i.e., Columbia River)	Discharge pipes	A discharge pipe would carry groundwater from the treatment system directly to the Columbia River.	No	A, C	Option is too costly for extracted water. Potential ecological impacts below MCL level (i.e., bioaccumulation in fish or biota of contaminants below MCLs).

NOTES:

1 Effective
2 Implementable/technically feasible
3. Cost effective

A Not effective
B Not implementable
C Not cost effective

MCL = maximum contaminant level
OU = operable unit

Table 4-6. Summary of In Situ Technologies.

General Response Action	Remedial Technology	Process Option	Description	Retained ?	Reasons	Comments
In situ	Physical	Air sparging	Air is injected into the aquifer to volatilization of organic compounds.	No	A, C	Costly to implement and effectiveness is dependent upon heterogeneous layers within the aquifer.
	Biological	Anaerobic bioremediation	Injection of biological substrate to enhance biological activity	Yes	1, 2, 3	Contingency approach; may assist with the more difficult source areas to treat.
	Thermal	Electrical resistance heating	Aquifer heating.	Yes	1, 2, 3	Contingency approach; may assist with the more difficult source areas to treat.

NOTES:

1 Effective
2 Implementable/technically feasible
3. Cost effective

A Not effective
B Not implementable
C Not cost effective

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5.0 REMEDIAL ACTION ALTERNATIVES

The alternatives presented in this section were developed by combining the representative process options identified in Section 4.0 into a range of comprehensive remediation strategies. These alternatives were specifically formulated to meet the RAOs identified in Section 3.0.

To date, investigations in the vadose zone have not identified continuing sources of principal threat contaminants (i.e., carbon tetrachloride) to the groundwater in the 200-ZP-1 OU (see Sections 2.4 and 2.5). Future potential threats to groundwater originating in the vadose zone will be addressed as part of the remedial actions within the overlying source OUs. However, the final remedial design must consider the impacts of potential vadose zone sources on contaminant distribution in the groundwater.

It should be noted that the alternatives assembled in this section target identified contamination within the aquifer, but do not account for potential future impacts from technetium-99 in the vadose zone near WMA-T or WMA-TX/TY because characterization efforts at these locations are ongoing. These characterization efforts are focusing on refining the understanding of contamination in both the vadose zone and the groundwater, as well as developing estimates of the mass and distribution of technetium-99. Because of its high mobility, the mass of technetium-99 in the vadose zone will be a significant consideration in the final remedial design (i.e., the quantity of technetium-99 in the vadose zone may present a future source of groundwater contamination because of its high mobility). Because the associated potential impacts to the aquifer have not yet been quantified, an uncertainty exists regarding the duration of remedial action necessary to achieve RAOs related to technetium-99.

Remedy alternatives developed in this FS will address contamination currently in 200-ZP-1 OU groundwater and will acknowledge the need for adaptability to adjust to changed circumstances if new information suggesting such changes becomes available. In Section 3.0, specific RAOs (#2 and #3) were formulated to respond in the event that a new source is discovered.

5.1 CRITERIA FOR THE DEVELOPMENT OF REMEDIAL ALTERNATIVES

The purpose of this FS and the overall remedy selection process is to identify remedial actions that eliminate, reduce, or control risks to human health and the environment (40 CFR 300). The national program goal of the FS process, as defined in the NCP, is to select remedies that are protective of human health and the environment, maintain protection over time, and minimize untreated waste. The NCP defines certain expectations for developing remedial action alternatives to achieve these goals. The criteria used to develop the alternatives (40 CFR 300.430) are as follows:

- Treatment should be used to address the principal threats by a waste unit wherever practical. Principal threats for which treatment is most likely to be appropriate include liquids, areas contaminated with high concentrations of toxic or radioactive compounds, and highly mobile materials.
- Engineering controls (e.g., 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 human health and the environment. In appropriate situations, treatment of principal threats

should be combined with engineering and institutional controls for treatment of residuals or untreated waste.

- Institutional controls (e.g., restrictions on water use, security, fencing, and deed restrictions) should be used to supplement engineering controls for short- and long-term management to prevent or limit exposure to hazardous substances or contaminated environmental media. The use of institutional controls should not substitute for active response measures as the sole remedy unless such active measures are determined not to be practical.
- Innovative (non-demonstrated) technologies should be considered when such technologies offer 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, where practical, within a timeframe that is reasonable given the particular circumstances of the site. When restoration of groundwater to beneficial uses is not practical, the EPA expects to limit, if possible, migration of the contaminants, prevent exposures to contaminated groundwater, and evaluate further risk reductions.

5.2 DESCRIPTION OF 200-ZP-1 OPERABLE UNIT REMEDIAL ALTERNATIVES

The representative process options selected in Section 4.0 were combined to formulate a range of comprehensive remedial alternatives to satisfy the RAOs for the 200-ZP-1 OU. Preliminary technical and functional requirements for the elements of each alternative are identified based on the RAOs and ARARs, as well as other considerations.

The remedial action alternatives range from no action without institutional controls, to active treatment such as a pump-and-treat system augmented with supplemental treatment of contaminated groundwater. The alternatives were formulated to encompass a wide range of possible outcomes and enhance compatibility with current operations and infrastructure. The alternatives include the following:

- Alternative #0 – No action: The NCP (40 CFR 300) requires consideration of a no action alternative. This alternative proposes that the site be left as-is, with no need for additional remedial activities, monitoring, or access restrictions (i.e., institutional controls). This alternative is only acceptable if current site conditions are protective of human health and the environment. This alternative is not discussed further in this section; however, the alternative is carried into the detailed analysis preformed in Section 6.0.
- Alternative #1 – Institutional controls supplemented by MNA (see Section 5.2.1): This alternative may be appropriate to protect human health and the environment in areas where groundwater contaminant concentrations exceed RAOs and monitoring is necessary to ensure continued effectiveness of remedial actions. The MNA processes include biodegradation, abiotic degradation (hydrolysis), volatilization, radioactive decay, sorption, dispersion, transformation, and dilution.

- Alternative #2 – Full-scale pump-and-treat, institutional controls, MNA, plus groundwater flow-path controls (see Section 5.2.2): The pump-and-treat system will address the COC by removing contaminant mass, while downgradient injection wells will slow migration, allowing additional time for MNA processes to work. Institutional controls are also incorporated into this alternative.
- Alternative #2 includes a robust, full-scale pump-and-treat remedy that includes options for final shutdown of the active treatment, supplemented by MNA and an associated contingency measures in the event that performance monitoring suggests a decrease in the effectiveness of natural attenuation processes. While current data do not suggest the presence of DNAPL or other active source zone in groundwater, contingency measures could also implement in situ technologies for treatment of newly discovered source material (Section 5.2.3).

5.2.1 Alternative #1 – Institutional Controls Supplemented by Monitored Natural Attenuation

5.2.1.1 Institutional Controls. The *Sitewide Institutional Controls Plan* (DOE/RL-2001-41) identifies the institutional controls for the current Hanford Site. It also describes how institutional controls are implemented and maintained, and it serves as a reference for the selection of institutional controls in the future. Institutional controls work in conjunction with the more active cleanup measures to protect human health and the environment during the cleanup process, as well as following the completion of cleanup for areas containing residual hazards. Therefore, existing institutional controls will continue as long as hazards remain that make the site unsuitable for unrestricted industrial use, which is currently anticipated to be until at least the year 2150. Institutional controls include the following:

- Administrative controls:
- Maintain the site listings and updates in the 200-ZP-1 OU facility and land-use plan; update changes or terminations agreed to by the agencies
- Provide public notices to stakeholders of changes in institutional controls
- Add new DOE directives, new DOE orders, or changes to List B of the operations and maintenance contract as they occur
- Control the use of groundwater via use restrictions, easements for monitoring, restrictive covenants, or land withdrawal documentation that would be deemed necessary to further protected the public and the environment if land use or ownership changes
- Maintain work control process in accordance with 10 CFR 835 and DOE G 441.1-1B
- Restrict and/or control soil disturbances to eliminate the potential spread of contamination.
- Access restrictions:
- Post and maintain visible access restrictions
- Control access as follows:
- Maintain Hanford Site access controls in accordance with *Safeguards and Security Program* (DOE O 470.4)

- Maintain restrictions on leasing or transferring property
- Maintain notification requirements in response to failed controls/corrective action.

As long as contaminants remain within the 200-ZP-1 OU groundwater at concentrations that pose a risk exceeding 1×10^{-4} (using an industrial scenario) under this alternative, a 5-year site review is required by the NCP (40 CFR 300.430[f][4][ii]). The 5-year reviews will be conducted to evaluate the effectiveness of the existing institutional controls, to evaluate the need for continued institutional controls, or to consider a supplemental action.

5.2.1.2 Monitoring. The *Hanford Site Ground Water Protection Management Plan* (DOE/RL-89-12) describes the approach for monitoring effectiveness of Hanford Site groundwater activities, which includes groundwater in the 200-ZP-1 OU. The plan ensures that monitoring at active waste disposal facilities complies with the requirements of RCRA and Washington State regulations, as well as the requirements for operational monitoring around reactor and chemical processing facilities and environmental surveillance monitoring. These efforts are assessed to determine the distribution and movement of existing groundwater contamination, to identify and characterize potential and emerging groundwater contamination problems, and to integrate the various groundwater projects to minimize redundancy.

Implementation of the groundwater monitoring requirements outlined in DOE/RL-89-12 and DOE/RL-91-50 are described in PNNL-11989. This plan includes a description of the monitoring well networks, constituents, sampling frequencies, and criteria used to design the monitoring program; identifies Federal and state groundwater monitoring requirements and regulations; and provides a list of wells, constituents, and sampling frequencies for groundwater monitoring conducted on the Hanford Site. Federal and state regulations include RCRA, CERCLA, and the WAC.

Groundwater monitoring in the 200-ZP-1 OU is incorporated and described in PNNL-11989; thus, no new monitoring components are required. Currently, there are approximately 90 wells that are monitored on an annual basis. Any changes to the monitoring approach would be defined during the final design phase of the selected remedy.

5.2.1.3 Natural Attenuation. According to EPA guidance (OSWER Directive 9200.4-17P), natural attenuation refers to the reliance on natural processes to achieve site-specific remedial objectives within a timeframe that is reasonable compared to other more active methods. The processes, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These in situ processes include biological degradation or stabilization; dispersion; dilution; sorption; volatilization; and the chemical stabilization, transformation, or destruction of contaminants:

Biodegradation: Micro-organisms are capable of degrading many contaminants including carbon tetrachloride, chloroform, and PCE. For biodegradation of carbon tetrachloride to occur, anaerobic conditions must exist within the aquifer and there must also be a source of organic carbon. Hanford sediments are naturally low in organic carbon and much of the groundwater system is aerobic. These conditions will likely limit the amount of biodegradation occurring. Biodegradation has been occurring within the aquifer, as indicated by the presence of chloroform and methylene chloride within the groundwater system.

- Abiotic degradation (hydrolysis): Though not yet confirmed with site-specific testing, abiotic degradation (hydrolysis) has been shown to convert carbon tetrachloride to carbon

dioxide and hydrogen chloride. The *Assessment of Carbon Tetrachloride Groundwater Transport in Support of Hanford Carbon Tetrachloride Innovative Technology Demonstration Program* (PNNL-13560) suggests a 100-year half-life for carbon tetrachloride undergoing abiotic degradation under normal conditions at the Hanford Site. These conditions consist of an aerobic environment. A more detailed analysis suggests that the half-life ranges from 41 to 100 years (PNNL-15937). Site specific testing under typical Hanford conditions and a variety of temperatures is currently underway for hydrolysis of carbon tetrachloride. Information on hydrolysis of the other chloromethanes is limited.

- Volatilization: Only organic compounds are expected to volatilize (i.e., carbon tetrachloride, PCE, and chloroform).
- Radioactive decay: Tritium has a half-life of approximately 12 years, making flow-path control a potentially effective part of the remedy.
- Sorption: Metals, radionuclides, and organics will sorb to soils.
- Dispersion: Contaminants such as carbon tetrachloride dissolved in groundwater tend to spread out as the groundwater moves.

5.2.1.4 Implementation. Environmental monitoring will evaluate the effectiveness of natural attenuation processes and measure the migration of contaminated groundwater. Criteria will be developed to trigger implementation of contingency measures in the event that natural attenuation is found to be occurring at an unacceptably slow rate (e.g., application of flow-path controls or an active treatment remedy). Additionally, institutional controls will be applied to protect potential receptors.

5.2.2 Alternative #2 – Full-Scale Pump-and-Treat, Institutional Controls, Monitored Natural Attenuation, Plus Groundwater Flow-Path Controls

A pump-and-treat system is currently operating in the 200-ZP-1 OU as an IRM targeting carbon tetrachloride, chloroform, and TCE near the water table. The current system is using 10 extraction wells with a threshold capacity of about 1,136 L/min (300 gallons per minute [gpm]). This alternative describes a remedy that includes a full-scale, robust pump-and-treat system. This pump-and-treat system is intended to remove approximately 95% of the contaminant mass in 200-ZP-1 OU groundwater. The remaining contaminant mass located in the northeast portion of the carbon tetrachloride groundwater contamination generally less than 100 µg/L will undergo enhanced MNA (see Section 5.2.2.4). A flow-path control regime will be implemented in that area to prolong the time available for natural attenuation processes to work. This alternative is specifically formulated to return 200-ZP-1 OU groundwater to beneficial use by achieving Federal MCLs for the contaminants listed in Section 3.3. Active treatment will remove contaminant mass from the following areas:

- High-concentration portions of the COC-contaminated groundwater within the 200-ZP-1 OU.
- The lower (or dispersed) concentration areas of COC-contaminated groundwater that exceed 100 µg/L.
- Areas of technetium-99 contamination near WMA-T and WMA-TX/TY. The conceptual remedy developed for this alternative does not account for technetium-99 in the vadose

zone at these locations because characterization efforts are still underway. The final remedial design will consider information from the investigation, because the quantity of technetium-99 in the vadose zone may present a future source of groundwater contamination that may impact cleanup times, extraction network configuration, and treatment train design.

The treatment train was evaluated using technologies that are known to work at the Hanford Site for the treatment of carbon tetrachloride and its degradation products, TCE, chromium (both chromium [III] and [VI]), and technetium-99. Nitrate, iodine-99, and tritium are expected to meet applicable discharge criteria as they are processed through the treatment system.

The FS assumes that vadose zone remedies will mitigate future threats to groundwater for the identified COCs. However, the potential for undiscovered contaminant source areas and for unanticipated contaminant influx from the vadose zone introduces uncertainty. This uncertainty primarily impacts the scale and duration of the pump and treat alternative, but may also have implications with respect to treatment technologies.

5.2.2.1 Extraction System. Implementation of the pump-and-treat alternative as a full-scale final remedial action involves the addition of approximately 14 to 27 new extraction wells spaced and located in order to remediate the high-concentration portion of the contaminated groundwater, the dispersed lower concentration portion of groundwater contamination (exceeding the 1×10^{-4} risk using an industrial scenario), and the area of the aquifer near WMA-T and WMA-TX/TY contaminated with technetium-99.

Two bounding cases were carried forward in this alternative: (1) a smaller system that was less expensive but capable of achieving the RAOs, and (2) a larger pump-and-treat system that was more costly but could achieve the RAOs within a shorter timeframe.

The systems evaluated included 14 to 27 extraction wells, each having an expected pumping rate of 227 L/min (60 gpm) for a total system extraction rate of approximately 3,180 to 6,113 L/min (840 to 1,615 gpm). The new wells would penetrate to a greater depth in the aquifer to more effectively capture contaminated groundwater. Half of the wells would be screened from approximately 67 to 97.5 m (220 to 320 ft), and the remainder would be screened at approximately 97.5 to 128 m (320 to 420 ft). In addition, 14 to 27 injection wells, 20 cm (8 in.) in diameter, would be installed and screened from 67 to 82.3 m (220 to 270 ft). Approximately 4,572 m (15,000 ft) of piping would be used to connect the new wells to the treatment system. Optimization of this design concept would occur during the remedial design.

5.2.2.2 Treatment System. The treatment train is suitable for treatment of the principal threat COCs listed in Section 3.0 of this FS, as well as for ensuring that constituents exceeding the MCL (as discussed in Section 3.3.3) are treated to restore groundwater to beneficial use and reduce cumulative risk. Specific consideration was made to include technologies that actively remove contaminant mass from the groundwater. The conceptual treatment train evaluated in this FS includes GAC, IX, and air strippers. These technologies were selected because there is significant site-specific operational data to support the evaluation of this remedy. The final treatment technologies and their configuration will be identified in the remedial design. This approach ensures that critical design inputs for the pump-and-treat system are considered, and that changes in the availability of technologies can be adequately incorporated (e.g., technologies screened out in Section 4.0 because they are inappropriate for the FS detailed and comparative

analysis may be considered during remedial design for incorporation in the final treatment system).

No treatment technology was included for tritium because suitable technologies are not available. However, as mentioned in Section 3.0, tritium is expected to decay to levels below a health concern within 150 years. Areas of tritium contamination are located within the capture zone of the pump-and-treat system and will be hydraulically contained during system operation, providing time for natural attenuation processes work. In addition, areas of tritium contamination from the permitted discharges at SALDS are not specifically targeted for capture. Total chromium, hexavalent chromium, and technetium-99 will be removed from groundwater using IX. The GAC and air strippers will remove TCE, as well as the degradation products of carbon tetrachloride. Preliminary analysis suggests that nitrate and iodine-129 may not need specific treatment. An evaluation of potential treatment methods for nitrate and iodine-129 is being conducted and the results of this evaluation will be incorporated into the remedial design process if further analysis indicates that treatment for these contaminants is needed. However, in the event that performance monitoring indicates that PRGs are not being met, a waiver of the MCLs for iodine-129 and nitrate may be required.

5.2.2.3 Flow-Path Control. Flow-path control (downgradient injection of treated effluent) is used to increase the travel time of contaminated groundwater not hydraulically contained by the pump-and-treat system toward potential ecological and human receptors. This will enhance natural attenuation processes by providing a longer timeframe to attain the RAOs. Figure 5-11 illustrates the treatment and containment components of Alternative #2.

The northern portion of the aquifer would be targeted for flow-path control to prevent COCs from migrating toward Gable Gap (Figure 5-22). Placement of a single or multiple injections wells between the area of groundwater contamination and Gable Gap would provide a means of altering the local groundwater gradient in a way that promotes a longer travel time eastward along the Central Plateau and toward the Columbia River (as opposed to through Gable Gap).

Source control and performance monitoring are fundamental aspects of this remedy component. Implementation would require the following elements:

- Modeling to support design of the flow-path control system
- Designing, siting, and installing wells to establish flow-path control
- Optimizing the system in response to performance data collected during remedy systemization and operations.

5.2.2.4 Enhanced Natural Attenuation. The pump-and-treat system described in this alternative is intended to capture and actively remove approximately 95% of the contaminant mass in 200-ZP-1 OU groundwater. The dispersed low-concentration contaminants outside of hydraulic capture of the pump-and-treat system would undergo enhanced MNA. Section 5.2.1 (Alternative #1) describes how the natural attenuation processes are expected to occur. The flow-path control regime described in the previous section is intended to augment and enhance this process. Figure 5-3 portrays the portion of groundwater contamination (generally less than 100 μg/L carbon tetrachloride) that is targeted for enhanced natural attenuation.

5.2.2.5 Requirements. Requirements for the 200-ZP-1 OU pump-and-treat system were derived from the ARARs and RAOs identified in Section 3.0 and Appendix B of this FS:

- The pump-and-treat system must meet the ARARs identified in Section 3.3 and Appendix B.
- Reinjected effluents must meet discharge criteria for specific constituents.
- A hazardous waste determination must be made on any disposed residue (e.g., filters or IX media).
- The pump-and-treat and disposal system must limit exposures to future site workers to as low as reasonably achievable.

5.2.2.6 Implementation Considerations. When designing for flow-path control, the following factors should be considered:

- Size of plume or contaminated property
- Groundwater flow rate and direction of flow
- Proximity of site to existing groundwater extraction wells
- Hydrogeologic conditions
- Pumping rate needed to control plume
- Positioning of extraction wells to achieve containment
- Expected height and profile of water table at steady-state pumping
- Expected concentration of contaminants in pumped water (modeled over time)
- Effects of reinjection of groundwater (if this option is being considered)
- Environmental effects of pumping (i.e., impact on water levels in nearby surface water)
- Site-specific natural attenuation mechanisms.

Specific locations of wells and the location and design of treatment trains would be determined during remedial design. A portion of the treated effluent would be reinjected into the aquifer upgradient of the high-concentration area to assist in mobilizing the remaining contamination, driving it toward the extraction wells.

Low concentrations (i.e., areas of groundwater contaminated with the COC at concentrations less than 100 μg/L) would be treated using MNA. Specific performance objections would be defined to evaluate the efficiency of MNA processes in this aquifer. Additional information on the implementation of MNA is discussed in Section 5.2.1. In the event that a persistent source zone (i.e., DNAPL) in the groundwater is identified during design investigation or routine monitoring, a source-zone treatment action (e.g., ERH or anaerobic bioremediation) may be implemented as a contingency measure.

5.2.3 Contingency Measures

The 200-ZP-1 OU CSM does not suggest DNAPL or other source zone within the aquifer system. Both the RI report (DOE/RL-2006-24) and the two DNAPL reports (DOE/RL-2006-58 and DOE/RL-2007-22) analyzed the mass balance. There exists a large uncertainty term in both the total carbon tetrachloride dispersed to the major waste sites as well as currently accounted carbon tetrachloride mass. Because of this uncertainty, the potential for a currently undiscovered DNAPL source term in the groundwater system is carried forward as an uncertainty in the 200-

ZP-1 conceptual contaminant distribution model. Should a DNAPL or persistent source term be identified through continued groundwater monitoring and characterization, or during installation or operation of the remedial design, proposed contingency measures will then be implemented to address the source term.

These measures were developed in order to assess the capabilities of technologies to treat a potential source zone. Based on the current understanding of contaminant morphology in the very high-concentration portion of the carbon tetrachloride-contaminated groundwater, it was assumed that a hypothetical source area of approximately 2–ha (5-ac) would present a conservative maximum size of a newly discovered area of source material. This hypothetical source zone would most likely be a single lens of DNAPL in fine-grained aquifer sediments and would not be continuous over a large area.

Note that these are contingency measures (i.e., not an independent remedy) and were developed for implementation in order to complement an existing operational remedy in the event that a source zone would be identified. The contingency measures developed for evaluation include two supplemental technology options to facilitate removal of contaminants from possible persistent source areas of the aquifer. The two supplemental technologies are in situ ERH and in situ anaerobic bioremediation. As applied here, heating targets VOCs (i.e., carbon tetrachloride, chloroform, and TCE) and degradation products. Anaerobic bioremediation is effective for organic contaminants.

In addition to the activities described under this pump-and-treat alternative, supplemental contingency measures would also include the following:

- Evaluation of indigenous micro-organisms
- Selection of suitable substrate(s)
- Design and construction of substrate injection system
- Design, sitting, and construction of an ERH system.

5.2.3.1 Electrical Resistance Heating. ERH is an in situ thermal treatment process, applied (in this instance) to facilitate the remediation of continuous source contamination (carbon tetrachloride, existing as DNAPL or as a dissolved high-concentration source material). See Figure 5-4 for an illustration of contaminant source material treatment in groundwater using ERH. Implementation will be contingent upon the presence of DNAPL or high-concentration source material, which to date has not been identified (see Section 2.5). If such a source is encountered, a 2–ha (5-ac) treatment area would be implemented that would include 345 wells to depth up to 99 m (325 ft). Well placement would target the lens of source material in the aquifer (not be entire aquifer thickness). The amount of heat required for operation of ERH treatment in 2 ha (5 ac) by 24.4 m (80 ft) would require approximately 48.6 kWh per acre-foot (estimated from 150 kWh per cubic meter). The ERH is intended to target suspected source-term areas where DNAPL is located within the pore spaces of fine-grained sediments (i.e., silts). PNNL-13560 identified three heating effects that may enhance remedial efforts:

- Heating may reduce the viscosity of the DNAPL, making it more susceptible to extraction in DNAPL form.
- Heating may also increase the solubility of the contaminant, facilitating more rapid dissolution.
- Sufficient heating can volatilize or enhance the solubility of the DNAPL. If not extracted with a SVE system, these vapors will dissolve in an aqueous phase at higher

concentrations than before heating, facilitating the remediation process via hydrolysis (see section 5.2.1.3) and using the pump-and-treat technology.

In the recommended configuration, hydrolysis, viscosity reduction, and solubility enhancement are the primary treatment mechanisms. The ERH process is expected to be a technologically feasible means of mobilizing DNAPL confined in the less permeable portions of the aquifer and, therefore, facilitates extraction.

5.2.3.2 Anaerobic Bioremediation. In situ anaerobic bioremediation is implemented by altering physical conditions in the aquifer to encourage the proliferation of existing or introduced micro-organisms that metabolize COCs. See Figure 5-5 for an illustration of contaminant source material treatment in groundwater using anaerobic bioremediation. This is done by injecting an electron-donor substrate into selected portions of the aquifer. Treatment would be applied to areas up to 2 ha (5 ac) and using 35 wells that are 20 cm (8 in.) in diameter and screened 67 to 91.4 m (220 to 300 ft) in depth.

Two classes of substrate are available. Insoluble substrates (e.g., vegetable oil) are long-lasting but have a limited radius of influence (approximately 7 m [23 ft]) from the injection well. Soluble substrates (e.g., molasses) disperse better in the aquifer but must be replenished more frequently. In situ anaerobic bioremediation requires the presence of desirable micro-organisms (either indigenous or introduced), sufficient substrate to encourage a thriving population, and sufficient time.

This technology is expected to be cost effective for addressing contamination in less permeable intervals of the aquifer (i.e., residual source areas) by reducing mass and impacting the migration of contaminants. Because contaminants are treated in situ (i.e., in place), there is no waste stream to manage or air emissions to control, and activity-based risks to human health and the environment are minimized.

5.2.3.3 Requirements. Requirements for the 200-ZP-1 OU pump-and-treat system were derived from the ARARs and RAOs identified in Section 3.0 and Appendix B of this FS:

- The pump-and-treat system must meet the ARARs identified in Section 3.4 (Appendix B).
- Reinjected effluents must meet discharge criteria for specific radionuclides.
- The pump and treat system will be designed to achieve the RAOs defined in Section 3.3.
- A hazardous waste determination must be made on any disposed residue (e.g., filters or IX media).
- The pump-and-treat and disposal system must limit exposures to future site workers to as low as reasonably achievable.

Figure 5-1. Illustration of Treatment and Containment Components of Alternative #2.

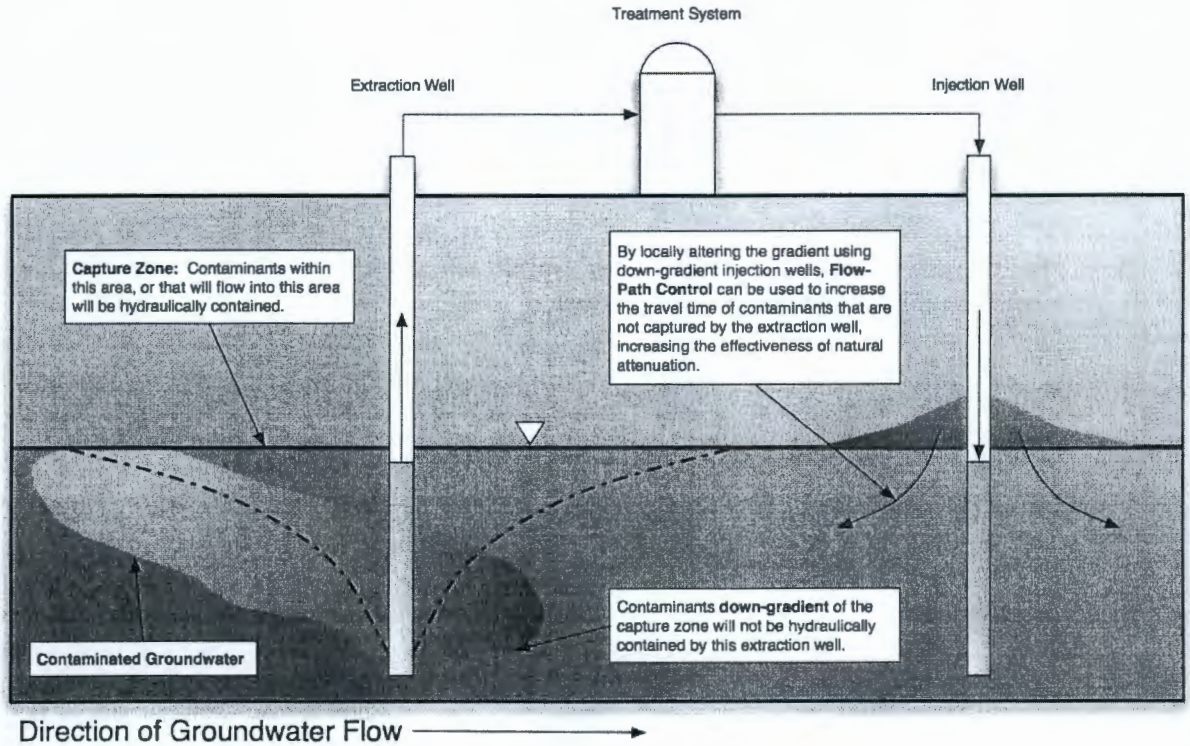


Figure 5-2. Targeted Flow-Path Control to Prevent the Contaminants of Concern from Migrating Toward Gable Gap.

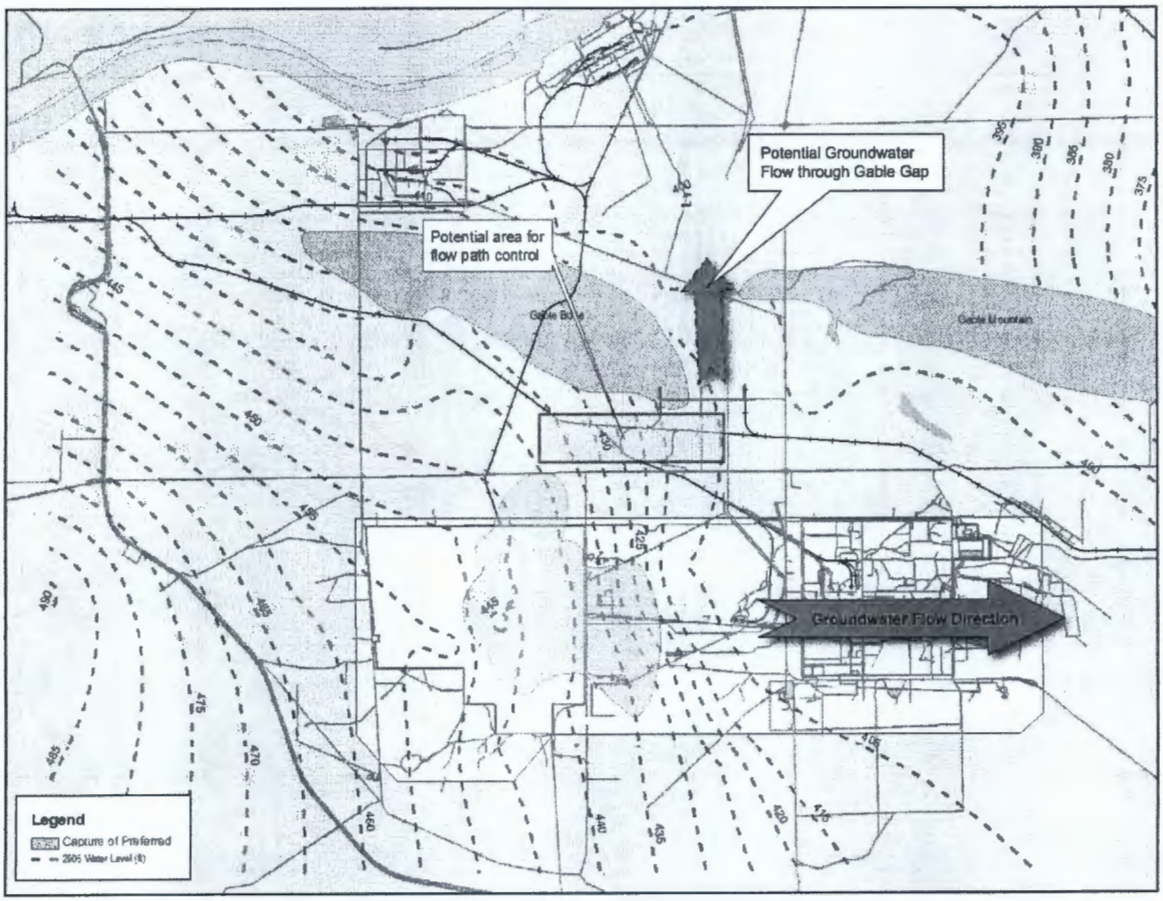


Figure 5-3. Area of Groundwater Contamination Planned for Enhanced Monitored Natural Attenuation as Part of Alternative #2.

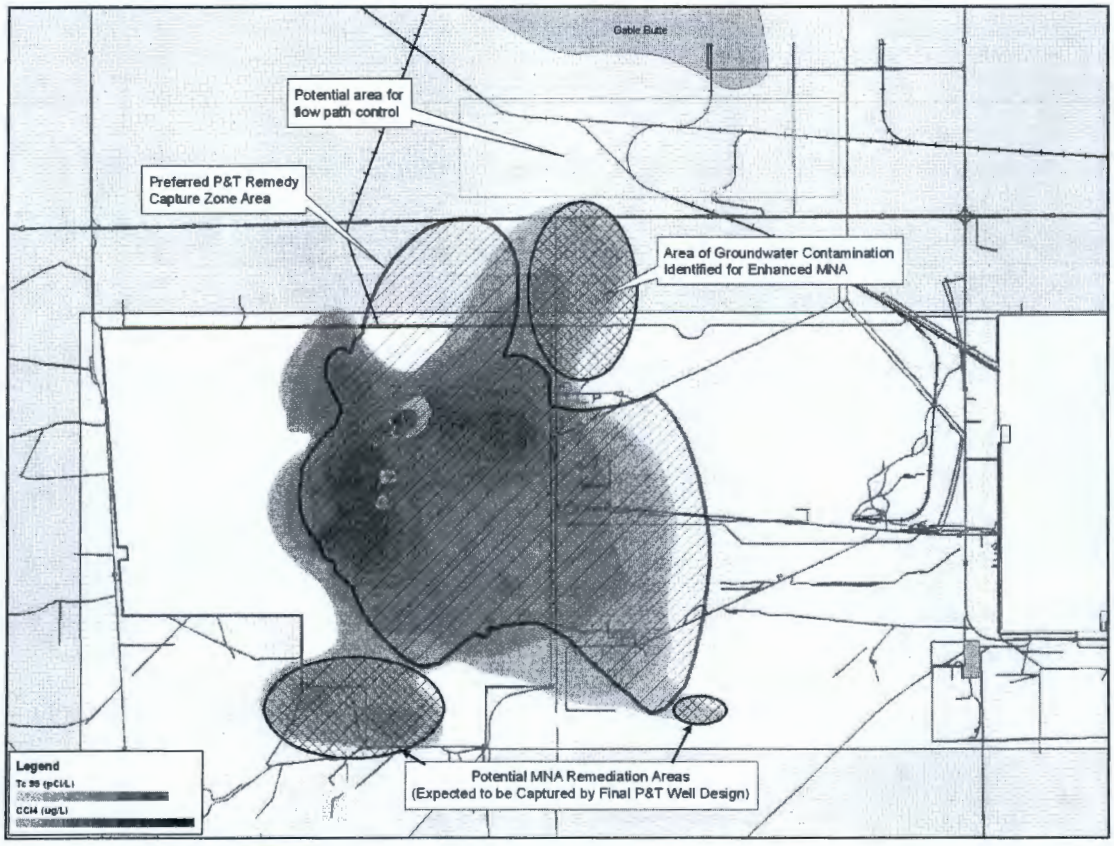


Figure 5-4. Illustration of Dense Nonaqueous Phase Liquid or Dissolved High-Concentration Source Material in Groundwater Undergoing Treatment Using Electrical Resistance Heating.

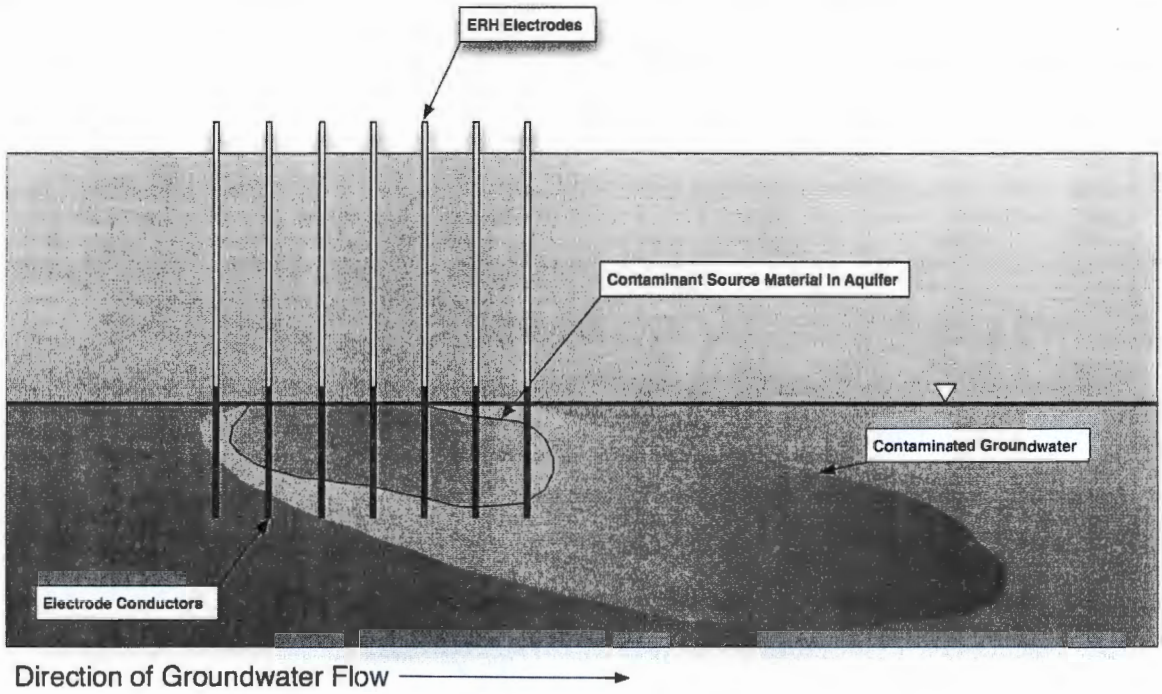
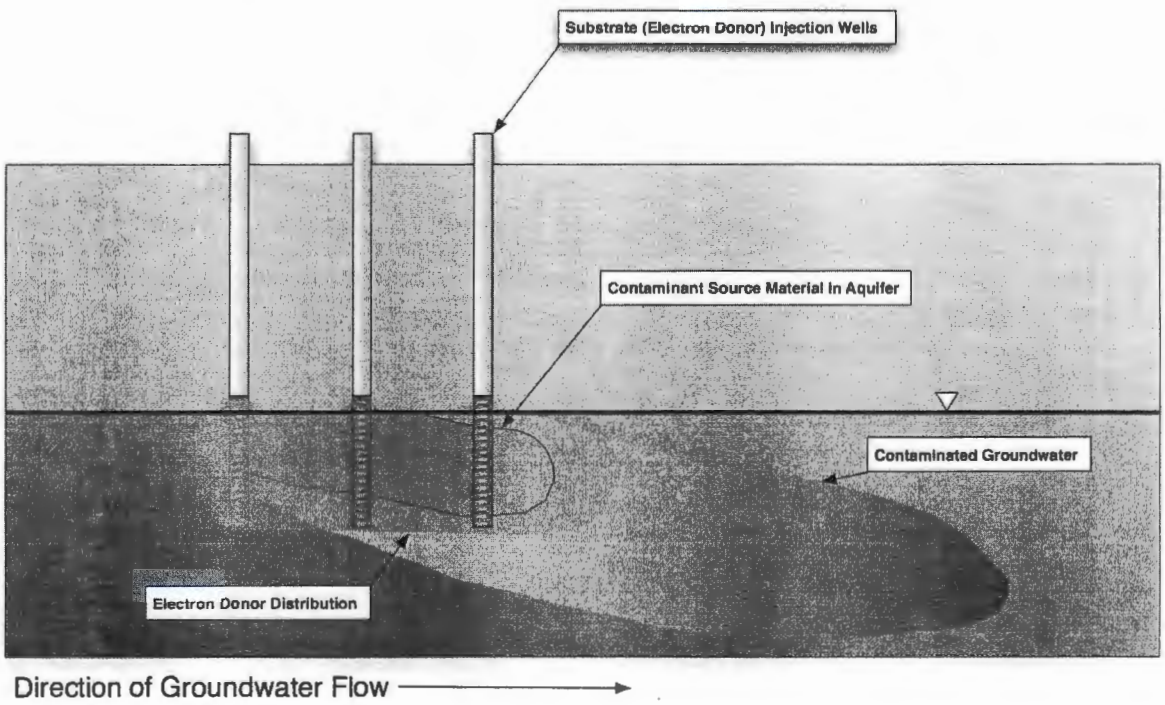


Figure 5-5. Illustration of Dense Nonaqueous Phase Liquid or Dissolved High-Concentration Source Material in Groundwater Undergoing Treatment Using Bioremediation.



6.0 DETAILED ANALYSIS OF ALTERNATIVES

In this section, the remedial alternatives developed in Section 5.0 are analyzed in detail. The results of this analysis are used in Section 7.0 for comparison of the remedial action alternatives. A preferred remedy is presented in Section 7.0 and is used to develop a final remedial action. This FS provides the technical background and analysis necessary to support the selection of a preferred remedy and development of a final remedial action.

6.1 PURPOSE OF DETAILED ANALYSIS

This section describes the purpose of the detailed analysis, provides an overview of the CERCLA evaluation criterion, and discusses each alternative in terms of these evaluation criteria. This analysis should provide sufficient supporting information to aid in the comparative analysis of Section 7.0 and allow an appropriate remedy to be selected.

6.2 OVERVIEW OF COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT OF 1980 EVALUATION CRITERIA

The remedial action alternatives are analyzed in detail with respect to the CERCLA evaluation criteria defined in the EPA guidance for RIs and FSs (EPA/540/G-89/004) to address the statutory requirements and the technical and policy considerations important for selecting remedial alternatives. The nine CERCLA criteria are as follows:

- Threshold criteria:
  1. Overall protection of human health and the environment
  2. Compliance with ARARs
- Primary balancing criteria:
  3. Long-term effectiveness and permanence
  4. Reduction of toxicity, mobility, or volume through treatment
  5. Short-term effectiveness
  6. Implementability
  7. Cost
- Modifying criteria:
  8. State/support agency acceptance
  9. Community acceptance.

A public comment period will be held as part of the Proposed Plan to formally assess the modifying criteria as the Proposed Plan is reviewed and final selection of a preferred alternative is made. As a result, modifications may occur to the remedial action alternatives, or new remedial action alternatives may be selected.

6.2.1 Overall Protection of Human Health and the Environment

Remedial action alternatives are assessed to determine whether they can adequately protect human health and the environment. This analysis provides a summary evaluation of how the alternative reduces risk through treatment, engineering, or institutional controls. The evaluation

also examines whether alternatives pose any unacceptable short-term risk or cross-media impacts (i.e., fate and transport of contaminants through land, air, or water). Overall protection of human health and the environment draws on the assessments of the other evaluation criteria, particularly long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs, which are discussed below.

6.2.2 Compliance with Applicable or Relevant and Appropriate Requirements

Evaluation with respect to this criterion addresses whether an alternative will meet identified Federal and state ARARs (as defined in CERCLA, Section 121 and Appendix B of this FS). The detailed analysis summarizes the requirements that are applicable or relevant and appropriate for each alternative and describes how the alternative meets those requirements. If an alternative is not expected to achieve compliance with a given ARAR, the basis for justifying one of the waivers allowed under CERCLA (40 CFR 300.430[f][1][ii][C]) is presented below:

1. The alternative is an interim measure and will become part of a total remedial action that will attain the applicable or relevant and appropriate Federal or state requirement.
2. Compliance with the requirement will result in greater risk to human health and the environment than other alternatives.
3. Compliance with the requirements 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 remedial actions within the state.

6.2.3 Long-Term Effectiveness and Permanence

Long-term effectiveness and permanence are criteria to evaluate the anticipated ability of the alternatives to maintain reliable protection of human health and the environment for the duration of risk above allowable levels once the RAOs are met. Alternatives will be assessed for the long-term effectiveness and permanence they afford, along with the degree of certainty that the alternative will prove successful. Factors that may be considered in this assessment include the following:

- The magnitude of residual risk from untreated waste or treatment residuals remaining at the conclusion of the remedial activities, including their volume, toxicity, and mobility.
- The adequacy, reliability, and durability of controls such as containment systems and institutional controls necessary to manage treatment residuals and untreated waste. For example, this factor addresses uncertainties associated with land disposal for providing long-term protection from 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 should the remedial action need replacement.

6.2.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

The degree to which the alternatives employ treatment or recycling to reduce toxicity, mobility, or volume will be assessed, including how the treatment is used to address the principal threats. This evaluation relates to the statutory preference for selecting a remedial action that employs treatment to reduce the toxicity, mobility, or volume of hazardous substances. Factors that will be considered, as appropriate, include the following:

- Treatment or recycling processes that the alternatives employ and the materials that they will treat.
- The amount of hazardous substance, pollutants, or contaminants that will be destroyed or recycled.
- The degree of expected reduction in toxicity, mobility, or volume of the waste because of the treatment or recycling and the specification of which reductions are occurring.
- The degree to which the treatment is irreversible.
- The type and quantity of residuals that will remain following treatment, taking into consideration their persistence, toxicity, mobility, and propensity to bioaccumulate.
- The degree to which treatment reduces the inherent hazards posed by the principal threats.

6.2.5 Short-Term Effectiveness

Short-term effects during implementation of the remedial action will be assessed, including the following:

- Short-term risks that might be posed to the community.
- Potential risks or hazards to workers, and the effectiveness and reliability of protective measures.
- Potential environmental effects and the effectiveness and reliability of mitigative measures.
- Time until protection is achieved.

6.2.6 Implementability

The ease or difficulty of implementing the alternatives will be assessed by considering the following types of factors, as appropriate:

- Technical feasibility, including technical difficulties and unknowns associated with constructing and operating the technology, reliability of the technology, ease of undertaking additional remedial actions, and ability to monitor the effectiveness of the remedy.
- Administrative feasibility, including activities required to coordinate with other offices and agencies and the ability and time needed to obtain any necessary approvals and permits for offsite actions from other agencies.
- Availability of required materials and services.

6.2.7 Cost

The cost estimates presented in this FS are order-of-magnitude level, as described in CERCLA guidance. These costs are based on a variety of information, including quotes from vendors and service providers in the area of the site, generic unit costs, conventional cost-estimating guides, and prior experience. The FS-level cost estimates shown have been prepared for guidance in project evaluation and implementation from information available at the time of the estimate. The bases for the costs presented in the following sections are discussed in Appendix C. The actual cost of the project will depend on true labor and material costs, actual site conditions, competitive market conditions, final project scope, the implementation schedule, and other variable factors. A significant uncertainty that would affect the cost is the actual volume of contaminated groundwater. Most of these uncertainties would affect all of the costs presented in this FS similarly and, therefore, are relative and have no real impact on the decision results.

Capital costs include those expenditures required to implement a remedial action. Both direct and indirect costs are considered in the development of cost estimates. Direct costs include construction costs or expenditures for equipment, labor, and materials required to implement a remedial action. Indirect costs include those associated with engineering, permitting (as required), construction management, and other services necessary to carry out a remedial action.

Annual operation and maintenance costs (which include operation labor, maintenance materials, and labor, energy, and purchased services) have also been estimated. The estimates include those operation and maintenance costs that may be incurred even after the initial remedial activity is complete.

6.3 ANALYSIS OF INDIVIDUAL ALTERNATIVES

The assembled remedial action alternatives represent a range of distinct waste management strategies that address human health and environmental concerns associated with the 200-ZP-1 OU. The selected alternative will be further refined as necessary during the preliminary remedial design phase. The description of the alternatives and the analysis with respect to the nine criteria presented below reflect the fundamental components of the various alternative approaches being considered for this OU.

The primary remedial process options forming each alternative are presented in Section 5.0. The technical description of each alternative with respect to appropriateness to each COC and overall protection of human health and the environment; compliance with ARARs; long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementablity; and cost are discussed in the following subsections.

Each alternative is analyzed in the context that there is no continuing source from the vadose zone. Remedies formulated for the vadose zone OUs are designed to protect groundwater resources. However, in the event of vadose zone treatment system failure, containment of contaminated source material moving from the vadose zone into groundwater is within the scope of 200-ZP-1 OU remedy development and optimization.

6.3.1 Alternative #0 – No Action

Alternative #0 is required under CERCLA (40 CFR 300.430[e][6]) to provide a baseline comparison to the other alternatives. This alternative assumes that there will be no institutional controls for the OU (i.e., the institutional controls currently in place would be lost and no

remedial action would be performed). Because remedial activities would not be implemented with the no action alternative, long-term human health and environment risks for the site essentially would be the same as those identified in the BRA.

6.3.1.1 Overall Protection of Human Health and the Environment. Alternative #0 provides no control of exposure to the contaminated areas and no reduction in risk to human health posed through ingestion of groundwater. It also allows for the possible continued migration of groundwater contamination. Using the transport simulation discussed in Appendix D, areas impacted in the future at concentrations posing a risk greater than 1×10^{-4} were identified and are shown in Figure 6-1.

6.3.1.2 Compliance with Applicable or Relevant and Appropriate Requirements. Because no action is being taken, this alternative would not invoke any ARARs.

6.3.1.3 Long-Term Effectiveness and Permanence. This alternative includes no controls for exposure and no long-term management measures. All current and potential future risks would remain under this alternative.

6.3.1.4 Reduction of Toxicity, Mobility, or Volume Through Treatment. This alternative provides no reduction in toxicity, mobility, or volume of the contaminated groundwater through treatment.

6.3.1.5 Short-Term Effectiveness. There would be no additional risks posed to the community, workers, or the environment as a result of this alternative being implemented.

6.3.1.6 Implementability. There are no implementability concerns posed by this remedy because no action would be taken.

6.3.1.7 Cost. The present-worth cost and non-discounted cost of Alternative #0 are estimated to be $0 because there would be no action taken. This is an assumed "walk-away" cost, and no actual calculations were performed.

Table 6-2 summarizes the previous discussion.

6.3.2 Alternative #1 – Institutional Controls Supplemented by Monitored Natural Attenuation

The institutional controls associated with this alternative are currently implemented onsite through the Sitewide institutional controls plan (DOE/RL-2001-41). Implementation of this alternative would include continuance of deed restrictions, public advisories, permit programs, monitoring, surveillance, and maintenance.

6.3.2.1 Overall Protection of Human Health and the Environment. The overall protection of human health and the environment provided under this alternative is high as long as institutional controls are in effect and natural attenuation processes are proven effective. Human health risks exceeding allowable levels are identified in the BRA for the unrestricted baseline scenario. Institutional controls currently in effect in at the Hanford Site mitigate those risks and are similar to the controls that would be implemented as part of this alternative. Institutional controls would eliminate human health risks because site access restrictions would eliminate or otherwise interrupt all exposure pathways identified in the BRA. In the absence of institutional

controls, the risk would be the same as those identified in Alternative #0 because no remediation or permanent engineered access controls are implemented.

6.3.2.2 Compliance with Applicable or Relevant and Appropriate Requirements. Exposure to groundwater with contaminant concentrations exceeding MCLs would be prevented under this alternative via groundwater monitoring and the implementation of institutional controls. Use of groundwater for drinking and/or agricultural purposes is prohibited under this alternative. Such uses would be in effect until remediation goals are achieved.

6.3.2.3 Long-Term Effectiveness and Permanence. Alternative #1 does not provide long-term engineered controls to limit exposure of human and ecological receptors to contaminated groundwater, although natural attenuation processes are expected to eventually achieve remediation goals. However, these remediation goals will most likely not be met by the year 2150. The effectiveness of this alternative for reducing risks to future workers inside the 200-ZP-1 OU boundary, and for hypothetical future outside the industrial land-use area, is limited to the duration of institutional controls (see Figure 6-2). If the institutional controls fail, the risks will exceed acceptable standards. This alternative would require a 5-year review until excess carcinogenic risk associated with the COCs is reduced to less then 1×10^{-4} or noncarcinogenic risk is reduced to less than or equal to a hazard quotient of 1.

6.3.2.4 Reduction in Toxicity, Mobility, or Volume Through Treatment. This alternative does not include treatment to reduce toxicity, mobility, or volume. A reduction in toxicity will occur via natural attenuation of contaminants (e.g., reduction, radioactive decay, and dilution). Using institutional controls to prevent and eliminate potential exposure pathways of contaminants provides the necessary reduction in risk to acceptable levels.

6.3.2.5 Short-Term Effectiveness. Institutional controls would prevent any exposure to discharge of contaminated groundwater above MCLs. Institutional controls enforce safety issues, monitoring, public awareness, etc., which minimize risk to the public and workers from potential short-term impacts. Risks associated with ecological resources would be minimized by imposing appropriate buffer zones and temporal restrictions, as well as by the presence of appropriate cultural resource experts.

6.3.2.6 Implementability. Institutional controls are currently implemented at the 200-ZP-1 OU and can be readily implemented in the event that additional institutional controls are needed.

6.3.2.7 Cost. The present-worth cost and non-discounted cost of Alternative #1 are estimated for a 30-year time period to be $3,100,000 and $4,800,000, respectively. Alternative #1 consists of seven general activities: institutional controls, site inspection and surveillance, existing site maintenance, MNA, reporting, site reviews, and monitoring. Costs are discussed in detail in Appendix C.

Table 6-2 summarizes the previous discussion.

6.3.3 Alternative #2 – Full-Scale Pump-and-Treat, Institutional Controls, Monitored Natural Attenuation, Plus Groundwater Flow-Path Controls

Pump-and-treat is currently operating as an IRM for the primary organic contaminants found at the 200-ZP-1 OU. In this alternative, groundwater contaminated with the COC is treated using extraction wells, an onsite air stripper, and GAC to meet long-term RAOs. Additional treatment

technologies that impact metal and radiological contaminants will need to be added to the current treatment train (e.g., IX). The treated groundwater is discharged to injection wells.

In order to capture and actively reduce 95% of the mass of the COC, the new system would include 14 to 27 new injection wells and 14 to 27 new extraction wells, with a combined flow rate of approximately 3,180 to 6,113 L/min (840 to 1,615 gpm). These wells will be located to capture the targeted portions of contaminated groundwater and to provide hydraulic containment, while contaminated groundwater is removed for ex situ treatment. This will impede further migration of the COC, while reducing risk through mass reduction. Contaminants not captured by the modified pump-and-treat system are expected to reach long-term RAOs via radioactive decay or natural attenuation enhanced by a flow-path control regime.

The groundwater model calculations (described in Appendix D) for this scenario indicate that the RAOs will be achieved. Monitoring will verify that groundwater cleanup goals have been reached and will be used to evaluate the effectiveness of the alternative.

In the remedy concept described in Section 5.0, treatment of the extracted groundwater is accomplished using a treatment train including IX, air stripping, and GAC. (Note that the final technology selection for the treatment train would not occur until the remedial design; the described technologies were included because of the long history of site-specific implementation. In some cases, a technology that was screened out in Section 4.0 may be found appropriate for inclusion in the final treatment system design.) The IX media is used to treat metal wastes including technetium-99, chromium (III), and hexavalent chromium using specially formulated resins with an exchangeable ion bonded to the resin via a weak ionic bond. This treatment will strip the groundwater of metals (e.g., technetium-99 and chromium) and other inorganic contaminants from the influent groundwater in order to treat and prepare the extracted groundwater to enter into the next phase of the treatment train. The air stripper (e.g., a counter-current packed tower where air enters at the bottom and exhausts at the top while the groundwater flows down through the media) would be designed to meet cleanup goals for the COC, degradation products of the COC, and constituents above the MCL. Exhaust air would be discharged through carbon beds to collect the volatiles by adsorption. Carbon would be regenerated or disposed after bed exhaustion.

Upon completion of groundwater treatment, the water would be returned to the aquifer. Injection of treated groundwater back into the aquifer will require compliance with the substantive requirements of *State Waste Discharge Permit Number ST 4511* (Ecology 2005). Treated water will be periodically sampled and tested for verification of cleanliness for reinjection.

Alternative #2 components include (1) use of institutional controls; (2) long-term groundwater monitoring; (3) MNA; (4) pumping of groundwater followed by a treatment train to remove the COC and its degradation products, and to ensure that discharge criteria are achieved; and (5) reinjection of treated effluent to drive contaminants toward the extraction well network, and implement a flow-path control regime to enhance MNA downgradient of the hydraulic capture zone. See Section 5.0 for more detailed discussion of the assembled alternative.

6.3.3.1 Overall Protection of Human Health and the Environment. Alternative #2 will replace the IRM pump-and-treat system implemented in accordance with the 200-ZP-1 OU Interim ROD (EPA/ROD/R10-95/114). The existing pump-and-treat system was designed for remediation of high-concentration portions of the carbon tetrachloride plume. Specifically, it was targeted at regions of >2,000 μg/L concentration.

As discussed in Section 5.0, Alternative #2 is designed to remove and treat the following:

- Contaminant mass in the high-concentration areas of carbon tetrachloride contamination.
- Contaminant mass from the areas of contamination that exceed 100 μg/L of carbon tetrachloride.
- Technetium-99 contamination near WMA-T and WMA-TX/TY. However, the conceptual remedy developed for this alternative does not account for technetium-99 in the vadose zone at these locations because characterization efforts are still underway. The final remedial design will consider information from the investigation, as the quantity of technetium-99 in the vadose zone may present a future source of groundwater contamination that may impact cleanup times, extraction network configuration, and treatment train design.

Implementation of the system (as described in this section and in Section 5.0) will capture the portions of the carbon tetrachloride contamination exceeding 100 μg/L (translating to an approximate risk of 1×10^{-4} using an industrial scenario), as well as treating other constituents to reduce cumulative risk. The pump-and-treat system will ensure the protection of human health and the environment. The treatment train technology will include an IX treatment system to treat metal and radionuclide contaminants (i.e., technetium-99 and chromium). This alternative will provide contaminant destruction (mass removal) of approximately 95% of the overall contaminant mass and will inhibit contaminated groundwater from migrating from the 200-ZP-1 OU toward the Columbia River as treatment occurs. Extraction of the groundwater in conjunction with the selected treatment train inhibits ingestion of contaminated groundwater by ecological and human receptors via reduction, degradation, and/or dilution of organic contaminants. The MNA processes will operate in the areas of the plumes outside of the pump-and-treat capture zone (see Figure 6-2 and Figure 5-3) where the carbon tetrachloride concentrations are generally less than 100 μg/L. This alternative would protect both human health and the environment by reducing risks to human health by ingestion of contaminated groundwater and will reduce the possibility of further environmental degradation. Areas of tritium contamination are located within the capture zone of the pump-and-treat system and will be hydraulically contained during system operation, providing time for natural attenuation processes to work.

The modeling results discussed in Appendix D provide further information on the estimated effectiveness of the pump-and-treat alternative and the impact on overall protection of human health and the environment.

This alternative employs additional treatment that would alter the flow of contaminated groundwater and increase the time it takes to migrate outside of the industrial land-use area. With MNA enhanced by flow-path control, the longitudinal dispersion of the contaminated groundwater will increase, allowing further degradation through radioactive decay and natural attenuation. As a result, this alternative greatly reduces the chances for ingestion of contaminated groundwater by any ecological receptor and reduces the possibility of further environmental degradation.

6.3.3.2 Compliance with Applicable or Relevant and Appropriate Requirements. This alternative would meet the applicable RAOs. To meet action-specific ARARs, the remedy's air emission system (e.g., the air stripper) would be designed to meet Washington State air pollution

control standards. Dangerous waste regulations may apply to wastes generated as a result of system operations and treatment of groundwater.

6.3.3.3 Long-Term Effectiveness and Permanence. In order to provide long-term effectiveness for this alternative, effective operation and maintenance of the pump-and-treat system is required. Removal of contaminant mass in the short term will enhance the long-term effectiveness of natural attenuation processes. Institutional controls would be used to limit risk to present and potential future users of the contaminated groundwater. While long-term effectiveness of institutional controls has been demonstrated, long-term monitoring will be necessary to ensure that natural attenuation is progressing as expected. Necessary modifications to the pump-and-treat system or institutional controls would be made based on performance and groundwater monitoring results. The flow-path control component of this alternative would alter the local flow of groundwater and allow additional time for natural attenuation processes to work on areas of contaminated groundwater not hydraulically captured by the pump-and-treat system's extraction wells. This alternative would require a 5-year review until excess carcinogenic risk associated with the COCs is reduced to less then 1×10^{-4} or noncarcinogenic risk is reduced to less than or equal to a hazard quotient of 1.

6.3.3.4 Reduction of Toxicity, Mobility, or Volume Through Treatment. The proposed treatment processes would reduce the volume of the contamination in the groundwater by removing/treating 95% of the mass of the contaminants (identified in Section 3.3), except for tritium in groundwater; however, this alternative does provide hydraulic containment for tritium. A reduction in toxicity for tritium (and the remaining mass of carbon tetrachloride, as well as other constituents discussed in Section 3.0) is expected to occur indirectly through enhanced MNA. Flow-path control would increase the migration time of contaminated groundwater, thus increasing the chance for natural attenuation processes to occur. This alternative meets the statutory preference for using treatment as the principal element because the principal threats are addressed through treatment.

To date, investigations in the vadose zone have not identified continuing sources of principal threat contaminants (i.e., carbon tetrachloride) to the groundwater in the 200-ZP-1 OU (see Sections 2.4 and 2.5). Future potential threats to groundwater originating in the vadose zone will be addressed as part of the remedial actions within the overlying source OUs. However, the final remedial design must consider the impacts of potential vadose zone sources on contaminant distribution in the groundwater.

It should be noted that the alternatives assembled in this section do not account for technetium-99 in the vadose zone near WMA-T or WMA-TX/TY because characterization efforts at these locations are ongoing. These characterization efforts are focusing on refining the understanding of contamination in both the vadose zone and the groundwater, and on developing estimates of the mass and distribution of technetium-99. Because of its high mobility, the mass of technetium-99 in the vadose zone will be a significant consideration in the final remedial design (i.e., the quantity of technetium-99 in the vadose zone may present a future source of groundwater contamination because of its high mobility).

While investigations to date have indicated that DNAPLs are not a concern in the groundwater at the 200-ZP-1 OU, the CSM presented in Section 2.5 accounts for the possibility that future characterization and performance-monitoring efforts may discover source areas of DNAPL or high-concentration carbon tetrachloride. One concern regarding the implementation of pump-

and-treat remedies is that they can be an inefficient method for remediation of DNAPL source zones and contaminated fine-grained units. In the event that such source areas are discovered during future characterization and monitoring, other source-zone treatment technologies (e.g., the contingency measures discussed Section 6.3.4) may be implemented to achieve RAOs.

6.3.3.5 Short-Term Effectiveness. This alternative can be constructed and operated with little or no additional risk to the public, workers, or the environment. The potential for slight, temporary increase of risk to the community (and workers) due to particulate emissions during construction of the pump-and-treat system would be controlled through the use of dust-control technologies (e.g., water or foam sprays). Exposure to COCs can be minimized by using proper personal protective equipment, using engineering controls, and following OSHA and DOE guidelines, rules, and regulations, as applicable.

6.3.3.6 Implementability. Pump-and-treat supplemented by flow-path control can be applied with straightforward and proven methods, and the remedy can be implemented using approximately 14 to 27 injection wells and between 14 and 27 extraction wells.

6.3.3.7 Cost. The present-worth cost and non-discounted cost of Alternative #2 are estimated to be $93,000,000 and $120,000,000, respectively. The present-worth cost of the 6,113-L/min (1,615-gpm) system would be approximately $180,000,000. Alternative #2 consists of seven general activities: institutional controls, site inspection and surveillance, existing site maintenance, MNA, reporting, site reviews, and monitoring. Alternative #2 specifically includes the costs associated with construction of the pump-and-treat system, IX systems annual operation and maintenance, performance monitoring (sampling), new well construction for 28 to 54 new wells, interconnecting piping, and flow-path control. It should be noted that flow-path control includes the strategic placement of the wells only and will be considered a no-cost option. Costs are discussed in detail in Appendix C.

Table 6-2 summarizes the previous discussion.

6.3.4 Contingency Measures

The 200-ZP-1 OU CSM does not indicate DNAPL or a source zone based on current understanding. In the event that a DNAPL or source zone area is discovered during monitoring or characterization, contingency technologies are available for to supplement treatment. These measures, while not presented as a specific alternative for analysis, are assessed for completeness. These measures would be implemented in addition to Alternative #2 and would consist of the same treatment train technologies as described in Alternative #2 (i.e., pumping, IX, GAC, and air stripping), and the measures incorporate either in situ ERH or in situ anaerobic bioremediation to address the hypothetical DNAPL or source area.

The ERH technology involves the use of electricity and applies it into the ground through electrodes. The electrodes can be installed either vertically within or horizontally underneath areas of groundwater contamination. Heating is achieved by passing three-phase or six-phase electrical current between electrodes, which are in electrical contact but out of phase with each other. As electrical current passes through the aquifer between electrodes, the natural electrical resistance of aquifer soils results in heating. Advantageously, high electrical conductivity zones include low-permeability silt or clay and areas where DNAPL or high-concentration, aqueous-phase contamination is likely to occur. ERH treatment would require air standards to be met

and, if selected, a collection mechanism for steam and contaminant vapors would be investigated further upon final design.

In situ anaerobic bioremediation relies on effective distribution of substrate and the subsequent activity of appropriate bacteria. A groundwater recirculation system would be used to distribute a soluble substrate (e.g., molasses) over large distances in an attempt to enhance reductive dechlorination of carbon tetrachloride and reduction of technetium-99. However, the success in stimulating dechlorination without producing hazardous byproducts, and contaminant reduction versus other types of anaerobic activity, is dependent upon the microbial ecology and groundwater geochemistry (e.g., presence of other electron acceptors). The ability to stimulate appropriate microbial activity would need to be evaluated to confirm whether RAOs would be met (PNNL-15954).

In addition, if future groundwater monitoring identifies unanticipated levels of contaminant flux from the vadose zone to the aquifer, then the scale, operating parameters, and duration of this alternative would be modified to mitigate any unacceptable levels of risk to human health or the environment.

6.3.4.1 Overall Protection of Human Health and the Environment. In addition to the same benefits that Alternative #2 has for protecting human health and the environment, this alternative provides additional treatment capabilities that may accelerate treatment of areas containing DNAPL or areas of low hydraulic conductivity.

In situ ERH would reduce risk to human health by treating potential DNAPL that can be a continuous long-term source of contamination in the groundwater. However, protection of human health and the environment is still maintained in Alternative #2. Anaerobic bioremediation would reduce risk to human health and the environment by dechlorination, reduction, or adsorption of the COC (carbon tetrachloride).

These measures would reduce risks to human health by ingestion of contaminated groundwater and would reduce the possibility of further environmental degradation.

6.3.4.2 Compliance with Applicable or Relevant and Appropriate Requirements. Implemented as a contingency to supplement another remedy, these measures would meet applicable RAOs. To meet action-specific ARARs, any air emission system incorporated in a final remedy would be designed to meet Washington State air pollution control standards.

In situ ERH is only applicable to organic compounds and will not assist in meeting chemical-specific ARARs, as well as other action-specific ARARs for inorganic or radionuclide contaminants. In situ ERH treatment would need to meet air emission requirements if the approach included vapor recovery.

In situ anaerobic bioremediation is likely to aid in meeting the chemical-specific ARARs, as well as other action-specific ARARs for the COC and its degradation products by the distribution of a soluble substrate, enhancing reductive dechlorination to these contaminants.

Underground Injection Control (UIC) Program registration may be required for injection of potable water for wetting of electrodes or wells intended for injecting substrate (WAC 173-218).

6.3.4.3 Long-Term Effectiveness and Permanence. The long-term effectiveness of this alternative would be enhanced by the application of in situ technologies that reduce the inherent hazards posed by areas difficult to remediate using pump-and-treat alone. In the unlikely event

that these treatment technologies fail, groundwater could still be extracted and treated, posing little risk of further groundwater contamination. Because the source of contamination will remain in-place, long-term monitoring, maintenance, and control would be required under this alternative. Institutional controls would be used to limit exposure to present and potential future users of the contaminated groundwater. This alternative would require a 5-year review.

6.3.4.4 Reduction of Toxicity, Mobility, or Volume Through Treatment. In situ ERH and anaerobic bioremediation are interchangeable in this alternative because they are used in conjunction with pump-and-treat technologies. In situ ERH would increase the mobility of DNAPLs, thus increasing the amount of contaminant available for collection and treatment. In situ anaerobic bioremediation would reduce contaminants to nonhazardous products or to insoluble chemical forms, enhancing the ability to extract and treat contaminants (PNNL-15954). This alternative meets the statutory preference for using treatment as the principal element because the principal threats are addressed through treatment.

6.3.4.5 Short-Term Effectiveness. This alternative can be constructed and operated with little or no additional risk to the public, workers, or the environment. In situ ERH has increased risks associated with operation of vapor-phase treatment processes and electrical/steam equipment. The risks associated with anaerobic bioremediation are primarily from the installation of wells. The potential for slight, temporary increase of risk to the community (and workers) due to particulate emissions during construction of pump-and-treat system would be controlled through the use of dust-control technologies (e.g., water or foam sprays). Exposure to hazardous constituents can be minimized by using proper personal protective equipment, using engineering controls, and following OSHA and DOE guidelines, rules, and regulations, as applicable.

6.3.4.6 Implementability. In situ ERH can be applied with straightforward and implementable methods but requires many more remediation wells than most of the other process options for in situ treatment. Implementation of in situ anaerobic bioremediation can also be difficult due to the number of wells required to apply the substrate. In addition, the large scale of such an anaerobic bioremediation poses difficulties in distributing substrate in a manner that promotes an effective treatment operation. (See Alternative #2 for a discussion of the implementability of the pump-and-treat portion of the remedy.)

6.3.4.7 Cost. The total present-worth and non-discounted costs for ERH are $172,000,000 and $175,000,000, respectively. The total present-worth and non-discounted costs for anaerobic bioremediation are $25,000,000 and $25,000,000, respectively. Costs are discussed in detail in Appendix C.

Table 6-2 summarizes the previous discussion.

Figure 6-1. Future Impacts at Concentrations Posing a Risk Greater Than 1 x 10^{-4} (Using an Industrial Scenario).

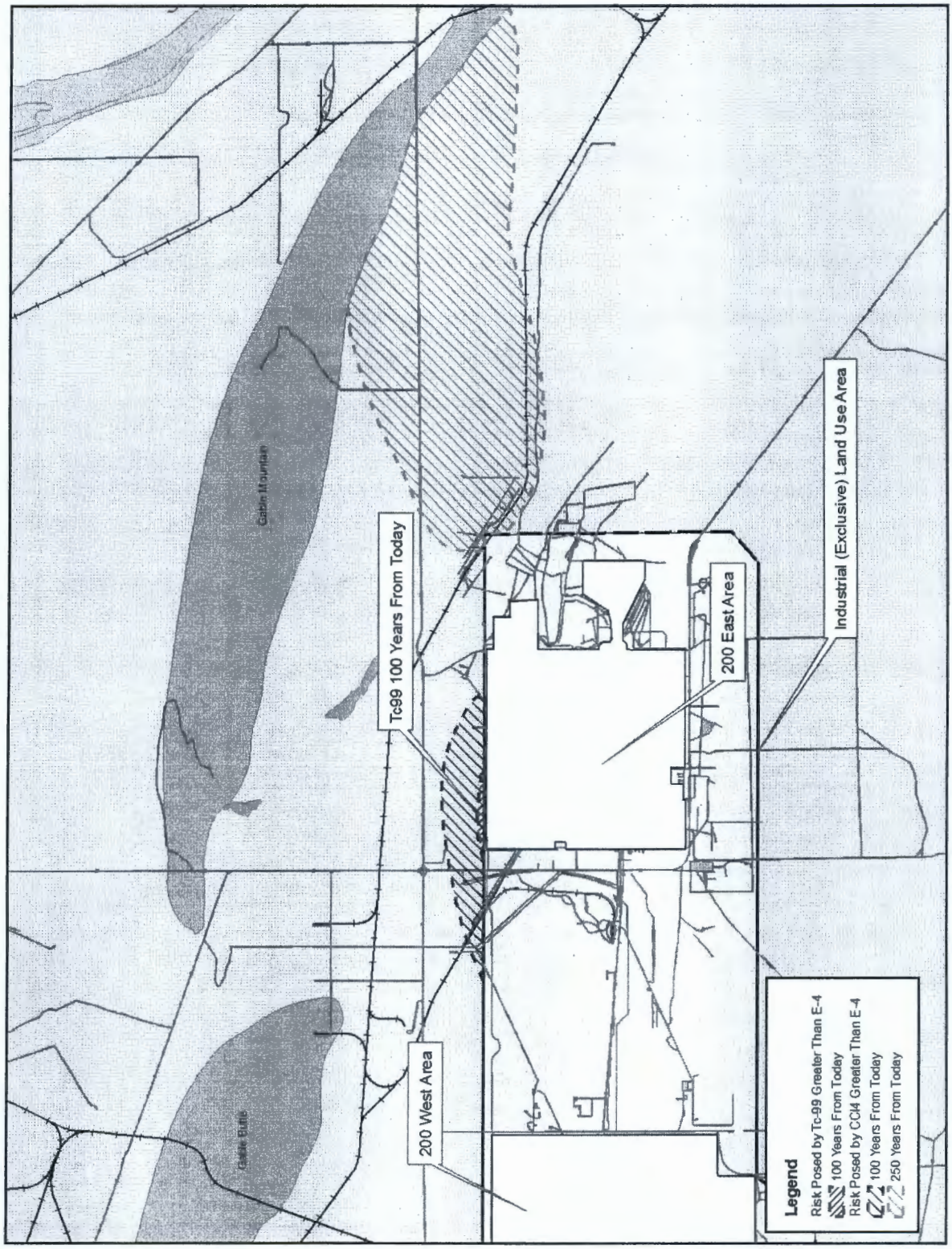


Figure 6-2. Areas Where Monitored Natural Attenuation Processes Will Operate Outside of the Pump-and-Treat Capture Zone.

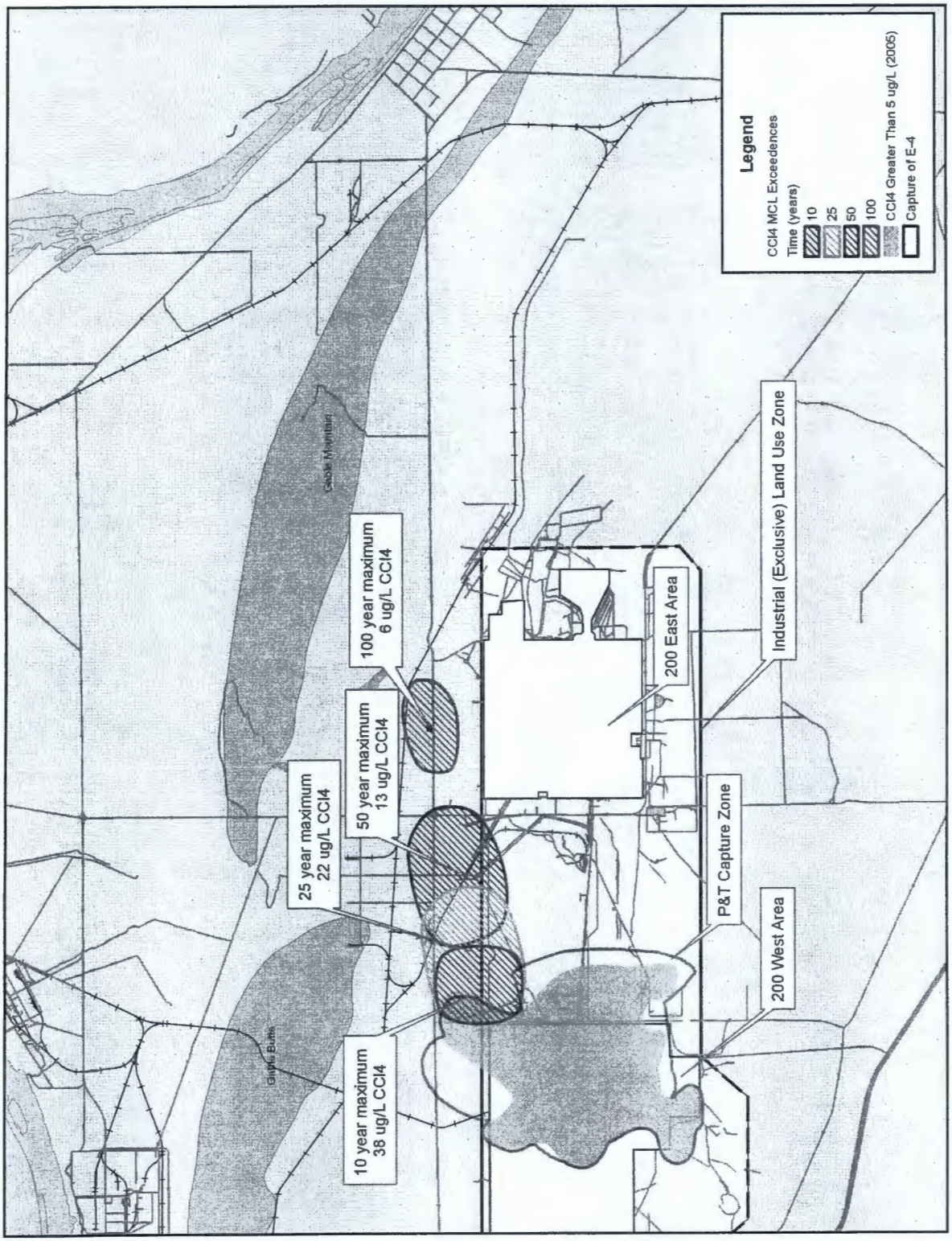


Table 6-1. Alternative Components.

Components of Remedy	Alternatives			
	#0	#1	#2	Contingency Measures
Institutional controls	No action	✓	✓	✓
Long-term monitoring		✓	✓	✓
Natural attenuation		✓	✓	✓
Pump-and-treat			✓	✓
Ex situ air stripping			✓	✓
In situ electrical resistance heating				✓
In situ anaerobic bioremediation				✓
Flow-path control			✓	✓
Granular activated carbon			✓	✓

Table 6-2. Summary of Alternatives. (5 sheets)

Criteria	Alternative #0 No Action	Alternative #1 Institutional Controls Supplemented by MNA	Alternative #2 Full-Scale Pump-and-Treat, Institutional Controls, MNA, Plus Groundwater Flow-Path Controls	Contingency Measures to Implement In Situ Technologies
Overall Protection of Human Health and the Environment				
Direct contact	No significant reduction in risk.	No significant reduction in risk	No significant reduction in risk	No significant reduction in risk.
Groundwater ingestion for existing users	No reduction in risk.	No reduction in risk.	Reduction in risk due to increase in of migration time prior to reaching the Columbia River.	Reduction in risk due to increase in of migration time prior to reaching the Columbia River.
Groundwater ingestion for future users	No reduction in risk.	No reduction in risk.	Additional containment may decrease risk for ingestion by increase the time it take to reach the Columbia River.	Additional containment may decrease risk for ingestion by increase the time it take to reach the Columbia River.
Environmental protection	Allows all COCs to continue migrating towards the Columbia River.	Allows all COCs to continue migrating towards the Columbia River.	Pump-and-treat with flow-path control lengthens migration time, providing additional time for radioactive decay and natural attenuation to occur.	Pump-and-treat with flow-path control lengthens migration time, providing additional time for radioactive decay and natural attenuation to occur.
Compliance with ARARs				
Chemical-specific ARARs	Does not meet groundwater standards.	Does not meet groundwater standards.	Would meet MCLs or a risk level of 1×10^{-4}.	Would meet MCLs or a risk level of 1×10^{-4}.
Location-specific ARARs	No location-specific ARARs were identified.	No location-specific ARARs were identified.	No location-specific ARARs were identified.	No location-specific ARARs were identified.
Action-specific ARARs	Would not invoke any action-specific ARARs because there will be no action.	Would not invoke any action-specific ARARs because there will be no engineered controls.	Would meet air release standards from air strippers and vapor extraction system. Would meet UIC and NPDES requirements.	Would meet air release standards from air strippers and vapor extraction system. Would meet UIC and NPDES requirements.
Other criteria and guidance	Would allow ingestion of groundwater that may exceed MCLs or a risk level of 1×10^{-4} for residential farmer users outside the core zone.	Would allow ingestion of groundwater that may exceed MCLs or a risk level of 1×10^{-4} for residential farmer users outside the core zone.	Would prevent ingestion of groundwater that may exceed MCLs or a risk level of 1×10^{-4} for residential farmer users outside the core zone.	Would prevent ingestion of groundwater that may exceed MCLs or a risk level of 1×10^{-4} for residential farmer users outside the core zone.

Table 6-2. Summary of Alternatives. (5 sheets)

Criteria	Alternative #0 No Action	Alternative #1 Institutional Controls Supplemented by MNA	Alternative #2 Full-Scale Pump-and-Treat, Institutional Controls, MNA, Plus Groundwater Flow-Path Controls	Contingency Measures to Implement In Situ Technologies
Long-Term Effectiveness and Permanence				
Direct contact – ingestion	Source has not been removed. Existing risk will remain.	Source has not been removed. existing risk will remain.	Risk is reduced; all groundwater is contained within the pump-and-treat system.	Risk is reduced; all groundwater is contained within the pump-and-treat system.
Groundwater – ingestion for existing users	Risk will increase do to the removal of institutional controls.	Under this alternative, groundwater use is prohibited until the year 2150.	Under this alternative, groundwater use is prohibited until the year 2150.	Under this alternative, groundwater use is prohibited until the year 2150.
Groundwater – ingestion for future users	Risk increases as area of contamination increases. Eventually natural attenuation and radioactive decay will decrease risk.	Future risk increases as plume migrates to residents. Eventually natural attenuation and radioactive decay will decrease risk.	Pump-and-treat will reduce risks via treatment, containment, and natural attenuation processes.	Pump-and-treat may reduce risks by allowing more time for radioactive decay and natural attenuation to reduce contamination.
Adequacy and reliability of controls	Lack of institutional controls and engineered controls over the remaining contamination. No reliability.	Lack of engineered controls over the remaining contamination. No reliability.	Pump-and-treat extraction controls contaminated groundwater.	Pump-and-treat extraction controls contaminated groundwater.
Need for 5-year review	Review would be required to ensure that adequate protection of human health and the environment is maintained.	Review would be required to ensure that adequate protection of human health and the environment is maintained.	Review would be required to ensure that adequate protection of human health and the environment is maintained.	Review would be required to ensure that adequate protection of human health and the environment is maintained.
Reduction of Toxicity, Mobility, or Volume Through Treatment				
Treatment process used	None.	None.	Extraction wells, injection wells IX, GAC and ex situ air stripping.	Extraction, IX, GAC, and groundwater air stripping; ERH and in situ anaerobic bioremediation.
Amount destroyed or treated	None.	Amount destroyed will depend on length of half-life and natural attenuation processes.	95% of all contaminated mass will be hydraulically contained; the remaining 5% will depend on the natural attenuation processes.	95% of all contaminated mass will be hydraulically contained; the remaining 5% will depend on the natural attenuation processes.
Reduction of toxicity, mobility, or volume	None.	Reduction will not be significant because no engineered treatment process would be implemented.	95% of all contaminated mass will be hydraulically contained or treatment to the 1×10^{-4} risk level.	95% of all contaminated mass will be hydraulically contained or treatment to the 1×10^{-4} risk level.

Table 6-2. Summary of Alternatives. (5 sheets)

Criteria	Alternative #0 No Action	Alternative #1 Institutional Controls Supplemented by MNA	Alternative #2 Full-Scale Pump-and-Treat, Institutional Controls, MNA, Plus Groundwater Flow-Path Controls	Contingency Measures to Implement In Situ Technologies
Irreversible treatment	None.	None.	Regeneration of carbon used for air-stream treatment.	Regeneration of carbon used for air-stream treatment.
Type and quantity residuals remaining after treatment	None.	None.	The 5% of COCs that will remain after treatment will be reduced through natural attenuation processes. Residual will be dependent on efficiency of natural attenuation processes.	The 5% of COCs that will remain after treatment will be reduced through natural attenuation processes. Residual will be dependent on efficiency of natural attenuation processes.
Statutory preference for treatment	Does not satisfy.	Satisfies.	Satisfies.	Satisfies.
Short-Term Effects				
Community protection	No increased risk to community.	No increased risk to community.	No increased risk to community, but increase in dust may occur during system installation.	No increased risk to community, but increase in dust may occur during system installation.
Worker protection	Risk to workers may increase due to loss of institutional controls.	No significant risk to workers.	Protection is required against dermal contact, vapor or dust inhalation during construction, and operation of vapor extraction system and air stripper.	Protection is required against dermal contact, vapor or dust inhalation during construction and operation of vapor extraction system, ERH and in situ anaerobic bioremediation, and air stripper.
Environmental impacts	Continues impact from existing conditions.	Continues impact from existing conditions.	Vapor extraction may impact air quality and odors but is monitored to ensure that air emissions are met. Aquifer draw-down during groundwater extraction.	Vapor extraction may impact air quality and odors but is monitored to ensure that air emissions are met. Aquifer draw-down during groundwater extraction.
Time until action is complete	Not applicable because no action is taken.	Not applicable because no engineered action is taken.	Groundwater remedial action will be completed when MCLs or a risk level of 1×10^{-4} is reached.	Groundwater remedial action will be completed when MCLs or a risk level of 1×10^{-4} is reached.

Table 6-2. Summary of Alternatives. (5 sheets)

Criteria	Alternative #0 No Action	Alternative #1 Institutional Controls Supplemented by MNA	Alternative #2 Full-Scale Pump-and-Treat, Institutional Controls, MNA, Plus Groundwater Flow-Path Controls	Contingency Measures to Implement In Situ Technologies
Implementability				
Ability to construct and operate	No construction or operation costs.	No construction or operation costs.	Pump-and-treat implemented at the site for carbon tetrachloride treatment; additional wells for flow-path control would need to be installed.	Pump-and-treat implemented at the site for carbon tetrachloride treatment. Installation of ERH and in situ anaerobic bioremediation.
Ease of doing more action if needed	May need to go through the FS/ROD process again.	May need to go through the FS/ROD process again.	Simple to extend groundwater extraction system and flow-path control system. May require expansion of existing treatment building.	Simple to extend groundwater extraction system and may require expansion of existing treatment building. Additional wells and monitoring may be needed for in situ technologies.
Ability to monitor effectiveness	No monitoring. Failure to detect COC contamination may lead to ingestion of contaminated groundwater.	Monitoring will provide notice of noncompliance before significant exposure occurs.	Monitoring will provide notice of noncompliance before significant exposure occurs.	Monitoring will provide notice of noncompliance before significant exposure occurs.
Ability to obtain approvals and coordinate with other agencies	No approval necessary.	No approval necessary.	UIC registration and vapor discharge and NPDES permits would be necessary.	UIC registration and vapor discharge and NPDES permits would be necessary.
Availability of services and capacities	No services or capacities required.	No services or capacities required.	Electric services and capacities are needed.	Electric services and capacities are needed.
Availability of equipment, specialists, and materials	None required.	Need specialists for monitoring of groundwater.	Need specialists and plant operators for installation and monitoring of system.	Need specialists and plant operators for installation and monitoring of system.
Availability of technologies	None required.	None required.	Treatment system may require pilot testing.	Treatment system may require pilot testing.

Table 6-2. Summary of Alternatives. (5 sheets)

Criteria	Alternative #0 No Action	Alternative #1 Institutional Controls Supplemented by MNA	Alternative #2 Full-Scale Pump-and-Treat, Institutional Controls, MNA, Plus Groundwater Flow-Path Controls	Contingency Measures to Implement In Situ Technologies	
Cost				ERH	Anaerobic Bioremediation
Capital cost:	$0	$35, 000	$43,000,000		
Non-discounted cost:	$0	$4,800,000	$120,000,000	$175,000000	$25,000,000
Present-worth cost:	$0	$3,100,000	$93,000,000 (800 gpm) $180,000,000 (1,615 gpm)	$172,000,000	$25,000,000

ARAR = applicable or relevant and appropriate requirement
COC = contaminant of concern
ERH = electrical resistance heating
FS = feasibility study
GAC = granular activated carbon
gpm = gallons per minute
IX = ion exchange
MCL = maximum contaminant level
MNA = monitored natural attenuation
NPDES = National Pollutant Discharge Elimination System
ROD = Record of Decision
UIC = underground injection control

7.0 COMPARATIVE ANALYSIS OF ALTERNATIVES

The 200-ZP-1 OU remedial action alternatives (developed in Section 5.0 and analyzed in detail in Section 6.0) 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.

Alternatives are compared based on two of the three CERCLA categories, including threshold criteria and primary balancing criteria. The third category, modifying criteria (including state and community acceptance), will not be addressed until the Proposed Plan has been issued for public review. These modifying criteria will be addressed in the responsiveness summary and the ROD, which will be prepared following the public comment period.

Sections 7.1 and 7.2 present the remedial alternative comparisons relative to each evaluation criterion. Table 7-2 summarizes the relative performance of each groundwater alternative for each evaluation criterion.

7.1 THRESHOLD CRITERIA

Threshold criteria are of greatest importance in the comparative analysis because they reflect the key statutory mandates of CERCLA. The threshold criteria that any viable alternative must meet are as follows:

- Overall protection of human health and the environment
- Compliance with ARARs.

The 200-ZP-1 OU remedial action alternatives are compared with respect to the threshold criteria and are discussed in the following subsections.

7.1.1 Overall Protection of Human Health and the Environment

The primary measure of this criterion is the ability of an alternative to attain RAOs for groundwater at the 200-ZP-1 OU. The alternatives are compared in Table 7-1 with respect to attainment of RAOs and are discussed below. A summary discussion is provided in Table 7-2.

All alternatives, except Alternative #0, would meet RAO #1 by implementing institutional controls, including access restrictions through at least the year 2150. All alternatives, except Alternative #0, meet RAO #1 (see Section 3.4.1) equally well because institutional controls are applied uniformly across all of the alternatives. However, Alternative #1 may not meet RAO #1 by the year 2150.

RAO #2 (see Section 3.4.2) would be met for Alternative #2 through the implementation of institutional controls, pump-and-treat, and additional supplemental technologies that may be applied to assist in further reducing groundwater contamination (in the event that DNAPL or a continuing source is discovered). Alternative #1 would most likely not fulfill RAO #2 because the natural attenuation processes will not provide sufficient reduction in contaminant mass (and as a result, toxicity) to ensure that MCLs are not exceeded at the industrial land-use boundary by the year 2150.

Achievement of RAO #3 (see Section 3.4.3) is obtained by identifying boundaries that define the high-concentration areas contaminated by principal treat COC. For carbon tetrachloride, this

boundary is established at 100 µg/L. This level was an important factor when selecting alternatives that can prevent further spread of groundwater contaminated with the principal threat COC. Alternative #2 was selected as a potential remedy because it provide mechanisms that allow for hydraulic control of contaminated groundwater, as well as the ability to decrease toxicity and mass through active treatment. Portions of the contaminated groundwater not hydraulically contained by the pump-and-treat system (approximately 5% of the contaminant mass) will undergo treatment via natural attenuation enhanced by flow-path control. Alternative #2 would meet RAO #3.

All of the alternatives would meet RAO #4 (see Section 3.4.4), the prevention or mitigation of risk to workers performing remedial action. Alternative #0 is the no action alternative, as no remedial action is implemented; therefore, there is no risk to workers. Alternative #2 implements institutional controls, which call for administrative controls to protect remediation workers from occupational health risks.

All of the alternatives, with the exception of Alternative #0, will meet RAO #5 via implementation of appropriate institutional controls.

7.1.2 Compliance with Applicable or Relevant and Appropriate Requirements

A summary of compliance with the ARARs is provided in Table 7-2. The ARARs were identified in Appendix B. No location-specific ARARs were identified for any of the described alternatives. Alternative #0 would not meet groundwater standards, nor would it invoke any action-specific ARARs because there will be no action taken. Alternative #1 would not meet groundwater standards because principal threat contaminants will not meet MCLs as implemented in RAO #1 and RAO #2 (i.e., by the year 2150). However, Alternative #1 will most likely achieve MCLs after the year 2150. Alternative #1 would fulfill other action-specific ARARs via administrative controls and monitoring. Alternative #2 would meet MCLs as implemented in RAO #1 and RAO #2, as well as the implementation of institutional controls.

7.2 BALANCING CRITERIA

The 200-ZP-1 OU alternatives are compared with respect to the balancing criteria in the following discussion. The primary balancing criteria to which relative advantages and disadvantages of the alternatives are compared include the following:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, and volume through treatment
- Short-term effectiveness
- Implementability
- Cost.

The first balancing criterion assesses the ability of the alternative to remain effective for the duration of elevated risk. The second balancing criterion addresses the statutory preference for treatment as a principal element of the remedy and the bias against offsite land disposal of untreated material. Together with the third and fourth criteria, they form the basis for determining the general feasibility of each potential remedy. The final criterion addresses whether the cost associated with a potential remedy are proportional to its overall effectiveness, considering both the cleanup period and operation and maintenance requirements during and following cleanup. Therefore, it can be determined whether a potential remedy is cost effective

relative to others. Key trade-offs among alternatives will most frequently relate to one or more of the balancing criteria.

7.2.1 Long-Term Effectiveness and Permanence

Alternative #0 would not provide any long-term effectiveness or permanence because no engineered controls would be implemented. Alternative #1 would only be effective if institutional controls are maintained and natural attenuation processes continue to work. Since the groundwater contamination is most likely still present at this time, an elevated risk would still remain to human and ecological receptors. Alternative #2 would provide long-term effectiveness and permanence because all RAOs may be met using these alternatives.

7.2.2 Reduction in Toxicity, Mobility, or Volume Through Treatment

Alternatives #0 and #1 would only implement treatment through natural attenuation processes. Pump-and-treat technologies implemented with Alternative #2 would reduce the mass, mobility, and volume of contaminated groundwater until the RAOs are achieved.

7.2.3 Short-Term Effectiveness

No added risks to the public or the environment would result from implementing any of these alternatives; thus, only worker risk during the implementation of the remedy would occur. Alternative #1 has the best short-term effectiveness as a result of existing institutional controls, and monitoring could be continued with no added risks or hazards to workers. Construction and operation with Alternative #2 can be implemented with little or no additional risk to the public, workers, or the environment. The potential for slight, temporary increase of risk to the community (and workers) due to particulate emissions during construction of the full-scale pump-and-treat system and well installation would be controlled with dust-control technologies (e.g., water or foam sprays). Exposure to the COC can be minimized by using proper personal protective equipment, using engineering controls, and following OSHA and DOE guidelines, rules, and regulations, as applicable.

7.2.4 Implementability

Implementation of Alternatives #0 and #1 would be the most readily available remedy because Alternative #0 requires no action and Alternative #1 is currently implemented through the Sitewide institutional controls plan (DOE/RL-2001-41). Alternative #2 incorporates a full-scale, robust groundwater pump-and-treat system that would be technically and administratively implementable.

7.2.5 Cost

The present-worth cost for Alternative #0 is $0, Alternative #1 is $3,100,000, and Alternative #2 is $93,000,000, although the present-worth cost of larger system would be approximately $180,000,000 (see Appendix C for further details). The costs associated with these activities can change substantially because of the use of the habitat by a variety of wildlife and the potential for discovery of cultural activities. All of these issues will need to be considered in the remedial design and planning.

7.3 PREFERRED REMEDY

Based upon the outcome of the comparative analysis presented in Section 7.2, Alternative #2 (full-scale pump-and-treat, institutional controls, MNA, plus groundwater flow-path controls) is recommended as the preferred remedy. Further details of the modeling analysis are presented in Appendix D. As discussed in Section 5.0, Alternative #2 is designed to return groundwater in the 200-ZP-1 OU to beneficial use through attainment of Federal MCLs and to remove and treat the following:

- Contaminant mass in the high-concentration areas of carbon tetrachloride contamination
- Contaminant mass from the areas of contamination that exceed 100 μg/L of carbon tetrachloride (approximately 95% of the mass for the contaminant)
- Technetium-99 contamination near WMA-T and WMA-TX/TY.

The preferred treatment remedy, augmented with a flow-control regime, includes between 14 and 27 injection wells and 14 and 27 extraction wells at the locations shown in Figures 7-2 and 7-3, respectively. Each extraction well is expected to pump at a rate of approximately 227 L/min (60 gpm) for a total system extraction rate of 3,180 to 6,113 L/min (840 to 1,615 gpm). The preferred remedy hydraulically captures 95% of the mass of carbon tetrachloride and treats constituents above the MCL to reduce cumulative risk and return groundwater to beneficial use. Additionally, this conceptual design captures the entire portion of the groundwater exceeding the 1×10^{-4} risk (using an industrial scenario) for the COC. The locations of wells that will address high-concentration areas of carbon tetrachloride and technetium-99 are shown in Figures 7-4 and 7-5. Table 7-3 summarizes the capture of the selected remedy. The final pump-and-treat remedy design is expected to be somewhere between the scenarios presented in Figures 7-2 and 7-3. Ranges for the relative cleanup times for the preferred pump-and-treat remedy are shown in Figure 7-6. The remedy relies on the operation of the pump-and-treat system to remove contaminant mass (and thereby reduce risk). After sufficient mass has been removed, the pump-and-treat system will cease operations and natural attenuation processes will be the primary mechanism for remediation. Actual cleanup times will vary based on final design and remedy implementation details such as well locations, well screen lengths, well screen depths, and retardation coefficients for the target compounds.

To date, investigations in the vadose zone have not identified continuing sources of principal threat contaminants (i.e., carbon tetrachloride) to the groundwater in the 200-ZP-1 OU (see Sections 2.4 and 2.5). Future potential threats to groundwater originating in the vadose zone will be addressed as part of the remedial actions within the overlying source OUs. However, the final remedial design must consider the impacts of potential vadose zone sources on contaminant distribution in the groundwater.

It should be noted that this Alternative #2 does not account for technetium-99 in the vadose zone near WMA-T or WMA-TX/TY because characterization efforts at these locations are ongoing. These characterization efforts are focusing on refining the understanding of contamination in both the vadose zone and the groundwater, and developing estimates of the mass and distribution of technetium-99. Because of its high mobility, the mass of technetium-99 in the vadose zone will be a significant consideration in the final remedial design (i.e., the quantity of technetium-99 in the vadose zone may present a future source of groundwater contamination because of its high mobility).

Contingency measures, as well as optimization of the preferred remedy, will be invoked in the event that a persistent source zone (e.g., DNAPL) is discovered during ongoing remedial system performance monitoring. These contingency measures were formulated to address small, discrete areas of DNAPL or very high-concentration contaminant that could potentially be found in the fine-grained, discontinuous sediments within the aquifer. In such a scenario, the areas targeted for treatment are expected to be distributed over a small area (less than 2 ha [5 ac]). Contingency measures evaluated for use in this FS include in situ treatment technologies such as ERH or anaerobic bioremediation. The need for continuous sampling, analysis, and modeling will occur throughout the lifetime of this remedy to assist in the performance evaluation and implementation.

Figure 7-1. Implementation of the Preferred Remedy Pump-and-Treat System.

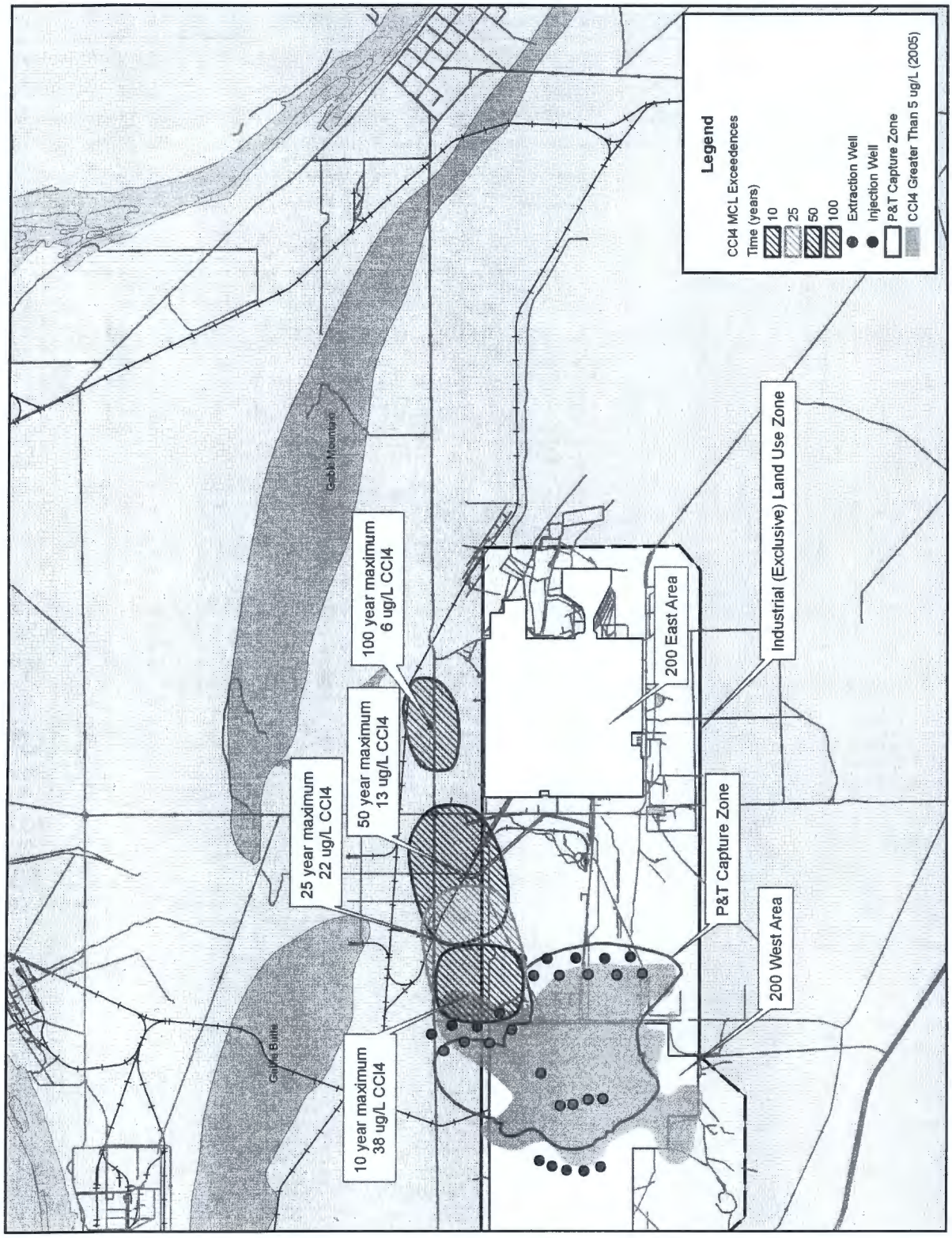


Figure 7-2. Calculated Capture Time of Groundwater for the Preferred Alternative (840 gpm).

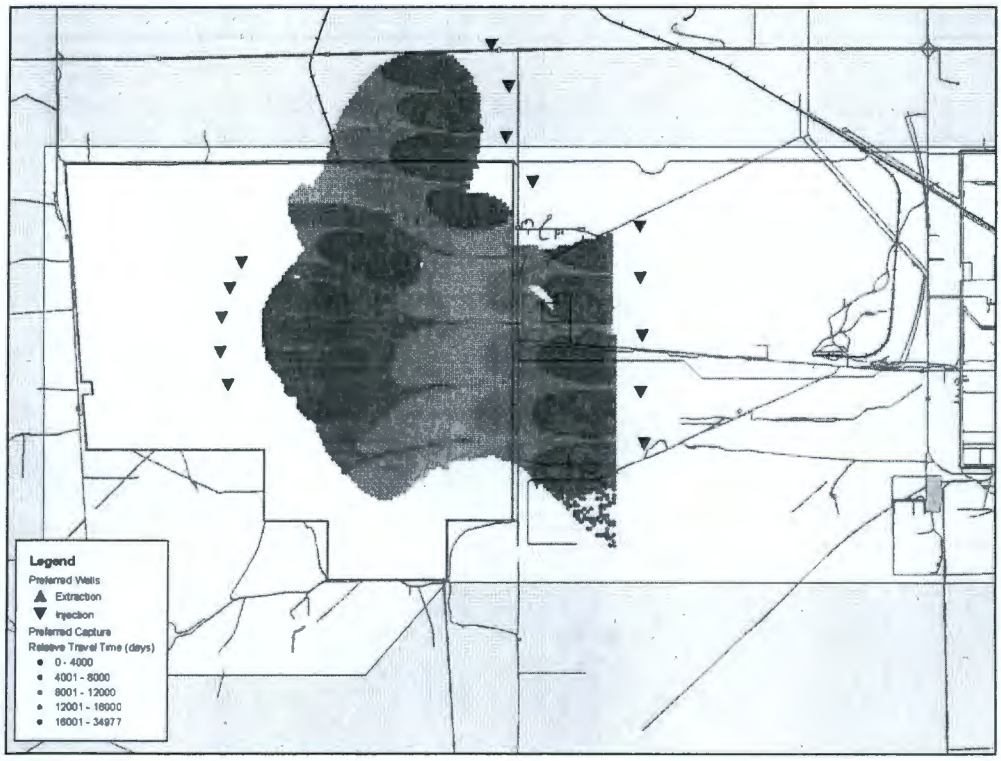


Figure 7-3. Calculated Capture Time of Groundwater for the Preferred Alternative (1,615 gpm).

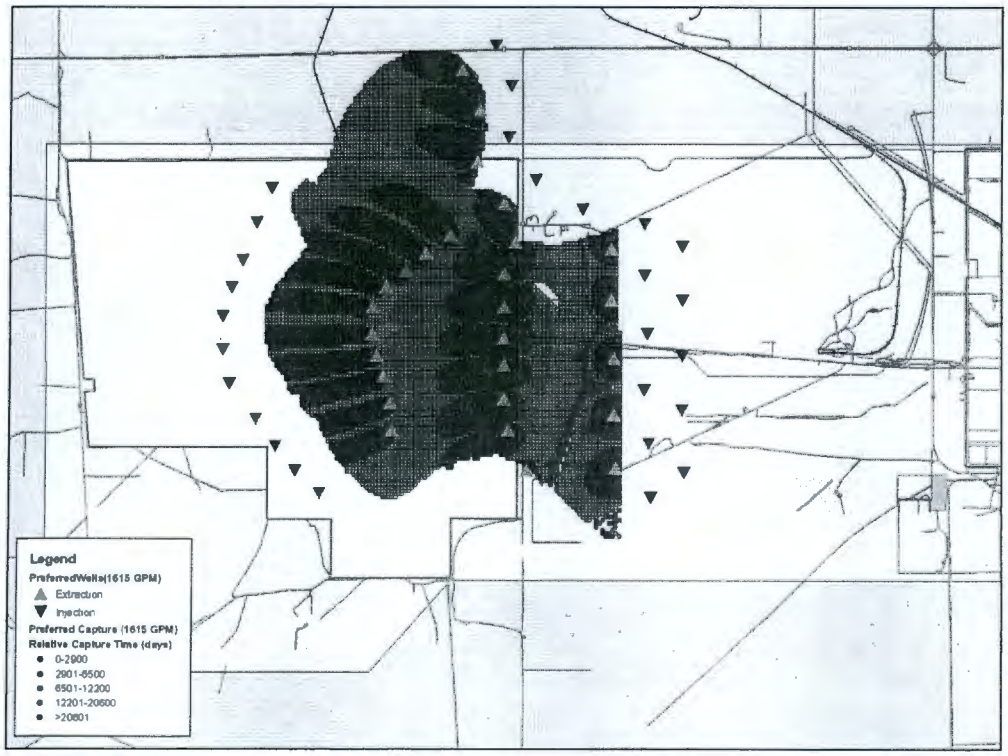


Figure 7-4. Well Locations for the Preferred Alternative (840 gpm).

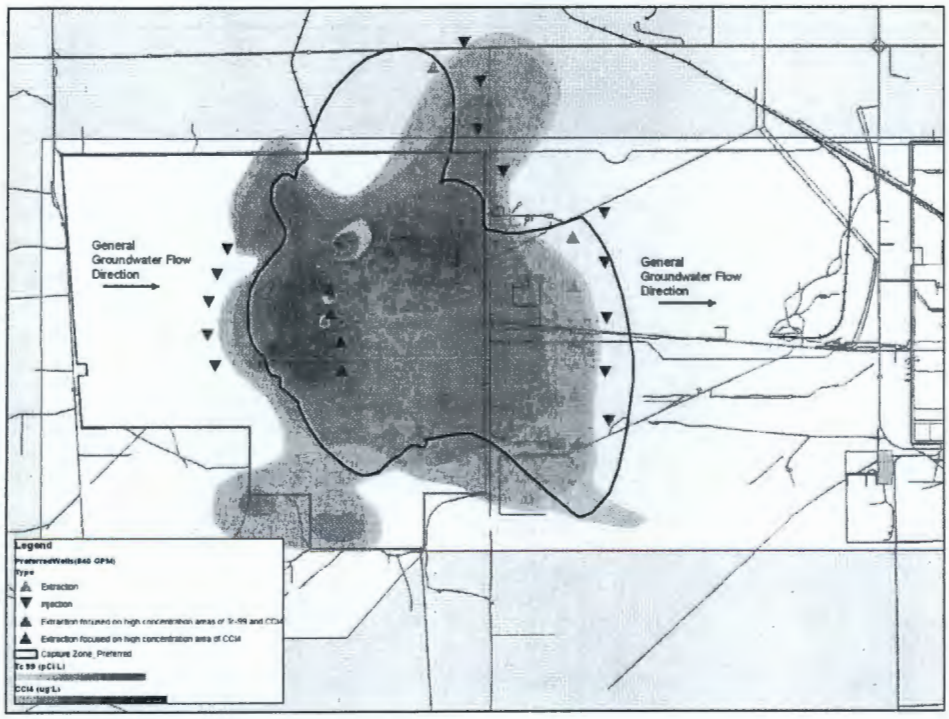


Figure 7-5. Well Locations for the Preferred Alternative (1,615 gpm).

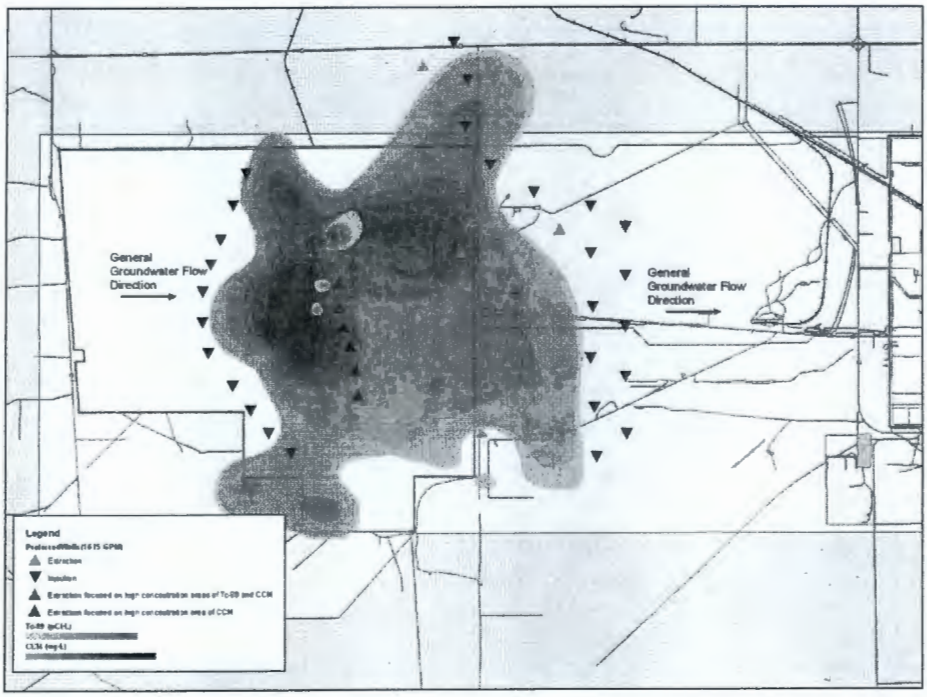


Figure 7-6. Relative Cleanup Time for Preferred Pump-and-Treat Remedy.

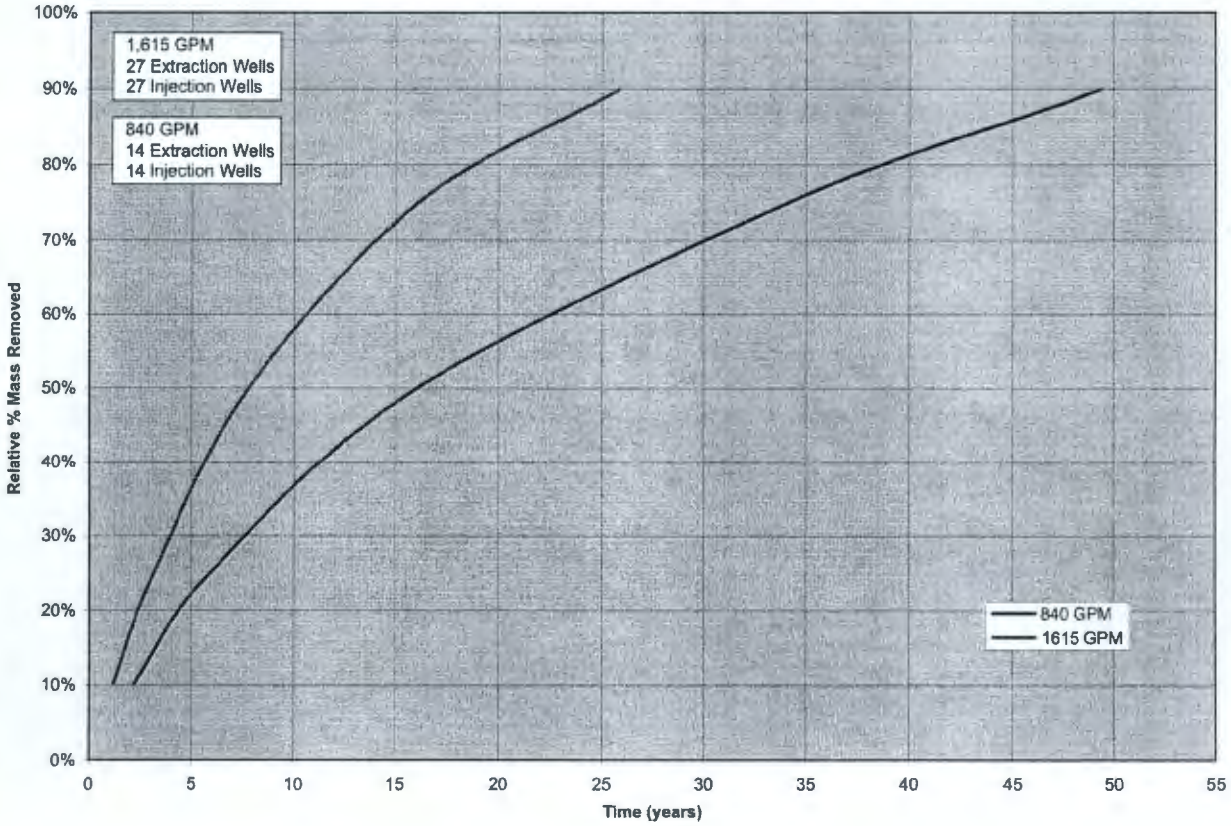


Table 7-1. Summary of Alternative Comparison with Respect to Attainment of Alternate Remedial Action Objectives.

Alternative	RAO #1	RAO #2	RAO #3	RAO #4	RAO #5
Alternative #0	No	No	No	Yes	No
Alternative #1	Yes	No	No	Yes	Yes
Alternative #2	Yes	Yes	Yes	Yes	Yes

NOTES:

RAO #1: Prevent or mitigate risk to human and ecological receptors associated with ingestion of and external exposure to contaminants in groundwater at levels that exceed ARARs and a carcinogenic risk of 1×10^{-4} or a hazard index of 1 (using an industrial scenario).

RAO #2: Prevent or mitigate the migration of contaminants in groundwater so contaminants do not reach levels in groundwater that exceed ARARs and a carcinogenic risk of 1×10^{-4} or a hazard index of 1 (using an industrial scenario).

RAO #3: Prevent the migration of high-concentration areas of principal threat contaminants in the 200-ZP-1 Operable Unit.

RAO #4: Prevent or mitigate occupational health risks to workers performing remedial action.

RAO #5: Provide the appropriate monitoring and institutional controls to ensure conditions suitable for future land uses.

No = does not meet RAOs
Yes = meets RAOs
ARAR = applicable or relevant and appropriate requirement
RAO = remedial action objective

Table 7-2. Summary of Comparative Analysis of 200-ZP-1 Operable Unit Alternatives.

Remedial Action Alternatives	Overall Protection of Human Health and the Environment	Compliance with ARARs and TBCs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume through Treatment	Short-Term Effects	Implementability	Cost
Alternative #0 – No action	This alternative does not meet the threshold criterion because it assumes that the institutional controls currently in place are no longer effective.	Would not invoke any ARARs that would need to be satisfied.	Will not provide any long-term effectiveness or permanence.	Some reduction in contamination may indirectly occur through radioactive decay and natural attenuation processes.	No added risk to the public or environment.	No implementation concerns are associated with the no action alternative.	$0
Alternative #1 – Institutional controls supplemented by MNA	Would provide protection through implementation of administrative controls.	Would not meet groundwater standards.	Provides protection only for the duration of implementation.	No physical treatment is being conducted; thus, no reduction of toxicity, mobility, or volume through this alternative, with the exception of natural attenuation.	No added risk to the public or environment.	No implementation concerns are associated with institutional controls.	$3,100,000
Alternative #2 – Full-scale pump-and-treat, institutional controls, MNA, plus groundwater flow-path controls	Flow-path control would slow migration of the contaminant plume, increase travel time to points of compliance, and allow MNA process to facilitate attaining the RAOs.	Results indicate that Alternative #2 would meet all RAOs and chemical-specific ARARs and TBCs identified.	Will provide long-term effectiveness and permanence for contaminated groundwater by removing the bulk of the COPCs, as well as increasing natural attenuation processes for further reduction in contaminated groundwater.	This alternative employs technology that is capable of significantly reducing contaminant mass in the aquifer.	No added risk to the public or environment.	Implementation of the pump-and-treat alternative would entail expansion of the existing system with additional wells.	$93,000,000 (840 gpm) $180,000,000 (1,615 gpm)

ARAR = applicable or relevant and appropriate requirement
COPC = contaminant of potential concern
gpm = gallons per minute
MNA = monitored natural attenuation
RAO = remedial action objective
TBC = to-be-considered

Table 7-3. Summary of the Contaminant Capture of Preferred Remedy.

Constituent	Captured Portion of Contamination Greater Than:	Fraction Captured
Chloroform	17.0 µg/L	1×10^{-4} risk
Carbon tetrachloride	93.9 µg/L	95% of mass
Tetrachloroethylene (PCE)	8 µg/L	1×10^{-4} risk
Technetium-99 (technetium-99)	1,732 pCi/L	1×10^{-4} risk
Tritium	83,161 pCi/L	1×10^{-4} risk

8.0 UNCERTAINTIES RELATED TO DECISION MAKING

The purpose of this section is to describe the uncertainties inherent to the analyses performed as part of the FS. Uncertainties are propagated throughout any evaluation of technical processes that have a scope as complex as environmental restoration. The uncertainty is a reflection of limited knowledge, engineering, and technical assumptions made during the evaluation. Examples of the uncertainties that propagate through the FS evaluations are in the areas of technology, cost, performance, policy, future land use, and health and ecological risk. Other associated uncertainties include the following:

- Uncertainties in estimating and evaluating health risk posed by contamination
- Uncertainty of estimating the extent of contamination and the resulting efficiency of the identified remedial alternative
- Uncertainty associated with the cost of implementing remedial technologies.

A summary of these uncertainties and their associated potential impacts is presented below.

8.1 UNCERTAINTIES ESTIMATING AND EVALUATING HEALTH RISK POSED BY CONTAMINATION

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. Some key areas of uncertainty evaluated in the risk assessment are as follows:

- Produce ingestion: Risks and hazards are significantly above target health goals due to ingesting homegrown produce watered with impacted groundwater. Calculated risks and hazards from ingestion of homegrown produce are dependent upon the concentration in the plant tissue and the produce ingestion rate. Plant tissue concentrations were estimated using health-protective modeling and likely over-estimate the amount of COPC that could be in the plant. Ingestion rates were selected to represent a rural farming population that would be expected to receive a significant portion of their produce from their own garden.
- Native American population: A Native American population was not quantitatively evaluated. With some exceptions, Native American exposures are similar in type to the residential farmer (e.g., both groups could be exposed via direct contact with contaminated materials and the food chain), but exposures may be different in kind (e.g., more time spent outdoors or greater consumption of native plants and animals) than the typical default exposures that EPA has developed for a residential population. Combined exposures to soil and groundwater for Native Americans result in an increase of about an order of magnitude (10 times) of the exposure of the residential farmer. Native American scenarios will be quantified and included in the risk assessment in the next revision of this document (see Appendix J).

8.1.1 Potential Impacts

Potential impacts associated with the first uncertainty described above would most likely not have an impact on protecting human health due to over-estimation of the amount of COPCs found in plant tissue. However, this over-estimation does potentially over-exaggerate the effects

contaminant exposure might have on target populations. Potential impacts associated with the second uncertainty described above are not expected to alter the proposed response, because cancer risks and non-cancer hazards for the residential farmer are already above target health goals under CERCLA (i.e., have an HI >1 and cancer risks greater than 1×10^{-4}). Increased exposures for a Native American population would not result in a change in action, as the risks already exceed the action threshold and require action to be taken.

8.2 UNCERTAINTY OF ESTIMATING THE EXTENT OF CONTAMINATION AND EFFICIENCY OF REMEDIAL ALTERNATIVE

The approach to estimating the extent of contamination was conducted with the understanding of the following:

- How the current distribution of contaminants developed
- For advectively dominated systems, whether the principal groundwater hydraulics can be represented using relatively simple methods
- Whether future changes in groundwater flow directions and/or rates are expected to occur in response to past activities
- Whether the principal directions and rates of migration can be approximated using relatively simple computational methods
- The likely fate of contaminants that will not be recovered by the remedy.

Once there was a clear understanding of these items, a modeling analysis was conducted to evaluate historic groundwater elevations and groundwater flow directions. This model was based on the assumption that the majority of the variability in groundwater elevations near the 200-ZP-1 OU could be described using analytical equations that superimpose the Theis equation for transient changes in head in response to extraction and/or injection (Theis 1935, Rouse 1949) upon a planar surface.

In order to execute this model, the following assumptions were made:

- Flow is dominantly two-dimensional.
- The aquifer is homogeneous and isotropic.
- Transport is dominated by advection, dispersion, and retardation.

Uncertainty in estimating the extent of contamination lies within these assumptions because (1) three-dimensional groundwater flow is not accounted for, and (2) the aquifer is not homogeneous and isotropic.

In certain areas of the 200 West Area of the Hanford Site, beneath the 200-ZP-1 OU, the Ringold Lower Mud Unit is present beneath the Ringold Unit E aquifer. The Lower Mud Unit is not continuous and is only present in localized areas. Several interpretations of locations of the Lower Mud Unit are based on boreholes in the 200 West Area that have been presented in previous reports. In locations where the Ringold Lower Mud Unit is present, it is typically underlain by the Ringold Unit A gravels and basalt bedrock.

Estimates of the mass and distribution of technetium-99 at these locations are still under development. Because of its high mobility, the mass of technetium-99 in the vadose zone will be a significant consideration in the final remedial design (i.e., the quantity of technetium-99 in the

vadose zone may present a future source of groundwater contamination because of its high mobility).

In addition, there remains a potential for undiscovered contaminant source areas and for unanticipated contaminant influx from the vadose zone. These introduce uncertainty regarding primarily the scale and duration of the pump and treat alternative, but may also have implications with respect to treatment technologies.

8.2.1 Potential Impacts

Potential impacts resulting from under-estimating the distribution of contaminants would not change the feasibility of the identified remedy. However, the design of the system may be altered to address the uncertainty (i.e., area extent of contamination is greater or less than predicted, and then additional well can be incorporated or the removal of wells can be incorporated in the design) to ensure capture of the contaminated groundwater. The assumptions made in the modeling will be verified during investigations to support the remedial design and monitoring the performance of the remedial system.

The location of the Lower Mud Unit may have the following impacts on a pump-and-treat remedy:

- Design and location of screened interval within a recovery well that is located within or near the Ringold Lower Mud
- Changes in capture zone width for a groundwater recovery well
- An increase in time to capture contaminants that may be present in the Lower Mud Unit.

As stated previously, the quantity of technetium-99 in the vadose zone may present a future source of groundwater contamination because of its high mobility. Once refined estimates of technetium-99 mass and distribution are available, the final remedial design will consider this data because it may impact estimated cleanup times, extraction network configuration, and treatment train design.

These potential impacts to a pump-and-treat remedy will be evaluated during the design phase for the 200-ZP-1 OU alternative.

8.3 UNCERTAINTY WITH THE COST OF REMEDIAL TECHNOLOGIES

The purpose of a cost estimate is to provide adequate information so alternatives can be compared. According to CERCLA guidance (*A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* [EPA/540/R-00/002]), cost estimates for each alternative are expected to be accurate within -30% to +50% of the actual costs:

Uncertainties related to Alternative #1 (institutional controls supplemented by MNA) are as follows:

- Annual monitoring costs
- Duration of monitoring
- Capital cost of implementing institutional controls and MNA.

Uncertainties related to Alternative #2 (full-scale pump-and-treat, institutional controls, MNA, plus groundwater flow-path controls) are as follows:

- Design capacity of the pump-and-treat system (i.e., extraction rate)

- Duration of the operation for the pump-and-treat system and flow-path control.

8.3.1 Potential Impacts

Potential impacts resulting from under-estimating the design capacity of the pump-and-treat system could lead to a significant rise in cost. In contrast, if the design capacity of the pump-and-treat system was over-estimated in the FS, a reduction in cost would then result during development of the final remedial design. The same pattern would occur if the duration of the pump-and-treat operation, or if the rate of consumable supply usage, was under-estimated or over-estimated. However, cost plays a limited role in the screening process, and the cost analysis is made on the basis of engineering judgment. The greatest cost consequences in site remediation are usually associated with the degree to which different general technology types (i.e., containment, treatment, excavation, etc.) are used. Using different process options within a technology type usually has a less significant effect on costs than does the use of a different technology (EPA/540/G-89/004).

9.0 CONCLUSIONS AND PATH FORWARD

The 200-ZP-1 OU FS resulted in a preferred alternative that is consistent with the CERCLA evaluation criteria. A summary of these processes and the path forward for the 200-ZP-1 OU are described in this section.

9.1 FEASIBILITY STUDY SUMMARY

Waste sources that contributed at the 200-ZP-1 OU may have included cribs and trenches that received liquid and/or solid waste in the past in the Z Plant and T Plant aggregate areas, WMA-T, WMA-TX/TY, and the SALDS. The major contamination found in the groundwater of 200-ZP-1 OU include technetium-99, carbon tetrachloride, tritium, nitrate, total chromium (both chromium [III] and hexavalent chromium exceed the MCL), iodine-129, and TCE. Carbon tetrachloride is classified as the principal threat contaminant.

The purpose of this FS was to develop and evaluate alternatives for remediation of the groundwater in the 200-ZP-1 OU. The alternatives considered provide a range of potential response actions that are appropriate to address site-specific conditions, including the following:

- Alternative #0 – No action
- Alternative #1 – Institutional controls supplemented by MNA
- Alternative #2 – Full-scale pump-and-treat, institutional controls, MNA, plus groundwater flow-path controls.

The alternatives were evaluated against seven of the nine CERCLA evaluation criteria defined in EPA/540/G-89/004. The remaining two criteria will be evaluated during the public comment period on the Proposed Plan.

The BRA was performed to assess and document the risks associated with contamination in the groundwater at the 200-ZP-1 OU. This risk assessment evaluated whether potential health risks are present if people encounter the solvent-, inorganic-, and radionuclide-impacted materials in their environment. The BRA identified 12 of the 15 possible COPCs listed in the 200-ZP-1 RI report (DOE/RL-2006-24) to be carried forward through the risk assessment process. The risk assessment identified one COC (carbon tetrachloride).

The BRA concluded that the risks from exposure to groundwater exceeded 1×10^{-4} (using an industrial scenario) at the 90th and 50th percentile concentration of contaminants in groundwater, due primarily to carbon tetrachloride, followed by technetium-99, for both residential and industrial drinking water exposures. Carbon tetrachloride's non-cancer hazards were also risk drivers and exceeded target health goals at the 90th and 50th percentile concentration of contaminants in groundwater. Although reductions in future concentrations were not quantified for carbon tetrachloride, the chemical's concentrations will decrease over time.

The RAOs developed in Section 3.0 provide a basis for evaluating the capability of a specific remediation alternative to achieve compliance with potential ARARs and/or an intended level of risk reduction in order to protect human health and the environment. The RAOs specific to the 200 Areas for soils, solid wastes, and groundwater were developed in the Implementation Plan (DOE/RL-98-28) Specific RAOs for this FS were defined based on the fate and transport of contaminants, projected land uses for the 200 Areas, and the 200-ZP-1 OU conceptual exposure model. The RAOs for this FS are as follows:

- RAO #1: Prevent or mitigate risk to human and ecological receptors associated with ingestion of, and external exposure to contaminants (carbon tetrachloride, technetium-99, total chromium, hexavalent chromium, nitrate, TCE, iodine-129, and tritium) in groundwater at levels that exceed ARARs or an excess carcinogenic risk of 1×10^{-4} using an industrial exposure scenario, or an HI of 1. This RAO is meant to return the groundwater to meet drinking water standards (MCLs).
- RAO #2: Prevent or mitigate the migration of contaminants (carbon tetrachloride, technetium-99, total chromium, hexavalent chromium, nitrate, TCE, iodine-129, and tritium) in groundwater so the contaminants do not reach levels in groundwater that exceed ARARs and excess carcinogenic risk of 1×10^{-4} using an industrial exposure scenario, or an HI of 1.
- RAO #3: Prevent the migration of high-concentration areas of contaminants (carbon tetrachloride, technetium-99, total chromium, hexavalent chromium, nitrate, TCE, iodine-129, and tritium) in the 200-ZP-1 OU and reduce the contaminant mass available for migration.
- RAO #4: Prevent or mitigate occupational health risks to workers performing remedial actions.
- RAO #5: Provide the appropriate monitoring and institutional controls to ensure conditions suitable for future land uses.

To show that RAO #1 has been achieved, it will be necessary to demonstrate that the MCL published in 40 CFR 141 for the COC and other constituents described in Section 3.3.3 have been met; or that the pathways for exposure to the contaminants above the MCLs have been mitigated. Achievement of RAO #2 will be shown when the applicable MCL for the COC has been met at the industrial land-use boundary by the year 2150. The proposed remedy will identify the appropriate locations at the industrial land-use boundary to assess whether MCLs are being met. Achievement of RAO #3 requires the identification of the boundaries defining the high-concentration areas contaminated by the principal threat COC, and that these areas are contained (either through natural processes or hydraulic controls). The portion of the aquifer exceeding 100 μg/L defines the high-concentration area of carbon tetrachloride; this number represents approximately 95% of the carbon tetrachloride mass in the 200-ZP-1 OU. RAO #4 will be achieved by meeting RAOs #1 and #2, by implementing existing Hanford Site standards for protection of industrial workers, and by continuing to implement existing institutional controls and monitoring requirements. RAO #5 will be achieved by implementing the appropriate institutional controls and monitoring requirements that are identified in the Interim ROD (EPA/ROD/R10-95/114) and the operation and maintenance plan. The institutional controls will also be located in the Sitewide institutional controls plan (DOE/RL-2001-41).

Technologies that may potentially meet the RAOs for the 200-ZP-1 OU were identified and screened. Representative process options that were retained after screening were combined into a range of alternatives to meet RAOs, and a preferred remedy was selected.

The remedial action alternatives range from no action without institutional controls, to active treatment through a pump-and-treat system augmented with supplemental treatment of contaminated groundwater. The alternatives were formulated to encompass a wide range of possible outcomes and enhance compatibility with current operations and infrastructure. The alternatives include the following:

- Alternative #0 – No action: The NCP (40 CFR 300) requires consideration of a no action alternative. This alternative proposes that the site be left as-is, with no need for additional remedial activities, monitoring, or access restrictions (i.e., institutional controls). This alternative is only acceptable if current site conditions are protective of human health and the environment. This alternative is not protective and, therefore, was not selected.
- Alternative #1 – Institutional controls supplemented by MNA: This alternative may be appropriate for protection of human health and the environment in areas where groundwater contaminant concentrations exceed RAOs and monitoring is necessary to ensure continued effectiveness of the remedial action(s). The MNA processes include biodegradation, abiotic degradation (hydrolysis), volatilization, radioactive decay, sorption, dispersion, transformation, and dilution.
- Alternative #2 – Full-scale pump-and-treat, institutional controls, MNA, plus groundwater flow-path controls: The pump-and-treat system will address the bulk of the COC contamination, while downgradient injections wells will slow migration, allowing additional time for natural attenuation processes to work. Institutional controls are also incorporated into this alternative.

Alternative #2 includes a pump-and-treat remedy that includes options for final shutdown of the active treatment, supplemented by MNA and associated contingency measures in the event that performance monitoring suggests a decrease in the effectiveness of natural attenuation processes, or that DNAPL or new source area is discovered during performance monitoring. The contingency measures will be adaptive, involving flow-path control, additional pump-and-treat, and additional localized implementation of the supplemental treatment technologies as necessary based on the monitoring results.

The five alternatives were analyzed in detail, both individually and in comparison with each other, with respect to CERCLA evaluation criteria, listed below:

- Threshold criteria:
  1. Overall protection of human health and the environment
  2. Compliance with applicable or relevant and appropriate requirements
- Balancing criteria:
  3. Long-term effectiveness and permanence
  4. Reduction of toxicity, mobility, or volume through treatment
  5. Short-term effectiveness
  6. Implementability
  7. Cost.

The modifying criteria, state acceptance, and community acceptance will be evaluated following public comment on the Proposed Plan. This allows the regulators to identify the alternatives that will mitigate unacceptable risks, meet threshold criteria, and meet balancing and modifying criteria.

The results of the detailed and comparative analysis with respect to the CERCLA evaluation are summarized in the following subsections.

9.1.1 Overall Protection of Human Health and the Environment

All of the alternatives, including Alternative #0, will meet RAO #4 (occupation health risks) by not implementing any remedial actions or by implementing institutional controls to eliminate human health risk through site access restrictions. Alternative #2 meets all of the RAOs by implementing institutional controls and by providing representative process options that treat and remove contaminant mass from the areas of concern, thus improving overall protection of human health and the environment. Alternative #0 does not meet RAOs #1, #2, #3, and #5 because it assumes that the institutional controls currently in place are no longer in effect. Loss of existing controls would allow the potential for exposure to contaminated groundwater. Alternative #1 will not meet RAOs #2 and #3 because natural attenuation processes most likely will not achieve MCLs before the year 2150 at the industrial land use boundary without an engineered remedy component.

9.1.2 Compliance with Applicable or Relevant and Appropriate Requirements

Alternative #0 (no action under CERCLA, Sections 104 and 106 authorities) applies to remedial actions only; thus, the no action alternative will not invoke any ARARs. Alternative #1 would achieve drinking water standards, although it would take much longer than Alternative #2. Alternative #2 would meet all RAOs and chemical-specific ARARs by the year 2150.

9.1.3 Long-Term Effectiveness and Permanence

Alternatives #0 and #1 only provide long-term effectiveness or permanence through natural attenuation processes. Alternative #2 would provide long-term effectiveness and permanence for contaminated groundwater by removing the bulk the COC. Long-term engineering controls would be implemented that will effectively mitigate risks to prevent future exposure to human and ecological receptors. These alternatives would effectively reduce risks associated with workers by execution of institutional controls, including access restriction and administrative controls.

9.1.4 Reduction of Toxicity, Mobility, or Volume Through Treatment

Treatment would not be administered with Alternatives #0 and #1. Some reduction in contamination may indirectly occur through radioactive decay and natural attenuation processes. Pump-and-treat is all-inclusive to Alternative #2 and would provide an irreversible treatment process that would reduce the volume of the contaminants in the groundwater by removing/ treating 95% of the mass of the COC. A reduction in toxicity for the remaining 5% of COC is expected to occur indirectly through natural attenuation processes.

9.1.5 Short-Term Effectiveness

Construction and operation of all alternatives can be implemented with little or no additional risk to the public, workers, or the environment. The potential for slight, temporary increases in risk to the community (and workers) due to particulate emissions during construction of a pump-and-treat system would be controlled with dust-control technologies (e.g., water or foam sprays). Exposure to the COC can be minimized by using proper personal protective equipment, using engineering controls, and following OSHA and DOE guidelines, rules, and regulations, as applicable.

9.1.6 Implementability

No implementability concerns are involved with Alternatives #0 and #1. A pump-and-treat system is currently operating in the 200-ZP-1 OU as an IRM, targeting carbon tetrachloride, chloroform, and TCE. Implementation of Alternative #2 would result in a full-scale, robust pump-and-treat system, with additional wells and varying treatment trains to address the COC. The number and location of wells, as well as the location and design of treatment trains, will be determined during the remedial design phase.

9.1.7 Cost

The present-worth cost for Alternative #0 is $0, Alternative #1 is $3,100,000, and Alternative #2 is $93,000,000, although the cost of the 6,113 L/min (1,615 gpm) system would be approximately $180,000,000 (see Appendix C for further details). Though Alternative #2 is the most expensive remedial alternative, it achieves the overall cleanup goal of restoring the groundwater to beneficial use in a timeframe consistent with land-use objectives. The costs associated with these activities can substantially change because of the use of the habitat by a variety of wildlife and the potential for discovery of cultural activities. All of these issues will need to be considered in the remedial design and planning.

9.2 PERFERRED REMEDY

Alternative #2 is the preferred remedy (full-scale pump-and-treat, institutional controls, MNA, plus groundwater flow-path controls). It includes between 14 to 27 injection wells and between 14 to 27 extraction wells at locations shown in Figure 7-2 and 7-3. Individual extraction wells are expected to pump at a rate of 227 L/min (60 gpm) providing a combined rate of between approximately 3,180 to 6,113 L/min (840 and 1,615 gpm). This design captures the entire portion of the groundwater exceeding the 1×10^{-4} risk using an industrial scenario. As discussed in Section 5.0, Alternative #2 is designed return groundwater in the 200-ZP-1 OU to beneficial use by achieving Federal MCLs. Active treatment components to the remedy will remove and treat the following:

- Contaminant mass in the high-concentration areas of carbon tetrachloride contamination.
- Contaminant mass from the areas of contamination that exceed 100 µg/L of carbon tetrachloride.
- Technetium-99 contamination near WMA-T and WMA-TX/TY. The conceptual remedy developed for this alternative does not account for technetium-99 in the vadose zone at these locations because characterization efforts are still underway. The final remedial design will consider information from the investigation because the quantity of technetium-99 in the vadose zone may present a future source of groundwater contamination that may impact cleanup times, extraction network configuration, and treatment train design.

9.3 PATH FORWARD

Remedy selection for the 200-ZP-1 OU will be based on information contained in the RI, BRA, and this FS, as well as input by risk managers, the public, and other interested parties. The path forward for completion of remedy selection for the 200-ZP-1 OU is described in the following subsections.

9.3.1 Proposed Plan

The Proposed Plan is the document issued to the public that identifies the preferred alternative. The document outlines pertinent information from the RI and FS and provides a summary of the alternatives that were evaluated. When the Proposed Plan for the 200-ZP-1 OU is issued, the Tri-Parties will hold a number of public meetings at which the Proposed Plan will be formally presented. The Tri-Parties will also open a public comment period during which oral and written comments from the public on the Proposed Plan will be considered. After the public comments have been reviewed, the Tri-Parties will sign a ROD that documents the final decision for the assessment. Along with the ROD, the Tri-Parties will issue a responsive summary that provides responses to all significant comments submitted during the public comment period.

9.3.2 Record of Decision

The ROD is a public document that will explain which cleanup alternatives will be used to clean up the 200-ZP-1 OU. Generally, the lead agency performs the following steps during the ROD development process:

- Preparing the draft ROD
- Briefing lead agency upper management on the ROD
- Submitting the draft ROD to other lead agency program offices and to the support agency for review and comment
- Reviewing and responding to comments and revising the ROD, if necessary
- Briefing the Regional Administrator or delegated decision maker (and, if necessary, the appropriate Headquarters manager or the Assistant Administrator of the EPA Office of Solid Waste and Emergency Response [OSWER]), as well as designated personnel in the support agency
- Submitting the ROD to the Regional Administrator or the Assistant Administrator of OSWER, if necessary, for signature (if a state or a Federal agency is the lead agency, both the lead agency and EPA should generally sign the ROD, except when it is a non-fund-financed state-lead enforcement site)
- Publishing the notice of ROD availability.

9.3.3 Post-Record of Decision

After the ROD is signed, new information may be received or generated that could affect the implementation of the remedy selected in the ROD or that could prompt the reassessment of that remedy. The information could be identified at any time during, immediately prior to, or after the implementation of the remedy. Where information is submitted by potentially responsible parties, the public, or the supporting agency after a ROD is signed, the lead agency must consider and respond to this information and place such comments and responses in the Administrative Record file when all of the following criteria are met (NCP [40 CFR 300.825(c)]):

- The comments contain significant information.
- The new information is not contained elsewhere in the Administrative Record file.
- The new information could not have been submitted during the public comment period.

- The new information substantially supports the need to significantly alter the remedial action.

The lead agency also may evaluate whether a remedy change is warranted on its own merits, even where the requirements of NCP (40 CFR 300.825[c]) are not triggered.

9.3.4 Remedial Design

The PRGs define unacceptable risk posed by specific contaminants, provide target cleanup goals for use during remedial design, and provide guidance during remediation. The specific number and locations of wells and the location and design of treatment trains will be determined during the remedial design phase. For optimization of the conceptual design, the treatment train (i.e., the more effective, inexpensive technology identified) can be implemented during the remedial design phase. The design of the system may be altered to address the uncertainty (i.e., area extent of contamination is greater or less than predicted, and then additional wells can be incorporated or the removal of wells can be incorporated in the design) to ensure capture of the contaminated groundwater. The assumptions made in the modeling will be verified during investigations to support the remedial design and monitoring the performance of the remedial system. The costs associated with the remedial design can substantially change because of the use of the habitat by a variety of wildlife and the potential for discovery of cultural resources. All of these issues will need to be considered in the remedial design and planning.

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10.0 REFERENCES

02-HAB-0006, 2002, *Consensus Advice #132: Exposure Scenarios Task Force on the 200 Area*, 2002, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

10 CFR 61, "Licensing Requirements for Land Disposal of Radioactive Waste," *Code of Federal Regulations*.

10 CFR 835, "Occupational Radiation Protection," *Code of Federal Regulations*.

40 CFR 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities," *Code of Federal Regulations*.

40 CFR 141, "National Primary Drinking Water Regulations," *Code of Federal Regulations*.

40 CFR 265, Subpart F; "Pertaining to Groundwater Monitoring," *Code of Federal Regulations*.

40 CFR 265, "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," *Code of Federal Regulations*.

40 CFR 268, "Land Disposal Restrictions," *Code of Federal Regulations*.

40 CFR 300 "National Oil and Hazardous Substances Pollution Contingency Plan," *Code of Federal Regulations*.

64 FR 61615, "Hanford Comprehensive Land-Use Plan Environmental Impact Statement (CLUP EIS), Hanford Site, Richland, Washington; Record of Decision (ROD)," *Federal Register*, Vol. 64, No. 218, pp. 61615, November 1999.

Allison, J. D., and T. L. Allison, 2005, *Partition Coefficients for Metals in Surface Water, Soil, and Waste*, U.S. Environmental Protection Agency, Office of Research and Development, Washington, D.C.

Atomic Energy Act of 1954, 42 U.S.C. 2011, et seq.

Beyke, G., and D. Fleming, 2005, "In-Situ Thermal Remediation of DNAPL and LNAPL Using Electrical Resistance Heating," in *Remediation* 15(3):5-22, Wiley Periodicals, Inc., Published on-line in Wiley Interscience.

BHI-00184, 1995, *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*, Bechtel Hanford Inc., Richland, Washington.

BHI-01757, 2005, *Data Quality Objectives Summary Report for the 100 Area and 300 Area Component of the River Corridor Baseline Risk Assessment*, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.Bouwer EJ and PL McCarty. 1983. Transformations of 1- and 2-Carbon Halogenated Aliphatic Organic Compounds Under Methanogenic Conditions. *Applied and Environ. Microbiology*. 45(4):1286-1294.*Clean Air Act of 1990*, 42 U.S.C. 7401, et seq.

Cobb GD and EJ Bouwer. 1991. Effects of Electron Acceptors on Halogentated Organic Compound Biotransformations in a Biofilm Column. *Environ. Sci. Technol.* 25:1068-1074.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. 9601, et seq.Corbin, R. A., B. C. Simpson, and M. J. Anderson (Nuvotec USA); W. F. Danielson III (Advanced Imaging Technologies); J. G. Field and T. E. Jones (CH2M HILL Hanford Group, Inc); and C. T. Kincaid (Pacific Northwest National Laboratory); 2005, *Hanford Soil Inventory Rev. 1*, RPP-26744, Rev. 0, CH2M HILL Hanford Group, Inc, Richland, WashingtonCP-16151, 2007, *Data Quality Objectives Summary Report Supporting the 200-ZP-1 Operable Unit Remedial Investigation/Feasibility Study Process*, Fluor Hanford, Inc., Richland, Washington.

DOE, 1994, *Secretarial Policy on the National Environmental Policy Act*, dated June 1994, U.S. Department of Energy, Washington, D.C.

DOE G 441.1-12, *Radiation Safety Training Guide* (for use with Title 10, Code of Federal Regulations, Part 835, Occupational Radiation Protection"), U.S. Department of Energy, Washington, D.C.

DOE O 435.1, *Radioactive Waste Management*, U.S. Department of Energy, Washington, D.C.

DOE O 470.4, *Safeguards and Security Program*, U.S. Department of Energy, Washington, D.C.

DOE/EH-413/9814, 1998, *Technical Impracticability Decisions for Ground Water at CERCLA Response Action and RCRA Corrective Action Sites*" RCRA/CERCLA Information Brief, dated August 1998, Office of Environmental Policy and Assistance, U.S. Department of Energy, Washington, D.C.

DOE/EIS-0222-F, 1999, *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement*, U.S. Department of Energy, Washington, D.C.

DOE/RL-89-12, 1995, *Hanford Site Ground Water Protection Management Plan*, Rev. 2, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-91-32, 1991, *ERA Engineering Evaluation Cost Analysis and Environmental Assessment for 200-W Area Carbon Tetrachloride Plume*, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-91-45, 1995, *Hanford Site Risk Assessment Methodology*, Rev. 3, U.S. Department of Energy/Richland, Washington.

DOE/RL-91-50, 2000, *Environmental Monitoring Plan, United States Department of Energy, Richland Operations Office*, Rev. 3, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-91-58, 1992, *Z Plant Source Aggregate Area Management Study Report*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-92-16, 1993, *200 West Groundwater Aggregate Area Management Study Report*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-96-07, 1996, *200-ZP-1 IRM Phase II Remedial Design Report*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-97-56, 1997, *Draft Hanford Site Manhattan Project and Cold War Era Historic District Treatment Plan*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-98-28, 1999, *200 Areas Remedial Investigation/Feasibility Study Implementation Plan – Environmental Restoration*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2001-41, 2002, *Sitewide Institutional Controls Plan for Hanford CERCLA Response Actions*, Rev. , U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2002-39, 2002, *Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2003-55, 2004, *Remedial Investigation/Feasibility Study Work Plan for the 200-ZP-1 Groundwater Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2004-55, 2005, *Remedial Investigation Report for the 200-PW-2 Uranium-Rich Process Waste Group and the 200-PW-4 General Process Condensate Group Operable Units*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2005-91, 2005, *Fiscal Year 2005 Annual Summary Report for the 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations,* Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2006-24, 2006, *Remedial Investigation Report for 200-ZP-1 Groundwater Operable Unit*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2006-51, 2006, *Remedial Investigation Report for the Plutonium/Organic-Rich Process Condensate/Process Waste Group Operable Unit: Includes the 200-PW-1, 200-PW-3, and 200-PW-6 Operable Units*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2006-58, 2006, *Carbon Tetrachloride Dense Non-Aqueous Phase Liquid (DNAPL) Source-Term Interim Characterization Report*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2006-73, 2007, *Fiscal Year 2006 Annual Summary Report for 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2007-22, 2007, *Carbon Tetrachloride Dense Non-Aqueous Phase Liquid (DNAPL) Source-Term Characterization Report Addendum*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE-STD-1098-99, 1992, *Radiological Control*, U.S. Department of Energy, Washington, D.C.

Ecology, 2005, *State Waste Discharge Permit Number ST 4511*, dated February 16, 2005, Washington State Department of Ecology, Olympia, Washington.

EM-51, 2000, *Recommendations and Preservation Options for Manhattan Project Signature Facilities at Oak Ridge and Hanford Reservations*, Advisory Council on Historic Preservation, Washington, D.C.

Endangered Species Act of 1973, 16 U.S.C. 35, et seq.

EPA, 2007, *Integrated Risk Information System (IRIS) Online Database*, accessed in March and April 2007 at http://www.epa.gov/iris/index.html, U.S. Environmental Protection Agency, Washington, D.C.

EPA/402-R-99-001, 1999, *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, Federal Guidance Report No. 13, Office of Radiation and Indoor Air, U.S. Environmental Protection Agency, Washington, D.C.

EPA/540/1-89/002, 1989, *Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual, Part A, Interim Final*, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C.

EPA/540/G-89/004, 1988, *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Interim Final,* OSWER Directive 9355.3-01, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C.

EPA/540/G-89/006, 1988, *CERCLA Compliance with Other Laws Manual; Interim Final,* U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C.

EPA/540/R-00/002, 1988, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study*, OSWER Directive 9355.0-75, U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C.

EPA/542-R-05/008, 2005, *Cost-Effective Design of Pump-and-Treat Systems*, OSWER Directive 9283.1-20, U.S. Environmental Protection Agency, Washington, D.C.

EPA/600/P-95/002Fa, 1997, *Exposure Factors Handbook*, Volumes I–III (update to *Exposure Factors Handbook EPA/600/8-89/043 (May 1989)*, dated August 1997, U.S. Environmental Protection Agency, Washington, D.C.

EPA/ROD/R10-95/110, 1995, *Record of Decision for the USDOE Hanford Environmental Restoration Disposal Facility Remedial Action*, dated January 1995, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington.

EPA/ROD/R10-95/114, 1995, *Record of Decision for the USDOE Hanford 200-ZP-1 Operable Unit Interim Remedial Measure*, dated May 1995, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington.

EPA Region 10, 2006, *Midnite Mine Superfund Site Spokane Indian Reservation, Washington, Record of Decision*, dated September 2006, U.S. Environmental Protection Agency, Region 10, Olympia, Washington.

EPA, Ecology, and DOE, 2001, *Hanford Federal Facility Agreement and Consent Order Community Relations Plan*, draft dated August 2001, U.S. Department of Energy, U.S. Environmental Protection Agency, and Washington State Department of Ecology, Olympia, Washington.

Fetter, C. W., 1999, *Contaminant Hydrogeology*, Second Edition, Prentice-Hall, Inc. Simon & Schuster, Upper Saddle River, New Jersey.

FH-0503130, 2005, *200 Area Unit Managers' Meeting Groundwater Operable Unit Status*, dated October 2005, Attachment 3, Fluor Hanford, Inc., Richland, Washington.

HAB 2002O-06, 2002, *Report of the Exposure Scenarios Task Force*, Hanford Advisory Board, Richland, Washington.

HAB Advice #132, 2002, *Exposure Scenarios Task Force on the 200 Area*, dated June 2002, Hanford Advisory Board, Richland, Washington.

Harris, S., and B. Harper, 2004, *Exposure Scenario for CTUIR Traditional Subsistence Lifeways*, dated September 2004, Department of Natural Resources, Pendleton, Oregon.

HFSUWG, 1992, *The Future for Hanford: Uses and Cleanup, The Final Report of the Hanford Future Site Uses Working Group*, dated December 1992, Hanford Future Site Uses Working Group, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Higley, B. A., D. E. Place, R. A. Corbin, and B. C. Simpson, 2004, *Hanford Defined Waste Model, Rev. 5*, RPP-19822, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

HNF-EP-0924, 1997, *History and Stabilization of the Plutonium Finishing Plant*, Fluor Hanford, Inc., Richland, Washington.

HNF-MP-003, 2006, *Integrated Environment, Safety, and Health Management System* [ISMS] *Description*, Rev. 12, Fluor Hanford, Inc., Richland, Washington.

Hooker BS, RS Skeen, MJ Truex, CD Johnson, BM Peyton, and DB Anderson. 1998. In Situ Bioremediation of Carbon Tetrachloride: Field Test Results. *Bioremed. Journal* 1(3):181-182.Johnson, C. D., M. J. Truex, and T.P. Clement, 2006, "Natural and Enhanced Attenuation of Chlorinated Solvents Using RT3D". PNNL-15937Lide, D. R. (ed.), 2006, CRC Handbook of Chemistry and Physics, CRC Press, Taylor & Francis, Boca Raton, Florida.

Liptak, B. G., 1997, *Environmental Engineers' Handbook*, Second Edition, Lewis Publishers, CRC Press, Boca Raton, Florida.

National Environmental Policy Act of 1969, 42 U.S.C. 4321, et seq.

National Historic Preservation Act of 1966, Public Law 102-575, 16 U.S.C. 470, et seq.

OSWER Directive 9200.4-17P, 1999, *Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

OSWER Directive 9285.6-03, 1991, *Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors. Interim Final*, dated March 1991, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.

PNL-5506, 1986, *Hanford Site Groundwater Changes – 1950 Through 1980, Data Observation and Evaluation*, Pacific Northwest Laboratory, Richland, Washington.

PNNL-6415, 2005, *Hanford Site National Environmental Policy Act (NEPA) Characterization Report*, Rev. 17, Pacific Northwest National Laboratory, Richland, Washington.

PNL-8971, 1993, Three-*Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 93 Status Report*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-11989, 2000, *Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project*, Rev. 2, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-12261, 2000, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13121, 2000, *Groundwater Monitoring and Tritium-Tracking Plan for 200 Area State-Approved Land Disposal Site*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13560, 2001, *Assessment of Carbon Tetrachloride Groundwater Transport in Support of Hanford Carbon Tetrachloride Innovative Technology Demonstration Program*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-13858, 2002, *Revised Hydrogeology for the Suprabasalt Aquifer System, 200 West Area and Vicinity, Hanford Site, Washington*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15239, 2005, *Carbon Tetrachloride and Chloroform Partition Coefficients Derived from Aqueous Desorption of Contaminated Hanford Sediments*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15301, 2006, *RCRA Assessment Plan for Single-Shell Tank Waste Management Area T*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15502, 2005, *Characterization of 200-UP-1 Aquifer Sediments and Results of Sorption-Desorption Tests Using Spiked Uncontaminated Groundwater*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15670, 2006, *Hanford Site Groundwater Monitoring for Fiscal Year 2005*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15892, 2006, *Hanford Site Environmental Report for Calendar Year 2005*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-15954, 2006, *Screening of Potential Remediation Methods for the 200-ZP-1 Operable Unit at the Hanford Site*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-16005, 2007, *RCRA Assessment Plan for Single-Shell Tank Waste Management Area TX-TY*, Pacific Northwest National Laboratory, Richland, Washington.

PNNL-16509, 2007, *Geostatistical Analyses of the Persistence and Inventory of Carbon Tetrachloride in the 200 West Area of the Hanford Site 2007*, Pacific Northwest National Laboratory, Richland, Washington.

RCW 70.94, "Washington Clean Air Act," *Revised Code of Washington*.

Resource Conservation and Recovery Act of 1976, 42 U.S.C. 6901, et seq.

Rittman, P. D., 2004, *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment*, Rev. 4, Fluor Government Group, Richland, Washington.

RL-TPA-90-001, 2007, *Tri-Party Handbook, Management Procedures*, "Maintenance of the Waste Information Data System (WIDS)," Guideline No. TPA-MP-14, "Maintenance of the Waste Information Data System (WIDS)," U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Rouse, H. (ed.), 1949, *Engineering Hydraulics: Proceedings of the Fourth Hydraulics Conference*, dated June 1949, Iowa Institute of Hydraulic Research, John Wiley and Sons, New York.

Superfund Amendments and Reauthorization Act of 1986, Public Law 99-499, as amended

Theis, C. V., 1935, "*The Relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage*," from Proceedings of the American Geophysical Union, 16th Annual Meeting, Part 2, in *Transactions of the American Geophysical Union*, pp. 519-524.

TR-2260-ENV, 2005, *Cost and Performance Report Multi-Site In Situ Air Sparging*, Technical Report, dated April 2005, U.S. Naval Facilities Engineering Command Headquarters, Engineering Service Center, Port Hueneme, California.

Tri-Party Agreement, 2003, *Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement)*, Rev. 6, 2 vols., as amended, 89-10, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington.

Truex, M. J., C. J. Murray, C. R. Cole, R. J. Cameron, M. D. Johnson, R. S. Skeen, and C. D. Johnson, 2001, "Assessment of Carbon Tetrachloride Groundwater Transport in Support of the Hanford Carbon Tetrachloride Innovative Technology Demonstration Program" PNNL-13560WAC 173-216, "State Waste Discharge Permit Program," *Washington Administrative Code*.

WAC 173-218, "Underground Injection Control," *Washington Administrative Code*.

WAC 173-303, "Dangerous Waste Regulations," *Washington Administrative Code*.

WAC 173-340, "Model Toxics Control Act – Cleanup," *Washington Administrative Code*.

WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides," *Washington Administrative Code*.

WAC 246-247, "Radiation Protection – Air Emissions," *Washington Administrative Code*.

WHC-MR-0391, 1992, *Field Trip Guide to the Hanford Site*, Westinghouse Hanford Company, Richland, Washington.

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