

Hydrogeologic Conceptual Model for the Carbon Tetrachloride and Uranium/ Technetium Plumes in the 200 West Area: 1994 Through 1999 Update

*Prepared for the U.S. Department of Energy, Richland Operations Office
Office of Environmental Restoration*

Submitted by: Bechtel Hanford, Inc.

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Hydrogeologic Conceptual Model for the Carbon Tetrachloride and Uranium/ Technetium Plumes in the 200 West Area: 1994 Through 1999 Update

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EXECUTIVE SUMMARY

This report updates the hydrogeologic conceptual model for the carbon tetrachloride and uranium/technetium plumes in the 200 West Area of the Hanford Site over the last 5 years (1994 through 1999). During this 5-year period, the Environmental Restoration Contractor (ERC) has been performing interim remedial actions at three operable units to remove the carbon tetrachloride and uranium/technetium contamination from the subsurface. These actions include the following:

- 200-ZP-2 soil vapor extraction system that is designed to remediate carbon tetrachloride in the vadose zone
- 200-ZP-1 extraction treatment injection system that is designed to remediate carbon tetrachloride, trichloroethene, and chloroform in the groundwater
- 200-UP-1 extraction treatment injection system that is designed to remediate the primary contaminants of technetium-99 and uranium and the secondary contaminants of carbon tetrachloride and nitrate in the groundwater.

The data collected during these remedial actions and during other 200 West Area characterization and monitoring activities have resulted in modifications to the understanding of the subsurface system and contaminant distribution.

The objective of this 5-year update is to address the aspects of the hydrogeologic conceptual model related to remediation of the carbon tetrachloride and uranium/technetium plumes. Specifically, the update focuses on the following activities:

- Integrate new data into the current understanding of the 200 West Area hydrogeologic conceptual model

- Integrate new data into the current understanding of the distribution of the major 200 West Area contaminant plumes and the contaminant inventory disposed to the soil column
- Document groundwater remediation system performance in relation to the updated conceptual model
- Describe general aquifer conditions and aquifer response to Hanford Site operations and remedial actions
- Discuss recent plume modeling results and how they support discussions of future remediation efforts
- Support development of a final Record of Decision for the remediation activities.

Updates to the hydrogeological conceptual model include the following observations:

- The sedimentary units of the vadose zone and unconfined aquifer have been categorized as hydrogeologic modeling units based on properties that generally affect groundwater flow (i.e., texture, sorting, and cementation). This new model should be useful for future modeling of contaminant movement and distributions.
- The Upper Ringold Unit has been found to extend further south within the 200 West Area and southeasterly beyond the 200 West Area than previously reported. Because this unit has a lower permeability than the overlying and underlying gravel-dominated units, it may affect aqueous and contaminant migration and distribution.
- Natural recharge from precipitation is most recently estimated at greater than 100 mm/yr in the carbon tetrachloride disposal area (Fayer and Walters 1995). This is the first time that an areally extensive quantitative distribution of recharge has been performed for the

Hanford Site. Natural recharge may continue to drive contaminants toward the groundwater.

- In 1995, the rate of decline of the water table increased, particularly in the central portion of 200 West near the Plutonium Finishing Plant (formerly named Z Plant) and the TX-TY tank farms, when liquid discharges to the soils were terminated per the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al. 1994) milestone series M-17. Some groundwater monitoring wells have already gone dry as a result of the declining water level, and numerous other wells are projected to go dry as the water table continues to decline.
- With the shut down of the 216-U-10 Pond in 1984 and the cessation of all liquid discharges in 1995, local groundwater mounds have been dissipating. As a result, the flow direction across the 200 West Area can begin to resume the regional west-to-east, pre-Hanford operations direction rather than the local radial flow patterns produced by the groundwater mounds.
- Groundwater flow directions underlying the carbon tetrachloride disposal sites are strongly influenced by the 200-ZP-1 groundwater pump-and-treat system, which has been operating at full-scale since 1996. Monitoring systems for some facilities (e.g., Low-Level Burial Ground waste management area 4) have been directly affected because of reversals in groundwater flow directions (DOE-RL 1999b). Operation of the 200-ZP-1 pump-and-treat system has also decreased the downward hydraulic gradient in the area of the extraction wells (mitigating downward movement of dissolved contaminants) by accelerating removal of the groundwater mound in the unconfined aquifer.
- Groundwater models have been used to predict the elevation of Hanford Site water levels to the year 2350, after the effects of surface liquid discharges have dissipated and approximate steady-state conditions reached (Cole et al. 1997). Based on these modeling results and because of irrigation practices in the Cold Creek Valley west of the Hanford

Site, it is predicted that water levels will not return completely to pre-Hanford conditions in the western portion of the Site.

- A diminution of the 1,000- $\mu\text{g/L}$ contour in the plume of dissolved carbon tetrachloride in the northern part of the 200 West Area has been observed. However, one well in this area has consistently maintained concentrations above 1,000 $\mu\text{g/L}$. This well is located far enough to the northwest of the known source cribs that the question of another carbon tetrachloride source in the northern part of the 200 West Area should be considered. In addition, the shape of the baseline plume in this area (west to east) implies another possible source of carbon tetrachloride in addition to the known sources south and east of the Plutonium Finishing Plant.
- Pump-and-treat extraction and injection operations have affected the distribution and concentrations of carbon tetrachloride in the high concentration (4,000 to 8,000 $\mu\text{g/L}$) centroid portion of the plume. The $>4,000\text{-}\mu\text{g/L}$ contour interval has expanded in size and now extends more northerly and easterly near the extraction wells. The steady or increasing concentrations over a larger area may imply the presence of dense non-aqueous phase liquid (DNAPL), residual carbon tetrachloride, or a higher partitioning coefficient than previously estimated.
- Dissolved carbon tetrachloride has been observed deep ($>10\text{ m}$ [32.8 ft]) within the unconfined aquifer and within the uppermost confined aquifer in the 200 West Area. At both the middle and bottom of the unconfined aquifer, the highest sample results underlie the high-concentration area of the water table plume. The presence of carbon tetrachloride deep in the aquifer implies that either DNAPL sank through the aquifer during disposal and is slowly dissolving, or that elevated dissolved concentrations were driven downward by groundwater hydraulic forces.
- Technetium-99 has been detected in groundwater removed by the 200-ZP-1 extraction wells. Concentrations have ranged from 20 to 286 pCi/L at the extraction wells (all concentrations are below the maximum contaminant level [MCL] of 900 pCi/L) for

samples collected in calendar year 1999. The source of this contamination has not been determined but could be the 216-Z-9 Crib or the TX-TY tank farms.

- Remediation of technetium-99 at the 200-UP-1 OU has nearly met the goal of 10 times (9,000 pCi/L) the MCL (DOE-RL 1999b).
- A substantial retardation factor (related to the distribution coefficient, K_d) is hindering remediation efforts for uranium, and little or no progress has been made toward meeting the remediation goal of 480 pCi/L. An empirical value of K_d for uranium, was calculated using field data collected during remediation operations. This evaluation yielded a K_d of 0.13 mL/g. Groundwater numerical modeling has shown that a small K_d (0.5 mL/g) significantly reduces the rate of plume movement from the 200 West Area (Chiaramonte et al. 1997).
- The ERC developed and applied a groundwater numerical model to predict the long-term impacts of contamination on the groundwater and to evaluate the effectiveness of current and proposed remedial actions (Chiaramonte et al. 1997). Based on this study, the mass of carbon tetrachloride (which is not being remediated) that has moved away from the source area in the 200 West Area is sufficient to cover the entire 200 Area Plateau and could potentially reach the Columbia River at concentrations above drinking water standards. Remediation of the high-concentration area in the central area of the plume will help to prevent further degradation of the unconfined aquifer, but only near the 200 West Area.
- Again, based on the ERC study, little benefit appears to be gained by active remediation of the technetium-99 and uranium plumes. If remediation were discontinued, it is predicted that concentrations of technetium-99 and uranium would fall below groundwater regulatory limits before leaving the 200 Area Plateau.

The collection of technical information during remedial operations and other investigations over the past 5 years has enhanced the understanding of the contaminants and the physical system in

which they are contained. This update to the conceptual model has been useful for identifying data gaps related to plume distribution and movement. Recommendations to address these data gaps are as follows:

- The lateral extent of carbon tetrachloride in the vadose zone and the vertical extent of carbon tetrachloride dissolved in the groundwater need better definition to support mass balance and remediation efforts.

Recommendations: (1) Characterize the deep distribution of carbon tetrachloride in groundwater by advancing new well installations to the uppermost confined aquifer and sampling for carbon tetrachloride, (2) install new groundwater wells to monitor deep within the unconfined aquifer, (3) reconfigure existing wells for groundwater and vadose sampling, and (4) reconfigure well 299-W-4-09 to determine carbon tetrachloride concentrations to the east of the 200-ZP-1 remediation site.

- The location, amount, and properties of DNAPL carbon tetrachloride within the subsurface need to be assessed to help focus and define remediation needs.

Recommendation: Measure rebound of carbon tetrachloride concentrations in groundwater during a period of shutdown of the 200-ZP-1 groundwater pumping operations. An increase in concentrations would indicate DNAPL.

- The extent of carbon tetrachloride nonequilibrium sorption in the vadose zone and groundwater needs to be determined to help account for the inventory and define remediation needs.

Recommendation: Conduct laboratory tests and analyses on representative Hanford Site sediments.

- The value and variability of the equilibrium partitioning coefficient (K_d) for carbon tetrachloride on site sediments need to be quantified to help account for the inventory and refine numerical predictions of carbon tetrachloride transport rates.

Recommendation: Conduct laboratory tests using site-specific soils and representative mixtures of organics.

- The residual saturation of carbon tetrachloride in the vadose zone should be quantified to help account for the carbon tetrachloride inventory, refine estimates of flux to the groundwater, and refine numerical modeling estimates of the depth of carbon tetrachloride within the aquifer.

Recommendation: Collect and analyze soil samples (i.e., split-spoon or core samples) in the vicinity of the disposal sites to determine the residual saturation.

- Estimates of the fate and location of the original carbon tetrachloride inventory discharged to the soil column need to be improved to support remediation efforts.

Recommendation: Re-evaluate the inventory mass balance based on more recent studies and data from current remedial actions in the groundwater and the vadose zone.

- The source(s) of the observed distribution of carbon tetrachloride in groundwater away from the known disposal sites should be evaluated to help focus source removal and groundwater remediation efforts.

Recommendation: Re-evaluate the hydraulic flow fields during and after the carbon tetrachloride disposal to determine if the distribution of carbon tetrachloride is reasonable based on the hydraulics alone or if a yet-to-be identified source contributed to the groundwater contamination.

- Volatilization of carbon tetrachloride from the groundwater to the vadose zone should be evaluated to support assessments of natural attenuation and remediation efforts.

Recommendation: Conduct a study, including field measurements near the groundwater/vadose zone interface, to quantify the volatilization process.

- The cause and significance of the variability in the ratio of carbon tetrachloride to chloroform detected in groundwater samples should be evaluated to support understanding of contaminant source, inventory, and distribution.

Recommendation: Conduct a systematic study of the carbon tetrachloride/chloroform relationship in both the vadose zone and groundwater using existing data.

- The identification and extent of a suspected technetium-99 plume to the east of the 200-ZP-1 pump-and-treat site should be evaluated to help support groundwater remediation efforts.

Recommendations: Sample well 299-W14-09 at depth for technetium and then reconfigure it as a monitoring well at the top of the unconfined aquifer. Conduct additional sampling for radionuclides at the 200-ZP-1 groundwater extraction wells and as part of system operations.

- The value and variability of the partitioning coefficient (K_d) of uranium at the 200-UP-1 site need to be defined to support numerical predictions of the rate of plume migration.

Recommendation: Conduct laboratory tests using site-specific soils and/or field tests to quantify the partitioning coefficient (K_d) for uranium on aquifer soils.

- Field monitoring data are needed to confirm the numerical modeling predictions that pump-and-treat remediation of technetium-99 and uranium is of little technical benefit

and that concentrations of technetium-99 and uranium will fall below groundwater regulatory limits through natural attenuation alone before leaving the 200 Area Plateau.

Recommendation: Shut down the pump-and-treat system at 200-UP-1 and implement a monitoring program to track plume movement and to measure rebound of uranium and technetium.

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ACRONYMS

BHI	Bechtel Hanford, Inc.
CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act of 1980</i>
CFEST	Coupled Fluid, Energy, and Solute Transport (computer code)
DBP	dibutyl phosphate
DBBP	dibutyl butyl phosphate
DNAPL	dense nonaqueous phase liquid
DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
EE/CA	engineering evaluation/cost analysis
EPA	U.S. Environmental Protection Agency
ERA	expedited response action
ERC	Environmental Restoration Contractor
ERDF	Environmental Restoration Disposal Facility
ETF	Effluent Treatment Facility
FY	fiscal year
GAC	granular activated carbon
MCL	maximum contaminant level
MTCA	<i>Model Toxics Control Act</i>
OU	operable unit
PCE	tetrachloroethylene
PNNL	Pacific Northwest National Laboratory
RAO	remedial action objective
RCRA	<i>Resource Conservation and Recovery Act of 1976</i>
ROD	Record of Decision
SALDS	State-approved land disposal site
SVE	soil vapor extraction
TBP	tributyl phosphate
TCE	trichloroethylene
Tri-Party Agreement	<i>Hanford Federal Facility Agreement and Consent Order</i>
UO ₃	Uranium Tri-Oxide (Plant)

METRIC CONVERSION CHART

The following conversion chart is provided to aid the reader in conversion.

Into Metric Units			Out of Metric Units		
<i>If You Know</i>	<i>Multiply By</i>	<i>To Get</i>	<i>If You Know</i>	<i>Multiply By</i>	<i>To Get</i>
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	0.0836	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	millibecquerel	0.027	picocuries

1.0 INTRODUCTION

The Environmental Restoration Contractor (ERC), Bechtel Hanford, Inc. (BHI), conducts groundwater remediation activities across the Hanford Site for the U.S. Department of Energy (DOE). The groundwater has been contaminated by a variety of chemical and radiological constituents associated with past liquid effluent disposal and by unintentional leaks and spills.

The ERC is currently performing interim remedial actions at three operable units (OUs) located in the 200 West Area of the Hanford Site. Operable units, as defined under the *Comprehensive Environmental Response, Compensation, and Liability Act 1980* (CERCLA), are established to address contamination issues in various areas of the Hanford Site. The three 200 West Area OUs currently using interim remedial action treatment systems are as follows:

- 200-ZP-2 – A vadose zone vapor extraction system that is designed to remediate carbon tetrachloride.
- 200-ZP-1 – A groundwater pump-and-treat system that is designed to remediate carbon tetrachloride, trichloroethylene (TCE), and chloroform.
- 200-UP-1 – A groundwater pump-and-treat system that is designed to remediate the primary contaminants of technetium-99 and uranium and the secondary contaminants of carbon tetrachloride and nitrate (Figure 1).

This report updates the hydrogeologic conceptual model of the 200 West Area as it relates to the primary contaminants being remediated by the three treatment systems.

The report is organized into five main sections. Section 1.0 discusses the scope of this document and provides background information. In Section 2.0, the hydrogeologic setting is presented, including updates on the geology, hydrogeology, and the hydraulic influence of the pump-and-treat operations. Section 3.0 includes a discussion of the contaminant distributions, and Section 4.0 provides a discussion of the contaminant transport. Data gaps and recommendations are provided in Section 5.0. Supporting information is contained in Appendix A.

1.1 SCOPE

This report updates the groundwater and vadose zone aspects of the hydrogeologic conceptual model for the 200 West Area. More specifically, this update discusses water level changes, contaminant movement both laterally and vertically in the saturated and unsaturated zones, geologic interpretations, and numerical modeling results. In addition, this report discusses the impact of the treatment systems on the contaminant plumes (i.e., carbon tetrachloride, uranium, and technetium-99) and the current status of groundwater conditions in the OUs located in the 200 West Area of the Hanford Site.

This report does not consider the tank farms, Low-Level Burial Grounds, or other *Resource Conservation and Recovery Act of 1976* (RCRA) facilities located in the 200 West Area.

1.2 OBJECTIVES

The overall objective of this report is to support current interim remedial action operations by presenting a refined conceptual model of the contaminant plumes and providing recommendations for additional data collection. The specific objectives of this report are as follows:

- Present the current understanding of the 200 West Area hydrogeologic conceptual model associated with the carbon tetrachloride, uranium, and technetium-99 plumes
- Document groundwater remediation system performance
- Describe general aquifer conditions and aquifer response to remedial actions

It is anticipated that this report will provide a vehicle for discussions on remediation efforts and will support development of a final Record of Decision (ROD) at these sites.

1.3 BACKGROUND

The following subsections provide a brief overview of the historical operations and the remedial action objectives (RAOs) for each of the three treatment systems located in the 200 West Area.

1.3.1 200-UP-1 Pump-and-Treat Operations

Initial operations consisted of a pilot-scale treatability test conducted from March 1994 to September 1995 (DOE-RL 1995c). The treatability test demonstrated that ion exchange was effective at removing uranium and technetium-99 from extracted groundwater to below U.S. Environmental Protection Agency (EPA) maximum contaminant level (MCL) guidelines. The Phase I pump-and-treat operations commenced September 25, 1995, using a single extraction well and a single injection well. Groundwater was treated onsite using ion-exchange technology and granular activated carbon (GAC). This system operated until February 7, 1997. During this period of time, operations continued with anticipation of the release of the *Interim Remedial Measure Proposed Plan for the 200-UP-1 Operable Unit, Hanford, Washington* (DOE-RL 1995b) and the issuance of a ROD.

On February 25, 1997, an interim remedial action ROD was issued for the 200-UP-1 pump-and-treat operations (DOE et al. 1997). The selected remedy consisted of extracting groundwater from the highest concentration zone of the uranium and technetium-99 groundwater plumes and routing the groundwater to the Effluent Treatment Facility (ETF) in the 200 East Area for treatment. Since initiation of Phase II operations on March 31, 1997, contaminated groundwater has been pumped from the extraction well and transported via pipeline, 11.3 km (7 mi) to the ETF. Treated groundwater is discharged to the State-Approved Land Disposal Site (SALDS) north of the 200 West Area.

The interim remedial action ROD (DOE et al. 1997) has the following specific RAOs:

- Reduce contamination in the areas with the highest concentrations of uranium and technetium-99 to below 10 times (480 µg/L) the cleanup level under the *Model Toxics Control Act* (MTCA) for uranium and 10 times (9,000 pCi/L) the MCL for technetium-99
- Reduce potential adverse human health risks by reducing contaminant mass
- Prevent further movement of these contaminants from the highest concentration areas
- Provide information that will lead to the development and implementation of a final remedy that will be protective of human health and the environment.

For additional site characterization and background information on the 200-UP-1 OU and pump-and-treat activity, refer to the *Remedial Investigation/Feasibility Study Work Plan for the 200-UP-1 Groundwater Operable Unit* (DOE-RL 1994), *200-UP-1 Groundwater Remedial Design/Remedial Action Work Plan* (DOE-RL 1997), and the *Engineering Evaluation/Conceptual Plan for the 200-UP-1 Groundwater Operable Unit Interim Remedial Measure* (BHI 1996b). Information regarding the progress of the 200-UP-1 pump-and-treat operations is provided in *200-UP-1 Groundwater Pump-and-Treat Phase I Annual Report, FY 1996* (BHI 1996a); *Fiscal Year 1997 Annual Report for the 100-NR-2, 200-UP-1, and 200-ZP-1 Pump-and-Treat Operations and Operable Units* (BHI 1998); and *Fiscal Year 1998 Annual Summary Report for the 200-UP-1, 200-ZP-1, and 100-NR-2 Pump-and-Treat Operations and Operable Units* (DOE-RL 1999b).

Previous conceptual model information is provided in the *Hydrogeologic Model for the 200 West Groundwater Aggregate Area* (Connelly et al. 1992) and the *200 West Groundwater Aggregate Area Management Study Report* (DOE-RL 1993). Numerical modeling is provided in the *Hanford Sitewide Groundwater Remediation Strategy – Supporting Technical Information* (BHI 1996c) and *Hanford Sitewide Groundwater Remediation Strategy – Groundwater Contaminant Predictions* (BHI 1997b).

1.3.2 200-ZP-1 Pump-and-Treat Operations

The 200-ZP-1 pump-and-treat system was implemented as an interim remedial action to prevent further movement of groundwater carbon tetrachloride contamination and to reduce contaminant mass. The system was implemented in a three-phased approach. Phase I operations consisted of a pilot-scale treatability test from August 29, 1994, to July 19, 1996. During this operating period, contaminated groundwater was removed through a single extraction well at a rate of about 150 L/min (45 gal/min), treated using GAC, and returned to the aquifer through an injection well. For more detailed information about operations during the treatability test, refer to the *200-ZP-1 Operable Unit Treatability Test Report* (DOE-RL 1995a).

Concurrent with Phase I operations, an interim action ROD (EPA 1995) was issued in June 1995, selecting the remedy using groundwater pump-and-treat technology to minimize further migration of carbon tetrachloride, chloroform, and TCE in the groundwater. Phase II operations

commenced August 5, 1996, in accordance with the interim action ROD and the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) Milestone M-16-04A (Ecology et al. 1994). Phase II operations ended on August 8, 1997, for transition to Phase III operations. The well field configuration during Phase II operations consisted of three extraction wells, pumping at a combined rate of about 570 L/min (150 gal/min), and a single injection well. Groundwater was treated using an air stripper and GAC for purging the air stream. For a detailed description of the treatment system setup and operation, refer to the *200-ZP-1 Interim Remedial Measure Quarterly Report, October - December 1996* (BHI 1997a).

Phase III operations were initiated on August 29, 1997, which satisfied Tri-Party Agreement Milestone M-16-04B. The well field was expanded to include six extraction wells and five injection wells, and pumping was increased to a combined rate of 720 L/min (190 gal/min). The treatment process for the Phase III system also uses air-stripping technology and GAC for remediating contaminated groundwater. Extraction wells were installed to contain the high-concentration portion of the carbon tetrachloride plume situated near the Plutonium Finishing Plant (formerly named Z Plant), as required by the interim action ROD.

The interim remedial action selected by the interim action ROD has the following specific RAOs and performance criteria:

- Prevent further movement of contaminants from the highest concentration area of the plume (i.e., contain contaminants inside the 2,000- to 3,000- $\mu\text{g/L}$ contour).
 - *Performance criterion 1:* Establish an inward hydraulic gradient within the 2,000- to 3,000- $\mu\text{g/L}$ carbon tetrachloride contour (the containment perimeter).
- Reduce contamination in the area of highest concentrations of carbon tetrachloride.
 - *Performance criterion 2:* Operate an interim remedial treatment system that will remove carbon tetrachloride, chloroform, and TCE, and will also measure the mass of carbon tetrachloride removed.
- Provide information that will lead to development of a final remedy that will be protective of human health and the environment.
 - *Performance criterion 3:* Evaluate aquifer and contaminant properties information collected during well installation and process operation.

For additional site characterization and background information on the 200-ZP-1 OU and pump-and-treat activity, refer to the *Engineering Evaluation/Conceptual Plan for the 200-ZP-1 Operable Unit Interim Remedial Measure* (BHI 1994), and the *200-ZP-1 IRM Phase II and III Remedial Design Report* (DOE-RL 1996a). Information regarding the progress of the 200-ZP-1 pump-and-treat operations is provided in BHI (1998) and DOE-RL (1999b).

Previous conceptual model information is provided by Connelly et al. (1992) and DOE-RL (1993). Numerical modeling is provided in BHI (1996c) and (1997b).

1.4 200-ZP-2 SOIL VAPOR EXTRACTION OPERATIONS

The 200-ZP-2 soil vapor extraction (SVE) operations were implemented as an expedited response action (ERA) to remove carbon tetrachloride contamination from the vadose zone, thereby minimizing any additional contamination of the groundwater. The first site evaluations, which included a pilot test of a SVE system, were conducted in 1991. Results of the initial ERA site evaluations were summarized in the *Expedited Response Action Proposal (EE/CA & EA) for 200 West Area Carbon Tetrachloride Plume* (DOE-RL 1991).

Based on the initial investigations and on the engineering evaluation and cost analysis (EE/CA), the preferred alternative for removing the carbon tetrachloride from the vadose zone was SVE followed by above-ground vapor treatment using GAC (DOE-RL 1991). In January 1992, the EPA and the Washington State Department of Ecology (Ecology) signed an action memorandum authorizing DOE to initiate SVE for cleanup of carbon tetrachloride (EPA and Ecology 1992). The first SVE system began operating in February 1992. By March 1993, three SVE systems were in operation, with a total extraction capacity of 85 m³/min. The three systems were operated at the 216-Z-1A tile field, 216-Z-9 Trench, and 216-Z-18 Crib. These three areas were selected for initial SVE operations because they were the primary known disposal sites for carbon tetrachloride. In August 1995, SVE operations were expanded to include the 216-Z-12 site. This disposal site was known to have received carbon tetrachloride, and ERA characterization activities indicated significant concentrations of carbon tetrachloride in the subsurface soil vapor.

A rebound study was conducted throughout the carbon tetrachloride SVE sites from November 1996 through July 1997 (Rohay 1997). The purpose of the study was to determine the increase in carbon tetrachloride vapor concentrations following shutdown of the extraction systems. All three SVE systems were shut down on November 4, 1996, and restarted on July 18, 1997. All three SVE systems continued to operate until September 30, 1997. During the time when the systems were off-line, carbon tetrachloride concentrations were monitored at 90 subsurface monitoring locations, ranging in depth from 1.5 to 64 m.

Based on the results of the rebound study and the declining rate of carbon tetrachloride removal during continuous extraction operations, the operating strategies for fiscal years (FYs) 1998 and 1999 were modified. Rather than operating all three SVE systems continuously, only the 14.2-m³/min system was used for carbon tetrachloride removal. During each of these two years, the 14.2-m³/min SVE system was operated for 3 months at the combined 216-Z-1A, 216-Z-18, and 216-Z-12 well fields and for 3 months at the 216-Z-9 well field. The SVE system was shut down for the winter from October through March in FY 1998 and in FY 1999.

For the 6-month period that the system was shut down during each of FYs 1998 and 1999, the rebound in carbon tetrachloride concentrations was monitored at nonoperational wells and probes covering both well fields. For the 3 months that the system was operated at the combined 216-Z-1A, 216-Z-18, and 216-Z-12 well fields, carbon tetrachloride concentrations were monitored at nonoperational wells and probes primarily at the 216-Z-9 well field. For the 3 months that the system was operated at the 216-Z-9

well field, carbon tetrachloride concentrations were monitored at nonoperational wells and probes primarily at the 216-Z-1A, 216-Z-18, and 216-Z-12 well fields.

The action memorandum (EPA 1992) described the purpose of the ERA as follows:

The purpose of this action is to mitigate the threat to site workers, public health, and the environment caused by the migration of carbon tetrachloride vapors through the soil column and into the groundwater. The action is an interim action taken to reduce the mass of carbon tetrachloride in the soil column beneath the 200 West Area pending the final cleanup activities associated with the 200-ZP-1 and 200-ZP-2 Operable Units.

For this report, the purpose statement above can be divided into the following four RAOs:

- Mitigate the threat to site workers
- Mitigate the threat to public health
- Mitigate the threat to the environment caused by the migration of contaminants from soil to groundwater
- Reduce the mass of carbon tetrachloride in the soil.

For additional site characterization and background information on the 200-ZP-2 OU and SVE activity, refer to DOE-RL (1991), Rohay et al. (1992), Rohay et al. (1993), Rohay (1995), Weekes and Glaman (1995), and Rohay (1996). Information regarding the progress of the 200-ZP-2 SVE operations is provided in Rohay (1997) and (1999).

Previous conceptual model information is provided in Rohay et al. (1994) and Rohay (1999). Numerical modeling is provided in Rohay and McMahon (1996) and Piepho (1996).

2.0 GEOLOGY AND HYDROGEOLOGY

2.1 GEOLOGY AND HYDROGEOLOGY

This section updates the geologic and hydrogeologic conceptual model of the 200 West Area using information collected or reported primarily since 1994.

2.1.1 Updates to the Geologic and Hydrogeologic Interpretation of the 200 West Area

The unconsolidated sediments overlying the Miocene Columbia River Basalt Group constitute the Ringold Formation, the Plio-Pleistocene unit, and the Hanford formation, in ascending order (Figure 2). Eolian or alluvial deposits of geologically recent origin may overlie the Hanford

formation. Lindsey (1991) classified the Hanford Site sediments into seven lithostratigraphic categories within the aforementioned formations. The lithologic, depositional, and especially hydraulic characteristics of the sediments exhibit enough variation that additional divisions were made for hydrogeologic modeling (Hartman 1999).

For modeling purposes, the suprabasalt sediments were examined and reassigned to hydrogeologic modeling units based on properties that generally affect flow (i.e., texture, sorting, porosity, and cementation) (Hartman 1999). This resulted in nine hydrogeologic model divisions from the initial seven lithologic/stratigraphic units (Lindsey 1991); seven of the hydrogeologic units are below the water table (Table 1). In general, the odd-numbered model units refer to transmissive sediments, whereas the even-numbered units are of low hydraulic conductivity or aquitards. The water table is found within hydrogeologic unit 5, which correlates to the Ringold Unit E and the lower sandy interval(s) of the Upper Ringold (as defined in Lindsey 1991). As represented in Figure 3, hydrogeologic unit 3 (Plio-Pleistocene carbonate unit), hydrogeologic unit 6 (Ringold Unit C), and hydrogeologic unit 7 (Ringold Units B and D) are graphically shown to be extensive and pervasive across the Hanford Site. However, hydrogeologic units 6 and 7 have not been encountered in boreholes in the 200 West Area.

Hydrogeologic unit 3, the Plio-Pleistocene, is present throughout the 200 West Area as the combined silt (early Palouse soil) and carbonate units. The early Palouse terminates within or near the southeast, south, and southwest boundaries of the 200 West Area (Figure 4). The carbonate unit thins to approximately 3 m to the southwest but maintains a thickness of 5 m or more throughout the remainder of the 200 West Area. The combined units attain a thickness of greater than 25 m locally in the central part of the 200 West Area and directly overlie the hydrogeologic unit 4 sediments (Upper Ringold).

Hydrogeologic unit 4, or the Upper Ringold (Lindsey 1995), has been depicted as not extending into or beyond the southern one-third of the 200 West Area. However, the unit was found to extend southeasterly into the Environmental Restoration Disposal Facility (ERDF) and was identified in boreholes between the 200 West Area and the ERDF site. This unit pinches out in one of the ERDF excavations. Hydrogeologic unit 4 sediments also have been identified in boreholes within the 200-UP-1 OU, as well as in deep holes near the southern boundary of the 200 West Area. The Upper Ringold thickness map (Figure 5) has been upgraded to reflect the known extent of the unit.

2.1.2 200 West Area Geology

Two geologic sections were constructed across the 200 West Area. The sections run northeast-southwest (A-A') (Figure 6) and northwest-southeast (B-B') (Figure 7) in a rough "X" pattern that crosses at well 299-W15-7, just north of the Plutonium Finishing Plant. Most of the wells used in the sections were selected because they were drilled into or through the Ringold Lower Mud Unit. Examination of the geologic sections, in addition to borehole information, resulted in the identification of characteristics that may directly influence contaminant transport or movement. Key aspects, consistent with past studies and conceptual models (except where noted), can be summarized as follows:

- **Ringold Formation**

- The Ringold Lower Mud, hydrogeologic unit 8, is persistent throughout the 200 West Area and is the base of the unconfined or semi-confined aquifer (consistent with Lindsey 1991 and Hartman 1999). The revised structure contour map of the Ringold Lower Mud within the 200 West Area is presented as Figure 8.
- Ringold Units D, B, and C of the Member of Wooded Island (hydrogeologic units 6 and 7) have not been identified in the stratigraphic column in the 200 West Area during drilling processes. Definitive marker beds are not distinctive or present and, without the markers, differentiation of these beds from either the Ringold Units A or E is difficult.
- The fluvial character of the Ringold Unit E (hydrogeologic unit 5), as probable braided stream deposits (Lindsey 1991), permits lateral migration through incised channels. Some channels will be relatively continuous, but many channels will be segmented due to the nature of braiding streams. This may be the reason for variable discharge rates in proximal wells where the screens are installed at the same horizon (i.e., in two wells 15.2 m [50 ft] apart, the discharge rate in one may be 180 L/min and in the other the rate may be as low as 60 L/min).
- The variability in vertical and lateral extent of post-depositional cementation (as iron oxides, carbonates, and/or silica) within the Ringold Unit E, combined with unpredictable heterogeneity and drilling techniques that severely disturb the samples, makes independent channel identification tenuous at best. When the overbank deposits and other fines associated with the Ringold Unit E are considered with the preceding information, it appears that preferential flow paths may be millimeters in width and meters in length. A combination of grain size, matrix components, presence or absence of silt or clay, plus the degree of cementation might allow differentiation of channels or channel segments.
- Locally abundant fluvial sands in the Upper Ringold (hydrogeologic unit 4) can be preferential pathways in the vadose zone for limited lateral transport through the dominantly silt unit or localized perched water accumulations in isolated lenses.

- **Plio-Pleistocene Unit**

- The carbonate unit (hydrogeologic unit 3) underlies the entire 200 West Area. Carbonate cement is discontinuous through the unit and variable in the degree of cementation. Where the cement is present, the unit provides a perched water platform. The low-permeability nature of the unit also provides a mechanism for lateral transport in the vadose zone.

- The early Palouse soils (hydrogeologic unit 2) are dominantly silt with sand and provide potential local perching horizons for downward migrating solutions. This horizon may serve as a lateral transport mechanism in the vadose zone.
- **Hanford formation**
 - Sediments of the Hanford fine-grained unit (Touchet Beds, discussed by Lindsey 1991) are of variable thickness but are dominantly sand with intercalated, discontinuous silt/sandy silt horizons. The silt lenses can provide local beds for perching water and platforms for lateral migration in the vadose zone.
 - Clastic dikes are variously oriented, vertical to sill-like, sand- to granule-filled fractures, found in nearly all fine-grained facies/units in the stratigraphic column above the water table (i.e., those strata above the Ringold Unit E [hydrogeologic unit 5]). Clastic dikes are abundant in the sand- and silt-dominated facies of the Hanford formation (Fecht et al. 1999). These dikes have been seen in cable tool cores and drive-barrel materials in the 200-UP-1 area and can provide pathways between, or through, the fine-grained units. However, some dikes have an external silt or clay “skin” that may prevent or significantly retard solution movement. The clastic dikes may be a significant influence in contaminant movement.

2.1.3 Vadose Zone Transport

Liquid movement is dependent on the degree of cementation, the amount of fines in the formation, initial saturation, and the characteristics of the solution pathway. A liquid entering the strata at the surface will disperse in a relatively narrow, cone-like pattern through the gravel and/or sand facies of the Hanford formation. This distribution will persist until a low-permeability silt or sandy silt is encountered, where movement along the vertical path will be restricted or slowed. The liquid will then travel laterally to where the unit pinches out or intersects a clastic dike with a sand to granule infilling, where it will again migrate vertically, or alternately sufficient hydraulic head will build up until breakthrough and the liquid moves through and below the fine-grained unit. At the contact with the Plio-Pleistocene unit, the liquid will be retarded and will tend to accumulate (historically this horizon has locally produced perched water, especially during the active discharge years when the major processing plants were in production). At this layer, the liquid will move laterally to clastic dikes or other fractures, or possibly to wells that have penetrated the formation and created a preferential pathway to the underlying Ringold Formation and/or the water table, or will again build up sufficient hydraulic head for movement through this unit.

2.2 HYDROGEOLOGY

Groundwater underlying the 200 West Area flows within a multi-aquifer system. The uppermost aquifer beneath the 200 West Area is unconfined and lies within an unconsolidated to semi-indurated gravel and sand sequence. The water table does fluctuate in response to barometric pressure changes, which is more typical of confined aquifers, because of the thick overlying

vadose zone. This phenomenon is discussed and explained in Weeks 1979. The base of the unconfined aquifer is the Ringold Lower Mud Unit. Beneath the carbon tetrachloride disposal sites, the unconfined aquifer is approximately 66-m thick (Auten and Reynolds 1997). Horizontal hydraulic conductivities in the aquifer range from approximately 1.8 cm/s to 3.5×10^{-4} cm/s with a geometric mean of 1.5×10^{-4} cm/s (Connelly et al. 1992). Anisotropy within a sedimentary unit generally ranges from 6:1 to 16:1 (ratio of radial to vertical conductivity). The lateral and vertical variability in transmissivity is illustrated at the carbon tetrachloride disposal site by the production rates of the six pump-and-treat extraction wells, which range from 63 L/min to 310 L/min for similarly completed and configured wells (DOE-RL 1999b).

The suprabasalt confined aquifer, composed of interbedded sands and gravels, extends from the Ringold Lower Mud Unit to the top of basalt bedrock. The basalt-confined aquifer system is comprised of relatively higher hydraulic conductivity zones separated by lower hydraulic conductivity basalt flow interiors.

Natural recharge from precipitation is estimated to be greater than 100 mm/yr in the carbon tetrachloride disposal area (Fayer and Walters 1995). Recharge from precipitation is higher in the coarse-textured soils with little or no vegetation, as are found in the 200 West Area (Hartman 1999). Within the 200 West Area, natural recharge may be further enhanced in local topographic depressions as a result of diversion of surface water runoff. For example, natural recharge may be enhanced at the 216-Z-1A tile field, which was originally constructed approximately 1.5 m (5 ft) below grade. Infiltration from the surface may have been reduced in 1964, prior to reactivation, when the tile field was covered with a sheet of 0.05-cm-thick polyethylene and may have been enhanced in 1993 when the tile field was covered with a gravel layer. Natural recharge may also be enhanced at the 216-Z-9 Trench, toward which the ground surface slopes from the west and the south.

2.2.1 Historic and Current Groundwater Conditions

Prior to the initiation of waste disposal activities at the Hanford Site, general groundwater flow appears to have been from west to east across the Site toward the Columbia River, with an average horizontal hydraulic gradient of 0.001 (Graham et al. 1981). Wastewater discharges to cribs, ditches, and ponds since 1943 have created local groundwater mounds in the 200 West Area. The locations and heights of the mounds have changed as wastewater discharge locations and rates have changed throughout the Hanford Site's operating history. The maximum water level change was as much as 25 m above pre-Hanford conditions, most notably in the area of the 216-U-10 Pond (U Pond) (Newcomer 1990).

In the early years of operations, the primary groundwater mound occurred north of Z Plant (now referred to as the Plutonium Finishing Plant) at the 216-T-4 Pond (T Pond) causing southward net groundwater flow across 200 West Area until the late 1950s (Figure 9). From the late 1950s through the present, the primary groundwater mound influencing flow directions has been at U Pond and its associated ditches and cribs in the southern half of the 200 West Area. During full operation, the U Pond complex received approximately 60% of the total volume of wastewater released in the 200 West Area (Newcomer 1990). Discharges to U Pond were terminated in late

1984; however, some discharges were still sent to the 216-U-14 Ditch, which formerly discharged into U Pond.

Primary surface discharge facilities near Z Plant (carbon tetrachloride source area) that were active during the 1980s and early 1990s were the 216-U-14 Ditch, the 284-WB Power Plant ponds, the 216-Z-20 Crib, and the 216-Z-21 Pond (Figure 10). After termination of discharges to the U Pond in 1984, mounding shifted to the north and northeast to the 216-U-14 Ditch until 1989 (Newcomer 1990). In 1995, liquid discharges to the surface soils were discontinued in accordance with the Tri-Party Agreement M-17 milestone series, with wastewater being routed to the ETF.

The presence of the mounds has affected the direction of groundwater movement by producing a radial flow pattern from the discharge areas and increasing the rate of groundwater movement from these areas (increased hydraulic gradients). With the cessation of liquid discharges, the elevations of both the regional water table and the local groundwater mounds have been declining, resulting in (1) a concomitant increase in the thickness of the vadose zone, and (2) changes in flow directions and rates that affect the distribution of contaminants in the groundwater and the local definitions of “upgradient” and “downgradient” (DOE-RL 1999b).

The current regional hydraulic gradient is 0.001 m/m with a current flow rate approximately 0.15 m/day across the site (DOE-RL 1999a). Groundwater flow rates and contaminant movement are expected to slow as the groundwater mound subsides and the regional water table declines. The current rate of water table decline is approximately 0.45 m/yr under the carbon tetrachloride site and under the uranium/technetium site (DOE-RL 1999b).

In conclusion, the hydraulic flow field in the 200 West Area has changed multiple times over the last 50 years. Many of the facilities produced local groundwater mounding, cause radial flow, and introduced variable groundwater flow patterns. It has been previously reported that the high-concentration area of the carbon tetrachloride plume might be situated northwest of the disposal sites (216-Z-9) because of a dipping stratigraphic unit, other unidentified disposal sites or leaks, and/or higher volumes of discharge to known source cribs (e.g., 216-Z-12) (Rohay 1999). While these are reasonable and potentially valid explanations for the distribution of the carbon tetrachloride plume, the historic complexities of changing aquifer hydraulics should be further evaluated.

2.2.2 200 West Area Water Table

The water table has been declining in the 200 West Area since the shutdown of the 216-U-10 Pond in 1984. A more recent significant cause of water level decline resulted from the termination of liquid discharges to the soils in 1995 (per Tri-Party Agreement M-17 milestone series). This change was accompanied by an accelerated rate of water level decline in the southern and central portion of the 200 West Area, including the Plutonium Finishing Plant area and the TX-TY tank farm to the north, but may be evident in most of the 200 West Area.

Four monitoring wells at the TX-TY tank farm show this accelerated rate of decline (Figure 11). Before 1995, the rate of water level decline was relatively steady, but the rate of decline increased in 1995, and by 1998 the decline appeared to be asymptotically approaching the

pre-1995 rate of decline. This change cannot be attributed to 200-ZP-1 remedial actions since operations did not start until September 1996, almost 1 year after the start of the increased rate of decline. This same change is apparently present at well 299-W8-1 (Figure 12) in the northern portion of the 200 West Area and is less clearly present at well 699-39-79 (Figure 13) west of the Plutonium Finishing Plant. It appears that termination of all surface discharges in 1995 increased the overall rate of water level decline in much of the 200 West Area.

Both ERC and Pacific Northwest National Laboratory (PNNL) groundwater models have been used to predict the future elevations of Hanford Site water levels after the effects of surface liquid discharges have dissipated and approximate steady-state conditions are reached. The pre-Hanford operations water table conditions are represented by the Hindcast map for the year 1944 (Figure 14). Because of irrigation practices in the Cold Creek Valley, it is predicted that water levels will not completely return to pre-Hanford conditions, most notably in the areas extending from 200 West Area upgradient to the Cold Creek area (Cole et al. 1997). Newcomer (1990) reports that two water users are irrigating crops at a total rate of 20,062 L/min (5,300 gal/min). Because this water originates in the basalt aquifer and is discharged to unconfined aquifer, this water represents a source of artificially generated "recharge." Figure 14 compares the Hindcast map to the predicted water table in the year 2350 and shows the overall higher hydraulic heads in the western part of the Hanford Site. Long-term placement and design of monitoring wells will need to account for these continuing changes in the water table.

Numerous shallow groundwater monitoring wells are projected to go dry as the water table in 200 West Area continues to decline. Several reports have been issued that have analyzed the impacts of water declines on monitoring wells, including Webber and McDonald (1994), Wurstner and Freshley (1994), and more recently DOE-RL (1996b). Five wells are reported as supporting multiple programs (DOE-RL 1999a). Additional monitoring wells should be installed if the ability to track contaminant plumes is affected by well loss due to declining water levels.

2.2.3 Vertical Hydraulic Gradients

Because of residual U Pond mounding and later mounding from other surface discharge facilities (e.g., the 216-U-14 Ditch and the 284-WB Power Plant ponds), hydraulic head has historically decreased with depth in the southern and central portion of the 200 West Area. Vertical groundwater gradients are downward from the unconfined to the confined system, with hydraulic head differences across the Ringold Lower Mud Unit becoming more pronounced into the basalt aquifer systems (Spane and Webber 1995). Some wells extending below this confining unit may have permitted the movement of contamination between the unconfined and confined aquifers because of open well perforations above and below the Ringold Lower Mud Unit (e.g., Auten and Reynolds 1997). As water levels in the 200 West Area continue to decline, the magnitude of the downward hydraulic gradient will decrease with less possibility that dissolved contaminants will be driven deeper into the aquifer.

2.2.4 Influence of Pump-and-Treat Operations on Groundwater Flow Directions

The current groundwater flow directions underlying the carbon tetrachloride disposal sites are strongly influenced by the 200-ZP-1 groundwater pump-and-treat system, which has been operating at full-scale since 1996. This system consists of six extraction wells to the east and

three injection wells to the west of the Plutonium Finishing Plant (Figure 10), operating at a treatment rate of about 760 L/min. A recirculation cell will eventually be established between the extraction and injection wells (DOE-RL 1999b). In the area of the Low-Level Burial Grounds waste management unit 4, the groundwater flow has changed from a radial flow pattern prior to 200-ZP-1 operations to groundwater now moving in the opposite direction beneath the facility from west to east (Figure 9). This change has affected the monitoring network for the facility, reversing the upgradient and downgradient wells (DOE-RL 1999b).

Operation of the 200-ZP-1 pump-and-treat system has decreased the downward hydraulic gradient in the area of the extraction wells (mitigating downward movement of dissolved contaminants) by removing the groundwater mound in the unconfined aquifer. The mound-generating downward gradient has also been decreasing as water levels re-equilibrate in the unconfined aquifer. The decrease in gradient is shown in Figure 15 for wells 299-W15-16 and 299-W15-17, which is 55 ft apart. Note that the water levels are approaching each other in elevation. Well 299-W15-17 is completed at the bottom of the unconfined aquifer and well 299-W15-16 is screened at the top of the unconfined aquifer. In contrast, injection of treated water has increased the downward hydraulic gradient in the area of the injection wells.

At the 200-UP-1 site, the effects of pumping are localized in the vicinity of the extraction well (170 L/min). Because groundwater is transported to the ETF and the injection well is no longer used, there are no mounding effects that would contribute to a downward hydraulic gradient (DOE-RL 1999b). In the area of the pumping well, however, an upward hydraulic gradient is generated because of the pumping from partially penetrating well screen. There are no known impacts on other groundwater monitoring facilities from 200-UP-1 operations.

3.0 CONTAMINANT DISTRIBUTION

Two OUs, as defined under CERCLA, have been established to address groundwater contamination beneath the 200 West Area. The 200-ZP-1 OU, which contains the carbon tetrachloride groundwater plume, is located primarily in the northern half of the 200 West Area. The 200-UP-1 OU, which contains the technetium-99 and uranium plumes, is located in the southern half of the 200 West Area.

Numerous OUs have also been established to address the source areas in the vadose zone beneath the 200 West Area. The 200-ZP-2 OU, which contains the carbon tetrachloride vadose zone plume, is located in the central portion of the 200 West Area.

3.1 CARBON TETRACHLORIDE (200-ZP-1 AND 200-ZP-2 OPERABLE UNITS)

Carbon tetrachloride contamination at the 200-ZP-1 and 200-ZP-2 OUs resulted from liquid waste disposal to the ground from the Plutonium Finishing Plant complex. Widespread contaminant plumes are present in the vadose zone and in the groundwater. The high concentrations of carbon tetrachloride dissolved in the groundwater and the large areal extent of

the plume (covering most of the 200 West Area) make remediation of the groundwater plume a priority at the Hanford Site.

3.1.1 Carbon Tetrachloride Source Characteristics

The primary known sources of carbon tetrachloride contamination in the 200 West Area are the subsurface infiltration facilities used for soil column disposal of aqueous and organic liquid wastes associated with plutonium recovery operations within the Plutonium Finishing Plant complex. Between 1955 and 1973, a total of 363,000 to 580,000 L (577,000 to 922,000 kg) of liquid carbon tetrachloride (in mixtures with other organic and aqueous actinide-bearing liquids) are estimated to have been discharged to the soil column at three subsurface disposal facilities near the Plutonium Finishing Plant: the 216-Z-9 Trench, the 216-Z-1A tile field, and the 216-Z-18 Crib (Figure 10).

The organic solutions consisted of 50% to 85% by volume carbon tetrachloride mixed with either tributyl phosphate (TBP), dibutyl butyl phosphonate (DBBP), or lard oil (Rohay and Johnson 1991). The solvent that was discharged to the soil column also contained dibutyl phosphate (DBP), which is a degradation product of TBP. The organic solutions were periodically discharged to the predominantly water-wetted soil column in small (100- to 200-L) batches.

These organic solutions were approximately 4% to 8% of the total volume of liquid waste discharged to the disposal facilities. From 1955 to 1973, approximately 13.2×10^6 L of aqueous wastewater were discharged to three primary disposal sites. The aqueous waste stream consisted of acidic, high-salt (sodium nitrate) wastewater containing these organic solutions in saturated amounts (<1%). Thus, carbon tetrachloride was introduced to the vadose zone as an aqueous phase and also as a dense nonaqueous-phase liquid (DNAPL) (Rohay 1999).

Three other sites in the vicinity of Z Plant also received carbon tetrachloride wastes: 216-Z-12 Crib, 216-Z-19 Ditch, and 216-T-19 tile field (Figure 10). The 216-Z-12 Crib received Z Plant analytical and development laboratory waste from 1959 to 1973 and is estimated to have received a small volume of organics, which included carbon tetrachloride (Kasper 1982). The 216-Z-19 Ditch was used to convey Z Plant process cooling water and steam condensate from 1971 to 1981. Apparently, carbon tetrachloride was also occasionally and/or accidentally released to this ditch (e.g., as a result of steam and/or cooling water coil leaks) because heavy organics were noted in the outfall (Rohay and Johnson 1991). Between 1973 and 1976, aqueous waste saturated with carbon tetrachloride was sent to the 242-T Evaporator. During this time frame, the 216-T-19 tile field received approximately 880 L (1,400 kg) of carbon tetrachloride in the overhead condensate discharged from this evaporator (Rohay et al. 1993).

3.1.2 Carbon Tetrachloride Mass Distribution

Approximately 750,000 kg of carbon tetrachloride (the average of the estimated range for the original total inventory) was discharged to the three primary disposal sites. Concentrations of carbon tetrachloride measured in groundwater and soil vapor in 1990, prior to remediation, were used with equilibrium partitioning relationships to account for approximately 35% of the total carbon tetrachloride inventory discharged to the soil column (WHC 1993) (Table 2). However, these relationships do not account for the non-equilibrium partitioning of carbon tetrachloride

within soil particles (the apparent “irreversible” adsorption) (Yonge et al. 1996). In 1990, the remaining 65% of the original inventory was believed to be in residual saturation and non-equilibrium sorption sites within the vadose zone and groundwater.

Based on the equilibrium partitioning relationships and the 1990 soil vapor data, 12% of the original inventory was estimated to be in the vadose zone: 4% in soil vapor, 2% in soil moisture, and 6% sorbed to solids (WHC 1993).

Evaporation and barometric pumping of carbon tetrachloride are estimated to have removed 21% of the original carbon tetrachloride inventory from the vadose zone between 1955 and 1990 (WHC 1993).

Based on the carbon tetrachloride plume map, the mass of carbon tetrachloride in the upper 10 m of the unconfined aquifer in 1990 was estimated to be 5,250 to 15,740 kg, accounting for 1% to 2% of the original inventory, depending on the value of porosity assumed (Rohay and Johnson 1991) (Table 3). A soil partitioning distribution coefficient (K_d) of 0.2 mL/g would result in an additional 2% to 8% of the carbon tetrachloride inventory sorbed to aquifer solids (Rohay et al. 1994).

Based on the mass of the carbon source (lard oil and butyl phosphates) and nitrate (electron acceptor) co-disposed with the carbon tetrachloride, Hooker et al. (1996) estimated that 1% of the carbon tetrachloride could have been transformed to chloroform by microbial dechlorination during initial discharge stages (Hooker et al. 1996). The chloroform levels observed in the vadose zone and aquifer correspond to a reductive dechlorination of 1% of the carbon tetrachloride. Biodegradation is probably no longer occurring within the vadose zone and groundwater because the naturally occurring total organic carbon in the soil is insufficient to fuel the process. The occurrence of any geochemical degradation of carbon tetrachloride has not been evaluated.

Approximately 78,000 kg of carbon tetrachloride have been removed from the subsurface (vadose zone and groundwater) since remediation of the site began in 1992. Between February 1992 and September 1998, SVE removed approximately 76,000 kg of carbon tetrachloride from the vadose zone (Rohay 1999). The mass removed is 84% of the mass initially estimated, based on equilibrium partitioning, to be contained within the vadose zone in vapor, dissolved, and adsorbed phases (Table 2). Concentrations in extracted soil vapor have declined significantly since 1992. However, concentration rebound during nonoperation of the SVE system indicates that carbon tetrachloride remains in the vadose zone.

The groundwater pump-and-treat system was constructed to contain carbon tetrachloride within the 2,000 $\mu\text{g/L}$ contour (DOE-RL 1999b). Between August 1994 and December 1998, the pump-and-treat system removed approximately 2,100 kg from the unconfined aquifer (DOE-RL 1999b). The mass removed is 33% to 99% of the mass initially estimated to be contained within the 2,000- $\mu\text{g/L}$ contour (Table 3). The persistence of the carbon tetrachloride concentrations implies that the initial mass calculation was incorrect (e.g., because of greater depth distribution), and/or K_d is greater than assumed, and/or the presence of a continuing source of carbon tetrachloride (residual or DNAPL) (Rohay 1999).

3.1.3 Carbon Tetrachloride Groundwater Plume Changes

The plume of dissolved carbon tetrachloride extends over 11 km² in the unconfined aquifer underlying the 200 West Area (Hartman 1999) (Figure 16). The zone of highest concentrations (4,000 to 8,000 µg/L) includes the 216-Z-9 Trench area, suggesting that the formerly discharged carbon tetrachloride may be providing a continuous source of contamination from the vadose zone to the groundwater. Based on dissolved phase concentrations in the upper 10 m of the unconfined aquifer in 1990 prior to remediation, nearly 60% of the groundwater mass of carbon tetrachloride was contained within about 10% of the area of the plume (Rohay and Johnson 1991) (Table 3). Carbon tetrachloride detections at depths greater than 10 m below the water table are discussed in Section 3.1.4.

Although the centroid of the plume has not migrated significantly under natural driving forces, the perimeter of the plume appears to be migrating southward based on increasing concentrations at well 299-W23-10 (Hartman 1999). A comparison of the 200 West Area carbon tetrachloride 1996 baseline plume map (Figure 16) with the 1998 plume map (DOE-RL 1999b) (Figure 17) also shows a diminution of the 1,000-µg/L contour in the northern part of the 200 West Area. The one exception in this area occurs at well 299-W10-20, which has consistently maintained concentrations above 1,000 µg/L (although in 1996 carbon tetrachloride dropped below 1,000 µg/L). Well 299-W10-20 is located far enough to the northwest of the Plutonium Finishing Plant plume that the question of another carbon tetrachloride source should be considered in the northern part of the 200 West Area. The shape of the baseline plume in this area (west to east) also implies that carbon tetrachloride originated from another or multiple sources (not necessarily from the Plutonium Finishing Plant area to the south). A more thorough evaluation of historical changes in the hydraulic flow field for the unconfined aquifer would help to determine the likelihood of a northern source.

Dissolved concentrations measured in well 699-39-79 at the western perimeter of the plume increased by an order of magnitude between March 1987 and August 1988, suggesting the arrival of the plume at that time (Dresel et al. 1993). Concentrations at well 699-39-79 have been impacted by injecting treated water at the nearby pump-and-treat injection wells (Figure 18), and the concentrations have fallen below detection limits. Other monitoring wells in the area can expect decreasing concentrations, particularly wells that support monitoring at the Low-Level Burial Grounds.

During the last 5 years, an increase and then decrease in carbon tetrachloride concentrations was observed in well 299-W18-21 in the southwestern part of the 200 West Area. Initial concentrations in this well were 200 µg/L in mid-1992. Carbon tetrachloride concentrations peaked at 1,800 µg/L in early 1995 and then decreased to about 200 µg/L by mid-1998 (Figure 19). It can be observed that carbon tetrachloride concentrations began declining in this well after liquid discharges to the soil were terminated in 1995 (per Tri-Party Agreement milestones). It is, thus, hypothesized that water table mounding to the northeast produced by the 216-Z-20 Trench, the 284-WB Power Plant ponds, and/or the 216-U-14 Ditch drove contaminated groundwater to the southwest, toward well 299-W18-21. Groundwater would have passed through the high-concentration area of the carbon tetrachloride plume (Figure 16). After soil discharges stopped in the 1995, groundwater flow direction reverted to a west-to-east direction. Cleaner groundwater entering from the west began diluting and pushing carbon

tetrachloride away from well 299-W18-21. Carbon tetrachloride concentrations have decreased since that time.

It has been suggested that groundwater contamination in the southwest portion of the 200 West Area aquifer may also be the result of vapor transport from the source cribs or from vapor cycling (i.e., carbon tetrachloride volatilizing from contaminated groundwater, diffusing through the vadose zone, and then contaminating clean groundwater) (Rohay 1999). The increased concentrations at well 299-W18-21 do not fit this scenario according to the hypothesis stated above because of the shallow carbon tetrachloride penetration expected through vapor exchange (only 1 to 2 m below the water table) and the relatively high groundwater concentrations (1,800 µg/L).

The phenomenon of vapor cycling is still possible in areas characterized by low groundwater concentrations. Vapor sampling of the vadose zone in areas where plume concentrations are now at the MCL and concordant sampling of groundwater at depths of 5 m or more below the water table would help to substantiate and possibly quantify this process. In some areas (e.g., well 299-W18-21) it is more likely that carbon tetrachloride is volatilizing to the vadose zone rather than from the vadose zone to the groundwater. It is recommended that moderate effort be expended to quantify this process.

It appears that the hydraulic flow field was conducive to movement of carbon tetrachloride to the southwest from the time that U Pond discharges ceased in 1984 to the termination of discharges to the 284-WB Power Plant ponds in 1995. This conclusion is based on the presence of the carbon tetrachloride slug in well 299-W18-21.

Concentrations of carbon tetrachloride in the central portion of the carbon tetrachloride plume continue to increase at the 200-ZP-1 extraction wells and in monitoring wells along the path from the central portion of the plume to the extraction wells. For example, at intermediate monitoring well 299-W15-31A (located west of 231-Z; Figure 10), increasingly higher concentrations of the dissolved plume are moving past this well toward the extraction wells (e.g., wells 299-W15-33 and 299-W15-34) (Figure 20). At some future opportune time, it would be useful to shut down pumping operations to see if groundwater concentration rebound. If rebound occurred (an increase in carbon tetrachloride concentrations), the presence of residual DNAPL in the aquifer would be implied. The ideal location for such a test would be at extraction well 299-W15-32 where concentrations have been decreasing (DOE-RL 1999b). Well 299-W15-32 is located near the 216-Z-9 Trench (the primary disposal site for carbon tetrachloride) and is the location where DNAPL would be expected.

In monitoring wells closest to the injection wells, concentrations are decreasing, as observed in well 699-39-79. As predicted by performance modeling (DOE-RL 1999a), a recirculation cell will eventually be established between the extraction wells and the injection wells, which will continue to lower concentrations in the monitoring wells between the extraction and injection wells.

Pump-and-treat extraction and injection operations have affected the distribution and concentrations of carbon tetrachloride in the centroid portion of the plume. The >4,000-µg/L contour interval has expanded in size and now extends more northerly and easterly to near the

extraction wells, although it may be slightly reduced in the southwest (Figure 21). Injection of treated groundwater at the upgradient location is beginning to dilute the carbon tetrachloride plume in this area. The increase in size of the 4,000- $\mu\text{g/L}$ contour and the concomitant steady or increasing concentrations in the interior wells may imply more than just aqueous-phase movement (dissolved carbon tetrachloride) toward the extraction wells (e.g., the presence of DNAPL, residual carbon tetrachloride, or a higher partitioning coefficient than previously estimated). Approximately 2,100 kg of carbon tetrachloride have already been removed, and no apparent reduction has been noted in concentrations in the high-concentration area. Therefore, the mass of carbon tetrachloride within the treatment area may be greater or may be distributed differently than what was assumed prior to beginning pump-and-treat remediation.

3.1.4 Deep Carbon Tetrachloride Distribution

Dissolved carbon tetrachloride has been observed deep (>10 m below the water table) within the unconfined aquifer and within the uppermost confined aquifer in the 200 West Area. Although the number of wells screened (or perforated) deep within the aquifer is limited, deep sampling has also been conducted during drilling of wells that were later completed at the water table and during well abandonment. Vertical contaminant profiling has also been conducted in older wells with long perforated intervals by using a packer to isolate discrete intervals or by using a depth-discrete sampling device (e.g., KABIS[™] bailer). Carbon tetrachloride groundwater concentrations for samples collected deeper than 10 m below the water tables are compiled in Appendix A. The data were collected from a variety of well configurations using different sampling and analytical methods during the last 12 years.

Vertical carbon tetrachloride profiles (based on data collected from at least two depths and extending deeper than 10 m below the water table in a single well) are available for 12 wells within the 200 West Area. Most of these wells are located within the high-concentration portion ($>1,000$ $\mu\text{g/L}$) of the carbon tetrachloride water table plume (Figure 22). Carbon tetrachloride concentrations have been observed to decrease with depth (e.g., well 299-W15-5), increase with depth and then decrease (e.g., well 299-W10-24), or remain relatively constant with depth (e.g., well 299-W15-7).

Two zones within the unconfined aquifer were selected to show the lateral distribution of deep carbon tetrachloride concentrations. Carbon tetrachloride concentrations detected in samples collected in the middle of the unconfined aquifer (between approximately 15 and 40 m below the water table) are plotted in Figure 23, and concentrations detected in samples collected at the bottom of the unconfined aquifer are plotted in Figure 24. Both of these figures include the carbon tetrachloride water table plume for reference. Groundwater concentrations in samples collected from wells with long perforated intervals (e.g., >15 m) were not included on these lateral distribution maps.

In both the middle and bottom of the unconfined aquifer, the highest concentrations primarily underlie the high-concentration area of the water table plume. Nine of the 15 mid-depth samples were collected below the area encompassed by this high-concentration zone, so this correlation is probably related to the sampling distribution. However, only five of the 12 bottom samples were

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collected below the area of the high-concentration zone, making this correlation more striking for the bottom of the unconfined aquifer.

At two locations near the periphery of the water table plume, carbon tetrachloride has been detected at higher concentrations at depth than in the overlying water table samples: well 699-48-77C (north of the 200 West Area) and well 299-W27-2 (south of the 200 West Area) (Hartman 1999). Initial concentrations detected 21 m below the water table in well 699-48-77C have been decreasing (from a high of 8 µg/L in March 1998), presumably in response to the treated water disposal at the adjacent SALDS crib. Effluent disposed to the soils at this site have produced a 2-m-high groundwater mound. In contrast, concentrations detected in nearby well 699-48-70D, screened across the water table, have not exceeded the MCL of 5 µg/L. Carbon tetrachloride has been detected in well 299-W27-2, screened just above a clay layer 55 m below the water table, at concentrations near the MCL. Carbon tetrachloride has not been detected at the water table in this vicinity. Because there are few wells screened in deeper parts of the unconfined aquifer, these data suggest that the horizontal extent of deep carbon tetrachloride at levels greater than the MCL may be considerably greater than previously reported (Hartman 1999).

Concentrations have been increasing in deep well 299-W15-17 from below the MCL of 5 µg/L to above the MCL (Figure 25). This well is screened approximately 60 m below the water table west of the Plutonium Finishing Plant. The companion water table well, 299-W15-16, has had elevated carbon tetrachloride concentrations (>1,000 µg/L) since sampling was initiated in 1988 and has also had the highest concentrations detected in any well in the 200 West Area groundwater. However, concentrations in the deep well have only increased above the MCL (5 µg/L) since 1998; the maximum concentration observed was 12 µg/L in January 1998.

Dissolved carbon tetrachloride has also been observed at concentrations exceeding the MCL within the confined aquifer system (i.e., in the Ringold Unit A gravels below the base of the unconfined aquifer). Concentrations ranging from 15 to 590 µg/L have been detected at a well south of the 216-Z-9 site (well 299-W15-5) (Auten and Reynolds 1997), at two wells near the T-TX-TY tank farms (wells 299-W10-24 and 299-W14-14) (Hartman 1999), and at a well near U Plant (well 299-W19-34B) (Ford 1995) (Figure 26). In the case of well 299-W15-5, it is likely that the well provided the preferential downward pathway prior to abandonment because it was perforated across the confining layer (i.e., the Ringold Lower Mud) for about 40 years, and the hydraulic gradient was known to be downward from the unconfined to the confined system during this time.

Numerical modeling of carbon tetrachloride flow and transport in the vadose zone indicates that the depth of penetration of carbon tetrachloride (dissolved and nonaqueous phases) into the aquifer depends upon the residual saturation in the vadose zone, which affects the flux to the aquifer, and the groundwater flow rate, which affects the lateral to vertical flux within the aquifer (Piepho 1996). For the higher value of residual saturation (0.01) used in the modeling, dissolved carbon tetrachloride reached approximately 20 m below the water table and nonaqueous-phase carbon tetrachloride reached approximately 10 m below the water table. For the lower value of residual saturation (0.0001) used in the modeling, dissolved carbon tetrachloride reached approximately 50 m below the water table, and nonaqueous-phase carbon tetrachloride reached

approximately 25 m below the water table. (Note: The nonaqueous phase case for a residual saturation of 0.0001 was not shown in Piepho 1996; the 25-m depth was estimated by analogy to higher residual saturation case.) Additional driving forces not included in the model may have been provided by downward hydraulic gradients created by wastewater discharges and local groundwater mounding. The rise and subsequent decline of the water table under the 200 West Area as a result of groundwater mounding may also have driven shallow contamination deeper.

The deep distribution of carbon tetrachloride is inconsistent with a vapor source of groundwater contamination. If carbon tetrachloride vapor were the source of the groundwater contamination, only a thin (1- to 2-m depth) dissolved plume would be expected at the water table. Therefore, the presence of deep carbon tetrachloride concentrations implies that either DNAPL sank through the aquifer and is slowly dissolving or that elevated dissolved concentrations were driven downward by the groundwater hydraulic forces. As has been noted for the water table plume, the presence of the deep plume in the vicinity of the known disposal sites over 25 years after disposal ceased suggests a continuing source such as DNAPL.

The ratio of carbon tetrachloride to chloroform in the deep carbon tetrachloride samples generally varies from 1 to 200 (Appendix A). Wells that are completed at the bottom of the aquifer (e.g., wells 299-W10-14, 299-W15-17, 299-W18-22, 299-W6-3, 299-W6-6, and 299-W7-3) have relatively low ratios that vary from 1 to 10. Wells that are profiled at multiple depths or perforated over significant thicknesses of the aquifer have highly variable ratios, and the cause of this variability is unknown. If all of the chloroform is present as a result of degradation of carbon tetrachloride, the ratio might indicate the source (or the age) of the contamination. If (as estimated by Hooker et al. 1996) 1% of the carbon tetrachloride degraded to chloroform and if the two dissolved contaminants migrated together, the carbon tetrachloride to chloroform ratio should be approximately 100. Hooker et al. (1996) believe that any microbial degradation occurred only during the early stages of carbon tetrachloride disposal, when a carbon source was available to fuel the process. Thus, low ratios of carbon tetrachloride to chloroform may indicate older sources of carbon tetrachloride when degradation rates might have been higher. Additional sources of chloroform (e.g., from chlorinated water) or anaerobic zones in the aquifer that promote continued degradation could also result in low carbon tetrachloride to chloroform ratios. On the other hand, high ratios may indicate the addition of “new” carbon tetrachloride that might be attributed to a continuing source of contaminant or the continued degradation of chloroform, which can occur aerobically.

3.1.5 Co-Contaminants

The 1989 essential material specification for carbon tetrachloride states that the carbon tetrachloride must be 99% pure (Rohay 1999). Based on the process used to manufacture carbon tetrachloride, it is believed that the carbon tetrachloride used in Z Plant operations was relatively pure. The other 1% would typically be long-chain alcohols used by industry as additives to prevent light degradation of the product.

However, carbon tetrachloride was not used as a pure-phase liquid, but was instead used as a mixture with other organics (e.g., TBP, DBBP, and lard oil). Three representative volumetric mixtures used were 85:15 carbon tetrachloride:TBP; 50:50 carbon tetrachloride:DBBP; and 75:25 carbon tetrachloride:lard oil (which degraded to a 50:50 mixture prior to soil column

disposal). The organic composites (even the carbon tetrachloride:lard oil mixture) were found to be denser and more viscous than water (Last and Rohay 1993). Vapor pressure of the carbon tetrachloride:DBBP and carbon tetrachloride:lard oil mixtures is only half that of the pure carbon tetrachloride and the carbon tetrachloride:TBP mixture. The interfacial tension between the 50:50 carbon tetrachloride:lard oil mixture and a 5 M sodium nitrate solution was found to be low, suggesting that the fluids may be somewhat miscible, allowing them to mix and behave more as an aqueous fluid (Last and Rohay 1993).

An 85:15 carbon tetrachloride:TBP mixture was used to make up the organic solution used in the plutonium recovery process. However, with exposure to ionizing radiation and nitric acid, the TBP within the solvent would gradually degrade to DBP. The DBP has a much greater affinity for plutonium than TBP and would not work in the process because of its poor stripping properties. It was the degraded solvent that was discharged to the soil column.

The major organic co-contaminants TBP, DBP, and DBBP associated with the carbon tetrachloride solvent waste streams were not analyzed in groundwater samples collected during the 1991 characterization activities. However, existing data for TBP and DBP acquired for other programs between 1987 and 1990 are available. Results for samples from several wells in the vicinity of the Z cribs, as well as from wells within the core of the carbon tetrachloride plume, were all below detection limits for TBP and DBP. The DBBP has not been previously analyzed. The apparent absence of TBP and DBP in 200 West Area groundwater is attributed to biodegradation of these organic constituents and/or to sorption because they have a moderate affinity for sediments (Ames and Serne 1991, Rohay and Johnson 1991). Soil and groundwater samples collected during drilling in 1992 were analyzed for TBP. The TBP was detected in only one sample from the vadose zone (in well 299-W15-217, at a depth of 24.6 m), and the result was below the limit of quantitation (Rohay et al. 1994); analyses for DBP and DBBP were not conducted. The lack of TBP in vadose soils suggests that TBP degrades relatively quickly. The lack of TBP detected in groundwater could also indicate that carbon tetrachloride was a relatively pure phase when it reached the groundwater. However, the differential partitioning and biodegradation of the components of these organic mixtures in Hanford Site sediments have not been determined.

Based on the mass of the carbon source (i.e., lard oil and butyl phosphates) and nitrate (electron acceptor) co-disposed with the carbon tetrachloride, Hooker et al. (1996) estimated that 1% of the carbon tetrachloride could have been transformed to chloroform by microbial dechlorination during initial discharge stages (Hooker et al. 1996). The chloroform levels observed in the vadose zone and aquifer correspond to a reductive dechlorination of 1% of the carbon tetrachloride. Biodegradation is probably no longer occurring within the vadose zone and groundwater because the naturally occurring total organic carbon in the soil is insufficient to fuel the process.

The high-concentration zones of the chloroform plume are approximately coincident with the high-concentration zones of the carbon tetrachloride plume. However, the chloroform plume is less extensive than the carbon tetrachloride plume.

Vadose zone sampling of soil and soil vapor in the source area has also detected methylene chloride, chloroform, TCE, tetrachloroethylene (PCE), trans-1,2-DCE, 1,1-DCA, 1,2-DCA, cis-1,2-DCE, 1,1,1-TCA, benzenes, xylenes, and toluene (Rohay et al. 1994).

Groundwater sampling within and beyond the source area has also detected chloroform, methylene chloride, TCE, and PCE (Rohay et al. 1994, DOE-RL 1999b).

Tetrachloroethylene and tetrabromoethane were used at different times in combination with carbon tetrachloride as a diluent for TBP or for cleaning agents (Smith 1973), with respect to the wastes discharged to the 216-Z-9 Trench.

Nitrate in the aqueous wastes discharged to the carbon tetrachloride source cribs has also produced an extensive groundwater plume. Because nitrate and carbon tetrachloride were co-contaminants in the aqueous-phase discharges, comparison of the distribution of the two groundwater plumes may help in understanding the major factors affecting plume movement. For example, although the K_d for carbon tetrachloride is not well known, the K_d for nitrate is known to be zero (i.e., nitrate is not retarded in groundwater). The maximum extent of the carbon tetrachloride (defined by the 5- $\mu\text{g/L}$ contour) and nitrate (defined by the 20-mg/L contour) plumes is similar to the north and northeast of the Plutonium Finishing Plant area, suggesting that carbon tetrachloride has behaved as a nonretarded contaminant in groundwater. However, the carbon tetrachloride plume extends farther to the west (upgradient) than the nitrate plume, suggesting that the groundwater contamination in this area was controlled by a mechanism other than the hydraulic flow field. The absence of nitrate and presence of carbon tetrachloride to the southwest of the former U Pond site suggests that the carbon tetrachloride lobe is not a result of southerly flow during the initial period of discharge.

Low plutonium-239/240 and americium-241 activities (<10 pCi/L) were detected in well 299-W15-8 adjacent to the 216-Z-9 Trench on two sampling dates (May 7, 1990, and November 13, 1991). The well went dry sometime after January 1992 and can no longer be sampled (Hartman 1999). The plutonium and americium contamination observed in groundwater at the 216-Z-9 site in well 299-W15-8 may signify soil column breakthrough or a preferential pathway in the well. Follow-up sampling of groundwater extracted by the pump-and-treat system at 216-Z-9 did not detect mobile species indicative of transuranic (Hartman 1999). Extraction well 299-W15-32, located next to the 216-Z-9 Trench, has been sampled for plutonium isotopes for the last several years and for neptunium-237 and americium-241 in FY 1998, without detecting any plutonium, neptunium, or americium. However, because this well draws water from a large area, the samples may not be representative of contaminant activities directly under the trench (Hartman 1999).

3.1.6 Technetium-99 in Groundwater Extracted by 200-ZP-1 Pump-and-Treat Operations

Technetium-99 has recently been detected in groundwater removed by the 200-ZP-1 extraction wells. The generally presumed source of technetium-99 is from the tank farms to the north. Samples collected on January 27, 1999, and April 17, 1999, contained technetium-99 levels that ranged from 20 to 286 pCi/L at the extraction wells (all concentrations are below the MCL of

900 pCi/L). The sample locations (Figure 10) and the concentrations of technetium-99 are as follows:

• Well 299-W15-33 (extraction well 1)	47 pCi/L	January 27, 1999
• Well 299-W15-34 (extraction well 2)	73 pCi/L	January 27, 1999
• Well 299-W15-35 (extraction well 3)	200/196 pCi/L	January 27, 1999/ April 17, 1999
• Well 299-W15-32 (extraction well 4)	286 pCi/L	January 27, 1999
• Well 299-W15-36 (extraction well 5)	43 pCi/L	January 27, 1999
• Well 299-W15-37 (extraction well 6)	20 pCi/L	January 27, 1999
• Influent tank (T-01)	100 pCi/L	April 17, 1999
• Water knock-out tank	Nondetect.	April 17, 1999
• System filters	Nondetect.	

Although a high technetium-99 concentration was observed in the closest extraction well to the TX-TY tank farm (i.e., well 299-W15-35), the highest concentration was measured at well 299-W15-32, which is located near the 216-Z-9 Trench. To reach well 299-W15-32, contamination from the tank farms would have had to flow past extraction well 299-W15-35. Movement in this direction does not seem likely because well 299-W15-35 is a hydraulic sink between the tank farms and well 299-W15-32. Since technetium-99 has not been detected in monitoring wells west of the extraction wells, it is tentatively concluded that technetium must be present southeast of the tank farms (i.e., east or southeast from well 299-W15-32) or west of well 299-W15-32 near the 216-Z-9 Trench.

The 216-Z-9 Trench area west of well 299-W15-32 also represents a potential source of technetium because of well 299-W15-8. Technetium was detected in this well at 410 pCi/L in 1992 (prior to going dry). However, other wells in this area have either shown no technetium (well 299-W18-7) or have exhibited low concentrations (<5 pCi/L at well 299-W15-6 from 1994 through 1995). Given this information, an eastern source still seems more probable.

The location or definition of a technetium plume east of well 299-W15-32 cannot be evaluated at this time because there are no unconfined aquifer monitoring wells in this area that could be sampled. The only available eastern well is 299-W14-09, which is completely below the Ringold Lower Mud Unit (i.e., in the confined aquifer). As far as is known, this well has never been sampled for technetium. Given that carbon tetrachloride concentrations are 40 to 50 µg/L at this well and the levels were as high as 500 µg/L at one time, it is possible that technetium-99 may also be present at depth. Plans are currently underway to sample this well for technetium

and then reconfigure it to provide a monitoring point in the unconfined aquifer. Because of other possible radionuclide contamination in this area, other radionuclide samples will also be collected (e.g., iodine and tritium).

3.2 TECHNETIUM-99 AND URANIUM (200-UP-1 OPERABLE UNIT)

3.2.1 Technetium-99 and Uranium Source Characteristics

The Uranium Tri-Oxide (UO₃) Plant discharged considerable volumes of liquid containing uranium and technetium-99 into five cribs located in the vicinity of the plant: the 216-U-1, 216-U-2, 216-U-8, 216-U-12, and 216-U-16 Cribs. Although each crib had the potential to impact groundwater, only the 216-U-1, 216-U-2, and 216-U-12 Cribs have been clearly identified as sources of the uranium and technetium-99 plumes found in this area. Based on estimates developed in 1994 prior to remediation using the pump-and-treat system, the uranium plume covered 0.46 km², contained an estimated 130 kg (0.2 Ci) of dissolved uranium, and was moving to the east at approximately 24 m/yr (BHI 1996b). Substantial quantities of uranium in a solid phase are found on the soil matrix within and under the cribs. Technetium-99 accompanied the discharge of uranium and, as estimated in 1994, the plume covered 0.75 km², contained 0.16 kg (2.8 Ci) of technetium-99, and was spreading to the east at approximately 37 m/yr.

The major groundwater contaminant plumes in this area developed as a result of the following series of events. Process wastewater from the UO₃ Plant consisting primarily of dilute nitric acid containing uranium, technetium-99, and other fission products was discharged to the soil column via two cribs (216-U-1 and 216-U-2) between 1952 and 1967. Over 70 soil column volumes of wastewater were discharged, thus easily transporting mobile constituents, particularly technetium-99, to the water table. However, most of the 4,000 kg of uranium discharged to the 216-U-1 and 216-U-2 Cribs was retained in the upper 20 m of the soil column. Subsequently (circa 1966 through 1967), smaller volumes of highly acidic decontamination wastes were discharged to the cribs. The discharge of acid resulted in the dissolution of the uranium held in the vadose zone. Only low concentrations of uranium were seen in the groundwater near the 216-U-1 and 216-U-2 Cribs during this period (BHI 1996b).

The mobile uranium fraction in the 216-U-1 and 216-U-2 Cribs or soil column was later transported to groundwater after large volumes of cooling water were discharged in 1984 to the 216-U-16 Crib, located less than 60 m away. Water from the adjacent crib spread laterally as a perched water layer. This perched water source reached the 216-U-1 and 216-U-2 Cribs and either carried the mobilized uranium down to groundwater along preferential pathways (e.g., outside of unsealed well casings adjacent to the 216-U-1 and 216-U-2 Cribs) or migrated downward through the soil column to the water table.

The discharge of cooling water was terminated in 1985, and a pump-and-treat effort was conducted to reduce the highest groundwater concentrations of uranium and technetium-99 in the immediate vicinity of the 216-U-1 and 216-U-2 Cribs (Baker et al. 1988). After 6 months of operation, treatment was terminated and groundwater concentrations rebounded to their pretreatment levels, although substantial quantities of uranium were removed.

3.2.2 Technetium-99 and Uranium Mass Distribution

In 1995, prior to the most recent remediation effort using the pump-and-treat system, the zones of highest concentration in the uranium and technetium-99 plumes were displaced eastward of the point of origin (216-U-1 and 216-U-2 Cribs). The uranium plume distribution pattern suggested that there could be a continuing source of uranium at or near the 216-U-1 and 216-U-2 Cribs because the head-end of the plume, as defined by the 20- $\mu\text{g/L}$ contour, included the area under the source cribs. This continuing source might be due to slow drainage of remobilized uranium from the vadose zone. The trend of uranium concentration in this area is downward, indicating that if drainage is continuing, it is at a low rate (BHI 1996c). The slow change in uranium concentrations may also be due to its propensity for sorption to soil. Enough time may not have elapsed for uranium to migrate away from the source cribs.

The technetium-99 plume distribution pattern does not suggest a continuing source of technetium-99. The head-end of this plume, as defined by the 900-pCi/L contour, has migrated east of the source cribs (Figure 27). The technetium-99 (technetate) anion also has a greater mobility than the uranium (uranyl) anion (BHI 1996b) and would be expected to migrate from the source area ahead of the uranium. Based on this distribution, a significant continuing source of technetium and uranium is not likely. If technetium does not have a source, it is unlikely that uranium does.

3.2.3 Technetium-99 Groundwater Plume Changes

Remediation of technetium-99 at the 200-UP-1 OU has nearly met the goal of 10 times (9,000 pCi/L) the MCL (DOE-RL 1999b). By the end of calendar year 1999, it is anticipated that this goal will be met, except possibly for one localized slug near well 299-W19-29 (Figure 26). As discussed in Section 3.2.6, modeling work completed by the ERC in 1996 (Chiaramonte et al. 1997) predicted that even with no remediation of this plume, the technetium-99 plume would dissipate to below the MCL (900 pCi/L) before reaching the 200 East Area (i.e., while still on the Central Plateau). Based on these conclusions and the success in remediating to date, the plume is expected to decay to below the MCL by natural attenuation processes before leaving the Central Plateau.

3.2.4 Uranium Groundwater Plume Changes

The uranium plume has not changed significantly since remediation activities were started at 200-UP-1. As discussed below (see Section 3.2.5), retarded movement (partitioning of uranium to the soils) is hindering remediation efforts (DOE-RL 1999b). Modeling by the ERC (Chiaramonte et al. 1997) under the scenario where uranium is assigned a small distribution coefficient (0.5 mL/g), predicts that the plume will not move from the 200 West Area in 200 years, and uranium concentrations will fall below the MCL by natural attenuation in the same period of time.

3.2.5 Empirical Calculation of Distribution Coefficient (K_d) for the Uranium Plume

The rate of uranium movement in the groundwater and the rate of remediation at the 200-UP-1 pump-and-treat system are dependent upon the degree to which uranium sorbs to the aquifer

sediments. This phenomenon is termed the distribution coefficient, and is defined as the equilibrium concentrations (partitioning) between the aquifer sediments and dissolved groundwater concentration. As shown by the ERC groundwater model, even a small distribution coefficient (K_d) will significantly reduce the rate of plume movement from the 200 West Area. The K_d for uranium on the Hanford Site is often assumed to be 2 mL/g (*Remedial Design Report/ Remedial Action Work Plan for the 100 Area* [DOE-RL 1998]), which is four times greater than the value used for the Chiaramonte (1997) groundwater model.

Field data collected during remediation operations provided an opportunity to estimate an empirical K_d value for uranium. This estimate is based on several assumptions that are not verifiable but appear to be reasonable.

Baseline plume maps for 200-UP-1 show technetium and uranium plumes covering about the same area (Figures 27 and 28). After about 5 years of operation, technetium concentrations have been reduced substantially in most wells to near the remedial action objective of 9,000 pCi/L (10 times the MCL), while uranium concentrations have remained essentially the same (DOE-RL 1999b). This difference in response to remediation is an indication that uranium sorbs to the soils and is much less mobile than technetium.

After the injection well (299-W19-36) was shut down in 1996, contaminant concentrations recovered in nearby monitoring wells and at the injection well. During this recovery period, it was observed that a technetium-99 slug apparently moved past one of the monitoring wells, 299-W19-28 (Figure 29). Following this slug, uranium concentrations began increasing in a similar manner, but lagging behind the technetium slug (Figure 30). By making several assumptions, this “delayed” uranium response was used to estimate a distribution coefficient for uranium. The following assumptions were made for this calculation:

- Technetium is assumed to move at the same rate as groundwater (nonretarded movement).
- The high concentrations of uranium and technetium-99 were co-located at the time of shutdown of the injection well.
- Based on contaminant trend plots shown in Figures 29 and 30, the following travel times to well 299-W19-28 from the time shutdown of the injection are as follows:
 - The injection well pump was shut off on February 7, 1997 (time = 0).
 - The technetium-99 plume peaked on October 14, 1997 (time = 249 days).
 - The uranium plume peaked on April 15, 1998 (time = 432 days).
- The average bulk density (ρ_b) and average total porosity (θ) of the aquifer sediments are 1.8 g/cm³ and 32%, respectively, taken from *Borehole Summary Report for 200-UP-1 Operable Unit, 200 West Area* (Kelty et al. 1995).
- K_d is related to the retardation factor (Rf) as $K_d = (Rf - 1)(\theta/\rho_b)$.

The retardation factor is defined as the ratio of the average groundwater velocity to the average solute velocity. Because both the technetium and uranium are assumed to travel the same distance to well 299-W19-28, the retardation factor can be determined by the ratio of the solute travel time (uranium) to the groundwater travel time (technetium).

Given these assumptions and field input parameters, the K_d was estimated at 0.13 mL/g, less than the groundwater model K_d of 0.5 mL/g, and the generally assumed Hanford Site value. This estimate may be less than the actual field value because the uranium plume did not recover to a peak (as did technetium). The uranium increase may also be affected by rebound (i.e., desorption from the sediments in addition to slug migration). That sorption of uranium to the soils does occur is confirmed by the slow to no response during remediation (concentrations in the groundwater are generally unchanged).

To better understand plume movement, it is recommended that a rebound test be conducted (i.e., a period of monitoring [e.g., 6 months] without operating the extraction well and monitoring contaminant concentrations) and that laboratory tests be performed to quantify the amount of uranium sorption to the soil (K_d). This information is important as a model input parameter for determining the rate of plume movement, concentration changes with time, and effectiveness of remediation. This information will ultimately support the final ROD.

3.2.6 Groundwater Modeling

Two recent Hanford Site-wide groundwater numerical models have been constructed and used to predict movement of contaminants from the 200 West Area. The ERC developed and applied a model to predict the long-term impacts of contamination on the groundwater and to evaluate the effectiveness of current and proposed remedial actions (Chiaramonte et al. 1997). Construction of the ERC model was initiated under Westinghouse Hanford Company and was completed by the ERC.

A second groundwater model was developed by PNNL to support the Hanford Groundwater Project and to predict future conditions of the unconfined aquifer as affected by cessation of Hanford Site operations, to assess the potential for contaminants to migrate via the groundwater pathway to the Columbia River, and to evaluate specific contaminant issues (Barnett et al. 1997). The numerical portion of the PNNL model is based on the Coupled Fluid, Energy, and Solute Transport (CFEST) code developed by Gupta et al. (1987). The conceptual model supporting the numerical code was constructed with nine layers, each representing major hydrogeologic unit within the unconfined aquifer system (Barnett et al. 1997). This model has not been used for predicting movement of carbon tetrachloride, uranium, and technetium plumes.

The ERC model is based on a three-dimensional numerical code developed by HydroGeologic, Inc., Herndon, Virginia, called the "Variably Saturated Analysis Model in Three Dimensions with Preconditioned Conjugate Gradient Matrix Solvers (VAM3DCG)." Conceptually, the model is divided into an upper and lower hydrogeologic unit (the Hanford formation and Ringold Formation, respectively), but the model could be further subdivided into three units within each of the major layers if desired. Hanford Site-wide model simulations were performed using the VAM3DCG Code for seven groundwater plumes, and four of these plumes are of interest for this conceptual model update. The purpose of the modeling was to predict how the major

groundwater contaminant plumes on the Hanford Site will move and change over time and for specific cases in response to remediation efforts. The four relevant plumes were carbon tetrachloride, technetium-99, uranium, and tritium.

Significant findings related to contaminant plume movement and remediation efforts for these plumes are discussed below. The model runs extended 200 years into the future (from 1995 to 2195).

3.2.6.1 Carbon Tetrachloride. The carbon tetrachloride groundwater plume covers most of the western part of the 200 West Area with a high-concentration region ($>2,000 \mu\text{g/L}$) centered around the Plutonium Finishing Plant (Figure 16). As previously noted, the high-concentration region of the plume is being remediated using pump-and-treat technology within the 200-ZP-1 OU. The larger, more widely distributed and diffuse portion of the plume is not being remediated at this time. Results of the ERC model provide significant insight into the current remediation effort and future remediation efforts. Conclusions from the ERC model predictions are summarized as follows:

- If left unremediated, concentrations of carbon tetrachloride above the drinking water standard ($5 \mu\text{g/L}$) will move off the 200 West Plateau in 200 years (Figure 31).
- The presence of a continuing carbon tetrachloride source has very little effect on the overall size of the plume but does produce an increase in concentrations (continuing degradation of groundwater) near the Plutonium Finishing Plant and east of the source area (Figure 32).
- If the current pump-and-treat remediation effort is successful (i.e., the high-concentration area is completely removed), carbon tetrachloride contamination will still move off the 200 Area Plateau in less than 200 years (i.e., plume concentrations and overall plume distribution is not noticeably modified by remediation efforts) (Figure 33).
- The use of a small retardation factor (0.114 mL/g) results in carbon tetrachloride staying within the 200 Area Plateau during the 200-year model period (Figure 34). However, at the current time there is no indication that dissolved carbon tetrachloride sorbs to aquifer sediments and is retarded in movement.

In summary, based on the ERC study, the mass of carbon tetrachloride that has moved away from the source area and that is not being remediated is sufficient to cover the entire 200 Area Plateau and potentially reach the Columbia River at concentrations above drinking water standards (although the 200-year model was not run for a long enough period of time to confirm that carbon tetrachloride would finally reach the river). Remediation of the high-concentration area will help to prevent further degradation of the unconfined aquifer, but only near the 200 West Area. Although this model did not account directly for natural attenuation processes (e.g., biodegradation, geochemical interactions, and volatilization), use of the low K_d was functionally equivalent. These processes are expected to mitigate the spread rate of the plume and, thereby, significantly reduce the extent and rate of plume movement. Future modeling efforts should include these processes in predicting plume movement. The generally assumed value of zero K_d should also be confirmed since any absorption would inhibit plume migration.

Remediation of the larger, more diffuse portion of the carbon tetrachloride plume (i.e., outside of the high-concentration area) appears to be paramount if the plume is to be restricted to the 200 Area Central Plateau.

3.2.6.2 Technetium-99 and Uranium. Technetium-99 and uranium contamination located to the southwest of the UO₃ Plant is currently being remediated using one extraction well and currently no injection wells (Figure 26). Groundwater is transported via pipeline and treated at the 200 East Area ETF. After treatment, the clean groundwater is disposed at the SALDS north of the 200 West Area. Results of the ERC model are instructive for remediation of these plumes and provide direction for the current remediation effort. Conclusions from the ERC model are as follows:

- Without remediation, the technetium-99 and uranium plumes do not move from the 200 Area Central Plateau in 200 years, and concentrations fall below the MCLs (Figures 35 and 36).
- Assuming that the uranium plume is remediated (i.e., the high-concentration portion of the plume is removed), modeling indicates that the plume reaches the 200 East Area in 200 years, and concentrations decline to less than the MTCA cleanup level (Figure 37).
- With no remediation of uranium and assuming a small retardation factor (K_d), the uranium plume does not leave the 200 West Area after 200 years. Only a small core area in the region of remediation remains above the MTCA cleanup level (Figure 38).

In conclusion, based on the ERC study, little technical benefit appears to be gained by remediating the technetium-99 and uranium plumes under the current pump-and-treat system operation. If remediation were discontinued, it is expected that concentrations of technetium-99 and uranium would fall below groundwater regulatory limits before leaving the 200 Area Plateau. In the case of technetium-99, this is even more likely, given that this plume has been substantially reduced through remediation activities. Field data demonstrate that uranium is sorbed to aquifer sediments and because of this has responded minimally to remediation efforts (DOE-RL 1999b). For those modeling runs that used a K_d , the rate and extent of plume movement was significantly diminished. Hence, uranium is not expected to move any significant distance from the 200 West Area before declining to below the MCL. Based on this modeling work, the minimal response of the uranium plume to remediation (Section 3.2.4) and the success in remediating the technetium (Section 3.2.3), it is recommended that the pump-and-treat system be shut down and a monitoring/plume tracking program be implemented. If plume concentrations were to exceed some “trigger-level,” the pump-and-treat system could be restarted.

3.2.6.3 Tritium. Multiple tritium groundwater plumes are present on the Hanford Site, including the 100 Areas, the 200 West Area, the 200 East Area, and from 200 East Area to the Columbia River (Hartman 1999). Of significance for this report is the tritium plume at the SALDS (Figure 1). The SALDS was purposely located in an area of relatively slow groundwater movement (low hydraulic conductivity) to maximize the time for plume decay prior to moving away from the 200 West Area, off the 200 Area Plateau through Gable Gap, and ultimately to the Columbia River. The results of the ERC model predicted the following:

- In 50 years, tritium concentrations will decrease below drinking water standards (20,000 pCi/L) across the Hanford Site, except for the SALDS.
- The tritium plume remains in the area of the SALDS.
- Between 50 and 100 years, tritium concentrations from the SALDS plume decline to below the drinking water standard.

Based on this modeling, it can be concluded that tritium will not leave the SALDS above MCLs.

The PNNL CFEST model was also used to predict plume movement at the SALDS (Barnett et al. 1997). Model input assumed that tritiated effluent would be discharged to the SALDS at rates ranging from 1 m³/day to over 350 m³/day, generally falling between 135 and 185 m³/day. It was further assumed that tritium went to the SALDS for approximately 30 years, with tritium-free discharges following for an additional 9 years. The modeling results were similar to the ERC model, predicting that the tritium plume remains near the SALDS. The similarity in results lends additional credence to the conclusion that tritium will not leave the 200 Area Plateau above drinking water standards.

4.0 CONTAMINANT TRANSPORT

4.1 VADOSE ZONE/GROUNDWATER INTERFACE

The capillary fringe forms the interface between the vadose and groundwater zones. Because the capillary fringe does not contain a connected gas phase, transport of contaminants through this zone must occur in the aqueous or DNAPL phase. The three main mechanisms for aqueous contaminant migration through the capillary fringe are diffusion and dispersion, advection, and fluctuations in the elevation of the water table (Pankow and Cherry 1996). These processes of aqueous-phase transport would produce a shallow groundwater plume (Pankow and Cherry 1996).

At the top of the capillary fringe, vapor-phase contaminants partition into the aqueous phase, and transport through the capillary fringe occurs by dispersion and diffusion along the aqueous-phase concentration gradient (Pankow and Cherry 1996). A vapor-phase source should result in a shallow (1- to 2-m thick) vertical distribution in the aquifer due to the relatively slow process of molecular diffusion, the process by which the carbon tetrachloride vapor enters the groundwater (Pinder and Abriola 1986). Pankow and Cherry (1996) point out that because molecular diffusion and dispersion are weak processes, advective transport due to infiltrating water is likely to be a more significant mechanism for transporting contaminants downward through the capillary fringe. At the carbon tetrachloride disposal sites, an infiltrating water mechanism would have been more viable during operations when large volumes of water were artificially recharging the groundwater.

The elevation of the water table can change in response to barometric pressure fluctuations, regional water table decline, and pump-and-treat operations. Each of these may influence carbon tetrachloride migration. The elevation of the unconfined aquifer water table below the carbon tetrachloride source cribs fluctuates up to 0.2 m/day in response to fluctuations in barometric pressure (Rohay et al. 1993). Over a 20-year period (1965 through 1985), the elevation of the water table rose and then declined 2 m; it is currently declining 0.45 m/yr. As the water table drops, contaminated vapors are drawn deeper into the expanded vadose zone and can partition into the newly exposed soil moisture. When the water table rises, the contaminated soil moisture will be incorporated into the groundwater system (Pankow and Cherry 1996). At the carbon tetrachloride site, the 2-m rise from 1965 to 1977 likely incorporated the carbon tetrachloride in that zone. The gradual but continual water table decline since 1977 would minimize additional contamination of the groundwater, but the daily fluctuations create a mixing zone that may continue to incorporate carbon tetrachloride. Temporary cessation of pump-and-treat operations at individual extraction wells would cause the water table to rise locally, incorporating carbon tetrachloride that migrated downward into the cone of depression. However, cessation of operations occurs infrequently and this mechanism may be insignificant with respect to degradation of groundwater quality.

Transport and partitioning of carbon tetrachloride vapor between the groundwater and vadose zone may contribute to the large “low concentration halo” surrounding the high-concentration core of the groundwater plume.

As a DNAPL moves into the tension-saturated portion of the capillary zone, it must displace water if continued downward migration is to occur. Since it is generally a nonwetting fluid with respect to water, there must be a sufficient buildup of capillary pressure to allow the organic liquid to overcome the entry pressure of the nearly water-saturated medium (Pankow and Cherry 1996). The DNAPL may also spread laterally at the top of the capillary fringe. The DNAPL reaching the 216-Z-9 capillary fringe prior to 1965 was likely incorporated into the groundwater by the rise of the water table between 1965 and 1977.

Potentially, a continued source of carbon tetrachloride to the groundwater in the area below the 216-Z-9 site exists because the centroid of the groundwater plume still includes the area underlying the disposal site. The carbon tetrachloride source may be within the vadose zone and/or within the aquifer. Numerical modeling of vadose zone flow and transport indicates that both dissolved and nonaqueous-phase carbon tetrachloride reached the groundwater beneath the 216-Z-9 Trench and may have continued to enter the aquifer for many years (Piepho 1996). This potential vadose zone source has been mitigated by SVE operations that began in 1992.

5.0 DATA GAPS AND RECOMMENDATIONS

The nature, extent, and rate of movement of the carbon tetrachloride, uranium, and technetium plumes have been evaluated, but several key data gaps currently exist. These data gaps are summarized below with a description of the uncertainties in the existing database being used to formulate the conceptual model. Recommendations to address the data gaps are included.

1. **Data gap:** The lateral extent of carbon tetrachloride in the vadose zone and the vertical extent of carbon tetrachloride in the groundwater need better definition. Improved definition of the contaminant distribution will support assessment of the carbon tetrachloride mass balance and the expected magnitude of the remediation efforts.

Recommendations: (A) To characterize the deep distribution of carbon tetrachloride in the groundwater, new well installations should be advanced through the unconfined aquifer to the uppermost confined aquifer and samples should be collected and analyzed for carbon tetrachloride (and other constituents). If a well had been planned for completion at the top of the unconfined aquifer, it could be backfilled and completed at the original targeted depth after sampling.

(B) New groundwater wells should be installed to monitor deep within the unconfined aquifer.

(C) Existing groundwater wells that have gone dry because of the declining water table elevation could be extended to collect deep groundwater samples or reconfigured to collect vapor samples in the vadose zone, particularly away from the crib disposal sites. Because these wells would not be compliant with current *Washington Administrative Code* standards, a variance would be required from Ecology.

(D) Well 299-W14-09, which is east of 200-ZP-1 groundwater extraction well 299-W15-32 and is perforated in the confined aquifer below the lower mud unit, should be sampled at depth and then reconfigured to monitor the top of the unconfined aquifer. In this area, there are no wells screened at the top of the unconfined aquifer; therefore, the lateral extent of the carbon tetrachloride plume is poorly defined. In addition, the groundwater samples could be used to identify other contaminant plumes (e.g., technetium-99) that may be present in this area, based on detection in groundwater extracted by the 200-ZP-1 pump-and-treat system (see Recommendation 10 below).

2. **Data gap:** Data are needed to determine the extent of the carbon tetrachloride non-equilibrium sorption in the vadose zone and groundwater. This information would help account for the inventory and help define remediation needs.

Recommendation: Laboratory tests and analyses should be performed on representative Hanford Site sediments.

3. **Data gap:** The partitioning coefficient (K_d) for carbon tetrachloride on site sediments and its variability across the site needs to be quantified (it may be equal to zero). This information would help refine the predictions of carbon tetrachloride transport rates using numerical models.

Recommendation: Laboratory tests using site-specific soils and representative mixtures of organics should be performed to quantify the partitioning coefficient (K_d) for carbon tetrachloride on Hanford Site sediments and its variability.

4. **Data gap:** The location, amount, and properties of DNAPL carbon tetrachloride within the subsurface need to be assessed. This information would help focus and define the remediation needs.

Recommendation: The 200-ZP-1 groundwater-pumping operations should be temporarily shut down (or an “opportune time” should be identified during an outage) to measure groundwater concentration rebound. If rebound occurred (an increase in carbon tetrachloride concentrations), the presence of residual DNAPL in the aquifer would be implied.

5. **Data gap:** The residual saturation of carbon tetrachloride (i.e., the carbon tetrachloride held in vadose zone sediments that is no longer mobile except through partitioning to pore water) should be quantified. This information would help account for inventory within the vadose and groundwater zones, refine the estimates of flux from the vadose zone to the groundwater, and refine the numerical modeling estimates of the depth of carbon tetrachloride in the aquifer.

Recommendation: Soil samples (split spoons or cores) in the vicinity of the disposal sites should be collected and analyzed to quantify the residual saturation. Because SVE operations have modified the distribution of subsurface carbon tetrachloride and possibly soil moisture beneath the disposal sites, part of this task is to identify suitable locations for data collection and measurements.

6. **Data gap:** Estimates of the fate and location of the original carbon tetrachloride inventory discharged to the soil column need to be improved; approximately 65% of the inventory could not be accounted for using data available in 1992 and equilibrium-partitioning relationships. Accounting for a larger percentage of the original inventory will allow better understanding of the extent of remediation required.

Recommendation: The inventory mass balance should be re-evaluated based on more recent studies and data from current remedial actions in the groundwater and the vadose zone.

7. **Data gap:** The high-concentration area of the carbon tetrachloride groundwater plume appears to be persistent but is situated northwest of the known carbon tetrachloride disposal sites. Low-concentration lobes of carbon tetrachloride exist to the south of the known disposal sites. Relatively high concentrations of carbon tetrachloride have been consistently detected near T Plant, north of the known disposal sites. The distribution of carbon tetrachloride away from known disposal sites might be the result of an unidentified source or the result of complex migration patterns driven by changing aquifer hydraulics. Identification of the sources of the groundwater plume will help focus source removal and groundwater remediation efforts.

Recommendation: The hydraulic flow fields during and after the carbon tetrachloride disposal should be re-evaluated to determine if the distribution of carbon tetrachloride is reasonable based on the hydraulics alone. The hydraulic flow field in the 200 West Area has changed multiple times over the last 50 years. Many of the facilities produced local

groundwater mounding, caused radial flow, and introduced complex flow patterns. Results of this evaluation may identify other contributing carbon tetrachloride disposal areas.

8. **Data gap:** In areas of high groundwater concentrations, carbon tetrachloride is probably volatilizing from the groundwater to the vadose zone. This potential migration of carbon tetrachloride out of the groundwater may contribute to natural attenuation of the plume, achievement of remedial objectives, and selection of remediation technologies.

Recommendation: A study, including field measurements near the groundwater/vadose zone interface, should be undertaken to quantify the volatilization process.

9. **Data gap:** The ratio of carbon tetrachloride to chloroform detected in deep groundwater samples generally varies from 1 to 200. The cause and significance of this variance is unknown but could potentially yield insights on contaminant source, inventory, and distribution.

Recommendation: A systematic study of the carbon tetrachloride/chloroform relationship in both the vadose zone and groundwater should be conducted using existing data.

10. **Data gap:** The identification and lateral and vertical extent of a suspected technetium-99 plume east of 200-ZP-1 extraction well 299-W15-32 cannot be evaluated at this time because there are no unconfined aquifer monitoring wells in this area. The only available eastern well is 299-W14-09, which is screened in the confined aquifer. This well has never been sampled for technetium. This information will support groundwater remediation efforts.

Recommendation: It is recommended that well 299-W14-09 be sampled at depth for technetium and then reconfigured to provide a monitoring well at the top of the unconfined aquifer. Because of other possible radionuclide contamination in this area, radionuclide sampling should also be performed for iodine-129 and tritium.

11. **Data gap:** Although technetium has been detected in groundwater extracted using the 200-ZP-1 pump-and-treat system, analyses have not been conducted to ascertain the presence of other mobile radionuclides. The presence of these contaminants in the system may impact operations.

Recommendation: Additional operational sampling for radionuclides should be conducted at 200-ZP-1 to ascertain whether technetium-99 and other radioactive contaminants (e.g., iodine-129 and tritium) are being removed by the extraction wells and are moving through the system.

12. **Data gap:** Low (<10 pCi/L) plutonium-239/240 and americium-241 activities were detected in a well adjacent to the 216-Z-9 Trench; however, the well has gone dry and can no longer be sampled. The plutonium and americium contamination observed in

groundwater at the 216-Z-9 site might signify soil column breakthrough or a preferential pathway in the well.

Recommendation: Follow-up sampling of groundwater from extraction well 299-W15-32, located next to the 216-Z-9 Trench, has resulted in no detections of plutonium, neptunium, and americium. However, because this well draws water from a considerable area, the samples may be dilute and not representative of contamination directly under the trench. Therefore, samples should be collected after the extraction well has been shut down for the rebound test and static sampling conditions are reached. Ideally, this sampling would be done using micro-purge techniques.

13. **Data gap:** Numerical predictions of the migration of the uranium plume are sensitive to the degree of uranium sorption to the soil, yet the value and variability of this parameter is not well known. This information is important as a model input parameter for determining the rate of plume movement, concentration changes with time, and effectiveness of remediation.

Recommendation: To better understand the uranium plume migration, it is recommended that laboratory tests using site-specific soils and/or field tests be conducted to quantify the partitioning coefficient (K_d) for uranium on aquifer soils.

14. **Data gap:** According to numerical modeling results, little technical benefit appears to be gained by remediating the technetium-99 and uranium plumes under the current 200-UP-1 pump-and-treat operation. If remediation were discontinued, numerical modeling indicates that concentrations of technetium-99 and uranium would fall below groundwater regulatory limits through natural attenuation before leaving the 200 Area Plateau. However, there are only minimal field monitoring data to confirm the results of the numerical modeling.

Recommendation: The pump-and-treat system at 200-UP-1 should be shut down and a monitoring program should be implemented to track plume movement and to measure rebound of uranium and technetium. These data would provide a measure of the rate of natural attenuation and an indication of the permanency of remediation in support of the final ROD.

6.0 REFERENCES

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Figure 1. 200 West Area Groundwater Operable Units and Facilities.

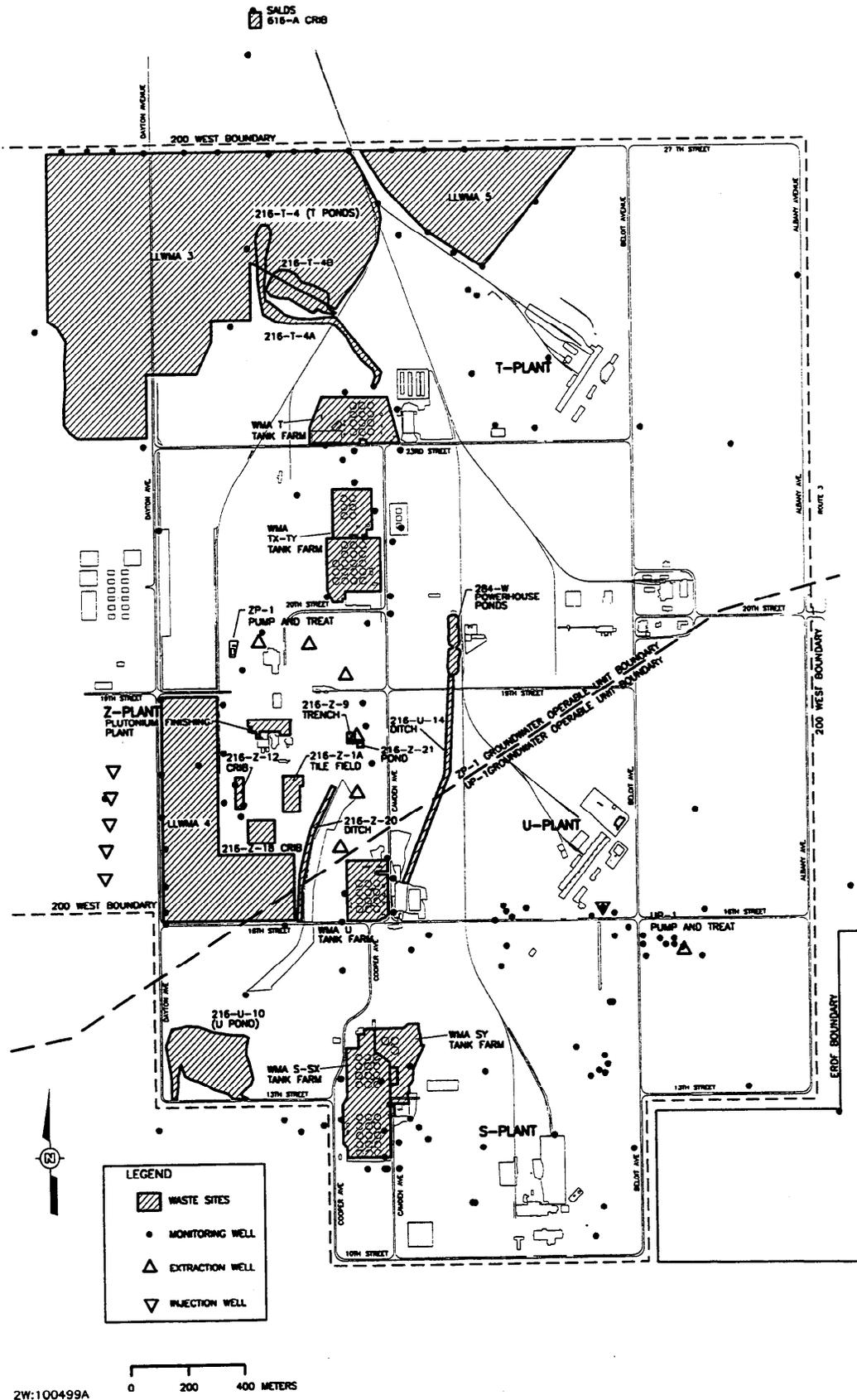


Figure 2. Surface Geologic Map for the Hanford Site (from Hartman 1999).

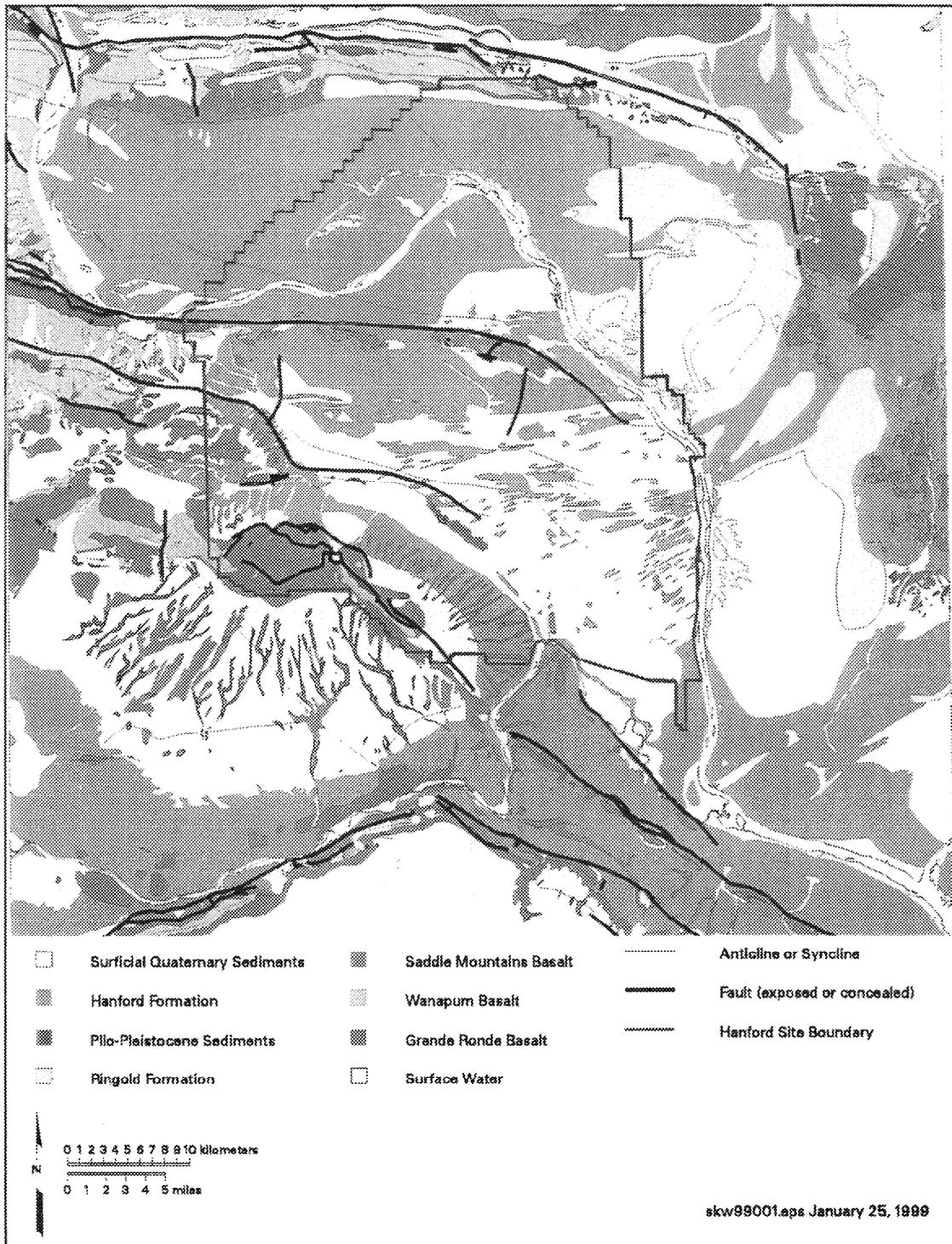
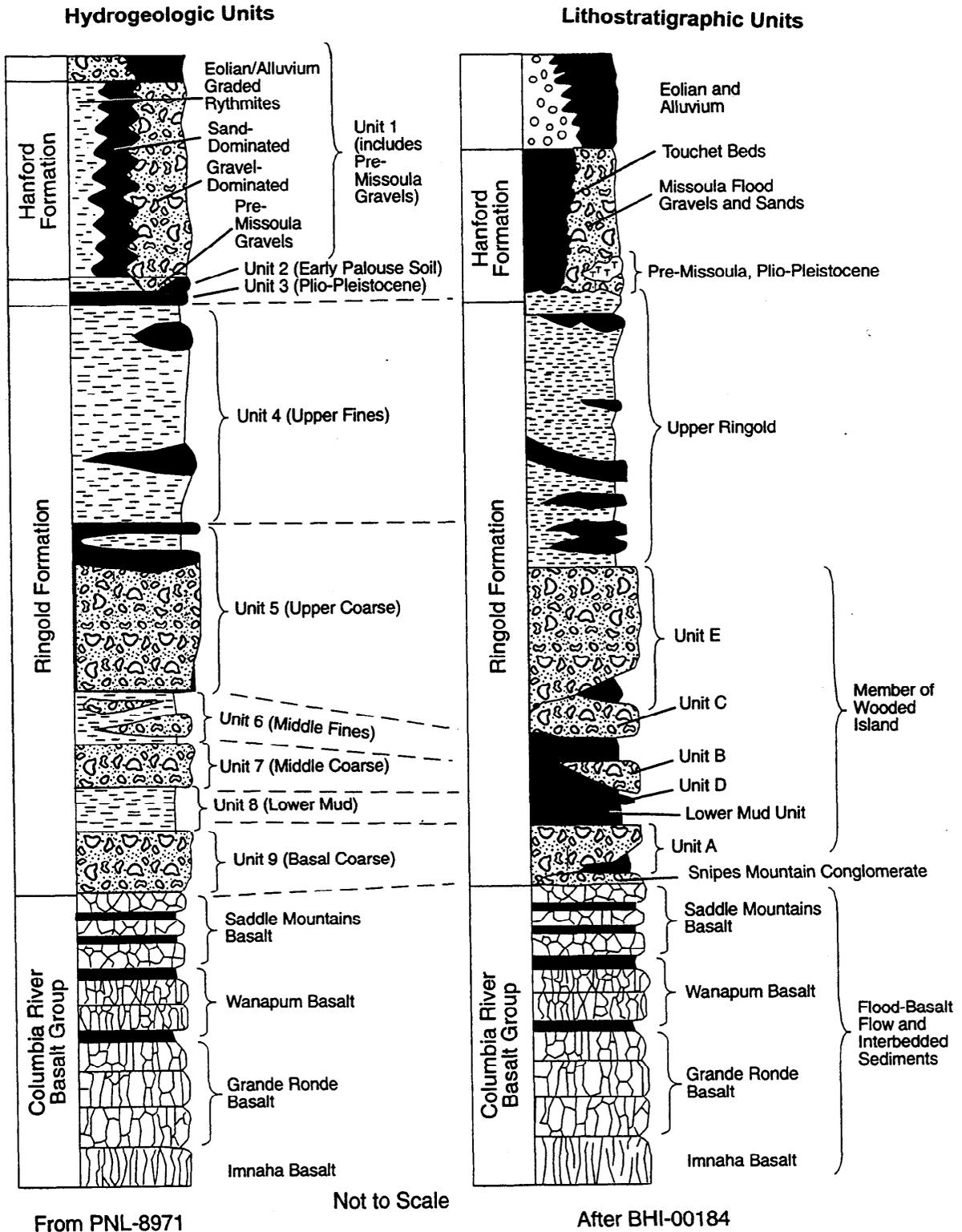


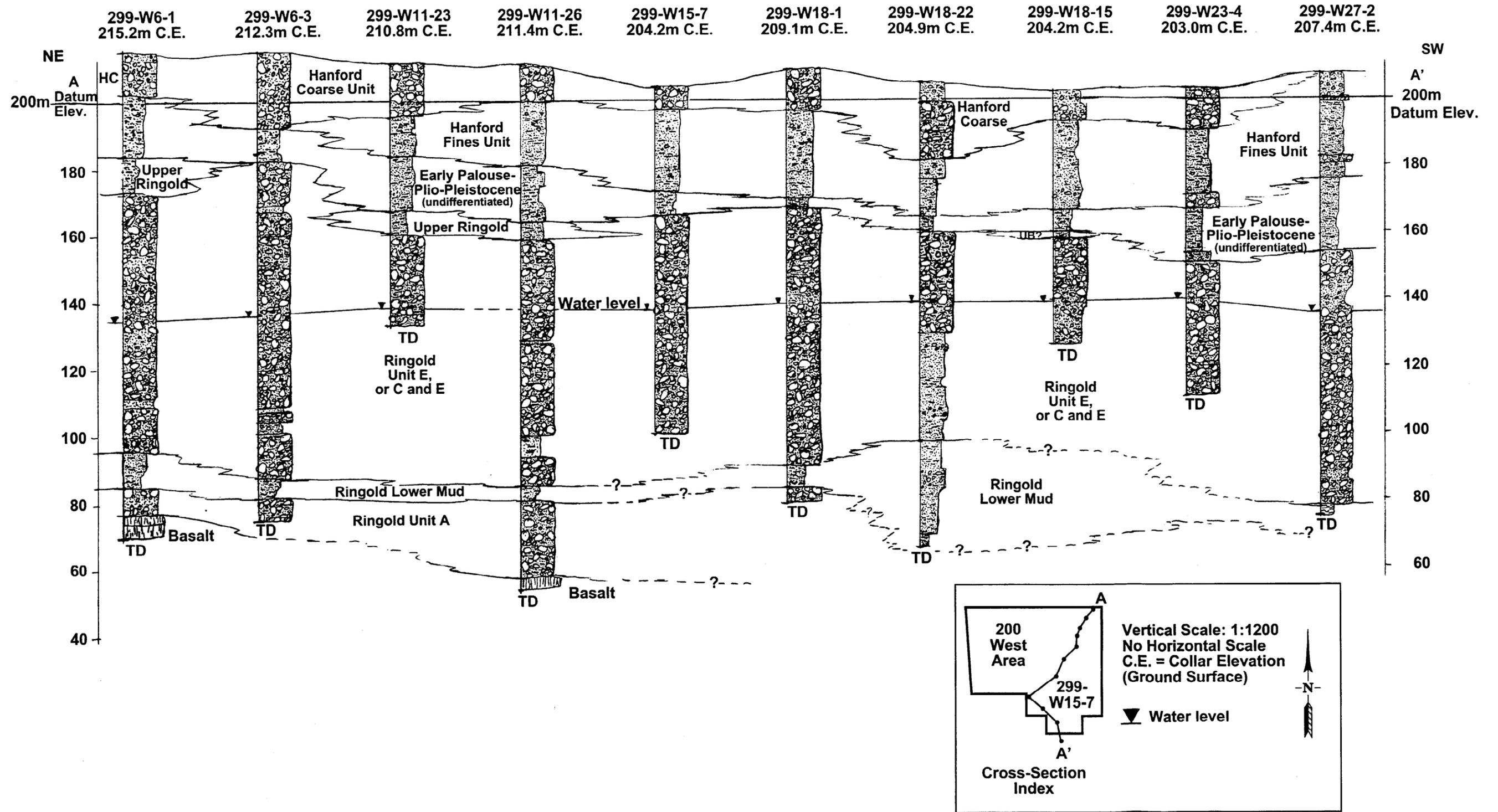
Figure 3. Comparison of Hydrogeologic Units and Lithostratigraphic Units for the Hanford Site (from Hartman 1999).



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200 West Area NE-SW Geologic Cross-Section

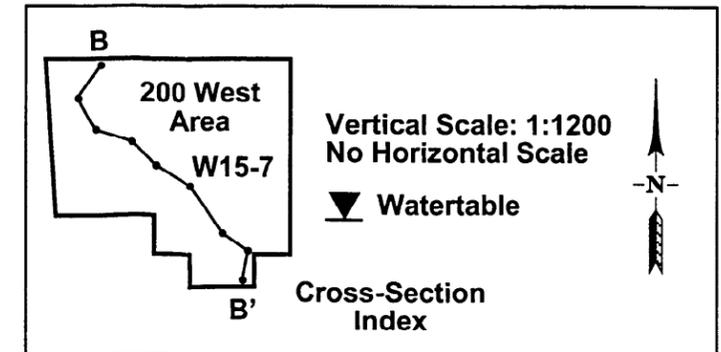
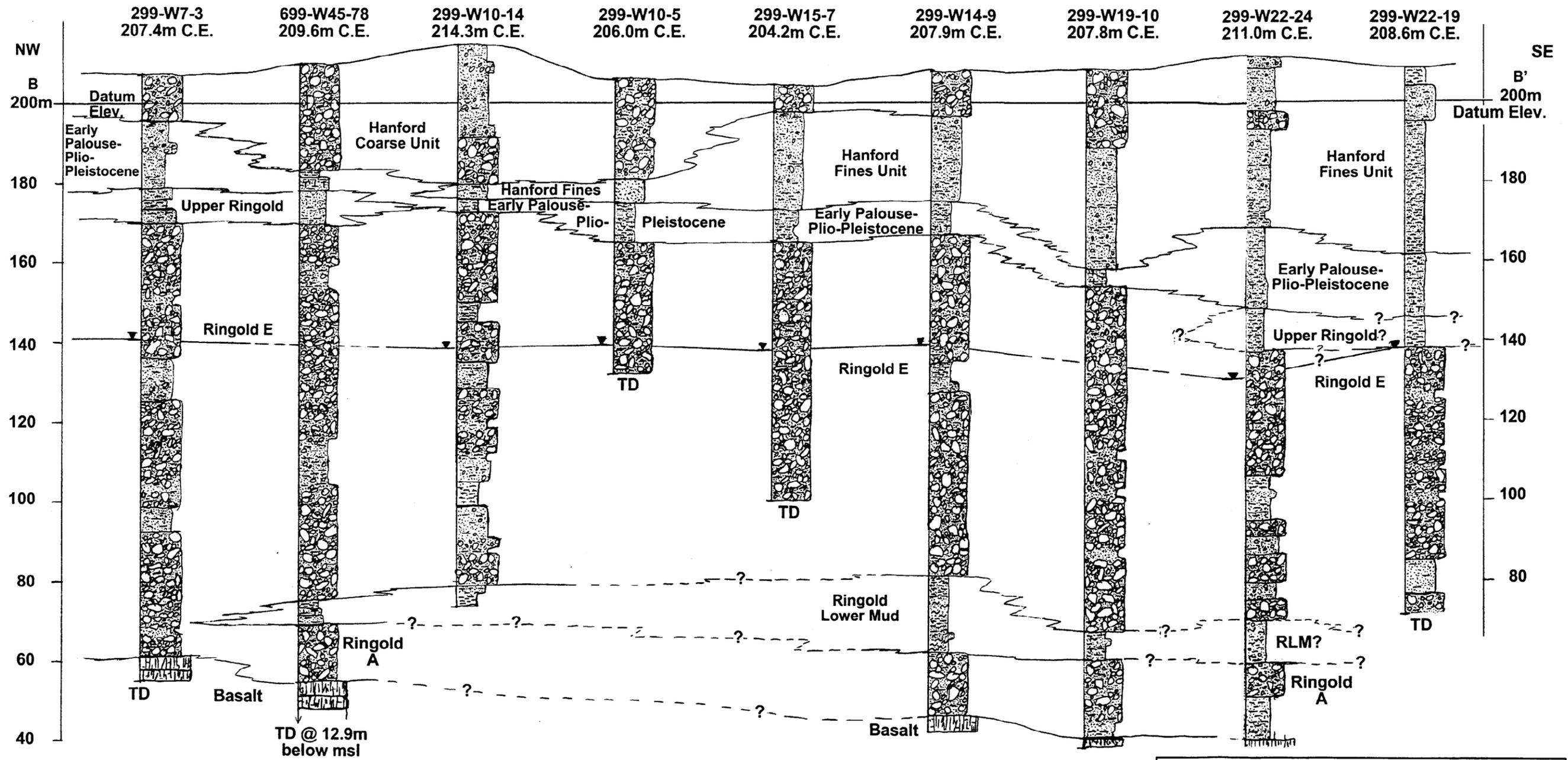
Figure 6. Geologic Cross-Section Northeast-Southwest
Across the 200 West Area.



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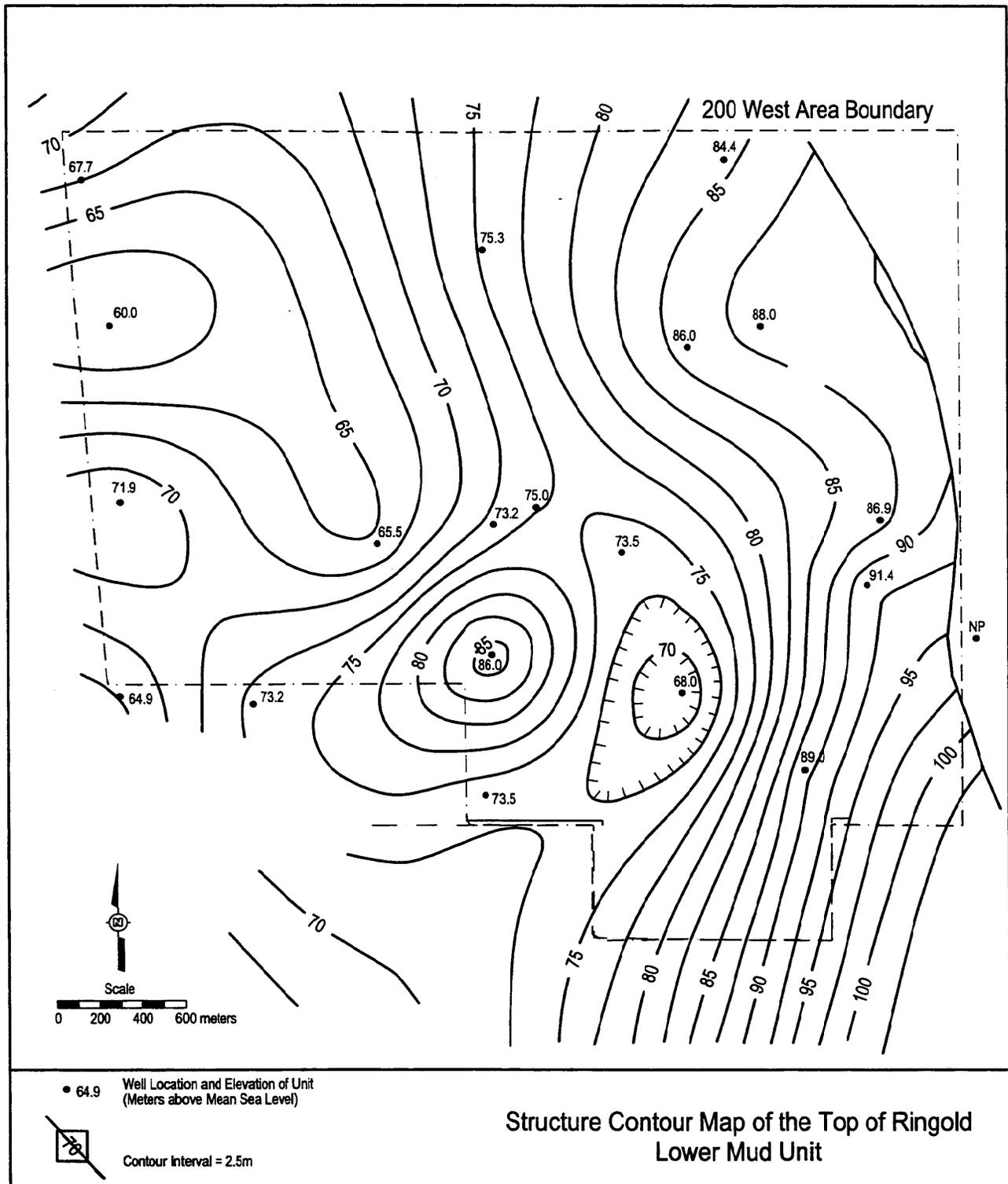
200 West Area NW-SE Geologic Cross-Section

Figure 7. Geologic Cross-Section Northwest-Southeast
Across the 200 West Area.



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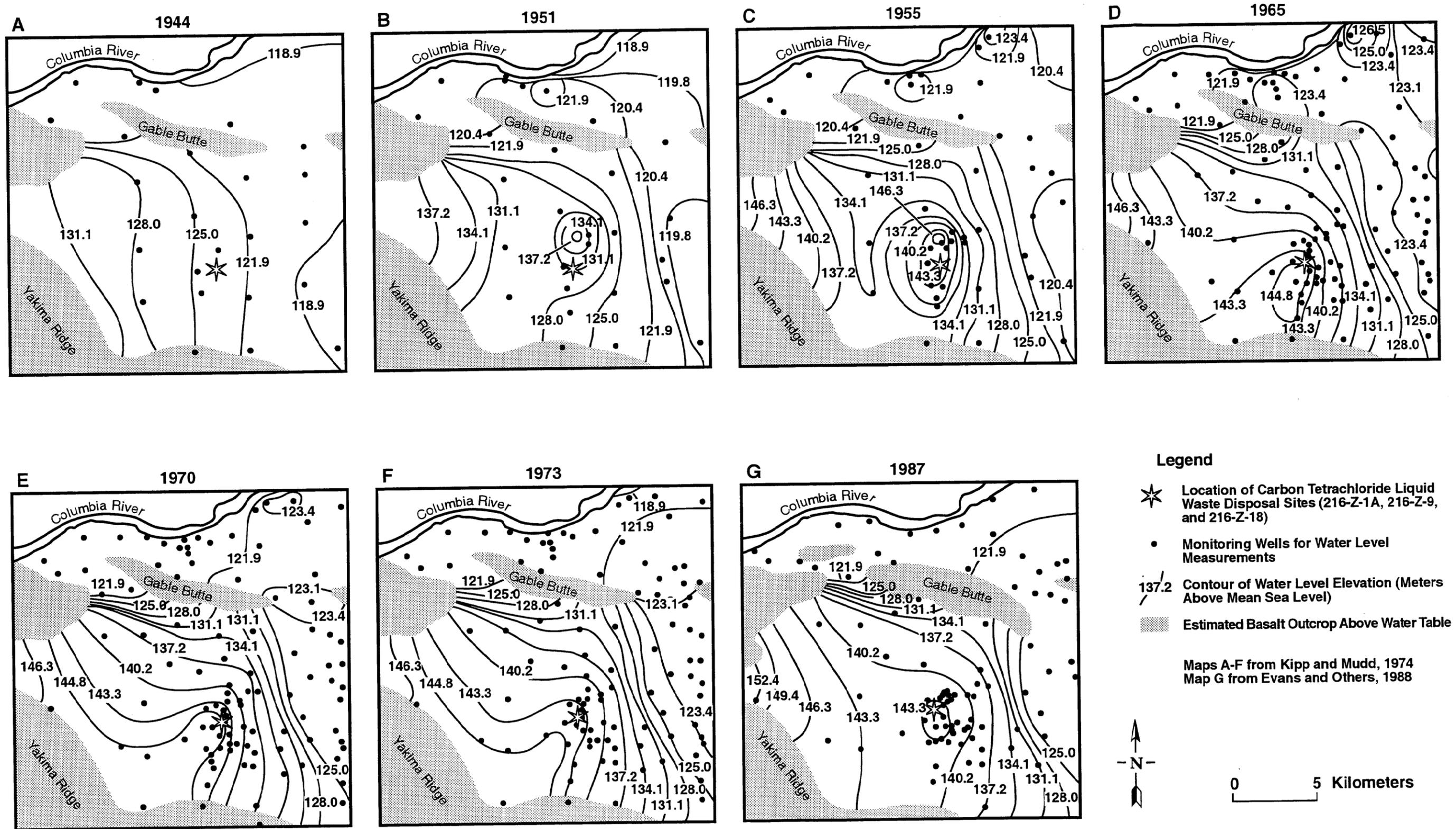
Figure 8. Structure Contour Map of the Top of Ringold Lower Mud Unit
(from Lindsey et al. 1991).



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Figure 9. Water Table in the Region of the 200 West Area, 1944-1987 (from DOE-RL 1991).



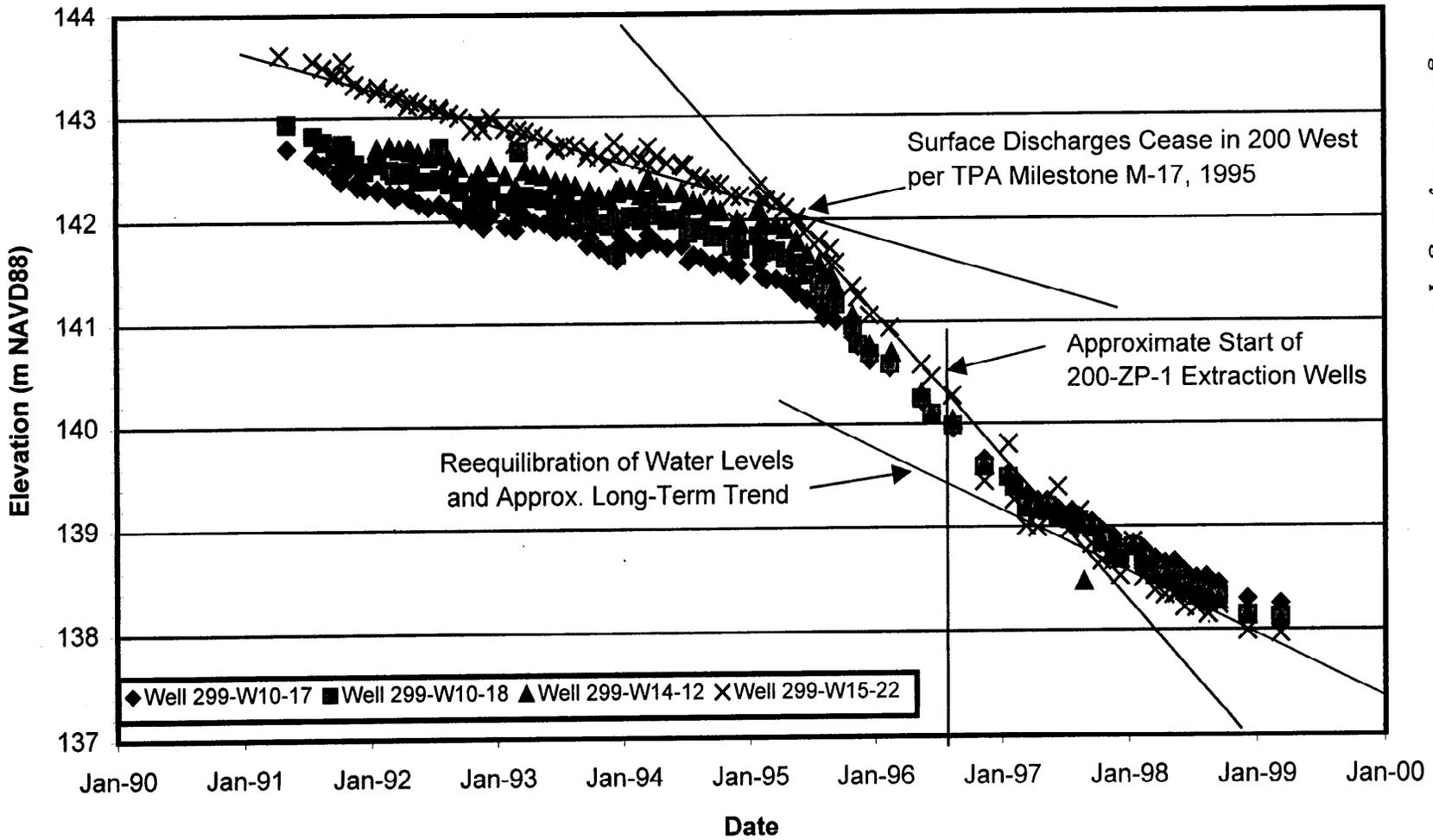


Figure 11. Hydrographs for Four TX-TV Tank Farm Wells.

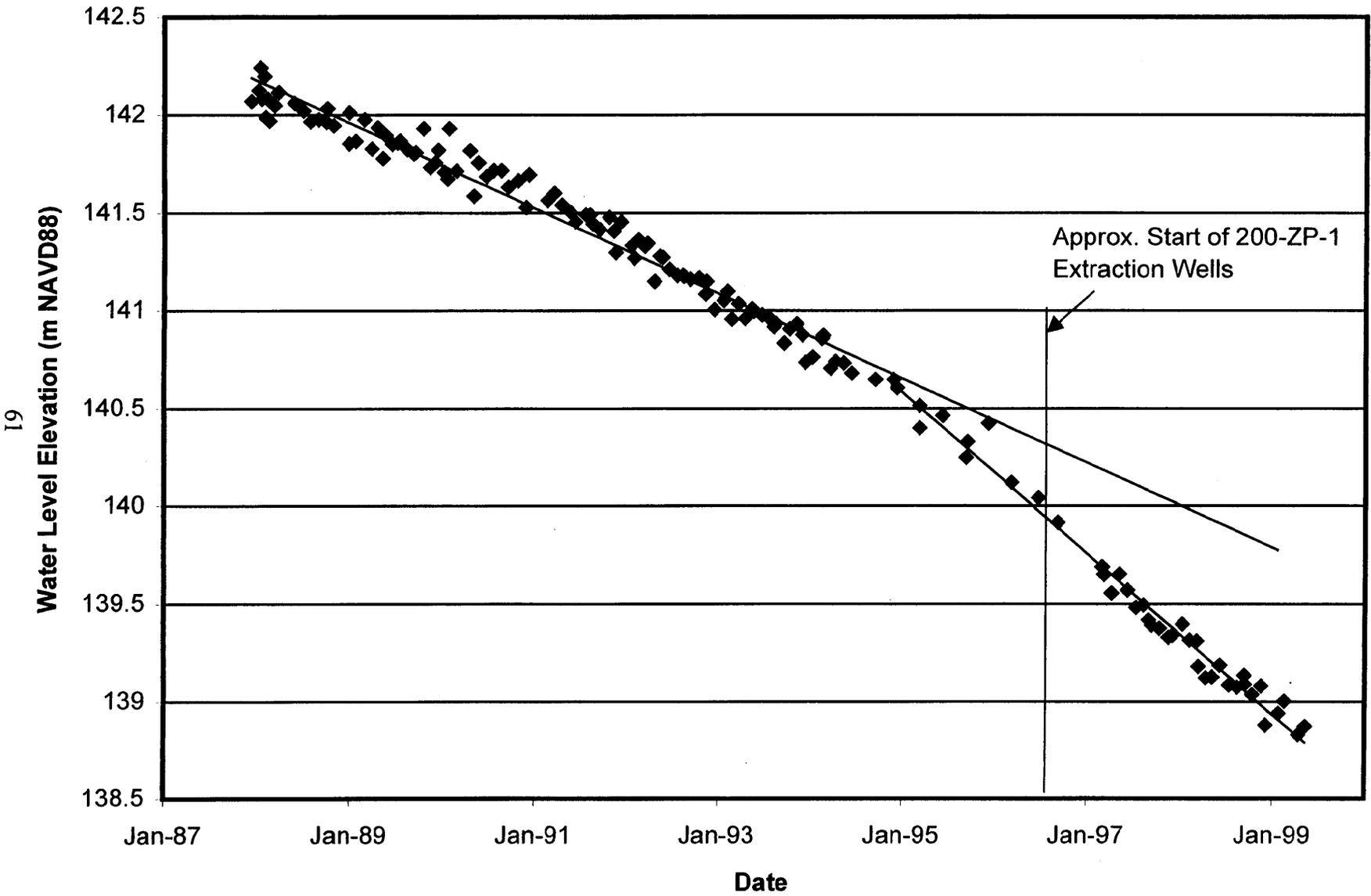


Figure 12. Hydrograph for Well 299-W8-1 at the North Boundary of the 200 West Area.

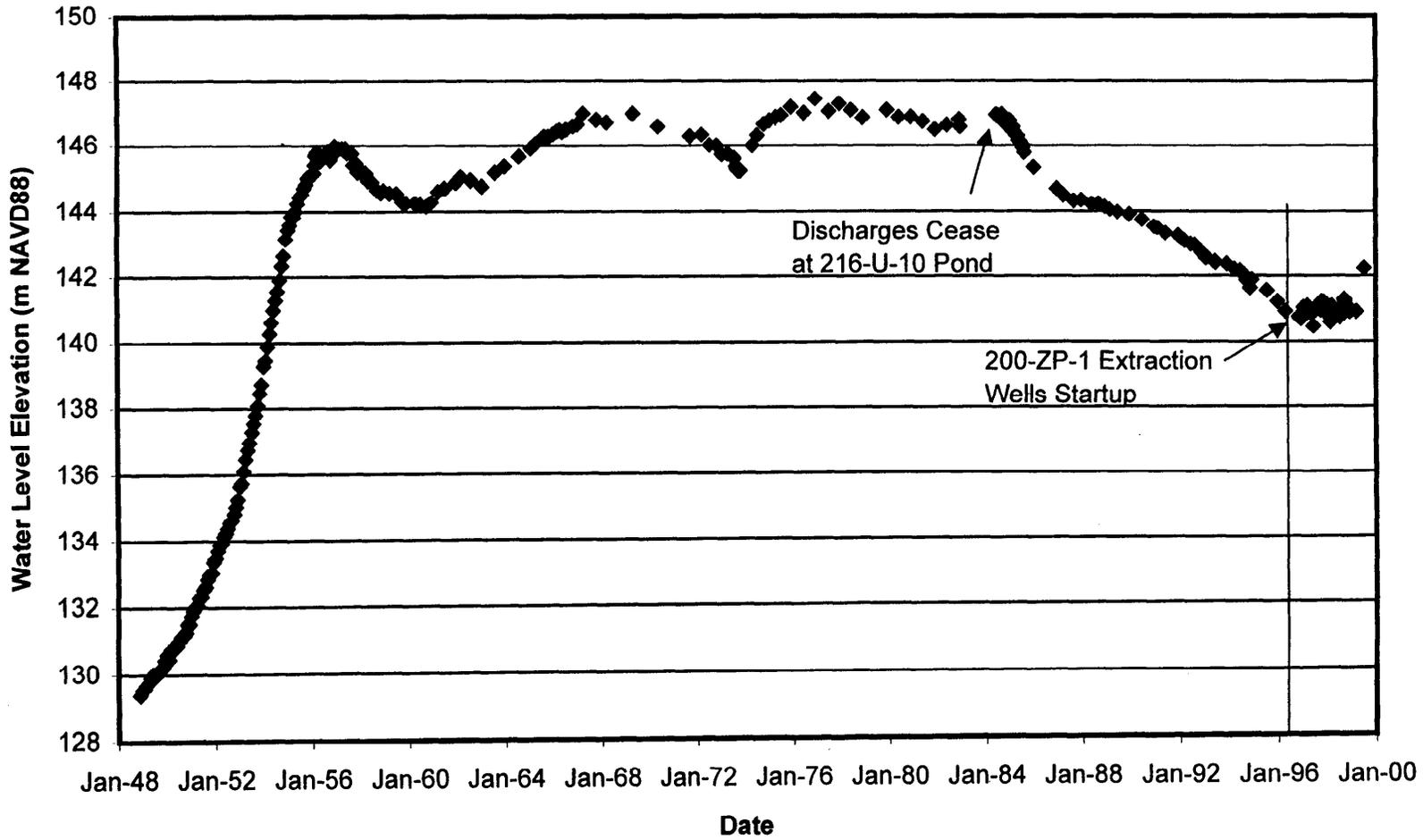
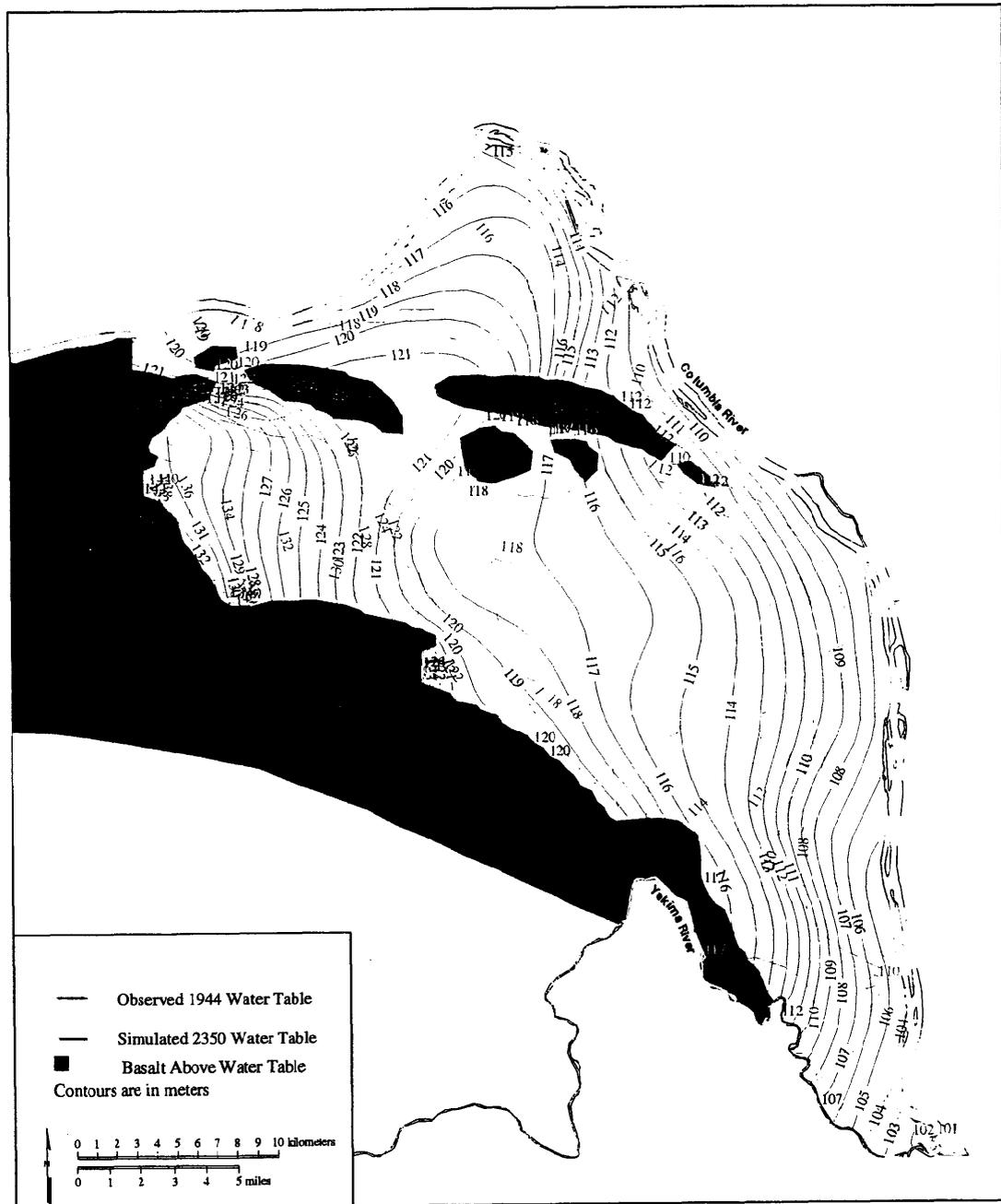


Figure 13. Hydrograph for Well 699-39-79 at the West Boundary of the 200 West Area.

Figure 14. Comparison of Hindcast Map of 1944 to Predicted Water Table Map in Year 2350 (after Cole et al. 1997).



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Figure 15. Difference in Water Level Elevation Between Wells 299-W15-16 and 299-W15-17.

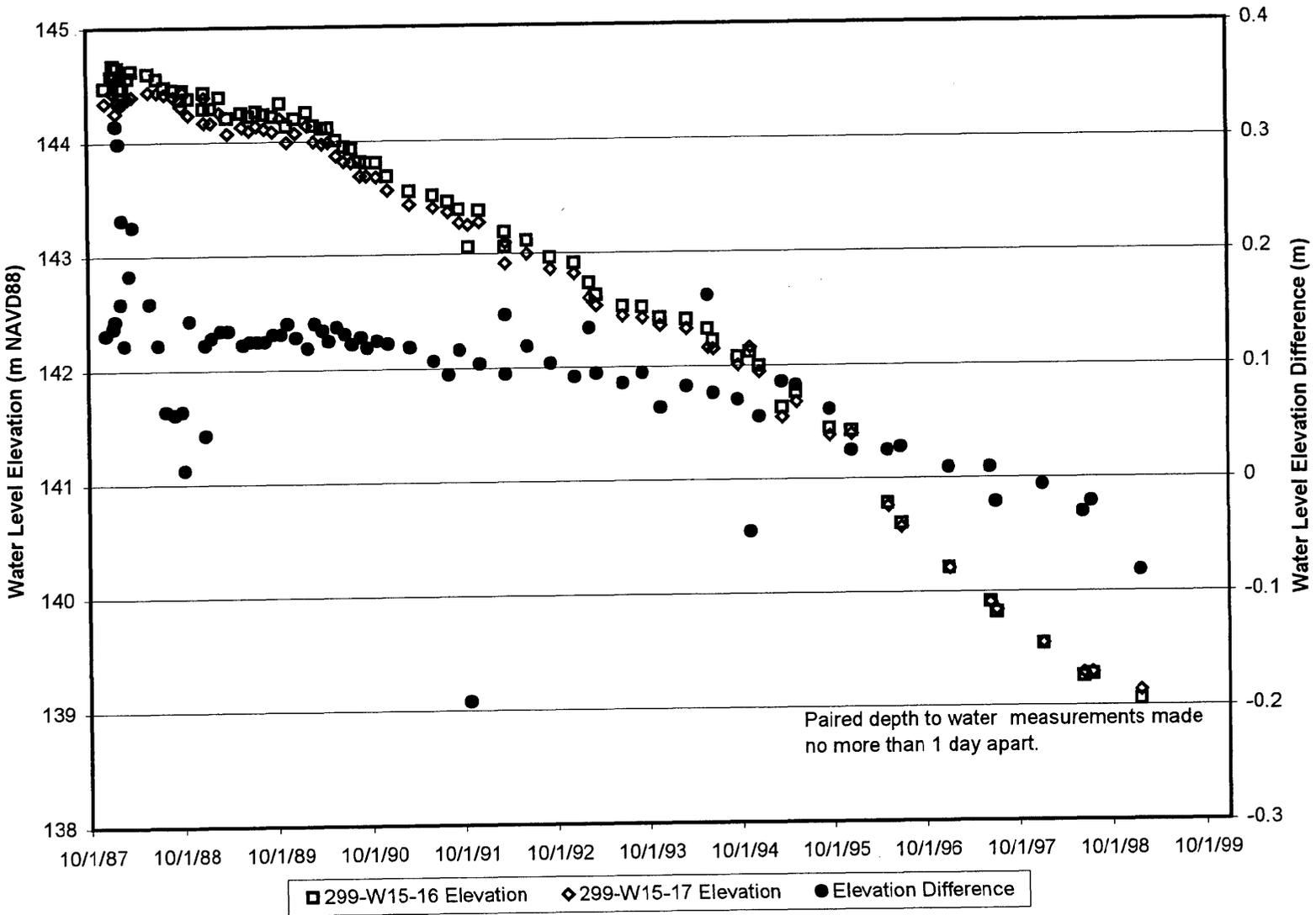


Figure 16. Baseline Distribution of Carbon Tetrachloride in Year 1996.

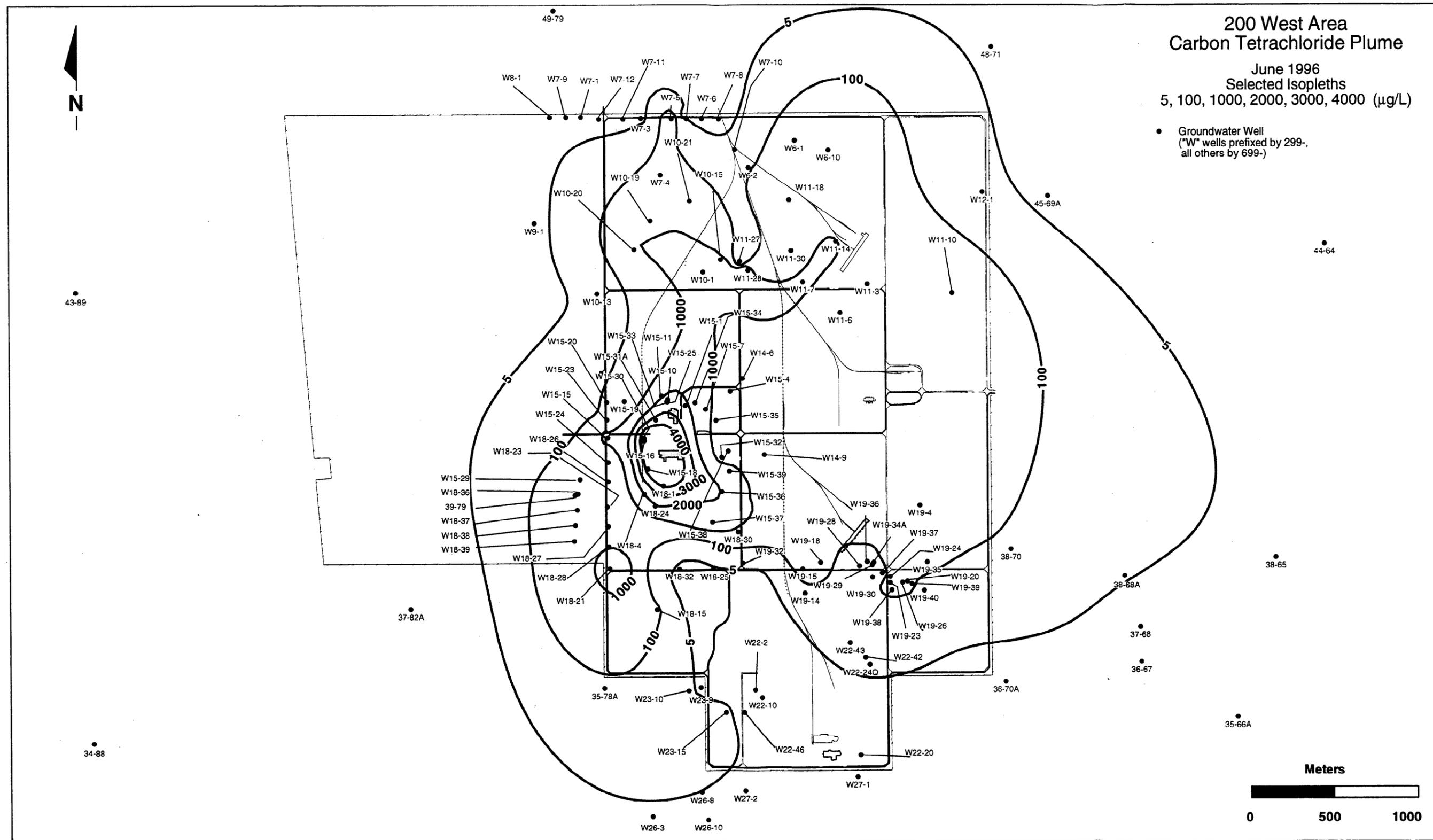
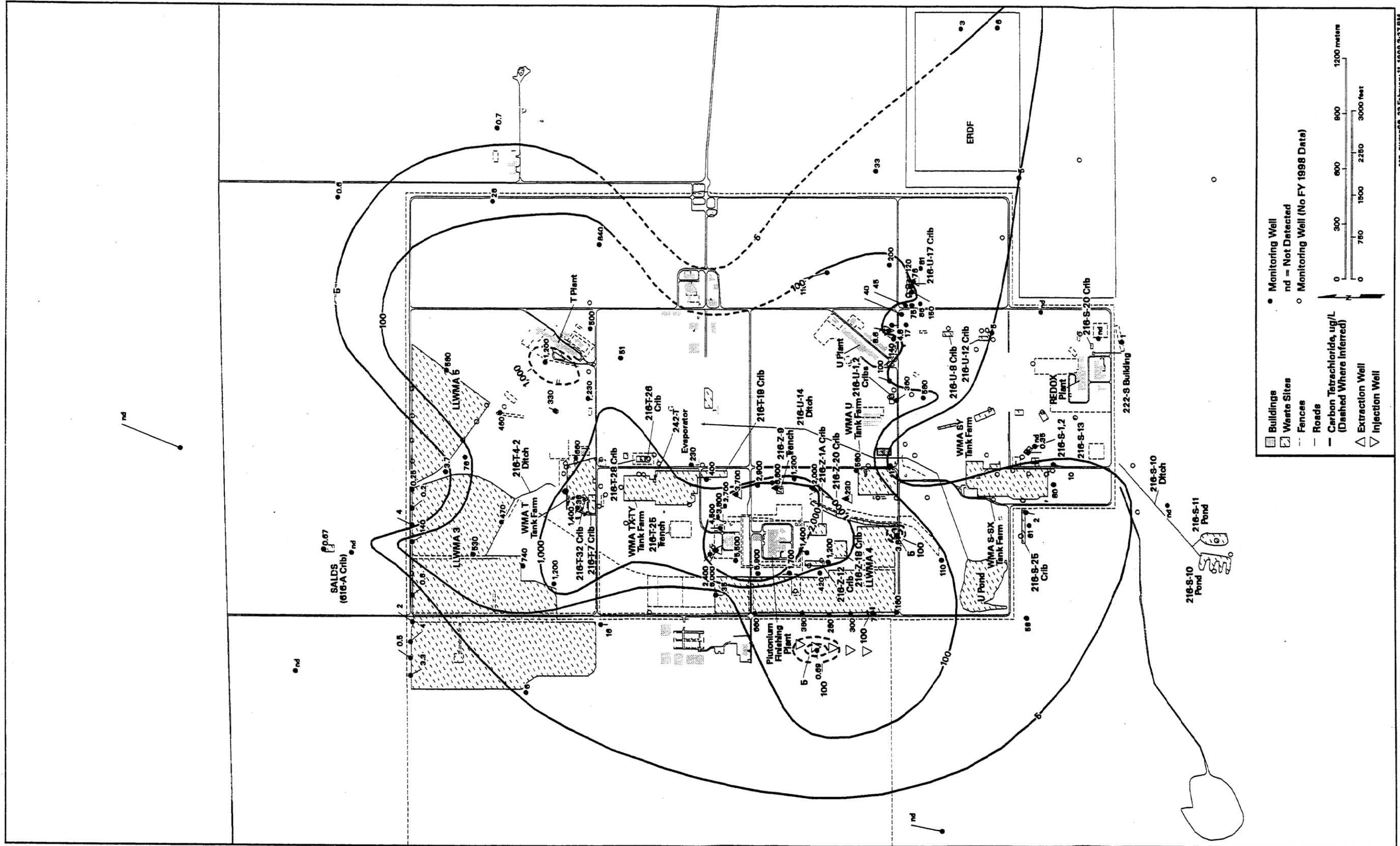


Figure 17. Distribution of Carbon Tetrachloride in Year 1998 (from Hartman 1999).



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Figure 19. Carbon Tetrachloride Concentrations in Well 299-W18-21 Since 1990.

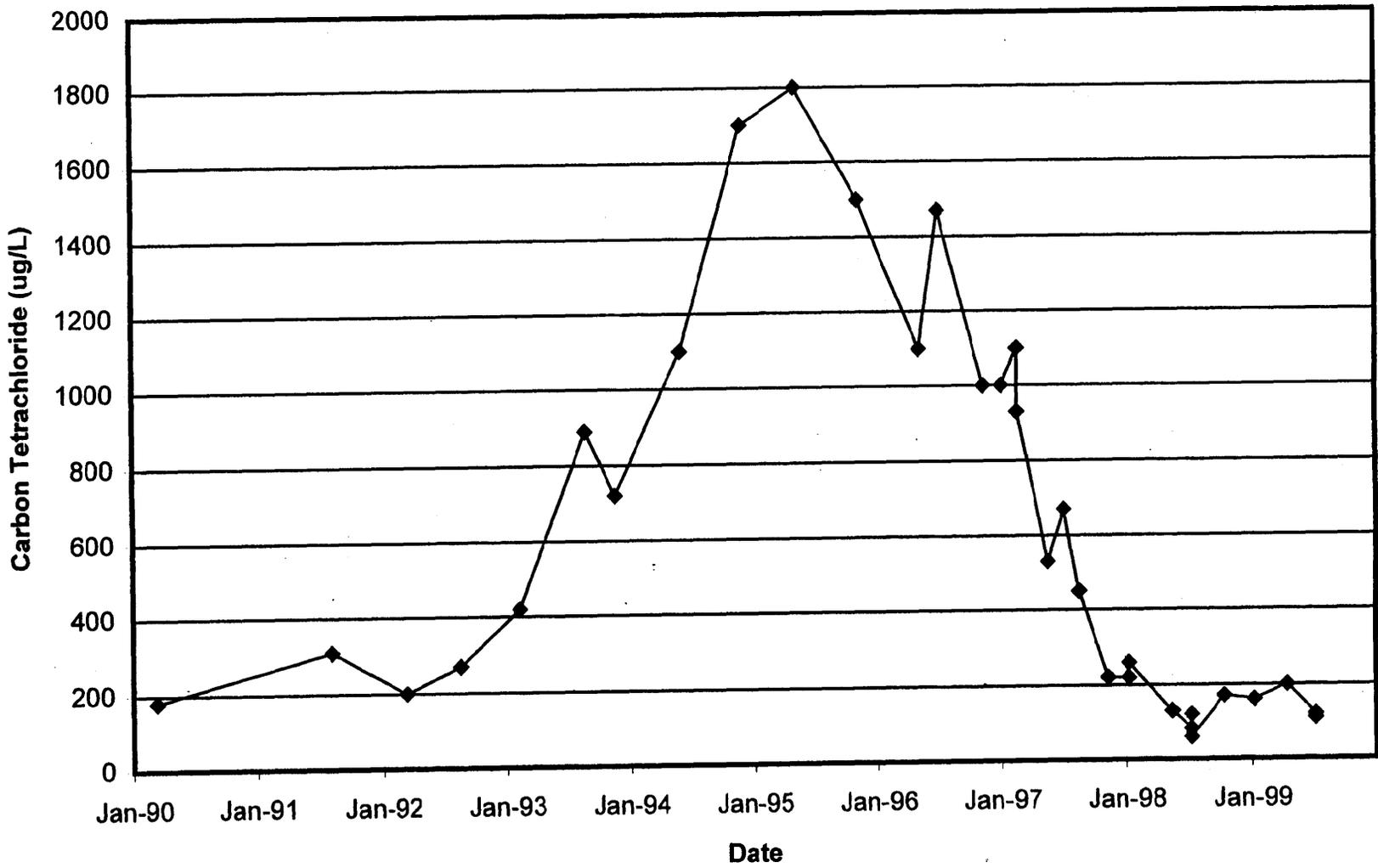
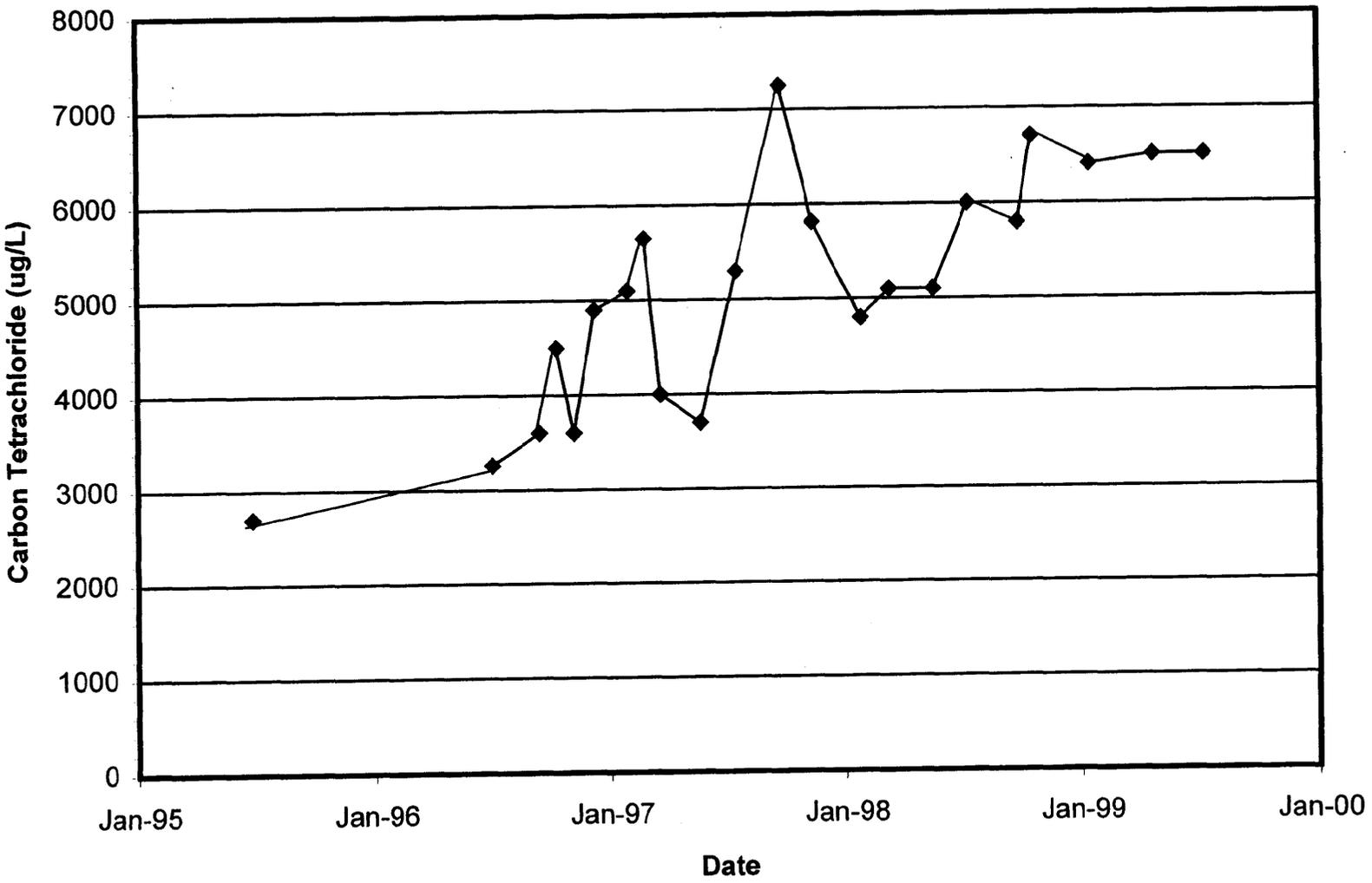


Figure 20. Carbon Tetrachloride Concentrations in Well 299-W15-31A Since 1995.



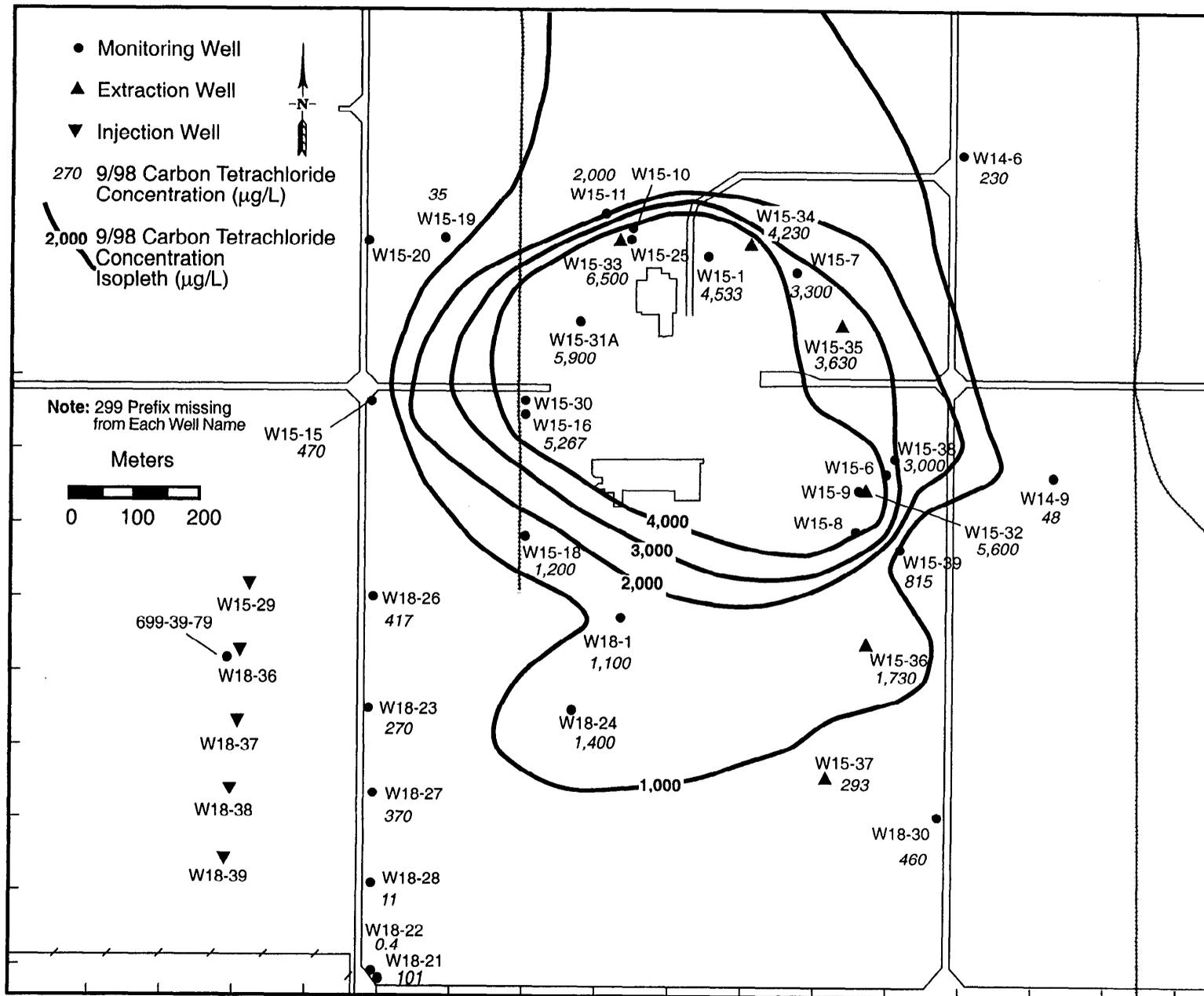
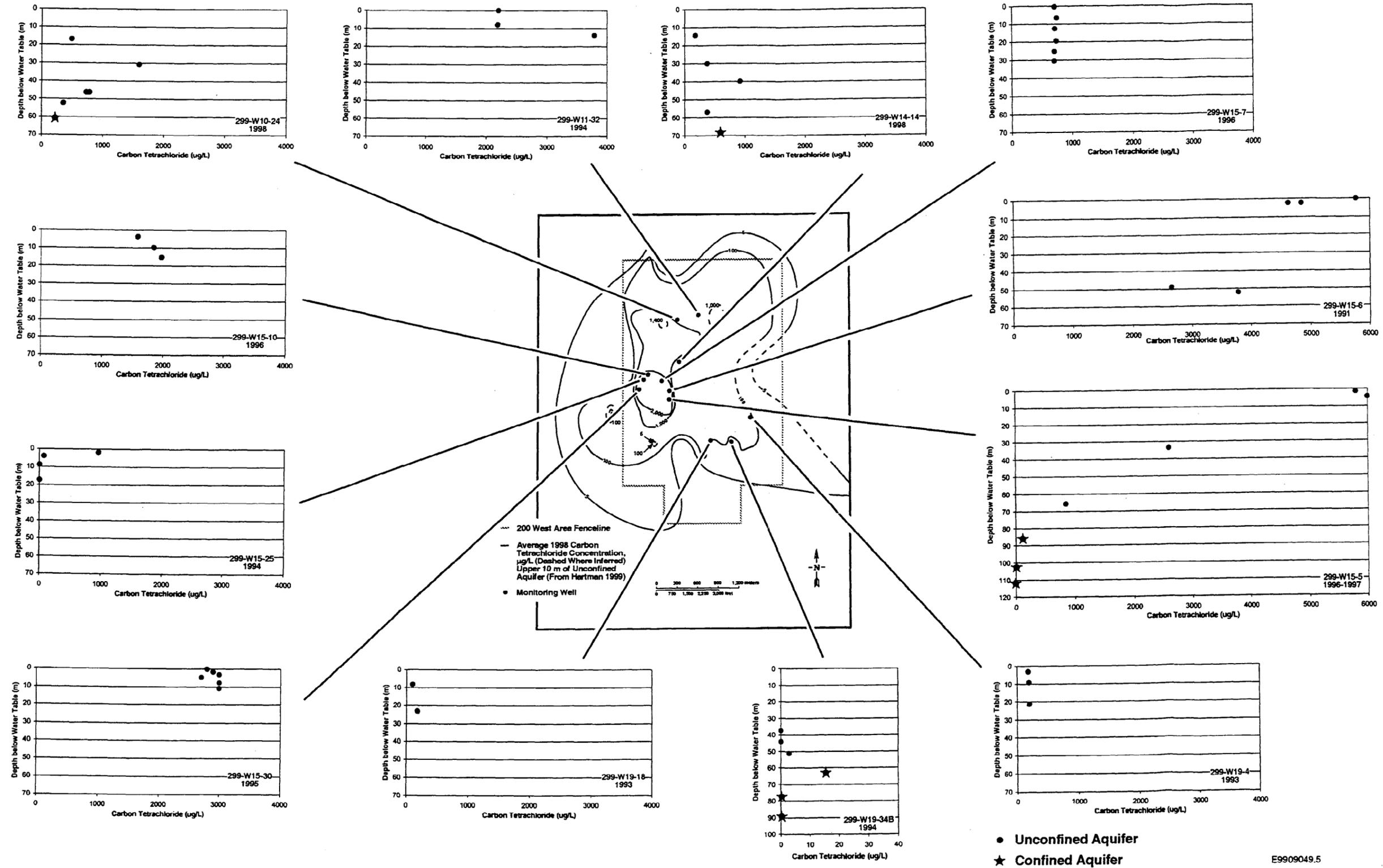


Figure 21. 200-ZP-1 Carbon Tetrachloride Remediation Area Plume as of September 1998 (from DOE-RL 1999b).

Figure 22. Depth Distribution of Carbon Tetrachloride in the Unconfined Aquifer in 200 West Area Between 1991 and 1998 Compared to the 1998 Concentration Contours at the Water Table.



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Figure 23. Distribution of Carbon Tetrachloride at Mid-Depth in the Unconfined Aquifer in 200 West Area Compared to the 1998 Concentration Contours at the Water Table.

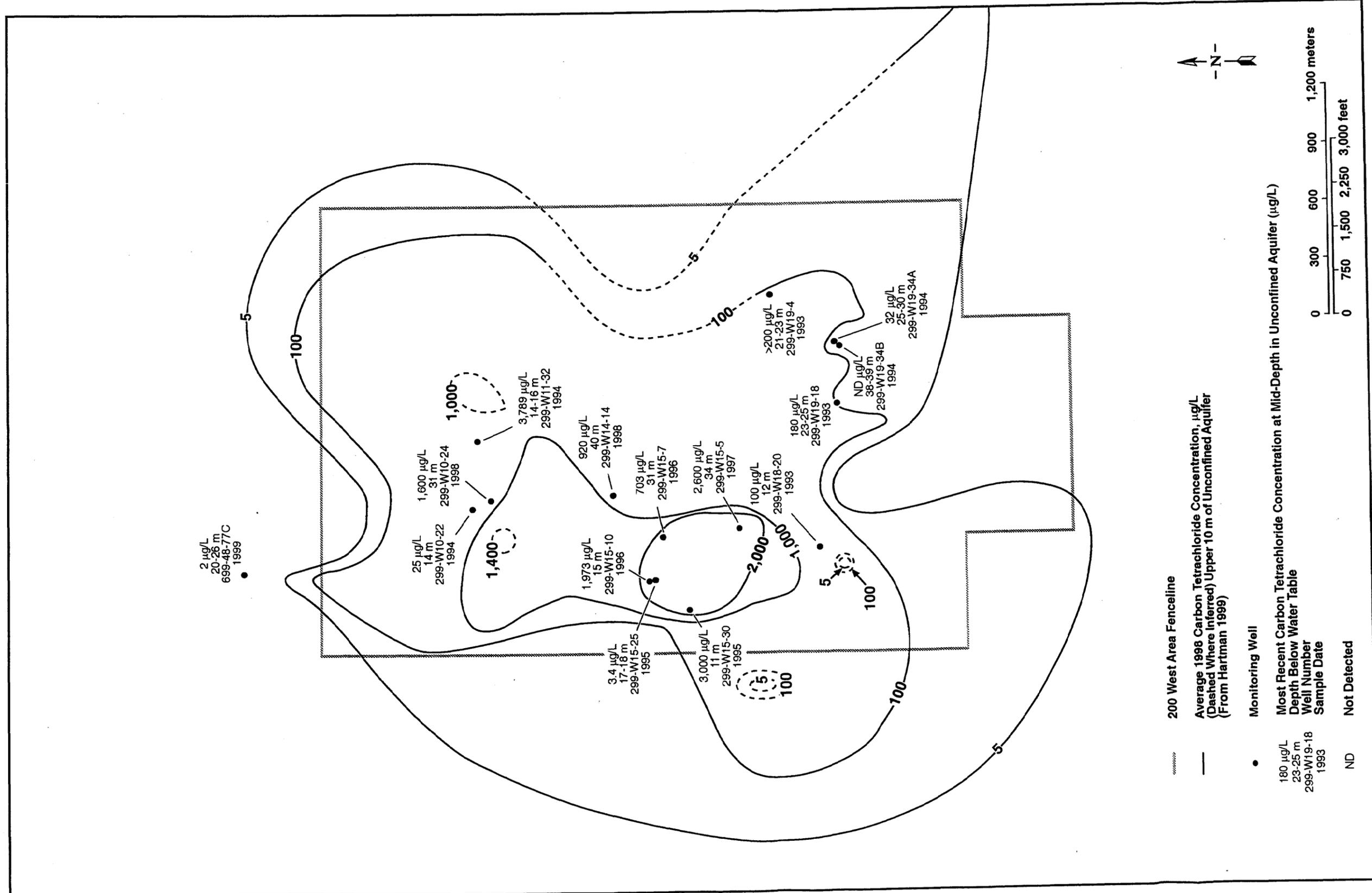


Figure 24. Distribution of Carbon Tetrachloride at the Bottom of the Unconfined Aquifer in 200 West Area Compared to the 1998 Concentration Contours at the Water Table.

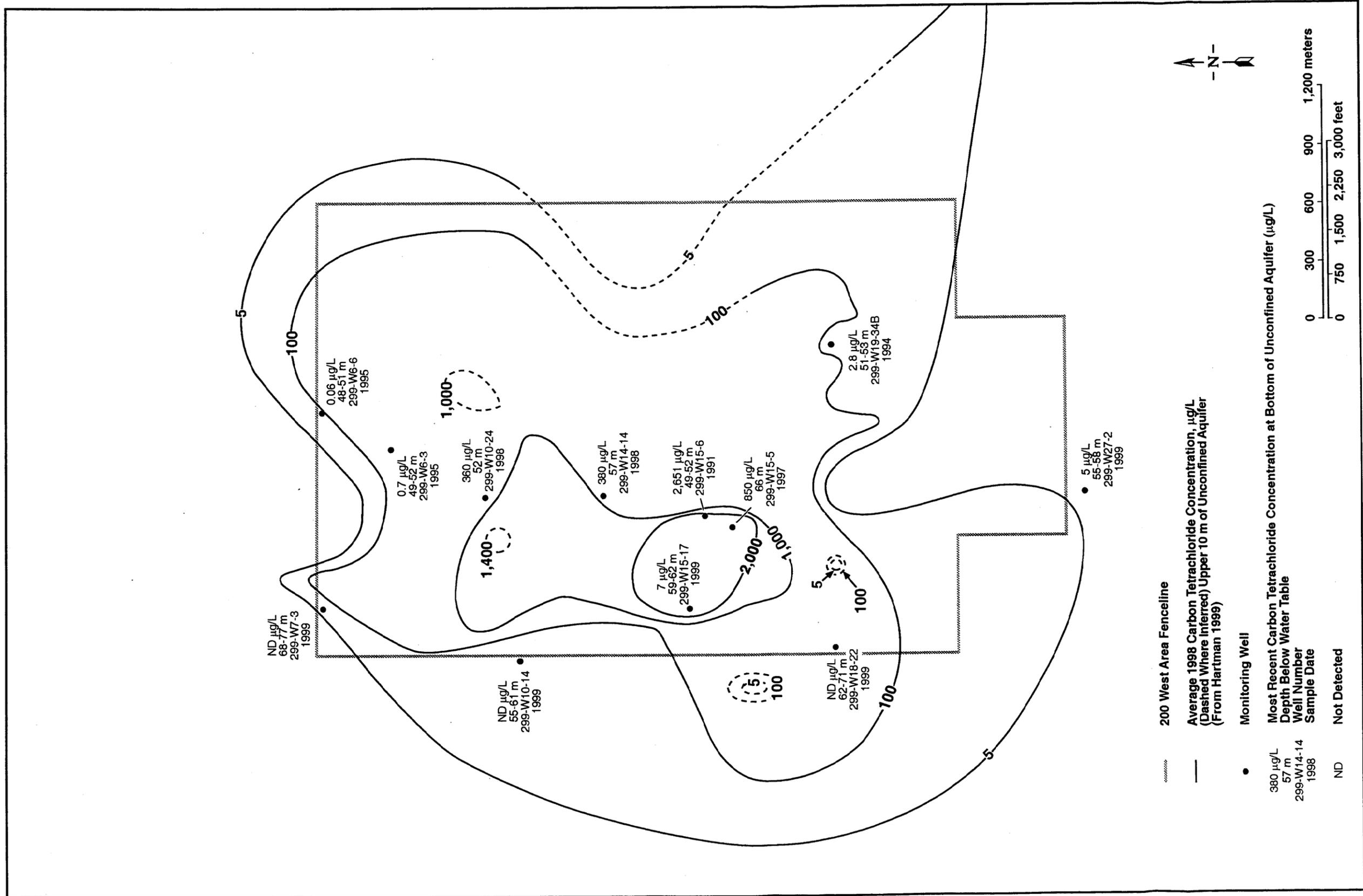


Figure 25. Changes in Carbon Tetrachloride Concentrations in Well 299-W15-16 (Top of Unconfined Aquifer) and Well 299-W15-17 (Bottom of Unconfined Aquifer).

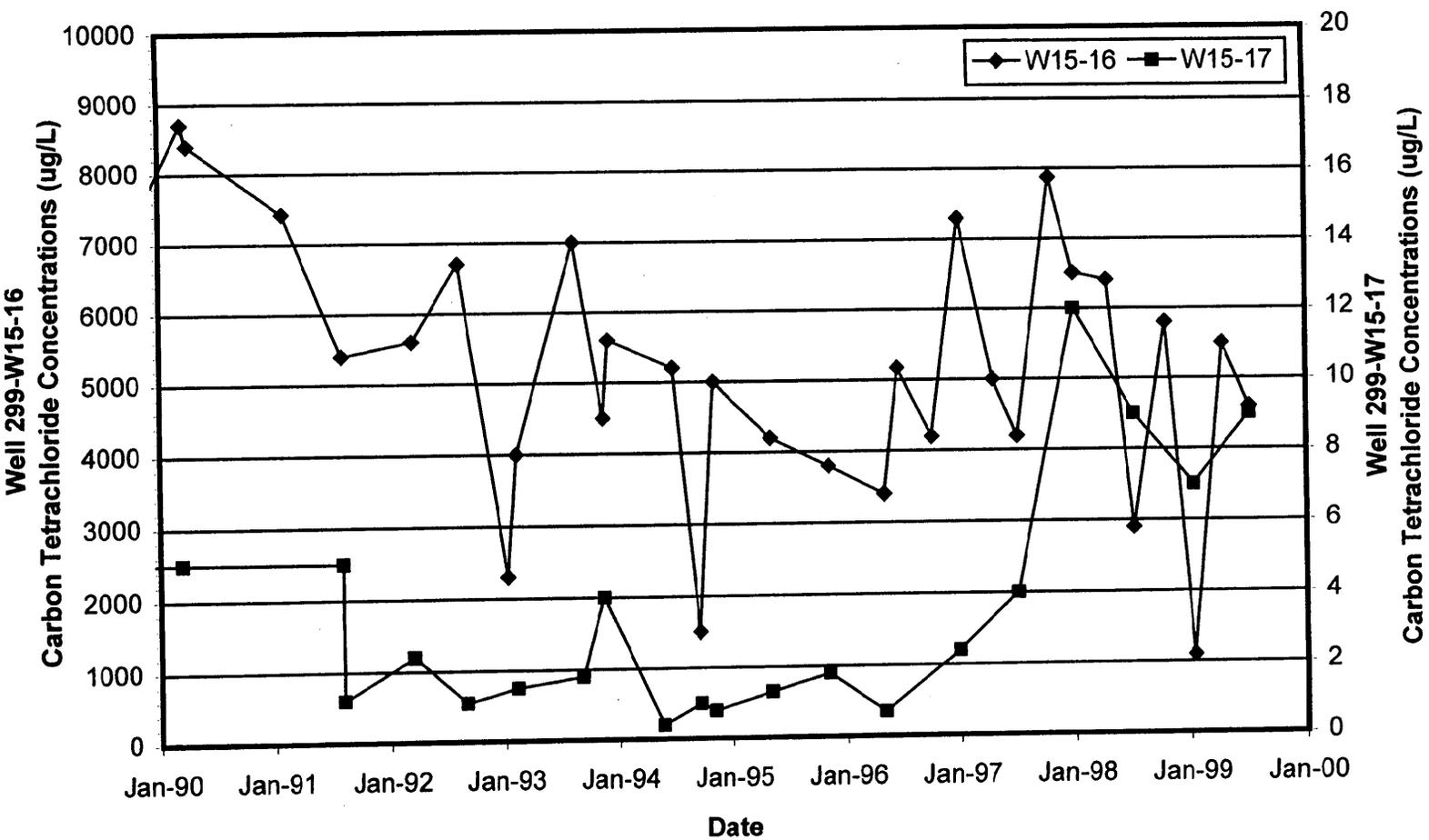
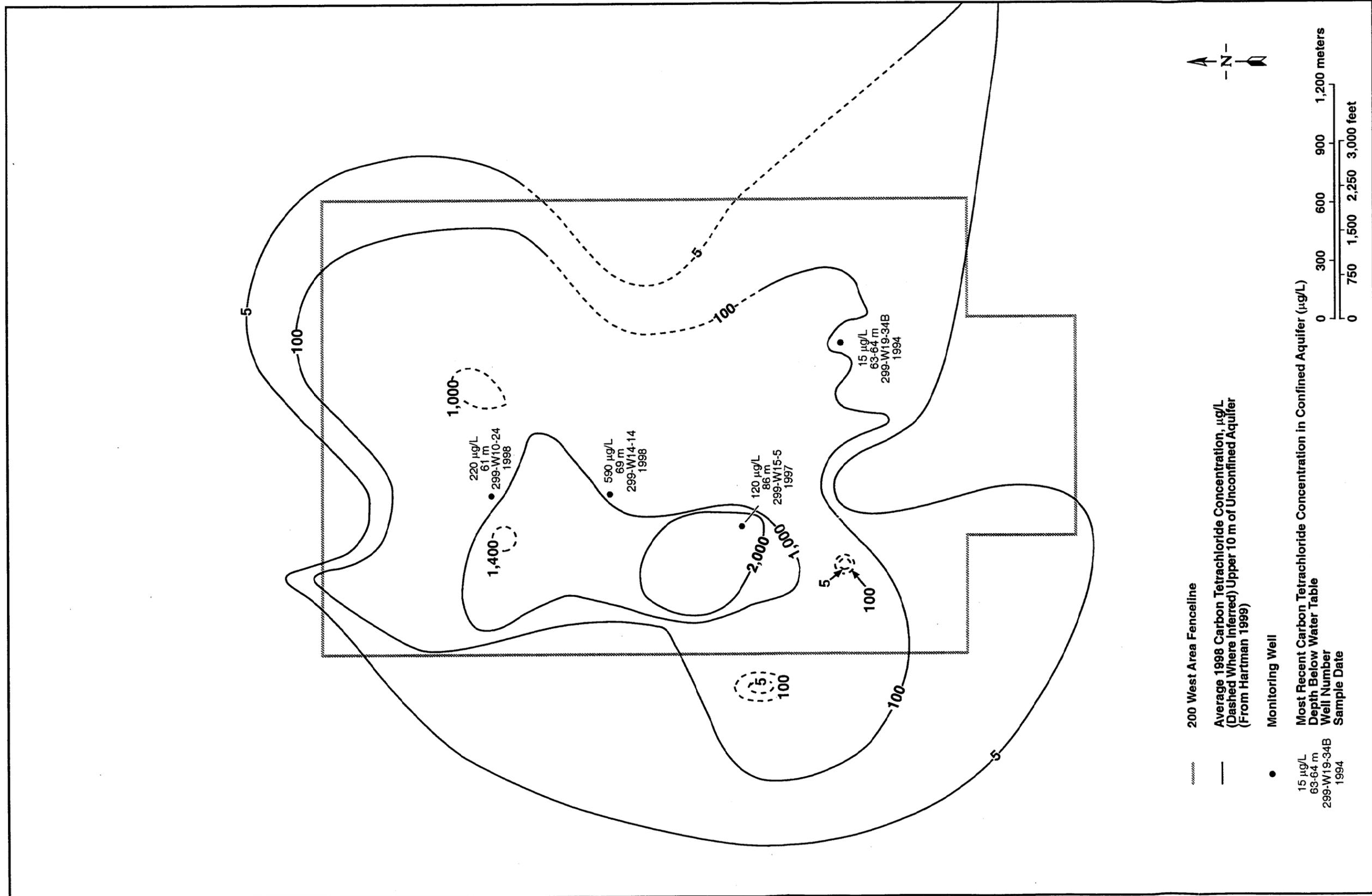


Figure 26. Distribution of Carbon Tetrachloride in the Confined Aquifer in 200 West Area Compared to the 1998 Concentration Contours at the Water Table.



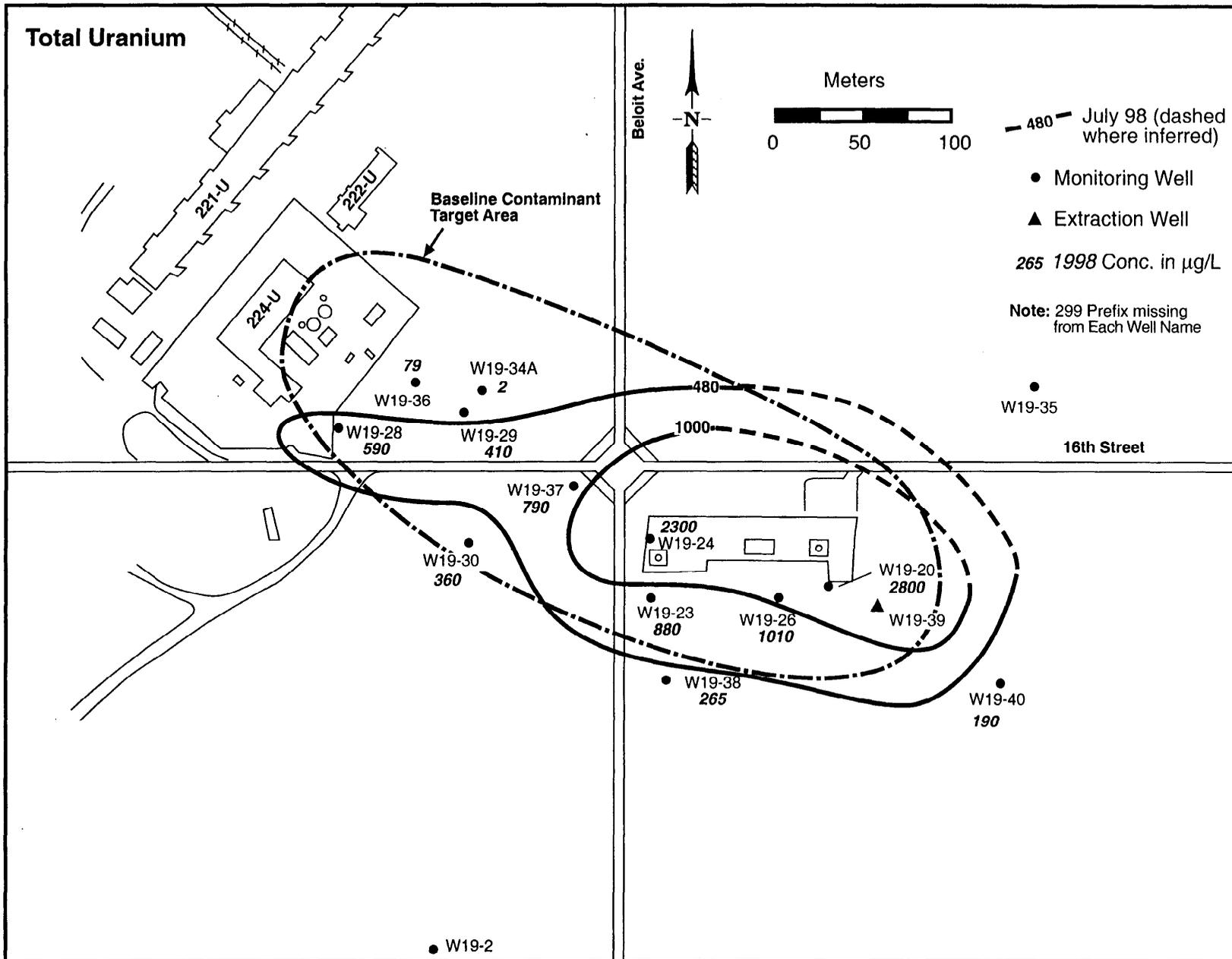


Figure 28. 200-UP-1 Remediation Site Uranium Contaminant Plume.

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Figure 29. Technetium-99 Concentrations in Well 299-W19-28.

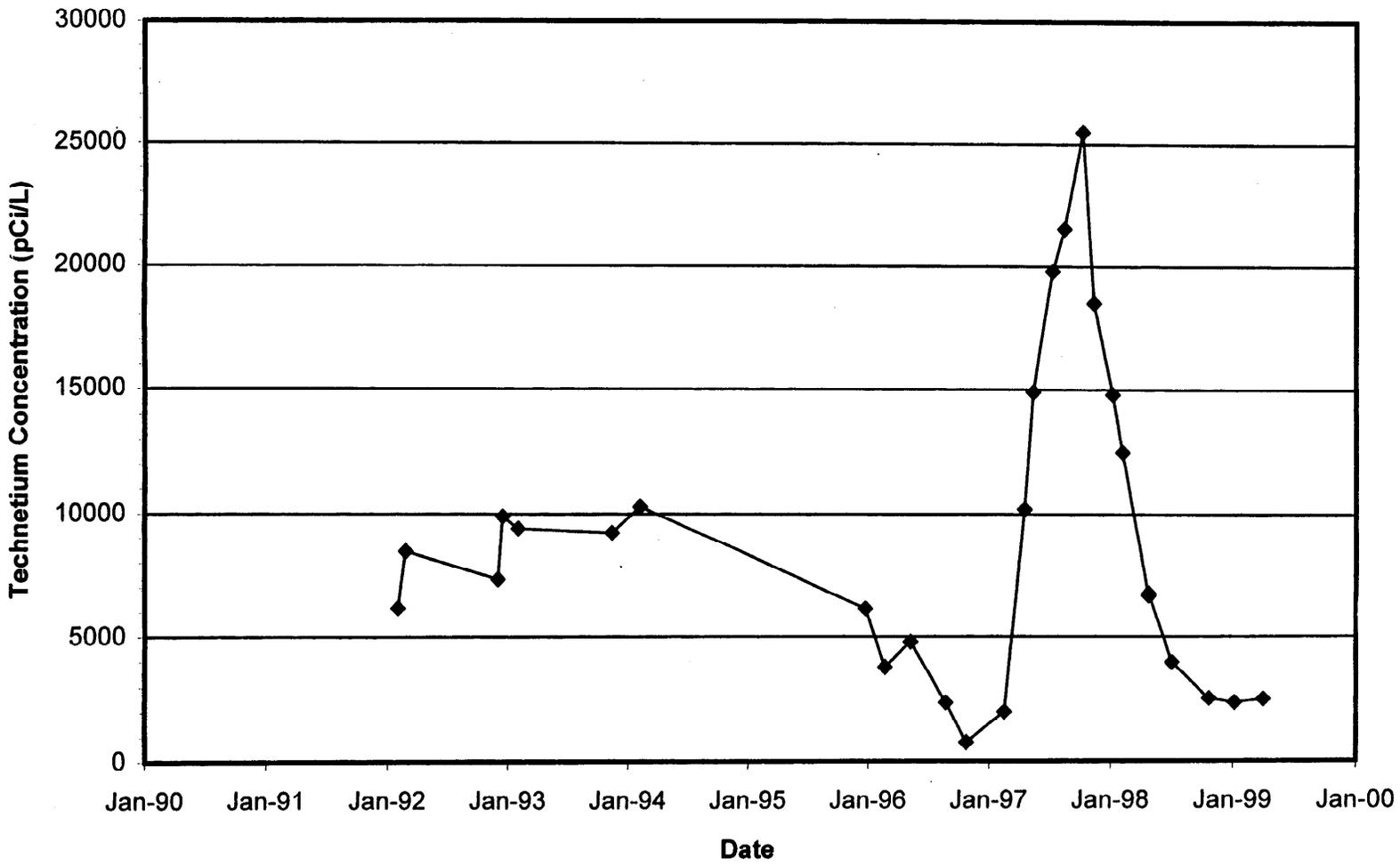


Figure 31. Predicted Carbon Tetrachloride Concentrations after 200 Years;
No K_d and No Source (from Chiaromonte et al. 1997).

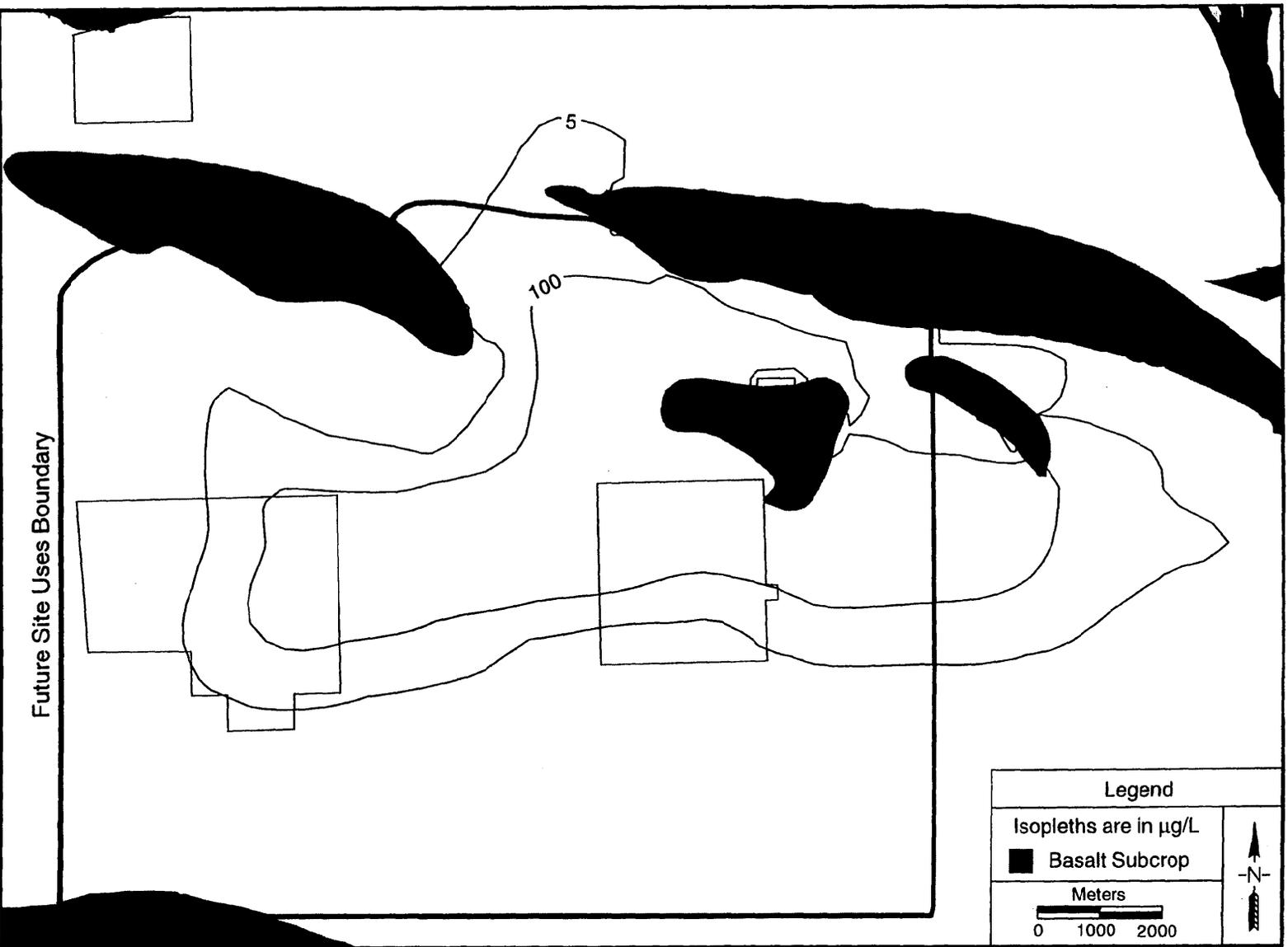


Figure 32. Predicted Carbon Tetrachloride Concentrations after 200 Years;
No K_d and Continuing Source (from Chiramonte et al. 1997).

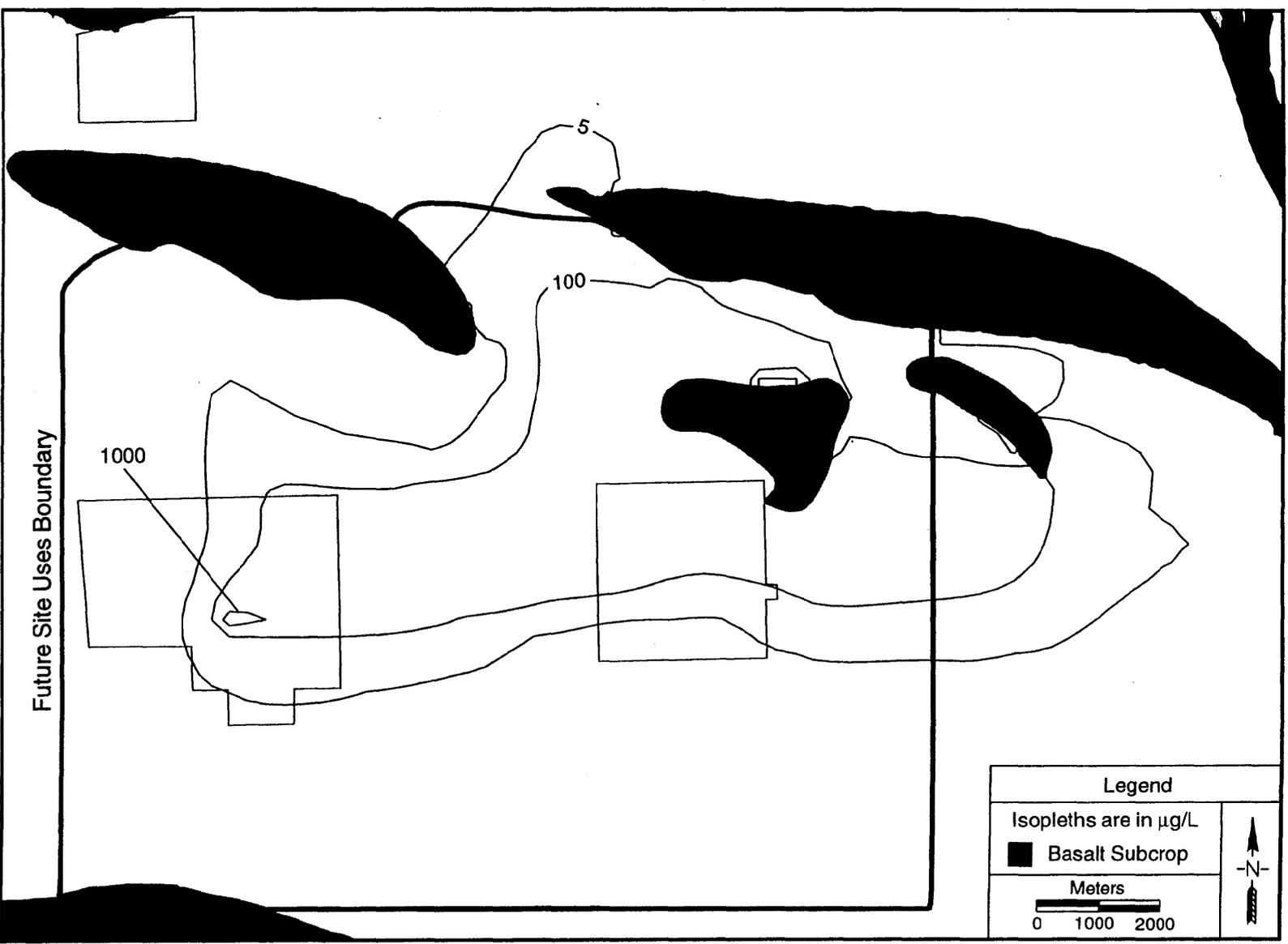


Figure 33. Predicted Carbon Tetrachloride Concentrations after Remediation and in 200 Years; No K_d and No Continuing Source (from Chiaramonte et al. 1997).

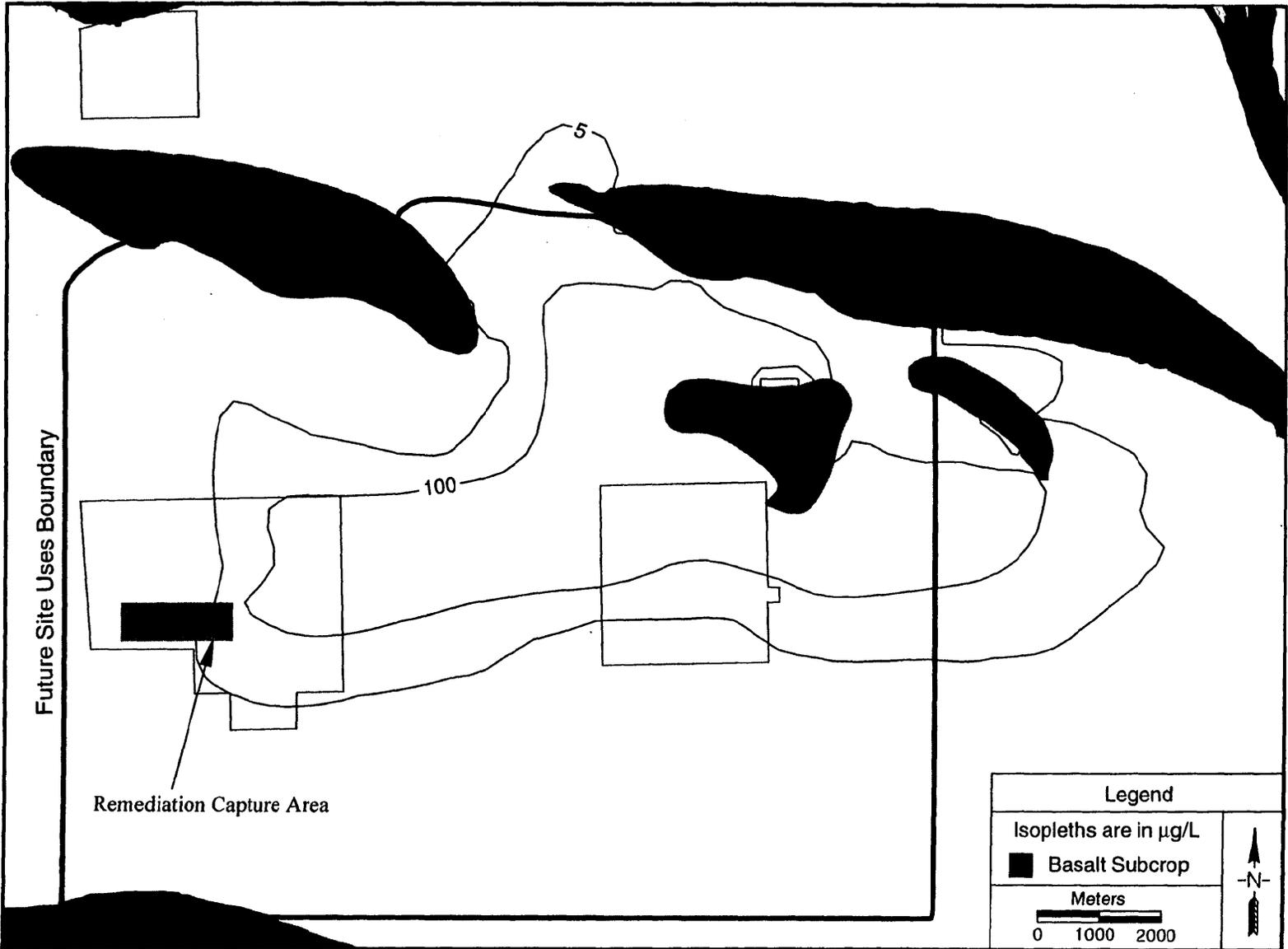


Figure 34. Predicted Carbon Tetrachloride Concentrations after 200 Years;
 $K_d = 0.114$ mL/g and Continuing Source (Chiaramonte et al. 1997).

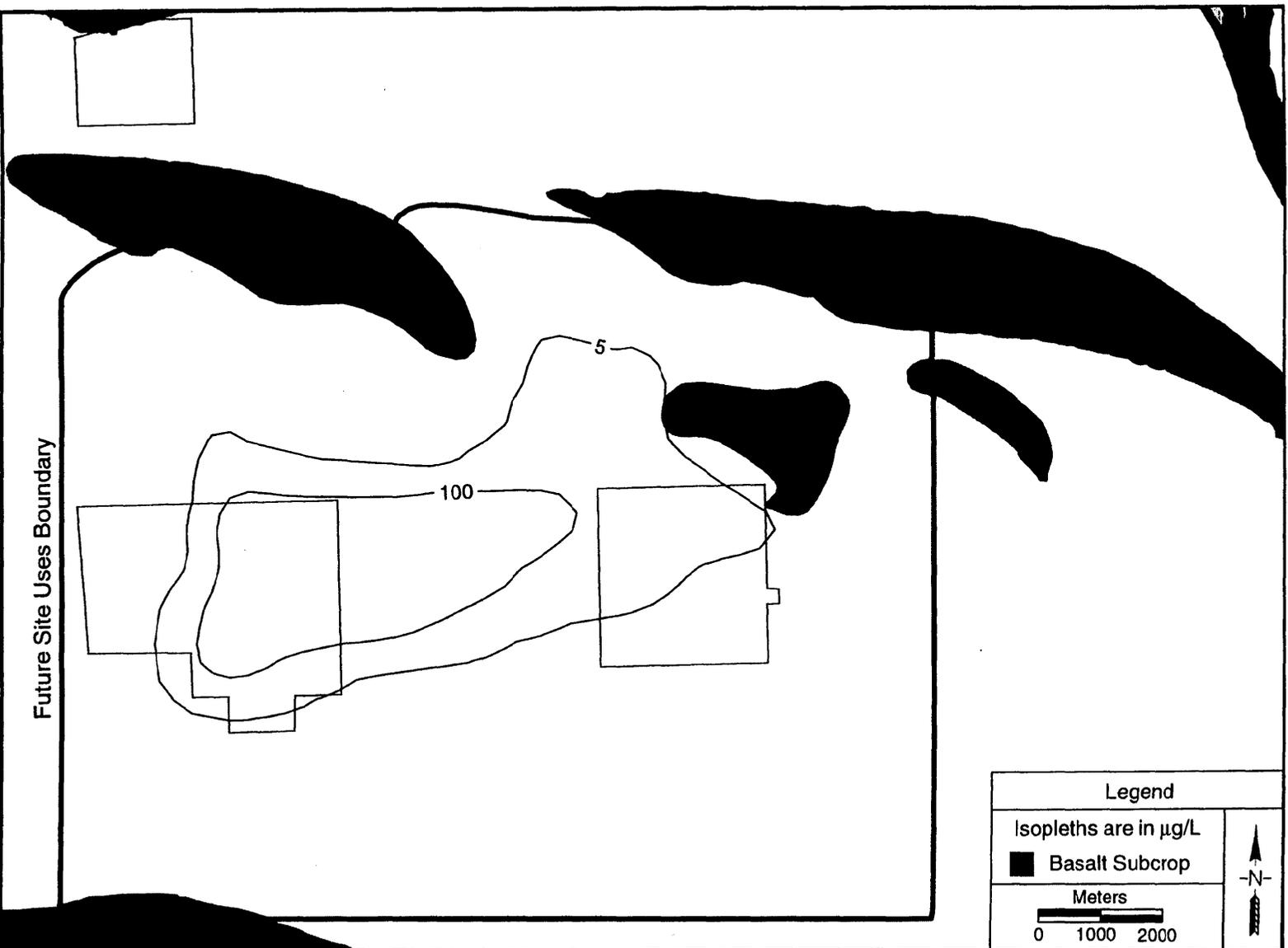


Figure 35. Predicted Technetium-99 Concentrations after 200 Years;
No K_d and No Continuing Source (from Chiaromonte et al. 1997).

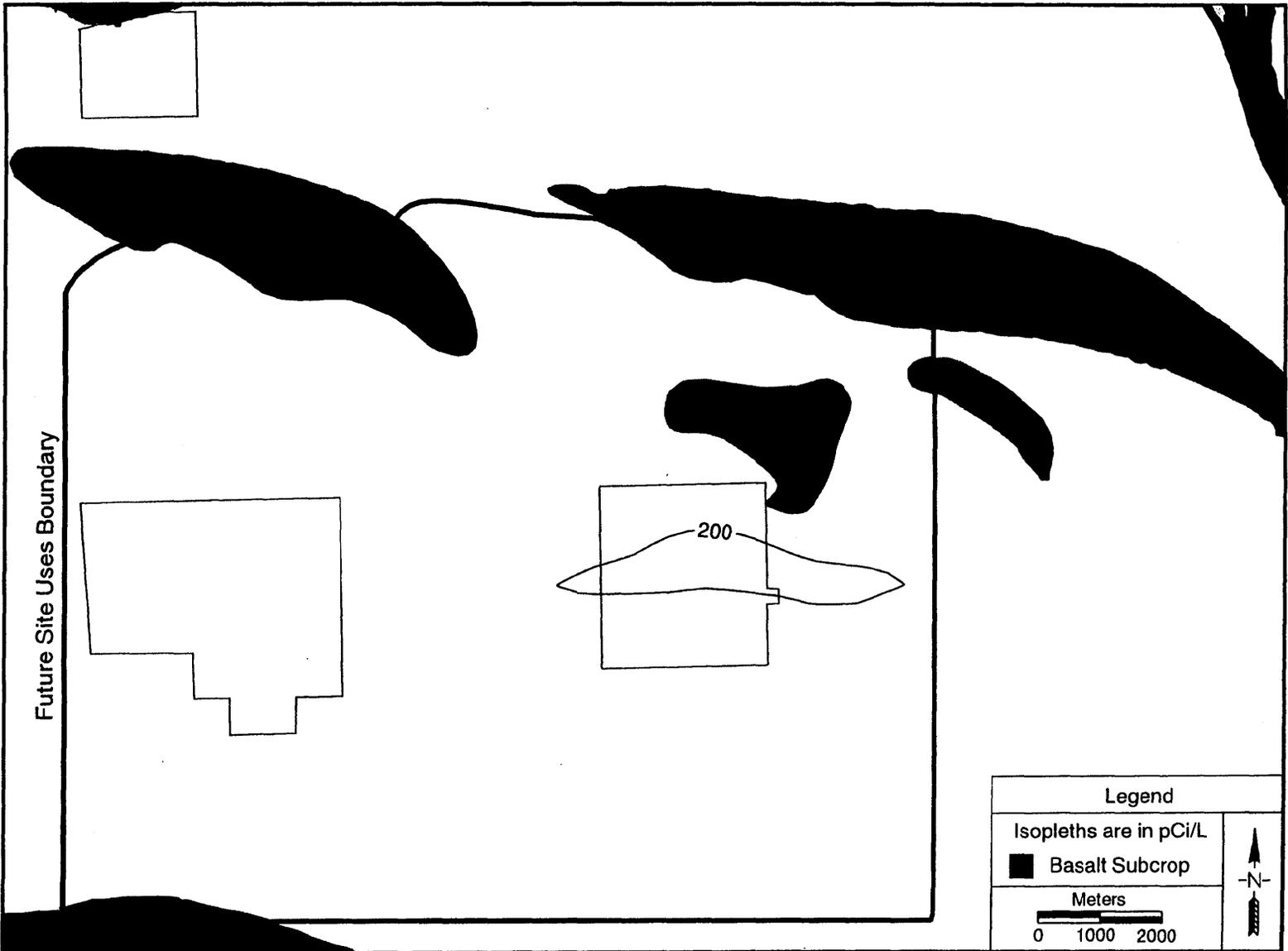


Figure 36. Predicted Uranium Concentrations after 200 Years; No K_d and No Continuing Source (from Chiamonte et al. 1997).

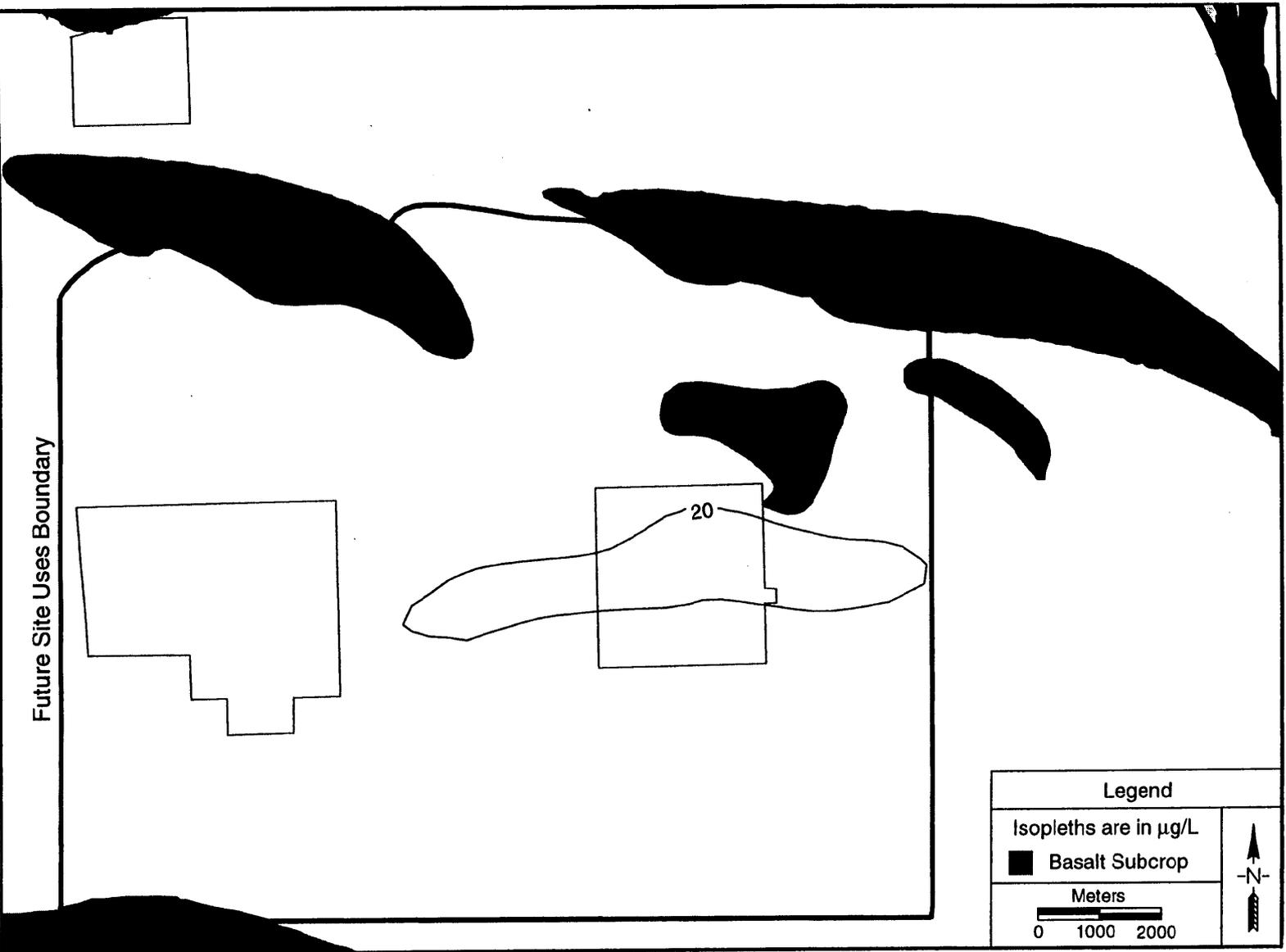


Figure 37. Predicted Uranium Concentrations after Remediation and in 200 Years;
No K_d and No Continuing Source (from Chiaromonte et al. 1997).

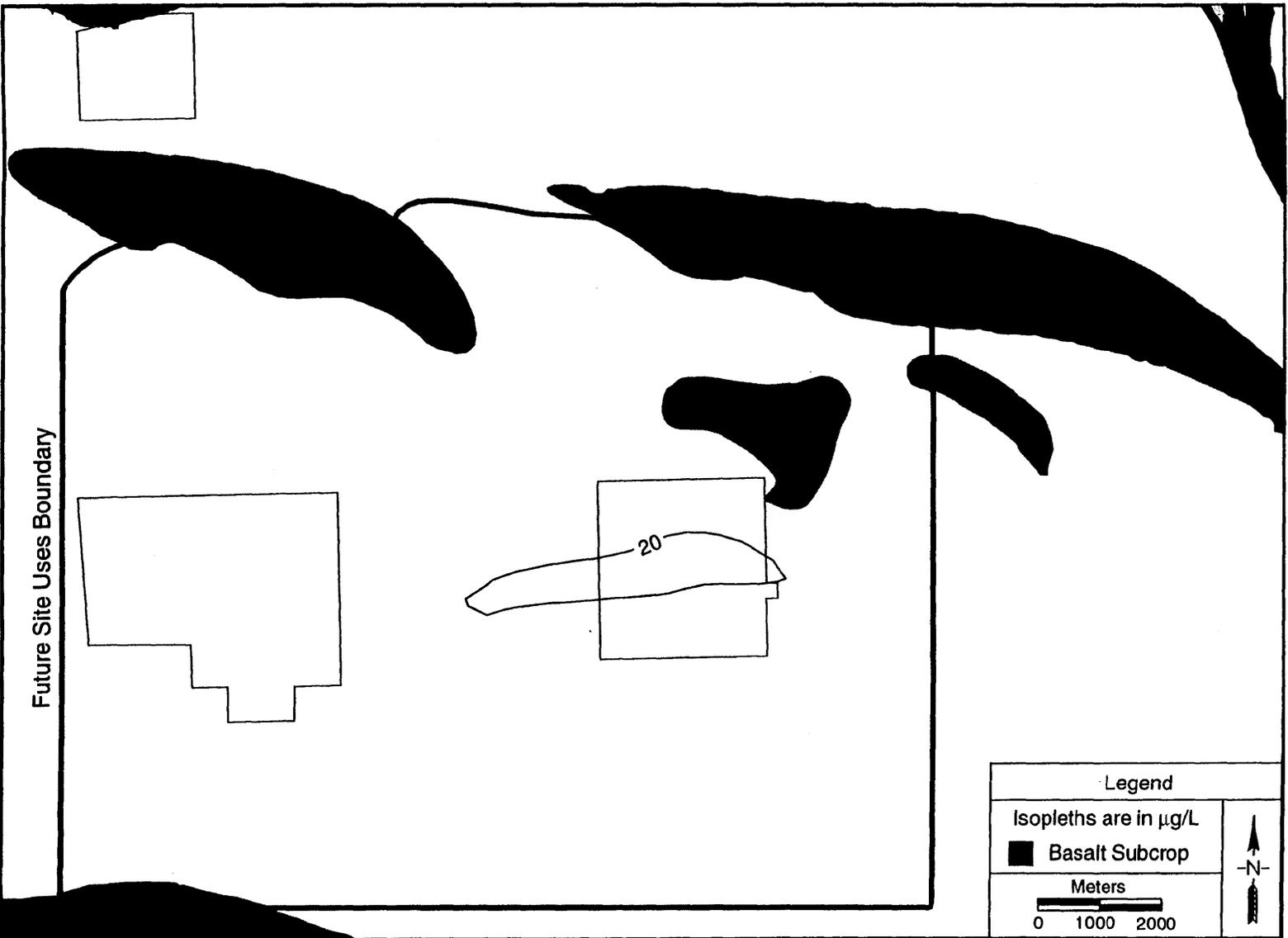
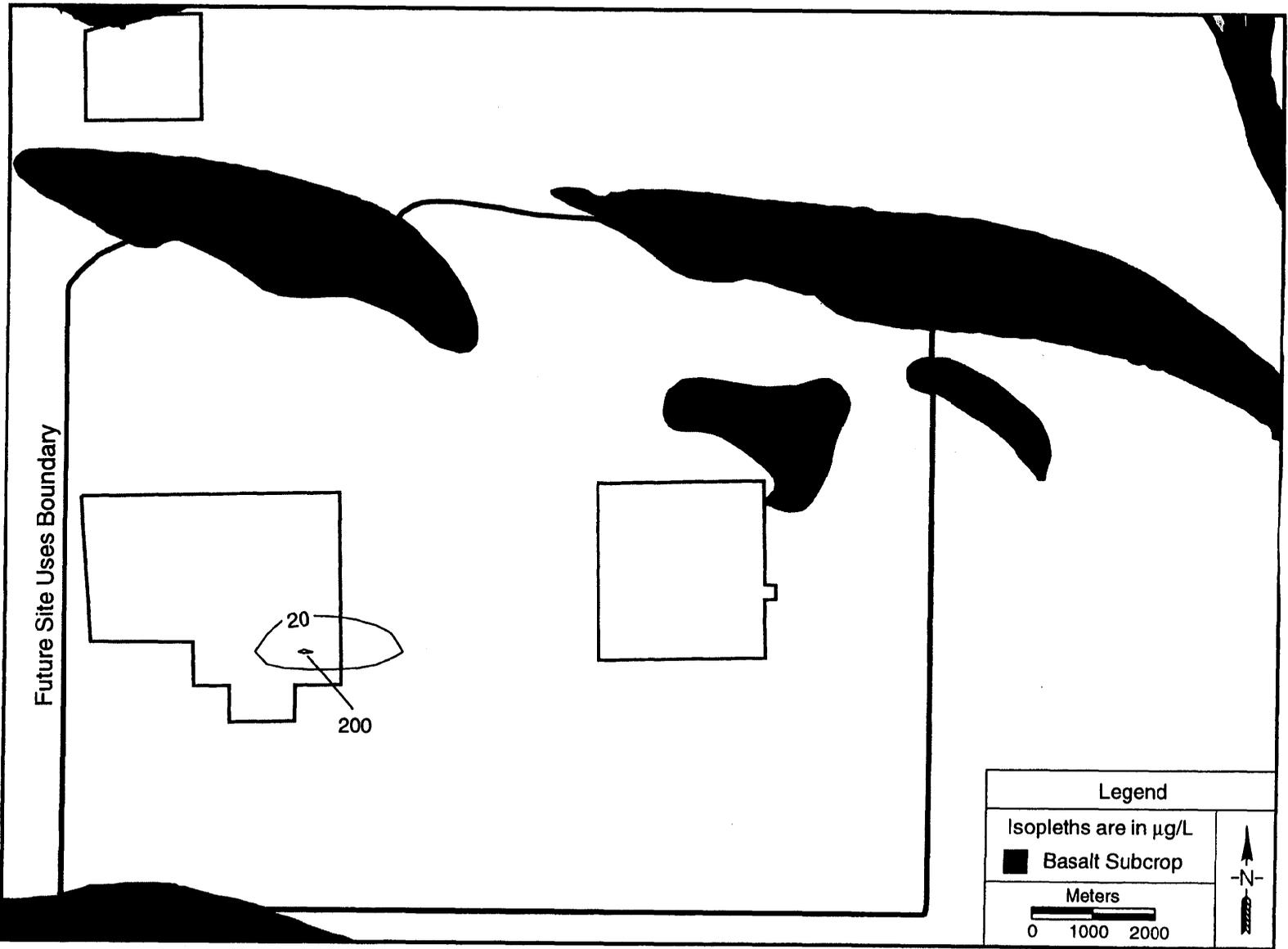


Figure 38. Predicted Uranium Concentrations after 200 Years; $K_d = 0.5 \text{ mL/g}$ and No Continuing Source (from Chiaromonte et al. 1997).



**Table 1. Major Hydrogeologic Units Used in Sitewide Three-Dimensional Model
(from Hartman 1999).**

Hydrogeologic Model Unit Number	Corresponding Geologic Unit	Lithologic Description
1	Hanford formation and pre-Missoula gravels	Glaciofluvial gravels and sands (catastrophic flood deposits)
2	Palouse soil	Fine-grained sediments and eolian silts
3	Plio-Pleistocene Unit	Buried soil horizon containing caliche and basaltic gravels
4	Upper Ringold muds	Fine-grained fluvial and lacustrine sediments
5	Middle Ringold (Unit E) and some Upper Ringold sands	Coarse-grained fluvial sediments, semi-indurated, poorly sorted sands and gravels with some silt
6	Ringold Unit C	Fine-grained fluvial and lacustrine sediments with some interbedded coarse-grained sediments
7	Middle Ringold (Units B and D)	Coarse-grained fluvial sediments
8	Lower Ringold Mud	Fine-grained fluvial and lacustrine sediments
9	Basal Ringold (unit A)	Fluvial sand and gravel
10	Columbia River Basalt Group	Basalt

Table 2. Disposition of Carbon Tetrachloride Inventory Discharged to the Soil Column.

Carbon Tetrachloride Disposition	Percent of Estimated Original Carbon Tetrachloride Inventory (Avg. 750,000 kg)	Estimated Mass of Carbon Tetrachloride (kg)	Reference
Estimated Using Pre-Remediation Data			
Equilibrium partitioning within vadose zone into vapor, dissolved, and adsorbed phases	12	91,000	WHC 1993
Lost to atmosphere	21	159,000	WHC 1993
Biodegraded	1	8,000 (4,385 for Z-9 only)	Hooker et al. 1996
Dissolved in upper 10 m of unconfined aquifer (assuming 30% porosity and no partitioning to aquifer solids)	2	15,740	Rohay and Johnson 1991
DNAPL/residual in vadose and/or unconfined aquifer	65	484,000	WHC 1993
Measured Using Remediation Data			
Removed from vadose zone using soil vapor extraction (1992 through 1998)	10	76,000	Rohay 1999
Removed from unconfined aquifer using pump and treat (1994 through 1998)	0.3	2,100	DOE-RL 1999b

Table 3. Mass Estimate of Carbon Tetrachloride Contained in Groundwater Plume in 1990 (from Rohay and Johnson 1991).

Contour Interval (µg/L)	Area (m ²)	Median Concentration (µg/L)	Calculated Mass (kg) ^a		Percent of Total	Cumulative Percent
			Porosity = 10%	Porosity = 30%		
10 to 100	8.34 E+06	55	460	1,380	8.75	8.75
100 to 1,000	3.09 E+06	550	1,700	5,100	32.39	41.14
1,000 to 2,000	0.64 E+06	1,500	970	2,900	18.44	59.58
2,000 to 3,000	0.30 E+06	2,500	760	2,280	14.49	74.07
>3,000	0.27 E+06	5,000	1,360	4,080	25.93	100.00
Total	12.65 E+06	---	5,250	15,740	100.00	---

^aAssuming a depth of 10 m.

APPENDIX A

**CARBON TETRACHLORIDE CONCENTRATIONS IN
SAMPLES COLLECTED AT DEPTHS >10 M BELOW THE WATER TABLE**

Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

A-1

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W6-3	04/16/1992	B064R0	N	5	U		1	J		5	48.7	51.9	51.6	Pos Disp	HEIS	
299-W6-3	06/11/1992	B06TM0	N	5	UP		5	UP		1	48.7	51.9	51.6	Pos Disp	HEIS	
299-W6-3	09/30/1992	B07HF3	N	5	U		5	U		1	48.7	51.9	51.6	Pos Disp	HEIS	
299-W6-3	12/08/1992	B07RP6	N	5	U		5	U		1	48.7	51.9	51.6	Pos Disp	HEIS	
299-W6-3	03/18/1993	B089T0	N	0.5	Q		1.1			0	48.7	51.9	51.6	Pos Disp	HEIS	
299-W6-3	06/10/1993	B08MD4	N	1.2	L		1.4	L		1	48.7	51.9	51.6	Pos Disp	HEIS	
299-W6-3	02/04/1994	B09ZF5	N	0.49	L		0.19	L		3	48.7	51.9	51.6	Pos Disp	HEIS	
299-W6-3	08/22/1994	B0C9Y4	N	0.45	L		0.53			1	48.7	51.9	51.6	Pos Disp	HEIS	
299-W6-3	03/02/1995	B0DWF4	N	1.1			0.74			1	48.7	51.9	51.6	Pos Disp	HEIS	
299-W6-3	09/14/1995	B0GH60	N	0.7			0.74			1	48.7	51.9	51.6	Pos Disp	HEIS	
299-W6-6	03/19/1992	B064S5	N	5	U		5	U		1	47.8	51.1	48.9	Pos Disp	HEIS	
299-W6-6	06/11/1992	B06TP1	N	5	U		5	U		1	47.8	51.1	48.9	Pos Disp	HEIS	
299-W6-6	09/04/1992	B078G8	N	5	U		5	U		1	47.8	51.1	48.9	Pos Disp	HEIS	
299-W6-6	12/08/1992	B07RQ7	N	5	U		5	U		1	47.8	51.1	48.9	Pos Disp	HEIS	
299-W6-6	03/17/1993	B089W3	N	5	U		5	U		1	47.8	51.1	48.9	Pos Disp	HEIS	
299-W6-6	09/10/1993	B096B0	N	0.87	U		0.4	U		2	47.8	51.1	48.9	Pos Disp	HEIS	
299-W6-6	02/09/1994	B09ZH0	N	0.12	U		0.04	U		3	47.8	51.1	48.9	Pos Disp	HEIS	
299-W6-6	08/24/1994	B0C9Z4	N	0.32	U		0.05	U		6	47.8	51.1	48.9	Pos Disp	HEIS	
299-W6-6	03/09/1995	B0DYD4	N	0.08	U		0.04	U		2	47.8	51.1	48.9	Pos Disp	HEIS	
299-W6-6	09/18/1995	B0GH73	N	0.06	L		0.03	U		2	47.8	51.1	48.9	Pos Disp	HEIS	

Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W7-3	10/03/1988	H000BPD0	N	5	U		5	U		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	12/29/1988	H000BPD4	N	5	U		5	U		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	03/20/1989	H000BPD8	N	5	U	1.8	5	U	1.8	1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	07/28/1989	H000BPF2	N	5	U	1.8	5	U	1.8	1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	09/15/1989	H000BPF6	N	5	U	1.8	5	U	1.8	1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	01/17/1990	H000BPG0	N	5	U	1.8	5	U	1.8	1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	05/07/1990	H000BPG4	N	5	U	1.8	5	U	1.8	1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	08/08/1991	B00JT4	N	5	U		5	U		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	11/08/1991	B01BG4	N	5	U		5	U		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	02/12/1992	B01V47	N	1.9			5	U		0	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	05/22/1992	B06MG4	N	5	U		0.56	J		9	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	08/28/1992	B074H0	N	5	U		5	U		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	12/03/1992	B07M85	N	5	U		5	U		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	02/10/1993	B084B7	N	5	U		5	U		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	05/17/1993	B08JQ4	N	0.87	U		0.48	L		2	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	08/25/1993	B09110	N	0.87	U		0.4	U		2	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	12/07/1993	B09KR9	N	0.13	L		0.3	L		0	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	02/25/1994	B0BDP4	N	0.32	LY		0.39	LY		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	08/15/1994	B0CB34	N	0.32	U		0.06	L		5	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	03/13/1995	B0DWS8	N	0.08	L		0.15	L		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	09/12/1995	B0GHC1	N	0.08	L		0.12	L		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	03/07/1996	B0HMK4	N	0.2	LH		0.03	U		7	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	09/17/1996	B0J9J9	N	0.5	U		0.4			1	68.0	76.5	71.9	Pos Disp	HEIS	

A-2

Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W7-3	03/12/1997	B0K390	N	0.5	U		0.6			1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	09/10/1997	B0LWW6	N	0.3	J		0.3	J		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	03/10/1998	B0N597	N	0.5	J		1	J		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	09/16/1998	B0PRJ0	N	0.5	J		1	JQ		1	68.0	76.5	71.9	Pos Disp	HEIS	
299-W7-3	03/10/1999	B0TWP1	N	0.15	U		1	J		0	68.0	76.5	71.9	Pos Disp	HEIS	
299-W10-14	10/04/1988	H0009GB4	N	5	U		5	U		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	01/03/1989	H0009GB8	N	5	U	1.8	7		2.1	1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	03/21/1989	H0009GC2	N	5	U	1.8	5	U	1.8	1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	07/27/1989	H0009GC6	N	5	U	1.8	5	U	1.8	1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	09/15/1989	H0009GD0	N	5	U	1.8	5	U	1.8	1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	01/10/1990	H0009GD4	N	5	U	1.8	5	U	1.8	1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	05/09/1990	H0009GD8	N	5	U	1.8	5	U	1.8	1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	08/14/1991	B00JV5	N	5	U		5	U		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	11/07/1991	B01BC9	N	5	U		5	U		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	02/05/1992	B01V19	N	5	UP		5	UP		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	05/26/1992	B06MC7	N	5	U		5	U		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	09/16/1992	B07454	N	5	U		5	U		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	12/04/1992	B07M60	N	5	U		5	U		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	02/09/1993	B084C3	N	5	UY		5	UY		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	02/09/1993	B084C4	N	5	UY		5	UY		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	07/19/1993	B08JS2	N	0.87	U		0.4	U		2	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	09/07/1993	B090Z4	N	0.87	U		0.4	U		2	55.3	61.4	53.5	Pos Disp	HEIS	

A-3

Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

A-4

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W10-14	12/01/1993	B09KQ1	N	0.12	U		0.05	L		2	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	02/18/1994	B0BDJ9	N	0.12	U		0.04	U		3	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	08/31/1994	B0C9W9	N	0.32	U		0.05	U		6	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	03/10/1995	B0DW81	N	0.08	U		0.04	U		2	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	09/05/1995	B0GH34	N	0.1	L		0.04	L		3	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	03/05/1996	B0HMJ4	N	0.04	U		0.03	U		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	09/04/1996	B0J9G2	N	0.5	U		0.2	U		3	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	03/11/1997	B0K341	N	0.5	U		0.2	U		3	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	09/08/1997	B0LWP1	N	0.14	U		0.17	U		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	03/09/1998	B0N4J5	N	0.2	JQ		0.2	JQ		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	09/10/1998	B0PR98	N	0.14	U		0.17	UQ		1	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-14	03/09/1999	B0TX81	N	0.15	U		0.09	U		2	55.3	61.4	53.5	Pos Disp	HEIS	
299-W10-22	09/01/1994	B09W13		5	U		5	U		1			0.0		WHC-EP-0815	
299-W10-22	09/01/1994	B09W14		5	U		5	U		1			0.0		WHC-EP-0815	Duplicate
299-W10-22	09/15/1994	B09W17		25			17			1			13.5		WHC-EP-0815	
299-W10-22	09/15/1994	B09W18		21			13			2			13.5		WHC-EP-0815	Split
299-W10-24	10/09/1998	B0R3F9	N	490	D		10			49			16.9		PNNL-12086	
299-W10-24	10/12/1998	B0R3D7	N	1600	DQ		25			64			30.8		PNNL-12086	
299-W10-24	10/13/1998	B0R3D9	N	730	DQ		13			56			46.3		PNNL-12086	

Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W10-24	10/13/1998	B0R3F7	N	780	DQ		13	D		60			46.3		PNNL-12086	
299-W10-24	10/15/1998	B0R3F1	N	360	D		7			51			52.2		PNNL-12086	
299-W10-24	10/16/1998	B0R3F3	N	220	DQ		6			37			61.0		PNNL-12086	
299-W11-32	01/24/1994	B07F70	N	2197			18			122	0.0	4.0	2.0		PNL-10422	
299-W11-32	01/10/1994	B09F60	N	2183			483			5	8.0	10.0	9.0		PNL-10422	
299-W11-32	01/12/1994	B07F72	N	3789			27			140	14.0	16.0	15.0		PNL-10422	
299-W14-9	10/04/1994	B0CXW3	N	66			2	J		33	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	11/08/1996	B0JKC0	N	420			22			19	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	11/08/1996	B0JKD5	N	490			23			21	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	11/08/1996	B0JKF7	N	500	D		50	U		10	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	02/27/1997	B0JY16	N	290			41			7	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	02/27/1997	B0JY29	N	280			40			7	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	05/21/1997	B0K5C9	N	50			122			0	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	05/21/1997	B0K5D0	N	49			98			1	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	08/25/1997	B0LLL7	N	27			20			1	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	08/25/1997	B0LLL8	N	120			100			1	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	11/14/1997	B0MD66	N	75			113			1	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	02/18/1998	B0N1V4	N	40			81			0	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	05/19/1998	B0NMT4	N	10			50			0	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	05/19/1998	B0NMW8	N	14			51			0	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	05/19/1998	B0NMW9	N	30			50			1	56.0	92.0		Submers	HEIS, BHI-01126	

A-5

Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W14-9	08/13/1998	B0PDD4	N	48			93			1	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	10/21/1998	B0R3B4	N	69			110			1	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	01/19/1999	B0TJP3	N	43			140			0	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	04/22/1999	B0V2D1	N	36			138			0	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-9	07/08/1999	B0VPL0	N	22			120			0	56.0	92.0		Submers	HEIS, BHI-01126	
299-W14-14	10/24/1998	B0R4X7	N	180	D		4	J		45			14.5		PNNL-12086	
299-W14-14	10/26/1998	B0R4X9	N	380	DQ		4	J		95			30.1		PNNL-12086	
299-W14-14	10/27/1998	B0R4Y1	N	920	DQ		9			102			39.8		PNNL-12086	
299-W14-14	10/27/1998	B0R509	N	920	DQ		9			102			39.8		PNNL-12086	
299-W14-14	11/03/1998	B0R4Y5	N	380	D		13	Q		29			56.9		PNNL-12086, HEIS	
299-W14-14	11/09/1998	B0R4Y7	N	590	D		25			24			68.5		PNNL-12086	
299-W14-14	12/10/1998	B0T3L4	N	140	D		14			10					HEIS	
299-W15-5	7/18/1996			5800			560			10			1.5		BHI-01121	
299-W15-5	5/16/1996			6000			300			20			4.6		BHI-01121	
299-W15-5	6/25/1997			2600			46			57			33.5		BHI-01121	
299-W15-5	7/16/1997			850			37			23			65.8		BHI-01121	
299-W15-5	7/24/1997			120			18			7			86.0		BHI-01121	
299-W15-5	8/6/1997			1	J		1	J		1			102.7		BHI-01121	
299-W15-5	8/12/1997			0	U		0	U					112.2		BHI-01121	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W15-6	02/06/1991			4851			23			211			2.4	Submers	DOE/RL-91-32	
299-W15-6	02/06/1991			4638			23			202			2.4	Submers	DOE/RL-91-32	Duplicate
299-W15-6	04/09/1991	B00JD0	N	5770			43			134			0.0	Bailer	DOE/RL-91-32	
299-W15-6	04/09/1991	B00JD1	N	3784			22			172			52.0	Bailer	DOE/RL-91-32	
299-W15-6	05/08/1991	B00JF5	N	2651			64			41	49.0	52.0	50.5	Pos Disp	DOE/RL-91-32	
299-W15-6	12/14/1990	H00070J5	N	2483			21			118	0.0	52.0			HEIS	
299-W15-6	03/11/1992	B063V4	N	2134			214			10	0.0	52.0			HEIS	
299-W15-6	07/19/1993	B08CZ4	N	2240			13			172	0.0	52.0			HEIS	
299-W15-6	10/03/1994	B0CXV4	N	590	D		25	U		24	0.0	52.0			HEIS	
299-W15-6	10/03/1994	B0CXW9	N	97			5	U		19	0.0	52.0			HEIS	
299-W15-6	10/24/1994	B0D4S7	N	794	D		4.5			176	0.0	52.0			HEIS	
299-W15-7	03/04/1988	H0009VD3	N	2310			19			122	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	11/29/1988	H0009VD6	N	2390			24			100	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	01/10/1992	B00NQ2	N	1700	P		5	UP		340	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	07/14/1992	B06Q71	N	2400	E		15			160	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	04/12/1993	B08CY9	N	2345			24			98	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	11/18/1993	B09D06	N	2200	D		17			129	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	04/07/1994	B0BQM1	N	1952			21			93	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	04/07/1994	B0BQM2	N	2686			25			107	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	09/15/1994	B0CXX1	N	1900			27	J		70	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	09/15/1994	B0CXX2	N	3	J		5	U		1	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	02/23/1995	B0DQ44	N	1300	D		15			87	0.0	40.6	5.2	Submers	HEIS	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W15-7	03/19/1996	B0H7Z3	N	1240			27			46	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	12/10/1996	B0JG4	N	2200			75			29	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	01/28/1997	B0JRC5	N	3200			47			68	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	01/28/1997	B0JRD0	N	3200			46			70	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	02/20/1997	B0JRD4	N	2300			39			59	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	03/19/1997	B0JRN9	N	2600			40			65	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	04/21/1997	B0K0V4	N	2000			32			63	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	06/23/1997	B0L925	N	2400			72			33	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	08/22/1997	B0LLL5	N	2400			50			48	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	10/20/1997	B0M635	N	3521			37			95	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	12/12/1997	B0MK41	N	2200			30			73	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	02/18/1998	B0N1T6	N	2700			29			93	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	04/20/1998	B0NDT1	N	2700			30			90	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	06/15/1998	B0NVH3	N	3300			29			114	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	08/14/1998	B0PDD2	N	2801			30			93	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	08/14/1998	B0PDD3	N	2400	D		24			100	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	10/15/1998	B0R392	N	4000			30			133	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	01/19/1999	B0TJN5	N	4100			37			111	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	04/14/1999	B0V2C2	N	3600			33			109	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	07/08/1999	B0VPL7	N	3900			27			144	0.0	40.6	5.2	Submers	HEIS	
299-W15-7	08/14/1996	B0HZ47		713			28.9			25			0.3	KABIS	BHI-01126, Darrach (1996)	
299-W15-7	08/14/1996	B0HZ49		745			52.6			14			6.5	KABIS	BHI-01126, Darrach (1996)	
299-W15-7	08/14/1996	B0HZ50		717			80			9			12.6	KABIS	BHI-01126, Darrach (1996)	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W15-7	08/14/1996	B0HZ51		738			93			8			19.4	KABIS	BHI-01126, Darrach (1996)	
299-W15-7	08/14/1996	B0HZ54		707			100			7			25.1	KABIS	BHI-01126, Darrach (1996)	
299-W15-7	08/14/1996	B0HZ55		703			113			6			30.5	KABIS	BHI-01126, Darrach (1996)	
299-W15-10	05/28/1987	H0009R34	N	2740			24			114	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	08/14/1987	H0009R37	N	2220			38			58	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	12/09/1987	H0009R39	N	3410			23			148	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	03/02/1988	H0009R43	N	3730			26			143	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	08/16/1988	H0009R45	N	4200			17			247	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	11/29/1988	H0009R47	N	3750			27			139	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	05/23/1990	H0009R48	N	2800		440	13		3	215	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	01/02/1991	H00070J6	N	1003			13			77	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	04/06/1993	B08D10	N	2327			10			233	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	04/07/1994	B0BQL5	N	2188			12			182	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	09/22/1994	B0CXX3	N	1900			100	U		19	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	03/23/1995	B0F6T0	N	770	E		15			51	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	03/23/1995	B0F6T1	N	18			5	U		4	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	09/12/1995	B0GKC8	N	1500	E		14			107	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	03/11/1996	B0H7Z7	N	1900			25			76	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	07/03/1996	B0HXH3	N	2286			22			104	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	11/12/1996	B0J2F5	N	2500			28			89	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	12/11/1996	B0JKG5	N	3100			42			74	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	01/27/1997	B0JRC6	N	4100			34			121	0.0	22.3	6.0	Submers	HEIS	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

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Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W15-10	02/26/1997	B0JRD5	N	3200			30			107	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	03/19/1997	B0JRP0	N	3200			33			97	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	04/21/1997	B0K0V7	N	2700			28			96	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	06/23/1997	B0L921	N	2300			45			51	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	06/23/1997	B0L926	N	3100	D		42			74	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	08/21/1997	B0LLL1	N	2700			33			82	0.0	22.3	6.0	Submers	HEIS	
299-W15-10	09/09/1996	B0HZ61		1587			68			23			3.5	KABIS	BHI-01126, Darrach (1996)	
299-W15-10	09/09/1996	B0HZ63		1847			59			31			9.5	KABIS	BHI-01126, Darrach (1996)	
299-W15-10	09/09/1996	B0HZ65		1973			54			37			15.3	KABIS	BHI-01126, Darrach (1996)	
299-W15-16	08/05/1995			3700			23			161			0.0	KABIS	PNNL-11470	
299-W15-16	08/05/1995			4200			29			145			1.5	KABIS	PNNL-11470	
299-W15-16	08/05/1995			4200			24			175			3.0	KABIS	PNNL-11470	
299-W15-16	08/05/1995			4200			29			145			4.6	KABIS	PNNL-11470	
299-W15-16	08/05/1995			3500			20			175			0.0	KABIS	PNNL-11470	Duplicate
299-W15-16	08/05/1995			4000			20			200			3.0	KABIS	PNNL-11470	Duplicate
299-W15-16	08/05/1995			4300			30			143			4.6	KABIS	PNNL-11470	Duplicate
299-W15-17	10/05/1988	H0009RS8	N	5	U		5	U		1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	12/30/1988	H0009RT2	N	5	U		5	U		1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	05/31/1989	H0009RT6	N	5	U	1.8	5	U	1.8	1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	09/27/1989	H0009RV0	N	5	U	1.8	3	U	1.8	2	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	03/12/1990	H0009RV4	N	5	U	1.8	5	U	1.8	1	58.5	61.6	59.8	Pos Disp	HEIS	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

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Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W15-17	08/06/1991	B00JW4	N	5	U		5	U		1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	08/06/1991	B00JW5	N	5	U		5	U		1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	08/06/1991	B00K29	N	1.2	J		0.8	J		2	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	03/17/1992	B06496	N	2.4			1.8			1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	09/01/1992	B07466	N	1.1	JG		5	UG		0	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	02/10/1993	B084F2	N	1.5	J		1.7	J		1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	09/08/1993	B09140	N	1.8	L		0.4	U		5	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	11/18/1993	B09K64	N	4			1.6			3	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	05/27/1994	B0BYN9	N	0.4	L		0.21	L		2	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	09/23/1994	B0CXY3	N	1	J		1	J		1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	11/09/1994	B0D7H0	N	0.79	L		0.91			1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	05/09/1995	B0FCM3	N	1.3			0.81			2	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	11/08/1995	B0GV85	N	1.8	B		1			2	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	05/07/1996	B0HRK9	N	0.7	X		0.88			1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	01/02/1997	B0JT88	N	2.4			1.8			1	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	07/08/1997	B0LH08	N	4	J		2	J		2	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	01/05/1998	B0MNN8	N	12			1	JQ		12	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	07/14/1998	B0P7R2	N	9			2	JQ		5	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-17	01/18/1999	B0TFH4	N	7			2	J		4	58.5	61.6	59.8	Pos Disp	HEIS	
299-W15-25	12/15/1994			964	D		297	D		3	1.8	2.4	2.1		BHI-00399	
299-W15-25	12/17/1994			75	D		450	D		0	3.9	5.7	4.8		BHI-00399	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W15-25	12/19/1994			1.6			480	D		0	8.8	8.8	8.8		BHI-00399	
299-W15-25	01/05/1995			3.4			504	D		0	17.3	17.9	17.6		BHI-00399	
299-W15-30	08/05/1995			2800			900			3			0.0		PNNL-11470	
299-W15-30	08/05/1995			2900			910			3			1.5		PNNL-11470	
299-W15-30	08/05/1995			3000			940			3			3.0		PNNL-11470	
299-W15-30	08/05/1995			2700			860			3			4.6		PNNL-11470	
299-W15-30	08/05/1995			3000			930			3			7.6		PNNL-11470	
299-W15-30	08/05/1995			3000			940			3			10.7		PNNL-11470	
299-W15-30	08/05/1995			2700			900			3			7.6		PNNL-11470	Duplicate
299-W15-30	08/05/1995			2700			1000			3			10.7		PNNL-11470	Duplicate
299-W15-30	6/23/1995	B0G021	N	3400	D		1100	D		3	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	7/2/1996	B0HXH8	N	4640			180			26	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	9/13/1996	B0HZ24	N	3900			110			35	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	10/10/1996	B0J2C7	N	5300			91			58	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	11/13/1996	B0JJV8	N	5000			72			69	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	12/9/1996	B0JKH0	N	5700			72			79	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	1/29/1997	B0JRD6	N	5900			74			80	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	1/29/1997	B0JRD7	N	6500			79			82	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	2/24/1997	B0JYW5	N	6500			49			133	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	3/20/1997	B0JRP7	N	6000			61			98	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	5/21/1997	B0K5C3	N	4000			50			80	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	7/17/1997	B0LB98	N	5700			57			100	0.0	8.2	0.3	Pos Disp	HEIS	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W15-30	7/17/1997	B0LB99	N	5900	D		37			159	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	9/23/1997	B0LX81	N	7100			56			127	0.0	8.2	0.3	Pos Disp	HEIS	
299-W15-30	9/23/1997	B0LX82	N	6700			52			129	0.0	8.2	0.3	Pos Disp	HEIS	
299-W18-1	4/26/1993	B08C61	N	3478			31			112	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	3/25/1994	B0BL03	N	2242			25			90	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	8/9/1994	B0CJ54	N	1800			35	J		51	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	8/9/1994	B0CJ55	Y	5	U		5	U		1	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	9/6/1994	B0CX59	N	2500			34	J		74	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	9/6/1994	B0CXT5	N	1700			29	J		59	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	9/6/1994	B0CXT6	N	5	U		5	U		1	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	2/24/1995	B0DGK3	N	2693	D		25			108	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	11/27/1995	B0GGB2	N	4100	D		43			95	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	7/16/1996	B0J3X7	N	2400	D		34			71	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	2/26/1997	B0JY24	N	1500			16			94	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	5/22/1997	B0K5D6	N	1100			13			85	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	8/21/1997	B0LLM3	N	1400			15			93	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	11/14/1997	B0MD71	N	1730			16			108	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	2/19/1998	B0N1V0	N	1400			12			117	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	5/19/1998	B0NMR0	N	770	D		14			55	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	5/19/1998	B0NMT9	N	2200			17			129	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	8/17/1998	B0PDC8	N	1100			11			100	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	10/15/1998	B0R393	N	1900			11			173	0.0	60.0	6.3	Submers	HEIS	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

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Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W18-1	1/19/1999	B0TJN7	N	1100			10			110	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	4/15/1999	B0V2C3	N	1400			10			140	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	4/15/1999	B0V2C4	N	1200			18	J		67	0.0	60.0	6.3	Submers	HEIS	
299-W18-1	7/8/1999	B0VPL8	N	1200			7			171	0.0	60.0	6.3	Submers	HEIS	
299-W18-2	3/20/1991	H0007302	N	929			654			1	0.0	17.8	2.3	Pos Disp	HEIS	
299-W18-2	1/12/1993	B07PT1	N	3200	E		300	E		11	0.0	17.8	2.3	Pos Disp	HEIS	
299-W18-2	8/11/1994	B0CJ56	N	3700			250	U		15	0.0	17.8	2.3	Pos Disp	HEIS	
299-W18-2	8/11/1994	B0CJ57	Y	5	U		5	U		1	0.0	17.8	2.3	Pos Disp	HEIS	
299-W18-2	10/11/1994	B0D4X8	N	4300			120	J		36	0.0	17.8	2.3	Pos Disp	HEIS	
299-W18-2	2/22/1995	B0DRQ7	N	2100			72	J		29	0.0	17.8	2.3	Pos Disp	HEIS	
299-W18-20	02/06/1991	H0007167	N	193			14			14			6.0		DOE/RL-91-32, WHC-EP-0674	
299-W18-20	03/20/1991	H0007305	N	173			15			12			6.0		DOE/RL-91-32, WHC-EP-0674	
299-W18-20	06/10/1992	B06TN2	N	170			20			9	0.0	3.0	1.5		WHC-EP-0674	
299-W18-20	03/01/1993	B08762	N	100			13			8			12.0		WHC-EP-0674	
299-W18-20	04/12/1993	B08DM4	N	35			5.4			6	0.0	3.0	1.5		WHC-EP-0674	
299-W18-22	10/05/1988	H0009XX2	N	5	U		5	U		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	12/30/1988	H0009XX6	N	5	U		5	U		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	06/15/1989	H0009XY0	N	5	U	1.8	5	U	1.8	1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	07/31/1989	H0009XY4	N	5	U	1.8	5	U	1.8	1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	09/22/1989	H0009XY8	N	5	U	1.8	5	U	1.8	1	62.0	71.4	70.7	Pos Disp	HEIS	

Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

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Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W18-22	03/09/1990	H0009XZ2	N	5	U	1.8	5	U	1.8	1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	08/06/1991	B00JZ2	N	5	U		5	U		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	03/16/1992	B064C6	N	5	U		5	U		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	08/21/1992	B074D3	N	5	U		5	U		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	02/17/1993	B084J7	N	5	U		5	U		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	09/01/1993	B09180	N	0.87	U		0.4	U		2	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	11/30/1993	B09K99	N	0.12	U		0.04	U		3	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	06/07/1994	B0BYP7	N	0.32	U		0.05	U		6	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	11/29/1994	B0D7L5	N	0.08	U		0.04	U		2	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	05/11/1995	B0FCQ8	N	0.34	L		0.04	U		9	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	11/10/1995	B0GVJ3	N	0.04	U		0.03	U		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	05/08/1996	B0HRL6	N	0.05	UX		0.07	U		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	01/02/1997	B0JTD8	N	0.5	U		0.3			2	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	07/09/1997	B0LH42	N	0.14	U		0.4	J		0	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	01/06/1998	B0MNM0	N	0.14	U		0.17	U		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	07/14/1998	B0P7V0	N	0.4	J		0.3	JQ		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	01/20/1999	B0TFL2	N	0.16	U		0.3	J		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W18-22	07/12/1999	B0VP23	N	0.15	U		0.3	J		1	62.0	71.4	70.7	Pos Disp	HEIS	
299-W19-4	12/09/1993	B09D09	N	230	DQ		3.1			74	0.0	78.8	3.2	Submers	HEIS	
299-W19-4	06/29/1994	B0C1M2	N	240			4	J		60	0.0	78.8	3.2	Submers	HEIS	
299-W19-4	06/29/1994	B0C1M4	N	280	E		3	J		93	0.0	78.8	3.2	Submers	HEIS	
299-W19-4	06/29/1994	B0C1M4DL	N	270	D		3	DJ		90	0.0	78.8	3.2	Submers	HEIS	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

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Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W19-4	06/29/1994	B0C1M6	N	230	J		3	J		77	0.0	78.8	3.2	Submers	HEIS	
299-W19-4	09/21/1994	B0CXR5	N	190			3	J		63	0.0	78.8	3.2	Submers	HEIS	
299-W19-4	09/29/1994	B0CXX7	N	230			3	J		77	0.0	78.8	3.2	Submers	HEIS	
299-W19-4	11/20/1995	B0GY17	N	260	D		3			87	0.0	78.8	3.2	Submers	HEIS	
299-W19-4	06/24/1996	B0HTK4	N	210	D		2			105	0.0	78.8	3.2	Submers	HEIS	
299-W19-4	06/18/1997	B0L2L3	N	25	Y		0.17	U		147	0.0	78.8	3.2	Submers	HEIS	
299-W19-4	06/11/1998	B0NTF9	N	110	D		4	J		28	0.0	78.8	3.2	Submers	HEIS	
299-W19-4	09/02/1993			180							3.1	4.6	3.9	Pos Disp	BHI-00149	
299-W19-4	09/02/1993			190							9.1	10.7	9.9	Pos Disp	BHI-00149	
299-W19-4	09/02/1993			200							21.3	22.9	22.1	Pos Disp	BHI-00149	>200 ug/L
299-W19-18	01/14/1988	H000B0Q0	N	23			5	U		5	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	07/22/1988	H000B0Q7	N	57			3	U		19	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	12/02/1988	H000B0R3	N	9			5	U		2	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	03/28/1990	H000B0R9	N	89		14	3	U	1.8	30	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	01/02/1991	H0007088	N	91			2.4			38	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	01/13/1992	B00NN1	N	122			3.5			35	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	10/27/1992	B07J62	N	143			2.7			53	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	04/08/1994	B0BKJ3	N	130			3	J		43	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	04/08/1994	B0BKJ5	N	140			3	J		47	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	04/08/1994	B0BKJ7	N	170			3	J		57	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	04/18/1994	B09D44	N	180	D		1.9	B		95	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	06/23/1994	B0C1M8	N	170			29			6	0.0	32.0	1.9	Submers	HEIS	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W19-18	10/27/1994	B0D584	N	260	D		2.9			90	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	04/06/1995	B0F868	N	282	D		6.8			41	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	05/13/1996	B0HDQ8	N	300			4	U		75	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	05/13/1996	B0HDQ9	N	370	E		4	J		93	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	05/15/1996	B0HSK1	N	260	D		2			130	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	06/26/1996	B0HGF0	N	330			4	U		83	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	07/29/1996	B0HYN1	N	300			2	U		150	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	08/29/1996	B0J092	N	270			4.6			59	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	08/29/1996	B0J093	N	270	D		25	U		11	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	09/17/1996	B0J0G0	N	290			3.3			88	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	06/17/1997	B0L3F8	N	24	Y		0.17	U		141	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	12/23/1997	B0MHX8	N	100	D		2	J		50	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	12/28/1998	B0T845	N	27			0.1	UQ		270	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	12/28/1998	B0T846	N	24			2	JQ		12	0.0	32.0	1.9	Submers	HEIS	
299-W19-18	12/30/1993			97.0							8.2	9.8	9.0	Pos Disp	BHI-00149	
299-W19-18	12/30/1993			180							23.2	24.7	24.0	Pos Disp	BHI-00149	
299-W19-34A	06/17/1994			32.0							24.7	29.6	27.2	Pos Disp	BHI-00149	
299-W19-34B	01/31/1995	B0DPR0	N	60			8			8			47.7	Submers	HEIS	
299-W19-34B	01/31/1995	B0DPR1	N	5	U		5	U		1			47.7	Submers	HEIS	
299-W19-34B	05/17/1995	B0FKG7	N	52			10			5			47.7	Submers	HEIS	
299-W19-34B	08/17/1995	B0GFG4	N	77			9			9			47.7	Submers	HEIS	
299-W19-34B	06/17/1994			0							37.5	39.0	38.3	Bladder	BHI-00149	<2 ug/L

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
299-W19-34B	06/27/1994			0							44.2	45.1	44.7	Bladder	BHI-00149	<2 ug/L
299-W19-34B	07/13/1994			2.8							51.2	52.7	52.0	Bladder	BHI-00149	
299-W19-34B	08/05/1994			15.4							62.8	64.0	63.4	Submers	BHI-00149	
299-W19-34B	08/22/1994			0							77.4	80.5	79.0	Submers	BHI-00149	<2 ug/L
299-W19-34B	09/12/1994			0							89.3	91.1	90.2	Submers	BHI-00149	<2 ug/L
299-W27-2	12/22/1992	B07T64	N	3.2			5	U		1	54.5	57.7	57.7	Pos Disp	HEIS	
299-W27-2	03/18/1993	B089B7	N	3.4	Q		5	U		1	54.5	57.7	57.7	Pos Disp	HEIS	
299-W27-2	07/08/1993	B08P40	N	4.3	L		0.56	L		8	54.5	57.7	57.7	Pos Disp	HEIS	
299-W27-2	09/27/1993	B096Y0	N	4.9	L		0.68	L		7	54.5	57.7	57.7	Pos Disp	HEIS	
299-W27-2	12/16/1993	B09P20	N	3.7	Q		0.3	L		12	54.5	57.7	57.7	Pos Disp	HEIS	
299-W27-2	01/20/1995	B0DFM4	N	5.3			0.35	L		15	54.5	57.7	57.7	Pos Disp	HEIS	
299-W27-2	06/19/1996	B0HTP7	N	3.1			0.07	U		44	54.5	57.7	57.7	Pos Disp	HEIS	
299-W27-2	06/03/1997	B0L381	N	4	J		0.17	U		24	54.5	57.7	57.7	Pos Disp	HEIS	
299-W27-2	06/09/1998	B0NTH9	N	5	J		0.6	J		8	54.5	57.7	57.7	Pos Disp	HEIS	
299-W27-2	06/08/1999	B0VKF6	N	5	J		0.5	J		10	54.5	57.7	57.7	Pos Disp	HEIS	
699-48-77C	05/23/1994	B0BTY4	N	4.2	L		0.81	L		5	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	08/10/1994	B0C7N8	N	4.4	L		0.76	L		6	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	10/31/1994	B0D5N8	Y	5			5	U		1	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	04/17/1995	B0FB20	N	3	J		5	U		1	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	04/17/1995	B0FB21	N	3	J		5	U		1	20.0	26.1	24.2	Pos Disp	HEIS	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
699-48-77C	07/12/1995	B0G4W6	N	5			5	U		1	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	10/24/1995	B0GTT3	N	4	JD		5	UD		1	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	01/15/1996	B0H2W6	N				0.6	J			20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	01/15/1996	B0H2Y6	N				0.7	J			20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	04/03/1996	B0HKW8	N				0.7	J			20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	07/15/1996	B0HLY0	N	6			0.7	J		9	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	10/23/1996	B0JGT6	N	5			0.9	J		6	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	01/23/1997	B0JH34	N	6			0.9	U		7	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	04/02/1997	B0JJB3	N	6			0.9	U		7	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	04/02/1997	B0JJB4	N	6			0.9	U		7	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	09/04/1997	B0LW94	N	6			0.9	U		7	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	12/17/1997	B0MM74	N	7			0.9	U		8	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	02/06/1998	B0N1Y6	N	8			0.9	U		9	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	02/06/1998	B0N1Y8	N	6			0.9	U		7	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	04/15/1998	K0N301	N	8			0.8	J		10	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	07/09/1998	K0N370	N	7			0.9	J		8	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	10/20/1998	K0N3H9	N	7			0.7	J		10	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	01/13/1999	K0N3N2	N	6			0.8	J		8	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	04/20/1999	K0N3W4	N	4	J		0.4	U		10	20.0	26.1	24.2	Pos Disp	HEIS	

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Table A-1. Carbon Tetrachloride Concentrations in Samples Collected at Depths >10 m Below the Water Table. (20 pages)

Well	Collect Date	Sample Number	Filtered?	Carbon Tetrachloride (CCl ₄)			Chloroform (CHCl ₃)			Ratio CCl ₄ /CHCl ₃	Screen/Sample Depth		Pump/Sample		Data Source	Comment
				ug/L	*	Error	ug/L	*	Error		Top (m bwt)	Bottom (m bwt)	Intake Depth (m bwt)	Sampling Method		
699-48-77C	07/13/1999	K0N3Y0	N	2	J		0.4	U		5	20.0	26.1	24.2	Pos Disp	HEIS	
699-48-77C	07/13/1999	K0N3Y6	N	2	J		0.4	U		5	20.0	26.1	24.2	Pos Disp	HEIS	

* Laboratory, Validation, and/or Review Qualifiers:

- B = Also detected in laboratory blank.
 - D = Sample was diluted prior to analysis.
 - E = Concentration exceeded instrument calibration range.
 - G = Record has been reviewed and determined to be correct, or the record has been modified to make it correct.
 - H = Laboratory holding time exceeded.
 - J = Concentration is estimated.
 - L = Method detection limit <= value < contract-required quantitation limit.
 - P = Potential problem. Collection/analysis circumstances makes value questionable.
 - Q = Result associated with suspect quality control data.
 - U = Analyzed for but not detected. Value reported is the quantitation limit.
 - X = Result manually entered or modified. Other specific flags and notes are described in hardcopy Sample Data Summary Package and/or Case Narrative.
 - Y = Same as X if more than one flag required; or, result suspect.
- m bwt = meters below water table
 HEIS = Hanford Environmental Information System
 Pos Disp = Positive Displacement Pump
 Submers = Submersible Pump
 KABIS = discrete depth groundwater sampling device, registered trademark of SIBAK Industries Limited Inc., Solana Beach, California.

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