START

0027201

PNL-8597
UC-630

REFINED CONCEPTUAL MODEL FOR THE VOLATILE ORGANIC COMPOUNDS-ARID INTEGRATED DEMONSTRATION AND 200 WEST AREA CARBON TETRACHLORIDE EXPEDITED RESPONSE ACTION

THIS PAGE INTENTIONALLY LEFT BLANK

G. V. Last
V. J. Rohay[a]

March 1993

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

(a) Westinghouse Hanford Company, Richland, Washington

9 3 1 2 9 0 1 1 3 3

APR 1993
RECEIVED
EDMC

THIS PAGE INTENTIONALLY
LEFT BLANK

Summary

This report presents a refined geohydrologic and geochemical conceptual model of the host site for the Volatile Organic Compounds-Arid Integrated Demonstration (VOC-Arid ID) and 200 West Area Carbon Tetrachloride (CCl_4) Expedited Response Action (ERA), based on the results from fiscal year 1992 site characterization activities.

The ERA was initiated in December 1990 to minimize or stabilize CCl_4 migration within the unsaturated (vadose) zone in the vicinity of three CCl_4 disposal sites in the 200 West Area (216-Z-1A tile field, 216-Z-9 trench, and 216-Z-18 crib). Implementation of this ERA was based on concerns that CCl_4 residing in the soils was continuing to spread to the groundwater and, if left unchecked, would significantly increase the area of groundwater contamination. A soil-vapor-extraction system began operating at the site in February 1992.

The VOC-Arid ID was initiated in March 1991 to acquire, develop, demonstrate, and deploy technologies for evaluation and cleanup of VOCs and associated contaminants in soils and groundwaters of arid U.S. Department of Energy sites. The area of CCl_4 contamination coincident with the ERA was selected as the initial demonstration site.

Site characterization activities in support of the two programs have been fully integrated into a single characterization program because of their similar objectives and scope. The objectives of this combined characterization program are to further refine the conceptual model of the site, to collect data in support of optimizing the effectiveness of the soil-vapor-extraction system for the ERA, and to collect baseline data in support of the demonstration of individual technologies for the VOC-Arid ID.

Results from fiscal year 1992 characterization activities suggest that the highest concentration of CCl_4 is located in the vicinity of the 216-Z-9 trench. This is supported by the higher surface soil-gas concentrations just north of the trench, the high CCl_4 subsurface soil-gas concentrations (over 10,000 ppm) observed in nearby wells and a 20-m-deep soil-gas port, the high CCl_4 concentrations observed in sediment samples from a nearby well drilled in 1992, and the observed concentrations of dissolved CCl_4 in groundwater samples from various depths near the 216-Z-9 trench. The highest concentrations of CCl_4 in the vadose zone appear to be associated with the early Palouse soil (informal name), which is a fine-grained loess deposit located at a depth of approximately 35 m, just above the Plio-Pleistocene unit (caliche).

9 3 1 2 9 0 1 1 3 4

Total VOC vapor concentrations (found to consist predominantly of CCl_4) measured in existing boreholes suggest a correlation with the rate of barometric pressure change. Additional airflow measurements in the boreholes indicate that barometric pressure change may constitute a significant release mechanism for VOCs out of the vadose zone through the boreholes and into the atmosphere.

Well-construction and waste-water-disposal histories suggest that some of the older existing wells, including deep groundwater wells, had the potential to provide a vertical conduit for the downward migration of CCl_4 and other contaminants directly to the aquifer. This is of particular concern near the 216-Z-9 trench, where perched water has been encountered.

Numerical flow simulations suggest that CCl_4 may have reached the groundwater beneath the 216-Z-9 trench irrespective of whether an unsealed borehole provided a direct pathway. These simulations also suggest that most of the free liquid CCl_4 that has not volatilized should now be located in the early Palouse soil and Plio-Pleistocene unit or the groundwater. These simulations are tenuous, in that there were no data available on dense nonaqueous-phase liquid residual saturation, many simplifying assumptions were made, and the effects of co-contaminants (e.g., tributyl phosphate, dibutyl butyl phosphonate, lard oil) were not addressed.

Rough order-of-magnitude estimates of the current CCl_4 inventory distribution suggest that 21% of the discharge inventory may have been lost to the atmosphere by natural flux through the soil and existing boreholes, that 12% is retained in the vadose zone (either in the air, soil moisture, or sorbed onto the soil), and that 2% may be dissolved in the aquifer. The remaining 65% has not been accounted for; perhaps CCl_4 is held in residual saturation and/or is biodegraded. Additional data concerning the CCl_4 distribution, residual saturation, sorption, and biodegradation are needed to reduce the large uncertainties in the rough estimates and the current conceptual model.

9 3 1 2 9 7 0 1 1 3 5

Acknowledgments

This work was supported by the Volatile Organic Compounds-Arid Integrated Demonstration Program, Office of Technology Development, and the 200 West Area Carbon Tetrachloride Expedited Response Action, Office of Waste Management and Environmental Restoration, U. S. Department of Energy.

The authors wish to thank the numerous technical and administrative staff from the Pacific Northwest Laboratory (PNL), Westinghouse Hanford Company (Westinghouse Hanford), and Kaiser Engineers Hanford Company who have contributed to this work. Thanks also go to Quadrel Services, Inc., for demonstration of their EMFLUX® technology.

Special thanks go to David Lanigan, Robert Lenhard, Llyn Doremus, Mickie Chamness, Jim Amonette, and Steve Yabusaki, PNL, and Mel Piepho, Al Law, Mike Connelly, and Kevin Lindsey, Westinghouse Hanford, whose work has been incorporated into this document. Thanks go to Jon Fancher, Westinghouse Hanford, for his contributions concerning the baseline soil-gas measurements. Also, thanks go to Jim Conca, Washington State University, and Judith Wright, PNL, for their contributions to the development of this conceptual model; to Rick Cameron, Ebasco Services, Inc., for his contributions to the borehole flux measurements; and to Brian Peters, Ebasco Services, Inc., for his work in estimating the carbon tetrachloride inventory distribution.

THIS PAGE INTENTIONALLY
LEFT BLANK

Contents

Summary iii

Acknowledgments v

1.0 Introduction 1.1

2.0 Conclusions and Recommendations 2.1

3.0 Background 3.1
- 3.1 Location and Layout 3.1
- 3.2 Plutonium Finishing Plant Operations 3.1
  - 3.2.1 Recuplex Plutonium Scrap Recovery Facility 3.4
  - 3.2.2 Plutonium Reclamation Facility 3.4
- 3.3 Waste Disposal Facilities 3.4

4.0 Environmental Setting 4.1
- 4.1 Meteorology 4.1
- 4.2 Geology 4.1
- 4.3 Hydrogeology 4.4
  - 4.3.1 Local Recharge 4.7
  - 4.3.2 Vadose Zone 4.7
  - 4.3.3 Perched Water 4.10
  - 4.3.4 Unconfined Aquifer 4.11

5.0 Nature and Extent of Contamination 5.1
- 5.1 Atmospheric Losses 5.1
  - 5.1.1 Soil/Air Interface 5.1
  - 5.1.2 Borehole Releases 5.2
- 5.2 Vadose Zone Contamination 5.5
  - 5.2.1 Near-Surface Soil-Gas Surveys 5.5
  - 5.2.2 Subsurface Soil-Gas Measurements 5.12
  - 5.2.3 Borehole Sediment Sampling 5.18
- 5.3 Groundwater Contamination 5.39
  - 5.3.1 Carbon Tetrachloride 5.39
  - 5.3.2 Chloroform 5.42
  - 5.3.3 Plutonium 5.42
  - 5.3.4 Vertical Distribution 5.44

6.0 Conceptual Model 6.1
- 6.1 Disposal Source Term 6.1
- 6.2 Vadose Zone Transport 6.1

9 3 1 2 9 0 1 1 3 7

6.3 Groundwater Contamination 6.8
6.4 Sorption 6.8
6.5 Biodegradation 6.8

7.0 References 7.1

Appendix A - Waste Stream Descriptions, Disposal Facility Descriptions, and Estimated Disposal Inventories at the VOC-Arid ID/ERA Site A.1

Appendix B - Geology of the VOC-Arid ID/ERA Site: An Update B.1

Appendix C - Groundwater Elevations Beneath the VOC-Arid ID/ERA Site C.1

Appendix D - Schematic Well Construction Diagrams and Completion Summary Table D.1

Appendix E - Volatile Organic, Chemical, and Radiological Analyses of Sediment and Groundwater Samples from the FY 1992 Near-Field and Crib Wells E.1

Appendix F - Averaged Carbon Tetrachloride Concentrations in Groundwater Beneath the 200 West Area F.1

9 3 1 2 9 7 0 1 1 3 8

Figures

3.1 Location of the VOC-Arid ID/ERA Site 3.2
3.2 Layout of the VOC-Arid ID/ERA Site 3.3
3.3 Schematic Design of the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-18 Crib 3.5
4.1 Structural Geology of the Hanford Site 4.2
4.2 Topography of the VOC-Arid ID/ERA Site 4.3
4.3 Location of Wells and Generalized Geologic Cross Sections Through the VOC-Arid ID/ERA Site 4.5
4.4 Stratigraphic Nomenclature for Geologic Units Beneath the VOC-Arid ID/ERA Site 4.6
4.5 Hydrogeologic Units of the Vadose Zone Beneath the VOC-Arid/ ID ERA Site 4.8
4.6 Generalized Geologic Cross Section Through the VOC-Arid ID/ERA Site 4.10
4.7 Characteristic Curves for the Hanford Formation Slackwater Deposits 4.12
4.8 Characteristic Curves for the Hanford Gravel Unit A 4.12
4.9 Characteristic Curves for the Early Palouse Soil 4.13
4.10 Characteristic Curves for the Plio-Pleistocene Unit 4.13
4.11 Characteristic Curves for the Upper Ringold Unit 4.14
4.12 Inferred Recharge Distribution Below the VOC-Arid/ID ERA Site 4.15
4.13 Potential Location of Perched Water Near the Three Waste Disposal Facilities of Interest 4.16
4.14 Transmissivity Map of the 200 West Area 4.17
4.15 Hydraulic Conductivity Map of the 200 West Area 4.18
4.16 Regional Potentiometric Map of the Unconfined Aquifer in the Vicinity of the 200 West Area - June 1992 ..... 4.20
4.17 Water-Table Map of the Unconfined Aquifer in the VOC-Arid/ID ERA Site - Spring 1992 ..... 4.21
5.1 Distribution of Maximum Baseline Well Head Measurements 5.4
5.2 Soil-Gas Sampling Network 5.6
5.3 Carbon Tetrachloride Soil-Gas Concentrations - May 1992 ..... 5.8
5.4 Chloroform Soil-Gas Concentrations - May 1992 ..... 5.9
5.5 Carbon Dioxide Soil Gas Concentrations - August 1992 ..... 5.10
5.6 Oxygen Soil-Gas Concentrations - August 1992 ..... 5.11
5.7 EMFLUX® Soil-Gas Collector Locations 5.13
5.8 Maximum Carbon Tetrachloride Concentrations Measured in Baseline Monitoring Well and Deep Soil-Gas Probe Network - December 1991-September 1992 ..... 5.15

9 3 1 2 9 0 1 1 3 9

5.9 Location of Volatile Organic Compounds Detected Above and Below the Caliche Layer During Well Drilling from January 1987 to September 1992 ..... 5.17
5.10 Location Map of Crib and Near-Field-Monitoring Wells 5.19
5.11 Analytical Results for Well 299-W15-216 ..... 5.25
5.12 Analytical Results for Well 299-W15-217 ..... 5.25
5.13 Analytical Results for Well 299-W18-246 ..... 5.31
5.14 Analytical Results for Well 299-W18-248 ..... 5.31
5.15 Analytical Results for Well 299-W18-247 ..... 5.37
5.16 Analytical Results for Well 299-W18-249 ..... 5.37
5.17 Carbon Tetrachloride Concentration Contours in the 200 West Area Groundwater - 1988 to 1992 ..... 5.40
5.18 Trend Plot of Carbon Tetrachloride Concentrations near the 200 West Area 5.41
5.19 Chloroform Concentration Contours in the 200 West Area Groundwater - 1988-1992 ..... 5.43
6.1 Schematic Illustration of the Conceptual Model for Carbon Tetrachloride Disposal and Migration Beneath the 216-Z-9 Trench 6.2
6.2 Three-Dimensional View of Numerically Simulated Water Flow Beneath the 216-Z-9 Trench 6.5

Tables

3.1 Waste Constituent Inventory Summary for the Three Carbon Tetrachloride Disposal Facilities 3.6
4.1 Physical Properties of Vadose Zone Sediments 4.11
4.2 Hydrologic Properties of the Unconfined Aquifer 4.20
5.1 Maximum Concentrations of Volatile Organic Compounds Detected in Samples from FY 1992 Soil-Gas Probes 5.7
5.2 EMFLUX® Emission Flux Rates 5.12
5.3 Chemical and Radiological Analytes Determined in Sediment and Groundwater Samples 5.21
5.4 Maximum Concentration of Target Constituents from Wells Near the 216-Z-9 Trench 5.22
5.5 Maximum Concentration of Target Constituents from Wells Near the 216-Z-1A Tile Field 5.28
5.6 Maximum Concentration of Target Constituents from Wells Near the 216-Z-18 Crib 5.34

9 3 1 2 9 7 0 1 1 4 0

6.1 Pore Column Volume Estimates 6.3
6.2 Estimated Depth of Organic Migration 6.6
6.3 Physical Properties of Carbon Tetrachloride 6.7

9 3 1 2 9 0 1 1 4 1

THIS PAGE INTENTIONALLY
LEFT BLANK

1.0 Introduction

Carbon tetrachloride (CCl_4) was found in the aquifer beneath the 200 West Area when monitoring wells installed in 1987 around the low-level burial grounds were first sampled (Last et al. 1989). In December 1990, the U.S. Environmental Protection Agency and the Washington Department of Ecology requested the U.S. Department of Energy (DOE) to proceed with detailed planning to implement an expedited response action (ERA) to minimize additional CCl_4 contamination of the groundwater. In January 1991, site investigations in support of an ERA for the site were initiated, and in February 1992, a soil-vapor-extraction system began to recover CCl_4 from the vadose zone. This ERA, a provision of the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA), is being implemented based on concerns that the CCl_4 residing in the soils was continuing to spread to the aquifer and, if left unchecked, would significantly increase the area of groundwater contamination. The purpose of this ERA is to minimize or stabilize the CCl_4 migration within the vadose zone beneath and away from the waste disposal facilities in the 200 West Area (DOE 1991).

The Volatile Organic Compounds-Arid Integrated Demonstration (VOC-Arid ID) is a DOE program targeted at the acquisition, development, demonstration, and deployment of technologies for evaluation and cleanup of VOCs and associated contaminants in soils and groundwater at arid DOE sites. Candidate technologies are being demonstrated in the areas of site characterization; performance prediction, monitoring, and evaluation; contaminant extraction and ex situ treatment; in situ remediation; and site closure and monitoring. The initial focus of the VOC-Arid ID is on the CCl_4 that was disposed to the vadose (unsaturated) zone along with other volatile and nonvolatile organic and aqueous wastes and transuranic radionuclides at the Hanford Site's 200 West Area.

Site investigations have been conducted in support of both the VOC-Arid ID and the ERA by the Pacific Northwest Laboratory (PNL)[(a)] and Westinghouse Hanford Company (Westinghouse Hanford). These investigations have been fully integrated to promote the efficient use of time and resources and to ensure that each activity provides the maximum usefulness to both programs.

The purpose of this report is to refine the conceptual model of the VOC-Arid ID/ERA site (DOE 1991; Last and Rohay 1991; Last et al. 1991) in light of recent site investigations

(a) PNL is operated for DOE by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

9 3 1 2 9 0 1 4 2

(Rohay 1991; Rohay et al. 1992a; and WHC 1991). This report presents the conclusions from this study, background information on the source of the CCl_4 contamination, general environmental setting, and previous site investigations. This report then discusses the state of knowledge concerning the nature, distribution, principal transport pathways and rates of contamination; the conceptual model; and the degradation mechanisms.

Also provided in this report is a listing of the cited references and several appendixes of pertinent background data. Appendix A contains information on the various waste streams discharged to the three waste disposal facilities. Appendix B is an update of the geology of the VOC-Arid ID/ERA site. Appendix C contains data on the wells and water-table elevations under the site. Appendix D provides schematic well-construction diagrams and completion summary for the fiscal year (FY) 1992 wells. Appendix E contains a complete listing of the volatile organic, chemical, and radiological analyses of both sediment and groundwater samples from the FY 1992 wells. Appendix F gives the averaged CCl_4 concentrations in 200 West Area groundwater.

9 3 1 2 9 7 0 1 1 4 3

2.0 Conclusions and Recommendations

Results from characterization activities carried out in FY 1992 have been used to refine the VOC-Arid ID and ERA site conceptual models. In this refined conceptual model, the highest concentration of CCl_4 is located in the vicinity of the 216-Z-9 trench. This is supported by the soil-gas survey results that indicate the highest surface soil-gas concentrations of CCl_4 (72 ppm) and chloroform ($CHCl_3$) are located just north of this trench. The highest subsurface CCl_4 concentrations (over 10,000 ppm) were measured at wells and a 20-m-deep gas probe installed just north of the trench. High CCl_4 concentrations (up to 37.8 ppm) were also found in sediment samples from a nearby crib-monitoring well (299-W15-217).

Sediment and subsurface soil-gas samples indicate that the highest concentrations of CCl_4 in the vadose zone are associated with the early Palouse soil (informal name) and the top of the Plio-Pleistocene unit, located at a depth of 35 to 40 m. The early Palouse soil is a fine-grained loess deposit, with high porosity, small pore-size distribution, and relatively low hydraulic conductivity; the Plio-Pleistocene unit is a calcium carbonate ($CaCO_3$) cemented (caliche) horizon with very low hydraulic conductivity. Numerical flow simulations appear to support the contention that the early Palouse soil is the primary repository for CCl_4 and other VOCs.

The total VOC vapor concentrations measured in existing boreholes suggest a correlation with barometric pressure changes. Additional airflow measurements in the boreholes indicate that barometric pressure change may constitute a significant release mechanism for VOCs out of the vadose zone (through boreholes) into the atmosphere and could account for 3% of the CCl_4 inventory estimated to have been discharged to the soil column. Ambient soil-surface flux measurements suggest natural fluxes of CCl_4 from the vadose zone, on the order of 0.25 $g/m^2/yr$, based on a rough estimate that 18% of the estimated discharged inventory may have been released to the atmosphere via natural flux from the soil surface.

Well-construction and waste-water-disposal histories suggest that some of the older existing wells, including deep groundwater wells, had the potential to provide a vertical conduit for the downward migration of CCl_4 and other contaminants directly to the aquifer. This is of particular concern near the 216-Z-9 trench, where perched water has been encountered. However, column pore volume estimates and numerical model simulations suggest that, at the 216-Z-9 trench, the wastes likely reached the water table irrespective of whether poorly sealed wells provided a preferential pathway.

Concentrations of dissolved CCl_4 detected in the groundwater have accounted for approximately 2% of the total CCl_4 inventory. Groundwater samples from one well indicate that there is deeply distributed CCl_4 near the 216-Z-9 trench (up to 5.8 ppm at the top of the aquifer and 3.8 ppm 52 m beneath the water table. However, the well itself may have provided the preferential pathway for the vertically distributed contaminants.

To reduce the uncertainties in the material balance estimates and the current conceptual model, additional data are needed on the CCl_4 distribution, the configuration and hydraulic properties of the subsurface media, the effect of natural barometric pumping, the physical behavior of the CCl_4 and co-contaminant mixtures (e.g., phase partitioning, residual saturation), and the chemical behavior of these contaminants (e.g., sorption, biodegradation). Additional soil-gas, sediment, and groundwater samples are needed to define the three-dimensional extent and concentration of CCl_4 in sufficient detail to permit reasonable calculation of the in situ inventories. Current rough order-of-magnitude estimates account for only 35% of the estimated original discharged inventory, and only 12% was accounted for currently in the vadose zone.

Additional information on the physical properties and configuration of the subsurface media and on the behavior of these contaminants in these media are needed to refine the physical transport parameters. Principal needs include a detailed determination of the major hydrogeologic units, including their unsaturated and saturated hydraulic conductivities relative to the contaminants of concern; the partitioning (soil, air, water, nonaqueous-phase liquid) of these contaminants; and the estimated residual nonaqueous-phase liquid saturations. These parameters are needed to improve numerical simulation of the site, to extrapolate between limited data sets on the distribution of the contaminants, and to refine estimates of the in situ inventories.

Additional information on the behavior of the CCl_4 and co-contaminant mixtures is needed to better describe the fate of the CCl_4 and its co-contaminants. Better estimates are needed concerning sorption, particularly in the vadose zone, diffusion, density-driven vapor flow, and degradation reactions and rates. These will assist refinement of numerical simulations of the site and reduce uncertainties in the inventory estimates.

3.0 Background

The Hanford Site has been a defense materials production complex since 1943. Liquid wastes containing CCl_4, generated during plutonium recovery processes operated at the Plutonium Finishing Plant (PFP), were discharged to nearby subsurface liquid waste disposal facilities from 1955 to 1973. These past discharges have contaminated the underlying soils and groundwater with CCl_4 and other associated hazardous and radioactive wastes. This section of the report describes the location and layout of the VOC-Arid ID/ERA site, the operational history of the PFP, and the waste disposal facilities of interest. Much of this information was taken from the ERA proposal (DOE 1991). Detailed disposal inventories are provided in Appendix A.

3.1 Location and Layout

The Hanford Site is located in south-central Washington state and is portioned into several operational areas (Figure 3.1). The 200 Areas (200 East and 200 West) are located near the center of the Hanford Site. The PFP is located in the west-central portion of the 200 West Area. The CCl_4-bearing liquid wastes from the PFP were discharged to the 216-Z-9 trench, located east of the PFP; to the 216-Z-1A tile field; and to the 216-Z-18 crib, located just south of the PFP (Figure 3.2).

3.2 Plutonium Finishing Plant Operations

The PFP (previously known as Z Plant) began operation in late 1949 to process plutonium nitrate solutions (extracted from irradiated uranium fuel rods) into final product (plutonium metal) forms (DOE 1991). Three process lines were operated in the PFP: the RG-RB line from 1949 to 1953, the A line from 1953 to 1979, and the C line from 1960 to 1973 (DOE 1992). These process lines generated side streams that contained recoverable quantities of plutonium, including scrap from machining of the plutonium metal shapes. Plutonium was recovered from these side streams by the Recuplex Plutonium Scrap Recovery Facility (Recuplex) and the Plutonium Reclamation Facility (PRF).

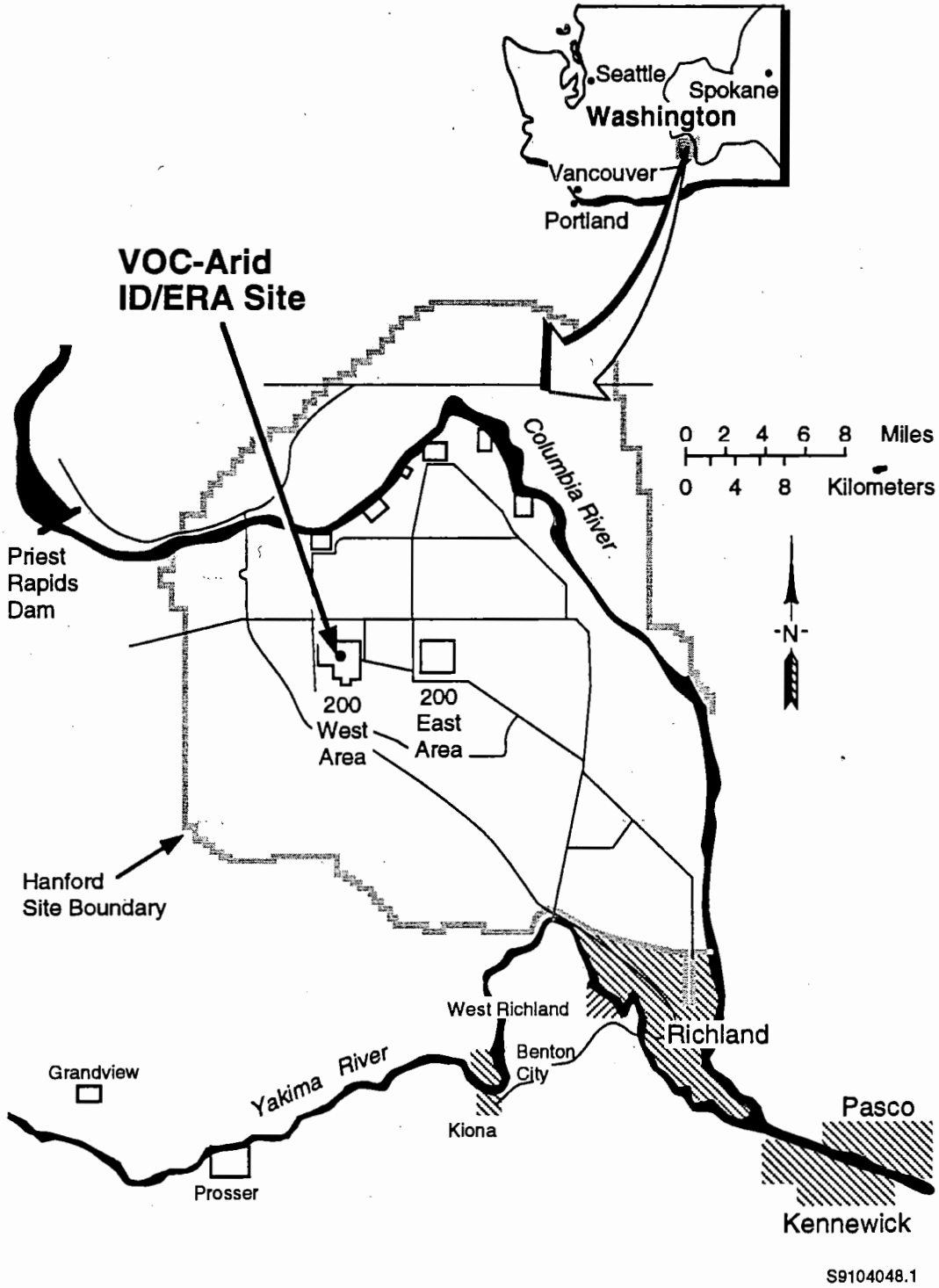


Figure 3.1. Location of the VOC-Arid ID/ERA Site

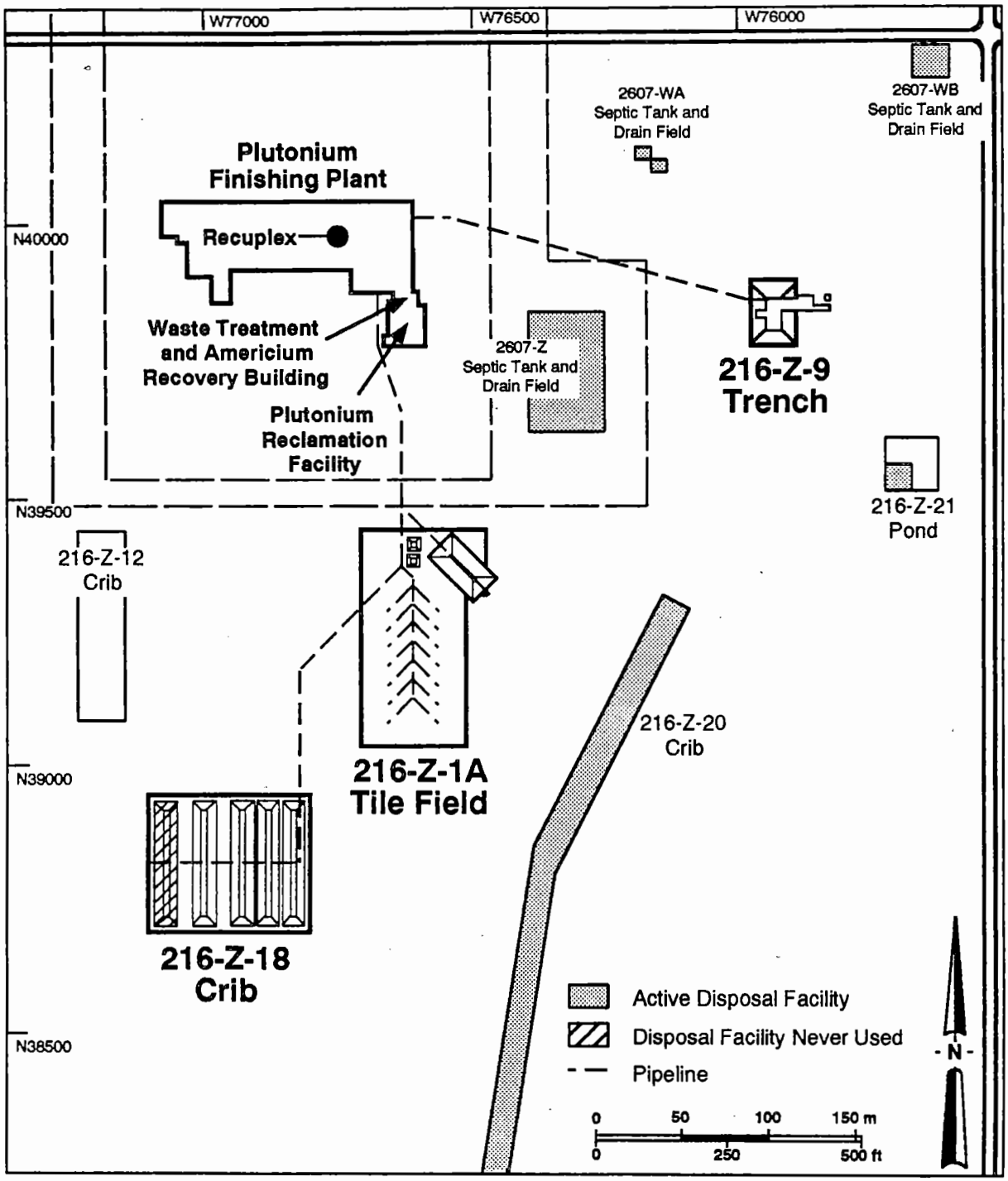


Figure 3.2. Layout of the VOC-Arid ID/ERA Site

3.2.1 Recuplex Plutonium Scrap Recovery Facility

Recuplex used the solvent-column-extraction technology and operated from 1955 through 1962 in the 234-5Z Building (DOE 1991). This process used nitric and hydrofluoric acids to convert plutonium solids (scrap) to plutonium nitrate and a CCl_4-tributyl phosphate (TBP) solvent to recover the plutonium solids from the plutonium nitrate solution (DOE 1992). A CCl_4:TBP ratio of 85:15 by volume was used. A criticality accident forced the closure of Recuplex in April 1962 (DOE 1992).

3.2.2 Plutonium Reclamation Facility

The PRF, housed in the 236-Z Building, replaced Recuplex in 1964 and operated until 1979. The PRF operated again from 1984 to May 1991 and it is planned to restart in the near future (DOE 1992). The PRF was designed to recover plutonium from both aqueous wastes and solid scrap from the PFP by using an improved solvent-column-extraction technology (similar to that used in the Recuplex process) at a CCl_4:TBP ratio of 80:20 (DOE 1992). The PRF also included the Waste Treatment and Americium Recovery Facility, located in the 242-Z Building and operated concurrently with the PRF (DOE 1991).

3.3 Waste Disposal Facilities

Spent aqueous extractant and organic solvents from the Recuplex and PRF processes were disposed to the soil column via subsurface infiltration facilities. Wastes from the Recuplex process were discharged to the 216-Z-9 trench. Wastes from the PRF were discharged from 1964 to 1973 to the 216-Z-1A tile field and the 216-Z-1, -2, and -18 cribs. Fabrication oil, or "lard oil," used in the PFP was also discharged to these waste disposal facilities. The physical design of these liquid waste disposal facilities was described by Last et al. (1991). Schematic drawings of the tile field and cribs are shown in Figure 3.3. A description of each waste stream, each waste disposal facility, and estimated disposal inventory is given in Appendix A. A summary of the estimated waste inventories is given in Table 3.1. A total of 363,000 to 580,000 L (577,000 to 922,000 kg) of CCl_4 is estimated to have been discharged to the soil column between 1955 and 1973 (DOE 1991). Current inventory calculations presented throughout this report used a total estimated discharge quantity of 750,000 L (1,192,000 kg).

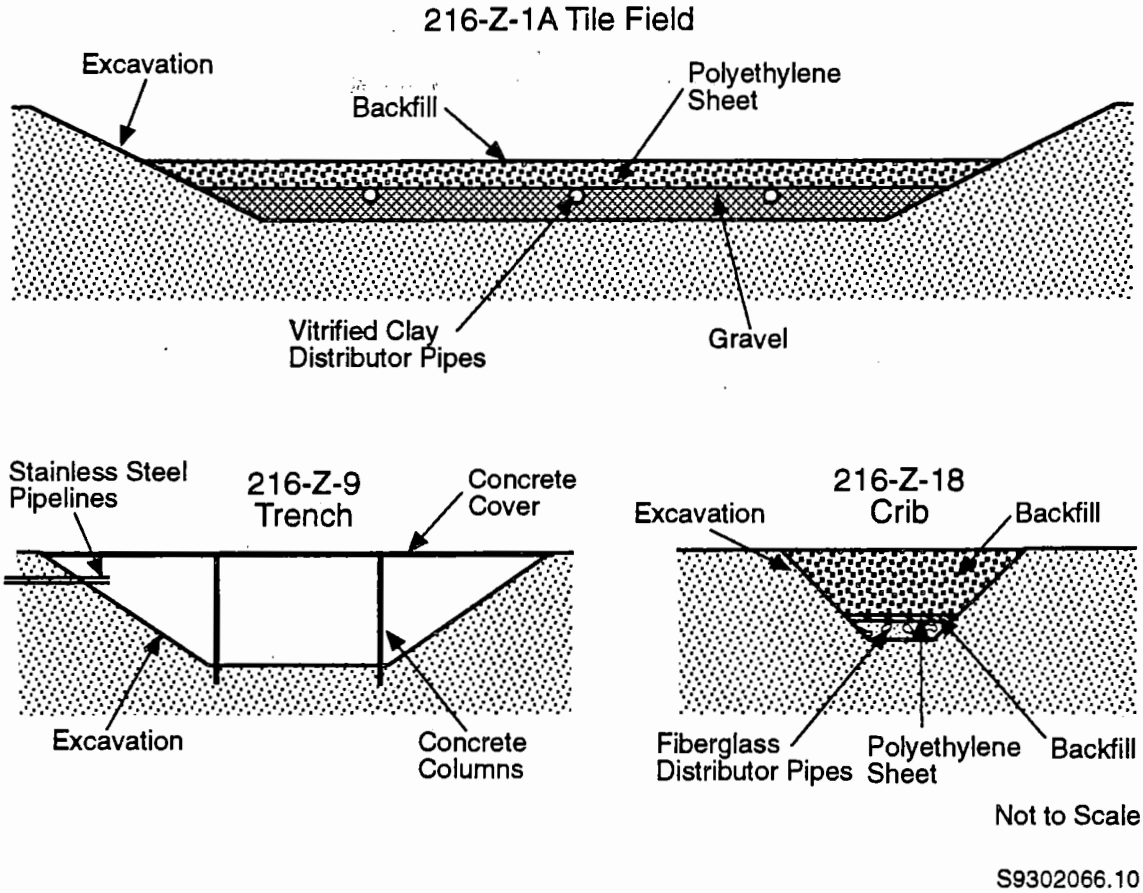


Figure 3.3. Schematic Design of the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-18 Crib

Table 3.1. Waste Constituent Inventory Summary for the Three Carbon Tetrachloride Disposal Facilities

Facility	Operating Dates	Waste Source	Total Volume (L)	Plutonium (kg)	CCl_4 (L)	TBP (L)	DBBP (L)	Lard Oil (L)
216-Z-9	1955 to 1962	Recuplex	4.09E+06	106[a]	8.3E+04 to 3.00E+05	2.79 E+04	4.65E+04	9.30E+03
216-Z-1A	1949 to 1959	Plutonium Finishing Plant crib overflow	1.00E+06	0.05	ND	ND	ND	ND
	1964 to 1969	Plutonium Reclamation Facility	5.20E+06	57	1.7E+05[b]	2.39E+04	2.75E+04	1.10E+04
216-Z-18	1969 to 1973	Plutonium Reclamation Facility	3.86E+06	23	1.10E+05	1.64E+04	1.91E+04	ND
Total			1.42E+07	186	3.63E+05 to 5.80E+05	6.82E+04	9.31E+04	2.03E+04

(a) 58 kg were later removed.
(b) Includes lard oil.
CCl_4 = Carbon tetrachloride; DBBP = dibutyl butyl phosphonate; TBP = tributyl phosphate.
ND = No data available.
Based on information from Owens (1981), DOE (1991, 1992), and Piepho et al. (1993).

4.0 Environmental Setting

This section describes the meteorology, geology, and hydrogeology of the VOC-Arid ID/ERA site.

4.1 Meteorology

The Hanford Site lies in a rainshadow on the east side of the Cascade Range, which results in its semiarid climate. The weather is monitored and recorded at the Hanford Meteorological Station, located 2.5 km northeast of the VOC-Arid ID/ERA site. The Hanford Site receives an annual average of 16 cm of precipitation, approximately half falling between November and February. The average yearly humidity at the Hanford Site between 1946 to 1980 was 54.4%, with a low of 32.2% in July and a high of 80% in December (Stone et al. 1983). The prevailing northwest winds result from cold air drainage out of the Cascade Range. Mean monthly wind speed from 1946 to 1980 averaged 3.4 m/s, with peak gust speeds from 28 to 36 m/s. Minimum winter temperatures vary from -33° to -6°C, and minimum summer temperatures vary from 38° to 46°C.

The average atmospheric pressure for the site is 29.2 in. of mercury. In general, the atmospheric pressure is higher in winter than in summer, though both the highest and lowest recorded pressures at the Hanford Site occurred during winter (DOE 1988). In 1990, average daily barometric pressure measured at the Hanford Meteorological Station ranged from approximately 28.6 to 29.9 in. of mercury (DOE 1991).

4.2 Geology

The Hanford Site is situated within the Pasco Basin, a structural depression in the Columbia Plateau, which accumulated thick deposits of Miocene continental flood basalts and younger sediments. The Pasco Basin is locally bisected by the Gable Mountain anticline (Figure 4.1). The Hanford Site's 200 West Area, containing the VOC-Arid ID/ERA site, is situated south of this anticline on the generally southward-dipping limb of the Cold Creek syncline. The VOC-Arid ID/ERA site lies at an elevation of approximately 200 m above mean sea level. The surface topography of the VOC-Arid ID/ERA site (shown in Figure 4.2) reflects numerous excavation and construction activities associated with nuclear materials production and waste management practices.

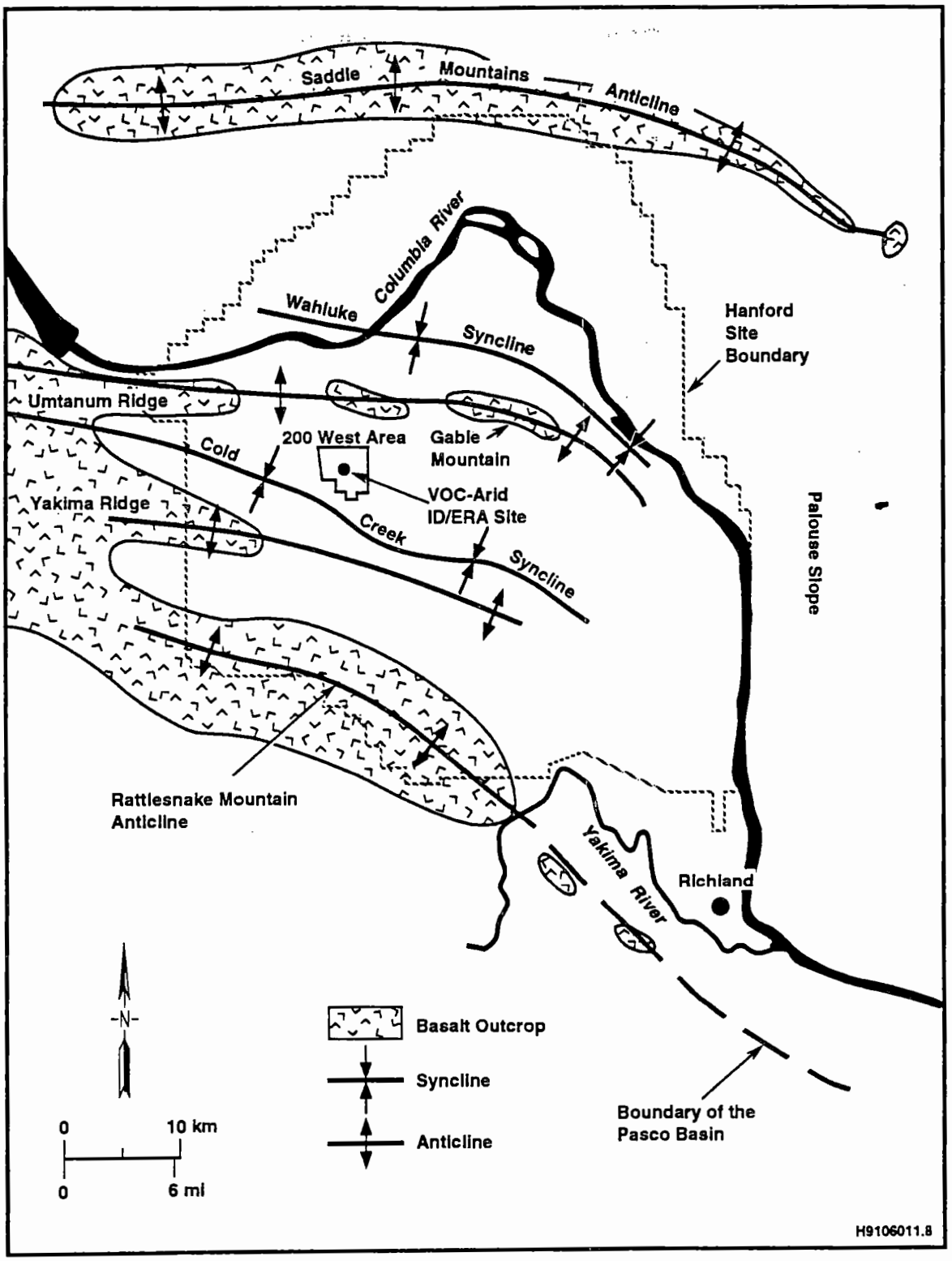


Figure 4.1. Structural Geology of the Hanford Site

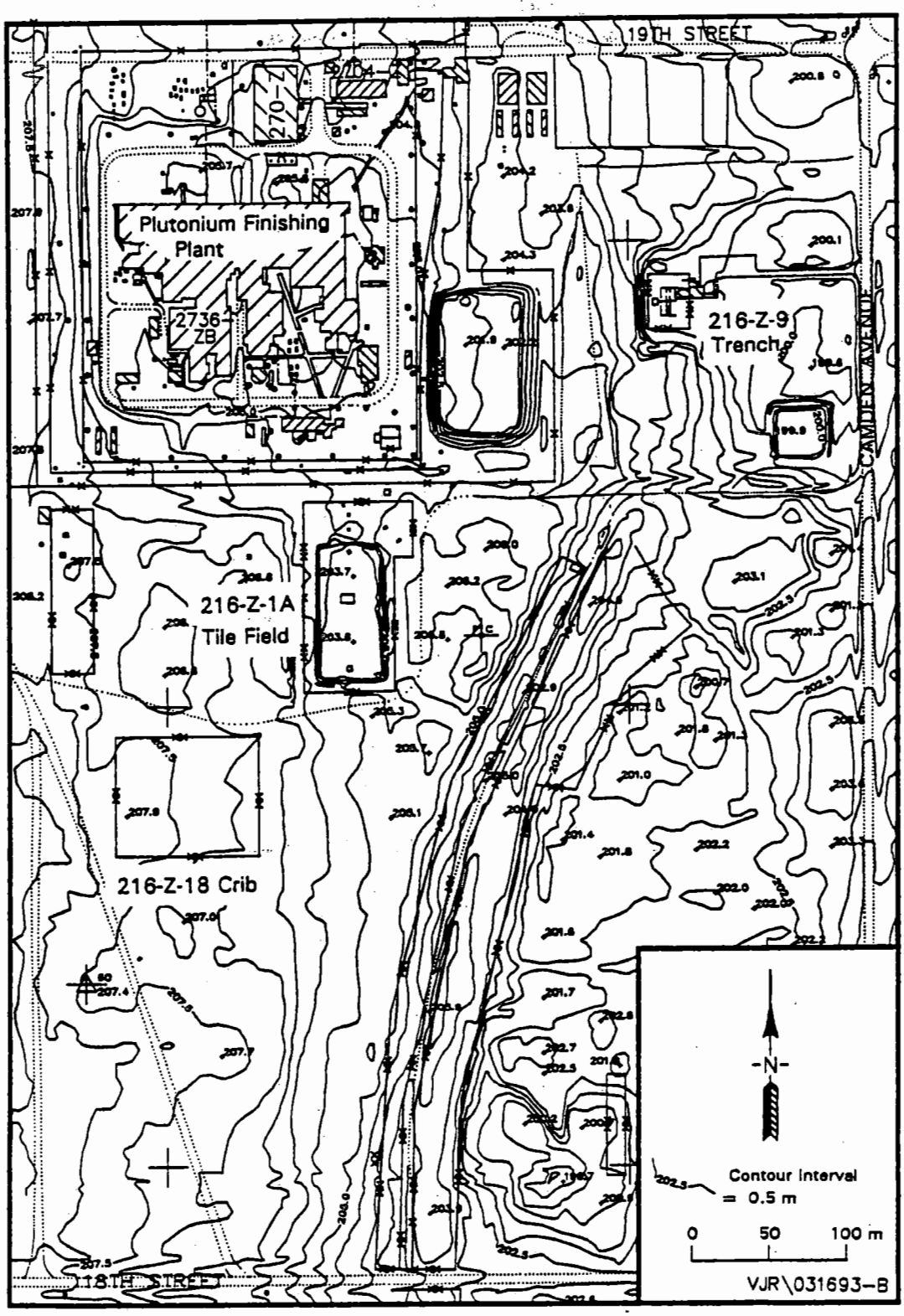


Figure 4.2. Topography of the VOC-Arid ID/ERA Site

9 3 1 2 9 0 1 1 5 4

The subsurface geology of the VOC-Arid ID/ERA site consists of a thick accumulation (> 150 m) of clastic sedimentary deposits overlying the Miocene Columbia River Basalt Group. These suprabasalt sediments include lithologic units assigned to the late Miocene to Pliocene Ringold Formation, the Plio-Pleistocene unit, the early Palouse soil (informal name), and the Pleistocene Hanford formation (informal name). A thin veneer of Holocene eolian sand locally overlies the Hanford formation.

The lithologic and stratigraphic relationships beneath the site have been refined from previous interpretations (DOE 1991, 1992; Last et al. 1991; WHC 1992), data from recently completed boreholes, and further interpretation of data from existing boreholes in the immediate vicinity of the site (Figure 4.3). Figure 4.4 illustrates the general stratigraphy and nomenclature of the principal geologic units. The lithology (i.e., composition, grain size, sorting, porosity, cementation, etc.) and stratigraphic relationships between the geologic units beneath the site and the updated surface (structure-contour) and isopach (thickness) maps of the principal stratigraphic units are given in Appendix B. The quality and quantity of borehole data vary greatly from borehole to borehole and are subject to multiple interpretations. In addition, many of the boreholes have not been accurately surveyed, resulting in uncertain elevations of the various geologic contacts by as much as a few meters. [Note: However, existing wells are currently being surveyed, and additional evaluation of borehole data in combination with detailed examination of archived sediment samples should reduce these uncertainties.]

4.3 Hydrogeology

The hydrogeology of the site is dominated by a thick, unsaturated zone (vadose zone) within the Hanford formation, early Palouse soil, Plio-Pliestocene unit, and upper Ringold Formation; an unconfined aquifer system within the Ringold Formation; and a system of confined aquifers within the Columbia River Basalt Group. Of primary interest to this study is the movement of water and contaminants within the vadose zone and the uppermost unconfined aquifer.

Groundwater flow in the unconfined aquifer is from areas of natural recharge from precipitation on and adjacent to basaltic ridges primarily west of the 200 West Area toward points of discharge to the east along the Columbia River. The annual natural recharge in the 200 Areas has been estimated (Gee 1987) at near zero (0.1 cm/yr) in areas with established vegetation and fine-grained soils. However, in areas devoid of vegetation and having coarse-grained or gravel-covered soils, much of the annual precipitation (as much as

9 3 1 2 9 7 0 1 1 5 5

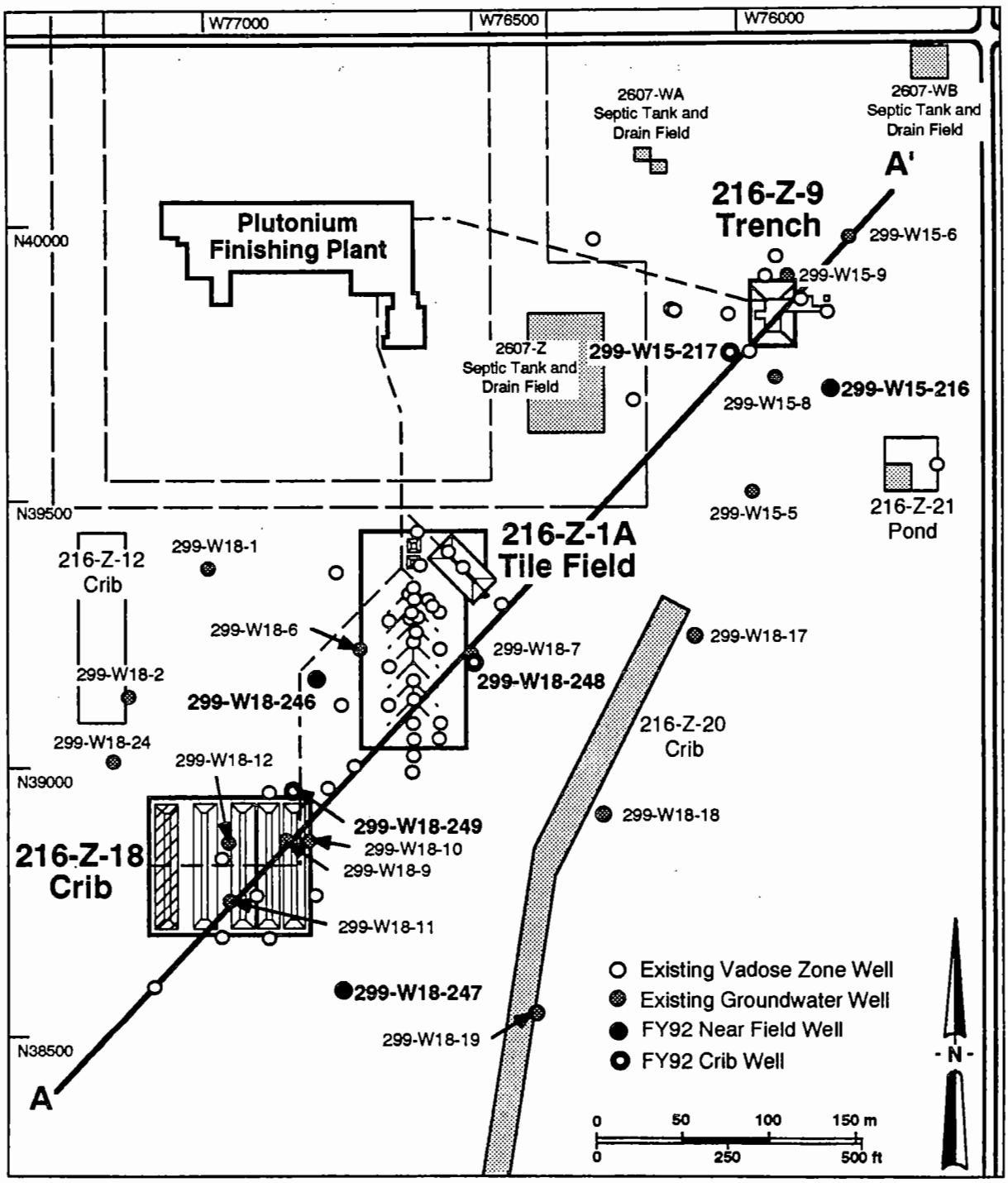


Figure 4.3. Location of Wells and Generalized Geologic Cross Section Through the VOC-Arid ID/ERA Site

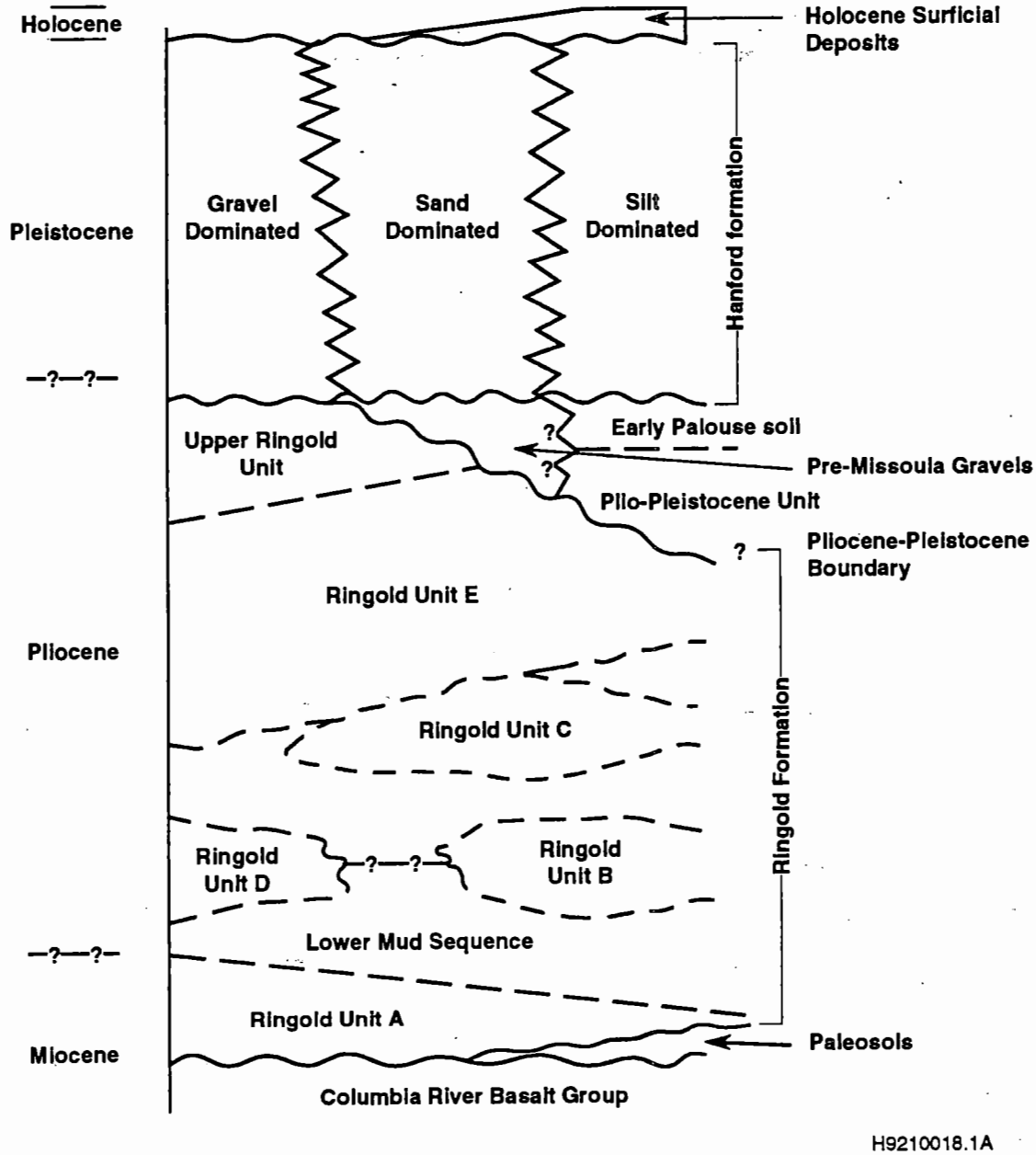


Figure 4.4. Stratigraphic Nomenclature for Geologic Units Beneath the VOC-Arid ID/ERA Site

10 cm/yr) may drain to the water table. Artificial recharge to the unconfined aquifer occurs in both the 200 West and 200 East areas from discharge of waste streams and cooling water to the soil column. Artificial recharge is estimated to be approximately 10 times the natural recharge at the Hanford Site (Graham et al. 1981).

4.3.1 Local Recharge

Several local sources of artificial recharge are present within the vicinity of the VOC-Arid ID/ERA site. These sources of recharge include two active liquid waste disposal sites (216-Z-20 crib and 216-Z-21 pond) and three sanitary tile fields (see Figure 3.2). Current annual discharge rates to these facilities are estimated as follows:

Facility	Annual Discharge (L/yr)
216-Z-20 crib	3.0E+08[a]
216-Z-21 pond	9.8E+07[a]
2607-Z drain field	8.4E+06 to 1.5E+07[a]
2607-WA drain field	2.2E+06[b]
2607-WB drain field	Unknown[b]

(a) DOE (1991).
(b) DOE (1992).

4.3.2 Vadose Zone

The vadose zone beneath the site ranges in thickness from 60 to 71 m. The geologic units found beneath this site have a wide range of textures (see Appendix B) and, thus, a wide range of hydraulic properties are expected. For discussion purposes, the vadose zone has been divided into ten hydrogeologic units (hydrofacies) based on the stratigraphic facies. These hydrogeologic units are, in descending order (Figure 4.5):

H_{SB} - Hanford sand unit B (upper sand unit)
H_{GB} - Hanford gravel unit B (upper gravel unit)
H_{MB} - Hanford silt (slackwater) unit B (lower fine unit)
H_{GA} - Hanford gravel unit A (lower gravel unit)
H_{SA} - Hanford sand unit A (lower sand unit)
H_{MA} - Hanford silt (slackwater) unit A (lower fine unit)
EP - early Palouse soil unit
PP - Plio-Pleistocene unit (caliche)
R_U - Ringold upper unit
R_{GE} - Ringold gravel unit E (unsaturated).

9 3 1 2 9 0 1 1 5 8

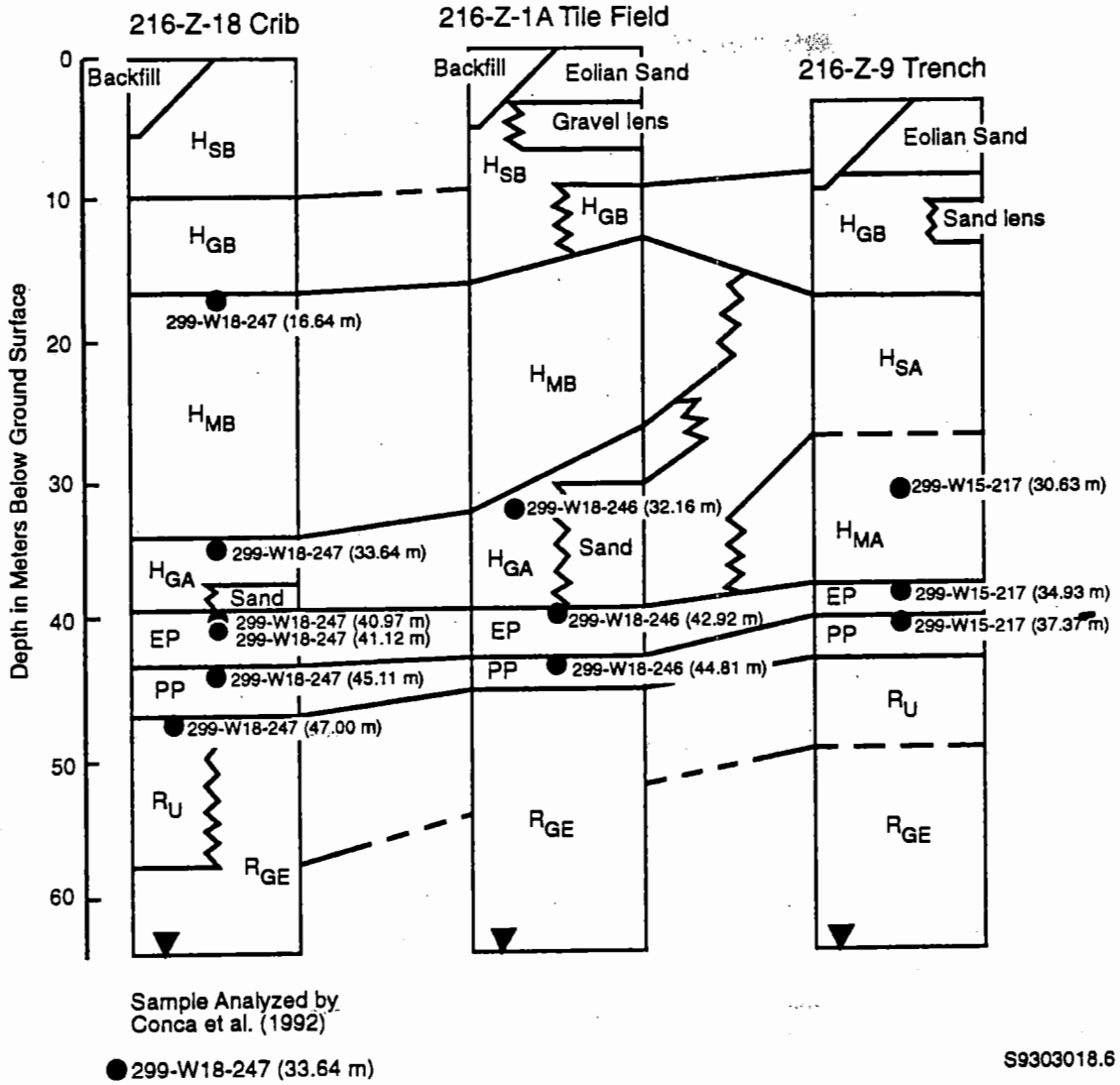


Figure 4.5. Hydrogeologic Units of the Vadose Zone Beneath the VOC-Arid ID/ERA Site

The thickness and configuration of these units vary beneath each of the three contaminant sources of interest (216-Z-1A, 216-Z-9, and 216-Z-18) and are discussed in detail in Appendix B. Figure 4.6 illustrates the general configuration of geologic materials beneath the VOC-Arid ID/ERA site.

The physical properties, including particle-size distribution and unsaturated hydraulic conductivities, of 12 samples collected from 3 boreholes installed during FY 1992 were reported by Conca et al. (1992). These samples represent six of the eight hydrogeologic

9 3 1 2 9 7 0 1 1 5 9

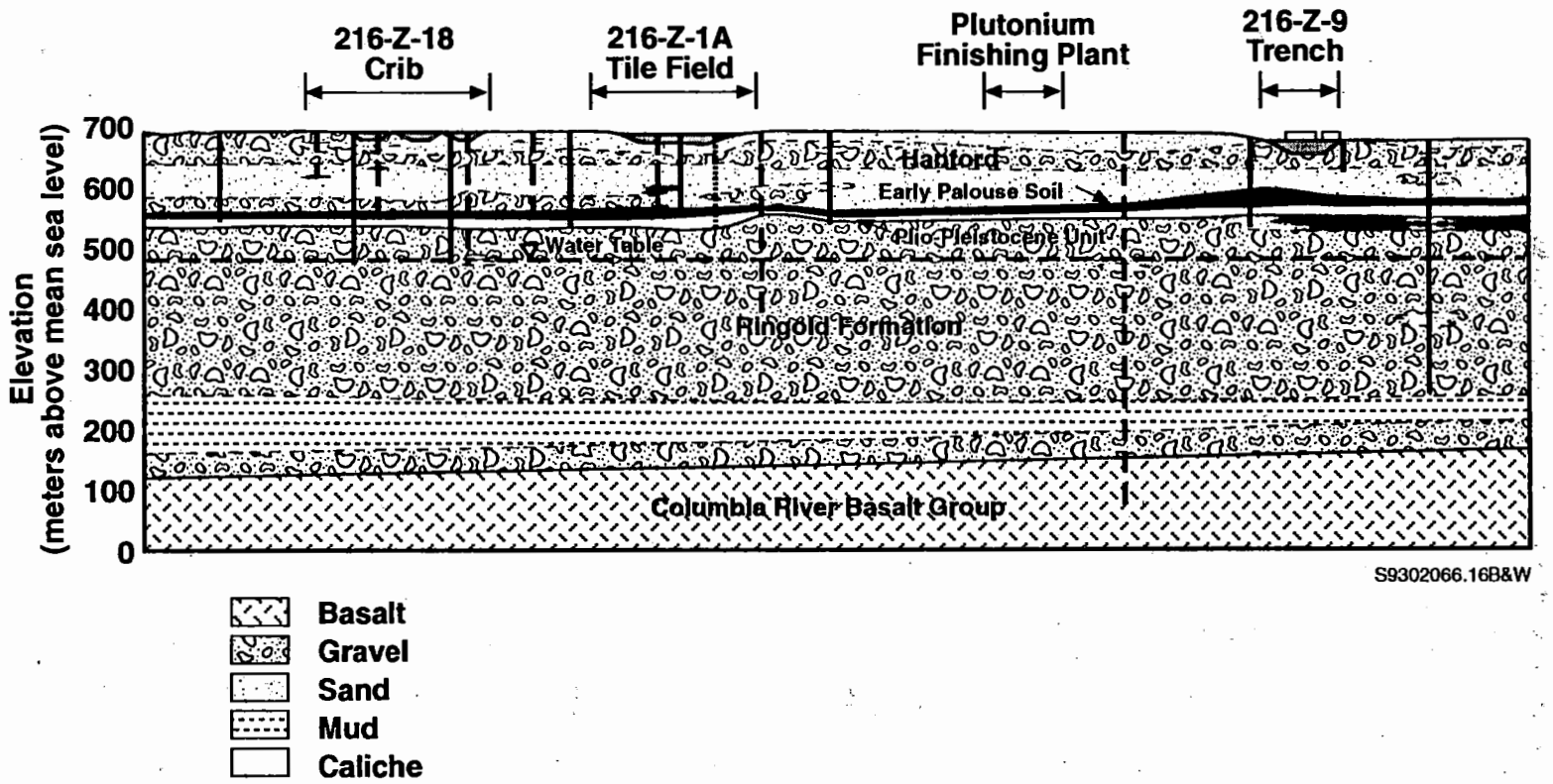


Figure 4.6. Generalized Southwest-Northeast Geologic Cross Section Through the VOC-Arid ID/ERA Site (location shown in Figure 4.3)

units (H_{MA}, H_{MB}, H_{GA}, EP, PP, and R_U; see Figure 4.5). A summary of the major particle sizes and field moisture contents for these units is presented in Table 4.1. Figures 4.7 through 4.11 illustrate the characteristic curves (unsaturated hydraulic conductivities at various moisture contents) of these units (Conca et al. 1992).

Field percolation tests were conducted by M.A. Chamness of PNL in the early 1980s in the immediate vicinity of the 216-Z-20 crib. Based on the ponded infiltration rates during these tests and assuming a unit hydraulic gradient, hydraulic conductivities for the upper Hanford formation materials were calculated and were found to range from 2.0E-02 to 3.5E-03 cm/s, over a volumetric water content range of 35% to 23.4% (M. A. Chamness, PNL).

The field moisture content and unsaturated hydraulic conductivities of the samples were compared (Conca et al. 1992) to infer a recharge estimate necessary for the sample to have reached/maintained that field moisture content. Based on this information, they inferred a moisture plume from the waste disposal facilities, as shown in Figure 4.12.

Also, Conca et al. (1992) compared the hydraulic conductivities of selected samples at various fluid contents, using pure liquid CCl_4, a CCl_4-saturated aqueous solution, and a simulated natural pore water. They concluded that the hydraulic conductivities measured using pure CCl_4 were much higher than those measured using the simulated pore water and the aqueous CCl_4 solution and that those of the pore water and the aqueous CCl_4 solution were nearly identical. In addition, they found that the bulk of the pore water initially saturating the samples was pushed out of the sample by the pure CCl_4 during these hydraulic conductivity tests. This suggests that the organic-phase CCl_4, which has much lower surface tension than water, may displace the bulk of the water saturating the pore spaces under saturated drainage conditions.

4.3.3 Perched Water

Perched water was encountered in 1992 near the 216-Z-9 trench at a depth of 28 to 33 m in well 299-W15-216. This water was perched on the early Palouse soil/ Plio-Pleistocene unit contact with the overlying fine-grained Hanford formation. It is hypothesized that the 216-Z-21 pond, which lies approximately 40 m southeast of this well, is the source of the water. The 216-Z-21 pond receives approximately 9.8E+07 L of water per year (DOE 1991). This is consistent with an estimate by M. A. Chamness of PNL that the maximum horizontal spreading from a 10-m-radius pond receiving 284 L/min (1.5E+08 L/yr) for 20 years would be approximately 62 m. [Note that the 216-Z-21 pond has been in service since only the 1980s.]

Table 4.1. Physical Properties of Vadose Zone Sediments

Well Number	Depth (m)	Hydrogeologic Units	Bulk Density (g/cc)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Field Moisture (%)
299-W18-247	16.64	H_{MB}	1.21	0	89	7	4	ND
	33.38	H_{GA}	1.63	3	93	2	2	5.2
	40.97	EP	1.27	ND	ND	ND	ND	ND
	41.12	EP	1.65	0	15	75	10	ND
	45.11	PP	1.76	35	36	20	9	34.7
	47.00	R_U	1.59	1	92	4	3	ND
299-W18-246	32.16	H_{GA}	1.66	40	55	4	1	ND
	42.92	EP	1.66	1	19	77	3	ND
	44.81	PP	1.66	ND	ND	ND	ND	ND
299-W15-217	30.63	H_{MA}	1.54	ND	ND	ND	ND	ND
	34.93	EP	1.79	ND	ND	ND	ND	ND
	37.37	PP	1.48	ND	ND	ND	ND	ND

After Conca et al. (1992).
ND = No data available.

Perched water has also been encountered near the 216-Z-20 crib in well 299-W18-29 (installed in 1991) at a depth of approximately 39 m (DOE 1992) and in other wells at various depths adjacent to the now decommissioned 216-U-10 pond. Figure 4.13 illustrates the potential extent of locally perched water within the study area, based on its known occurrence and assuming a 62-m radius around each active waste disposal facility.

4.3.4 Unconfined Aquifer

The uppermost aquifer beneath the site is unconfined and lies within the Ringold Formation. The top of the aquifer, represented by the water table, lies within gravel unit E. The lower portion of this aquifer, contained within gravel unit A, is locally confined

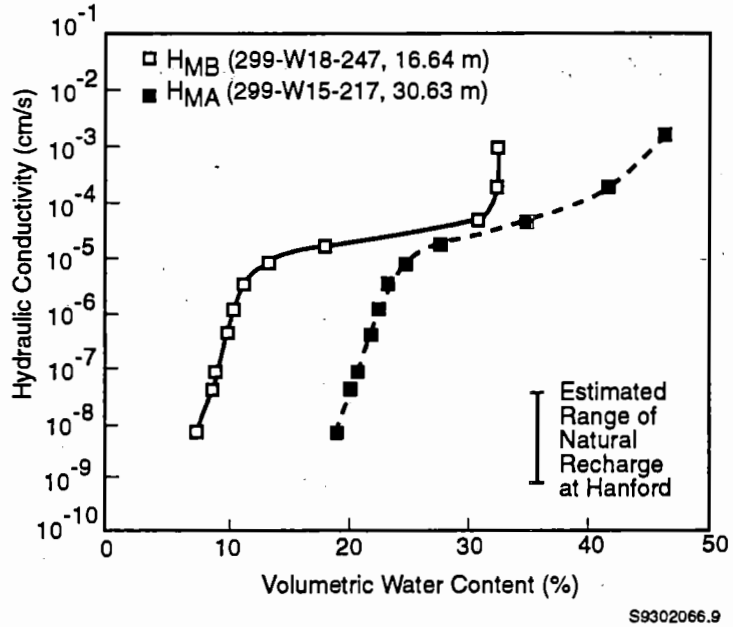


Figure 4.7. Characteristic Curves for the Hanford Formation Slackwater Deposits (after Conca et al 1992)

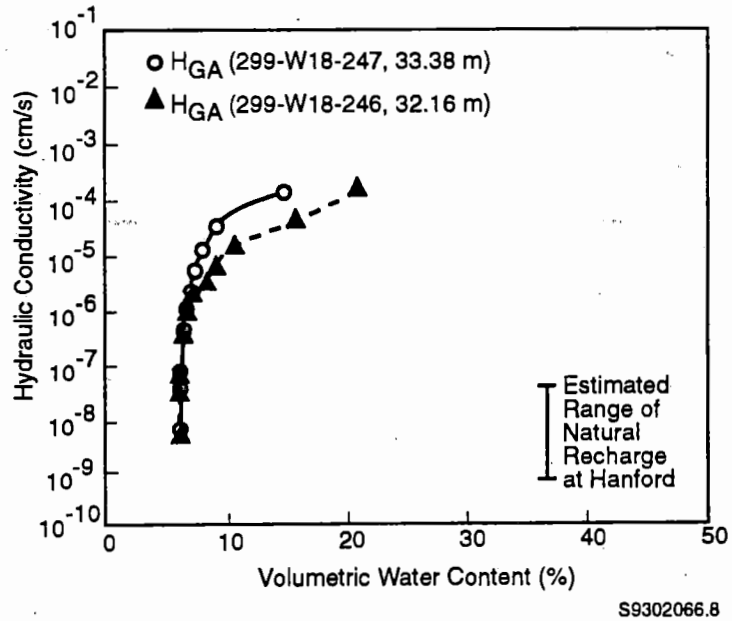


Figure 4.8. Characteristic Curves for the Hanford Gravel Unit A (after Conca et al. 1992)

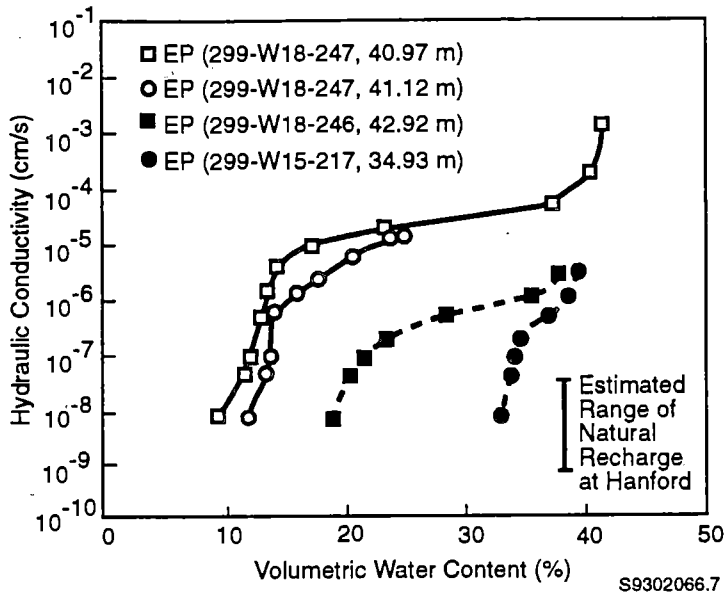


Figure 4.9. Characteristic Curves for the Early Palouse Soil (after Conca et al. 1992)

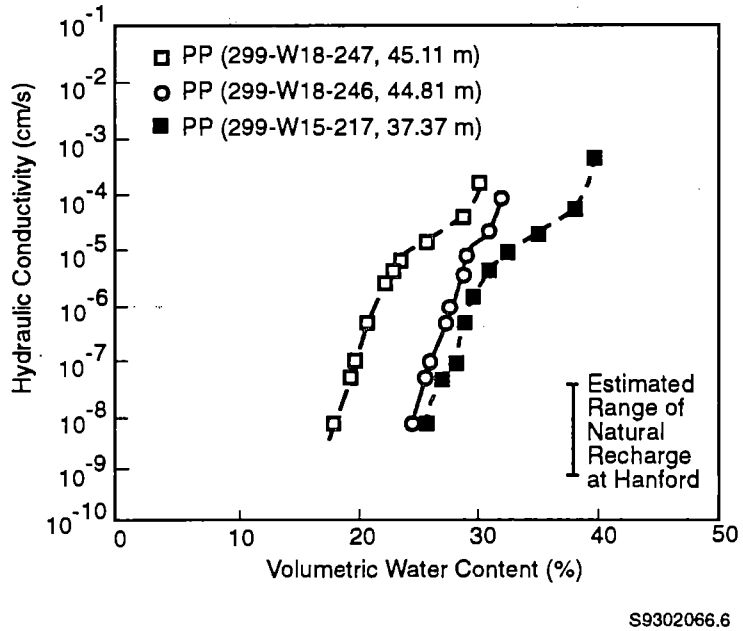


Figure 4.10. Characteristic Curves for the Plio-Pleistocene Unit (after Conca et al. 1992)

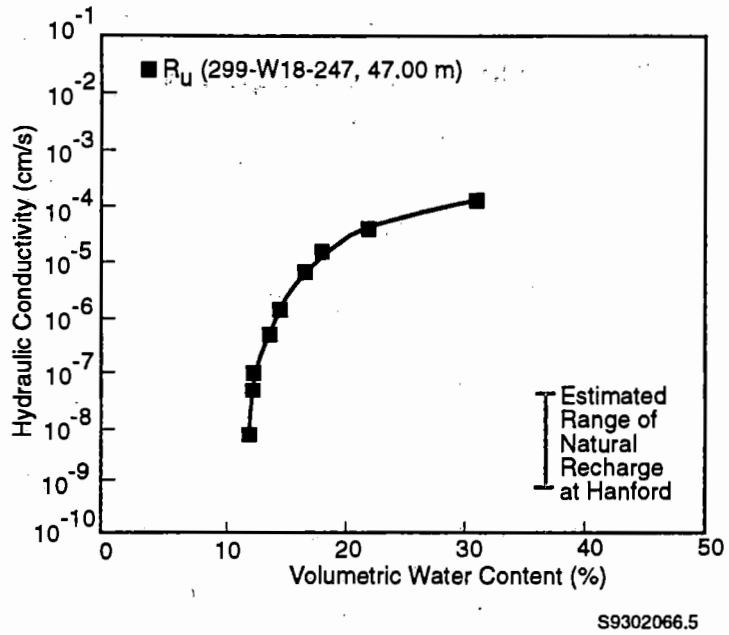


Figure 4.11. Characteristic Curves for the Upper Ringold Unit (after Conca et al. 1992)

beneath the lower mud unit of the Ringold Formation. The hydrogeology of the uppermost aquifer beneath the VOC-Arid ID/ERA site is represented by the following four principal hydrogeologic units (see Figure 4.4):

R_{GE} - Ringold gravel unit E (saturated)
R_{LM} - Ringold lower mud unit
R_{GA} - Ringold gravel unit A
S_{EM} - Saddle Mountains Basalt, Elephant Mountain Member.

Transmissivity and hydraulic conductivity values for saturated gravel unit E (R_{GE}) of the Ringold Formation have been calculated from aquifer test results. WHC (1992) lists the values from 47 wells within the 200 West Area. Transmissivity values from the top of the aquifer range from 2 to 4,700 m^2/d, with hydraulic conductivity values of 0.3 to 1,500 m/d. The bottom of the aquifer (within the lower portion of gravel unit E) ranged in transmissivity from 39 to 84 m^2/d, with a hydraulic conductivity of approximately 0.01 cm/s. WHC (1992) also constructed maps of the transmissivity and hydraulic conductivity values (Figures 4.14 and 4.15). Storativity values for this unit have been estimated to range from 0.001 to 0.038 (Last et al. 1989). Table 4.2 lists the principal hydrologic properties of the major hydrogeologic units.

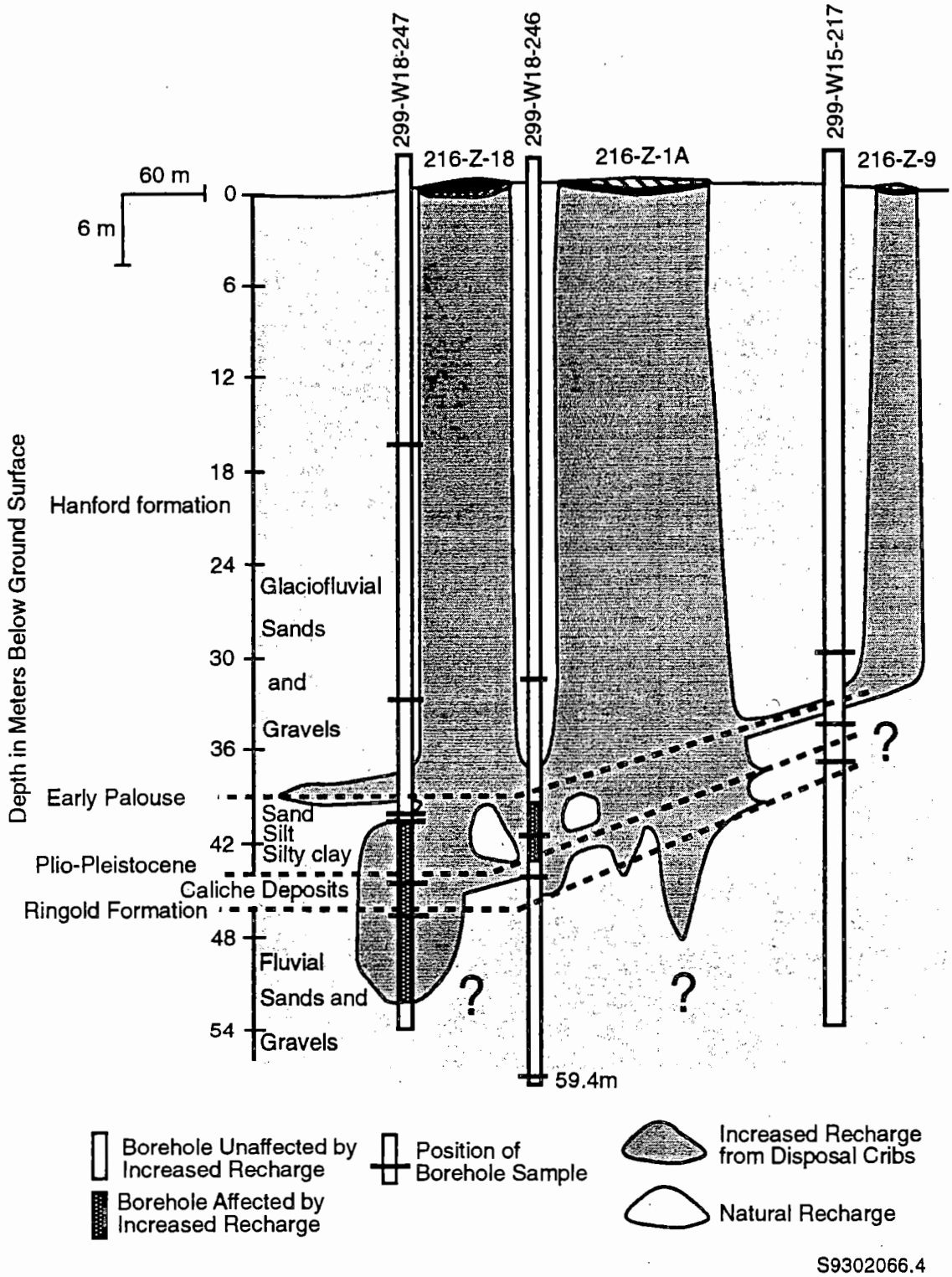


Figure 4.12. Inferred Recharge Distribution Below the VOC-Arid ID/ERA Site (after Conca et al. 1992)

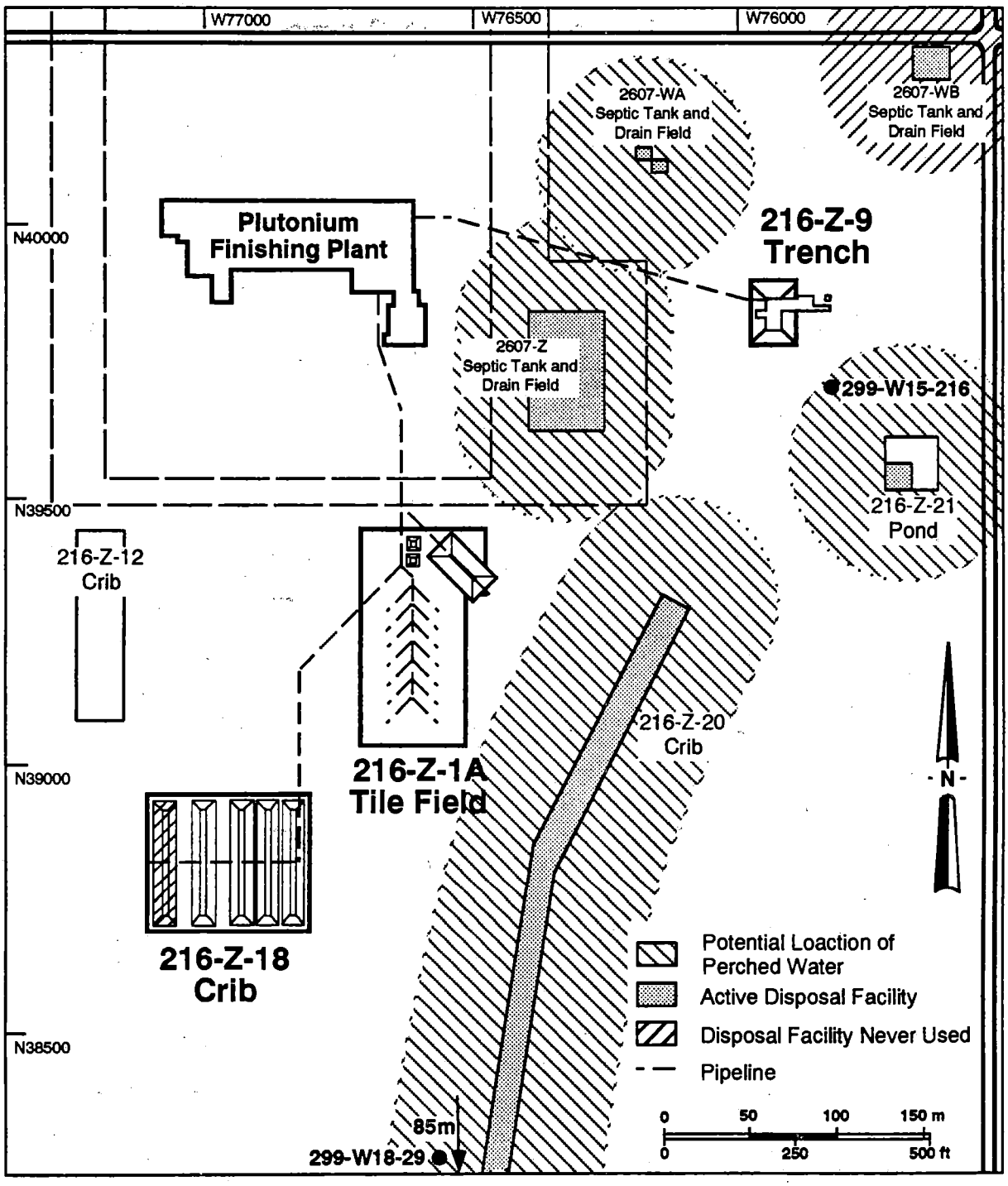
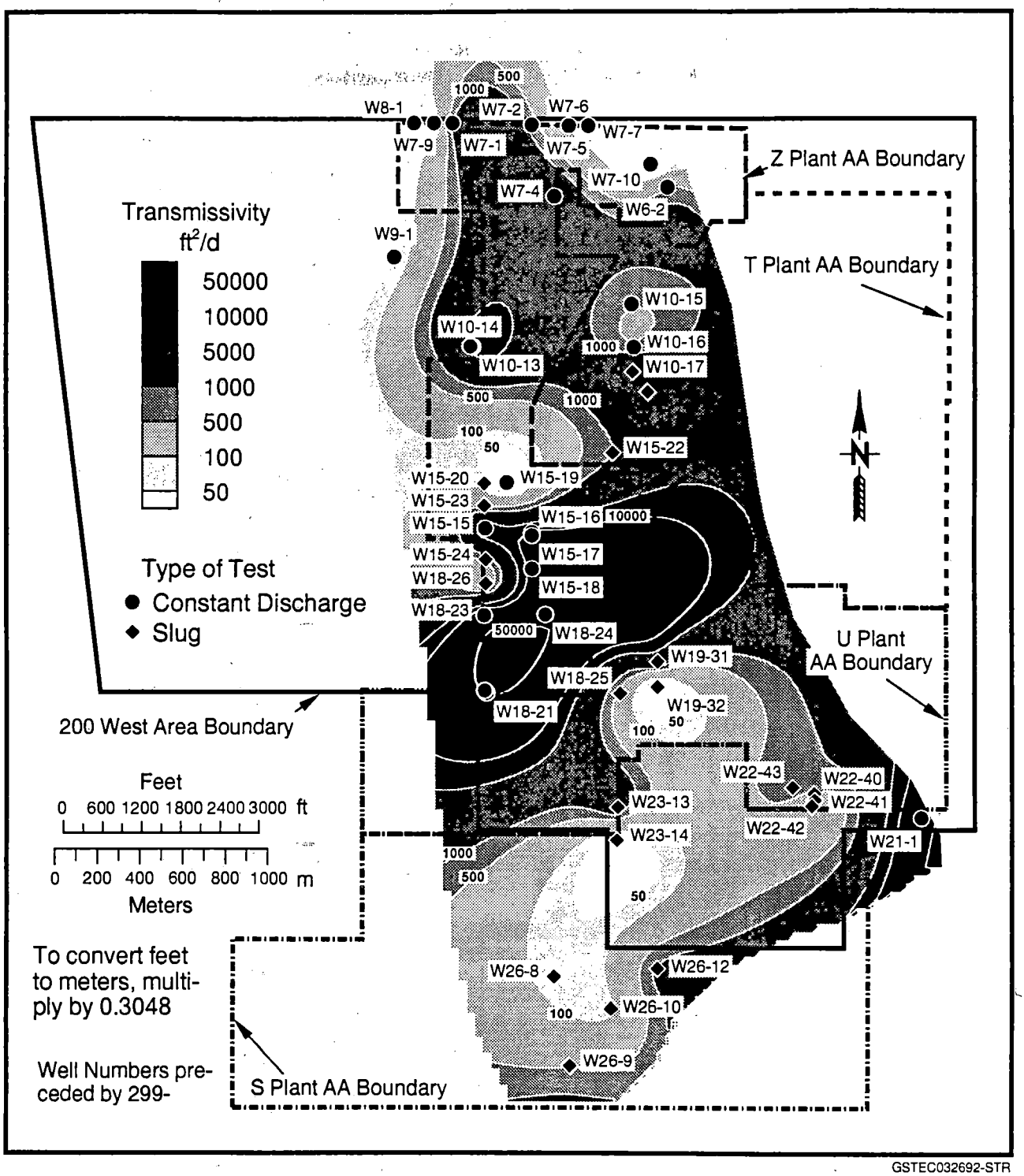


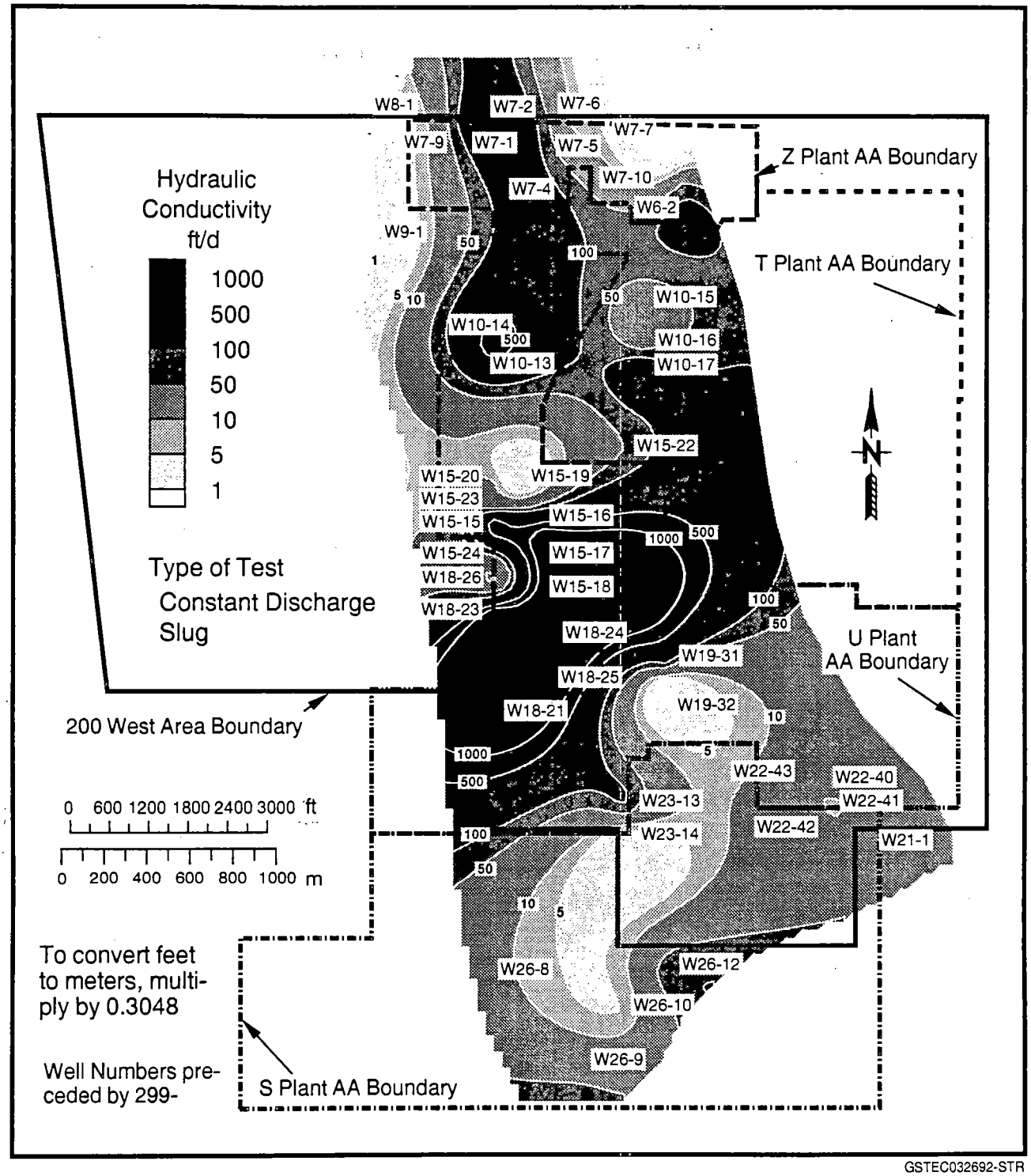
Figure 4.13. Potential Location of Perched Water Near the Three Waste Disposal Facilities of Interest

9 3 1 2 9 7 0 1 1 6 7



GSTEC032692-STR

Figure 4.14. Transmissivity Map of the 200 West Area (from WHC 1992)



GSTEC032692-STR

Figure 4.15. Hydraulic Conductivity Map of the 200 West Area (from WHC 1992)

Table 4.2. Hydrologic Properties of the Unconfined Aquifer

Well Number	Hydrogeologic Units	Sample	Transmissivity (m^2/d)	Conductivity (m/d)	Storatitivity
299-W15-16	R_{GE} (top)	Aquifer test	1,115	366	0.03
299-W15-17	R_{GE} (top)	Aquifer test	1,115	366	ND
299-W18-21	R_{GE} (top)	Aquifer test	4,738	1,554	ND
299-W18-24	R_{GE} (top)	Aquifer test	4,087	1,341	0.001
299-W18-22	R_{GE} (bottom)	Aquifer test	39	13	ND
ND	R_{LM}	ND	ND	0.03-3.0	0.002
ND	R_{GA}	ND	ND	0.001-0.61	ND

After Graham et al. (1981), Last et al. (1989), and WHC (1992)
ND = No data available.

Regional groundwater flow is generally from west to east (Newcomer et al. 1991). The present direction of groundwater flow in the vicinity of the 200 West Area is largely influenced by a groundwater mound caused by past artificial recharge to the now inactive 216-U-10 pond. Prior to deactivation of the pond, this groundwater mound had risen over 20 m above pre-Hanford conditions. Since the pond's decommissioning in 1984, the groundwater mound has been decreasing, causing the water table to drop as much as 5 m beneath the PFP in 8 years. This mound now appears to be centered northeast of the former 216-U-10 pond (Figure 4.16). Continuing liquid discharges to other sites southeast of the PFP (e.g., the 216-Z-20 crib and portions of the 216-U-14 ditch) may be responsible in part for this apparent shift (DOE 1991). This groundwater mound is expected to be the dominant force influencing local groundwater flow for a number of years.

The water table in the vicinity of the CCl_4 disposal sites for spring 1992 is shown in Figure 4.17. In general, groundwater elevations decrease radially to the north, west, and east (underlying the waste disposal facilities), reflecting the mound shown in Figure 4.16. Water-table elevations in this area dropped nearly 0.6 m between June 1991 and June 1992. Water levels in well 299-W18-15, near the former 216-U-10 pond, dropped at the same rate, suggesting that the major drop in water level is related primarily to the pond's decommissioning.

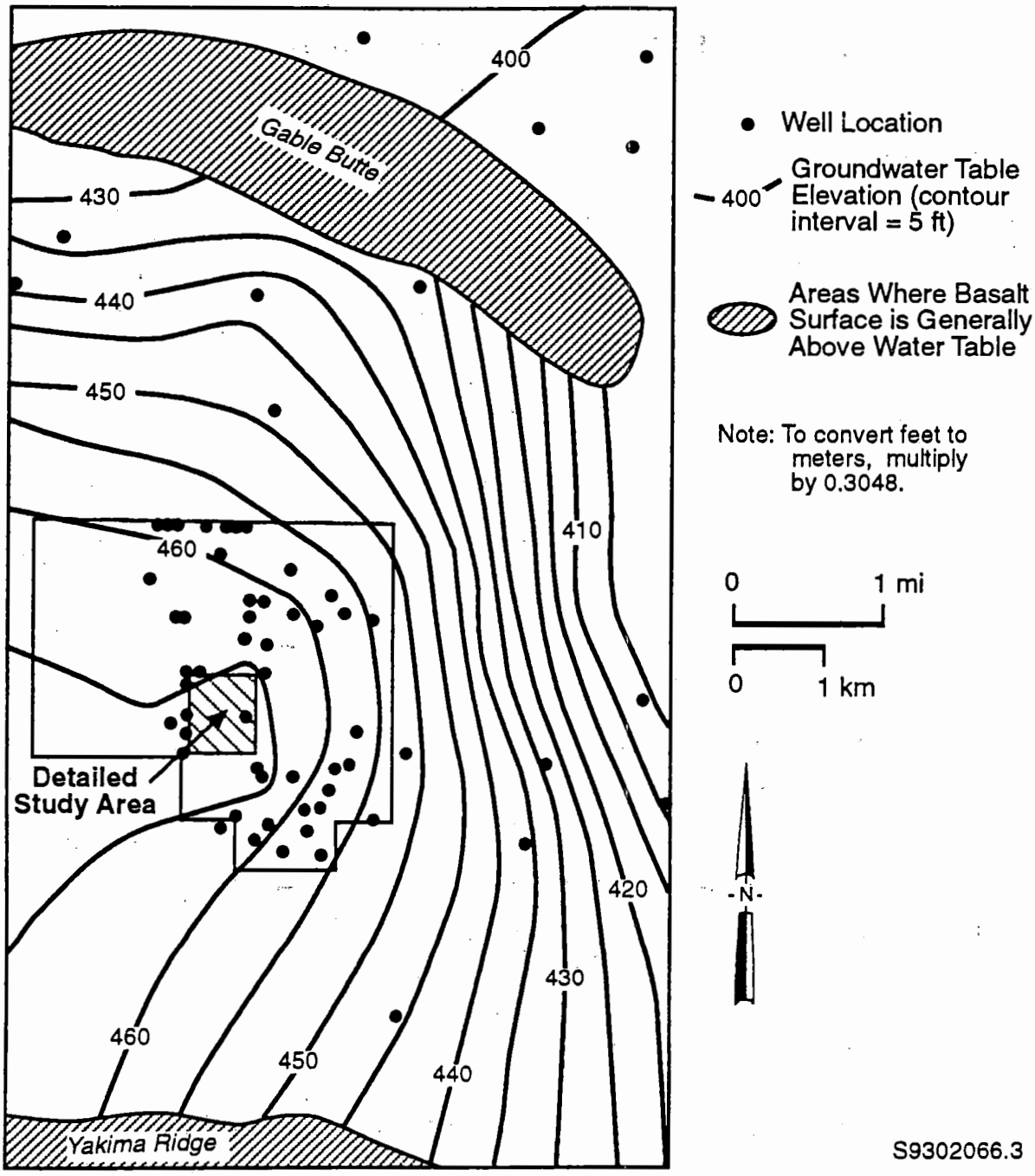


Figure 4.16. Regional Potentiometric Surface Map of the Unconfined Aquifer in the Vicinity of the 200 West Area - June 1992 (after Kasza et al. 1992)

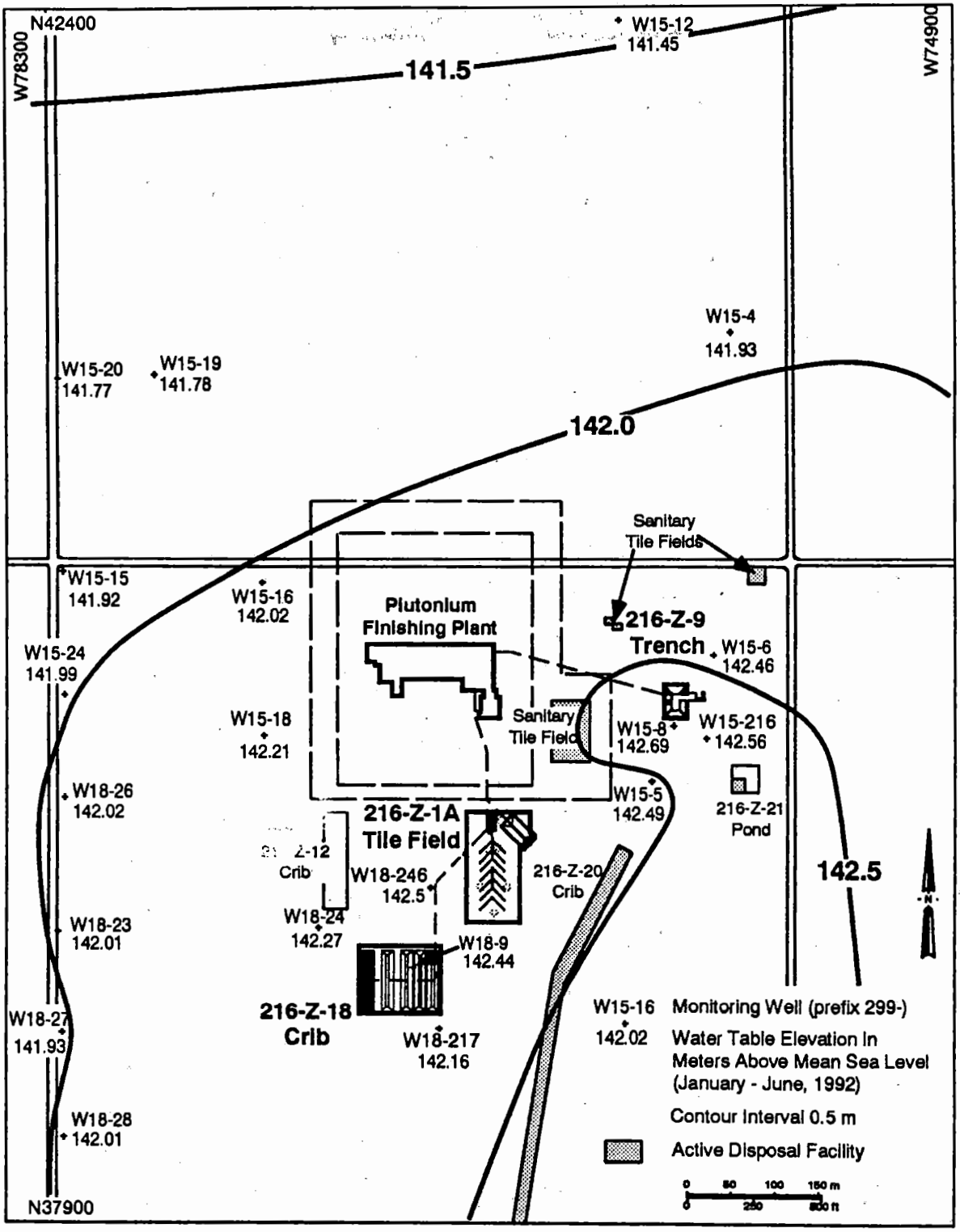


Figure 4.17. Water-Table Map of the Unconfined Aquifer in the VOC-Arid/ID ERA Site - Spring 1992

The elevations used to prepare the water-table map shown in Figure 4.17 are provided in Appendix C and were extracted from the Hanford Groundwater Data Base (HGWDB). Although most of the data are from March 1992, data were used from January through June 1992 to obtain the coverage needed. Water levels dropped by nearly 0.3 m during this 6-month period. In addition, it should be noted that the number of significant figures does not indicate accuracy. While steel-tape readings can be made to ±0.3 cm, the greatest uncertainty is in the elevation of the well casing, for which an uncertainty of ±30 cm is likely (DOE 1991). Finally, the continuing liquid discharges to nearby liquid waste disposal facilities and sanitary drain fields and the uncertainty in the extent and infiltration of the perched water in this area complicate the interpretation of the water-level data shown in Figure 4.17.

9 3 1 2 9 7 0 1 1 7 3

5.0 Nature and Extent of Contamination

This section presents information regarding the nature and distribution of contaminants found beneath the 216-Z-1A tile field, 216-Z-9 trench, and 216-Z-18 crib. Also presented are current estimates of the quantity of CCl_4 released to the atmosphere, retained in the vadose zone, and present within the groundwater. This information is based primarily on the results of the ongoing VOC-Arid ID and ERA investigations.

5.1 Atmospheric Losses

The CCl_4 vapor may move from the subsurface to the atmosphere at the soil/air interface or along pathways, such as existing wells. The following two sections on the natural flux of VOCs are based on an estimate of the atmospheric losses of CCl_4 (WHC 1993) and on field measurements made in support of the ERA (Rohay and Cameron 1992; Fancher 1993).

5.1.1 Soil/Air Interface

The quantity of CCl_4 lost to the atmosphere in 1990 from the soil/air interface, based on diffusion of the vapor phase from the water table to the ground surface, is estimated (WHC 1993) to be 0.15 $g/m^2/yr$, or 1,800 kg/yr, for the area overlying the groundwater plume. It is estimated that, between 1955 and 1990, 18% of the total CCl_4 inventory was lost to the atmosphere through natural soil flux (WHC 1993). For these rough order-of-magnitude estimates, it is assumed that 750,000 kg of CCl_4 were discharged to the soil column between 1955 and 1973.

The distribution and concentration of the CCl_4 vapor in the vadose zone was calculated, based on 1) the distribution and concentration of the dissolved phase in the unconfined aquifer, 2) the corresponding equilibrium concentration of vapor just above the water table, and 3) a linear interpolation between the vapor concentration at the water table (64-m depth) and an assumed concentration of zero at the ground surface (DOE 1991). To calculate the vapor loss to the atmosphere, it was assumed that the contaminated vapor diffused to 1 m below the ground surface. Air in the upper 1 m of the soil column was assumed to be swept out by fluctuations in barometric pressure, based on the measured range in the barometric pressure for 1992 (WHC 1993).

To calculate the historical atmospheric losses, it was assumed that the upper 1 m of the soil column were swept clean 52 times per year by barometric pressure fluctuations

9 3 1 2 9 0 1 1 7 4

(WHC 1993). During the period of discharge, it was assumed that soil vapor in the upper 1 m was saturated with CCl_4 and was confined to the cross-sectional area of the crib and that the atmospheric loss rate remained constant. After discharge ceased, the CCl_4 was assumed to diffuse outward and downward until it reached the estimated 1990 configuration. Atmospheric losses were assumed to decline steadily at a yearly rate designed to match the 1,800-kg/yr rate calculated for 1990. The total calculated quantity of CCl_4 lost during the operational period (1955 to 1973) was calculated to be 54,000 kg. From 1955 to 1990, the total loss to the atmosphere through the soil surface is calculated to be 137,000 kg (WHC 1993).

The EMFLUX® passive soil-gas-sampling technology, owned and operated by Quadrel Services, Inc., of Ijamsville, Maryland, was deployed on August 6, 1992 and retrieved on August 10, 1992. The ambient soil-surface flux ranged from 111 to 686 $ng/m^2/min$ (0.06 to 0.36 $g/m^2/yr$) near the 216-Z-9 trench.

5.1.2 Borehole Releases

During the period 1949 to 1992, boreholes were drilled to characterize and/or monitor liquid waste disposal facilities in the 200 West Area. For example, in the vicinity of the three CCl_4 disposal facilities, 58 boreholes are potentially available for monitoring. Rohay and Cameron (1992) have documented that many of these wells serve as pathways for soil vapor to reach the atmosphere.

The boreholes with open (screened, perforated, or open bottom) intervals naturally breathe in response to meteorological phenomena, most notably fluctuations in barometric pressure. Thus, when barometric pressure is higher than the pressure in the soil near the open interval, fresh air moves through the borehole and into the soil pores exposed at the open interval. When barometric pressure is lower than the pressure in the soil near the open interval, the process operates in reverse; the borehole exhales, and soil vapor moves from the formation at the open interval through the borehole and out to the atmosphere. The soil-vapor-contaminant concentration venting from the boreholes depends in part on the permeability and contaminant concentration of the soils at the open interval, the amount of open interval, the static residence time of the air in the formation (to permit diffusion from the soil or liquid phase to the gas phase), and the rate of change of the barometric pressure.

The boreholes were installed by several contractors using different drilling and completion methods; some completions have since been modified. Most of the open intervals range in depth from 23 to 48 m below the surface. Construction details for CCl_4 area boreholes are provided in the ERA proposal (DOE 1991).

9 3 1 2 9 7 0 1 1 7 5

Continuous airflow measurements have been recorded at several boreholes associated with the CCl_4 disposal facilities since June 1992. The longest continuous data record is available for well 299-W18-6 on the west side of the 216-Z-1A tile field. However, continuous data on the CCl_4 concentration in that airflow are available for only 2 periods within 8 days in September 1992 at well 299-W18-6. The highest measured CCl_4 concentration at this borehole was approximately 80 parts per million by volume (ppmv). The airflow and contaminant data suggest that several grams per hour of CCl_4 could be venting from the borehole during exhalation events (e.g., when barometric pressure is falling; Rohay and Cameron 1992). It should be noted that well 299-W18-6 has a perforated interval open to the vadose zone just above the water table and far below the Plio-Pleistocene unit (caliche). Thus, the soil concentrations near the open interval in this well are probably lower than soil concentrations near open intervals elsewhere within the vadose zone, particularly open intervals just above the caliche layer. This suggests that wells open at intervals different than that of well 299-W18-6 may provide much greater mass flux.

As part of the baseline monitoring program for the soil-vapor-extraction system (Fancher 1993), 43 wells, at distances of 0 to 90 m from the CCl_4 disposal facilities, have been monitored twice per week since December 1991. The wells are monitored with field-screening instruments at the well head, which provide an indication of the CCl_4 concentration in the air within the well. The observed contaminant concentrations range from 0 to over 10,000 ppmv total organic vapor. These data are instantaneous samples that represent one point in the borehole-venting cycle. Work is continuing to determine the relationship between the venting cycles and barometric pressure fluctuations for various well configurations (Rohay and Cameron 1993).

The CCl_4 concentrations of soil gas exhaling from a well have been correlated with the flow rate of the gas and the rate of barometric pressure change. A zero reading may be indicative of an inhalation event, while the maximum baseline monitoring value for each well is judged to have the greatest likelihood of representing equilibrium conditions. Lower readings could be the effect of dilution from the previous inhalation event or the rapid transport of air that does not allow time to reach equilibrium conditions. Attainment of equilibrium conditions between exhalation events may not always have been achieved prior to taking the measurements; thus, the maximum values measured to date represent only an estimate of the subsurface concentrations. Of the 43 wells monitored, the maximum concentrations were less than 10 ppmv in 4 wells, between 11 and 100 ppmv in 20 wells, between 101 and 1,000 ppmv in 13 wells, between 1,001 and 10,000 ppmv in 5 wells, and greater than 10,000 ppmv in 1 well (Figure 5.1). During an exhalation event, the CCl_4 concentrations venting from boreholes increase from zero to a maximum value and

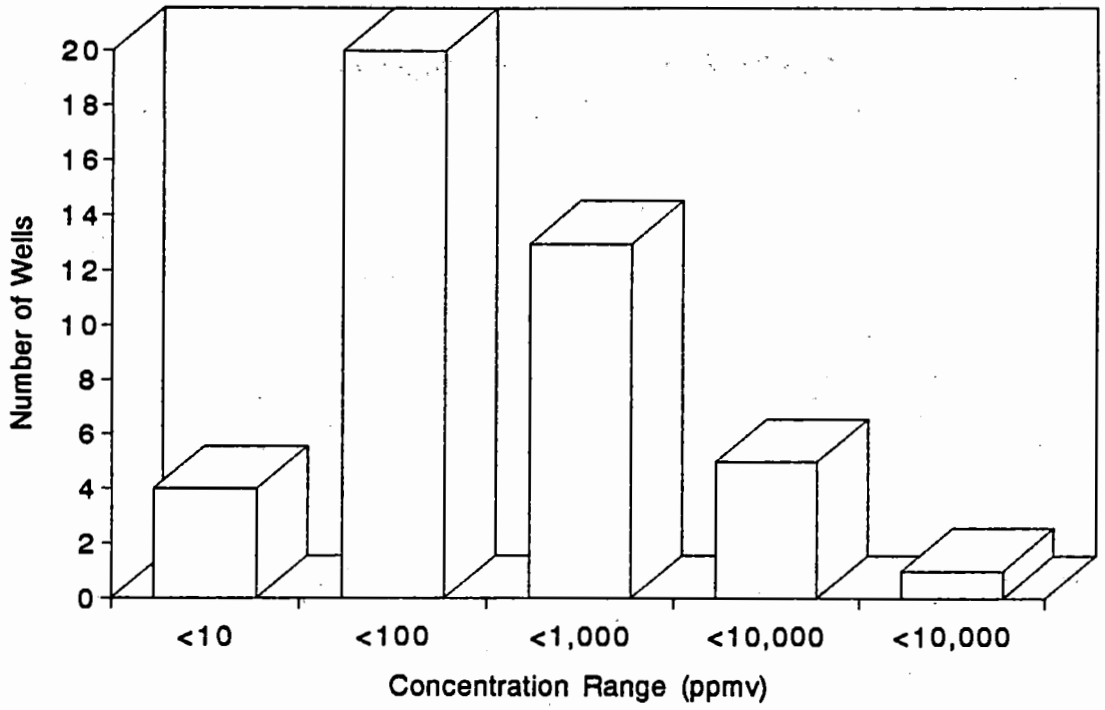


Figure 5.1. Distribution of Maximum Baseline Monitoring Well Head Measurements

then decrease back to zero. Therefore, the average of the vented CCl_4 concentrations measured during baseline monitoring were used to estimate the natural flux from each borehole.

For this estimation of natural flux, the wells were assumed to be comparable despite their various ages, locations, depths, and completions. The average vented concentrations were contoured for the CCl_4 area, based on the baseline monitoring well network. However, all wells located within each contour interval were assumed to provide release pathways during the years they had intervals open to both the subsurface and the atmosphere. Based on airflow measurements in the boreholes and on the baseline monitoring data, it is estimated that the wells breathe out half of the year at an average flow of 0.14 m^3/min. Using the mid-range value for each concentration contour interval and the number of years each borehole within that contour interval was available to provide a potential pathway, it is estimated that 22,200 kg of CCl_4 (or 3% of the estimated CCl_4 inventory) may have been released to the atmosphere through existing boreholes between 1955 and 1990 (WHC 1993).

5.2 Vadose Zone Contamination

This section discusses the nature and extent of CCl_4 contamination within the vadose zone and is based on the results of soil-gas surveys, subsurface soil-gas measurements, and sediment sampling.

The quantity of CCl_4 estimated to be in the vadose zone overlying the groundwater plume is 91,000 kg, or 12% of the total CCl_4 inventory discharged to the soil column (WHC 1993). This estimate assumes that there are two sources for the vadose zone CCl_4: 1) the dissolved groundwater plume, from which CCl_4 is assumed to volatilize and diffuse into the vadose zone and 2) the residual CCl_4, which is assumed to remain in the vadose zone under the three primary CCl_4 disposal facilities. The concentrations volatilizing from the groundwater plume are assumed to be in equilibrium with groundwater concentrations for 1991 (DOE 1991). The residual CCl_4 concentrations are estimated from soil-gas concentrations measured in baseline monitoring wells between December 1991 and September 1992 (Fancher 1993).

5.2.1 Near-Surface Soil-Gas Surveys

Soil-gas investigations fall into two main activities: baseline monitoring of selected soil-gas ports and conducting new soil-gas surveys throughout the VOC-Arid ID/ERA site. A description of these activities is presented in Rohay et al. (1992b) and Fancher (1993).

The soil-gas-sampling network consists of 22 soil-gas probes installed during FY 1991 near the 216-Z-18 crib (DOE 1991) and 60 soil-gas probes installed along 4 transects in FY 1992 (Rohay et al. 1992a) (Figure 5.2). Selected probes in the FY 1991 network have been monitored approximately twice per week since December 1991 using an organic vapor monitor. The details of this baseline monitoring are discussed by Fancher (1993). Soil-gas samples from all 60 FY 1992 probes were analyzed in a mobile laboratory for VOCs via gas chromatography and measured in the field for carbon dioxide (CO_2), oxygen (O_2), and total organic vapor concentrations.

5.2.1.1 Gas Chromatograph Analyses

The constituents detected and their maximum values are shown in Table 5.1 (refer also to Figure 5.2). Figures 5.3 and 5.4 illustrate the distribution of CCl_4 and $CHCl_3$, respectively, as measured in May 1992. By far, the largest concentration of CCl_4 and $CHCl_3$ appears to be located just to the north of the 216-Z-9 trench. These plumes were drawn using GeoView™ (Computer Systems, Austin, Texas), which uses a moving,

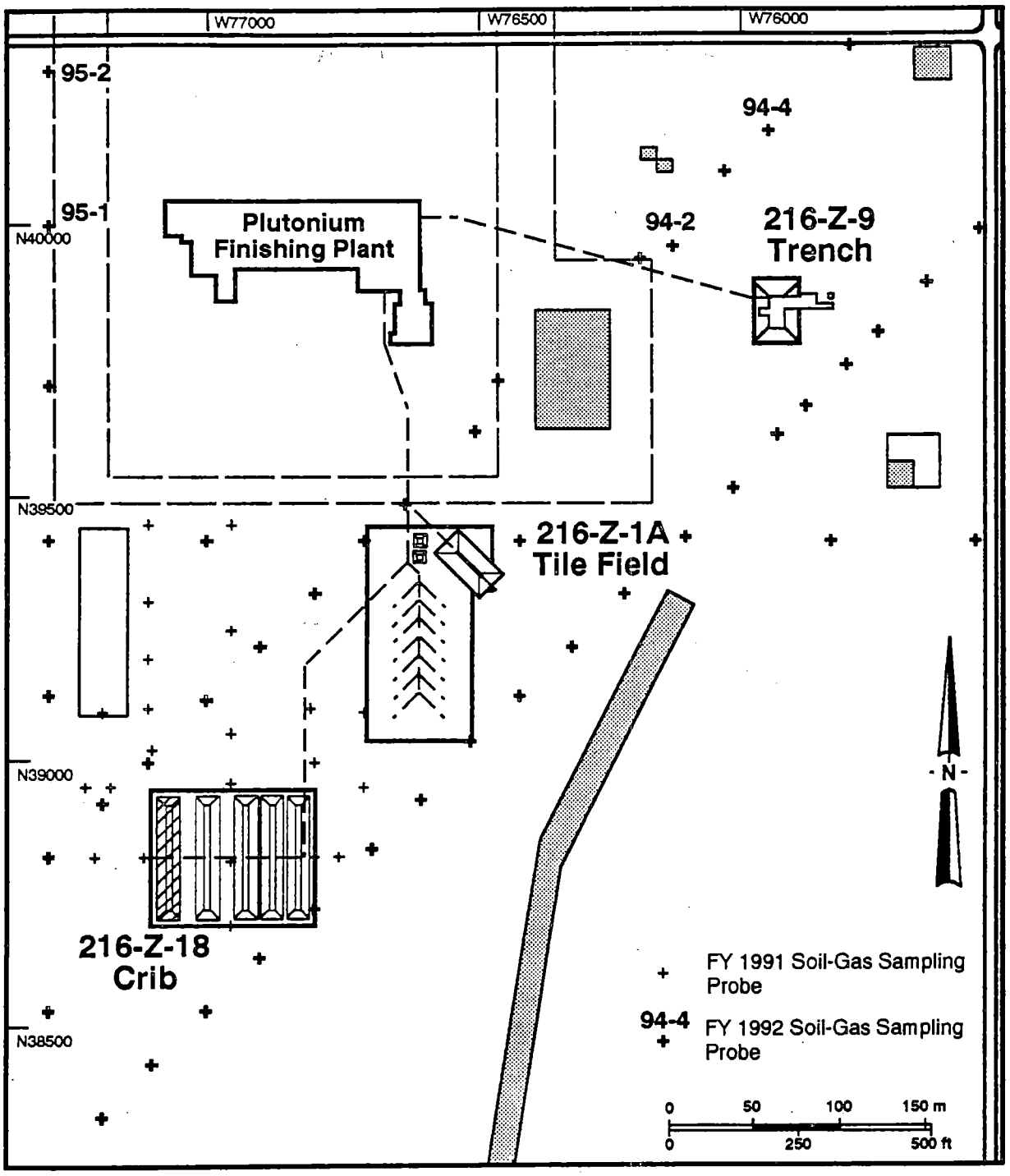


Figure 5.2. Soil-Gas Sampling Network

Table 5.1. Maximum Concentrations of Volatile Organic Compounds Detected in Samples from FY 1992 Soil-Gas Probes

	CCl_4 (ppmv)	$CHCl_3$ (ppmv)	TCE (ppmv)	PCE (ppmv)
Maximum concentration	72.7	0.92	0.08	0.06
Soil-gas location	94-4	94-2	95-2	95-1

CCl_4 = Carbon tetrachloride
$CHCl_3$ = Chloroform
PCE = Perchloroethylene
TCE = Trichloroethylene

weighted, least-squares surface to interpolate values on a 33- by 25-mesh grid. Extension of the plumes to the north, away from our sampling transects, is considered to be an artifact of this interpolation scheme and is not bounded by any sampling data.

5.2.1.2 Carbon Dioxide and Oxygen Screening

On August 6 and 7, 1992, all but two (those inside the PFP protected area) of the soil-gas probes were measured in the field for CO_2 and O_2 content using a Gastechtor Model 32520X (Gastech, Inc., Newark, California). Figures 5.5 and 5.6 illustrate the distribution of these constituents. Again, the concentration maps are subject to the same limitations noted above. The locations of high CO_2 (>0.5%) and low O_2 (<19.9%) content have been correlated with their proximity to each other, a backfilled ditch (and the presence of numerous insects in the soil-gas housing), a small surface depression near the intersection of two dirt roads, or a relatively new sanitary tile field.

5.2.1.3 Passive Soil-Gas Technology Demonstrations

Two passive soil-gas technologies were deployed at the site for demonstration purposes. The EMFLUX® technology was deployed on August 6 and retrieved on August 10, 1992. The emission flux rates from the vicinity of the 216-Z-9 trench ranged from 111 to 686 ng/m^2/min (Table 5.2). Figure 5.7 shows the location of each sample. These data indicate that the highest flux rate of CCl_4 from the soil/air interface is northeast of the 216-Z-9 trench, suggesting that higher near-surface concentrations of CCl_4 are located there. However, it is puzzling that $CHCl_3$ was not detected at all of the sampling points.

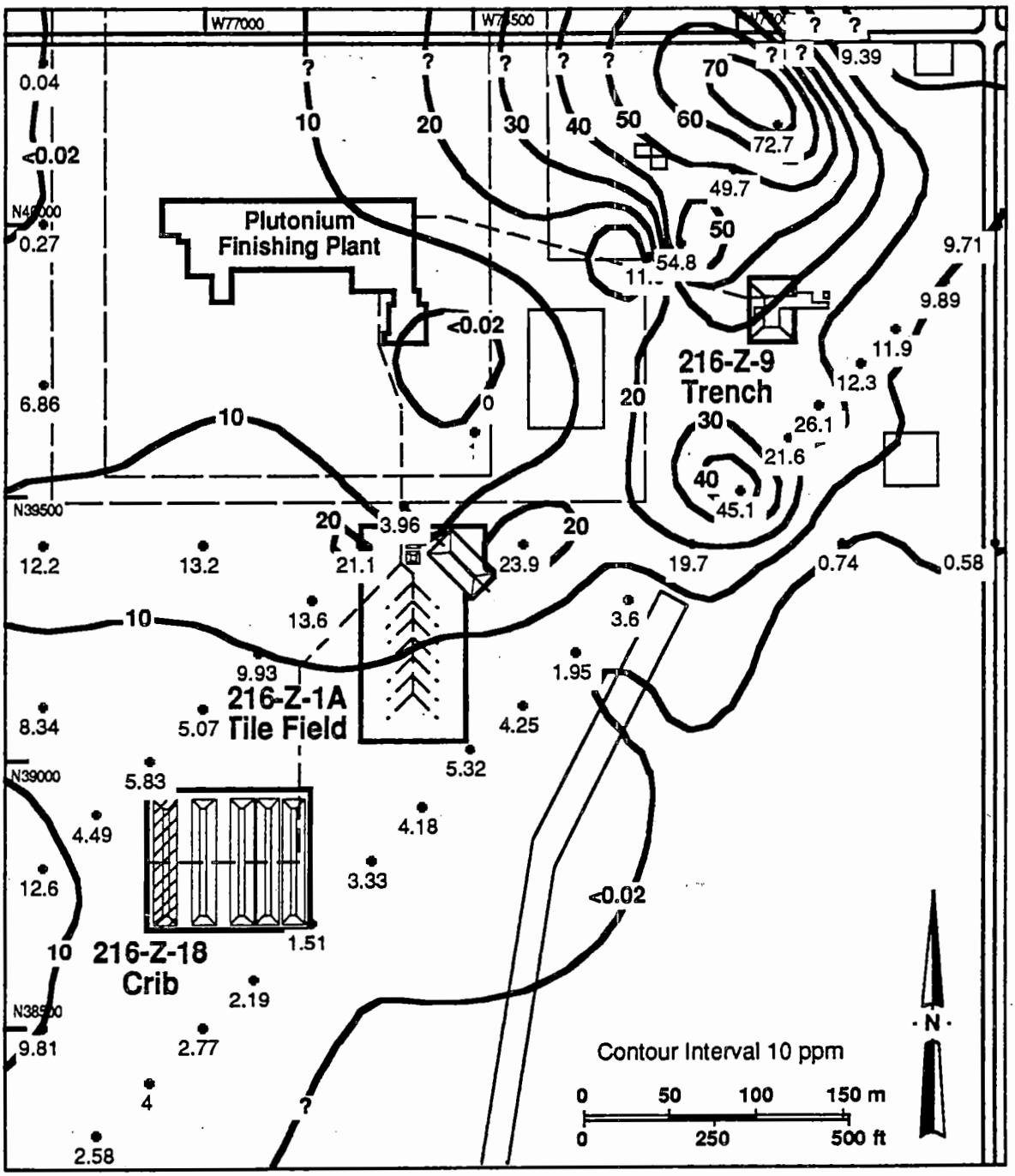


Figure 5.3. Carbon Tetrachloride Soil-Gas Concentrations - May 1992

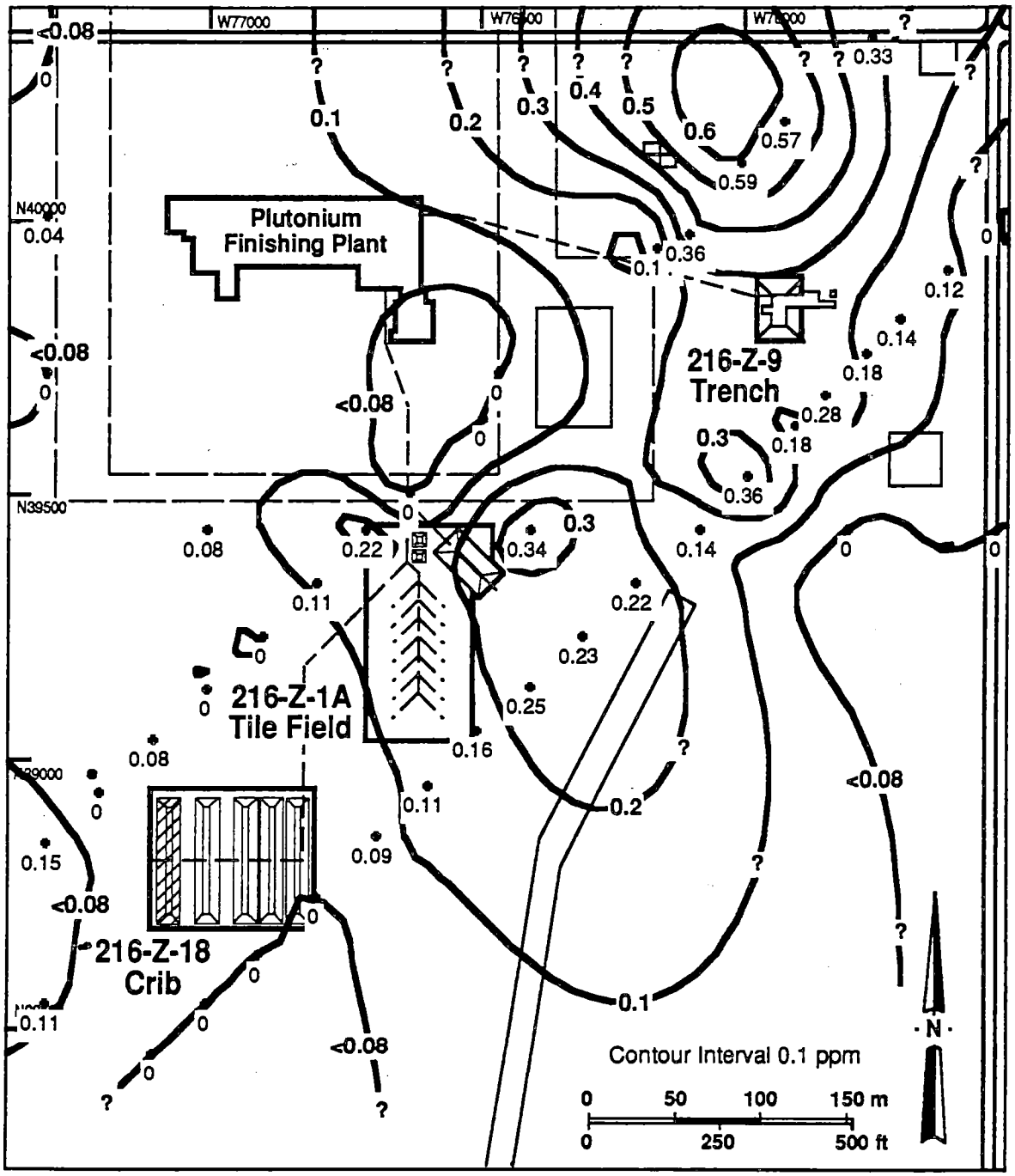


Figure 5.4. Chloroform Soil-Gas Concentrations - May 1992

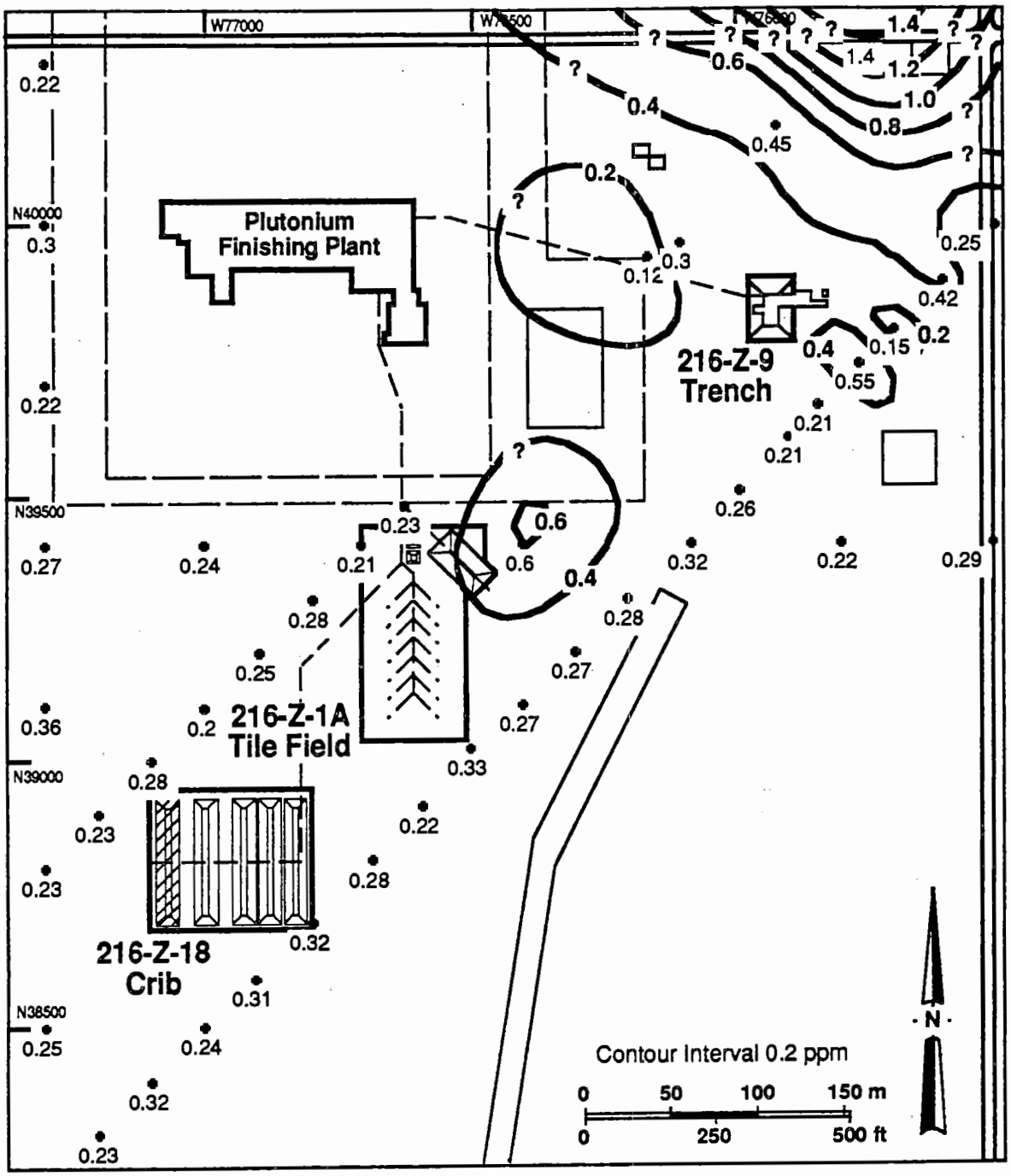


Figure 5.5. Carbon Dioxide Soil-Gas Concentrations - August 1992

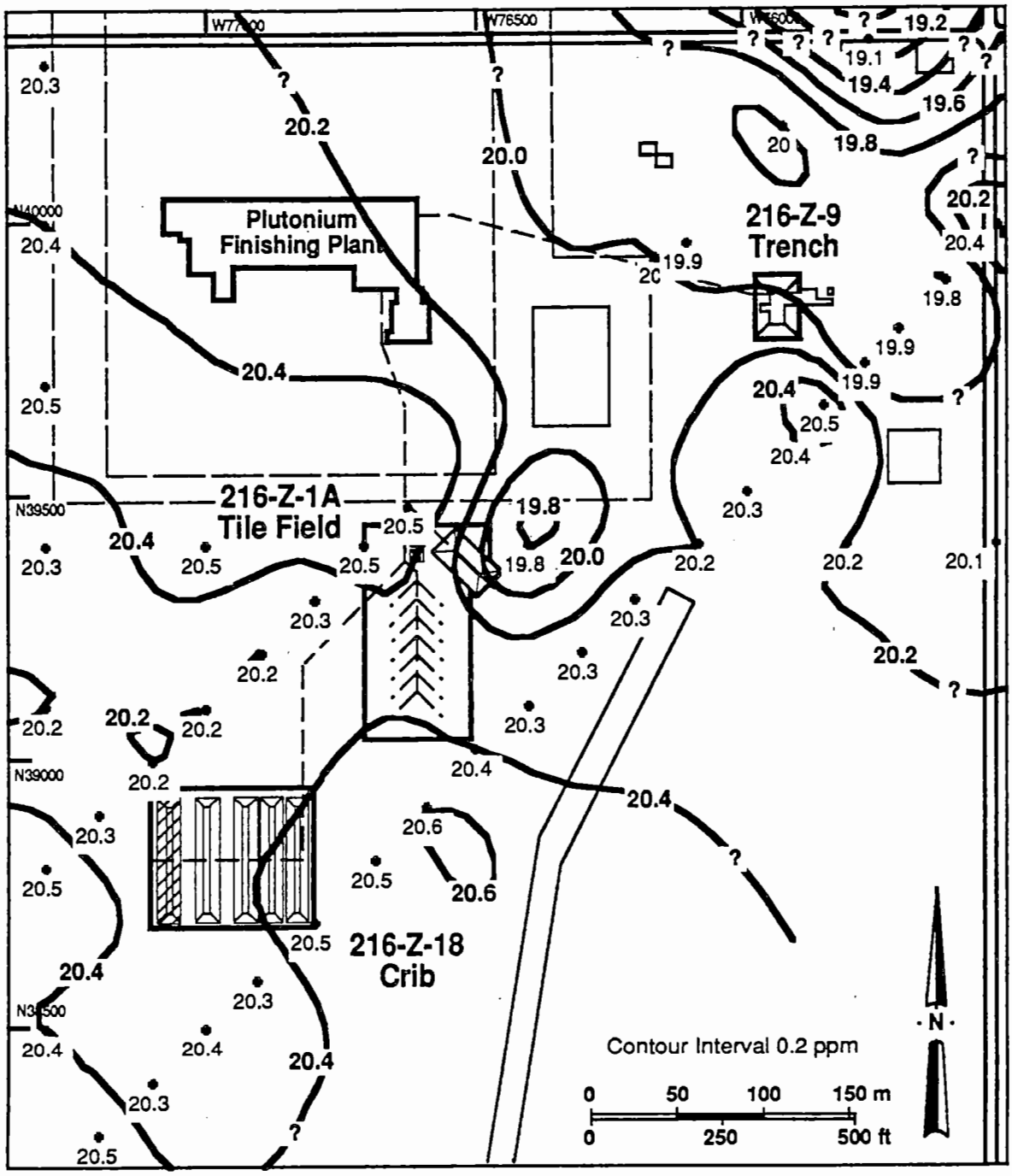


Figure 5.6. Oxygen Soil-Gas Concentrations - August 1992

Table 5.2. EMFLUX® Emission Flux Rates ($ng/m^2/min$)

	Sample Location									
	1	2	3	4	5	6	7	8	9	10
Carbon tetrachloride	111.3	349.5	199.5	127.4	280.2	686.3	227.2	198.7	230.2	---
Chloroform	0.8	2.3	1.1	---	---	18.3	3.4	2.2	1.4	---
Tetrachloroethylene	---	10.4	---	---	---	2.4	9.4	4.4	0.8	---
Toluene	---	1.6	---	---	---	---	---	---	---	---
Acetone	---	2.8	---	---	---	---	1.6	---	---	---

--- Denotes values below the reported quantitation level.

The PETREX technology (owned and operated by the Northeast Research Institute, Inc., Farmington, Connecticut) was deployed on August 11, 1992 and the last of the samplers was recovered on September 17, 1992. The results of these analyses have not yet been fully received.

5.2.1.4 Baseline Monitoring

Eleven of the FY 1991 soil-gas probes have been monitored twice per week between December 1991 and September 1992 (Fancher 1993). Total VOC concentrations measured using an organic vapor monitor have ranged from 0 to over 10 ppmv at each probe during this time. The highest concentration observed was 97 ppmv as probe N-9 northwest of the 216-Z-1A and - 18 disposal facilities (see Figure 5.2). The distribution of these maximum values for the FY 1991 network is consistent with the results of the May 1992 measurements of the FY 1992 soil-gas network, which also indicates relatively higher $CC1_4$ concentrations northwest of these disposal facilities (see Figure 5.3). The baseline soil-gas network has since been expanded to include probes near the 216-Z-9 trench.

5.2.2 Subsurface Soil-Gas Measurements

Concentrations of CCl_4 in the vadose zone have been detected in the soil-gas samples during baseline monitoring of wells and two deep soil-gas probes, in the soil gas extracted by the vapor-extraction system, at the well heads during drilling, and in the in situ soil-gas samples collected during drilling.

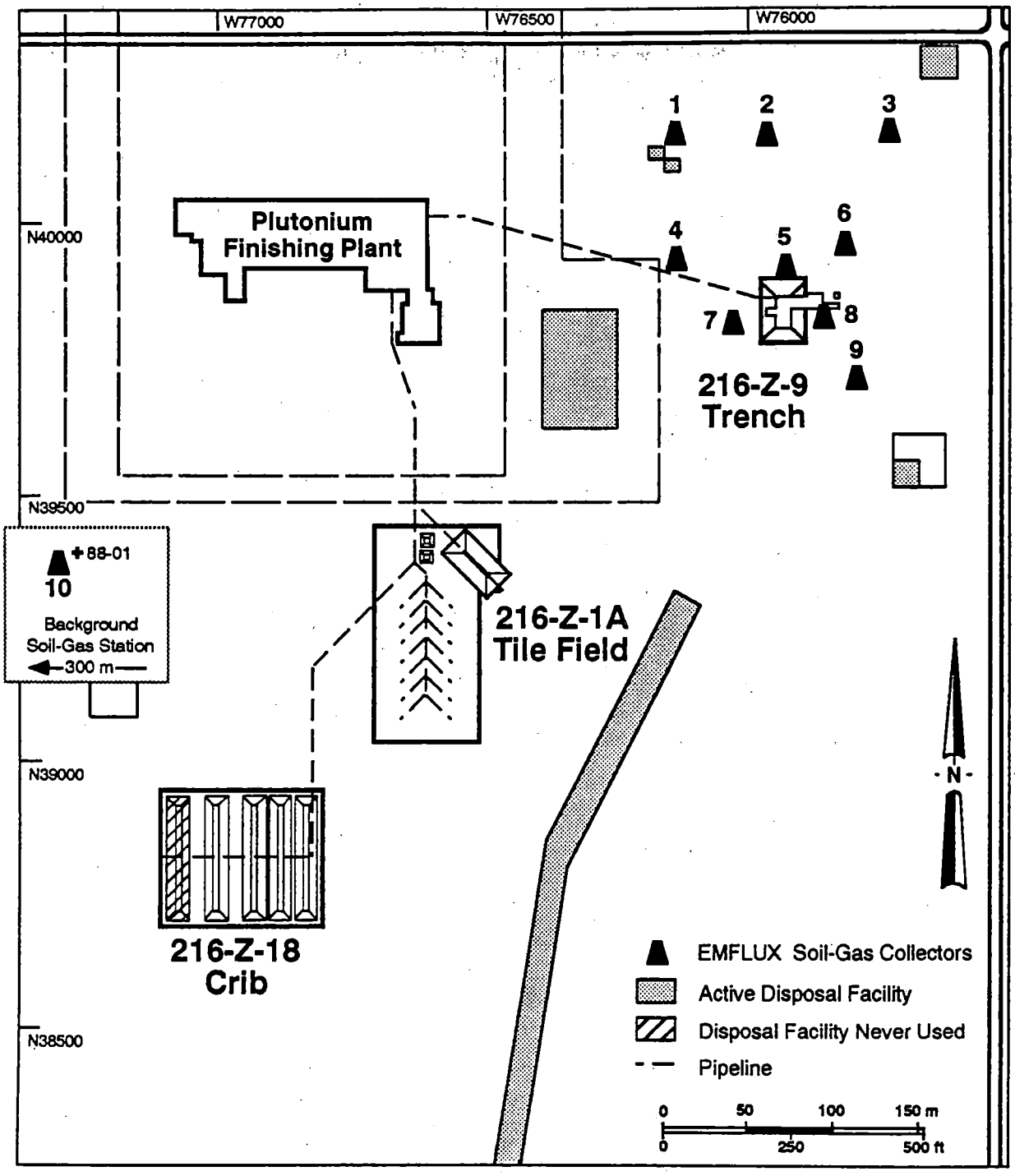


Figure 5.7. EMFLUX® Soil-Gas Collector Locations

5.2.2.1 Baseline Monitoring

As part of the baseline monitoring program for the vapor-extraction system (Fancher 1993), 43 wells and 2 deep soil-gas probes have been monitored twice per week since December 1991. The two deep soil-gas probes were emplaced near the 216-Z-9 trench using a cone penetrometer: one probe, located near well 299-W15-6, was emplaced at the 20-m depth; the other probe is located near wells 299-W15-84 and -217 and was emplaced at the 12-m depth. The wells and deep soil-gas probes are monitored using an organic vapor monitor. The only VOC is assumed to be CCl_4, based on its predominance in samples analyzed via gas chromatography. The contaminant concentrations fluctuate in response to changes in the barometric pressure; observed CCl_4 concentrations (measured as total organic vapor) range from 0 to over 10,000 ppmv (Fancher 1993).

Because a zero reading may be indicative of an inhalation event, the maximum baseline monitoring value for each well is judged to have the greatest likelihood of representing equilibrium conditions. The maximum values for the baseline monitoring well and deep soil-gas probe network measured between December 1991 and September 1992 (WHC 1993) are contoured in Figure 5.8. In constructing this figure, it was assumed that the wells are comparable despite their differing ages, locations, depths, and completions. In addition, the distribution of the vapor shown on this figure may be limited by the extent of the well network. The baseline well network includes wells open to the vadose zone above the caliche and wells open below the caliche. VOC concentrations exceeding 10,000 ppmv were observed from intervals both above and below the caliche north/northeast of the 216-Z-9 trench. VOC concentrations exceeding 1,000 ppmv were observed from intervals both above and below the caliche northwest of the 216-Z-1A tile field and 216-Z-18 crib. These data suggest that CCl_4 vapors, and/or liquids that diffuse into the vapor phase, may be migrating laterally in different directions away from these waste disposal facilities.

5.2.2.2 Vapor-Extraction System Sampling

Downhole soil-vapor sampling was conducted during pilot tests of the vapor-extraction system at the 216-Z-1A tile field in April 1991 (DOE 1991). The initial tests were conducted at four wells (299-W18-87, -150, -167, and -171) to assess the vertical and lateral distribution of VOCs. During these tests, the vapor-extraction system was operated at its lowest sustainable flow rate (approximately 1.4 m^3/min), and gas samples were collected from the inlet piping. The samples were analyzed in a laboratory using a gas chromatograph/mass spectrometer. These tests found that the CCl_4 vapor concentrations generally increased with depth below the ground surface at the tile field. The highest concentration was 100 ppmv from well 299-W18-150 at a depth of approximately 26 m. The test results

9 3 1 2 9 7 0 1 1 8 7

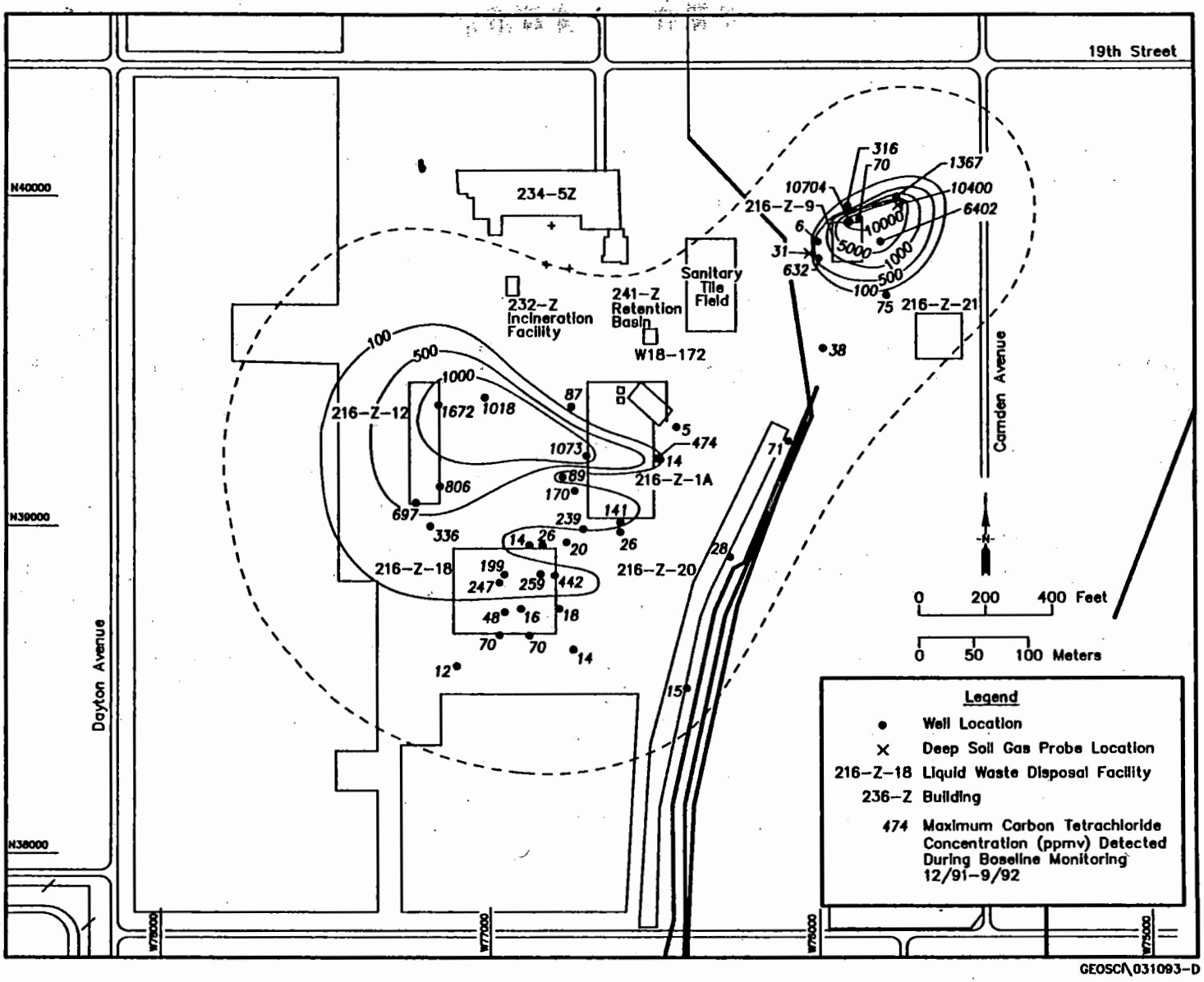


Figure 5.8. Maximum Carbon Tetrachloride Concentrations Measured in Baseline Monitoring Well and Deep Soil-Gas Probe Network December 1991-September 1992 (from WHC 1993).

further indicated that concentrations of CCl_4 (up to 89 ppmv) had migrated to a depth of at least 40 m below the tile field and laterally at least 24 m outside the perimeter of the tile field, based on the tests conducted at well 299-W18-87.

Long-term vent tests were conducted at wells 299-W18-167 and -171. An 80-h venting test was conducted at well 299-W18-171 in the 35- to 42-m-depth interval in April 1991. During this test, the initial CCl_4 concentration was 200 ppmv, which gradually increased to 600 to 700 ppmv after 30 h of venting. A peak of 915 ppmv was observed 67 h into the test. The venting flow rate was 8.5 to 8.8 m^3/min, with a well vacuum of 89 to 102 cm of water. This vent test produced an apparent induced vacuum at well 299-W18-150, approximately 21 m away (DOE 1991). Air permeability testing of a slightly silty, medium to fine sand unit at the approximate 18-m depth in well 299-W18-171 yielded permeability estimates ranging from 2 to 5.7 darcies (DOE 1991). A 24-h vent test was conducted at well 299-W18-167 in the 35- to 36-m-depth interval. At this well, CCl_4 concentrations remained fairly constant, between 180 and 200 ppmv (DOE 1991).

Vapor samples collected during these pilot tests at the 216-Z-1A tile field were also analyzed for other VOCs. $CHCl_3$ was detected but it was below the quantitation limits, which ranged from 5 to 10 ppmv (DOE 1991).

The vapor-extraction system began operating at the tile field in February 1992, using existing wells perforated at the approximate 35-m depth. In general, the wells are perforated across the contact between a finer grained and coarser grained unit. Usually, the vapor-extraction system has been extracting from four wells simultaneously. When the CCl_4 concentration in an extraction well drops significantly, the vapor-extraction system is switched to a different well to optimize production. Average CCl_4 concentrations in the combined vapor stream drawn from wells within the tile field have gradually increased from approximately 400 ppmv in August 1992 to approximately 1,000 ppmv in November 1992 at average flow rates ranging from 124 to 210 ft^3/min. The increase in CCl_4 suggests that the vapor plume is steadily being drawn in toward the extraction wells by the vapor-extraction system.

5.2.2.3 Well Head Detections

CCl_4 or chlorinated hydrocarbons have been detected at the well head using field-screening instruments during drilling in over half of the 99 wells drilled in the 200 West Area between January 1987 and September 1992 (Figure 5.9). The wells are differentiated with respect to whether the organic was detected from intervals above and/or below the Plio-Pleistocene caliche layer, which occurs at depths of approximately 40 m in the 200 West Area and is up to 15 m thick. Most of the reported detections were below the caliche

9 3 1 2 9 7 0 1 1 8 9

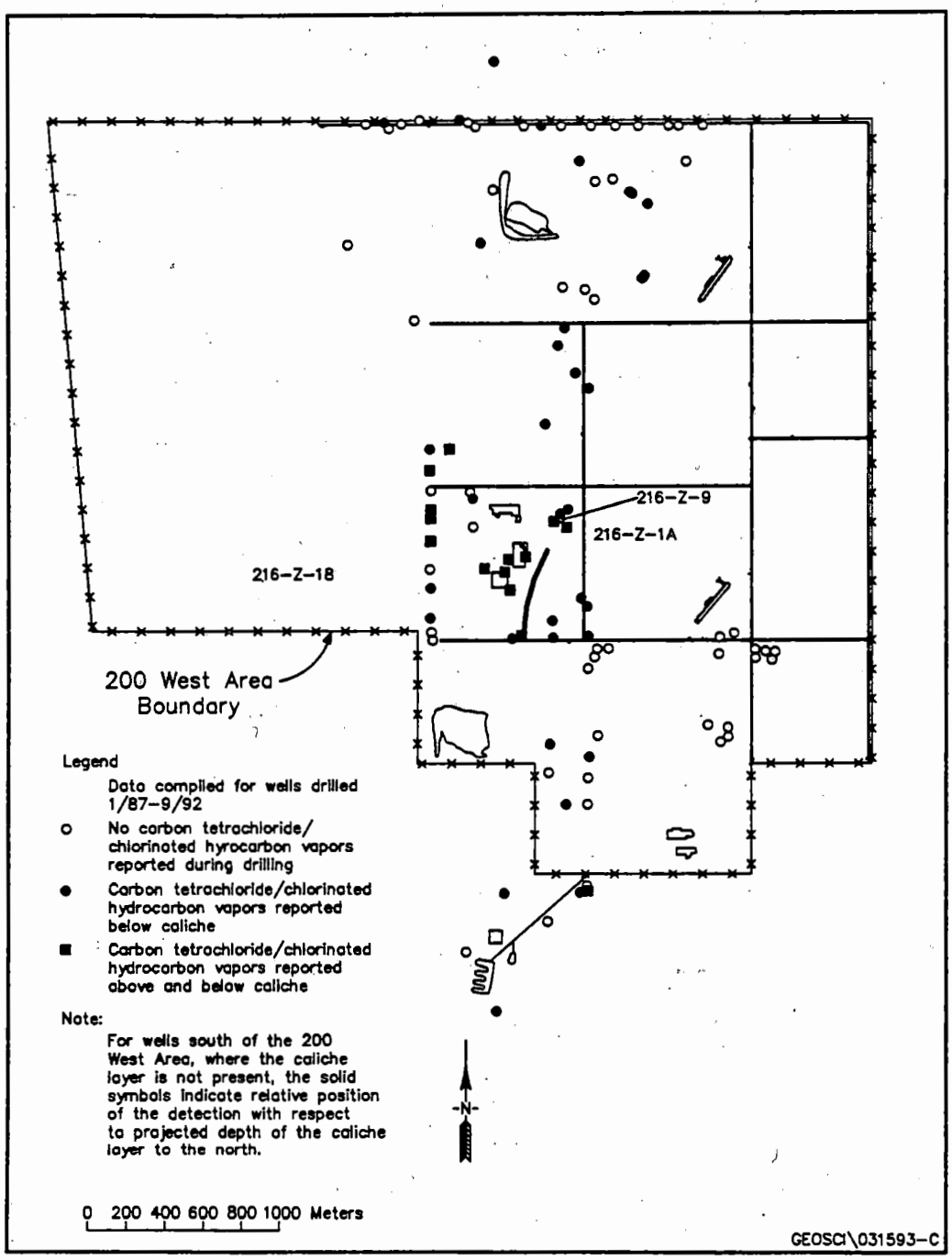


Figure 5.9. Location of Volatile Organic Compounds Detected Above and Below the Caliche Layer During Well Drilling from January 1987 to September 1992

layer, though all wells drilled adjacent to the CCl_4 disposal facilities, and some wells drilled west and south of the 216-Z-18 crib, had detections both above and below the caliche layer. It should be noted that CCl_4 vapor may be present in the subsurface but remain undetected at the well head if the well is not venting during drilling operations. The CCl_4 vapor observed above the caliche layer may have been transported via density-driven vapor-phase flow and diffusion down to and along the caliche surface or it may have volatilized from sorbed or migrating liquid-phase CCl_4.

5.2.2.4 In Situ Soil-Gas Sampling

In situ soil-gas samples were collected using the Science & Engineering Associates Membrane Instrumentation and Sampling Technique (SEAMIST; Santa Fe, New Mexico) during drilling of six wells adjacent to the CCl_4 disposal facilities during 1992 (Rohay and McLellan 1992). SEAMIST uses a sample tube lowered into the borehole, followed by an impermeable membrane that is deployed by pressurized air. The membrane is forced out of a canister (where it is tightly rolled and contained) by eversion into the borehole. As the membrane is deployed, it presses against the borehole casing wall (i.e., in the same manner as continuous packer). The displaced air is pumped out of the well, filtered for contaminants, and discharged into the air at the surface. The sample tube is used to collect vapor samples from the formation at the bottom of the borehole. A pump is used to pull the vapor to the surface, where it is screened with a field-monitoring device until the level of the contaminant has reached its maximum concentration, at which point a syringe sample is collected for analysis using gas chromatography.

A total of 37 samples were collected from depths ranging from 6 to 60 m. In general, concentrations of CCl_4 were highest in soil-gas samples collected within the early Palouse soil and Plio-Pleistocene unit but were higher also in samples from other fine-grained units. The highest concentrations of CCl_4 were detected in soil-gas samples from well 299-W15-217 adjacent to the 216-Z-9 trench. In that well, CCl_4 concentrations appear to increase with depth toward the caliche. The deepest SEAMIST sample from well 299-W15-217 was analyzed via gas chromatography and indicated 7,125 ppmv CCl_4 at the 24-m depth.

5.2.3 Borehole Sediment Sampling

Borehole (sediment) samples were collected from 6 recently drilled wells: 3 wells installed juxtaposed to the cribs (so called "crib wells") and 3 wells installed away (25 to 50 m) from the cribs (so called "near-field wells"). Groundwater samples were also collected during the drilling of the three near-field wells. Figure 5.10 illustrates the location of these wells.

9 3 1 2 9 7 0 1 1 9 1

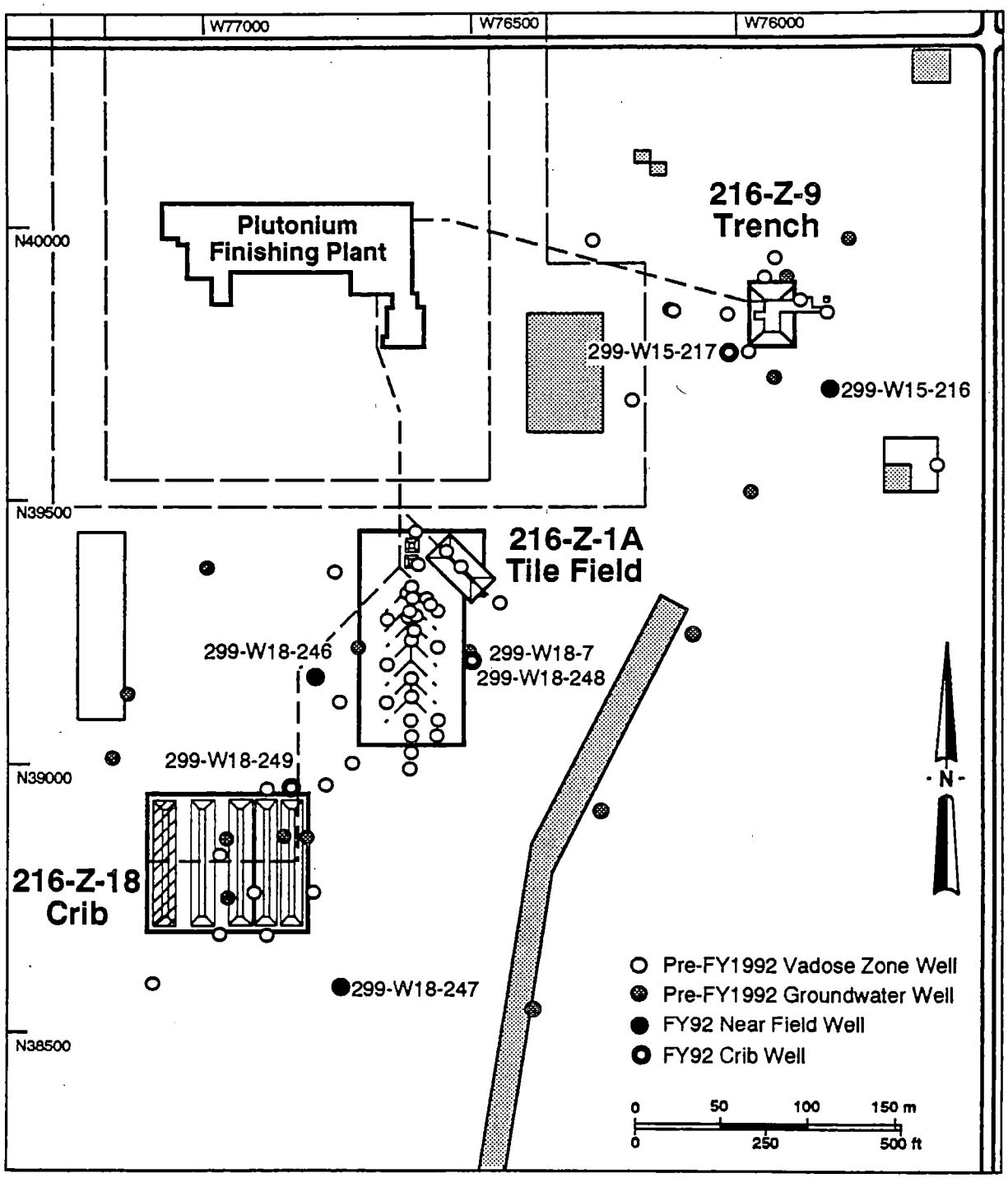


Figure 5.10. Location Map of Crib and Near-Field-Monitoring Wells

The three near-field vadose-zone-monitoring/vapor-extraction wells (299-W15-216, 299-W18-246, and 299-W18-247) were drilled in the vicinity of the three waste disposal facilities to further refine the conceptual model and to support vapor-extraction system operations. Of principal interest was the nature and distribution of CCl_4 and co-contaminants in the vadose zone. The well locations were selected to aid investigation of whether CCl_4 liquid and/or vapor is draining by density transport down the slopes of a local Plio-Pleistocene ridge (see Appendix B). These boreholes were drilled approximately 6 m into the unconfined aquifer. Sediment samples were collected for chemical analyses approximately every 6 m and groundwater samples were collected approximately every 1.5 m. The lower portion of the borehole was then grouted and the wells completed with two 3-m screened intervals: one just below and one just above the Plio-Pleistocene unit (Appendix D).

The three crib-monitoring wells (299-W15-217, 299-W18-248, and 218-W249) were installed (one each) adjacent to each of the three waste disposal facilities (see Figure 5.10) to further refine the conceptual model. Of principal interest was identification of the VOCs and co-contaminants present, the phase of these constituents, their concentration, and their distribution in the immediate vicinity of the cribs. These wells were drilled only to the top of the Plio-Pleistocene unit and were completed as vapor-extraction wells with a 4.6-m screened interval situated to span the contact between the early Palouse soil and lower Hanford formation sediments (see Appendix D). Sediment samples were collected for chemical analyses approximately every 1.5 m.

Details on the drilling and completion activities, materials encountered, and sampling and handling methods used can be found in Rohay et al. (1992b). Construction details for these wells are summarized in Appendix D. Table 5.3 lists the chemical and radiological analytes determined for sediment and groundwater samples from these wells. Target constituents not analyzed include dibutyl phosphate, dibutyl butyl phosphonate (DBBP), monobutyl phosphate, triglycerides, aluminum, rubidium, plutonium, americium, and strontium (WHC 1991). These analyses were prohibitively expensive and, thus, were either not analyzed for or a less expensive screening-type analysis (e.g., gross alpha, gross beta) was substituted. Results of these analyses are included in Appendix E. The following discussions summarize the sediment and groundwater sample results, addressing the nature and distribution of contaminants found in the vadose zone and groundwater beneath and adjacent to each waste disposal facility.

5.2.3.1 216-Z-9 Trench

Well 299-W15-216 is located approximately 46 m southeast of the 216-Z-9 trench, while well 299-W15-217 is located approximately 12 m southwest of the trench. Table 5.4

Table 5.3 Chemical and Radiological Analytes Determined in Sediment and Groundwater Samples

Volatile Organics[a]	Anions[a]	Semivolatile Organics[a]	Metals[a]	Radionuclides
Methylene chloride	**Fluoride**	o-Creosol	Antimony	Soil Analytes
trans-1,2-Dichloroethylene	**Chloride**	m-Creosol	Barium	^{60}Co
1,1-Dichloroethane	**Nitrate ion**	p-Creosol	Beryllium	^{106}Ru
cis-1,2-Dichloroethylene	Nitrite ion	Decane	**Cadmium**	^{125}Sb
Chloroform	Bromide	Dodecane	**Calcium**	^{137}Cs
1,1,1-Trichlorethane	**Phosphate**	Tetradecane	**Chromium**	^{212}Pb
Carbon tetrachloride	**Sulfate**	Napthalene	Cobalt	^{214}Pb
1,2-Dichloroethane		Pentachlorophenol	Copper	^{226}Ra
Benzene		Phenol	**Iron**	^{224}Ra
Trichloroethylene		**Tributyl phosphate**	**Magnesium**	Total alpha activity
Toluene			Manganese	Total beta activity
Tetrachloroethylene			**Nickel**	
Ethylbenzene			Potassium	Water Analytes
M+P-xylene			Silver	^{60}Co
O-xylene			Sodium	^{106}Ru
Acetone			Tin	^{125}Sb
			Vanadium	^{137}Cs
			Zinc	Total Alpha
				Total Beta
			Soil Analytes	
			Cyanide	
			Mercury	
			Lead	

(a) Unless specifically designated, analyses for these constituents were performed for both the sediment and groundwater samples.
Bold analytes are target constituents believed disposed to the facilities of interest (WHC 1991).

summarizes the maximum concentration of target analytes and other constituents of interest detected in these wells. Well 299-W15-217 had the highest CCl_4 concentration observed in a sediment sample to date (37,817 ppb), which was found at a depth 34.7 m. Note that the maximum CCl_4 and $CHCl_3$ concentrations decreased dramatically (two to three orders of magnitude) between the crib well (299-W15-217) and the near-field well (299-W15-216). However, the maximum concentration of methylene chloride was found in the near-field well. Methylene chloride is a common laboratory contaminant and, thus, these results may not be representative of actual vadose zone concentrations. Note that minor concentrations of trichloroethylene (TCE); tetrachloroethylene (perchloroethylene; PCE); and their degradation products, trans-1,2-dichloroethylene (trans-1,2-DCE), 1,1-dichloroethane (1,1-DCA), and 1,1,1-trichlorethane (1,1,1-TCA), were also detected in the crib well. Only PCE was detected in the near-field well. Minor concentrations of benzene, toluene, and xylene (BTX) compounds were also found in the crib well, while only toluene was detected in the near-field well. Figures 5.11 and 5.12 illustrate the vertical distribution of selected volatile organics relative to the stratigraphy and moisture content of

Table 5.4. Maximum Concentration of Target Constituents from Wells Near the 216-Z-9 Trench

Analyte	Units	Detection Level	Crib Well 299-W15-217 Max. Soil Conc.	Depth (m)	Near-Field Well 299-W15-216 Max. Soil Conc.	Depth (m)	Near-Field Well 299-W15-216 Max. GW Conc.
Target Volatile Organics							
Methylene chloride	ppb	5[a]	669	30.9	2,754	15.1	630
$CHCl_3$	ppb	2[a]	248	34.7	<2		976
CCl_4	ppb	2[a]	37,817	34.7	67	15.1	4,479
TCE	ppb	2[a]	13	34.7	<2		0.9
PCE	ppb	2[a]	28	34.7	7	15.1	2.6
MEK	ppb	2[a]	NR		NR		NR
Other Volatile Organics							
trans-1,2-DCE	ppb	2[b]	8	7.5	<5		<0.5
1,1-DCA	ppb	2[b]	18	34.7	<5		1.2
1,1,1-TCA	ppb	2[b]	3	34.7	<2		<2
Benzene	ppb	2[b]	3	16.5-24.6	<2		<0.5
Toluene	ppb	2[b]	400	35.2	348	35.4	<0.5
Ethylbenzene	ppb	2[b]	4	35.2	<2		<0.5
M+P-xylene	ppb	2[b]	~9	35.2	<2		<0.5
O-xylene	ppb	2[b]	~3	35.2	<2		<0.5
Acetone	ppb	2[b]	NR		ND		~19
Target Semivolatile Organics							
TBP	µg/kg	58	62[b]	24.6	ND		ND
DBP			NA		NA		NA
DBBP			NA		NA		NA
MBP			NA		NA		NA
Triglycerides (lard oil)			NA		NA		NA
Other Semivolatile Organics							
Decane	µg/kg	54	ND		ND		ND
Dodecane	µg/kg	31	ND		ND		ND
Tetradecane	µg/kg	52	ND		ND		ND
Phenol	µg/kg	49	220[b]	30.9	ND		ND
Unknown oxyhydrocarbon	µg/kg		28,000	6.3	NR		ND
Target Metals							
Aluminum			NA		NA		NA
Iron	µg/kg	2,000	31,000,000	7.8	25,000,000	36.8	110,000
Cadmium	µg/kg	1,000	ND		ND		ND
Magnesium	µg/kg	10,000	7,700,000	37.1	12,000,000	35.5	21,000
Chromium	µg/kg	2,000	21,000	24.6	18,000	33.7	62
Nickel	µg/kg	3,000	20,000	24.6	31,000	39.2	67

Table 5.4. (contd)

Analyte	Units	Detection Level	Crib Well 299-W15-217 Max. Soil Conc.	Depth (m)	Near-Field Well 299-W15-216 Max. Soil Conc.	Depth (m)	Near-Field Well 299-W15-216 Max. GW Conc.
Target Anion/Cations							
Chloride	µg/kg	400	54,000	24.6	1,900	36.8-39.2	14,000
Fluoride	µg/kg	200	2,600	37.1	1,300	35.5-36.8	800
Calcium	µg/kg	10,000	140,000,000	37.1	160,000,000	35.5	51,000
Nitrate	µg/kg	400	1,600,000	37.1	6,500	15.0	2,300
Sulfate	µg/kg	1,000	69,000	24.6	15,000	36.8	16,000
Phosphate	µg/kg	800	ND		ND		ND
Target Radionuclides							
Plutonium			NA		NA		NA
Americium			NA		NA		NA
^{90}Sr			NA		NA		NA
Uranium			NA		NA		NA
Gamma emitters							
^{60}Co	pCi/L						2.9
^{106}Ru	pCi/L						29.5
^{125}Sb	pCi/L						6.84
^{137}Cs	pCi/L						3.47
^{212}Pb	pCi/g		1.01	35.3	1.35	33.8	NR
^{214}Pb	pCi/g		1.73	37.1	1.16	33.8	NR
^{226}Ra	pCi/g		1.66	37.1	1.17	33.8	NR
^{224}Ra	pCi/g		1.01	35.3	1.38	33.8	NR
Gross alpha	pCi/g		11.1	37.1	10.7	15.2	17.5
Gross beta	pCi/g		27.5	16.6	24.8	15.2	15.1

(a) Detection level varies with sample size and dilution factor.
(b) Below limit of quantitation.
GW = Groundwater.
NA = Not analyzed.
ND = Not detected.
NR = Not reported.

wells 299-W15-216 and -217, respectively. Note that the highest concentrations of volatile organics were found at approximately the 35-m depth (in the early Palouse soil) of the crib well (see Figure 5.12).

Probably the most significant findings of the semivolatile analyses were the detection of tributyl phosphate (TBP) in one sample at the 24.6-m depth of well 299-W15-217 and undetermined oxyhydrocarbons (possibly related to lard oil) at the 6.3-m depth. These have been the only detections of these compounds in any well (new or existing) to date. Phenol was also detected in one sample from the crib well. Several other phenolic compounds, shown as being detected in the analysis tables in Appendix E, are laboratory surrogates added to the sample to track the analytical technique.

THIS PAGE INTENTIONALLY
LEFT BLANK

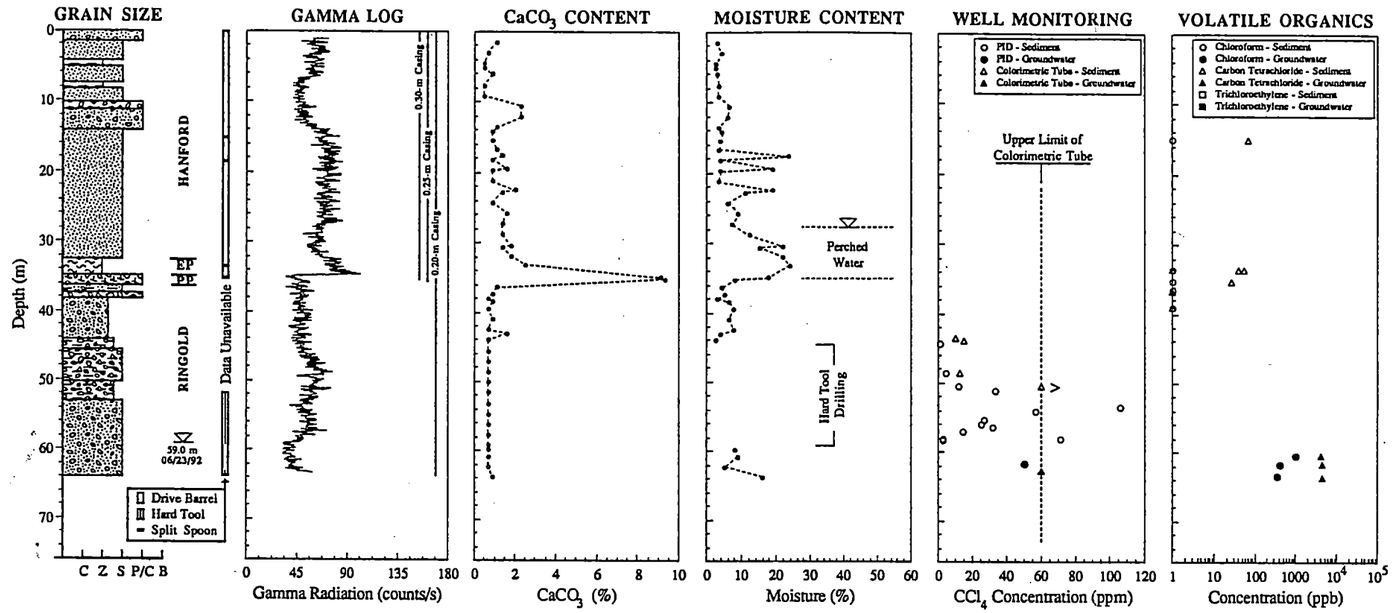


Figure 5.11. Analytical Results for Well 299-W15-216

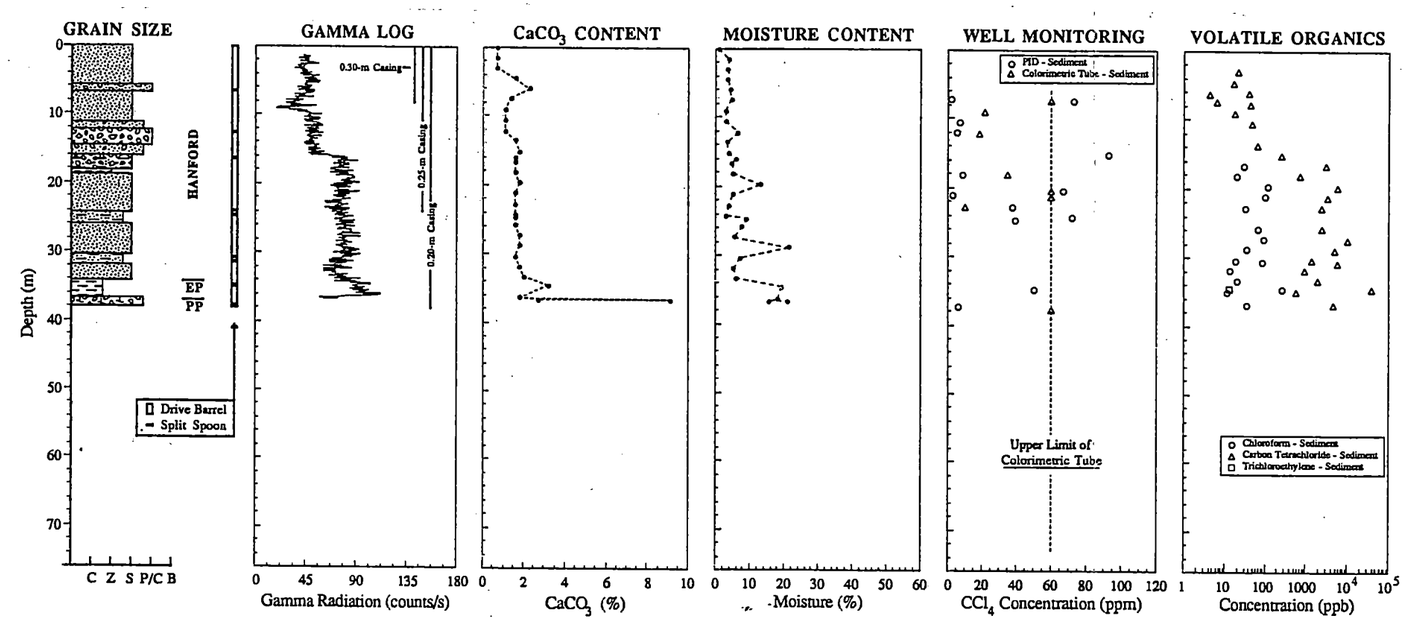


Figure 5.12. Analytical Results for Well 299-W15-217

THIS PAGE INTENTIONALLY
LEFT BLANK

Also worthy of note are the high concentrations of nitrate found in the crib well below the 25-m depth. This suggests the presence of aqueous nitrate wastes disposed to this trench.

Groundwater samples collected from well 299-W15-216 contained high maximum concentrations of CCl_4 (4,479 ppb), $CHCl_3$ (976 ppb), and methylene chloride (630 ppb) (see Table 5.4 and Appendix E). Trace amounts (up to 2.6 ppb) of TCE, PCE, and 1,1-DCA were detected, as was acetone (up to ~19 ppb). Minor amounts of fission products (e.g., up to 29.5 pCi/L ^{106}Ru) were also detected. It should be noted that the three groundwater samples from this well were collected at different depths while drilling of the well progressed. These samples were collected with a teflon bailer, after some attempt was made to develop the formation and the mud was allowed to settle out. Thus, these samples should not be considered totally representative of the aquifer.

5.2.3.2 216-Z-1A Tile Field

Well 299-W18-246 is located approximately 30 m west of the 216-Z-1A tile field, and well 299-W18-248 is located approximately 5 m east of the tile field, juxtaposed to well 299-W18-7. Table 5.5 summarizes the maximum concentration of target analytes and other detected constituents of interest for wells 299-W18-246 and -248; note that the maximum concentrations of CCl_4 are only approximately 30% higher in well 299-W18-246, west of the tile field, than in well 299-W18-248 to the east. Only slight amounts of $CHCl_3$, TCE, and PCE were found in crib well 299-W18-248, but they were also found in the near-field well at this site. Again, the maximum concentration of methylene chloride was found in the near-field well, farther away from the tile field, but it is a common laboratory contaminant and may not be representative of vadose zone concentrations. Although only minor concentrations of TCE and PCE (maximum of 30 and 21 ppb, respectively) were observed, larger concentrations of their degradation products, trans-1,2 -DCE (~150 ppb), 1,1-DCA (~100 ppb), and cis-1,2-DCE (~80 ppb), were detected in the crib well. This suggests that the TCE and PCE disposed to this facility might be older or at least is more degraded than that disposed to the 216-Z-9 trench and/or the 216-Z-18 crib. None of these degradation products were found in near-field well 299-W18-246. Minor concentrations of toluene (maximum of 133 and 126 ppb, respectively) were detected in both wells, but no other BTX compounds were found. Figures 5.13 and 5.14 illustrate the vertical distribution of selected volatile organics relative to the stratigraphy and moisture content of wells 299-W18-246 and -248, respectively; note that the highest concentrations of volatile organics were found below the 16-m depth (in the lower portions of the Hanford formation and in the early Palouse soil) of both wells. The maximum concentrations of CCl_4 were found at depths of approximately 41 to 45 m, just above the caliche (see Figure 5.14).

Table 5.5. Maximum Concentration of Target Constituents from Wells Near the 216-Z-1A Tile Field

Analyte	Units	Detection Level	Crib Well 299-W18-248 Max. Soil Conc.	Depth (m)	Near-Field Well 299-W18-246 Max. Soil Conc.	Depth (m)	Near-Field Well 299-W18-246 Max. GW Conc.
Target Volatile Organics							
Methylene Chloride	ppb	5[a]	2,264	19.8	19,854[b]	59.3	672
$CHCl_3$	ppb	2[a]	31	19.8	3[c]	17.3	~3,600
CCl_4	ppb	2[a]	1,093	41.1	772	44.8	1,009
TCE	ppb	2[a]	30	19.8	1	17.3	2.5
PCE	ppb	2[a]	21	19.8	3	17.3	1
MEK	ppb	2[a]	NR		ND		~9
Other Volatile Organics							
trans-1,2-DCE	ppb	2[a]	~150	19.8	<50		<0.5
1,1-DCA	ppb	2[a]	~100	19.8	<50		1.1[c]
cis-1,2-DCE	ppb	2[a]	~80	19.8	<50		<0.5
1,1,1-TCA	ppb	2[a]	NR		<10		<0.5
Benzene	ppb	2[a]	<25		<25		1.1
Toluene	ppb	2[a]	133	19.8	126	43.3	0.7
Ethylbenzene	ppb	2[a]	<25		<25		0.3[c]
M+P-xylene	ppb	2[a]	<25		<25		0.2[c]
O-xylene	ppb	2[a]	<25		<25		2.9
Acetone	ppb	2[a]	ND		ND		~144
Target Semivolatile Organics							
TBP	µg/kg	58	ND		ND		ND
DBP			NA		NA		NA
DBBP			NA		NA		NA
MBP			NA		NA		NA
Triglycerides (lard oil)			NA		NA		NA
Other Semivolatile Organics							
Decane	µg/kg	54	ND		ND		ND
Dodecane	µg/kg	31	ND		ND		ND
Tetradecane	µg/kg	52	ND		ND		ND
Phenol	µg/kg	49	ND		880	44.6	ND
Unknown oxyhydrocarbon	µg/kg		NR		NR		NR
Target Metals							
Aluminum			NA		NA		NA
Iron	µg/kg	2,000	230,000,000	6.0	22,000,000	17.2	660,000
Cadmium	µg/kg	1,000	ND		ND		ND
Magnesium	µg/kg	10,000	89,000,000	42.7	21,000,000	44.6	550,000
Chromium	µg/kg	2,000	100,000	18.2	22,000	43.3	2,900
Nickel	µg/kg	3,000	16,000	31.2	17,000	43.3	3,000

Table 5.5. (contd)

Analyte	Units	Detection Level	Crib Well 299-W18-248 Max. Soil Conc.	Depth (m)	Near-Field Well 299-W18-246 Max. Soil Conc.	Depth (m)	Near-Field Well 299-W18-246 Max. GW Conc.
Target Anion/Cations							
Chloride	µg/kg	400	9,400	6.0	20,000	17.2	26,000
Fluoride	µg/kg	200	6,600	38.6	2,800	44.6	1,200
Calcium	µg/kg	10,000	230,000,000	42.7	190,000,000	44.6	550,000
Nitrate	µg/kg	400	6,900	31.2	11,000	17.2	140,000
Sulfate	µg/kg	1,000	26,000	6.0	45,000	17.2	23,000
Phosphate	µg/kg	800	ND		ND		ND
Target Radionuclides							
Plutonium			NA		NA		NA
Americium			NA		NA		NA
^{90}Sr			NA		NA		NA
Uranium			NA		NA		NA
Gamma emitters							
^{60}Co	pCi/L						4.44
^{106}Ru	pCi/L						55.3
^{125}Sb	pCi/L						8.92
^{137}Cs	pCi/L						3.92
^{212}Pb	pCi/g		1.01	35.3	1.82	43.1	NR
^{214}Pb	pCi/g		1.73	37.1	2.94	44.6	NR
^{226}Ra	pCi/g		1.66	37.1	2.81	44.6	NR
^{224}Ra	pCi/g		1.01	35.3	1.89	43.1	NR
Gross alpha	pCi/g		18.5	42.8	29.4	44.6	19.6
Gross beta	pCi/g		27.5	16.6	24.7	43.1	27.6

(a) Detection level varies with sample size and dilution factor.
(b) Observed varied methylene chloride impurities in purge-and-trap methanol but not this great. Possibly something around drill site.
(c) Observed but below <5 reported values for chloroform.
(c) Below limit of quantitation
GW = Groundwater.
NA = Not analyzed.
ND = Not detected.
NR = Not reported.

No semivolatile organics were identified, except phenol that was detected in one sample from near-field well 299-W18-246. As discussed earlier, several other phenolic compounds were listed in the analyses and are shown in the analysis tables in Appendix E. These have, however, been determined to be laboratory surrogates added to the sample to track the analytical technique.

Groundwater samples from well 299-W18-246, near the 216-Z-1A tile field, also yielded high maximum concentration values for CCl_4 (1,009 ppb), $CHCl_3$ (~3,600 ppb), and methylene chloride (672 ppb); note that the maximum concentration of $CHCl_3$ was higher than that for CCl_4. This maximum value, however, is at least an order of magnitude higher than

THIS PAGE INTENTIONALLY
LEFT BLANK

9 3 1 2 9 7 0 1 2 0 1

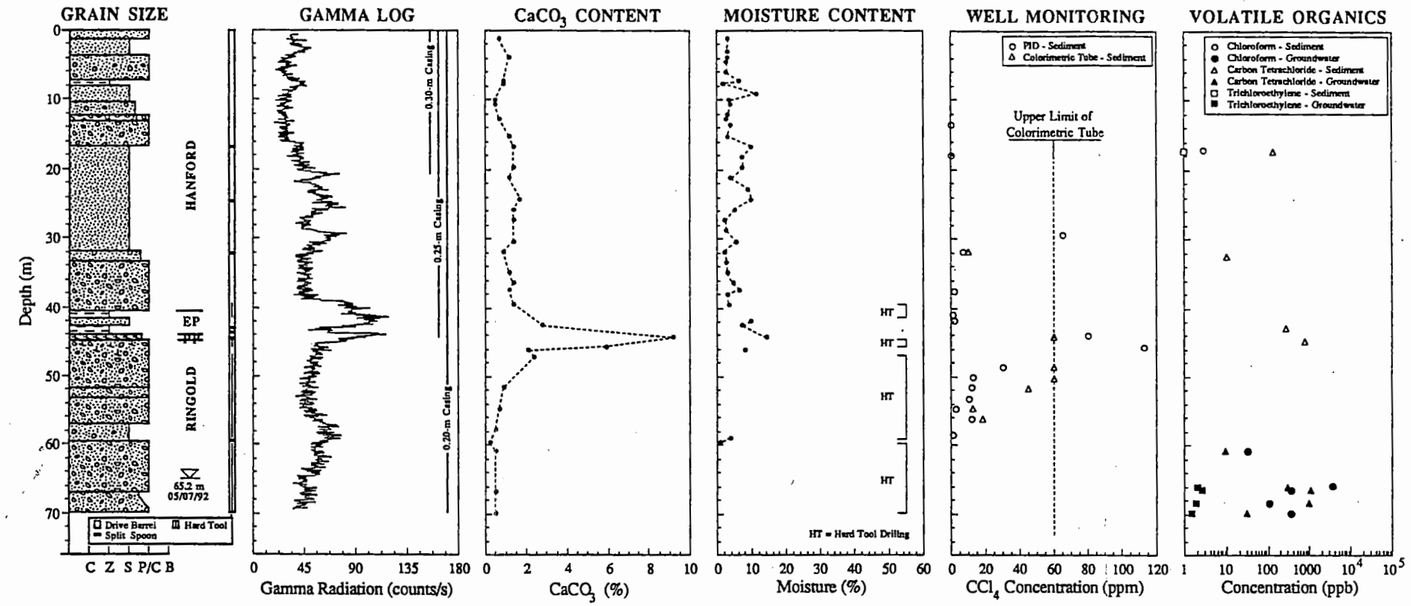


Figure 5.13. Analytical Results for Well 299-W18-246

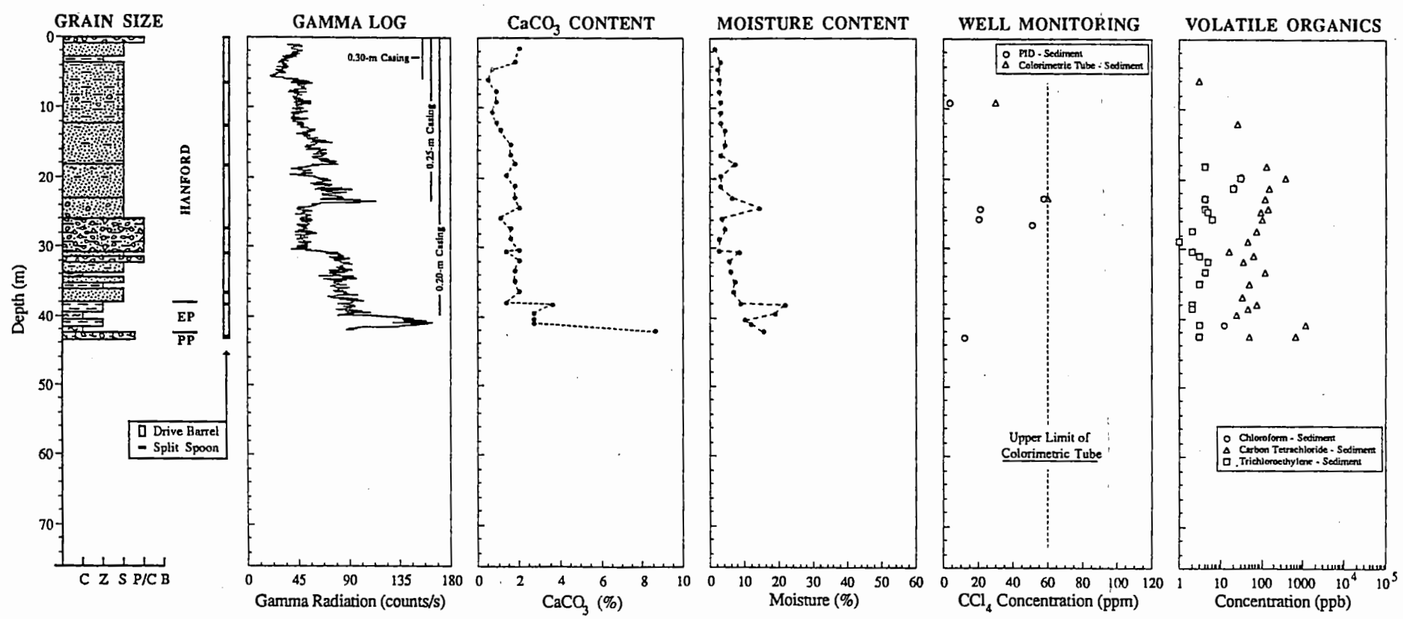


Figure 5.14. Analytical Results for Well 299-W18-248

THIS PAGE INTENTIONALLY
LEFT BLANK

that found in the other five groundwater samples collected from this well. Thus, this might be the result of some unrecognized sampling or analysis error. Again, trace amounts (up to 2.5 ppb) of TCE, PCE, and 1,1-DCA were found. Methyl ethyl ketone (MEK), at concentrations up to ~9 ppb, was found for the first time. BTX compounds, up to 2.9 ppb, were also found, along with acetone at concentrations up to ~144 ppb. The same fission products found beneath the 216-Z-9 trench were also found in the groundwater beneath the 216-Z-1A tile field but at slightly higher levels (e.g., up to 55.3 pCi/L ^{106}Ru).

5.2.3.3 216-Z-18 Crib

Well 299-W18-247 is a near-field well located approximately 40 m southeast of the 216-Z-18 crib. Well 299-W18-249 is located approximately 3 m north of the crib (see Figure 5.10). Table 5.6 summarizes the maximum concentration of target analytes and other constituents of interest detected in these wells. Some variation in the sample concentrations between these two wells may be the effect of the different drilling methods used. Well 299-W18-247 was drilled using a sonic drilling rig (with a top drive air hammer) and continuous core barrel methods, while well 299-W18-249 was drilled using a conventional cable-tool drill rig with drive-barrel and split-spoon-sampling methods.

The maximum concentration of CCl_4 observed in sediment samples from well 299-W18-249 (1,957 ppb), on the northern side of the 216-Z-18 crib, was over twice that found in well 299-W18-247 (717 ppb) to the southeast. Only slight amounts of $CHCl_3$, TCE, and PCE were found in crib well 299-W18-249 and none of these were detected in the near-field well. Again, high concentrations of methylene chloride were reported, but these may be related to laboratory contamination rather than actual vadose zone contamination. Virtually none of the TCE/PCE degradation products (i.e., trans-1,2-DCE, 1,1-DCA, and cis-1,2-DCE) observed at the 216-Z-9 and 216-Z-1A waste disposal facilities were detected in samples from the 216-Z-18 crib, except for 1,1,1-TCA that was found at a maximum concentration of 103 ppb in the crib well. However, relatively high concentrations of BTX compounds (2,961 to 3,427 ppb toluene, 34 to 61 ppb ethylbenzene, 42 to 266 ppb M+P-xylene, and 116 to 150 ppb O-xylene) were found in both the crib and near-field wells. Note that the higher concentrations were found in the near-field well that is farthest from the crib. This suggests a different source for the BTX compounds located southeast of the crib.

Figures 5.15 and 5.16 illustrate the vertical distribution of selected volatile organics relative to the stratigraphy and moisture content of wells 299-W18-247 and -249, respectively. Note that the highest concentrations of volatile organics were found below the 16-m depth, located in the lower fine-grained portions of the Hanford formation and

Table 5.6. Maximum Concentration of Target Constituents from Wells Near the 216-Z-18 Crib

Analyte	Units	Detection Level	Crib Well 299-W18-249 Max. Soil Conc.	Depth (m)	Near Field Well 299-W18-247 Max. Soil Conc.	Depth (m)	Near Field Well 299-W18-247 Max. GW Conc.
Target Volatile Organics							
Methylene chloride	ppb	5[a]	89,996	30.2	[b]		1.9
$CHCl_3$	ppb	2[a]	23	30.2	<5		183
CCl_4	ppb	2[a]	1,957	44.2	717	41.3	418
TCE	ppb	2[a]	8	30.2	<1		1
PCE	ppb	2[a]	6	30.2	<1		0.2[b]
MEK	ppb	2[a]	NR		ND		~93
Other Volatile Organics							
trans-1,2-DCE	ppb	2[a]	<5	19.8	<50		<0.5
1,1-DCA	ppb	2[a]	<5	19.8	<50		<3
cis-1,2-DCE	ppb	2[a]	<2	19.8	<50		<0.5
1,1,1-TCA	ppb	2[a]	103	30.6	<10		<2
Benzene	ppb	2[a]	11	30.6	<25		1
Toluene	ppb	2[a]	2,961	39.1	3,427	17.0	1.2
Ethylbenzene	ppb	2[a]	34	39.1	61		1
M+P-xylene	ppb	2[a]	42	39.1	266		0.2[b]
O-xylene	ppb	2[a]	116	12.0	150		0.6
Acetone	ppb	2[a]	NR		ND		~1,050
Target Semivolatile Organics							
TBP	µg/kg	58	ND		ND		ND
DPB			NA		NA		NA
DBBP			NA		NA		NA
MBP			NA		NA		NA
Triglycerides (lard oil)			NA		NA		NA
Other Semivolatile Organics							
Decane	µg/kg	54	110[c]	44.7	ND		ND
Dodecane	µg/kg	31	110[c]	44.7	ND		ND
Tetradecane	µg/kg	52	29[c]	44.7	ND		ND
Phenol	µg/kg	49	ND		700	47.2	ND
Unknown oxyhydrocarbon	µg/kg		NR		NR		NR
Target Metals							
Aluminum			NA		NA		NA
Iron	µg/kg	2,000	35,000,000	18.2	33,000,000	17.0	180,000
Cadmium	µg/kg	1,000	ND		1,000	47.2	15
Magnesium	µg/kg	10,000	8,500,000	44.7	7,900,000	41.5	61,000
Chromium	µg/kg	2,000	200,000	24.8	28,000	47.2	170
Nickel	µg/kg	3,000	13,000	11.4	18,000	41.5-47.2	370

Table 5.6. (contd)

Analyte	Units	Detection Level	Crib Well 299-W18-249 Max. Soil Conc.	Depth (m)	Near Field Well 299-W18-247 Max. Soil Conc.	Depth (m)	Near Field Well 299-W18-247 Max. GW Conc.
Target Anion/Cations							
Chloride	µg/kg	400	16,000	11.4	4,200	17.0	8,200
Fluoride	µg/kg	200	500	7.0	1,600	47.2	1,900
Calcium	µg/kg	10,000	230,000,000	44.7	80,000,000	45.6	160,000
Nitrate	µg/kg	400	7,100	24.8	3,400	17.0	4,300
Sulfate	µg/kg	1,000	28,000	11.4	6,500	45.6	32,000
Phosphate	µg/kg	800	ND		ND		ND
Target Radionuclides							
Plutonium			NA		NA		NA
Americium			NA		NA		NA
^{90}Sr			NA		NA		NA
Uranium			NA		NA		NA
Gamma emitters							
^{60}Co	pCi/L						12.4
^{106}Ru	pCi/L						68.5
^{125}Sb	pCi/L						4.32
^{137}Cs	pCi/L						5.4
^{212}Pb	pCi/g		1.36	44.7	NR		NR
^{214}Pb	pCi/g		1.11	44.7	NR		NR
^{226}Ra	pCi/g		0.98	44.7	4.07	45.5	NR
^{224}Ra	pCi/g		1.41	44.7	1.53	41.3	NR
Gross alpha	pCi/g		13	44.7	10.2	45.5	10.1
Gross beta	pCi/g		24.4	44.7	18.5	33.9	15.3

(a) Detection level varies with of sample size and dilution factor.
(b) No results reported because of methylene chloride impurities in purge-and-trap methanol.
(c) Below limit of quantitation.
GW = Groundwater.
NA = Not analyzed.
ND = Not detected.
NR = Not reported.

in the early Palouse soil. The maximum CCl_4 concentrations were found at depths of approximately 41 and 44 m in the early Palouse soil just above the caliche.

Although TBP was not detected in these samples, a variety of other semivolatile organics were identified, if not quantified. These included decane, dodecane, and tetradecane in samples from depths of 30.6 and 44.7 m in well 299-W18-249, juxtaposed to the crib; and phenol at several depths in near-field well 299-W18-247. Other phenolic compounds reported in the analysis tables (see Appendix E) are simply laboratory surrogates added to the sample to track the analytical technique.

THIS PAGE INTENTIONALLY
LEFT BLANK

9 3 1 2 9 0 1 2 0 6

Figure 5.15. Analytical Results for Well 299-W18-247

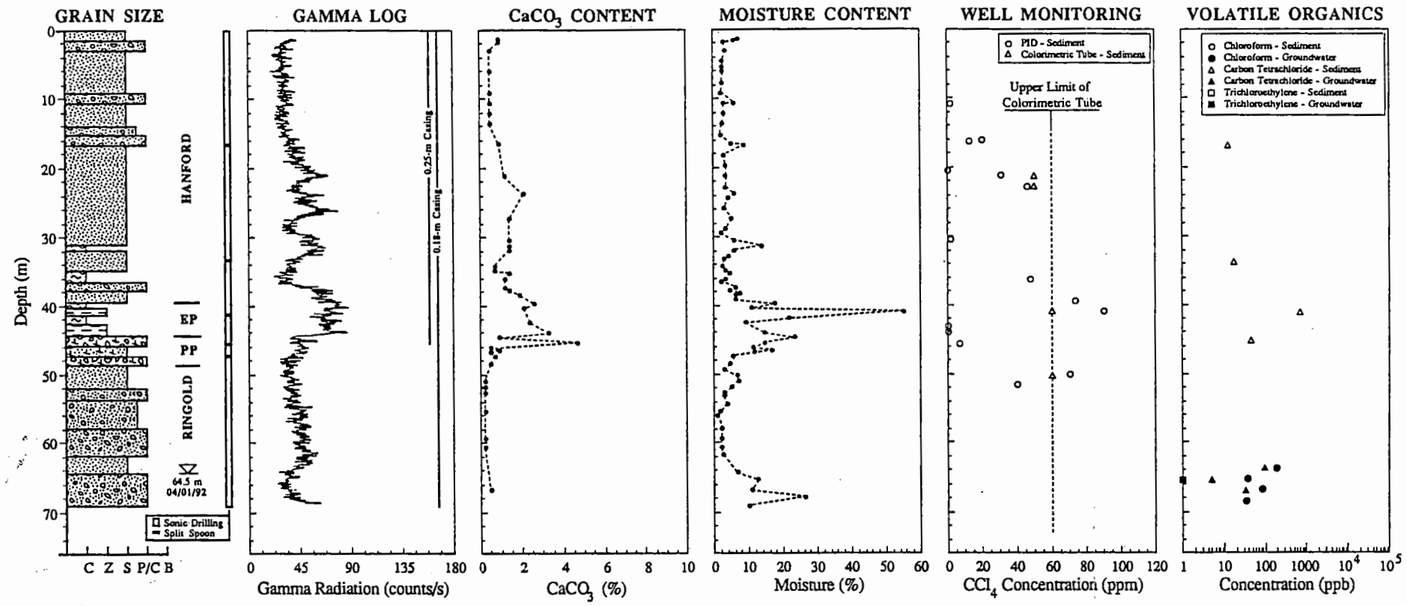
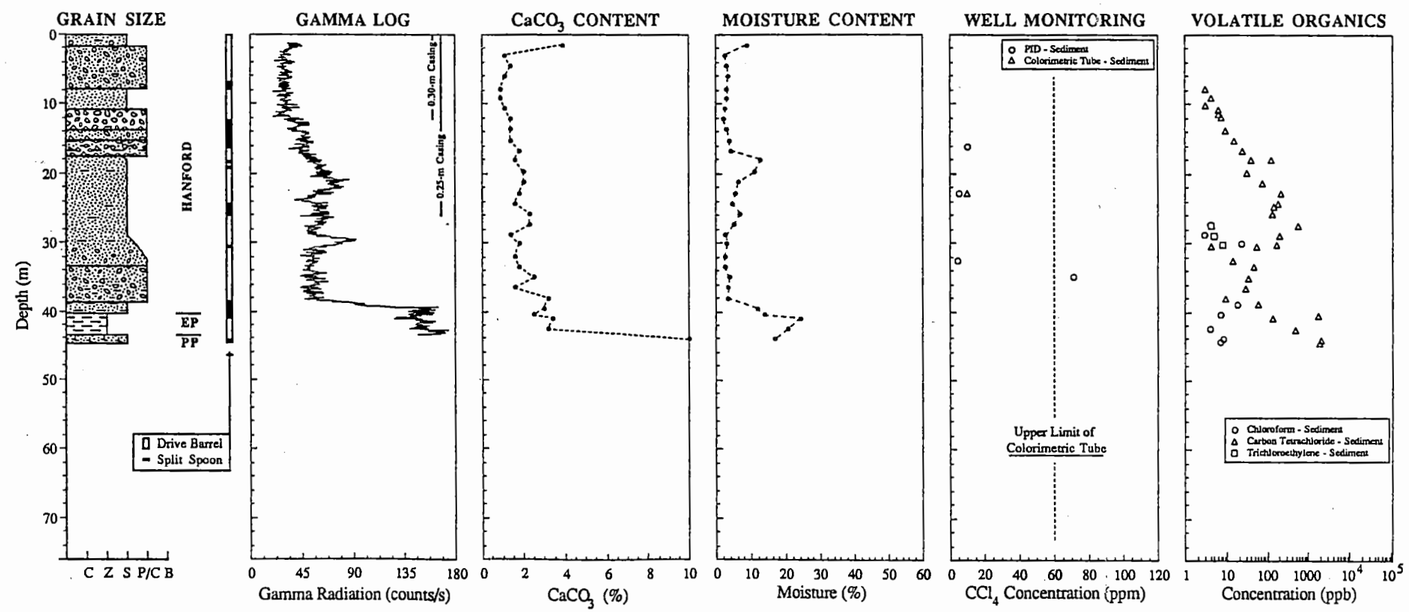


Figure 5.16. Analytical Results for Well 299-W18-249



THIS PAGE INTENTIONALLY
LEFT BLANK

Also noteworthy is that cadmium was detected, at the 1,000-μg/kg detection level, in the 47.2-m sample from well 299-W18-247. This is the only sediment sample where cadmium was detected. It is also interesting to note that cadmium was also detected in one groundwater sample from this well, though at a much lower concentration (15 μg/kg).

The groundwater samples from well 299-W18-247 yielded lower maximum concentrations of CCl_4 (418 ppb), $CHCl_3$ (183 ppb), and methylene chloride (1.9 ppb) and approximately the same concentrations of TCE and PCE (up to 1 ppb). Maximum concentrations of the BTX compounds remained approximately the same as those near the 216-Z-1A tile field (up to 1.2 ppb). However, the maximum concentrations of acetone and MEK increased (up to ~1,050 and ~93 ppb, respectively). Concentrations of the fission products also increased slightly (e.g., up to 68.5 pCi/L ^{106}Ru).

5.3 Groundwater Contamination

The unconfined aquifer beneath the VOC-Arid ID/ERA site has been contaminated by CCl_4 disposed to the three waste disposal facilities. The following sections discuss the contaminants of concern found in each of the major contaminant plumes.

5.3.1 Carbon Tetrachloride

Figure 5.17 illustrates the location (relative to the CCl_4 disposal facilities) of the dissolved CCl_4 plume in the unconfined aquifer. The plume extends over an area of more than 12 km^2 in the 200 West Area. The concentration data collected in FY 1992 were combined with previous CCl_4 data (January 1988 through October 1992) to update the plume map from 1991 (DOE 1991). The data were combined because of the limited amount of data available for each sampling period. Average values were used for wells with multiple sampling results (Appendix F). The maximum concentration amount, or drinking water standard, for CCl_4 is 5 μg/L (EPA 1976), which is also the detection level for the standard gas chromatograph/mass spectrometer analytical method. The minimum contour shown in Figure 5.17 is 10 μg/L (i.e., ppb).

Although all the monitoring wells used to construct the groundwater plume map are screened in the upper 10 m of the aquifer, the well network includes both Resource Conservation and Recovery Act of 1976-type (RCRA) wells and older wells of uncertain integrity. Uncertainties in contaminant concentrations associated with the older wells include the possibility of preferential pathways along the outside of the casing, the mix of submersible and positive displacement piston pumps, and the variety in the type and length of perforated or screened intervals. In addition, another uncertainty is introduced by the

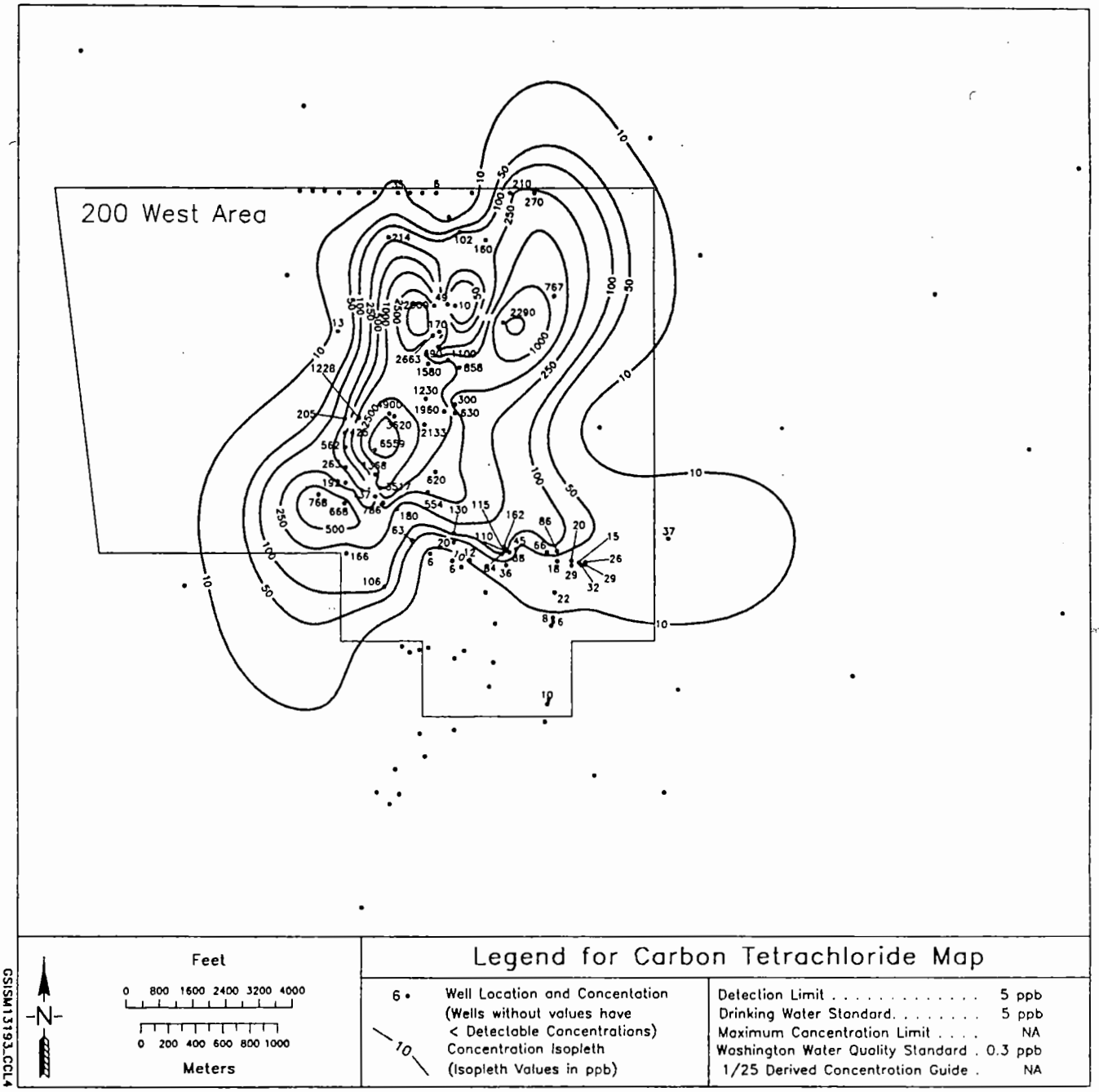


Figure 5.17. Carbon Tetrachloride Concentration Contours in the 200 West Area Ground Water - 1988 to 1992

placement of the pump intake in relation both to the distribution of the contaminant within the aquifer and to the continuing drop in the water table (DOE 1991). Also adding to these uncertainties is the change in 1990 in the contracted analytical laboratory.

The distribution of the CCl_4 plume appears to be controlled, at least in part, by the variation in hydraulic conductivity within the unconfined aquifer (see Figure 4.15). The area of highest CCl_4 concentrations (>5000 µg/L) lies northwest of the discharge area, which is consistent with the local slope of the water table away from the disposal facilities (see Figure 4.17) and the location of the disposal facilities within the zone of highest hydraulic conductivity (>1,000 ft/d).

The extent of the plume has not changed significantly since 1991 (DOE 1991), probably in part because the data set was averaged in both cases. The core of high concentrations remains adjacent to the northwestern edge of the CCl_4 disposal facilities. A secondary maximum in the groundwater concentrations is apparently underlying the T Tank Farm area to the north. Additional wells sampled in 1992 on the perimeter of the plume were used to constrain its lateral extent, particularly northeast and southwest of the 200 West Area (Figure 5.18)

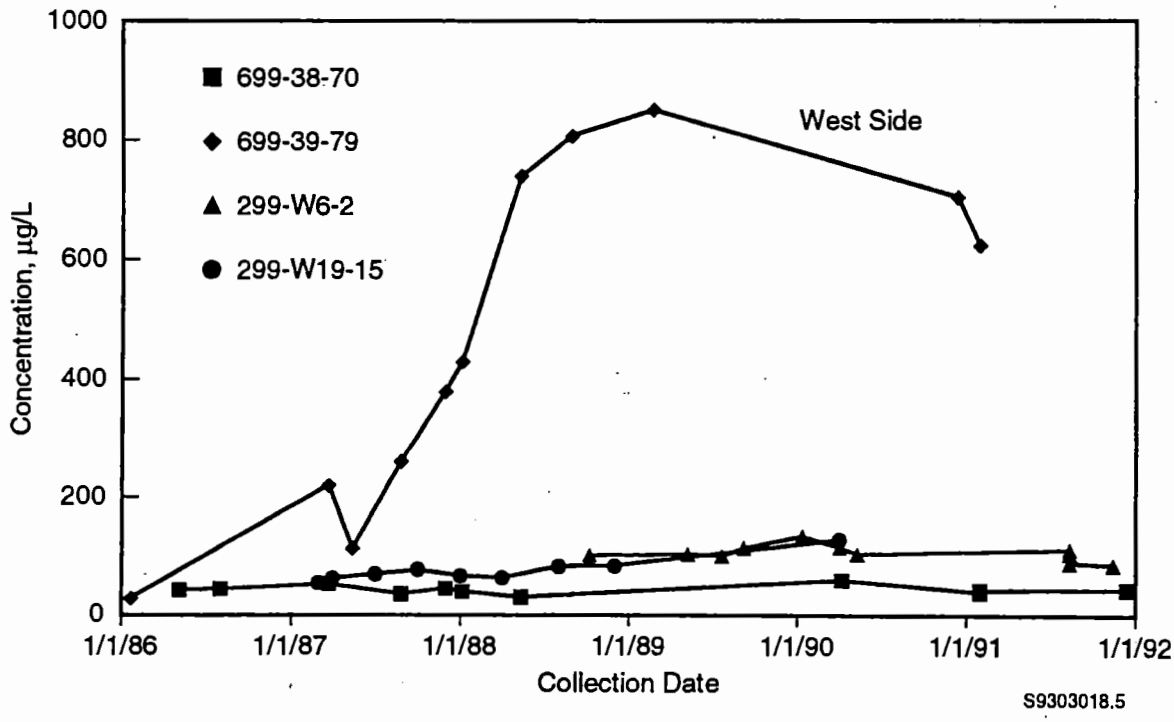


Figure 5.18. Trend Plot of Carbon Tetrachloride Concentrations Near the 200 West Area (after Evans et al. 1992)

Analytical results from individual wells can be used to construct concentration trends and to infer plume movement. For example, CCl_4 concentrations in wells at the eastern (699-38-70), northern (299-W6-2), and southern (299-W19-15) edges of the groundwater plume (see Figure 5.18) have been relatively constant at low levels since 1987, but concentrations in a well at the western edge (699-39-79) increased by an order of magnitude between March 1987 and August 1988, followed by a slight decrease and leveling off between 1989 and 1992 (see Figure 5.18) (Evans et al. 1992; Woodruff and Hanf 1992). Evans et al. (1992) suggest that these data indicate some plume movement to the west, with the leading edge of the plume now just beyond well 699-39-79 .

Other concentration trends are less clear. CCl_4 concentrations in well 299-W15-16, which has had the highest CCl_4 concentration detected in 200 West Area groundwater, fluctuated between 6,650 and 8,700 ppb between October 1988 and April 1990, dropped to 4,450 ppb in August 1991, and increased to 6,700 ppb by August 1992. However, because of the change in analytical laboratories in 1990, the analytical scatter may be a result of difficulties associated with analysis of high-level samples that require dilution (Evans et al. 1992).

Based on the 1991 concentration contours (DOE 1991), the upper 10 m of the aquifer were estimated to contain 5,250 to 15,740 kg of dissolved CCl_4, which accounts for approximately 2% of the estimated inventory discharged to the three waste disposal facilities (WHC 1991).

5.3.2 Chloroform

The distribution of the $CHCl_3$ plume detected in the unconfined aquifer is similar to that of the CCl_4 plume in shape, but its extent is more limited (Figure 5.19). The $CHCl_3$ is probably present as a degradation product of the CCl_4, though chlorinated waste water is discharged to the sanitary tile fields throughout the 200 West Area. The highest $CHCl_3$ concentrations, located at the 216-Z-9 trench, are actually higher than the CCl_4 levels in the same samples (Evans et al. 1992). The secondary concentration maximum is located under the 216-Z-1A and 216-Z-18 waste disposal facilities. The drinking water standard for $CHCl_3$ is 100 μg/L (EPA 1976).

5.3.3 Plutonium

Only one groundwater well in the 200 West Area, 299-W15-8 adjacent to the 216-Z-9 trench, contained $^{239/240}Pu$ contamination. $^{239/240}Pu$ was first measured in this well in 1990 at a concentration of 8.3 pCi/L, which exceeded a calculated drinking water standard of 1.2 pCi/L (Evans et al. 1992). ^{238}Pu was also detected at a concentration of 0.14 pCi/L.

9 3 1 2 9 7 0 1 2 1 0

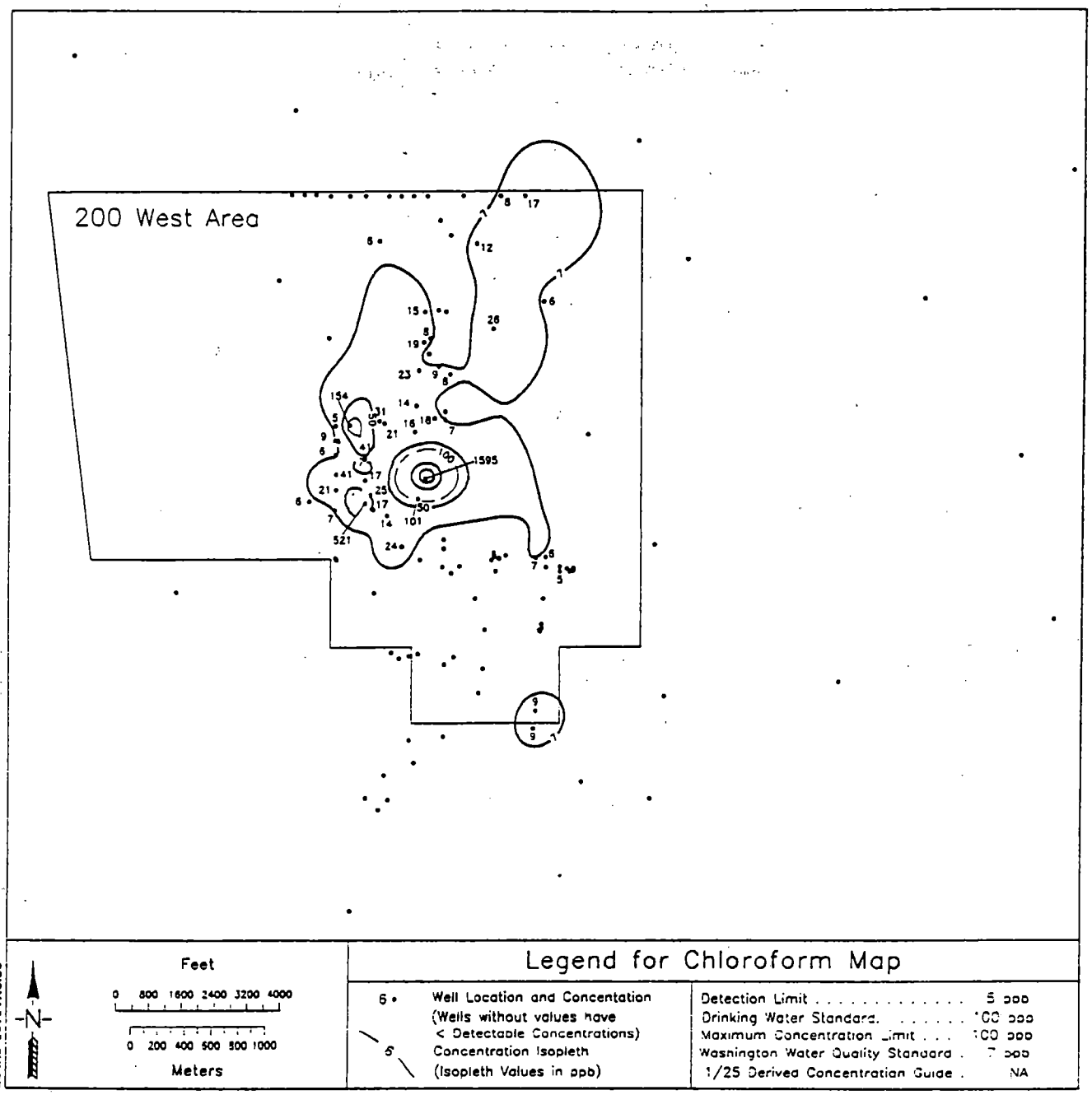


Figure 5.19. Chloroform Concentration Contours in the 200 West Area Groundwater - 1988-1992

This well was resampled in 1991 and yielded concentrations of 1.9 and 0.03 pCi/L for $^{239/240}Pu$ and ^{238}Pu, respectively. ^{241}Am was measured at a concentration of 5.9 pCi/L. Filtered samples from the same 1991 sampling event yielded no detectable plutonium, confirming that the transuranics were associated with particulate material (Evans et al. 1992).

5.3.4 Vertical Distribution

Results of preliminary deep interval sampling in well 299-W15-6, which has a 52-m-long perforated interval within the unconfined aquifer, suggest that there is deeply distributed CCl_4 and $CHCl_3$ within the aquifer, at least near the 216-Z-9 trench. A bailed sample and a pumped sample from the bottom of the interval in 1991 contained 3,784 and 2,651 μg/L CCl_4, respectively; samples near the water table contained 5,770 and 4,700 μg/L (bailed and pumped), respectively. There is also a suggestion of CCl_4 at depths below the water table in well 299-W18-17 at the 216-Z-20 crib. A sample, representative of the 6- to 9-m depth, collected in 1990 contained 2,000 μg/L CCl_4; a sample pumped from 1.5 m below the water table in 1991 contained 1,004 μg/L CCl_4; however, the mechanism by which the contaminants reached these depths is uncertain (DOE 1991).

It should be noted that two wells west of the CCl_4 disposal facilities are screened at the bottom of the aquifer (299-W18-22, 465 m southwest of the 216-Z-18 crib and 299-W15-17, 400 m northwest of the 216-Z-1A tile field). CCl_4 is below detection levels in samples from these wells, though it is present in groundwater samples from companion wells screened at the water table (DOE 1991).

6.0 Conceptual Model

This section presents current hypotheses concerning the source term, vadose zone transport, sorption, groundwater contamination, and biological degradation of the contaminants of concern (principally CCl_4) at the VOC-Arid ID/ERA site. This information represents an update to the conceptual model of the site as presented in DOE (1991), Last and Rohay (1991), and Last et al. (1991). Figure 6.1 illustrates many of the concepts discussed below.

6.1 Disposal Source Term

CCl_4 was discharged to the soil column via subsurface infiltration facilities (cribs) as an organic solution with TBP, DBBP, and/or lard oil, with CCl_4 consisting of 50% to 85% by volume. These organic solutions made up only approximately 4% to 8% of the total volume of waste discharged to the cribs. The predominant wastes discharged were acidic, high-salt (sodium nitrate), aqueous wastes containing the above organic liquids in saturation amounts. Organic-phase waste solutions were periodically discharged to the predominantly water-wetted soil column in small (100- to 200-L) batches. Thus, CCl_4 was present and migrated in the vadose zone in saturated conditions in the aqueous phase and as a separate, nonaqueous phase (both in combination with other organics).

6.2 Vadose Zone Transport

Once discharged to the crib, the liquid wastes infiltrate into the underlying soils and migrate under their own hydraulic gradients. An infiltration rate or recharge rate into the soil column can be estimated for each crib from the area of the crib bottom and average annual discharges. These range from 1 to 10 $L/m^2/d$ (Table 6.1). Average infiltration rates from percolation tests in the 216-Z-20, -21 crib areas have been reported by M. A. Chamness of PNL as ranging from 1,900 to 2,850 $L/m^2/d$. Thus, the field-measured infiltration rate of the soil column appears to be far in excess (two orders of magnitude) of the estimated recharge rate from the cribs. Under these conditions, it is doubtful that the soil column ever became fully saturated or that the cribs exceeded the infiltration capacity, at least for any appreciable period of time. Crawley (1969), however, did suggest that a buildup of liquid waste was suspected in the head end of the 216-Z-1A tile field. This suggests that the infiltration capacity of that first one-third of the crib had been exceeded

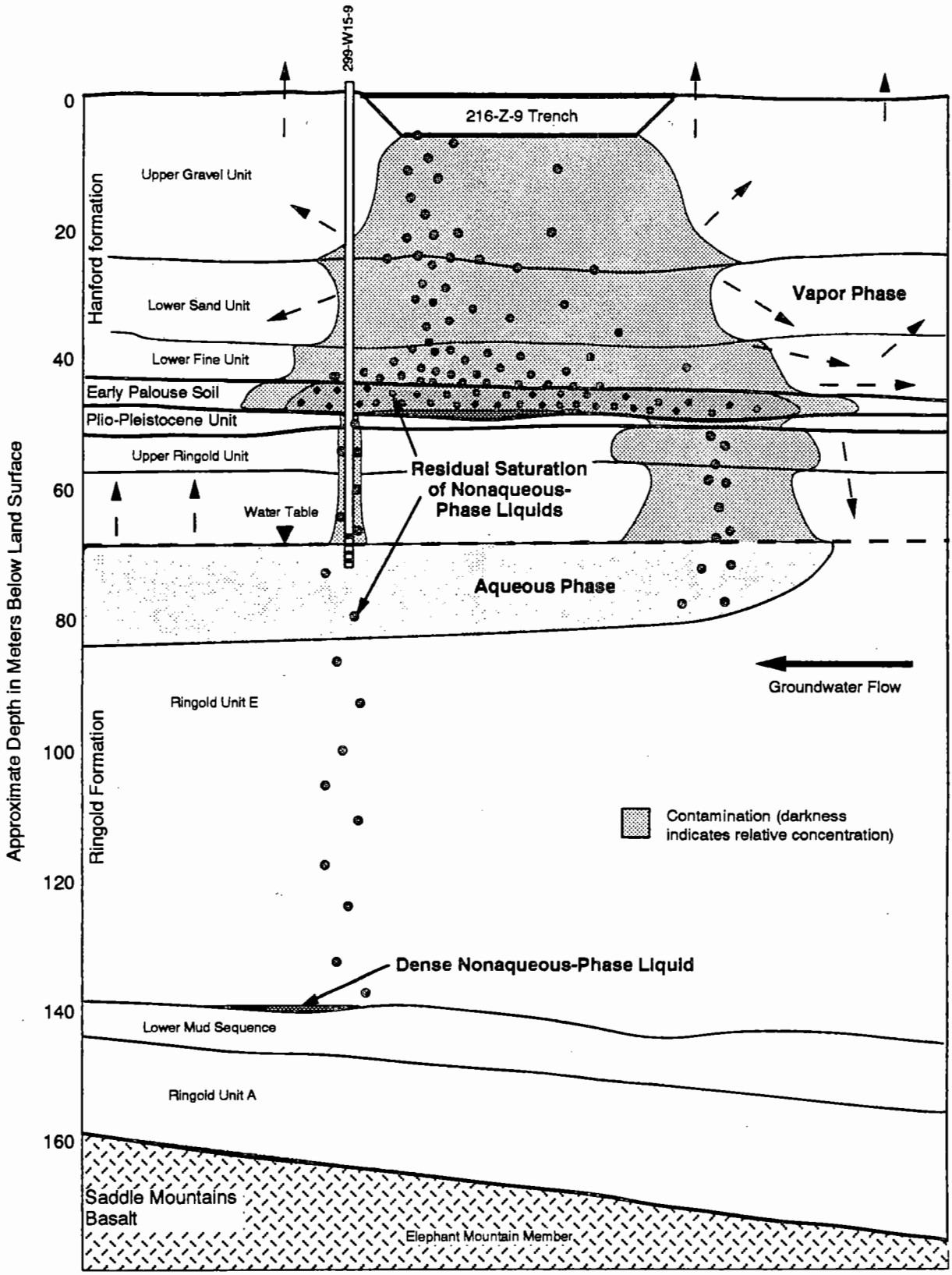


Figure 6.1. Schematic Illustration of the Conceptual Model for Carbon Tetrachloride Disposal and Migration Beneath the 216-Z-9 Trench

Table 6.1. Pore Column Volume Estimates

Waste Disposal Facility	North-South Length (m)	East-West Length (m)	Bottom Area (m^2)	Depth to Water (m)	Average Annual Discharge (L)	Infiltration Rate ($L/m^2/d$)	Porosity (%)	Column Pore Volume (L)	Total Discharge Volume (L)	% Pore Volume
216-Z-1A	84	35	2,940	57	1.15E+06	1.07	30	5.03E+07	6.21E+06	12
216-Z-9	18.3	9.1	167	57.6	6.08E+05	10.00	30	2.88E+06	4.09E+06	142
216-Z-18[a]	63	3	189	59			30	3.35E+06	3.86E+06	
[b]			756		9.74E+05	3.53		1.34E+07		29

(a) For one of the 5 trenches present in the 216-Z-18 crib (see Appendix A).
(b) For the 4 trenches that received waste.

by the discharge volumes perhaps as a result of plugging of the soil pores by fine particulates or other solids. It should also be noted that the 216-Z-1A tile field had received other wastes from 1949 to 1959, so the soil column was already partially saturated.

It is possible to evaluate which crib most likely had the waste break through to the groundwater by comparing the total volume discharged to the column pore volume beneath each crib (i.e., bottom area x depth to water x porosity; assuming 30% porosity). Table 6.1 showed that the 216-Z-1A and -18 waste disposal facilities received only 12% and 29% of their estimated column pore volumes, respectively, while the 216-Z-9 trench received 142% of its column pore volume. It must be noted that these are only rough estimates. If the porosity were smaller or if the entire column pore volume were not used (e.g., streaming of the wastes down preferential pathways occurred), then these values would be higher. Conversely, if the waste plume spread out, increasing its column pore volume, then these values would be smaller. In any case, the 216-Z-9 trench is more likely to have had waste reach the groundwater strictly by downward percolation. Because the aqueous waste contained CCl_4 in saturated amounts, it is likely that some CCl_4 reached the groundwater via the aqueous phase. Conca et al. (1992) interpreted a near-vertical moisture plume beneath the CCl_4 cribs, with some spreading occurring only on the early Palouse and Plio-Pleistocene surfaces (see Figure 4.12).

Numerical flow simulations (simulating the movement of water and liquid CCl_4) completed to date by S. B. Yabusaki of PNL suggest also that it is possible that CCl_4 may have migrated to the water table from the 216-Z-9 trench irrespective of whether an unsealed borehole or other preferential pathway may have been present (Piepho et al. 1993). These simulations are tenuous, in that no data on nonaqueous-phase liquid residual saturation were available and that several simplifying assumptions were made. Further, the

physical properties of pure CCl_4 were used in these simulations, not those of the CCl_4: TBP, DBBP, and/or lard oil mixtures. Three-phase flow simulations (water, liquid CCl_4, and air) suggest that most of the free liquid CCl_4 that has not evaporated should now be located in the early Palouse soil and Plio-Pleistocene unit or in the groundwater (i.e., not in the Hanford formation). These simulations also predict that horizontal spreading in the vadose zone should have been minimal, even though a 10 to 1 horizontal to vertical anisotropy was assumed. Again, uncertainties still exist, and these simulations had been simplified.

Numerical simulations of water flow released to the 216-Z-9 trench suggest some horizontal spreading of the aqueous plume may have occurred at the Hanford coarse-grained unit/fine-grained unit boundary, but that little lateral spreading may have occurred below that (Figure 6.2).

Because of the low discharge rates to the cribs and the high infiltration rate of the Hanford formation sediments, it is suspected that the moisture content of the soil column, at least beneath the 216-Z-1A and -18 cribs, was potentially never fully saturated. Under these conditions, it is believed that the soil pores contained aqueous, nonaqueous, and vapor phases. At the time of discharge, the aqueous-phase fluids were fully saturated with the CCl_4/organic mixtures. Thus, little of the nonaqueous-phase organic would move into the aqueous phase. However, liquid CCl_4 has a high vapor pressure and would volatilize easily into the vapor phase. Because liquid CCl_4 is immiscible with water and the soil column is assumed to be water wetted, the CCl_4 would move under its own hydraulic gradient. Conca et al. (1992) suggested, based on fluid density and viscosity differences, that the hydraulic conductivity of liquid CCl_4 through a subsurface porous medium should be twice that of water.

As nonaqueous-phase liquid CCl_4 moves down through the soil column under its own hydraulic gradient, some of the liquid CCl_4 will become discontinuous and will be held up in the soil pores. This is referred to as residual saturation. Conca et al. (1992) observed the characteristic behavior of water, water saturated with CCl_4, and liquid-phase CCl_4 in two water-wetted sediment samples and reported that the retention of liquid-phase CCl_4 was half that of water or the aqueous-phase CCl_4 solution. Thus, if the field moisture content of the soil were 5% under a given unsaturated flow condition, then it can be estimated to retain 2.5% CCl_4 under the same conditions. It should be noted that these are strictly empirically derived estimates based on two samples and should be viewed with some caution.

A rough estimate of how far the nonaqueous organic-phase liquid may have traveled downward through the soil column as a continuous organic liquid phase (i.e., at saturations greater than the residual) can be calculated by assuming a single residual saturation for the

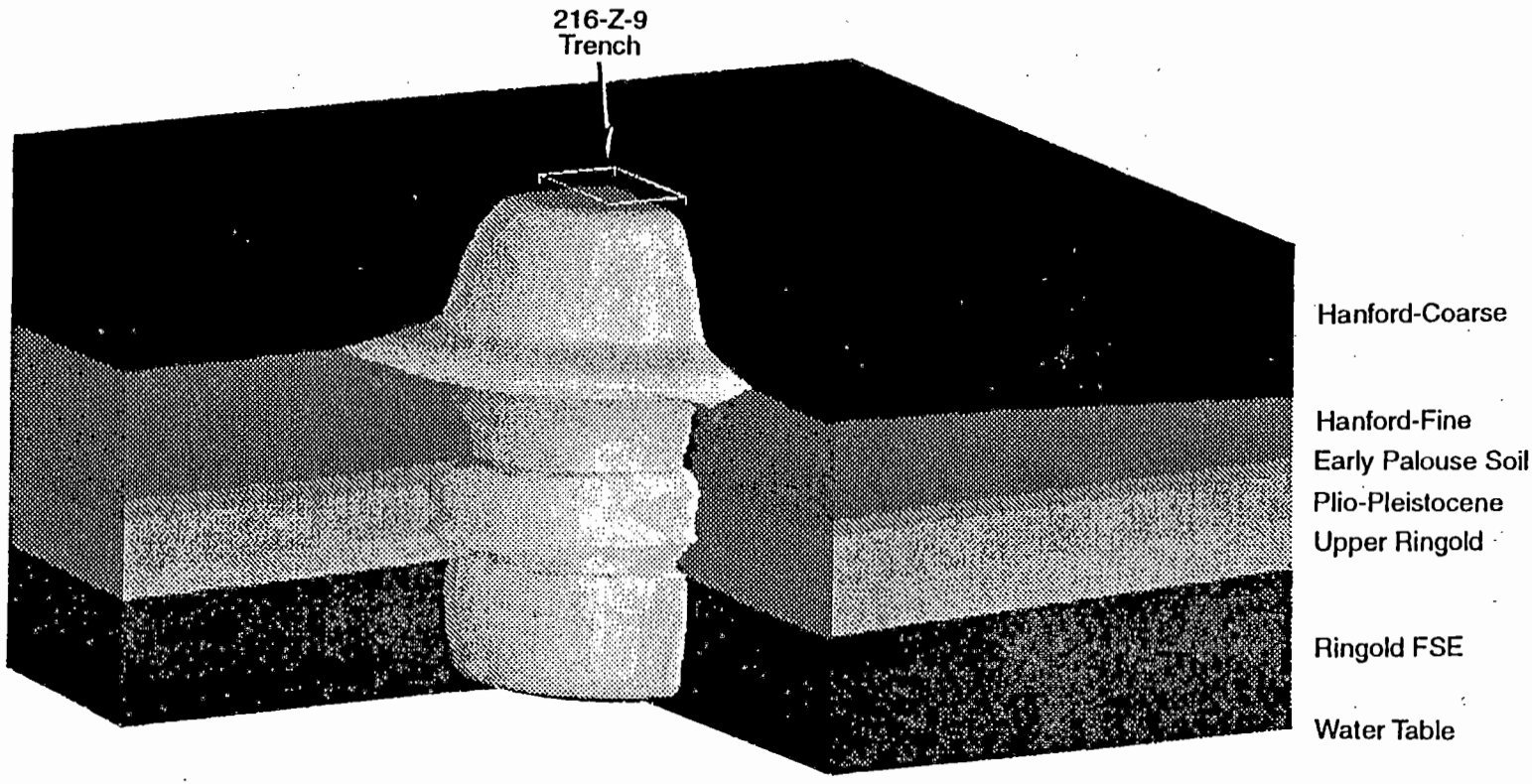


Figure 6.2. Three Dimensional View of Numerically Simulated Water Flow Beneath the 216-Z-9 Trench (S. B. Yabusaki, Pacific Northwest Laboratory)

entire pore column volume of 2.5% and assuming that the organic was evenly distributed across the crib bottom area. Table 6.2 lists the relative depth of nonqueous-phase-liquid migration for each facility. Note that the migration depth calculated for the 216-Z-9 trench is over an order of magnitude greater than that of the other two cribs. It also seems plausible that much of the organic nonaqueous-phase liquid may have been retained in the soil column because of the residual saturation.

Because liquid CCl_4 is volatile, once it is retained in the unsaturated pore space, it would likely partition into the vapor phase. The density of CCl_4 vapor is over 50% greater than that of vapor normally found in uncontaminated soils. This contrast in densities is hypothesized to result in density-driven advection, which can act to move CCl_4 downward and laterally, via diffusion, from the disposal facilities and provide a continuous source of contamination to the groundwater. Upward migration and release of the VOC vapors to the atmosphere occur via both the ambient soil surface and boreholes perforated or otherwise open to the vadose zone. The ambient soil-surface flux has been measured using the EMFLUX® soil-gas technology as ranging from 111 to 686 $ng/m^2/min$ (0.06 to 0.36 $g/m^2/yr$) in the 216-Z-9 trench area. The average soil-surface flux for the area overlying the groundwater plume is estimated to be 285 $g/m^2/min$ (0.15 $g/m^2/yr$) (WHC 1993). The wells breathe in response to barometric pressure changes and other meteorological phenomena. The flux from a single borehole is estimated to range from several grams to several tens of grams per hour during an exhalation event (Rohay and Cameron 1992). The CCl_4 released from wells in the vicinity of the cribs between 1955 and 1990 is estimated to be 22,200 kg (or 3% of the discharged inventory) (WHC 1993). It has been estimated (WHC 1993) that approximately 21% of the total CCl_4 inventory may have been lost to the atmosphere via the soil surface and borehole venting since soil column disposal

Table 6.2. Estimated Depth of Organic Migration

Waste Disposal Facility	North-South Length (m)	East-West Length (m)	Bottom Area (m^2)	Porosity (%)	Total Organic Discharge (L)	Residual Saturation (%)	Depth of Migration (m)
216-Z-1A	84	35	2,940	30	1.75E+05	2.5	8
216-Z-9	18.3	9.1	167	30	8.30E+05 to 3.00E+05	2.5	66 to 28
216-Z-18[a]	63	3	189				
[b]			756	30	1.10E+05	2.5	19

(a) For one of the 5 trenches present in the 216-Z-18 crib (see Appendix A).
(b) For the 4 trenches that received waste.

was initiated. Also, WHC (1993) estimated that 12% of the inventory was retained in the vadose zone air, water, and soil, leaving 65% unaccounted for, which might be attributed to residual saturation of nonaqueous-phase liquid wastes and/or biodegradation.

Transport and inventory partitioning estimates have been made using pure liquid-phase CCl_4 properties. However, the CCl_4 was not discharged as a pure liquid but as a mixture with other organics (TBP, DBBP, and lard oil). R. J. Lenhard of PNL measured the liquid properties (density, viscosity, interfacial tension, and vapor pressure) of three representative mixtures: 85:15 CCl_4:TBP, 50:50 CCl_4:DBBP, and 50:50 CCl_4:lard oil, and are presented in Table 6.3. Lenhard concluded that the organic composites (even the CCl_4:lard oil mixture) are denser and more viscous than water. Vapor pressure of the CCl_4:DBBP and CCl_4:lard oil mixtures is only half that of the pure CCl_4 and the CCl_4:TBP mixture. Lenhard also found that the interfacial tension between the 50:50 CCl_4:lard oil mixture and a 5 M $NaNO_3$ solution was low, suggesting that the fluids may be somewhat miscible, allowing them to mix and behave more as an aqueous fluid.

Table 6.3. Physical Properties of Carbon Tetrachloride

	Units	Pure CCl_4	85 CCl_4:15 TBP	50 CCl_4:50 DBBP	50 CCl_4:50 Lard Oil	Water
Liquid density	(g/mL @ 20°C)	1.59[a]	1.51	1.27	1.25	1.00[a]
Viscosity	(centipoise)	1.00[a]	5.75	4.50	10.50	0.97[a]
Interfacial tension w/air	(dynes/cm)		31.0	32.0	33.0	
Interfacial tension w/water	(dynes/cm)	45[a]	23	11	18	
Interfacial tension w/5 M $NaNO_3$	(dynes/cm)		11	19	7	
Vapor pressure	(cm H_2O @ 25°C)	130	100	52	60	
Saturated vapor concentration	(mg/L)	754[a]				
Vapor density	–	1.65[a]				(air = 1.0)[a]
Henry's Law constant	(dimensionless)	9.40E-01[a]				NA
Solubility in water	(mg/L @ 20°C)	800[a]				NA

From R. J. Lenhard, Pacific Northwest Laboratory, personal communication.
(a) DOE (1991).

6.3 Groundwater Contamination

An estimated 2% of the total CCl_4 inventory can be accounted for in the top 10 m of the unconfined aquifer beneath the 200 West Area (DOE 1991). In at least one location, dissolved CCl_4 has been found 52 m below the water table; however, the mechanism by which the CCl_4 reached this depth is uncertain. Some separate, liquid-phase CCl_4/organic mixture may be present in the form of residual saturation or, perhaps, as a perched, dense, nonaqueous-phase-liquid pocket within the aquifer, but these have not been observed.

6.4 Sorption

It has been estimated (WHC 1993) that 6% of the original CCl_4 inventory is contained (sorbed) in the soil. This estimate was based on a calculated distribution coefficient (K_d) for aqueous-phase CCl_4 of 0.192 mL/g and assumed partitioning estimates. This value is consistent with batch K_d experiments by K. Cantrell of PNL, who estimated K_d values for CCl_4 aqueous solutions on Hanford soil to range between 0.0 and 1.3 mL/g. It was noted in WHC (1993) that the level of uncertainty in the soil inventory estimates was large and that additional measurements of soil mineralogy and soil-water-partitioning coefficients would help refine the analysis of the vadose zone inventory.

6.5 Biodegradation

WHC (1993) suggested that a portion of the 65% of the inventory unaccounted for in their residual inventory estimates might be explained by subsurface biodegradation of the CCl_4. Microbiological analyses (in draft report, *Survival and in Situ Stimulation of Microorganisms in Deep Vadose Zone Paleosols*, by J. K. Fredrickson of PNL) of sediment samples from wells 299-W15-217 and 299-W18-246 have shown increased viable counts (on the order of 1 to 6.6 colony-forming units) of culturable, aerobic, heterotrophic bacteria within the early Palouse soil and the Plio-Pliestocene unit. These microorganisms were metabolically active, displaying activity levels on the order of 32.8% to 62.2% $^{14}CO_2$ within the vicinity of these CCl_4 disposal sites. The relationship between these microorganisms and any biodegradation of the CCl_4, however, has not been determined. Lenhard et al. (1992) reported that microbial degradation of CCl_4 has been demonstrated with a number of bacteria; however, the conditions that favor biodegradation are predominantly anaerobic or microaerophilic, and, thus, biodegradation in the vadose zone may be rather limited.

9 3 1 2 9 7 0 1 2 2 0

In the groundwater under denitrifying conditions, the CCl_4 will degrade to CO_2 and $CHCl_3$. Given the right microcosm, this degradation process can occur after only 3 weeks. Under methanogenic conditions, the CCl_4 can completely degrade to CO_2. Considerable variation has been observed in CCl_4 degradation even in similar samples, suggesting that microbial populations and their associated activities can be heterogeneous.

9 3 1 2 9 0 1 2 2 1

THIS PAGE INTENTIONALLY
LEFT BLANK

7.0 References

Crawley, D. T. 1969. *Plutonium-Americium Soil Penetration at 234-5 Building Crib Sites.* ARH-1278, Atlantic Richfield Hanford Company, Richland, Washington.

Conca, J. L., J. V. Wright, T. Montano, and Xiaobing Chen. 1992. *VOC-Arid Site Integrated Demonstration, R&D Characterization and Monitoring Technologies, Subtask 2 Milestone Report, Centrifuge Technology for Vadose Zone Transport Measurements.* Washington State University Tri-Cities, Richland, Washington.

DOE. 1988. *Consultation Draft, Site Characterization Plan, Reference Repository Location, Hanford Site, Washington.* DOE/RW-0164, 9 Volumes, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, Washington, D.C.

DOE. 1991. *Expedited Response Action Proposal (EE/CA & EA) for 200 West Area Carbon Tetrachloride Plume.* DOE/RL-91-32, Draft B, U.S. Department of Energy, Richland, Washington.

DOE. 1992. *Z Plant Source Aggregate Area Management Study Report.* DOE/RL-91-58, Draft A, U.S. Department of Energy, Richland, Washington.

EPA. 1976. *National Interim Primary Drinking Water Regulations.* EPA-570/9-76-003, Office of Water Supply, U.S. Environmental Protection Agency, Washington, D.C.

Evans, J. C., R. W. Bryce, and D. J. Bates. 1992. *Hanford Site Ground-Water Monitoring for 1991.* PNL-8284, Pacific Northwest Laboratory, Richland, Washington.

Fancher, J. D. 1993. *200 West Carbon Tetrachloride Expedited Response Action Baseline Monitoring Data Package.* WHC-SD-EN-DP-063, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Gee, G. W. 1987. *Recharge at the Hanford Site: Status Report.* PNL-6403, Pacific Northwest Laboratory, Richland, Washington.

Graham, M. J., M. D. Hall, S. R. Strait, and W. R. Brown. 1981. *Hydrology of the Separations Area.* RHO-ST-42, Rockwell Hanford Operations, Richland, Washington.

9 3 1 2 9 0 1 2 2 2

Kasza, G. L., M. J. Hartman, F. N. Hodges, and D. C. Weekes. 1992. *Groundwater Maps of the Hanford Site, June 1992*. WHC-EP-0394-5, Westinghouse Hanford Company, Richland, Washington.

Last, G. V., and V. J. Rohay. 1991. *Carbon Tetrachloride Contamination, 200 West Area, Hanford Site*. PNL-SA-19564, Pacific Northwest Laboratory, Richland, Washington.

Last, G. V., B. N. Bjornstad, M. P. Bergeron, D. W. Wallace, D. R. Newcomer, J. A. Schramke, M. A. Chamness, C. S. Cline, S. P. Airhart, and J. S. Wilbur. 1989. *Hydrogeology of the 200 Areas Low-Level Burial Grounds--An Interim Report*. PNL-6820, 2 Volumes, Pacific Northwest Laboratory, Richland, Washington.

Last, G. V., R. J. Lenhard, B. N. Bjornstad, J. C. Evans, K. R. Roberson, F. A. Spane, J. E. Amonette, and M. L. Rockhold. 1991. *Characteristics of the Volatile Organic Compounds-Arid Integrated Demonstration Site*. PNL-7866, Pacific Northwest Laboratory, Richland, Washington.

Lenhard, R. J., M. A. Gerber, and J. E. Amonette. 1992. *Preliminary Evaluation of Selected in Situ Remediation Technologies for Volatile Organic Compound Contamination at Arid Sites*. PNL-8333, Pacific Northwest Laboratory, Richland, Washington.

Newcomer, D. R., K. D. Pohlod, and J. P. McDonald. 1991. *Water-Table Elevations on the Hanford Site, 1990*. PNL-7693, Pacific Northwest Laboratory, Richland, Washington.

Piepho, M. G., A. G. Law, M. P. Connelly, and K. A. Lindsey. 1993. *Vadose Zone Modeling of Carbon Tetrachloride in 200 West Area of the Hanford Site*. WHC-SD-EN-TI-112, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Rohay, V. J. 1991. *200 West Carbon Tetrachloride Expedited Response Action Phase II Site Evaluation Work Plan*. WHC-SD-EN-AP-059, Westinghouse Hanford Company, Richland, Washington.

Rohay, V. J., and R. J. Cameron. 1992. *Field Measurements of Natural Soil-Gas Venting Cycles in Boreholes at the Hanford Site*. WHC-SA-1710-VA, Westinghouse Hanford Company, Richland.

Rohay, V. J., and R. J. Cameron. 1993. *FY 93 Wellfield Enhancement Work Plan*. WHC-SD-EN-AP-114, Rev. O, prepared by V. J. Rohay, Westinghouse Hanford Company, and R. J. Cameron, Ebasco Services, Inc., for Westinghouse Hanford Company, Richland, Washington.

Rohay, V. J., and G. W. McLellan. 1992. *Integrated Test Plan for Demonstration of a Sonic Drilling System and the SEAMIST System*. WHC-SD-EN-AP-075, Rev. O, Westinghouse Hanford Company, Richland, Washington.

Rohay, V. J., G. V. Last, V. L. King, and L. A. Doremus. 1992a. *FY92 Site Characterization Status Report and Data Package for the Carbon Tetrachloride Site*. WHC-SD-EN-TI-063, Rev. 0, prepared by V. J. Rohay and V. L. King, Westinghouse Hanford Company, and G. V. Last and L. A. Doremus, Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

Rohay, V. J., G. V. Last, D. C. Lanigan, and L. A. Doremus. 1992b. *FY 93 Site Characterization Work Plan for the VOC-Arid ID and 200 West Area Carbon Tetrachloride ERA*. WHC-SD-EN-AP-109, Rev. 0, prepared by V. J. Rohay, Westinghouse Hanford Company, and G. V. Last, D. C. Lanigan, and L. A. Doremus, Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

Stone, W. A., J. M. Thorp, O. P. Gifford, and D. J. Hoitink. 1983. *Climatological Summary for the Hanford Area*. PNL-4622, Pacific Northwest Laboratory, Richland, Washingtion.

WHC. 1991. *FY 92 Site Characterization Work Plan for the Volatile Organic Compounds - Arid Integrated Demonstration Site, Hanford's 200 West Area*. WHC-SD-EN-AP-063, Rev. 1, prepared by G. V. Last, Pacific Northwest Laboratory, and V. J. Rohay, Westinghouse Hanford Company, for Westinghouse Hanford Company, Richland, Washington.

WHC. 1992. *Hydrogeologic Model for the 200 West Groundwater Aggregate Area*. WHC-SD-EN-TI-014, Rev. 0, prepared by M. P. Connelly and B. H. Ford, Westinghouse Hanford Company, and J. V. Borghese, Pacific Northwest Laboratory, for Westinghouse Hanford Company, Richland, Washington.

WHC. 1993. *Carbon Tetrachloride Atmospheric Losses and Residual Inventory Beneath 200 West Area*. WHC-SD-EN-TI-101, Rev. 0, prepared by Ebasco Services, Inc., for Westinghouse Hanford Company, Richland, Washington.

Woodruff, R. K., and R. W. Hanf, eds. 1992. *Hanford Site Environmental Report for Calendar Year 1991*. PNL-8148, Pacific Northwest Laboratory, Richland, Washington.

9 3 1 2 9 0 1 2 4

Appendix A

Waste Stream Descriptions, Disposal Facility Descriptions, and Estimated Disposal Inventories at the VOC-Arid ID/ERA Site

9 3 1 2 9 0 1 2 2 5

Appendix A

Waste Stream Descriptions, Disposal Facility Descriptions, and Estimated Disposal Inventories at the VOC-Arid ID/ERA Site

This appendix provides a description of the various waste streams discharged to the 216-Z-9 trench, 216-Z-1A tile field, and 216-Z-18 crib. Also described are the waste disposal facilities and their estimated inventories.

9 3 1 2 9 0 1 2 6

A.1 Waste Streams

Three principal waste streams were discharged to the 216-Z-9, -1A, and -18 facilities: aqueous wastes, organic wastes, and "lard oil."

Aqueous Wastes

Aqueous wastes amounted to approximately 95% of the total waste discharges to the aforementioned waste disposal facilities. These wastes have been characterized as an acidic, high-salt, (5 to 6 M) sodium nitrate ($NaNO_3$) solution containing low levels of plutonium and other transuranic elements. Primary constituents consisted of nitric acid, fluoride, and phosphate (DOE 1992). Waste from the Recuplex solvent column extraction consisted of aluminum, magnesium, sodium, calcium, and other metallic nitrate salts. These aqueous wastes were accumulated in a large stainless steel tank and were periodically batch neutralized to a pH of 2.5 by the addition of sodium hydroxide (DOE 1991). Organic liquids, consisting of carbon tetrachloride (CCl_4), tributyl phosphate (TBP), and dibutyl butyl phosphonate (DBBP), were found in saturation amounts in the aqueous phase (DOE 1991).

Organic (Solvent) Wastes

Two organic streams (solvents) were used in the Recuplex/Plutonium Reclamation Facility (PRF) processes: a TBP-based solvent and a DBBP-based solvent. The TBP-based solvent consisted of CCl_4 and TBP. The Recuplex process primarily used a ratio of

85:15 CCl_4 to TBP, while the PRF process used a ratio of 80:20 CCl_4 to TBP (DOE 1991). Tetrachloroethylene (also referred to as perchloroethylene [PCE]) was also used, at times, in combination with CCl_4 (DOE 1991). Ionizing radiation and nitrous acid would eventually degrade the TBP to dibutyl phosphate (DBP). The degraded solvent was periodically discharged, in batches, to the soil column and replaced with a fresh batch of solvent. Each batch of TBP-based solvent amounted to approximately 200 L (DOE 1991). The DBBP-based solvent stream was used for batch rework of aqueous liquid from the primary extraction column that exceeded plutonium concentration discharge specifications and/or for the americium recovery processes (DOE 1991). The Recuplex process used a ratio of 50:50 CCl_4 to DBBP, while the PRF process used a ratio of 70:30 CCl_4 to DBBP. The DBBP-based solvent was then stripped of plutonium and discharged, again to the soil column and in batch mode. Each batch of DBBP-based solvent amounted to approximately 100 L.

"Lard Oil"

A lubricating/cutting oil (also referred to as fabrication ["fab"] or "lard" oil), consisting of a 75:25 CCl_4 to lard oil mixture, was used as a lubricant on plutonium cutting and milling tools. Also, CCl_4 was used to clean the cutting oil from the millings and work surfaces (DOE 1991). The used lubrication oil, with a new estimated ratio of 50:50 CCl_4 to lard oil mixture, was discharged to the same waste disposal facilities as the organic and aqueous wastes.

A.2 Liquid Waste Disposal Facilities and Associated Inventories

The physical design of the disposal facilities and their estimated inventories are described below. Additional detail is provided in Last et al. (1991) and DOE (1991).

216-Z-9 Trench

The 216-Z-9 trench is an enclosed, underground trench (or chamber), covered by a 0.23-m-thick concrete pad (DOE 1991). The base of the trench is 18.3 m long by 9.1 m wide by 6.4 m deep (DOE 1991). All concrete surfaces are lined with acid-resistant brick. The 36.6- by 27.5-m concrete trench cover is supported by six 7-m-tall concrete columns (DOE 1991). Waste was discharged to the trench via one of two 3.8-cm stainless steel pipelines that terminated approximately 5 m above the bottom of the trench. Figure A.1 is a schematic drawing of this facility.

9 3 1 2 9 7 0 1 2 2 7

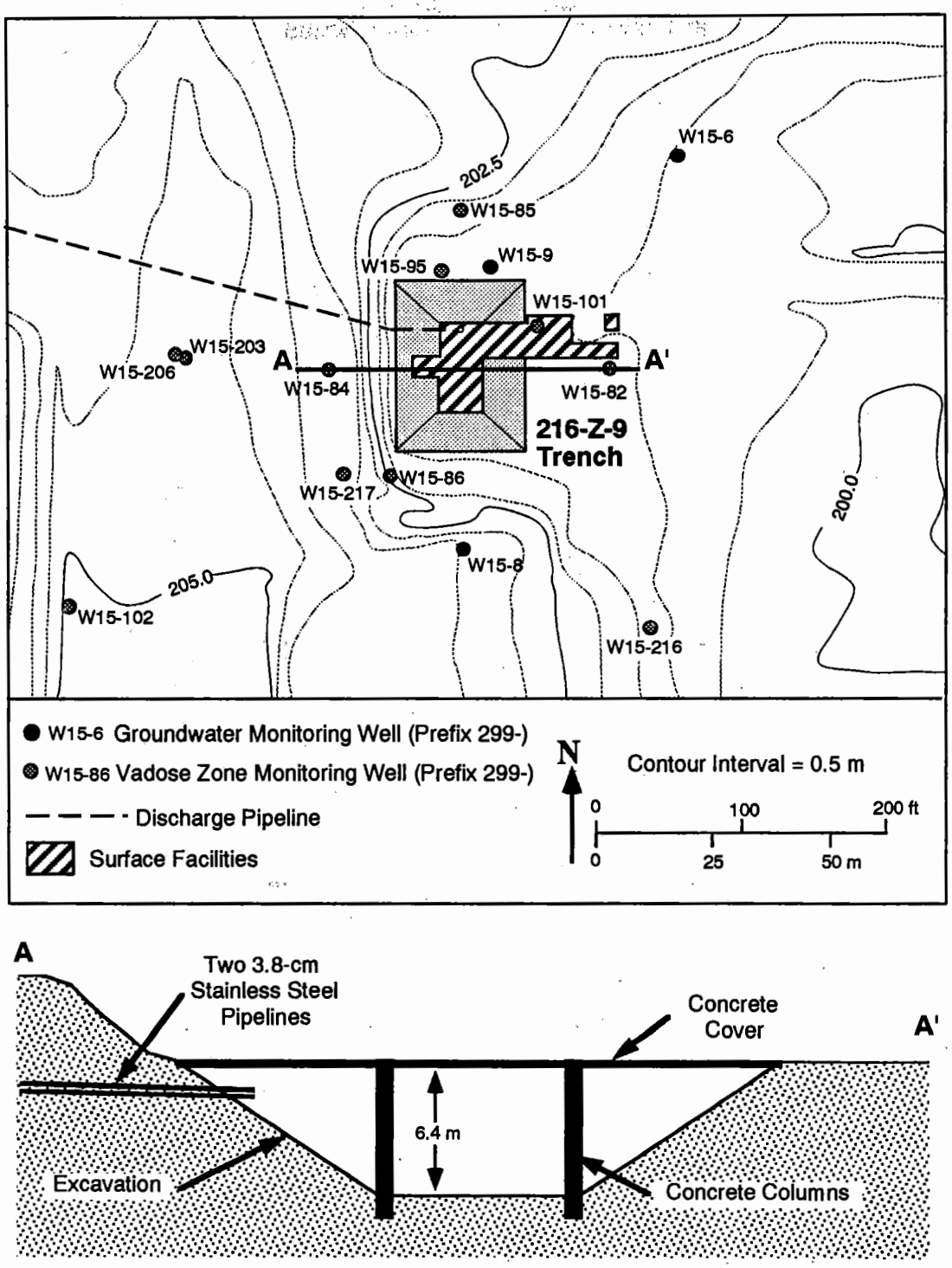


Figure A.1. Map and Schematic Cross Section Through the 216-Z-9 Trench

The 216-Z-9 trench operated from July 1955 through June 1962 and received all the organic and aqueous wastes discharged to the soil from the Recuplex process. The 216-Z-9 trench received no other wastes. Table A.1 provides the estimated waste discharge history and Table A.2 provides an estimated waste constituent inventory for this facility.

Table A.1. Estimated Waste Discharge History for the 216-Z-9 Trench

Year	Total Liquid Discharged (L)	Total Aqueous Waste Discharged (L)	Total TBP Waste Discharged (L)	Total DBBP Waste Discharged (L)	Total "Lard Oil" Waste Discharged (L)
1955	2.60E+05	2.55E+05	3.01E+03	1.51E+03	6.02E+02
1956	4.60E+05	4.14E+05	2.73E+04	1.36E+04	5.46E+03
1957	5.40E+05	4.94E+05	2.73E+04	1.36E+04	5.46E+03
1958	7.00E+05	6.55E+05	2.65E+04	1.32E+04	5.29E+03
1959	5.60E+05	5.13E+05	2.78E+04	1.39E+04	5.56E+03
1960	6.20E+05	5.72E+05	2.81E+04	1.41E+04	5.62E+03
1961	7.70E+05	7.07E+05	3.73E+04	1.86E+04	7.46E+03
1962	1.80E+05	1.65E+05	8.71E+03	4.36E+03	1.74E+03
Total	4.09E+06	3.77E+06	1.86E+05	9.30E+04	3.72E+04

Based on information from Owens (1981), DOE (1991, 1992), and Piepho et al. (1993).

216-Z-1A Tile Field

The 216-Z-1A tile field is similar in design to that of a common septic tank drain field. The tile field was constructed in 1949 to receive overflow liquid waste from three adjacent cribs: 216-Z-1, -2, and -3. Construction of the tile field was initiated with a 5.8-m-deep excavation, having floor dimensions of approximately 35 by 84 m (Price et al. 1979). The floor of the excavation sloped (1%) slightly to the south and was covered by a 1.2-m-thick layer of cobbles. A herringbone pattern of 20-cm-dia. vitrified clay pipe was placed on the cobble layer (Figure A.2). The piping system was then overlaid with 15 cm of cobbles and 1.5 m of sand and gravel.

Table A.2. Estimated Waste Constituent Inventory for the 216-Z-9 Trench

Year	Total Liquid Discharged (L)	Total Aqueous Waste Discharged (L)	Total Plutonium Discharged (g)	Total TBP Discharged (L)	Total DBBP Discharged (L)	Total "Lard Oil" Discharged (L)	Total CCl_4 Discharged (L)
1955	2.60E+05	2.55E+05	6.45E+02	4.52E+02	7.53E+02	1.51E+02	3.76E+03
1956	4.60E+05	4.14E+05	2.25E+03	4.09E+03	6.82E+03	1.36E+03	3.41E+04
1957	5.40E+05	4.94E+05	5.19E+03	4.09E+03	6.82E+03	1.36E+03	3.41E+04
1958	7.00E+05	6.55E+05	7.04E+03	3.97E+03	6.62E+03	1.32E+03	3.31E+04
1959	5.60E+05	5.13E+05	5.34E+03	4.17E+03	6.96E+03	1.39E+03	3.48E+04
1960	6.20E+05	5.72E+05	5.68E+03	4.22E+03	7.03E+03	1.41E+03	3.51E+04
1961	7.70E+05	7.07E+05	8.79E+03	5.59E+03	9.32E+03	1.86E+03	4.66E+04
1962	1.80E+05	1.65E+05	3.42E+03	1.31E+03	2.18E+03	4.36E+02	1.09E+04
Total	4.09E+06	3.77E+06	3.84E+04[a]	2.79E+04	4.65E+04	9.30E+03	2.33E+05[b]

(a) 58 kg were removed in the 1976-1978 mining operation. This was 54% higher than originally estimated and led to a 54% correction factor to the inventory estimates, resulting in a total inventory estimate of 106 kg, with 48 kg still remaining (Ludowise 1978)

(b) Total CCl_4 inventory estimates range from 8.3E+04 to 3.00E+05 L.

Based on information from Owens (1981), DOE (1991, 1992), and Piepho et al. (1993).

The tile field was used in this configuration from 1949 to 1959. The waste stream discharged to the three cribs and overflowing to the tile field consisted of neutral to basic (pH 8 to 10) process waste and analytical and development laboratory waste from the Plutonium Finishing Plant via the 241-Z-361 settling tank.

Prior to reactivation of the 216-Z-1A tile field in 1964, a sheet of 0.05-cm-thick polyethylene and a 30-cm-thick layer of sand and gravel were added and the liquid waste discharge piping was routed directly to its central distributor pipe. Between 1964 and 1969, a 5-cm-dia. stainless steel pipe was progressively inserted inside the central distributor pipe to divide the tile field into three operational sections (216-Z-1AA, -1AB, and -1AC). During that period, the tile field received the aqueous and organic waste from the PRF. No other waste disposal facility received PRF wastes during that period, except on two

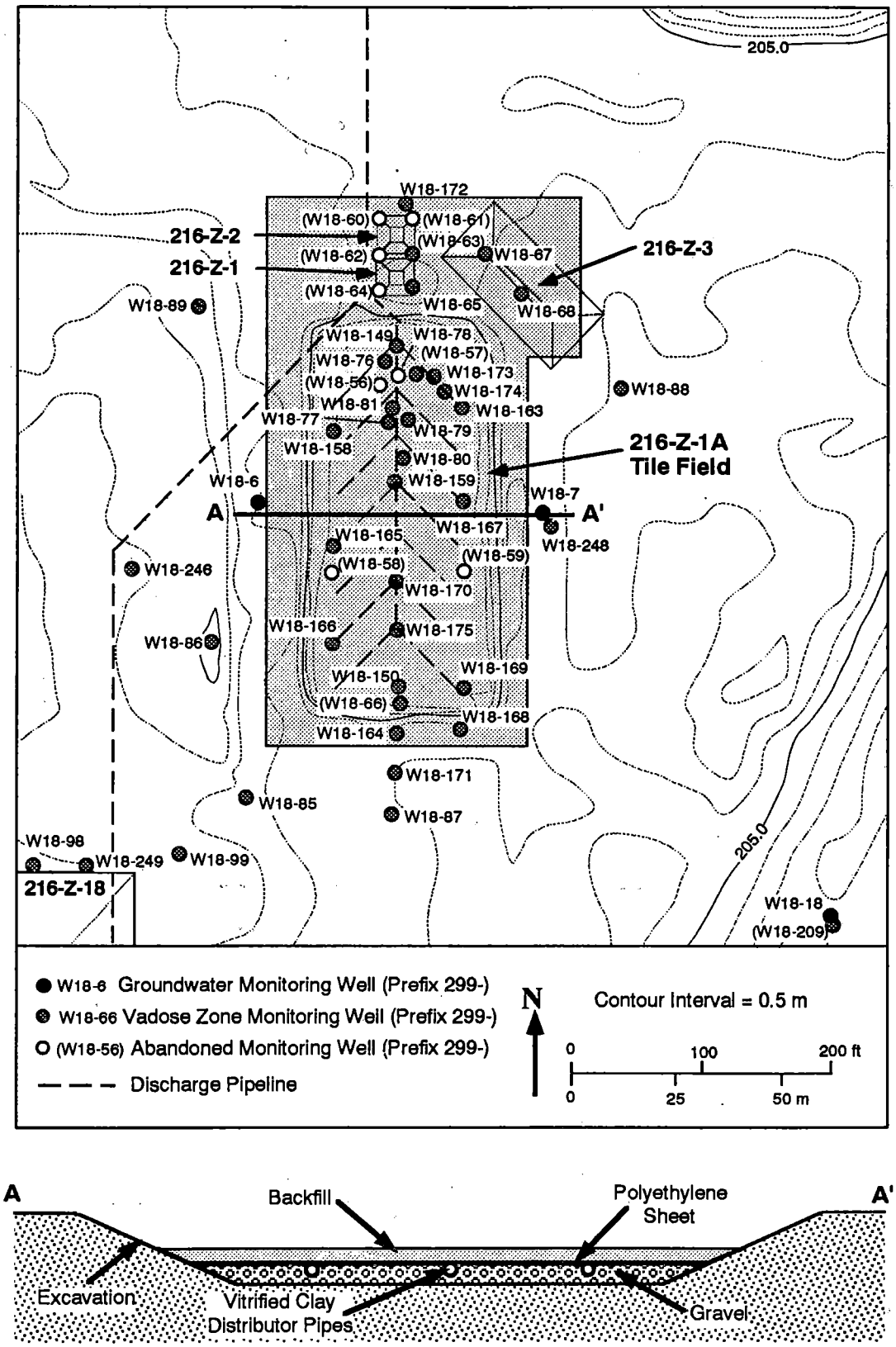


Figure A.2. Map and Schematic Cross Section Through the 216-Z-1A Tile Field

9 3 1 2 9 7 0 1 2 3 1

brief occasions while modifications were made to the piping system. On those two occasions, the waste was discharged to the adjacent 216-Z-1 and -2 cribs. Table A.3 provides the estimated waste discharge history and Table A.4 provides an estimated waste constituent inventory for the 216-Z-1A tile field.

Table A.3. Estimated Waste Discharge History for the 216-Z-1A Tile Field

Year	Total Liquid Discharged (L)	Total Aqueous Waste Discharged (L)	Total TBP Waste Discharged (L)	Total DBBP Waste Discharged (L)	Total "Lard Oil" Waste Discharged (L)
1949	6.00E+04	6.00E+04	NR	NR	NR
1950	1.00E+05	1.00E+05	NR	NR	NR
1951	1.00E+05	1.00E+05	NR	NR	NR
1952	1.00E+05	1.00E+05	NR	NR	NR
1953	1.00E+05	1.00E+05	NR	NR	NR
1954	1.00E+05	1.00E+05	NR	NR	NR
1955	1.00E+05	1.00E+05	NR	NR	NR
1956	1.00E+05	1.00E+05	NR	NR	NR
1957	1.00E+05	1.00E+05	NR	NR	NR
1958	1.00E+05	1.00E+05	NR	NR	NR
1959	4.00E+04	4.00E+04	NR	NR	NR
1960	Inactive	--	--	--	--
1961	Inactive	--	--	--	--
1962	Inactive	--	--	--	--
1963	Inactive	--	--	--	--
1964	4.40E+05	4.20E+05	1.01E+04	7.75E+03	1.86E+03
1965	9.20E+05	8.79E+05	2.11E+04	1.62E+04	3.89E+03
1966	1.50E+06	1.43E+06	3.45E+04	2.64E+04	6.34E+03
1967	1.19E+06	1.14E+06	2.74E+04	2.10E+04	5.04E+03
1968	1.00E+06	9.55E+05	2.30E+04	1.76E+04	4.22E+03
1969	1.55E+05	1.48E+05	3.56E+03	2.73E+03	6.55E+02
Total	6.21E+06	5.97E+06	1.20E+05	9.18E+04	2.20E+04

NR = Not reported.
Based on information from Owens (1981), DOE (1991, 1992), and Piepho et al. (1993).

Table A.4. Estimated Waste Constituent Inventory for the 216-Z-1A Tile Field

Year	Total Liquid Discharged (L)	Total Plutonium Discharged (L)	Total TBP Discharged (L)	Total DBBP Discharged (L)	Total "Lard Oil" Discharged (L)	Total CCl_4 Discharged (L)
1949	6.00E+04	3.00E+00	NR	NR	NR	NR
1950	1.00E+05	5.00E+00	NR	NR	NR	NR
1951	1.00E+05	5.00E+00	NR	NR	NR	NR
1952	1.00E+05	5.00E+00	NR	NR	NR	NR
1953	1.00E+05	5.00E+00	NR	NR	NR	NR
1954	1.00E+05	5.00E+00	NR	NR	NR	NR
1955	1.00E+05	5.00E+00	NR	NR	NR	NR
1956	1.00E+05	5.00E+00	NR	NR	NR	NR
1957	1.00E+05	5.00E+00	NR	NR	NR	NR
1958	1.00E+05	5.00E+00	NR	NR	NR	NR
1959	4.00E+04	2.00E+00	NR	NR	NR	NR
1960	Inactive	–	–	–	–	–
1961	Inactive	–	–	–	–	–
1962	Inactive	–	–	–	–	–
1963	Inactive	–	–	–	–	–
1964	4.40E+05	1.43E+04	2.02E+03	2.33E+03	9.29E+02	1.44E+04
1965	9.20E+05	1.10E+04	4.23E+03	4.86E+03	1.94E+03	3.02E+04
1966	1.50E+06	1.66E+04	6.90E+03	7.93E+03	3.17E+03	4.93E+04
1967	1.19E+06	6.99E+03	5.48E+03	6.31E+03	2.52E+03	3.92E+04
1968	1.00E+06	7.60E+03	4.60E+03	5.29E+03	2.11E+03	3.28E+04
1969	1.55E+05	8.16E+02	7.13E+02	8.19E+02	3.27E+02	5.09E+03
Total	6.21E+06	5.74E+04	2.39E+04	2.75E+04	1.10E+04	1.71E+05

NR = Not reported.
Based on information from Owens (1981), DOE (1991, 1992), and Piepho et al. (1993).

9 3 1 2 9 7 0 1 2 3 3

216-Z-18 Crib

The 216-Z-18 crib operated as a replacement for the 216-Z-1A tile field, receiving aqueous and organic wastes from the PRF between 1969 and 1973. This drain-field-type crib consists of five parallel trenches, each 63 m long by 3 m wide and ranging from 4.5 to 5.5 m deep (Figure A.3). The floor of each trench was covered with approximately 0.3 m of gravel. Two, parallel, 7.6-cm-dia., fiberglass-reinforced, epoxy distributor pipes were placed on the gravel layer within each trench. A central pipe, consisting of a 7.6-cm-dia. steel pipe, connects each trench. Another layer of approximately 0.3 m of gravel was placed over the distributor pipes in each trench. The gravel was covered by a membrane barrier (polyethylene) that was then covered with approximately 15 cm of sand and backfilled to grade. The westernmost trench never received any waste (WHC 1991). Table A.5 provides the estimated waste discharge history and Table A.6 provides an estimated waste constituent inventory for the 216-Z-18 crib.

A.3 References

DOE. 1991. *Expedited Response Action Proposal (EE/CA & EA) for 200 West Area Carbon Tetrachloride Plume*. DOE/RL-91-32 Draft B, U.S. Department of Energy, Richland, Washington.

DOE. 1992. *Z Plant Source Aggregate Area Management Study Report*. DOE/RL-91-58 Draft A, U.S. Department of Energy, Richland, Washington.

Last, G. V., R. J. Lenhard, B. N. Bjornstad, J. C. Evans, K. R. Roberson, F. A. Spane, J. E. Amonette, and M. L. Rockhold. 1991. *Characteristics of the Volatile Organic Compounds-Arid Integrated Demonstration Site*. PNL-7866, Pacific Northwest Laboratory, Richland, Washington.

Ludowise, J. D. 1978. *Report on Plutonium Mining Activities at 216-Z-9*. RHO-ST-21, Rockwell Hanford Operations, Richland, Washington.

Owens, K. W. 1981. *Existing Data on the 216-Z Liquid Waste Sites*. RHO-LD-114, Rockwell Hanford Operations, Richland, Washington.

Piepho, M. G., A. G. Law, M. P. Connelly, and K. A. Lindsey. 1993. *Vadose Zone Modeling of Carbon Tetrachloride in 200 West Area of the Hanford Site*. WHC-SD-EN-TI-112, Rev. O, Westinghouse Hanford Company, Richland, Washington.

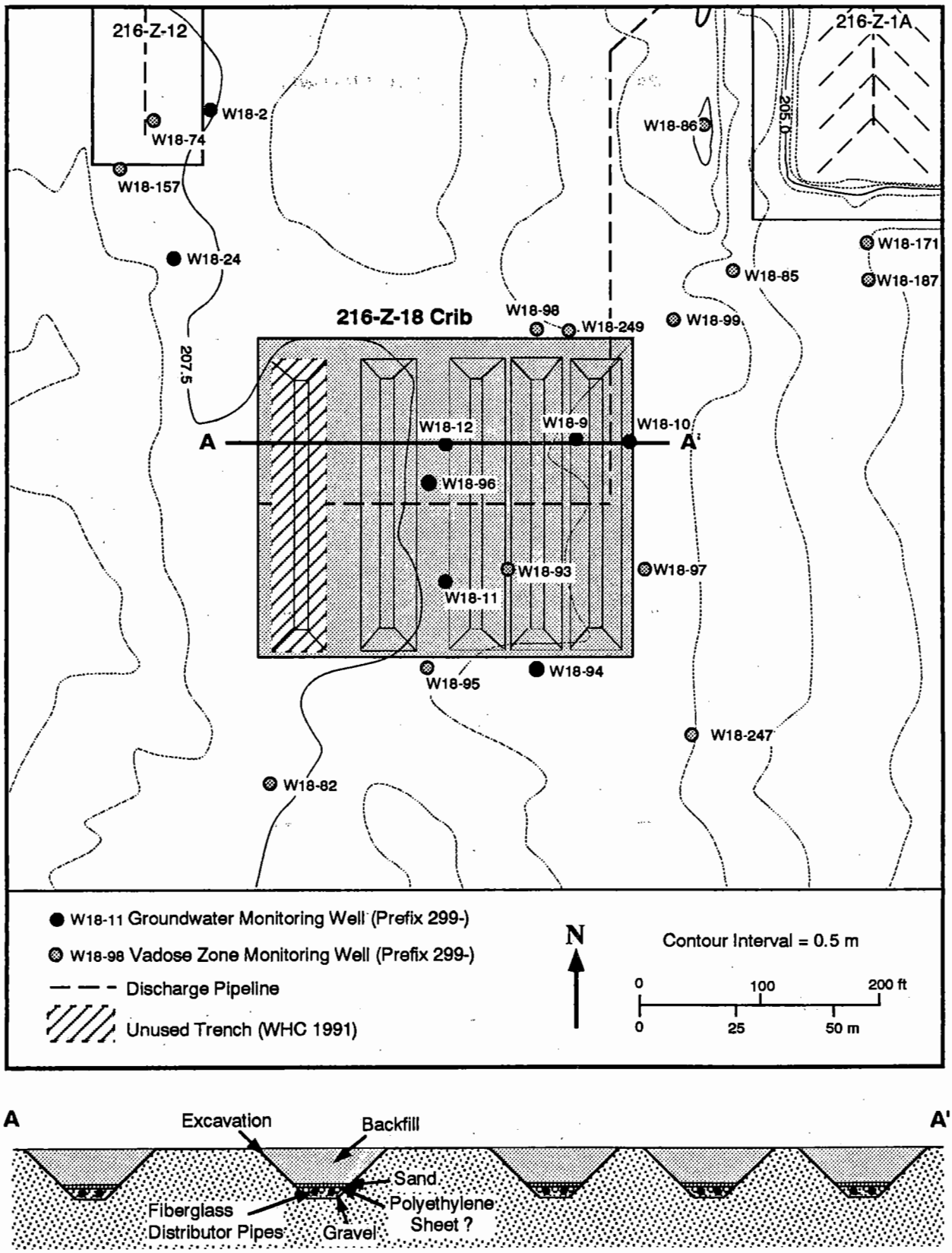


Figure A.3. Map and Schematic Cross Section Through the 216-Z-18 Crib

9 3 1 2 9 7 0 1 2 3 5

Table A.5. Estimated Waste Discharge History for the 216-Z-18 Crib

Year	Total Liquid Discharged (L)	Total Aqueous Waste Discharged (L)	Total TBP Waste Discharged (L)	Total DBBP Waste Discharged (L)	Total "Lard Oil" Waste Discharged (L)
1969	5.72E+05	5.50E+05	1.21E+04	9.44E+03	NR
1970	7.99E+05	7.69E+05	1.69E+04	1.32E+04	NR
1971	8.84E+05	8.51E+05	1.87E+04	1.46E+04	NR
1972	1.24E+06	1.19E+06	2.63E+04	2.05E+04	NR
1973	3.66E+05	3.52E+05	7.75E+03	6.04E+03	NR
Total	3.86E+06	3.72E+06	8.18E+04	6.37E+04	NR

NR = Not reported.
Based on information from Owens (1981), DOE (1991, 1992), and Piepho et al. (1993).

Table A.6. Estimated Waste Constituent Inventory for the 216-Z-18 Crib

Year	Total Liquid Discharged (L)	Total Plutonium Discharged (g)	Total TBP Discharged (L)	Total DBBP Discharged (L)	Total "Lard Oil" Discharged (L)	Total CCl_4 Discharged (L)
1969	5.72E+05	4.27E+03	2.42E+03	2.83E+03	NR	1.63E+04
1970	7.99E+05	5.01E+03	3.38E+03	3.96E+03	NR	2.28E+04
1971	8.84E+05	5.53E+03	3.74E+03	4.38E+03	NR	2.52E+04
1972	1.24E+06	6.87E+03	5.25E+03	6.14E+03	NR	3.53E+04
1973	3.66E+05	1.27E+03	1.55E+03	1.81E+03	NR	1.04E+04
Total	3.86E+06	2.30E+04	1.64E+04	1.91E+04	NR	1.10E+05

NR = Not reported.
Based on information from Owens (1981), DOE (1991, 1992), and Piepho (1993).

9 3 1 2 9 0 1 2 3 6

Price, S. M., R. B. Kasper, M. K. Additon, R. M. Smith, and G. V. Last. 1979. *Distribution of Plutonium and Americium Beneath the 216-Z-1A Crib: A Status Report*. RHO-ST-17, Rockwell Hanford Operations, Richland, Washington.

WHC. 1991. *FY 92 Site Characterization Work Plan for the Volatile Organic Compounds-Arid Integrated Demonstration Site, Hanford's 200 West Area*. WHC-SD-EN-AP-063, Rev. 1, prepared by G. V. Last, Pacific Northwest Laboratory, and V. J. Rohay, Westinghouse Hanford Company, for Westinghouse Hanford Company, Richland, Washington.

9 3 1 2 9 7 0 1 2 3 7

9 3 1 2 9 0 1 2 3 8

Appendix B

Geology of the VOC-Arid ID/ERA Site: An Update

THIS PAGE INTENTIONALLY
LEFT BLANK

Appendix B

Geology of the VOC-Arid ID/ERA Site: An Update

This appendix provides a detailed description of the lithology (i.e., composition, grain size, sorting, porosity, cementation, etc.) and stratigraphic relationships between geologic units beneath the Volatile Organic Compound-Arid Integrated Demonstration/Expedited Response Action (VOC-Arid ID/ERA) site. These refined interpretations are based on evaluation of the following types of data: 1) driller's logs, 2) particle-size analyses, 3) calcium carbonate ($CaCO_3$) analyses, 4) moisture-content analyses, 5) geologist's logs, and 6) gross gamma logs. These data were evaluated in accordance with characteristics identified by Bjornstad (1985) and DOE (1988) and to distinguish between primary geologic units. Interpretations and nomenclature were based on those by WHC (1991, 1992). The quality and quantity of borehole data vary greatly from borehole to borehole and are subject to multiple interpretations. In addition, many of the boreholes have not been accurately surveyed, so elevation of the various geologic contacts may be off a few meters.

The subsurface geology of the VOC-Arid ID/ERA site consists of a thick accumulation (>150 m) of clastic sedimentary deposits overlying bedrock of the Miocene Columbia River Basalt Group. These suprabasalt sediments include lithologic units assigned to the late Miocene to Pliocene Ringold Formation, the Plio-Pleistocene unit, the early Palouse soil (informal name), and the Pleistocene Hanford formation (informal name). A thin veneer of Holocene eolian sand locally overlies the Hanford formation. Figure B.1 illustrates the general stratigraphy and nomenclature for the units beneath the site. Each of these principal geologic units is described below. The estimated elevation of the interpreted geologic contacts used throughout this appendix are provided in Table B.1. Figure B.2 is the location map of wells used at the VOC-Arid ID/ERA site, and Figures B.3 through B.6 give the detailed cross sections through the site.

Elephant Mountain Member

The Columbia River Basalt Group (Swanson et al. 1979) forms the bedrock beneath the site and contains the regionally extensive confined aquifer system. The Elephant

9 3 1 2 9 0 1 2 3 9

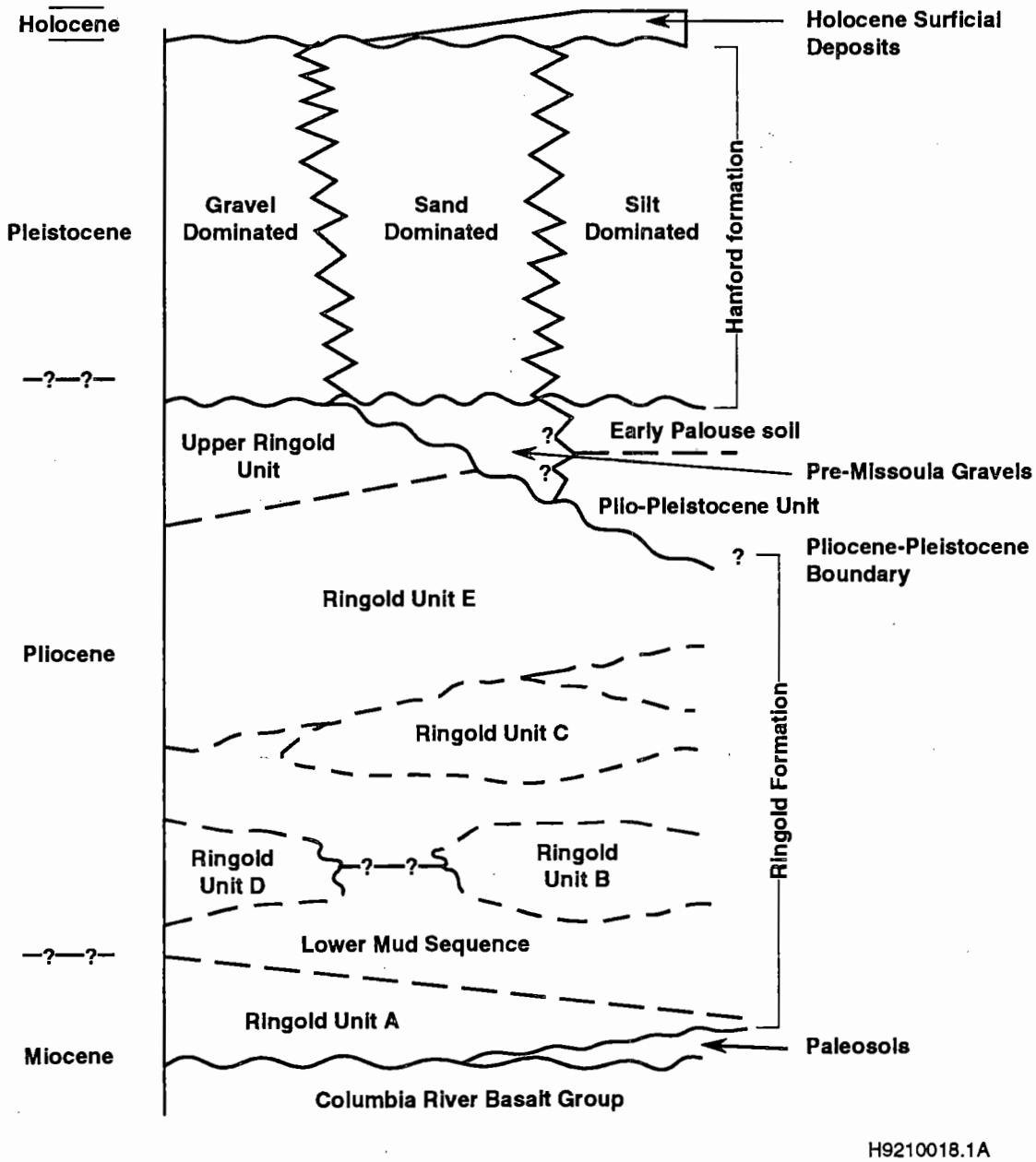


Figure B.1. Generalized Stratigraphy and Nomenclature of the VOC-Arid ID/ERA Site

Table B.1. Elevation of Geologic Contacts Used in this Report

Well Number	Cross-Section	Plant Coordinates North	Plant Coordinates West	Grnd/Pad Elevation (m-MSL)	Drill Depth (m)	Elevation in Meters Above Mean Sea Level: Holocene Backfill	Holocene Sand	Hanford Upper Sand	Hanford Upper Gravel	Hanford Lower Fine B	Hanford Lower Gravel	Hanford Lower Sand	Hanford Lower Fine A	Early Palouse Soil	Plio-Pleistocene	Ringold Formation Upper Unit	Ringold Formation Unit E	Ringold Formation Lower Mud	Ringold Formation Unit A	SMF Elephant Mtn.
299-W15-5	A	39537'	75984'	203.5	182.6	NP	203	NP	194	NP	NP	185	175	168	165	162	156	73	56	43
299-W15-6	A	40005'	75765'	200.7	125.0	NP	201	NP	197	NP	NP	189	182	171	169	164	157	ETD	-	-
299-W15-8	D	39740'	75910'	202.9	62.8	NP	203	NP	197	NP	NP	186	175	171	168	165	156	ETD	-	-
299-W15-9		39930'	75890'	201.3	59.4	NP	201	NP	191	NP	NP	189	-	169	167	165	159	-	-	-
299-W15-14		39990'	78089'	211.9	177.1	-	212	210	-	184	-	-	-	169	164	160	159	72	67	40
299-W15-16		40269'	77387'	208.0	74.4	-	208	205	-	-	-	-	-	165	164	158	155	-	-	-
299-W15-17		40221'	77387'	207.8	137.2	-	-	208	-	-	-	-	-	167	164	156	154	75	-	-
299-W15-18		39705'	77383'	208.1	74.1	-	-	208	-	-	-	-	-	168	167	163	157	-	-	-
299-W15-20		41028'	78120'	211.9	74.7	-	-	212	-	189	-	-	-	170	165	-	159	-	-	-
299-W15-23		40680'	78119'	210.3	73.1	-	-	210	-	182	-	-	-	166	163	160	155	-	-	-
299-W15-84	D	39860'	76000'	203.7	33.5	NP	204	NP	198	NP	NP	189	178	ETD	-	-	-	-	-	-
299-W15-86	A,D	39790'	75958'	200.6	43.9	NP	201	NP	198	NP	NP	187	178	170	166	163	ETD	-	-	-
299-W15-202	D	39995'	76250'	204.2	53.6	NP	204	203	NP	NP	NP	183	178	170	168	165	154	ETD	-	-
299-W15-203		39873'	76100'	205.1	6.1	NP	205	ETD	-	-	-	-	-	-	-	-	-	-	-	-
299-W15-206	D	39873'	76104'	205.1	3.7	NP	205	ETD	-	-	-	-	-	-	-	-	-	-	-	-
299-W15-208	D	39600'	75650'	199.9	6.1	NP	200	NP	197	ETD	-	-	-	-	-	-	-	-	-	-
299-W15-216	D	39698'	75793'	201.6	64.0	202	201	197	NP	NP	NP	188	179	169	167	164	157	ETD	-	-
299-W15-217	A, D	39811'	75998'	203.8	37.6	NP	204	NP	198	NP	NP	188	179	169	167	ETD	-	-	-	-
299-W18-1	B	39388'	77013'	207.3	130.1	NP	NP	207	197	194	176	NP	NP	169	167	163	156	ETD	-	-
299-W18-2	C	39120'	77150'	207.6	85.3	NP	208	204	200	192	176	NP	NP	168	166	161	156	ETD	-	-
299-W18-4	C	39150'	77375'	208.5	85.3	NP	208	207	200	196	173	NP	NP	171	169	162	155	ETD	-	-
299-W18-6	C	39212'	76706'	206.0	91.4	NP	206	201	193	191	179	NP	NP	171	162	NP	159	ETD	-	-
299-W18-7	A	39204'	76491'	206.2	91.4	NP	206	202	196	189	NP	179	174	168	166	NP	157	ETD	-	-
299-W18-9	A	38852'	76846'	207.1	67.1	NP	NP	207	197	189	174	NP	NP	167	162	159	155	ETD	-	-
299-W18-10	A	38847'	76803'	207.1	67.1	NP	NP	207	196	192	175	NP	NP	166	163	158	154	ETD	-	-
299-W18-11	A	38735'	76955'	208.2	67.1	NP	NP	208	198	191	175	NP	NP	169	165	NP	161	ETD	-	-
299-W18-15		36990'	77152'	200.5	57.9	-	-	200	-	190	-	-	-	164	157	-	151	-	-	-
299-W18-17	C	39258'	76091'	204.1	80.8	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ETD	-	-
299-W18-18		38903'	76270'	203.6	80.8	-	-	204	-	182	-	-	-	167	164	-	159	-	-	-
299-W18-19		38503'	76403'	204.2	76.2	-	-	204	-	-	-	-	-	173	171	-	161	-	-	-
299-W18-20	B	38103'	76477'	203.3	76.2	NP	203	NP	202	190	185	NP	NP	175	171	163	157	ETD	-	-
299-W18-22		37831'	78109'	202.8	135.6	-	-	203	-	180	-	-	-	166	160	-	156	69	-	-
299-W18-23		38987'	78120'	211.5	77.7	-	-	211	-	179	-	-	-	167	163	-	157	-	-	-
299-W18-24		38998'	77180'	207.9	73.1	-	-	208	-	-	-	-	-	173	170	166	162	-	-	-
299-W18-26		39477'	78097'	212.1	76.2	-	-	212	-	182	-	-	-	168	165	159	156	-	-	-
299-W18-59	A	39161'	76552'	203.3	45.7	NP	203	202	194	190	NP	174	171	168	164	NP	159	ETD	-	-
299-W18-82	A	38570'	77101'	207.3	44.5	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ETD	-	-	-
299-W18-83	A	38409'	77240'	207.3	45.1	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	ETD	-	-	-
299-W18-84	A	38249'	77386'	207.3	45.7	NP	207	NP	203	189	176	NP	NP	170	162	ETD	-	-	-	-
299-W18-85	A	38989'	76717'	206.3	45.7	NP	206	204	199	191	175	NP	NP	168	163	ETD	-	-	-	-
299-W18-86		39106'	76742'	207.7	45.7	-	-	208	-	-	-	-	-	167	162	-	-	-	-	-
299-W18-88	A	39298'	76432'	206.3	45.7	NP	206	202	NP	191	NP	181	176	167	164	ETD	-	-	-	-
299-W18-93		38744'	76905'	202.7	42.7	-	203	199	-	187	-	-	-	162	-	-	-	-	-	-

Table B.1. (contd)

Well Number	Cross-Section	Plant Coordinates North	Plant Coordinates West	Grnd/Pad Elevation (m-MSL)	Drill Depth (m)	Elevation in Meters Above Mean Sea Level: Holocene Backfill	Holocene Sand	Hanford Upper Sand	Hanford Upper Gravel	Hanford Lower Fine B	Hanford Lower Gravel	Hanford Lower Sand	Hanford Lower Fine A	Early Palouse Soil	Plio-Pleis-tocene	Ringold Formation Upper Unit	Ringold Formation Unit E	Ringold Formation Lower Mud	Ringold Formation Unit A	SMF Elephant Mtn.
299-W18-95	A	38665'	76970'	202.7	24.4	NP	203	200	192	186	ETD	-	-	-	-	-	-	-	-	-
299-W18-97	B	38745'	76790'	207.6	25.9	208	NP	205	197	191	ETD	-	-	-	-	-	-	-	-	-
299-W18-99	A	38949'	76768'	202.7	41.1	NP	203	200	192	187	171	NP	NP	162	ETD	-	-	-	-	-
299-W18-150	A	39075'	76601'	203.9	39.0	204	NP	200	195	190	174	NP	NP	170	ETD	-	-	-	-	-
299-W18-159	C	39228'	76602'	204.1	39.6	204	NP	199	NP	191	176	NP	NP	169	ETD	-	-	-	-	-
299-W18-166		39108'	76650'	203.7	41.8	-	204	199	-	-	-	-	-	168	163	-	-	-	-	-
299-W18-167	C	39214'	76552'	203.9	40.8	204	NP	199	193	190	176	NP	172	168	163	ETD	-	-	-	-
299-W18-168		39043'	76552'	203.9	39.9	-	204	201	-	-	-	-	-	169	ETD	-	-	-	-	-
299-W18-175	A	39117'	76600'	204.2	39.6	204	-	200	194	190	-	-	-	168	-	-	-	-	-	-
299-W18-246	C	39149'	76779'	207.7	53.4	NP	208	204	198	191	176	NP	NP	167	163	NP	161	ETD	-	-
299-W18-247	B	38621'	76747'	206.7	69.2	NP	207	205	204	190	172	NP	NP	167	162	159	148	ETD	-	-
299-W18-248	A	39202'	76482'	206.1	42.3	NP	206	203	197	194	NP	180	176	168	164	ETD	-	-	-	-
299-W18-249	B	38940'	76841'	207.2	41.8	NP	207	205	196	189	174	NP	NP	167	163	ETD	-	-	-	-

- = Not Determined.
NP = Not Present.
NR = No Record.
ETD = Exceeds Total Depth.

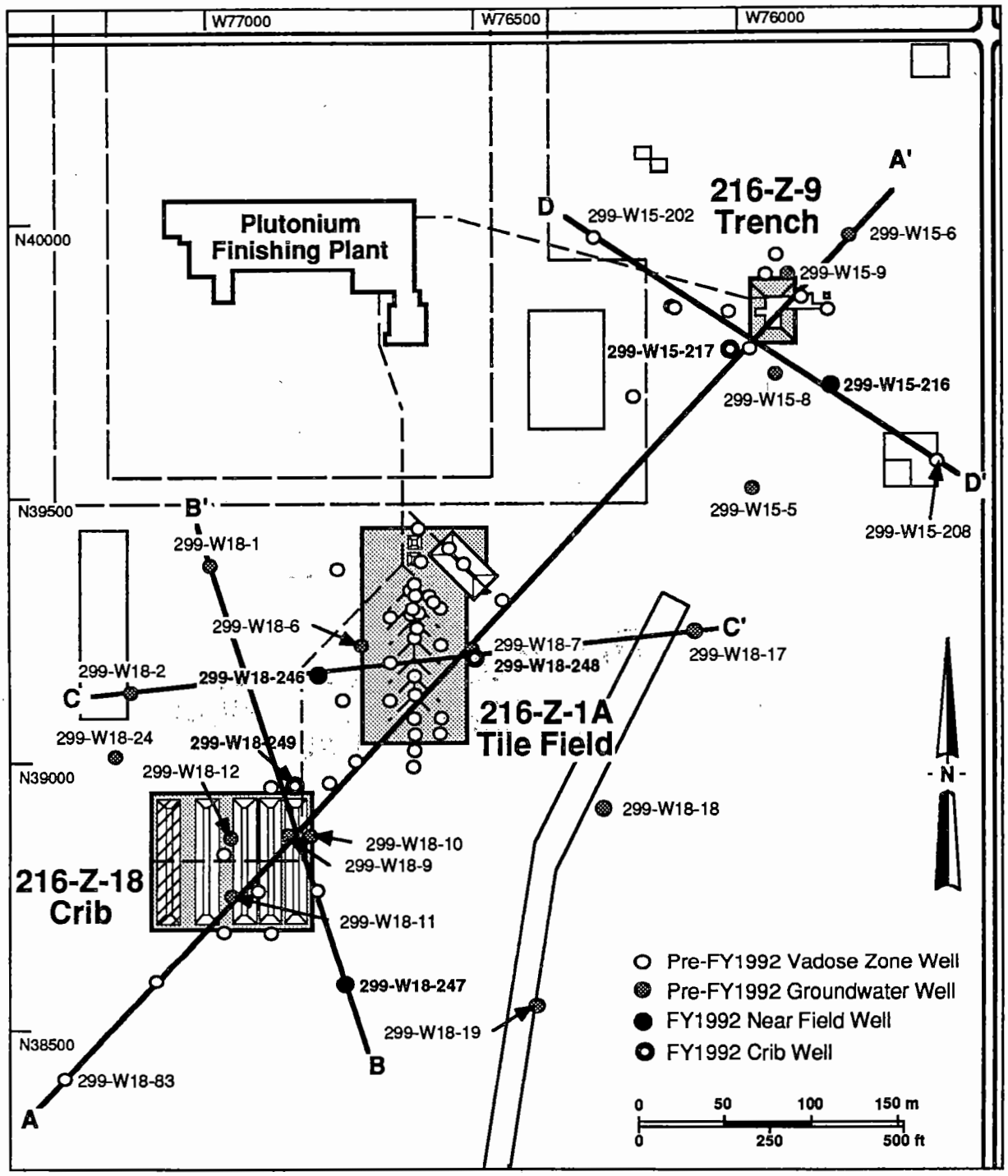


Figure B.2. Location of Wells and Cross Sections Within the VOC-Arid ID/ERA Site

THIS PAGE INTENTIONALLY
LEFT BLANK

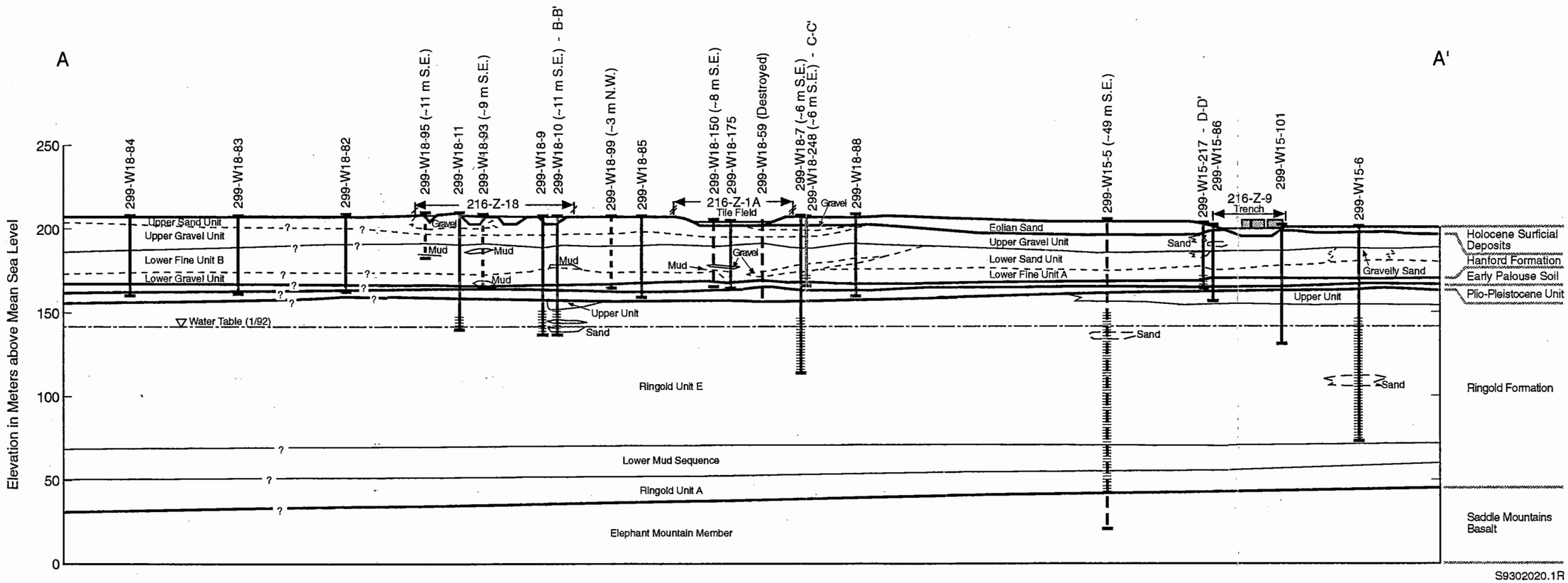


Figure B.3. Geologic Cross Section A-A'

THIS PAGE INTENTIONALLY
LEFT BLANK

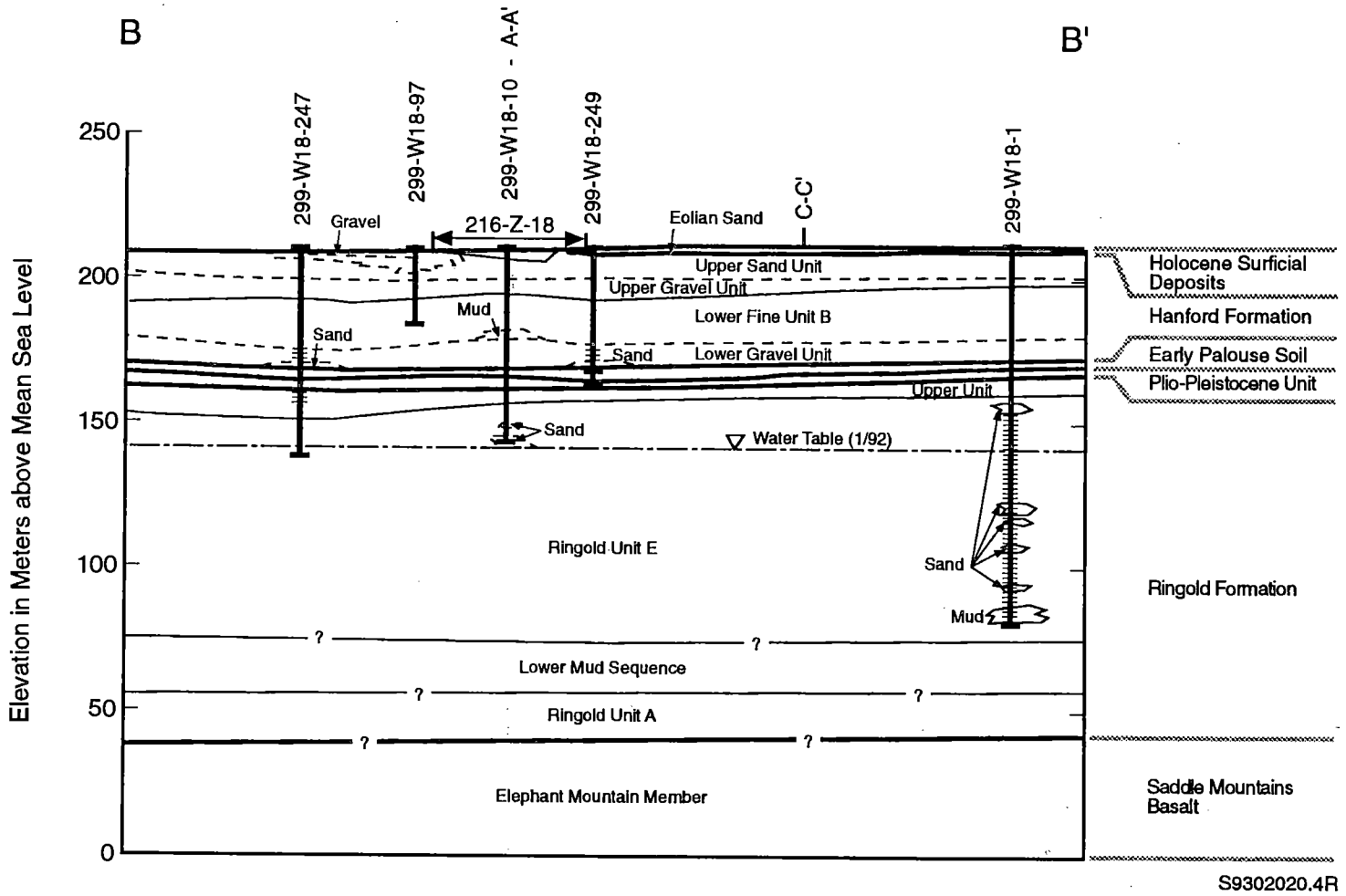


Figure B.4. Geologic Cross Section B-B′

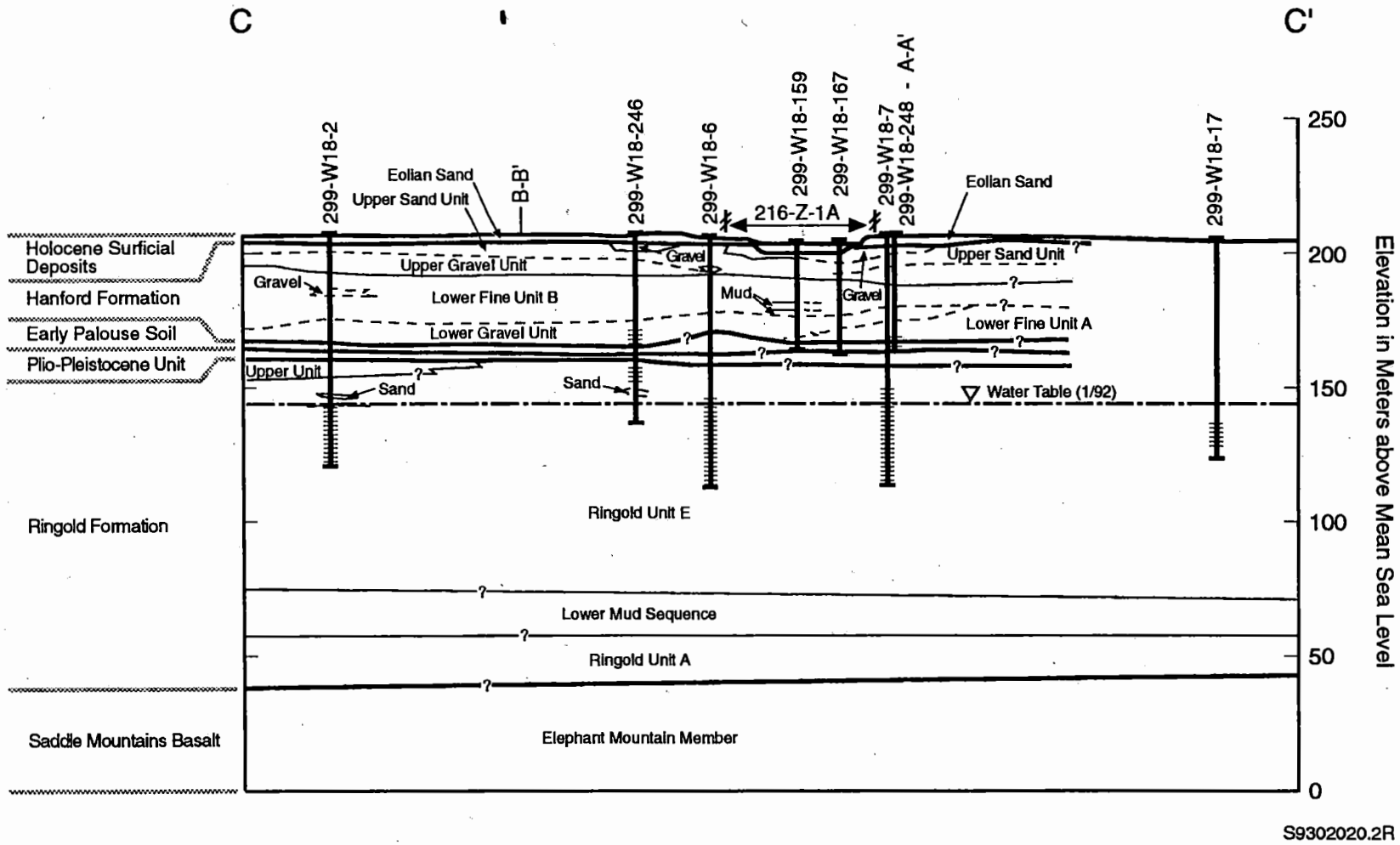


Figure B.5. Geologic Cross Section C-C'

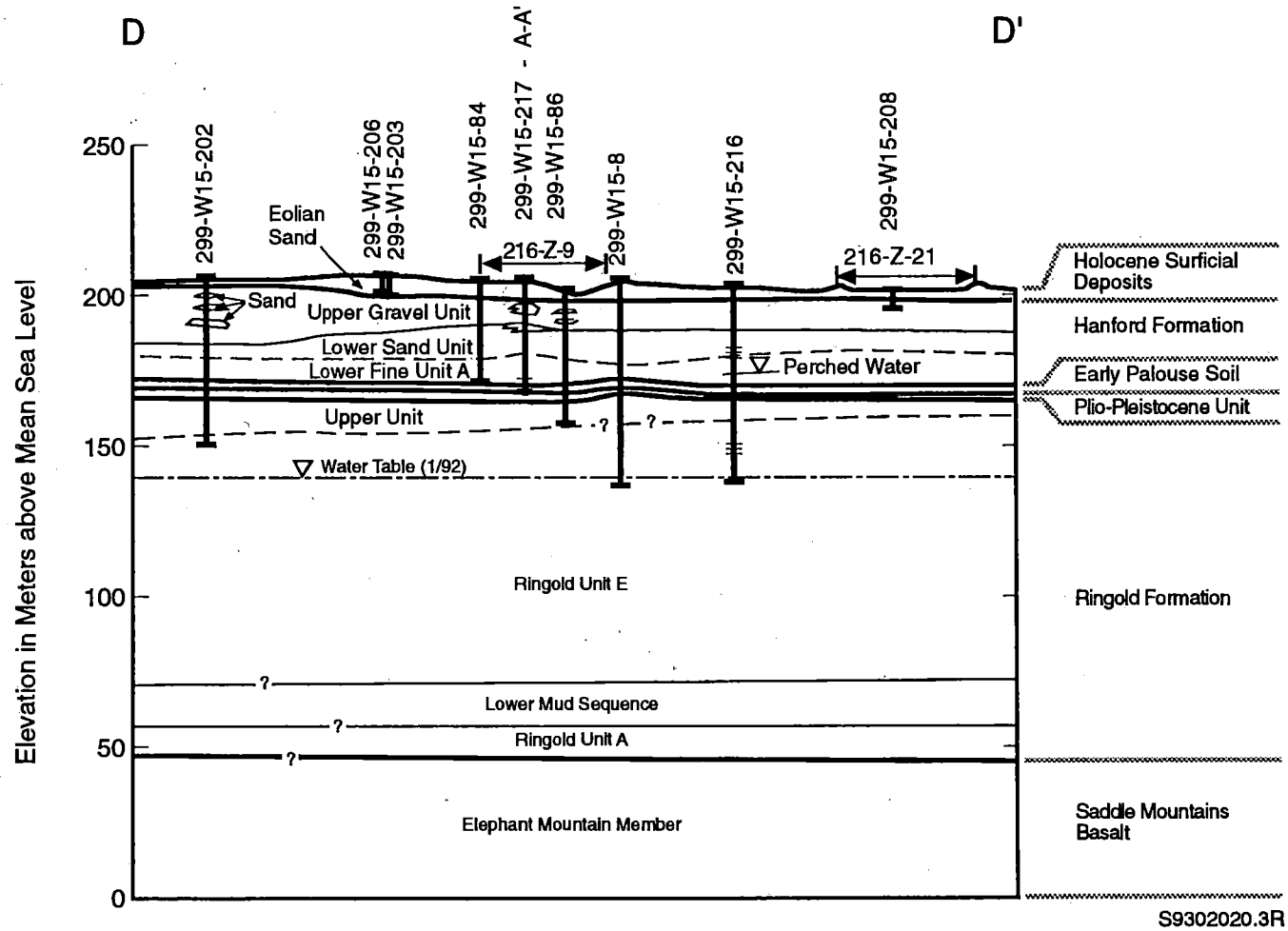


Figure B.6. Geologic Cross Section D-D′

Mountain Member of the Saddle Mountains Basalt is the uppermost unit in the area and is continuous beneath the site. Hydrologically, the Elephant Mountain Member acts as an aquiclude, confining the Rattlesnake Ridge aquifer beneath it and forming the base of the unconfined, suprabasalt, aquifer system. The surface of this unit dips gently to the southwest toward the axis of the Cold Creek syncline (Figure B.7).

Ringold Formation

Four stratigraphically separated lithologic units (or facies associations as defined by WHC 1991) have been identified in boreholes in the vicinity of the site. In ascending order, these facies associations consist of 1) a lower fluvial gravel unit (gravel unit A); 2) a lower sequence of overbank and lacustrine deposits (lower mud sequence); 3) an upper fluvial gravel unit (gravel unit E); and 4) an upper unit of fluvial sands, overbank deposits, and lacustrine sediments (upper unit).

Gravel unit A corresponds to the coarse-grained subunit of the basal Ringold unit of Tallman et al. (1979), DOE (1988), and Last et al. (1989). This fluvial gravel unit directly overlies the Elephant Mountain Member. WHC (1991) describes the fluvial gravel facies association as dominantly clast-supported granule to cobble gravel with a sandy matrix. Composition of the clasts is variable. Intercalated lenticular sand and silt are common in this area. Typical particle-size distributions and $CaCO_3$ contents from this unit are shown in Table B.2. This unit is continuous throughout the site, and is approximately 14 m thick beneath the site. This unit generally dips to the southwest toward the axis of the Cold Creek syncline (WHC 1991).

The lower mud sequence corresponds to the undifferentiated fine-grained portion of the basal Ringold unit and lower Ringold of DOE (1988) and Last et al. (1989) and to the lower Ringold unit of Tallman et al. (1979). WHC (1991) describes this unit as overbank and lacustrine deposits. Overbank deposits are further described as laminated to massive silt, silty fine-grained sand, and paleosols containing variable amounts of pedogenic $CaCO_3$. The lacustrine deposits are further described as plane laminated to massive clay, with thin silt and silty sand interbeds. Typical particle-size distributions and $CaCO_3$ contents for the lower mud unit were shown in Table B.2. This fine-grained unit creates a confining layer to water movement and locally forms the bottom of the unconfined aquifer. This unit is present everywhere beneath the site, but thins and pinches out in the north-eastern portion of the 200 West Area. The thickness of this unit is approximately 16 m beneath the VOC-Arid ID/ERA site. The surface of the lower mud sequence is somewhat irregular and dips to the south and southwest (Figure B.8).

9 3 1 2 9 7 0 1 2 4 8

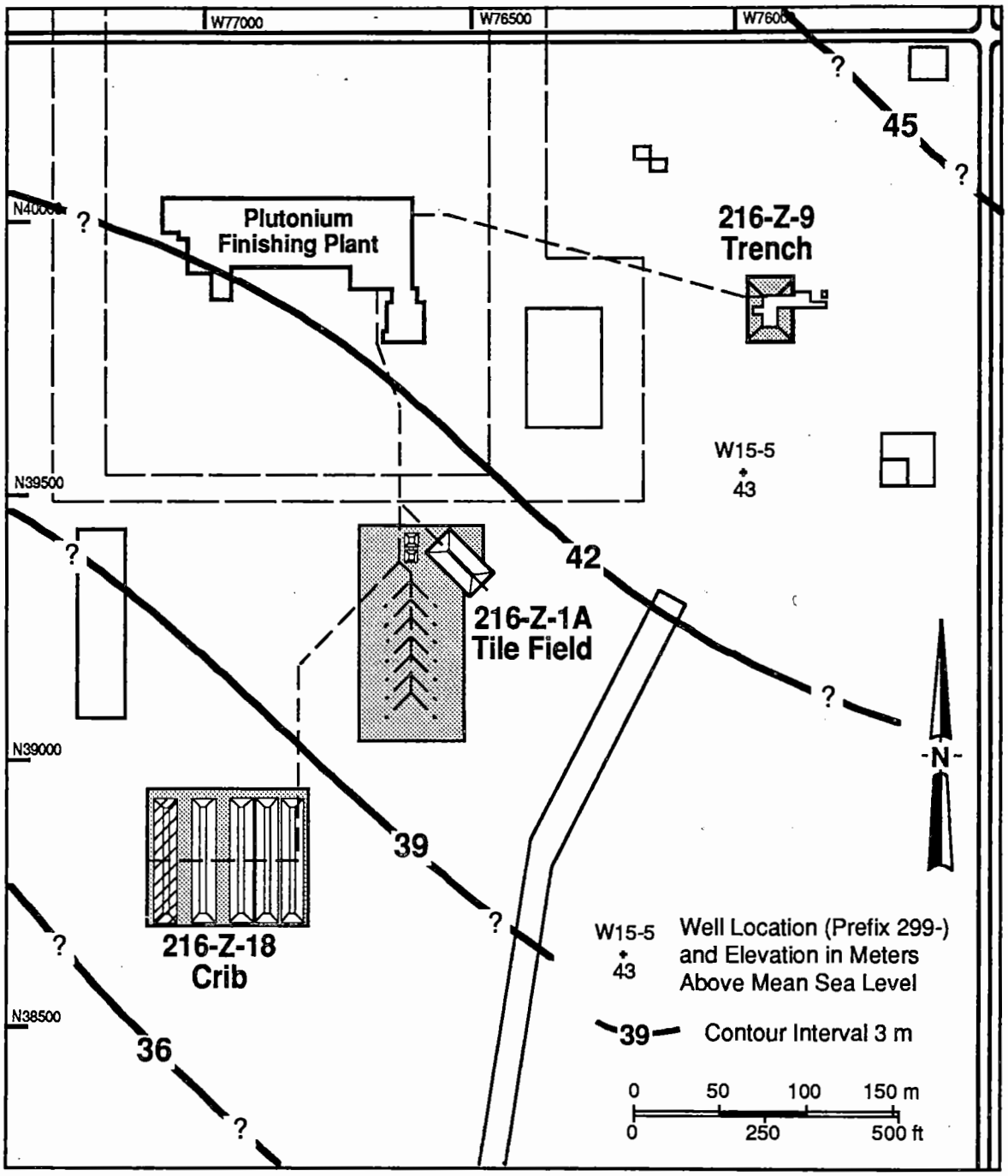


Figure B.7. Structure Contour Map of the Elephant Mountain Member Beneath the VOC-Arid ID/ERA Site (contours extrapolated from data outside study area)

Table B.2. Typical Particle-Size and Calcium Carbonate Values for Geologic Materials Beneath the VOC-Arid ID/ERA Site

Formation /Unit	Sediment Class Description	Borehole /Depth (m)	Gravel >2 mm	Very Coarse Sand 1-2 mm	Coarse Sand 0.5-1 mm	Medium Sand 0.25-0.5 mm	Fine Sand 0.125-0.25 mm	Very Fine Sand 0.063-0.125 mm	Mud <0.063 mm	CaCO3 Content %
Holocene										
Eolian Sand	slightly muddy, fine to very fine Sand	299-W15-5 3.0m	0.0 %	0.7 %	4.9 %	13.1 %	30.9 %	33.9 %	16.5 %	0.5 %
Hanford										
Upper Sand	gravelly, very coarse to coarse Sand	299-W18-85 4.6 m	20.5 %	39.0 %	20.0 %	7.1 %	4.5 %	3.0 %	5.9 %	0.5 %
Upper Gravel	sandy Gravel	299-W18-85 12.2 m	50.1 %	24.6 %	15.9 %	4.3 %	1.8 %	1.1 %	2.1 %	0.6 %
Lower Mud B	muddy, fine to very fine Sand	299-W18-85 19.8 m	0.0 %	0.1 %	0.9 %	6.9 %	29.9 %	36.3 %	26.0 %	3.1 %
	medim to fine Sand	299-W18-85 21.3 m	0.3 %	2.8 %	18.6 %	46.7 %	21.3 %	5.0 %	5.4 %	1.2 %
Lower Gravel	muddy, sandy, Gravel	299-W18-85 36.6 m	46.7 %	17.8 %	9.0 %	6.9 %	5.1 %	3.7 %	10.8 %	1.1 %
Lower Sand	slightly muddy, coarse to medium	299-W15-5 25.9 m	1.6 %	9.3 %	25.1 %	28.2 %	14.7 %	7.8 %	13.3 %	2.1 %
Lower Mud A	slightly muddy, medium to fine Sand	299-W15-5 29.0 m	0.7 %	5.5 %	16.0 %	29.4 %	20.8 %	14.0 %	13.6 %	1.3 %
Early Palouse Soil										
	muddy Sand	299-W15-5 36.6 m	0.0%	0.9%	6.3%	16.5%	15.7%	18.4%	42.2%	2.2%
	sandy Mud	299-W18-85 42.7 m	0.5%	1.4%	6.0%	10.1%	6.3%	13.3%	62.3%	2.5%
Plio-Pleistocene Unit	calcareous, gravelly, muddy, Sand	299-W15-5 38.1 m	21.6%	10.6%	7.6%	8.8%	9.2%	9.9%	32.4%	12.8%
	calcareous,muddy, fine Sand	299-W18-85 47.7 m	2.2%	5.7%	10.4%	18.4%	20.3%	19.0%	24.1%	22.8%
Ringold										
Upper Unit	Sightly muddy, slightly gravelly, coarse to med. Sand	299-W15-5 45.7 m	7.3 %	8.3 %	22.5 %	30.5 %	10.3 %	6.7 %	14.5 %	4.0 %
Unit E	muddy, sandy, Gravel	299-W15-5 56.4 m	58.7 %	12.4 %	4.0 %	7.9 %	7.3 %	3.8 %	5.9 %	0.3 %
Lower Mud Sequence	muddy, medium to fine Sand	299-W15-5 137.2 m	0.9 %	2.4 %	5.5 %	21.4 %	21.6 %	14.0 %	34.3 %	1.6 %
Unit A	sandy Gravel	299-W15-5 147.8 m	40.1 %	33.4 %	17.1 %	4.5 %	1.2 %	1.2 %	2.6 %	0.3 %

Note: Well 299-W15-5 was drilled using hard-tool methods. Thus, the particle-size data may not be totally representative.

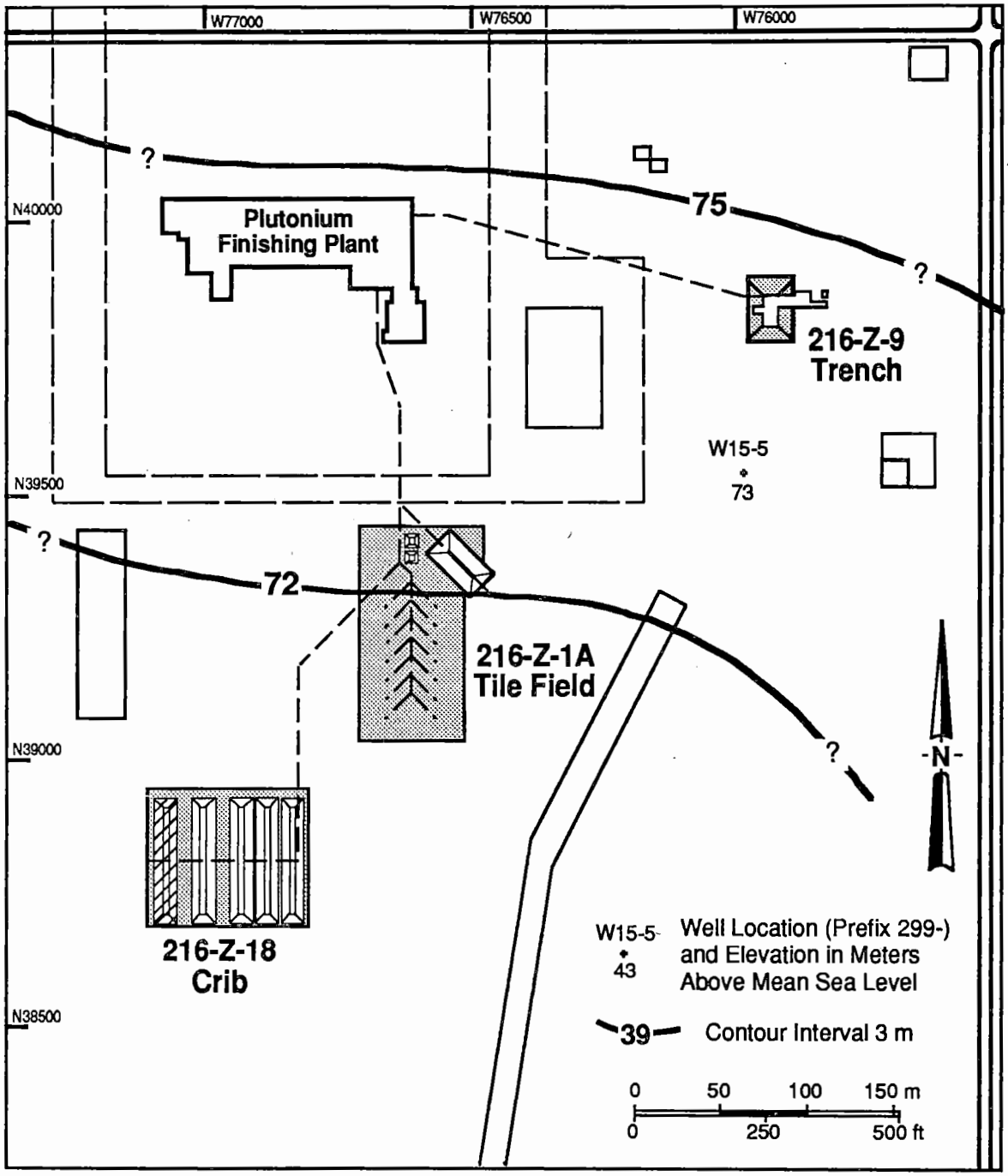


Figure B.8. Structure-Contour Map of the Ringold Lower Mud Sequence Beneath the VOC-Arid ID/ERA Site (the contours were extrapolated from data outside the study area)

Gravel unit E, which is approximately 84 m thick, is present everywhere beneath the site. The character of the unit is similar to that of other fluvial gravel facies of the Ringold Formation (i.e., clast-supported granule to cobble gravel, with a sandy matrix and intercalated lenticular sand and silt). WHC (1992) describes the unit's recognizable characteristics as 1) coarse texture, 2) high proportion of quartzite and granitic clasts, 3) relatively low $CaCO_3$ content, 4) partial consolidation, and 5) relatively low natural-gamma response. Table B.2 presented typical particle-size distributions and $CaCO_3$ content data for this unit. The top of this unit is irregular but generally dips to the southeast (Figure B.9).

The upper unit consists of silty overbank deposits and fluvial sands. The overbank deposits are described as laminated to massive silt, silty fine-grained sand, and paleosols containing variable amounts of pedogenic $CaCO_3$ (WHC 1991). The fluvial sand facies are described as quartzo-feldspathic sands displaying crossbedding and crosslamination. The contact with gravel unit E is gradational and is defined by the transition where light-colored arkosic sand exceeds the amount of gravel. Predominant characteristics of this unit include 1) abundance of well-sorted sand; 2) light color, caused by abundance of quartz and feldspar material over mafic material; and 3) variable natural-gamma response. Typical particle-size distributions and $CaCO_3$ contents were given in Table B.2. This unit is very discontinuous across the site as a result of post-Ringold erosion. The thickness of the unit, as shown in Figure B.10, varies from 1 to 14 m. The surface of the unit generally dips to the south-southwest (Figure B.11).

Plio-Pleistocene Unit

The Plio-Pleistocene unit represents a highly weathered paleosurface that developed atop the Ringold Formation (Brown 1959, 1960). While some aggradation of new material may be associated with this unit, much of the material is the result of in situ weathering of the uppermost Ringold Formation. Two distinct facies have been recognized (DOE 1988): pedogenic calcrete and basaltic detritus. The calcrete facies (locally referred to as the caliche layer) generally consists of carbonate-rich silt and sand interfingered with carbonate-poor silts and sands. The thickness and degree of caliche development within the Plio-Pleistocene unit vary considerably from one location to another, with the concentration of $CaCO_3$ cement (caliche) exceeding 30% by weight in some samples (see Table B.2). In places, this secondary cement may completely fill the voids between sedimentary particles, making it relatively impermeable. However, WHC (1991) describes this caliche layer as moderately to highly fractured. In general, the $CaCO_3$ content decreases to the south, while the abundance of basaltic clasts increases (WHC 1992). Particle-size analysis of borehole samples from the site indicate a significant amount of gravel and sand-size clasts, though much of this could be attributed to aggregated silts held

9 3 1 2 9 7 0 1 2 5 2

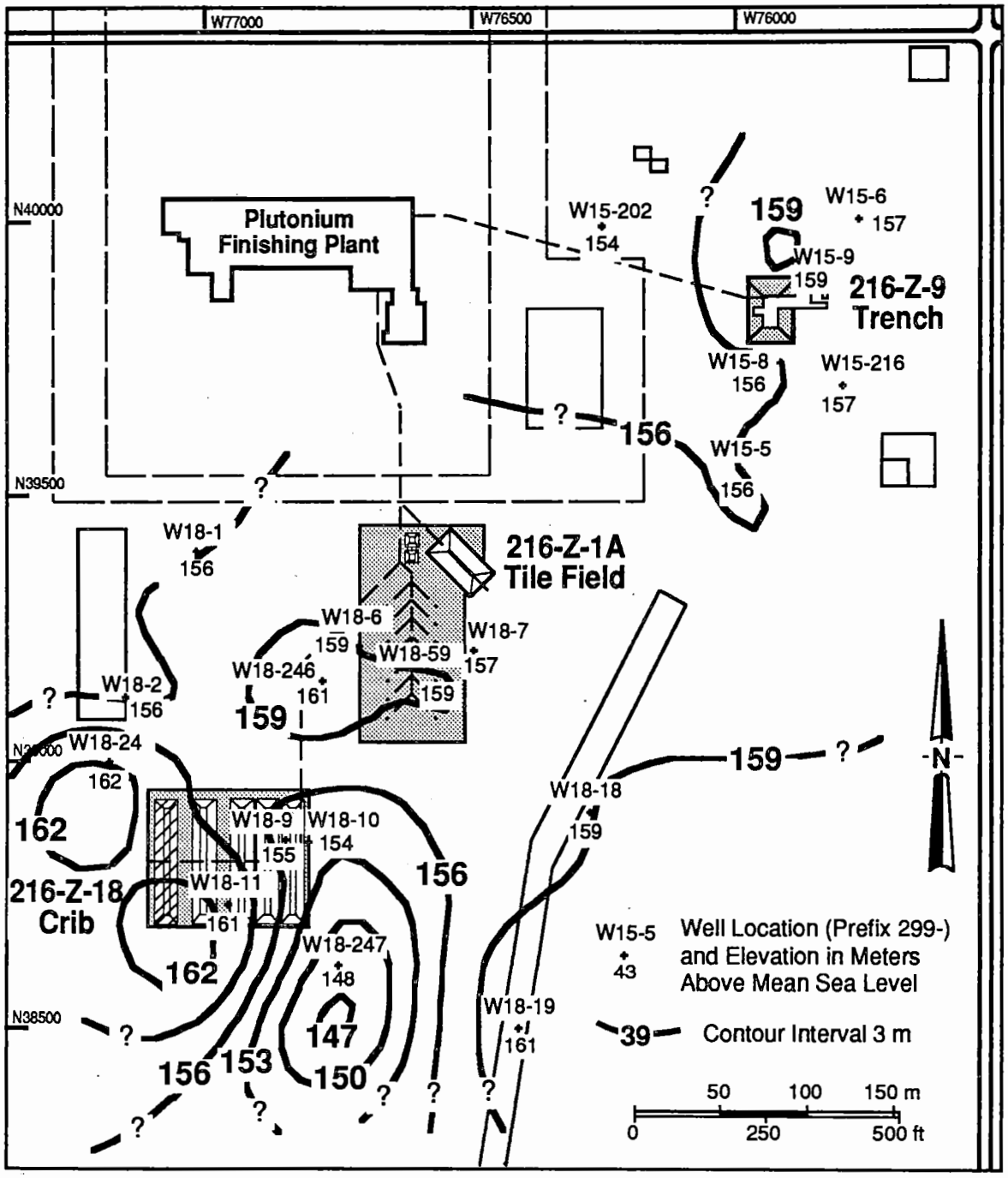


Figure B.9. Structure-Contour (top-of) Map of the Ringold Unit E Beneath the VOC-Arid ID/ERA Site

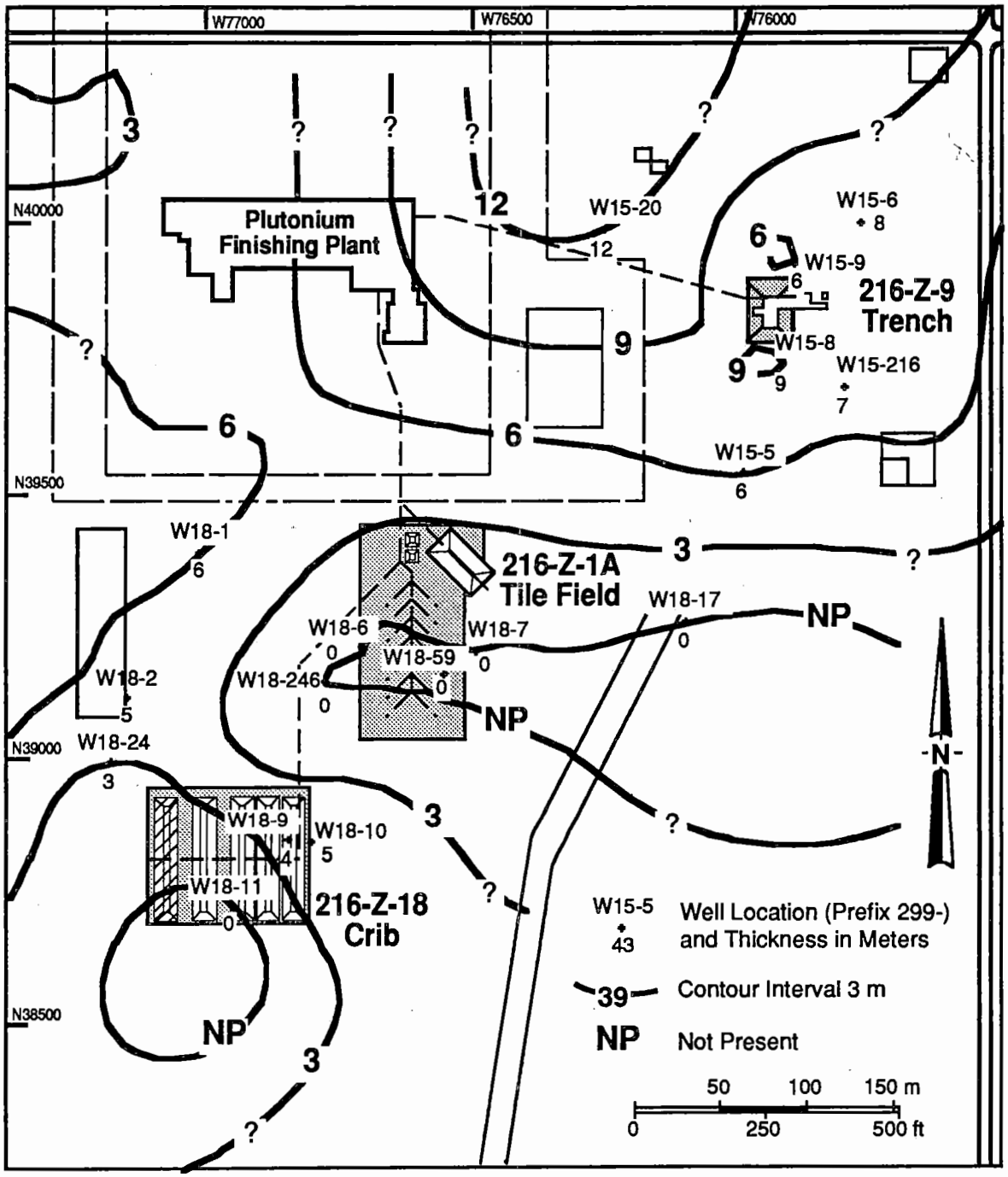


Figure B.10. Isopach Map of the Upper Ringold Unit Beneath the VOC-Arid ID/ERA Site

9 3 1 2 9 7 0 1 2 5 4

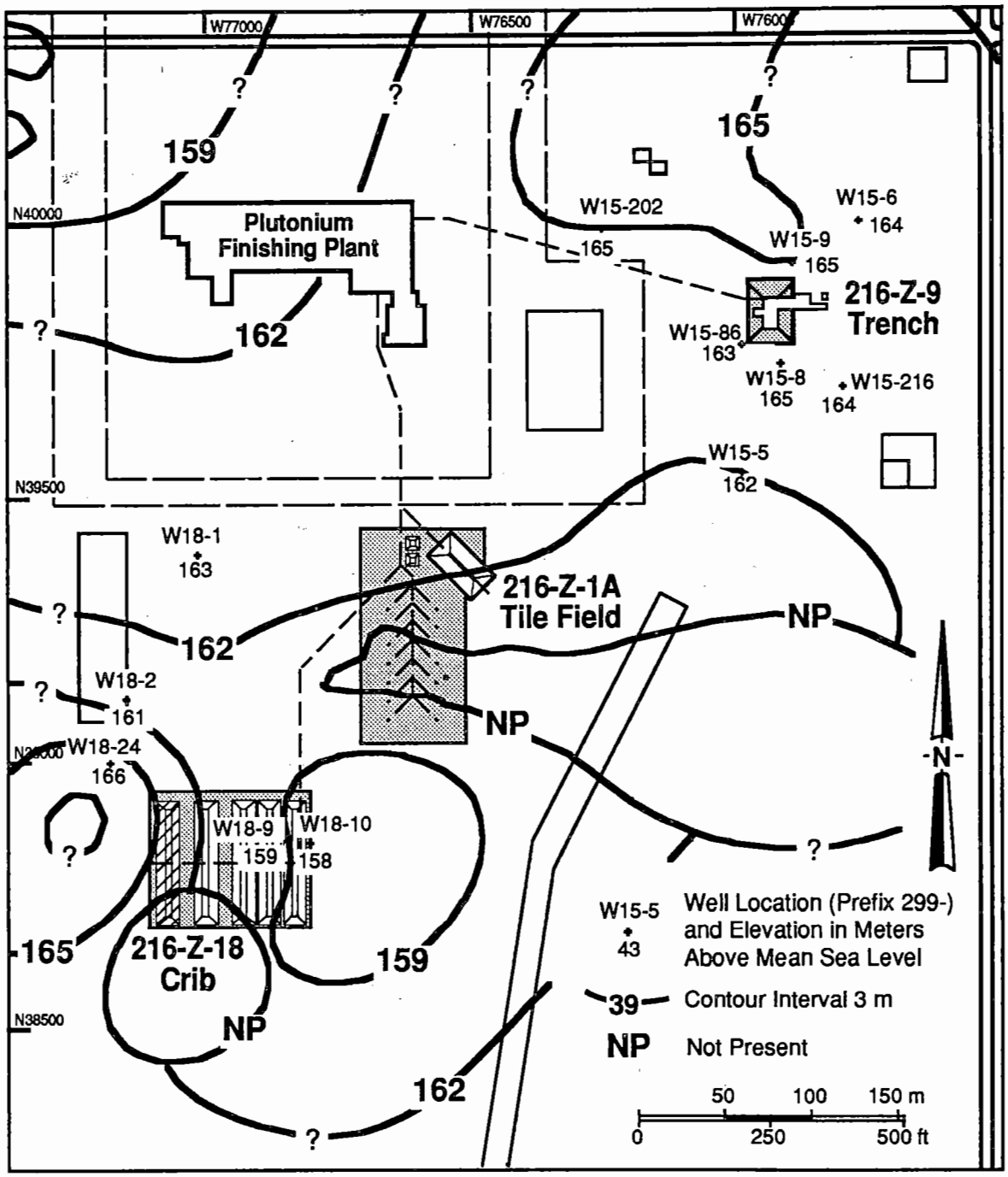


Figure B.11. Structure-Contour (top of) Map of the Upper Ringold Unit Beneath the VOC-Arid ID/ERA Site

together by the calcite cement (see Table B.2). The differentiating features of this unit are its 1) high degree of $CaCO_3$ cement (exceeding 4% by weight), 2) presence of root traces and animal burrows in core samples; and 3) predominantly white color (Bjornstad 1990).

The Plio-Pleistocene unit (Bjornstad 1984, 1985) appears to be a continuous stratum beneath the site, even though its thickness is very irregular, ranging from 2 to 6 m thick (Figure B.12). WHC (1992) suggests that a good probability exists that erosional windows are present in areas of considerable thinning. The upper surface of this unit is highly irregular but generally dips to the south and southwest (Figure B.13).

Early Palouse Soil

The early Palouse soil (informal name) is another continuous stratum beneath the site and consists of an unconsolidated, muddy, fine sand to fine sandy mud believed to be loess (windblown silt and sand) that blankets the Plio-Pleistocene unit. This eolian deposit was derived from either the reworked Plio-Pleistocene unit or the upper Ringold material (Brown 1960). This unit is generally unconsolidated and less calcareous (<4% by weight) than the underlying Plio-Pleistocene unit and has a higher natural-gamma response. The upper contact of this unit is poorly defined, grading into the lower part of the Hanford formation and is generally differentiated from the Hanford formation by 1) greater $CaCO_3$ content, 2) cohesive structure in core samples, 3) uniform fine-grained texture, and 4) high natural-gamma response. Typical particle-size distributions and $CaCO_3$ contents were shown in Table B.2. The thickness of this unit varies irregularly, generally thickening to the south (Figure B.14). The top of this unit is also irregular and dips southward (Figure B.15).

Hanford Formation

The Hanford formation (informal name) is divided into three main facies: 1) gravel dominated, 2) sand dominated, and 3) slackwater. The distribution of these facies beneath the site, as interpreted in cross section (see Figures B.3 through B.6), yields two generalized stratigraphic units consistent with those of WHC (1991, 1992).

The lower unit is consistent with the fine-grained sequence described by WHC (1992) and the basal slackwater sequence described by Last et al. (1989). This unit is dominantly silt, silty sand, and sand typical of the slackwater facies and is interbedded with coarser sands of the sand-dominated facies. A discontinuous, gravel-dominated sequence at the base of this unit locally underlies the southwestern portion of the site and is present beneath all of the 216-Z-18 crib and most of the 216-Z-1A tile field (see Figure B.3). The

9 3 1 2 9 7 0 1 2 5 6

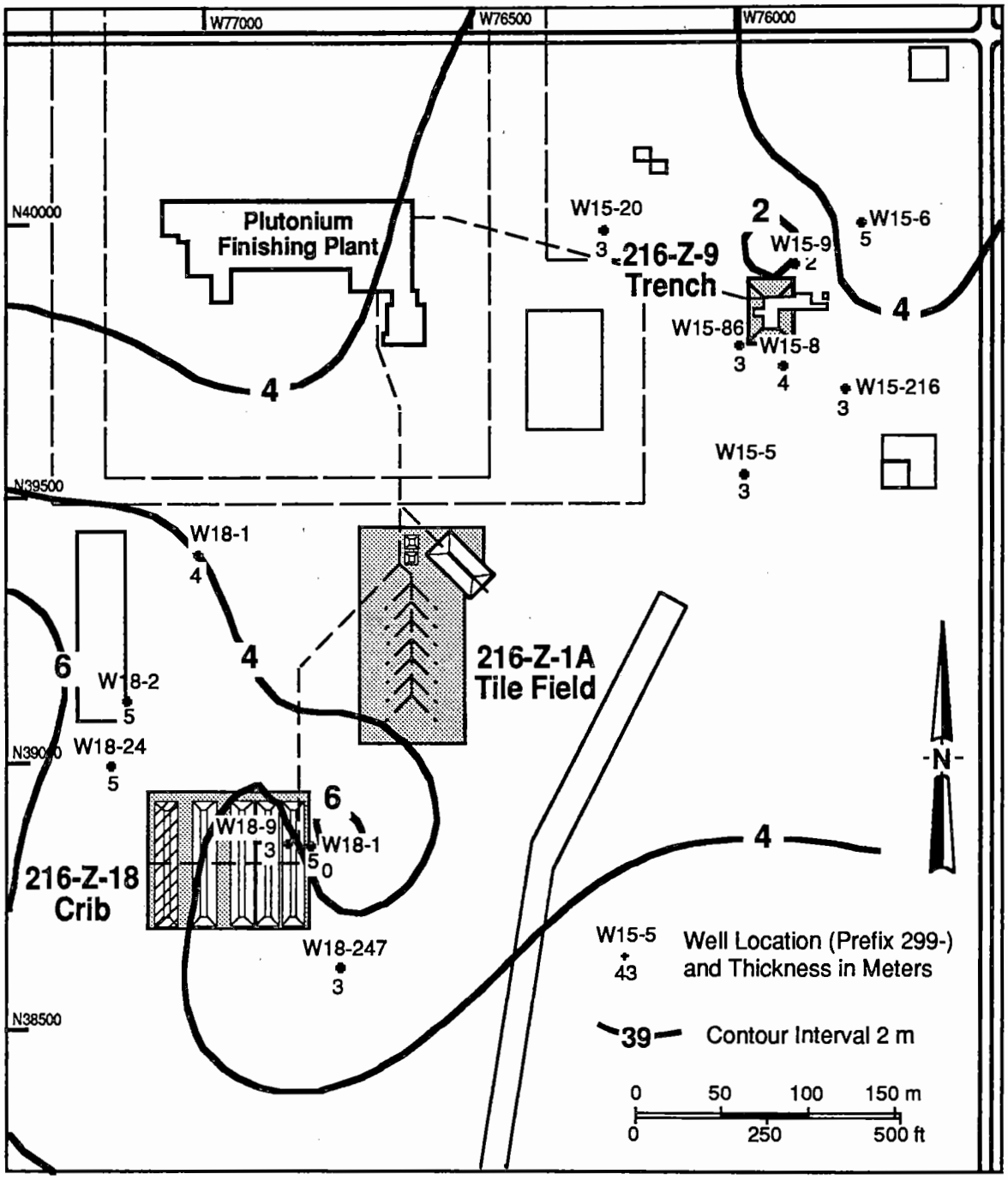


Figure B.12. Isopach Map of the Plio-Pleistocene Unit Beneath the VOC-Arid ID/ERA Site

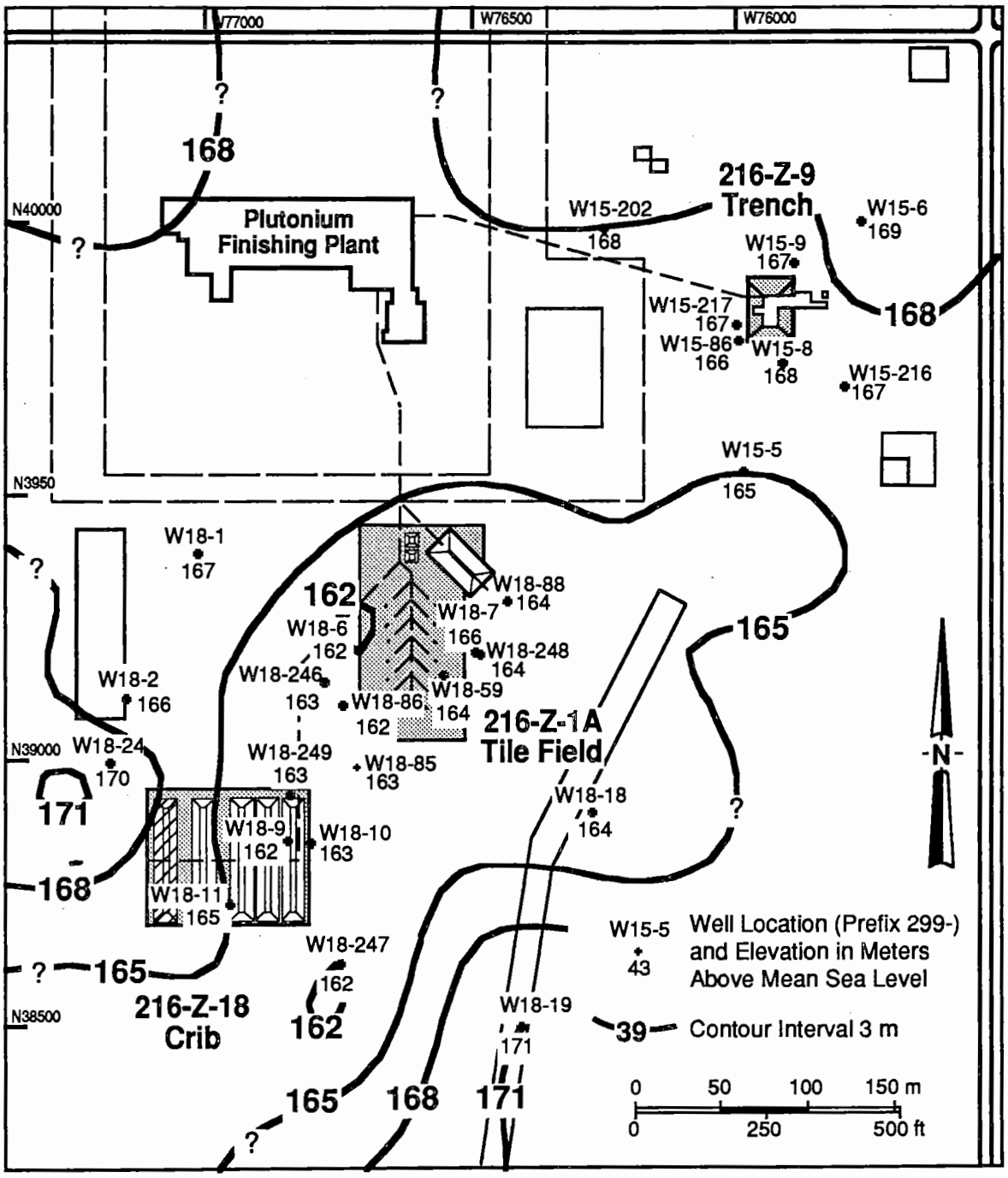


Figure B.13. Structure-Contour (top-of) Map of the Plio-Pleistocene Unit Beneath the VOC-Arid ID/ERA Site

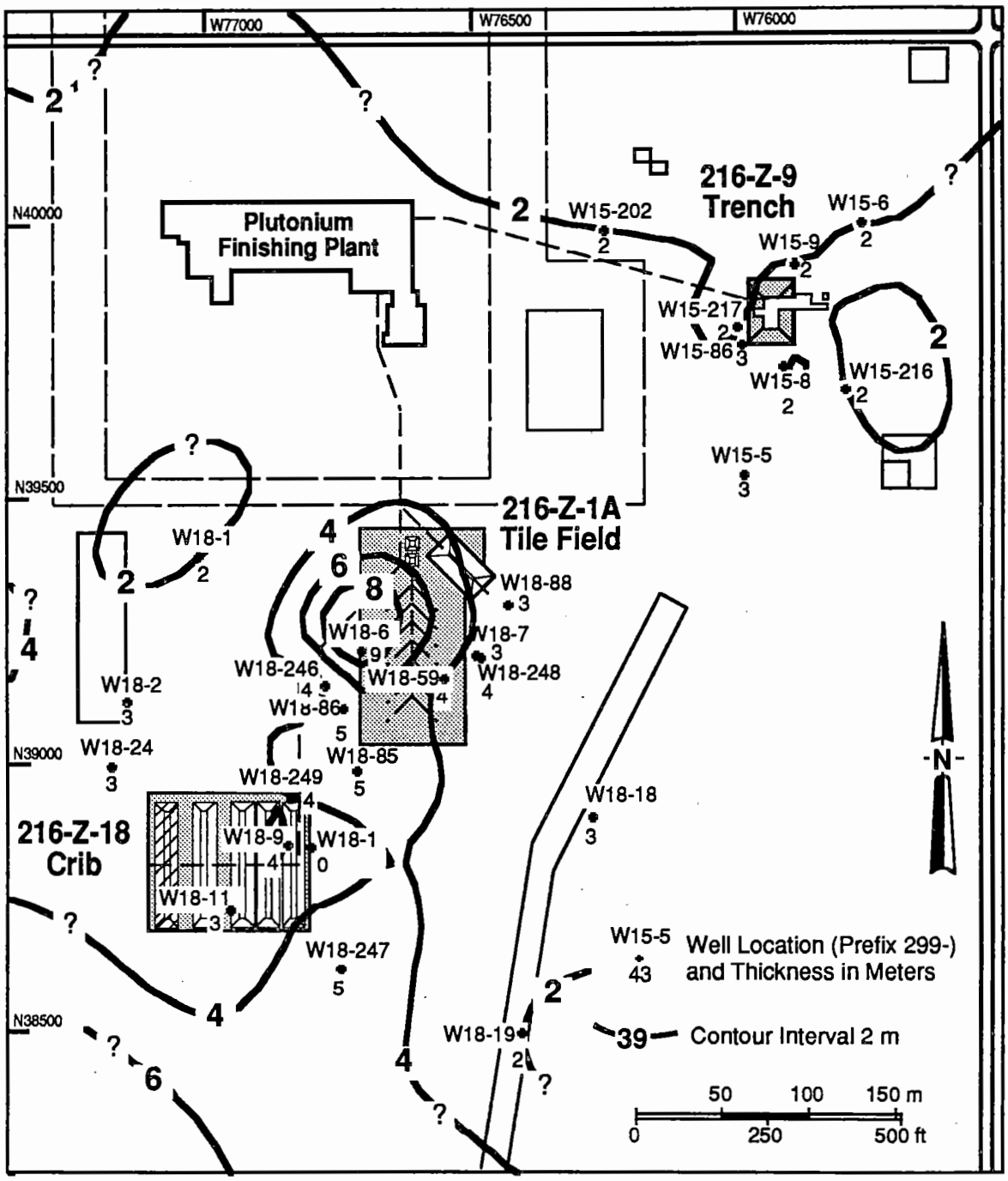


Figure B.14. Isopach Map of the Early Palouse Soil Beneath the VOC-Arid ID/ERA Site

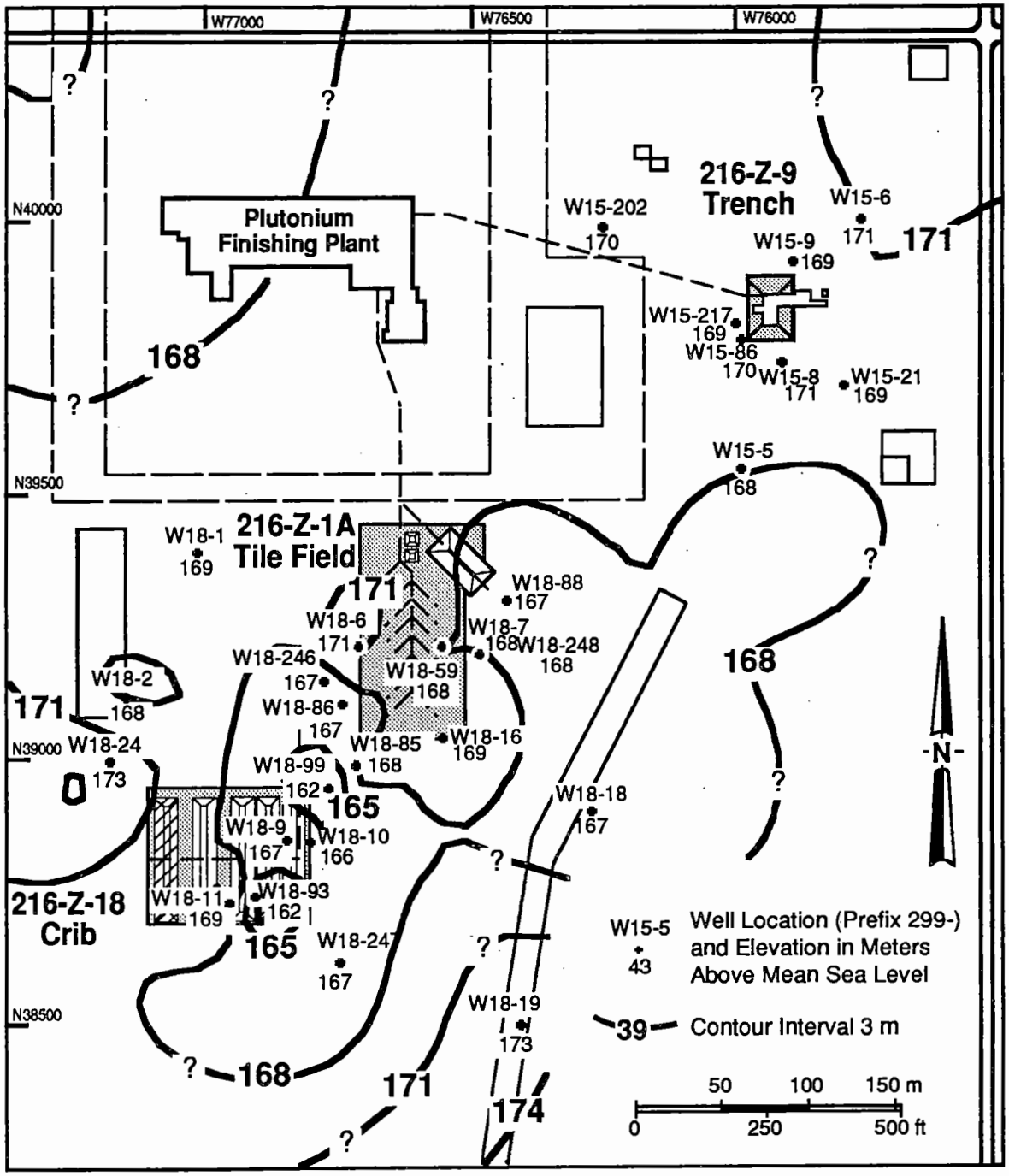


Figure B.15. Structure-Contour (top-of) Map of the Early Palouse Soil Beneath the VOC-Arid ID/ERA Site

thickness of this gravel-dominated facies of the lower unit ranges to a maximum of approximately 17 m. The slackwater portion of this lower unit can be divided into two units in the northwestern portion of the site: a finer grained (medium to very fine) sand overlain by a coarser grained (coarse to medium) sand. The thickness of the slackwater facies ranges from a maximum of approximately 20 m. Typical particle-size distributions and $CaCO_3$ contents for the lower unit were shown in Table B.2. The upper contact of this unit is generally sharp, with the gravel-dominated facies of the upper coarse-grained unit overlying the fine slackwater facies of the lower unit.

Last et al. (1989) and WHC (1992) reported an elongated erosional scour through the lower slackwater sequence in this area. However, the interpretations here (as displayed in Figures B.3 through B.6) suggest that the lower fine-grained/slackwater unit is continuous beneath the site. This interpretation distinguishes between the lower, gravel-dominated sequence at the base of the lower unit and the gravel-dominated sequence of the upper coarse-grained unit.

The upper unit is consistent with the coarse-grained sequence described by Last et al. (1989) and WHC (1992). This unit consists of interstratified gravel, sand, and lesser silt. Gravel-dominated deposits dominate in the lower portion of this unit, while sand-dominated deposits are prevalent in the upper portion. The gravel-dominated deposits are typically pebble to boulder gravels, with a coarse sand matrix. In places, these gravels are clast supported and lack any matrix displaying an open framework appearance. These deposits display massive to large forset bedding. Both the gravels and coarser sand fractions contain a high percentage of basaltic clasts. The sand-dominated deposits consist of coarse to fine sand and display planar to low-angle bedding to crossbedded ripples. Table B.1 illustrated the typical particle-size and $CaCO_3$ content data for these facies. Minor, laterally discontinuous, silty and gravelly deposits are found locally. The thickness and distribution of individual facies are variable. The thickness of the Hanford formation is shown in Figure B.16.

Holocene Surficial Deposits

Holocene-age eolian sand deposits locally blanket the surface of the Hanford formation. Much of these deposits, consisting of medium to very fine-grained and occasionally silty sands, have been removed by construction activities.

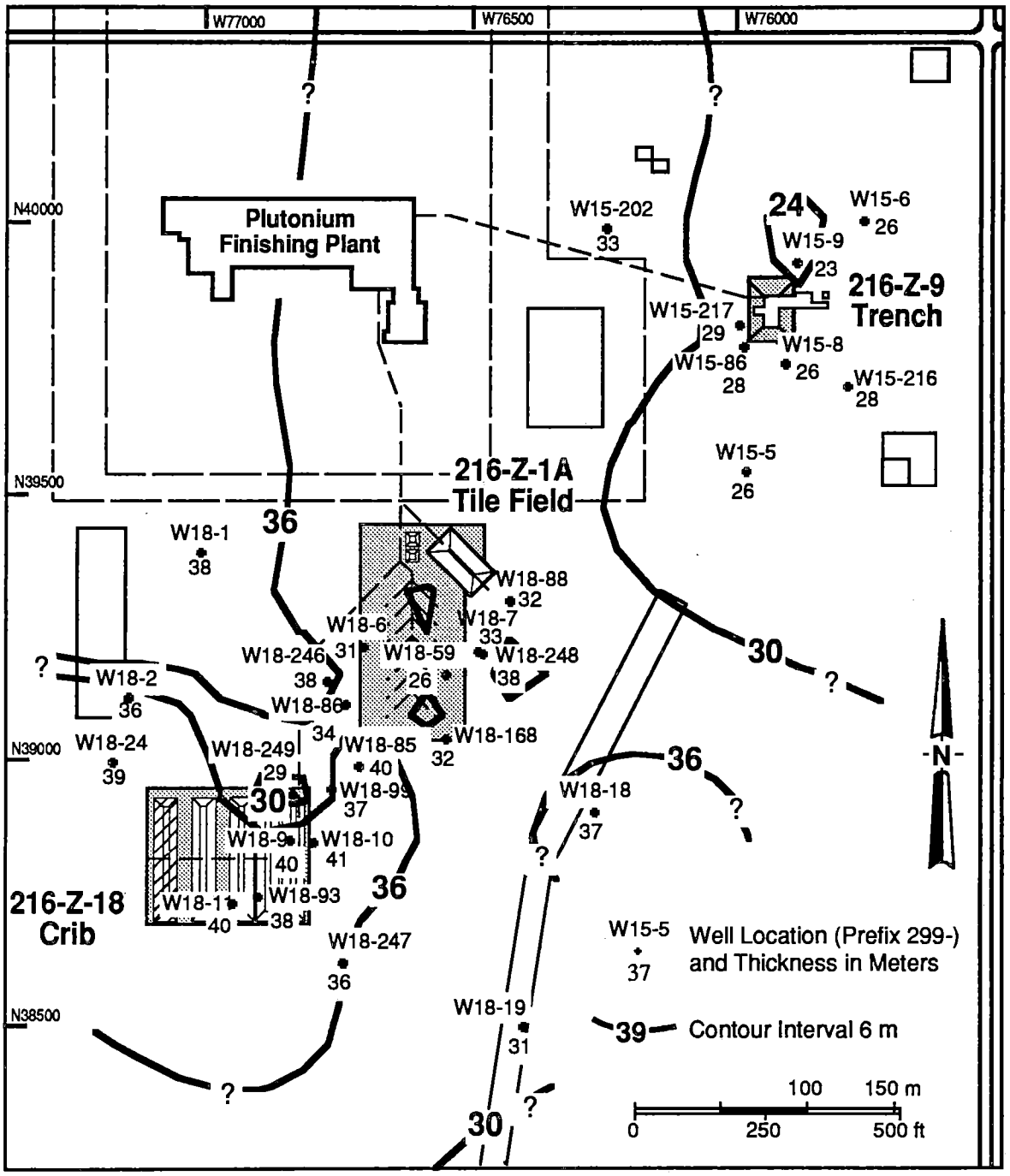


Figure B.16. Isopach Map of the Hanford Formation Beneath the VOC-Arid ID/ERA Site

References

Bjornstad, B. N. 1984. *Suprabasalt Stratigraphy Within and Adjacent to the Reference Repository Location*. SD-BWI-DP-039, Rockwell Hanford Operations, Richland, Washington.

Bjornstad, B. N. 1985. "Late-Cenozoic Stratigraphy and Tectonic Evolution Within a Subsiding Basin, South-Central Washington." *Geological Society of America Abstracts with Programs* 17(7):524.

Bjornstad, B. N. 1990. *Geohydrology of the 218-W-5 Burial Ground, 200 West Area, Hanford Site*. PNL-7336, Pacific Northwest Laboratory, Richland, Washington.

Brown, D. J. 1959. *Subsurface Geology of Hanford Separation Areas*. HW-61780, General Electric Company, Richland, Washington.

Brown, D. J. 1960. *An Eolian Deposit Beneath 200-West Area*. HW-67549, General Electric Company, Richland, Washington.

DOE. 1988. *Consultation Draft, Site Characterization Plan, Reference Repository Location, Hanford Site, Washington*. DOE/RW-0164, 9 Volumes, Office of Civilian Radioactive Waste Management, U.S. Department of Energy, Washington, D.C.

Last, G. V., B. N. Bjornstad, M. P. Bergeron, D. W. Wallace, D. R. Newcomer, J. A. Schramke, M. A. Chamness, C. S. Cline, S. P. Airhart, and J. S. Wilbur. 1989. *Hydrogeology of the 200 Areas Low-Level Burial Grounds - An Interim Report*. PNL-6820, 2 Volumes, Pacific Northwest Laboratory, Richland, Washington.

Swanson, D. A., T. L. Wright, P. R. Hooper, and R. D. Bentley. 1979. *Revisions in Stratigraphic Nomenclature of the Columbia River Basalt Group*. Bulletin1457-G, U.S. Geological Survey, Washington, D.C.

Tallman, A. M., K. R. Fecht, M. C. Marratt, and G. V. Last. 1979. *Geology of the Separations Areas, Hanford Site, South-Central Washington*. RHO-ST-23, Rockwell Hanford Operations, Richland, Washington.

WHC. 1991. *Geologic Setting of the 200 West Area: An Update*. WHC-SD-EN-TI-008, Rev. 0, K. A. Lindsey and M. P. Connelly, Westinghouse Hanford Company, and B. N. Bjornstad, Pacific Northwest Laboratory, for Westinghouse Hanford Company, Richland, Washington.

WHC. 1992. *Hydrogeologic Model for the 200 West Groundwater Aggregate Area*. WHC-SD-EN-TI-014, Rev. 0, prepared by M. P. Connelly and B. H. Ford, Westinghouse Hanford Company, and J. V. Borghese, Pacific Northwest Laboratory, for Westinghouse Hanford Company, Richland, Washington.

9 3 1 2 9 7 0 1 2 6 4

9 3 1 2 9 0 1 2 6 5

Appendix C

Groundwater Elevations Beneath the VOC-Arid ID/ERA Site

Appendix C

Groundwater Elevations Beneath the VOC-Arid ID/ERA Site

Water-Level Elevations in Vicinity of Carbon Tetrachloride Disposal Sites

Well[a]	EW[b]	NS[b]	Date	Head[c] (feet above mean sea level)
W15-5	75984	39537	6/09/92	467.50
W15-6	75765	40005	3/11/92	467.38
W15-8	75910	39740	1/13/92	468.15
W15-15	78103	40330	3/17/92	465.61
W15-16	77387	40269	3/17/92	465.74, 466.18
W15-18	77383	39705	3/17/92	466.54, 466.62
W15-19	77772	41041	3/17/92	465.17
W15-20	78120	41028	3/17/92	465.14
W15-24	78096	39851	3/17/92	465.85
W15-216	75792.5	39698.3	6/02/92	569.12 perched
W15-216	75792.5	39698.3	6/22/92	467.72
W18-9	76846	38852	5/07/92	467.31
W18-21	78080	37794	3/17/92	465.92
W18-22	78109	37831	3/17/92	465.26
W18-23	78120	38987	3/17/92	465.92
W18-24	77180	38998	3/17/92	466.75
W18-25	76034	37786	3/26/92	468.74
W18-26	78097	39477	3/17/92	465.93
W18-27	78103	38607	3/17/92	465.65
W18-28	78096	38214	3/17/92	465.91
W18-29	76560	37952	3/17/92	545.75 perched
W18-30	75541	38493	3/26/92	468.43
W18-31	76032	38105	3/26/92	468.18
W18-246	76779.4	39148.7	5/07/92	467.52
W18-247	76747.3	38620.8	4/01/92	466.39
W19-1	75491	37613	2/26/92	469.19
W19-12	75456	38052	3/26/92	467.74
W19-27	75072	37629	2/27/92	467.50
W19-31	75457	38275	3/26/92	467.28
W19-32	75459	37887	3/26/92	467.81
W19-91	75269	37617	3/11/92	562.26 perched

(a) Well numbers preceded by 299-.
(b) EW/NS are Hanford Coordinates.
(c) To convert feet to meters, multiply by 0.3048.

9 3 1 2 9 0 1 2 6 6

9 3 1 2 9 0 1 2 6 7

Appendix D

Schematic Well Construction Diagrams and Completion Summary Table

THIS PAGE INTENTIONALLY
LEFT BLANK

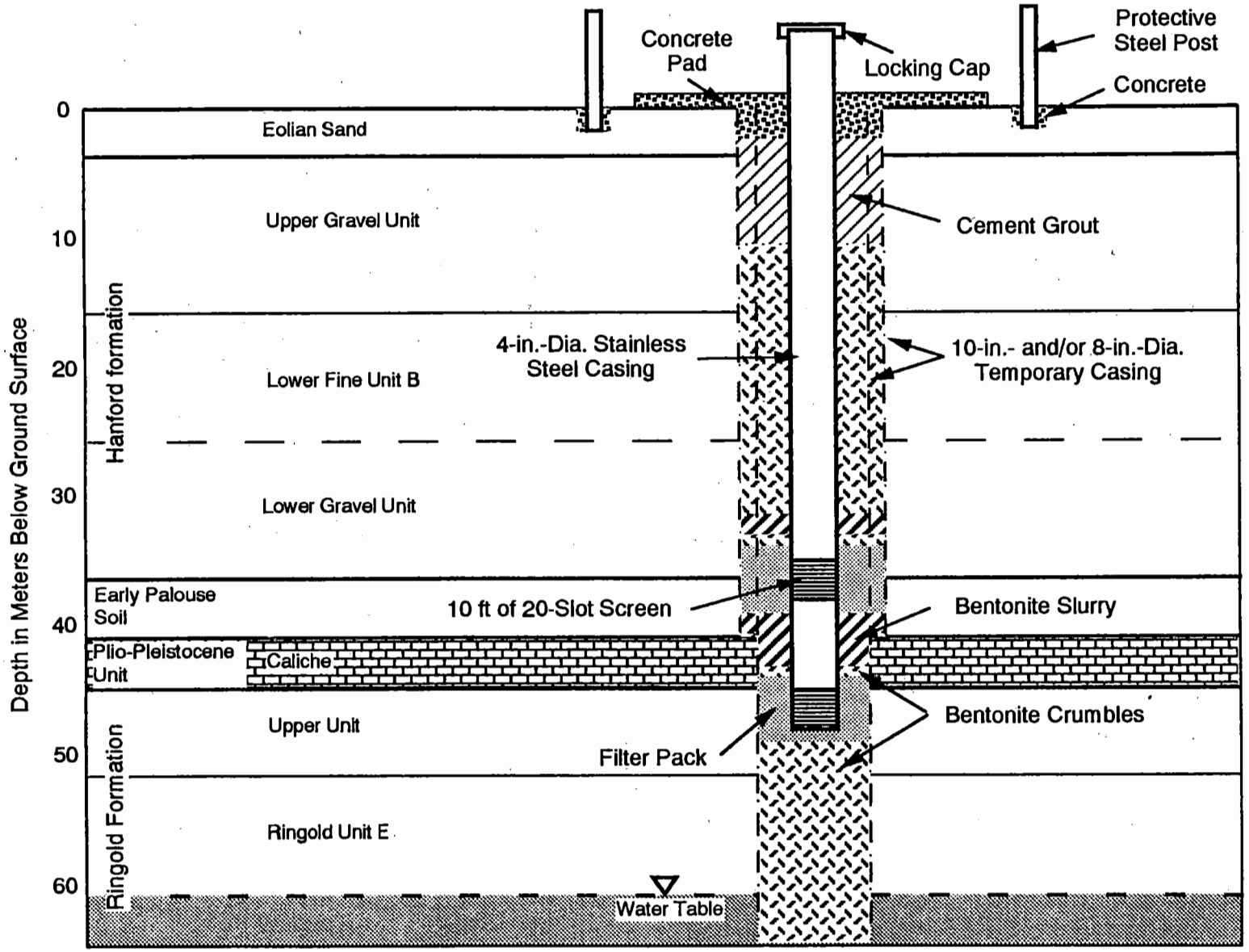


Figure D.1. Schematic Diagram of an FY 1992 Near-Field Vadose-Zone-Monitoring/Vapor-Extraction Well

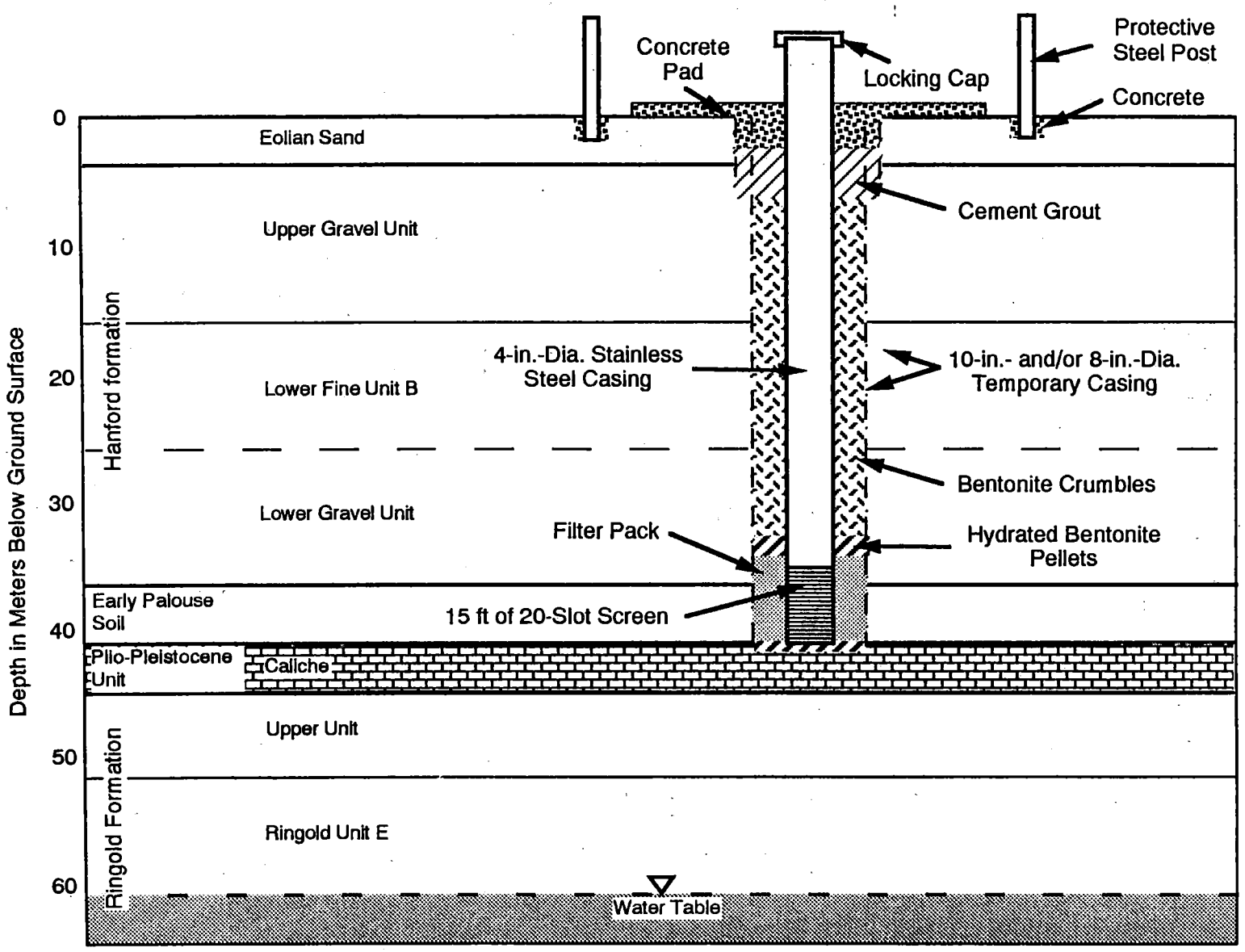


Figure D.2. Schematic Diagram of an FY 1992 Crib-Monitoring Well.

Well Construction Information for the FY 1992 Near-Field and Crib Wells

Well Number	Plant Coordinates		Casing Elevation	Ground/Pad Elevation	Drill Depth	Depth To Water	Well Dia. (in.)	Depth To Bottom	Screened/Perforated Interval	Date Completed
	North	West								
299-W15-216	39698.3	75792.5	663.81	661.42	210.0	193.7	4	184.6	69.7-79.8[a] 174.5-184.6	July 1992
299-W15-217	39810.6	75998.4	672.05	668.71	123.4	NA	4	122.2	106-121	July 1992
299-W18-246	39148.7	76779.4	683.47	681.32	230.0	213.8	4	175.2	120.0-130.0 164.9-174.9	June 1992
299-W18-247	38620.8	76747.3	681.30	678.09	227.2	211.7	4	227.2	119-129 162-172	May 1992
299-W18-248	39201.6	76481.5	679.22	676.11	141.0	NA	4	138.9	123.2-138.6	June 1992
299-W18-249	38940.1	76840.6	682.15	679.74	146.7	NA	4	137.0	121.7-136.7	July 1992

(a) Perched water at 92.3 ft.
All units in feet above mean sea level unless indicated otherwise. To convert feet to meters, multiply by 0.3048.

Appendix E

Volatile Organic, Chemical, and Radiological Analyses of Sediment and Groundwater Samples from the FY 1992 Near-Field and Crib Wells

9 3 1 2 9 0 1 2 7 1

Analytical Results VOLATILE ORGANIC COMPOUNDS 299-W15-216 (CT-1)

HEIS Sample Number	Sample Matrix	Depth (m)	Methylene Chloride (ppb)	trans-1,2-Dichloro-ethylene (ppb)	1,1-Dichloro-ethane (ppb)	cis-1,2-Dichloro-ethylene (ppb)	Chloro-form (ppb)	1,1,1-Tri-chloro-ethane (ppb)	CC14 (ppb)	1,2-Di-chloro-ethane (ppb)	Benzene (ppb)	Trichloro-ethylene (ppb)	Toluene (ppb)	Tetra-chloro-ethylene (ppb)	Ethyl-benzene (ppb)	M+P-Xylene (ppb)	O-Xylene (ppb)	Acetone (ppb)
B067J2	Soil	15.04	2754	<50	<50	<50	<5	<10	67	ND	<25	<1	<25	7	<25	<25	<25	ND
B067K1	Soil	33.67	<5	<5	<5	<2	<2	<2	54	<2	<2	<2	171	<2	<2	<2	<2	ND
B066V1	Soil	33.67	338	<5	<5	<2	<2	<2	40	<2	<2	<2	220	<2	<2	<2	<2	ND
B066V2	Soil	33.67	198	<5	<5	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	ND
B066V6	Soil	35.36	<5	<5	<5	<2	<2	<2	27	<2	<2	<2	348	<2	<2	<2	<2	ND
B066W4	Soil	36.80	<5	<5	<5	<2	<2	<2	<2	<2	<2	<2	13	<2	<2	<2	<2	ND
B066W8	Soil	39.24	428	<5	<5	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	ND
B066Z3	Water	60.56	630 (a)	<0.5	1.2	<0.5	976 (a)	<2	4148 (b)	<2	<0.5	0.8	<0.5	2.4	<0.5	<0.5	<0.5	~1½ (d)
B066Z6	Water	61.87	160 (a)	<0.5	<3	<0.5	410 (a)	<2	4479 (b)	<2	<0.5	0.9	<0.5	2.6	<0.5	<0.5	<0.5	ND
B066Z7	Water	63.61	28 (c)	<0.5	<3	<0.5	350 (c)	<2	4437 (b)	<2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	ND

(a) 1:20 dilution necessary
(b) 1:50 dilution necessary
(c) 1:10 dilution necessary
(d) estimate from previous calibration

ND = Not Detected

E.1

Analytical Results VOLATILE ORGANIC COMPOUNDS 299-W15-217 (ID-1)

HEIS Sample Number	Sample Matrix	Depth (m)	Methylene Chloride (ppb)	trans-1,2-Dichloro-ethylene (ppb)	1,1-Dichloro-ethane (ppb)	cis-1,2-Dichloro-ethylene (ppb)	Chloro-form (ppb)	1,1,1-Tri-chloro-ethane (ppb)	CC14 (ppb)	1,2-Di-chloro-ethane (ppb)	Benzene (ppb)	Trichloro-ethylene (ppb)	Toluene (ppb)	Tetra-chloro-ethylene (ppb)	Ethyl-benzene (ppb)	M+P-Xylene (ppb)	O-Xylene (ppb)
B06K01	Soil	1.52	6	<5	<5	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
B06K02	Soil	3.05	<5	<5	<5	<2	<2	<2	20	<2	<2	<2	<2	<2	<2	<2	<2
B06K03	Soil	4.57	6	<5	<5	<2	<2	<2	16	<2	<2	<2	<2	<2	<2	<2	<2
B06K04	Soil	6.10	<5	<5	<5	<2	<2	<2	38	<2	<2	<2	<2	<2	<2	<2	<2
B06K07	Soil	6.32	<5	<5	<5	<2	<2	<2	4	<2	<2	<2	<2	<2	<2	<2	<2
B06K09	Soil	7.47	90	8	7	<2	<2	<2	6	<2	<2	<2	<2	<2	<2	<2	<2
B06K12	Soil	7.85	<5	<5	<5	<2	<2	<2	41	<2	<2	<2	<2	<2	<2	<2	<2
B06K10	Soil	9.14	67	<5	<5	<2	<2	<2	17	<2	<2	<2	<2	<2	<2	<2	<2
B06K14	Soil	10.67	<5	<5	<5	<2	<2	<2	47	<2	<2	<2	<2	<2	<2	<2	<2
B06JZ2	Soil	12.42	<5	<5	<5	<2	<2	<2	60	<2	<2	<2	<2	<2	<2	<2	<2
B06K16	Soil	13.72	67	<5	<5	<2	<2	<2	61	<2	<2	<2	<2	<2	<2	<2	<2
B06K17	Soil	15.24	<5	<5	<5	<2	<2	<2	239	<2	<2	<2	<2	<2	<2	<2	<2
B06VW8	Soil	16.47	<5	<5	<5	<2	8	<2	330	<2	3	<2	3	8	<2	<2	<2
B06VX0	Soil	16.47	<5	<5	<5	<2	6	<2	212	<2	<2	<2	<2	8	<2	<2	<2
B06VX1	Soil	16.47	<5	<5	<5	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
B06K20	Soil	16.76	215	<5	<5	<2	29	<2	2928 (a)	<2	<2	<2	<2	13	<2	<2	<2
B06K21	Soil	18.29	<5	<5	<5	<2	20	<2	705	<2	<2	<2	<2	12	<2	<2	<2
B06K22	Soil	19.81	75	<5	<5	<2	115	<2	5698 (b)	<2	<2	<2	<2	17	<2	<2	<2
B06K24	Soil	21.34	<5	<5	<5	<2	96	<2	3068 (c)	<2	<2	<2	<2	15	<2	<2	<2
B06K25	Soil	22.86	<5	<5	<5	<2	33	<2	2333 (d)	<2	<2	<2	<2	14	<2	<2	<2
B06VX4	Soil	24.61	<5	<5	<5	<2	17	<2	1770	<2	3	<2	2	14	<2	<2	<2
B06K28	Soil	25.91	31	<5	<5	<2	66	<2	2336 (e)	<2	<2	<2	20	15	3	<2	<2
B06K29	Soil	27.43	<5	<5	<5	<2	88	<2	9445 (f)	ND	<2	<2	<2	21	<0.2	<0.2	<0.2
B06K30	Soil	28.96	<5	<5	<5	<2	34	<2	4876 (g)	<2	ND	<2	<2	19	<2	<2	<2
B06K31	Soil	30.48	<5	<5	<5	<2	18	<2	1280	<2	2	<2	<2	13	<2	<2	<2
B06VX8	Soil	30.86	669	<5	<5	<2	82	<2	5369 (h)	<2	<2	<2	<2	11	<2	<2	<2
B06K32	Soil	32.00	8	<5	<5	<2	13	<2	906	<2	<2	<2	4	11	<2	<2	<2
B06K33	Soil	33.53	<5	<5	<5	<2	20	<2	1879	<2	<2	<2	<2	11	<2	<2	<2
B06K34	Soil	34.75	14	<5	18	<2	248	3	37817	<2	<2	13*	<2	28	<2	<2	<2
B06VY2	Soil	35.16	<5	<5	<5	<2	11	<2	551	<2	<2	<2	400	5	4	~9.0	~3.0
B06VY4	Soil	37.14	<5	<5	<5	<2	35	<2	4377 (i)	<2	<2	<2	<2	17	<2	<2	<2

(a) dilution volume = 120
(b) dilution volume = 224
(c) dilution volume = 125
(d) dilution volume = 114
(e) dilution volume = 119
(f) dilution volume = 244
(g) dilution volume = 183.5
(h) volume correction = 146
(i) volume correction = 268

ND = Not Detected

Analytical Results **VOLATILE ORGANIC COMPOUNDS** **299-W18-246 (CT-2)**

HEIS Sample Number	Sample Type	Dept (m)	Methylene Chloride (ppb)	trans-1,2-Dichloro-ethylene (ppb)	1,1-Dichloro-ethane (ppb)	cis-1,2-Dichloro-ethylene (ppb)	Chloro-form (ppb)	1,1,1-Tri-chloro-ethane (ppb)	CC14 (ppb)	1,2-Di-chloro-ethane (ppb)	Benzene (ppb)	Trichloro-ethylene (ppb)	Toluene (ppb)	Tetra-chloro-ethylene (ppb)	Ethyl-benzene (ppb)	M+P-Xylene (ppb)	O-Xylene (ppb)	Acetone (ppb)	MEK (ppb)
B01WS2	Soil	17.31	(a)	<50	<50	<50	3 (b)	<10	133	ND	<25	1	<25	3	<25	<25	<25	ND	ND
B01WT5	Soil	32.61	(a)	<50	<50	<50	<5	<10	10	ND	<25	<1	<25	<1	<25	<25	<25	ND	ND
B01WQ0	Soil	43.28	ND	<50	<50	<50	<5	<10	261	ND	<25	<1	126	<1	<25	<25	<25	ND	ND
B066R2	Soil	44.81	ND	<50	<50	<50	<5	<10	772	ND	<25	<1	<25	<1	<25	<25	<25	ND	ND
B066S8	Soil	59.31	19854 (c)	<50	<50	<50	<5	<10	<1	ND	<25	<1	<25	<1	<25	<25	<25	ND	ND
none	Water	60.96	ND	<50	<50	<50	<5	<10	<1	ND	<25	<1	<25	<1	<25	<25	<25	ND	ND
none	Water	60.96	3.4	<0.5	<3	<0.5	32	<2	9.6	<2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	ND	ND
B01WP4	Water	66.17	672 (d)	<0.5	1.1 (e)	<0.5	~3600 (d)	<2	293 (d)	<2	1.1	2.1	0.7	1	0.3 (e)	0.2 (e)	2.9	~144	ND
B01WP5	Water	36.24	97	<0.5	<3	<0.5	361 (d)	<2	1009 (d)	<2	<0.5	2.5	<0.5	0.6	<0.5	<0.5	1.0	~12	ND
B01WP6	Water	68.58	34	<0.5	<3	<0.5	105 (d)	<2	919 (d)	<2	<0.5	1.8	<0.5	0.6	<0.5	<0.5	<0.5	~16 (f)	~2 (f)
B01WP7	Water	70.10	37	<0.5	<3	<0.5	344 (g)	<2	30	<2	0.5	1.5 (e)	0.2 (e)	0.7	<0.5	<0.5	<0.5	~3	~9

(a) impurities in methanol
(b) observed but below <5 reported values for chloroform
(c) observed varied CH2Cl2 impurities in purge and trap methanol but not this great. Possibly something around drill site.
(d) 1:20 dilution necessary for analysis
(e) observed but below LDL
(f) results determined from previous calibration
(g) 1:10 dilution necessary for analysis

ND = Not Detected

Analytical Results **VOLATILE ORGANIC COMPOUNDS** **299-W18-247 (CT-3)**

HEIS Sample Number	Sample Type	Depth (m)	Methylene Chloride (ppb)	trans-1,2-Dichloro-ethylene (ppb)	1,1-Dichloro-ethane (ppb)	cis-1,2-Dichloro-ethylene (ppb)	Chloro-form (ppb)	1,1,1-Tri-chloro-ethane (ppb)	CC14 (ppb)	1,2-Di-chloro-ethane (ppb)	Benzene (ppb)	Trichloro-ethylene (ppb)	Toluene (ppb)	Tetra-chloro-ethylene (ppb)	Ethyl-benzene (ppb)
B01WD0	Soil	17.02	(a)	<50	<50	<50	<5	<10	13	ND	<25	<1	3427	<1	61
B01WG2	Soil	33.83	(a)	<50	<50	<50	<5	<10	17	ND	<25	<1	<25	<1	<25
B01WH6	Soil	41.27	(a)	<50	<50	<50	<~4 (b)	<10	717 (c)	ND	<25	<1	333	<1	1 (b)
B01WK1	Soil	45.26	(a)	<50	<50	<50	<5	<10	47	ND	<25	<1	<25	<1	<25
B01WL4	Soil	47.15	(a)	<50	<50	<50	<5	<10	<1 (d)	ND	<25	<1	<25	<1	<25
B01WV8	Water	64.01	1.9 (f)	<0.5	<3	<0.5	183 (e)	<2	95 (e)	<2	1	0.5 (f)	1.2	0.2 (f)	1
B01WW2	Water	65.53	<5	<0.5	<3	<0.5	36	<2	418 (e)	<2	<0.5	1	<0.5	0.2 (f)	<0.5
B01WW4	Water	67.06	1.3	<0.5	<3	<0.5	84 (e)	<2	32	<2	0.4 (f)	0.4 (f)	0.4 (f)	<0.5	0.4 (f)
B01WW7	Water	68.58	<5	<0.5	<3	<0.5	34	<2	0.2 (f)	0.4 (f)	0.2 (f)	<0.5	<0.5	<0.5	<0.5

HEIS Sample Number	Sample Type	Depth (m)	M+P-Xylene (ppb)	O-Xylene (ppb)	Acetone (ppb)	MEK (ppb)	MBK? (ppb)
B01WD0	Soil	17.02	266.0	150.0	ND	ND	ND
B01WG2	Soil	33.83	<25	<25	ND	ND	ND
B01WH6	Soil	41.27	5 (b)	3 (b)	ND	ND	ND
B01WK1	Soil	45.26	<25	<25	ND	ND	ND
B01WL4	Soil	47.15	<25	<25	ND	ND	ND
B01WV8	Water	64.01	0.2 (f)	0.6	~1050	~93	~4
B01WW2	Water	65.53	<0.5	<0.5	~36	~1	ND
B01WW4	Water	67.06	<0.5	<0.5	~152	~12	ND
B01WW7	Water	68.58	<0.5	<0.5	~46	~4	ND

(a) no results reported because of CH2Cl2 impurities in purge and trap GR methanol
(b) below reported < value
(c) injected volume 0.1 ml, lab notebook reference 53707-105-4
(d) impurities in purge and trap GR. methanol
(e) 1:10 dilution necessary
(f) observed but below LDL

ND = Not Detected

Analytical Results VOLATILE ORGANIC COMPOUNDS 299-W18-248 (ID-3)

HEIS Sample Number	Sample Type	Depth (m)	Methylene Chloride (ppb)	trans-1,2-Dichloro-ethylene (ppb)	1,1-Dichloro-ethane (ppb)	cis-1,2-Dichloro-ethylene (ppb)	Chloro-form (ppb)	1,1,1-Tri-chloro-ethane (ppb)	CC14 (ppb)	1,2-Di-chloro-ethane (ppb)	Benzene (ppb)	Trichloro-ethylene (ppb)	Toluene (ppb)	Tetra-chloro-ethylene (ppb)	Ethyl-benzene (ppb)	M+P-Xylene (ppb)	O-Xylene (ppb)	Acetone (ppb)
B06JL1	VOA	6.02	NR	<50	<50	<50	<5	<10	~3	ND	<25	<1	<25	<1	<25	<25	<25	ND
B06JS9	VOA	12.12	4679	<50	<50	<50	<5	<10	26	ND	<25	<1	<25	<1	<25	<25	<25	ND
B06JT6	VOA	18.29	1062 (a)	<50	<50	<50	<5	<10	126	ND	<25	4	40	5	<25	<25	<25	ND
B06JT9	VOA	19.81	2264 (a)	~150	~100	~80	31	NR	360	ND	<25	30	133	21	<25	<25	<25	ND
B06JV0	VOA	21.34	771 (a)	~100	~75	<50	21	<10	147	ND	<25	21	84	10	<25	<25	<25	ND
B06JV1	VOA	22.86	538 (a)	<50	<50	<50	<5	<10	115	ND	<25	4	<25	4	<25	<25	<25	ND
B06JV2	VOA	24.35	<100	<50	<50	<50	<5	<10	137	ND	<25	4	<25	5	<25	<25	<25	ND
B06JV5	VOA	24.77	<100	<50	<50	<50	<5	<10	95	ND	<25	5	<25	5	<25	<25	<25	ND
B06JV7	VOA	25.91	<100	<50	<50	<50	<5	<10	99	ND	<25	6	<25	6	<25	<25	<25	ND
B06JV8	VOA	26.52	Not Analyzed, per GV Last.															
B06JW1	VOA	27.20	Not Analyzed, per GV Last.															
B06JW3	VOA	27.43	116 (a)	<50	<50	<50	<5	<10	74	ND	<25	2	<25	2	<25	<25	<25	ND
B06JW4	VOA	28.96	181 (a)	<50	<50	<50	<5	<10	44	ND	<25	<1	<25	<1	<25	<25	<25	ND
B06JW5	VOA	30.48	194 (a)	<50	<50	<50	<5	<10	16	ND	<25	2	<25	<1	<25	<25	<25	ND
B06JW9	VOA	31.17	1858	<50	<50	<50	<5	<10	61	ND	<25	3	<25	3	<25	<25	<25	ND
B06JX1	VOA	32.00	153 (a)	<50	<50	<50	<5	<10	35	ND	<25	5	<25	3	<25	<25	<25	ND
B06JX2	VOA	33.53	<100 (a)	<50	<50	<50	<5	<10	116	ND	<25	4	<25	4	<25	<25	<25	ND
B06JX3	VOA	35.05	113	<5	<5	<2	<2	<2	50	<2	<2	3	<2	2	<2	<2	<2	ND
B06JX8	VOA	36.58	122 (a)	<5	<5	<2	<2	<2	63	ND	<2	2	<2	2	<2	<2	<2	ND
B06JX6	VOA	36.96	578	<5	<5	<2	<2	<2	32	<2	<2	<2	26	<2	<2	<2	<2	ND
B06JX9	VOA	38.10	<5	<5	<5	<2	<2	<2	72	<2	<2	2	<2	<2	<2	<2	<2	ND
B06JY3	VOA	38.63	<5	<5	<5	<2	<2	<2	45	<2	<2	2	59	<2	<2	<2	<2	ND
B06JR7	VOA	39.62	<5	<5	<5	<2	<2	<2	24	<2	<2	<2	<2	<2	<2	<2	<2	ND
B06JR9	VOA	41.15	<5	<5	<5	<2	12	<2	1093	<2	<2	3	<2	<2	<2	<2	<2	ND
B06JZ5	VOA	42.67	<5	<5	<5	<2	<2	<2	51	<2	<2	<2	<2	<2	<2	<2	<2	ND
B06JS2	VOA	42.75	<5	<5	6	<2	3	<2	644	<2	<2	3	<2	<2	<2	<2	<2	ND

(a) CH2Cl2 impurities in MEOH batch (Batch #2)

ND = Not Detected

Analytical Results **VOLATILE ORGANIC COMPOUNDS** **299-W18-249 (ID-2)**

HEIS Sample Number	Sample Matrix	Depth (m)	Methylene Chloride (ppb)	trans-1,2-Dichloro-ethylene (ppb)	1,1-Dichloro-ethane (ppb)	cis-1,2-Dichloro-ethylene (ppb)	Chloro-form (ppb)	1,1,1-Tri-chloro-ethane (ppb)	CC14 (ppb)	1,2-Di-chloro-ethane (ppb)	Benzene (ppb)	Trichloro-ethylene (ppb)	Toluene (ppb)	Tetra-chloro-ethylene (ppb)	Ethyl-benzene (ppb)	M+P-Xylene (ppb)	O-Xylene (ppb)
BO6VY9	Soil	6.98	134	<5	<5	<2	<2	<2	<2	<2	<2	<2	4	<2	3	4	4
B06704	Soil	7.92	80	<5	<5	<2	<2	<2	3	<2	<2	<2	<2	<2	<2	<2	<2
B06705	Soil	9.14	<5	<5	<5	<2	<2	<2	4	<2	<2	<2	<2	<2	<2	<2	<2
B06VZ3	Soil	9.54	<5	<5	<5	<2	<2	<2	<2	<2	<2	<2	3	<2	<2	<2	<2
B06VZ7	Soil	10.21	<5	<5	<5	<2	<2	<2	3	<2	<2	<2	3	<2	<2	<2	<2
B06W01	Soil	10.82	<5	<5	<5	<2	<2	<2	6	<2	2	<2	466	<2	<2	<2	<2
B06W05	Soil	11.43	272 (a)	<5	<5	<2	<2	<2	6	<2	<2	<2	9	<2	<2	<2	<2
B06W09	Soil	11.98	<5	<5	<5	<2	<2	<2	7	<2	<2	<2	1162	<2	14	10	116
B06709	Soil	13.72	1992	<5	<5	<2	<2	<2	9	<2	<2	<2	130	<2	27	14	<2
B06710	Soil	15.24	237	<5	<5	<2	<2	<2	15	<2	<2	<2	<2	<2	<2	<2	<2
B06711	Soil	16.76	56	<5	<5	<2	<2	<2	24	<2	<2	<2	<2	<2	<2	<2	<2
B06712	Soil	17.98	17	<5	<5	<2	<2	<2	122	<2	<2	<2	<2	<2	<2	<2	<2
B06W12	Soil	18.17	<5	<5	<5	<2	<2	<2	39	<2	<2	<2	46	<2	<2	<2	<2
B06714	Soil	19.81	125	<5	<5	<2	<2	<2	31	<2	<2	<2	<2	<2	<2	<2	<2
B06715	Soil	21.34	<5	<5	<5	<2	<2	<2	74	<2	<2	<2	<2	<2	<2	<2	<2
B06716	Soil	22.86	126	<5	<5	<2	<2	<2	216	<2	<2	<2	<2	<2	<2	<2	<2
B06717	Soil	24.38	<5	<5	<5	<2	<2	<2	184	<2	<2	2	<2	2	<2	<2	<2
B06W16	Soil	24.81	10983 (b)	<5	<5	<2	<2	<2	139	<2	<2	<2	62	<2	<2	<2	<2
B06719	Soil	25.91	1108	<5	<5	<2	<2	<2	133	<2	<2	<2	<2	<2	<2	<2	<2
B06720	Soil	27.43	83	<5	<5	<2	4	<2	566	ND	<2	4	<2	4	<2	<2	<2
B06721	Soil	28.96	559	<5	<5	<2	3	<2	188	<2	<2	5	<2	5	<2	<2	<2
B06722	Soil	30.18	89996	<5	<5	<2	23	13	168	<2	<2	8	77	6	14	8	7
B06W20	Soil	30.63	<5	<5	<5	<2	<2	<2	53	<2	4	<2	<2	<2	<2	<2	<2
B06W22	Soil	"	<5	<5	<5	<2	<2	103	<2	<2	<2	2	<2	2	<2	<2	<2
B06W23	Soil	"	<5	<5	ND	<2	<2	5	4	<2	11	<2	5	<2	<2	<2	3
B06723	Soil	32.61	<5	<5	<5	<2	<2	<2	14	<2	<2	<2	17	<2	8	3	69
B06724	Soil	33.53	89	<5	<5	<2	<2	<2	44	<2	<2	<2	<2	<2	<2	<2	<2
B06726	Soil	35.05	1325	<5	<5	<2	<2	<2	34	<2	<2	<2	<2	<2	<2	<2	<2
B06727	Soil	36.58	<5	<5	<5	<2	<2	<2	28	<2	<2	<2	<2	<2	<2	<2	<2
B06728	Soil	38.10	<5	<5	<5	<2	<2	<2	9	<2	<2	<2	<2	<2	<2	<2	<2
B06W25	Soil	39.11	88800	<5	<5	<2	18	<2	58	<2		<2	2961	<2	34	42	34
B06731	Soil	40.54	1612	<5	<5	<2	7	<2	1618	<2	<2	<2	<2	<2	<2	<2	<2
B06732	Soil	41.15	79	<5	<5	<2	<2	<2	134	ND	<2	<2	<2	<2	<2	<2	<2
B06733	Soil	42.67	27731	<5	<5	<2	4	<2	481	<2	<2	<2	2	<2	<2	<2	<2
B06734	Soil	44.20	1613	<5	<5	<2	8	<2	1957	<2	<2	<2	<2	<2	<2	<2	<2
B06W28	Soil	44.71	<5	<5	<5	<2	7	<2	1755	ND	<2	<2	12	2	<2	<2	<2

(a) high CH2Cl2 in background control also
(b) 1:100 dilution ratio necessary for analysis

ND = Not Detected

Analytical Results CHEMICAL 299-W15-216 (CT-1)

HEIS Sample Number	Sample Type	Depth (m)	Flouride (F) (µg/Kg)	Chloride (Cl) (µg/Kg)	Nitrate Ion (NO3) (µg/Kg)	Nitrite Ion (NO2) (µg/Kg)	Bromide (Br) (µg/Kg)	Phosphate Ion (PO4) (µg/Kg)	Sulfate (SO4) (µg/Kg)	Cyanide (CN) (µg/Kg)	Mercury (Hg) (µg/Kg)	Lead (Pb) (µg/Kg)	o-cresol (µg/Kg)	m-cresol (µg/Kg)	p-cresol (µg/Kg)	Decane (µg/Kg)	Dodecane (µg/Kg)	Tetra-decane (µg/Kg)
Limit of Detection =>			200	400	400	400	500	800	1000	3000	400	500	660	660	660	66000	66000	66000
B067J2	Soil	15.04	ND	1400	6500	ND	ND	ND	3000	ND	ND	4100	ND	ND	ND	ND	ND	ND
B067K1	Soil	33.67	ND	800	ND	ND	ND	ND	ND	ND	ND	11000	ND	ND	ND	ND	ND	ND
B066V6	Soil	35.52	1300	1500	1200	ND	ND	ND	9100	ND	ND	1500	ND	ND	ND	ND	ND	ND
B066W4	Soil	36.80	1300	1900	800	ND	ND	ND	15000	ND	ND	2600	ND	ND	ND	ND	ND	ND
B066W8	Soil	39.24	600	1900	500	ND	ND	ND	3000	ND	ND	1900	ND	ND	ND	ND	ND	ND
			(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)		Not		(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
Limit of Detection =>			100	200	200	200	500	400	500		Analyzed		10	10	10	1000	1000	1000
B066Z3	Water	60.56	700	14000	2300	ND	ND	ND	16000		for		ND	ND	ND	ND	ND	ND
B066Z6	Water	61.87	600	4600	900	ND	ND	ND	15000		Ground		ND	ND	ND	ND	ND	ND
B066Z7	Water	63.61	800	5900	700	ND	ND	ND	16000		Water		ND	ND	ND	ND	ND	ND

HEIS Sample Number	Sample Type	Depth (m)	Naph-thalene (µg/Kg)	Penta-chloro-phenol (µg/Kg)	Phenol (µg/Kg)	Tributyl Phosphate (µg/Kg)	2-Fluoro-phenol (µg/Kg)	Phenol, d6 (µg/Kg)	Nitro-benzene, d5 (µg/Kg)	Fluro-Biphenyl (µg/Kg)	2,4,6-Tribromo-phenol (µg/Kg)	Terphenyl, d14 (µg/Kg)	Antimony (Sb) (µg/Kg)	Barium (Ba) (µg/Kg)	Beryllium (Be) (µg/Kg)	Cadmium (Cd) (µg/Kg)	Calcium (Ca) (µg/Kg)	Chromium (Cr) (µg/Kg)
Limit of Detection =>			660	3300	660	660							20000	2000	300	1000	10000	2000
B067J2	Soil	15.04	ND	ND	ND	ND	6100	4200	2300	2300	4500	2700	ND	87000	370	ND	8600000	12000
B067K1	Soil	33.67	ND	ND	ND	ND	7600	5200	3000	2900	5400	3000	ND	110000	620	ND	1400000	18000
B066V6	Soil	35.52	ND	ND	ND	ND	7700	5400	3500	3900	7200	3700	ND	73000	300	ND	160000000	5900
B066W4	Soil	36.80	ND	ND	ND	ND	7800	6400	3100	3400	7900	3700	ND	110000	310	ND	1100000	17000
B066W8	Soil	39.24	ND	ND	ND	ND	5700	3700	2200	2400	4000	1900	ND	72000	340	ND	5700000	10000
			(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
Limit of Detection =>			10	50	10	10							200	20	3	10	100	20
B066Z3	Water	60.56	ND	ND	ND	ND	104	60.9	138	75.8	170	64	ND	180	ND	ND	31000	22
B066Z6	Water	61.87	ND	ND	ND	ND	141	62.8	83.8	64.4	118	56	ND	330	ND	ND	42000	38
B066Z7	Water	63.61	ND	ND	ND	ND	80.1	48	69.4	88.2	146	55.6	ND	480	ND	ND	51000	62

HEIS Sample Number	Sample Type	Depth (m)	Cobalt (Co) (µg/Kg)	Copper (Cu) (µg/Kg)	Iron (Fe) (µg/Kg)	Magnesium (Mg) (µg/Kg)	Manganese (Mn) (µg/Kg)	Nickel (Ni) (µg/Kg)	Potassium (K) (µg/Kg)	Silver (Ag) (µg/Kg)	Sodium (Na) (µg/Kg)	Tin (Sn) (µg/Kg)	Vanadium (V) (µg/Kg)	Zinc (Zn) (µg/Kg)
Limit of Detection =>			2000	2000	2000	10000	1000	3000	30000	2000	30000	10000	3000	1000
B067J2	Soil	15.04	6500	9600	16000000	5300000	400000	13000	1500000	ND	180000	ND	30000	35000
B067K1	Soil	33.67	8200	20000	21000000	7700000	360000	16000	2900000	ND	300000	ND	36000	53000
B066V6	Soil	35.52	3500	20000	7700000	12000000	130000	6000	660000	ND	550000	ND	28000	17000
B066W4	Soil	36.80	11000	22000	25000000	4600000	270000	15000	740000	ND	2500000	ND	78000	41000
B066W8	Soil	39.24	9100	16000	21000000	6100000	340000	31000	790000	ND	1000000	ND	54000	39000
			(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
Limit of Detection =>			20	20	20	100	10	30	300	20	300	100	30	10
B066Z3	Water	60.56	ND	32	11000	9800	1000	ND	6900	ND	22000	ND	ND	36
B066Z6	Water	61.87	30	90	33000	13000	2400	63	6200	ND	20000	ND	56	80
B066Z7	Water	63.61	32	120	110000	21000	2200	67	10000	ND	26000	ND	86	93

ND Not Detected

Analytical Results CHEMICAL 299-W15-217 (ID-1)

HEIS Sample Number	Sample Type	Depth (m)	Flouride (F) (µg/Kg)	Chloride (Cl) (µg/Kg)	Nitrate Ion (NO3) (µg/Kg)	Nitrite Ion (NO2) (µg/Kg)	Bromide (Br) (µg/Kg)	Phosphate Ion (PO4) (µg/Kg)	Sulfate (SO4) (µg/Kg)	Cyanide (CN) (µg/Kg)	Mercury (Hg) (µg/Kg)	Lead (Pb) (µg/Kg)	o-cresol (µg/Kg)	m-cresol (µg/Kg)	p-cresol (µg/Kg)	Decane (µg/Kg)	Dodecane (µg/Kg)	Tetra-decane (µg/Kg)
Limit of Detection =>			200	400	400	400	500	800	1000	3000	400	500	244	163	144	54	31	52
B06K07	Soil	6.32	1600	1400	13000	ND	ND	ND	18000	ND	ND	8000	ND	ND	ND	ND	ND	ND
B06K12	Soil	7.85	ND	600	2700	ND	ND	ND	17000	ND	ND	2100	ND	ND	ND	ND	ND	ND
B06JZ2	Soil	12.42	300	600	2200	ND	ND	ND	27000	ND	ND	2600	ND	ND	ND	ND	ND	ND
B06VW8	Soil	16.47	300	7600	20000	ND	ND	ND	17000	ND	ND	4700	ND	ND	ND	ND	ND	ND
B06VX4	Soil	24.61	800	54000	65000	ND	ND	ND	69000	ND	ND	7600	ND	ND	ND	ND	ND	ND
B06VX8	Soil	30.86	700	16000	260000	ND	ND	ND	25000	ND	ND	5900	ND	ND	ND	ND	ND	ND
B06VY2	Soil	35.16	1000	5100	350000	ND	ND	ND	7800	ND	ND	5000	ND	ND	ND	ND	ND	ND
B06VY4	Soil	37.14	2600	12000	1600000	ND	ND	ND	22000	ND	ND	2800	ND	ND	ND	ND	ND	ND

HEIS Sample Number	Sample Type	Depth (m)	Naph-thalene (µg/Kg)	Penta-chloro-phenol (µg/Kg)	Phenol (µg/Kg)	Tributyl Phosphate (µg/Kg)	2-Fluoro-phenol (µg/Kg)	Phenol, d6 (µg/Kg)	Nitro-benzene, d5 (µg/Kg)	Fluro-Biphenyl (µg/Kg)	2,4,6-Tribromo-phenol (µg/Kg)	Terphenyl, d14 (µg/Kg)	Unknown Oxyhydro-carbon (µg/Kg)	Antimony (Sb) (µg/Kg)	Barium (Ba) (µg/Kg)	Beryllium (Be) (µg/Kg)	Cadmium (Cd) (µg/Kg)	Calcium (Ca) (µg/Kg)
Limit of Detection =>			15	132	49	58								20000	2000	300	1000	10000
B06K07	Soil	6.32	ND	ND	ND	ND	6600	4600	2700	3400	6800	3200	28000	ND	92000	590	ND	12000000
B06K12	Soil	7.85	ND	ND	ND	ND	5700	4100	2200	2800	5900	2800	20000	ND	77000	480	ND	10000000
B06JZ2	Soil	12.42	ND	ND	ND	ND	5100	4700	2500	2900	4900	1800	ND	ND	60000	ND	ND	6400000
B06VW8	Soil	16.47	ND	ND	ND	ND	4900	4800	2600	2900	4200	1800	ND	ND	61000	ND	ND	8000000
B06VX4	Soil	24.61	ND	ND	ND	62 J	5000	4900	2700	3100	4400	2000	ND	ND	64000	400	ND	960000
B06VX8	Soil	30.86	ND	ND	220 J	ND	4100	4100	2300	2700	3800	2000	ND	ND	78000	380	ND	8800000
B06VY2	Soil	35.16	ND	ND	ND	ND	4300	4200	2300	2700	3800	1600	ND	ND	92000	330	ND	23000000
B06VY4	Soil	37.14	ND	ND	ND	ND	3000	2800	1400	1900	3000	1400	ND	ND	110000	ND	ND	140000000

HEIS Sample Number	Sample Type	Depth (m)	Chromium (Cr) (µg/Kg)	Cobalt (Co) (µg/Kg)	Copper (Cu) (µg/Kg)	Iron (Fe) (µg/Kg)	Magnesium (Mg) (µg/Kg)	Manganese (Mn) (µg/Kg)	Nickel (Ni) (µg/Kg)	Potassium (K) (µg/Kg)	Silver (Ag) (µg/Kg)	Sodium (Na) (µg/Kg)	Tin (Sn) (µg/Kg)	Vanadium (V) (µg/Kg)	Zinc (Zn) (µg/Kg)
Limit of Detection =>			2000	2000	2000	2000	10000	1000	3000	30000	2000	30000	10000	3000	1000
B06K07	Soil	6.32	9400	14000	21000	29000000	5500000	380000	9300	1900000	ND	1200000	ND	89000	57000
B06K12	Soil	7.85	8200	10000	14000	31000000	5300000	380000	8400	1200000	ND	1500000	ND	80000	55000
B06JZ2	Soil	12.42	9800	8900	16000	26000000	4800000	28000	15000	820000	ND	390000	ND	64000	44000
B06VW8	Soil	16.47	15000	7100	13000	20000000	5700000	290000	16000	1600000	ND	230000	ND	41000	39000
B06VX4	Soil	24.61	21000	8300	18000	19000000	6400000	340000	20000	2500000	ND	270000	ND	37000	48000
B06VX8	Soil	30.86	15000	7600	13000	17000000	5600000	310000	15000	2000000	ND	210000	ND	33000	40000
B06VY2	Soil	35.16	14000	7000	14000	19000000	6000000	350000	15000	1800000	ND	280000	ND	45000	44000
B06VY4	Soil	37.14	1100	5800	16000	10000000	7700000	270000	10000	940000	ND	640000	ND	24000	20000

ND Not Detected
J Below Limit of Quantitation

Analytical Results CHEMICAL 299-W18-246 (CT-2)

HEIS Sample Number	Sample Type	Depth (m)	Flouride (F) (µg/Kg)	Chloride (Cl) (µg/Kg)	Nitrate Ion (NO3) (µg/Kg)	Nitrite Ion (NO2) (µg/Kg)	Bromide (Br) (µg/Kg)	Phosphate Ion (PO4) (µg/Kg)	Sulfate (SO4) (µg/Kg)	Cyanide (CN) (µg/Kg)	Mercury (Hg) (µg/Kg)	Lead (Pb) (µg/Kg)	o-cresol (µg/Kg)	m-cresol (µg/Kg)	p-cresol (µg/Kg)	Decane (µg/Kg)	Dodecane (µg/Kg)	Tetra-decane (µg/Kg)
Limit of Detection =>			200	400	400	400	500	800	1000	3000	400	500	660	660	660	66000	66000	66000
B01WS0	Soil	17.24	ND	20000	11000	ND	ND	ND	45000	ND	ND	3700	ND	ND	ND	ND	ND	ND
B01WT5	Soil	32.54	500	3500	7400	ND	ND	ND	12000	ND	ND	3300	ND	ND	ND	ND	ND	ND
B01WQ0	Soil	43.30	400	1200	6600	ND	ND	ND	6000	ND	ND	5300	ND	ND	ND	ND	ND	ND
B066R2	Soil	44.58	2800	2000	10000	ND	ND	ND	19000	ND	ND	ND	ND	ND	ND	ND	ND	ND
B066S8	Soil	59.33	900	3500	3100	ND	ND	ND	3100	ND	ND	5000	ND	ND	ND	ND	ND	ND
			(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)		Not		(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
Limit of Detection =>			100	200	200	200	500	400	500		Analyzed		10	10	10	1000	1000	1000
B01WP4	Water	66.17	900	26000	3000	13000	ND	ND	23000		for		ND	ND	ND	ND	ND	ND
B01WP5	Water	66.72	500	7500	140000	200	ND	ND	20000		Ground		ND	ND	ND	ND	ND	ND
B01WP6	Water	68.58	700	7200	140000	400	ND	ND	20000		Water		ND	ND	ND	ND	ND	ND
B01WP7	Water	70.10	1200	6700	25000	35000	ND	ND	22000				ND	ND	ND	ND	ND	ND

HEIS Sample Number	Sample Type	Depth (m)	Naph-thalene (µg/Kg)	Penta-chloro-phenol (µg/Kg)	Phenol (µg/Kg)	Tributyl Phosphate (µg/Kg)	2-Fluoro-phenol (µg/Kg)	Phenol, d6 (µg/Kg)	Nitro-benzene, d5 (µg/Kg)	Fluro-Biphenyl (µg/Kg)	2,4,6-Tribromo-phenol (µg/Kg)	Terphenyl, d14 (µg/Kg)	Antimony (Sb) (µg/Kg)	Barium (Ba) (µg/Kg)	Beryllium (Be) (µg/Kg)	Cadmium (Cd) (µg/Kg)	Calcium (Ca) (µg/Kg)	Chromium (Cr) (µg/Kg)
Limit of Detection =>			660	3300	660	660							20000	2000	300	1000	10000	2000
B01WS0	Soil	17.24	ND	ND	ND	ND	5400	4700	2700	2500	3500	2600	ND	98000	ND	ND	9700000	13000
B01WT5	Soil	32.54	ND	ND	ND	ND	6300	4800	2900	2600	4800	2800	ND	58000	400	ND	9000000	14000
B01WQ0	Soil	43.30	ND	ND	ND	ND	7200	5300	2900	2700	5700	3000	ND	97000	500	ND	20000000	22000
B066R2	Soil	44.58	ND	ND	880	ND	6800	5000	3100	2800	5600	2700	ND	75000	ND	ND	190000000	6000
B066S8	Soil	59.33	ND	ND	ND	ND	6600	5000	3000	3000	1700	3300	ND	30000	ND	ND	2300000	14000
			(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
Limit of Detection =>			10	50	10	10							200	20	3	10	100	20
B01WP4	Water	66.17	ND	ND	ND	ND	130	37	70	73	150	72	ND	11000	ND	ND	550000	2900
B01WP5	Water	66.72	ND	ND	ND	ND	100	32	72	81	150	85	ND	100	ND	ND	55000	30
B01WP6	Water	68.58	ND	ND	ND	ND	110	39	68	65	180	67	ND	130	ND	ND	53000	ND
B01WP7	Water	70.10	ND	ND	ND	ND	51	27	63	59	130	43	ND	900	ND	ND	79000	300

HEIS Sample Number	Sample Type	Depth (m)	Cobalt (Co) (µg/Kg)	Copper (Cu) (µg/Kg)	Iron (Fe) (µg/Kg)	Magnesium (Mg) (µg/Kg)	Manganese (Mn) (µg/Kg)	Nickel (Ni) (µg/Kg)	Potassium (K) (µg/Kg)	Silver (Ag) (µg/Kg)	Sodium (Na) (µg/Kg)	Tin (Sn) (µg/Kg)	Vanadium (V) (µg/Kg)	Zinc (Zn) (µg/Kg)
Limit of Detection =>			2000	2000	2000	10000	1000	3000	30000	2000	30000	10000	3000	1000
B01WS0	Soil	17.24	8000	17000	22000000	5100000	380000	11000	1700000	ND	410000	ND	57000	45000
B01WT5	Soil	32.54	6000	22000	18000000	4700000	250000	12000	1100000	ND	310000	ND	40000	41000
B01WQ0	Soil	43.30	6000	34000	17000000	8500000	270000	17000	2600000	ND	400000	ND	31000	40000
B066R2	Soil	44.58	4000	22000	5600000	21000000	120000	6000	840000	ND	440000	ND	23000	12000
B066S8	Soil	59.33	5000	36000	10000000	3000000	190000	16000	620000	ND	290000	ND	16000	22000
			(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
Limit of Detection =>			20	20	20	100	10	30	300	20	300	100	30	10
B01WP4	Water	66.17	1300	2800	340000	550000	86000	3000	160000	ND	100000	ND	3700	6400
B01WP5	Water	66.72	ND	30	30000	15000	640	30	5500	ND	18000	ND	ND	20
B01WP6	Water	68.58	ND	ND	21000	14000	780	ND	6400	ND	20000	ND	ND	30
B01WP7	Water	70.10	100	290	660000	46000	10000	260	13000	ND	31000	ND	220	380

ND Not Detected

Analytical Results CHEMICAL 299-W18-247 (CT-3)

HEIS Sample Number	Sample Type	Depth (m)	Flouride (F) (µg/Kg)	Chloride (Cl) (µg/Kg)	Nitrate Ion (NO3) (µg/Kg)	Nitrite Ion (NO2) (µg/Kg)	Bromide (Br) (µg/Kg)	Phosphate Ion (PO4) (µg/Kg)	Sulfate (SO4) (µg/Kg)	Cyanide (CN) (µg/Kg)	Mercury (Hg) (µg/Kg)	Lead (Pb) (µg/Kg)	o-cresol (µg/Kg)	m-cresol (µg/Kg)	p-cresol (µg/Kg)	Decane (µg/Kg)	Dodecane (µg/Kg)	Tetra-decane (µg/Kg)
Limit of Detection =>			200	400	400	400	500	800	1000	3000	400	500	660	660	660	66000	66000	66000
B01WD0	Soil	17.02	300	4200	3400	ND	ND	ND	5800	ND	ND	5100	ND	ND	ND	ND	ND	ND
B01WF9	Soil	33.76	ND	400	600	ND	ND	ND	2800	ND	ND	3300	ND	ND	ND	ND	ND	ND
B01WJ5	Soil	41.50	600	1200	900	ND	ND	ND	4300	ND	ND	14000	ND	ND	ND	ND	ND	ND
B01WK5	Soil	45.64	1100	3100	1700	ND	ND	ND	6500	ND	ND	5800	ND	ND	ND	ND	ND	ND
B01WL2	Soil	47.23	1600	1100	1300	ND	ND	ND	5800	ND	ND	3700	ND	ND	ND	ND	ND	ND
			(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	Not Analyzed for Ground Water			(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
Limit of Detection =>			100	200	200	200	500	400	500				10	10	10	1000	1000	1000
B01WV7	Water	64.01	1900	8200	2000	700	ND	ND	32000				ND	ND	ND	ND	ND	ND
B01WW0	Water	65.53	1100	4100	4000	ND	ND	ND	22000				ND	ND	ND	ND	ND	ND
B01WW5	Water	67.06	1400	8000	4300	800	ND	ND	25000				ND	ND	ND	ND	ND	ND
B01WW8	Water	68.58											ND	ND	ND	ND	ND	ND

HEIS Sample Number	Sample Type	Depth (m)	Naph-thalene (µg/Kg)	Penta-chloro-phenol (µg/Kg)	Phenol (µg/Kg)	Tributyl Phosphate (µg/Kg)	2-Fluoro-phenol (µg/Kg)	Phenol, d6 (µg/Kg)	Nitro-benzene, d5 (µg/Kg)	Fluro-Biphenyl (µg/Kg)	2,4,6-Tribromo-phenol (µg/Kg)	Terphenyl, d14 (µg/Kg)	Antimony (Sb) (µg/Kg)	Barium (Ba) (µg/Kg)	Beryllium (Be) (µg/Kg)	Cadmium (Cd) (µg/Kg)	Calcium (Ca) (µg/Kg)	Chromium (Cr) (µg/Kg)
Limit of Detection =>			660	3300	660	660							20000	2000	300	1000	10000	2000
B01WD0	Soil	17.02	ND	ND	160	ND	2700	2500	1200	1200	1800	1100	ND	120000	400	ND	11000000	11000
B01WF9	Soil	33.76	ND	ND	ND	ND	3000	2800	1400	1400	2200	1500	ND	54000	400	ND	6800000	14000
B01WJ5	Soil	41.50	ND	ND	340	ND	2900	2800	1100	1000	2300	1500	ND	160000	1000	ND	13000000	24000
B01WK5	Soil	45.64	ND	ND	520	ND	6300	6000	3100	2500	3600	3300	ND	120000	500	ND	80000000	17000
B01WL2	Soil	47.23	ND	ND	700	ND	6800	6000	3200	2700	5000	3400	ND	120000	500	1000	48000000	28000
			(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
Limit of Detection =>			10	50	10	10							200	20	3	10	100	20
B01WV7	Water	64.01	ND	ND	ND	ND	77	50	66	57	100	55	ND	82	ND	ND	86000	ND
B01WW0	Water	65.53	ND	ND	ND	ND	87	44	80	74	120	87	ND	230	ND	ND	30000	ND
B01WW5	Water	67.06	ND	ND	ND	ND	86	49	71	73	120	87	ND	1800	ND	ND	110000	52
B01WW8	Water	68.58	ND	ND	ND	ND	79	39	64	70	120	51	ND	2000	6.3	15	160000	170

HEIS Sample Number	Sample Type	Depth (m)	Cobalt (Co) (µg/Kg)	Copper (Cu) (µg/Kg)	Iron (Fe) (µg/Kg)	Magnesium (Mg) (µg/Kg)	Manganese (Mn) (µg/Kg)	Nickel (Ni) (µg/Kg)	Potassium (K) (µg/Kg)	Silver (Ag) (µg/Kg)	Sodium (Na) (µg/Kg)	Tin (Sn) (µg/Kg)	Vanadium (V) (µg/Kg)	Zinc (Zn) (µg/Kg)
Limit of Detection =>			2000	2000	2000	10000	1000	3000	30000	2000	30000	10000	3000	1000
B01WD0	Soil	17.02	14000	22000	33000000	5900000	520000	11000	1800000	ND	690000	ND	86000	62000
B01WF9	Soil	33.76	5000	14000	16000000	4300000	240000	10000	1100000	ND	280000	ND	36000	35000
B01WJ5	Soil	41.50	9000	23000	22000000	7900000	440000	18000	5000000	ND	350000	ND	41000	63000
B01WK5	Soil	45.64	8000	41000	22000000	7100000	230000	12000	3100000	ND	1100000	ND	69000	46000
B01WL2	Soil	47.23	8000	25000	21000000	6600000	360000	18000	2200000	ND	590000	ND	49000	43000
			(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)	(µg/L)
Limit of Detection =>			20	20	20	100	10	30	300	20	300	100	30	10
B01WV7	Water	64.01	ND	ND	ND	30000	ND	ND	6500	ND	31000	ND	ND	ND
B01WW0	Water	65.53	ND	ND	11000	9800	870	ND	5900	ND	31000	ND	30	30
B01WW5	Water	67.06	240	160	38000	28000	12000	250	13000	ND	31000	ND	66	580
B01WW8	Water	68.58	340	270	180000	61000	15000	370	20000	ND	27000	ND	320	900

ND Not Detected

Analytical Results CHEMICAL 299-W18-248 (ID-3)

HEIS Sample Number	Sample Type	Depth (m)	Flouride (F) (µg/Kg)	Chloride (Cl) (µg/Kg)	Nitrate Ion (NO3) (µg/Kg)	Nitrite Ion (NO2) (µg/Kg)	Bromide (Br) (µg/Kg)	Phosphate Ion (PO4) (µg/Kg)	Sulfate (SO4) (µg/Kg)	Cyanide (CN) (µg/Kg)	Mercury (Hg) (µg/Kg)	Lead (Pb) (µg/Kg)	o-cresol (µg/Kg)	m-cresol (µg/Kg)	p-cresol (µg/Kg)	Decane (µg/Kg)	Dodecane (µg/Kg)	Tetra-decane (µg/Kg)
Limit of Detection =>			200	400	400	400	500	800	1000	3000	400	500	244	163	144	54	31	52
B06JL1	Soil	6.02	ND	9400	2700	ND	ND	ND	26000	ND	ND	2100	ND	ND	ND	ND	ND	ND
B06JS9	Soil	12.12	300	8100	1000	ND	ND	ND	17000	ND	ND	6200	ND	ND	ND	ND	ND	ND
B06JT6	Soil	18.24	ND	1500	5000	ND	ND	ND	6000	ND	ND	4600	ND	ND	ND	ND	ND	ND
B067V5	Soil	24.77	ND	2600	2200	400	ND	ND	8000	ND	ND	1600	ND	ND	ND	ND	ND	ND
B06JW1	Soil	27.20	400	3400	2400	1600	ND	ND	11000	ND	ND	1900	ND	ND	ND	ND	ND	ND
B06JW9	Soil	31.17	ND	6400	6900	ND	ND	ND	7000	ND	ND	6400	ND	ND	ND	ND	ND	ND
B06JX6	Soil	36.96	1900	3700	4000	ND	ND	ND	4800	ND	ND	4700	ND	ND	ND	ND	ND	ND
B06JY3	Soil	38.63	6600	4400	4300	ND	ND	ND	10000	ND	ND	5100	ND	ND	ND	ND	ND	ND
B06JS2	Soil	42.75	1200	4000	4200	ND	ND	ND	12000	ND	ND	1500	ND	ND	ND	ND	ND	ND

HEIS Sample Number	Sample Type	Depth (m)	Naph-thalene (µg/Kg)	Penta-chloro-phenol (µg/Kg)	Phenol (µg/Kg)	Tributyl Phosphate (µg/Kg)	2-Fluoro-phenol (µg/Kg)	Phenol, d6 (µg/Kg)	Nitro-benzene, d5 (µg/Kg)	Fluro-Biphenyl (µg/Kg)	2,4,6-Tribromo-phenol (µg/Kg)	Terphenyl, d14 (µg/Kg)	Antimony (Sb) (µg/Kg)	Barium (Ba) (µg/Kg)	Beryllium (Be) (µg/Kg)	Cadmium (Cd) (µg/Kg)	Calcium (Ca) (µg/Kg)	Chromium (Cr) (µg/Kg)
Limit of Detection =>			15	132	49	58							20000	2000	300	1000	10000	2000
B06JL1	Soil	6.02	ND	ND	ND	ND	4600	4400	3000	2700	5600	3000	ND	65000	300	ND	6600000	9400
B06JS9	Soil	12.12	ND	ND	ND	ND	4900	4500	2900	2700	5600	3200	ND	44000	ND	ND	7200000	6800
B06JT6	Soil	18.24	ND	ND	ND	ND	5000	4500	2700	2500	6900	3100	ND	92000	350	ND	9300000	100000
B067V5	Soil	24.77	ND	ND	ND	ND	5200	5000	3200	2900	7100	3500	ND	65000	ND	ND	5900000	9000
B06JW1	Soil	27.20	ND	ND	ND	ND	4400	3900	2800	2700	5900	3000	ND	82000	ND	ND	7100000	8500
B06JW9	Soil	31.17	ND	ND	ND	ND	4900	4400	3300	2900	6200	3100	ND	96000	530	ND	9600000	18000
B06JX6	Soil	36.96	ND	ND	ND	ND	7300	5900	3900	3800	7600	4200	ND	57000	330	ND	9300000	15000
B06JY3	Soil	38.63	ND	ND	ND	ND	6500	5000	3100	3400	7000	3800	ND	120000	390	ND	14000000	17000
B06JS2	Soil	42.75	ND	ND	ND	ND	7300	5500	3300	3500	7700	3500	ND	120000	ND	ND	230000000	4800

HEIS Sample Number	Sample Type	Depth (m)	Cobalt (Co) (µg/Kg)	Copper (Cu) (µg/Kg)	Iron (Fe) (µg/Kg)	Magnesium (Mg) (µg/Kg)	Manganese (Mn) (µg/Kg)	Nickel (Ni) (µg/Kg)	Potassium (K) (µg/Kg)	Silver (Ag) (µg/Kg)	Sodium (Na) (µg/Kg)	Tin (Sn) (µg/Kg)	Vanadium (V) (µg/Kg)	Zinc (Zn) (µg/Kg)
Limit of Detection =>			2000	2000	2000	10000	1000	3000	30000	2000	30000	10000	3000	1000
B06JL1	Soil	6.02	8200	24000	230000000	4300000	250000	ND	820000	ND	540000	ND	59000	500000
B06JS9	Soil	12.12	9000	17000	2500000	4200000	270000	ND	790000	ND	390000	ND	56000	45000
B06JT6	Soil	18.24	6100	12000	17000000	4900000	310000	ND	1700000	ND	240000	ND	37000	42000
B067V5	Soil	24.77	4100	8600	12000000	3600000	20000	ND	1000000	ND	190000	ND	ND	29000
B06JW1	Soil	27.20	8000	16000	20000000	3300000	240000	ND	740000	ND	630000	ND	57000	41000
B06JW9	Soil	31.17	8500	15000	19000000	6400000	350000	16000	2700000	ND	290000	ND	37000	52000
B06JX6	Soil	36.96	6500	13000	15000000	4300000	230000	15000	1200000	ND	300000	ND	33000	34000
B06JY3	Soil	38.63	6900	13000	17000000	5400000	310000	11000	2300000	ND	460000	ND	41000	38000
B06JS2	Soil	42.75	3800	13000	6800000	8900000	760000	5500	1000000	ND	360000	ND	16000	13000

ND Not Detected

Analytical Results CHEMICAL 299-W18-249 (ID-2)

HEIS Sample Number	Sample Type	Depth (m)	Flouride (F) (µg/Kg)	Chloride (Cl) (µg/Kg)	Nitrate Ion (NO3) (µg/Kg)	Nitrite Ion (NO2) (µg/Kg)	Bromide (Br) (µg/Kg)	Phosphate Ion (PO4) (µg/Kg)	Sulfate (SO4) (µg/Kg)	Cyanide (CN) (µg/Kg)	Mercury (Hg) (µg/Kg)	Lead (Pb) (µg/Kg)	o-cresol (µg/Kg)	m-cresol (µg/Kg)	p-cresol (µg/Kg)	Decane (µg/Kg)	Dodecane (µg/Kg)	Tetra-decane (µg/Kg)
	Limit of Detection =>		200	400	400	400	500	800	1000	3000	400	500	244	163	144	54	31	52
B06VY9	Soil	6.98	500	2300	4500	ND	ND	ND	19000	ND	ND	3100	ND	ND	ND	ND	ND	ND
B06VZ3	Soil	9.54	200	9400	2000	ND	ND	ND	13000	ND	ND	3000	ND	ND	ND	ND	ND	ND
B06VZ7	Soil	10.21	ND	9200	1400	ND	ND	ND	15000	ND	ND	3200	ND	ND	ND	ND	ND	ND
B06W01	Soil	10.82	300	12000	1700	ND	ND	ND	16000	ND	ND	2600	ND	ND	ND	ND	ND	ND
B06W05	Soil	11.43	500	16000	2100	ND	ND	ND	28000	ND	ND	2600	ND	ND	ND	ND	ND	ND
B06W09	Soil	11.98	300	13000	1900	ND	ND	ND	11000	ND	ND	2100	ND	ND	ND	ND	ND	ND
B06W12	Soil	18.17	200	8300	3500	ND	ND	ND	4400	ND	ND	3600	ND	ND	ND	ND	ND	ND
B06W16	Soil	24.81	300	12000	7100	ND	ND	ND	10000	ND	ND	8600	ND	ND	ND	ND	ND	ND
B06W20	Soil	30.63	ND	4400	4100	ND	ND	ND	6900	ND	ND	5400	ND	ND	ND	40 J	19 J	ND
B06W25	Soil	39.11	400	2300	1500	ND	ND	ND	4000	ND	ND	7000	ND	ND	ND	ND	ND	ND
B06W28	Soil	44.71	ND	1400	1400	ND	ND	ND	2800	ND	ND	5500	ND	ND	ND	110 J	110 J	29 J

HEIS Sample Number	Sample Type	Depth (m)	Naph-thalene (µg/Kg)	Penta-chloro-phenol (µg/Kg)	Phenol (µg/Kg)	Tributyl Phosphate (µg/Kg)	2-Fluoro-phenol (µg/Kg)	Phenol, d6 (µg/Kg)	Nitro-benzene, d5 (µg/Kg)	Fluro-Biphenyl (µg/Kg)	2,4,6-Tribromo-phenol (µg/Kg)	Terphenyl, d14 (µg/Kg)	Antimony (Sb) (µg/Kg)	Barium (Ba) (µg/Kg)	Beryllium (Be) (µg/Kg)	Cadmium (Cd) (µg/Kg)	Calcium (Ca) (µg/Kg)	Chromium (Cr) (µg/Kg)
	Limit of Detection =>		15	132	49	58							20000	2000	300	1000	10000	2000
B06VY9	Soil	6.98	ND	ND	ND	ND							ND	81000	320	ND	7000000	9600
B06VZ3	Soil	9.54	ND	ND	ND	ND	5300	5100	2900	3000	4100	2900	ND	100000	500	ND	13000000	13000
B06VZ7	Soil	10.21	ND	ND	ND	ND	5100	5100	2800	2900	3700	2700	ND	92000	500000	ND	11000000	11000
B06W01	Soil	10.82	ND	ND	ND	ND	5100	5000	2900	2900	3800	2700	ND	86000	300	ND	15000000	11000
B06W05	Soil	11.43	ND	ND	ND	ND	4400	4600	2600	2900	4300	2700	ND	100000	500	ND	15000000	13000
B06W09	Soil	11.98	ND	ND	ND	ND	4500	4700	2700	2900	4000	2700	ND	9000	ND	ND	3100000	ND
B06W12	Soil	18.17	ND	ND	ND	ND	4300	4400	2600	2900	4300	2600	ND	120000	600	ND	13000000	7000
B06W16	Soil	24.81	ND	ND	ND	ND	7800	6900	3900	3300	6400	3600	ND	110000	500	ND	15000000	20000
B06W20	Soil	30.63	ND	ND	ND	ND	6700	5800	3300	2700	5300	2900	ND	86000	ND	ND	9500000	18000
B06W25	Soil	39.11	ND	ND	ND	ND	6100	5300	2900	2400	4900	2800	ND	120000	ND	ND	15000000	16000
B06W28	Soil	44.71	ND	ND	ND	ND	6600	5600	3100	2700	1500	2900	ND	88000	ND	ND	23000000	20000

HEIS Sample Number	Sample Type	Depth (m)	Cobalt (Co) (µg/Kg)	Copper (Cu) (µg/Kg)	Iron (Fe) (µg/Kg)	Magnesium (Mg) (µg/Kg)	Manganese (Mn) (µg/Kg)	Nickel (Ni) (µg/Kg)	Potassium (K) (µg/Kg)	Silver (Ag) (µg/Kg)	Sodium (Na) (µg/Kg)	Tin (Sn) (µg/Kg)	Vanadium (V) (µg/Kg)	Zinc (Zn) (µg/Kg)
	Limit of Detection =>		2000	2000	2000	10000	1000	3000	30000	2000	30000	10000	3000	1000
B06VY9	Soil	6.98	10000	17000	30000000	4900000	360000	12000	940000	ND	470000	ND	77000	55000
B06VZ3	Soil	9.54	17000	16000	34000000	6600000	450000	14000	1200000	ND	1600000	ND	98000	61000
B06VZ7	Soil	10.21	18000	14000	32000000	5700000	470000	14000	920000	ND	1600000	ND	110000	56000
B06W01	Soil	10.82	15000	14000	28000000	5300000	350000	14000	860000	ND	1800000	ND	1200000	60000
B06W05	Soil	11.43	19000	16000	35000000	5900000	430000	130000	1000000	ND	1800000	ND	1200000	60000
B06W09	Soil	11.98	ND	2000	4700000	2000000	71000	ND	350000	ND	650000	ND	7000	38000
B06W12	Soil	18.17	22000	15000	35000000	5000000	5900000	10000	1200000	ND	1900000	ND	110000	540000
B06W16	Soil	24.81	9000	20000	22000000	7400000	430000	15000	2800000	ND	410000	ND	45000	52000
B06W20	Soil	30.63	6000	12000	19000000	6100000	330000	12000	2000000	ND	550000	ND	43000	36000
B06W25	Soil	39.11	12000	17000	28000000	6600000	530000	16000	2200000	ND	750000	ND	67000	47000
B06W28	Soil	44.71	8000	18000	20000000	8500000	280000	18000	1900000	ND	990000	ND	49000	38000

ND Not Detected
J Below Limit of Quantitation

RADIONUCLIDE ANALYSES FOR CT WELLS

299-W15-216 (CT-1)

HEIS Sample Number	Sample Type	Depth (m)	Alpha (pci/g)	Beta (pci/g)	Co-60 (pci/g)	Ru-106 (pci/g)	Sb-125 (pci/g)	Cs-137 (pci/g)	Pb-212 (pci/g)	Pb-214 (pci/g)	Ra-226 (pci/g)	Ra-224 (pci/g)
B067J3	Soil	15.19	10.70	24.80	0.0162	-0.0809	0.0392	-0.0136	0.55	0.418	0.491	0.569
B066V0	Soil	33.82	10.70	21.50	-0.0111	-0.297	-0.0307	-0.0231	1.35	1.16	1.17	1.38
B066V6	Soil	35.52		17.60	0.0737	-0.0876	-0.0729	-0.00417	NR	NR	NR	NR
B066W3	Soil	36.65	3.04	11.60	0.00172	-0.105	0.0263	0.0122	0.66	0.511	0.489	0.669
B066W9	Soil	39.40	5.58	16.80	-0.0171	-0.278	-0.0198	-0.00275	0.529	0.471	0.368	0.535
			(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)
B066Z3	Water	60.56	3.61	9.14	2.19	29.5	6.14	1.16	NR	NR	NR	NR
B066Z6	Water	61.87	17.50	15.10	0	-12.5	6.84	3.47	NR	NR	NR	NR
B066Z7	Water	63.61	3.30	5.72	0	-11.9	5.47	-0.504	NR	NR	NR	NR

299-W18-246 (CT-2)

HEIS Sample Number	Sample Type	Depth (m)	Alpha (pci/g)	Beta (pci/g)	Co-60 (pci/g)	Ru-106 (pci/g)	Sb-125 (pci/g)	Cs-137 (pci/g)	Pb-212 (pci/g)	Pb-214 (pci/g)	Ra-226 (pci/g)	Ra-224 (pci/g)
B01WS1	Soil	17.39	2.18	12.1	0.0134	0.00178	0.0337	0.0131	NR	NR	0.731	0.983
B01WT6	Soil	32.69	6.2	24.1	0.00655	0.15	-0.0841	-0.0118	0.746	0.537	0.567	0.778
B01WP9	Soil	43.14	7.66	24.7	-0.00102		0.0303	-0.0347	1.82	1.34	1.3	1.89
B066R2	Soil	44.58	29.4	26.1	-0.0138	0.262	-0.02	-0.0305	0.373	2.94	2.81	-0.355
B066S9	Soil	59.48	7.45	25.8	0.0158	-0.447	-0.0769	-0.0163	1.66	1.04	0.779	1.69
			(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)
B01WP4	Water	66.17	19.6	27.6	-3.57	8.74	4.23	1.81	NR	NR	NR	NR
B01WP5	Water	66.72	5.03	5.51	-1.63	9.68	-0.555	1.51	NR	NR	NR	NR
B01WP6	Water	68.58	0.112	5.34	2.8	55.3	7.64	0.0915	NR	NR	NR	NR
B01WP7	Water	70.10	8.51	20.5	4.44	12	8.92	3.92	NR	NR	NR	NR

299-W18-247 (CT-3)

HEIS Sample Number	Sample Type	Depth (m)	Alpha (pci/g)	Beta (pci/g)	Co-60 (pci/g)	Ru-106 (pci/g)	Sb-125 (pci/g)	Cs-137 (pci/g)	Pb-212 (pci/g)	Pb-214 (pci/g)	Ra-226 (pci/g)	Ra-224 (pci/g)
B01WC9	Soil	16.87	1.99	13.00	NR	0.0406	0.0222	-0.0142	NR	NR	0.687	1.02
B01WF8	Soil	33.91	1.53	18.50	0.0302	-0.0406	0.0607	0.046	NR	NR	NR	0.776
B01WJ6	Soil	41.35	5.43	12.00	0.00754	-0.0142	0.123	-0.0404	NR	NR	0.974	1.53
B01WK4	Soil	45.49	10.20	11.60	0.04	-0.163	-0.0743	0.0261	NR	NR	4.07	0.472
B01WL3	Soil	47.38	4.32	14.70	0.0287	0.0169	NR	0.0578	NR	NR	NR	0.847
			(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)	(pci/L)
B01WV9	Water	64.01	9.44	15.30	-0.26	-28.10	4.32	2.95	NR	NR	NR	NR
B01WW1	Water	65.53	6.84	12.40	-7.96	7.28	0.752	5.4	NR	NR	NR	NR
B01WW3	Water	67.06	3.29	10.10	12.4	13.1	-8.56	3.39	NR	NR	NR	NR
B01WW6	Water	68.58	10.10	13.00	0.297	68.5	0.36	-1.48	NR	NR	NR	NR

NR - Not Reported

299-W15-217 (ID-1)

HEIS Sample Number	Sample Type	Depth (m)	Alpha (pci/g)	Beta (pci/g)	Co-60 (pci/g)	Ru-106 (pci/g)	Sb-125 (pci/g)	Cs-137 (pci/g)	Pb-212 (pci/g)	Pb-214 (pci/g)	Ra-226 (pci/g)	Ra-224 (pci/g)
B06K08	Soil	6.48	10.6	14.1	-0.00782	-0.1	0.0524	-0.0179	NR	NR	NR	NR
B06K12	Soil	7.85	6.54	20.9	0.0157	-0.0635	0.0625	-0.00333	NR	NR	NR	NR
B06JZ3	Soil	12.27	6.21	17.6	0.0069	0.0516	0.0282	-0.0188	0.485	0.39	0.384	0.507
B06VW9	Soil	16.63	8.67	27.6	0.0275	-0.203	0.025	-0.00318	0.683	0.52	0.514	0.711
B06VX5	Soil	24.77	7.04	22.7	0.0261	0.133	0.025	0.0174	0.91	0.735	0.667	0.948
B06VX9	Soil	31.01	5.53	22.5	0.00481	0.0518	-0.00402	-0.00366	0.653	0.539	0.52	0.674
B06VY3	Soil	35.31	7.13	22	0.00303	-0.0548	-0.00992	-0.00274	1.01	0.768	0.823	1.01
B06VY4	Soil	37.14	11.1	21.4	0.00395	-0.109	-0.0579	-0.0287	0.396	1.73	1.66	0.409

299-W18-249 (ID-2)

HEIS Sample Number	Sample Type	Depth (m)	Alpha (pci/g)	Beta (pci/g)	Co-60 (pci/g)	Ru-106 (pci/g)	Sb-125 (pci/g)	Cs-137 (pci/g)	Pb-212 (pci/g)	Pb-214 (pci/g)	Ra-226 (pci/g)	Ra-224 (pci/g)
B06VZ0	Soil	7.13	5.19	17.4	-0.00578	-0.256	-0.0242	-0.00142	0.411	0.432	0.339	0.421
B06VZ4	Soil	9.69	7.49	19.3	3.25E-03	0.144	6.90E-03	1.13E-02	0.475	0.391	0.312	0.497
B06VZ8	Soil	10.36	6.66	16.2	-1.18E-02	-0.104	0.015	-3.81E-03	0.431	0.428	0.426	0.45
B06W02	Soil	10.97	5.13	17.5	-2.43E-04	2.93E-02	-2.45E-02	-3.72E-03	0.45	0.344	0.344	0.471
B06W06	Soil	11.58	5.82	13.5	1.36E-02	0.108	6.76E-03	5.99E-03	0.428	0.381	0.353	0.448
B06W09	Soil	11.98	5.18	17.3	0.0169	0.298	0.0335	-0.0514	0.595	0.515	0.431	0.622
B06W13	Soil	18.32	6.53	15.8	0.0128	-0.0306	0.00264	-0.0131	0.477	0.441	0.488	0.499
B06W17	Soil	24.96	7.01	17	-0.0255	-0.0592	0.0226	0.0278	0.831	0.661	0.704	0.872
B06W21	Soil	30.78	5.69	18.9	0.00076	-0.0244	0.0567	-0.00289	0.495	0.378	0.446	0.519
B06W26	Soil	39.23	10.2	24.4	0.00824	-0.184	0.0619	-0.0237	1.13	0.837	0.833	1.18
B06W28	Soil	44.71	13	21.2	-0.00246	0.191	0.0147	-0.0474	1.36	1.11	0.98	1.41

299-W18-248 (ID-3)

HEIS Sample Number	Sample Type	Depth (m)	Alpha (pci/g)	Beta (pci/g)	Co-60 (pci/g)	Ru-106 (pci/g)	Sb-125 (pci/g)	Cs-137 (pci/g)	Pb-212 (pci/g)	Pb-214 (pci/g)	Ra-226 (pci/g)	Ra-224 (pci/g)
B06JS4	Soil	6.48	4.57	14.3	0.00597	-0.0366	0.0301	-0.0269	0.573	0.461	0.473	0.595
B06JS9	Soil	12.12	5.27	13.4	0.0224	0.156	0.0133	-0.00958	0.385	0.38	0.397	0.399
B06JT5	Soil	18.09	6.04	21.5	0.0132	0.326	-0.036	0.00946	0.683	0.578	0.579	0.705
B067V6	Soil	24.92	8.3	17.5	-0.00777	0.0878	0.00767	-0.00347	0.537	0.403	0.521	0.552
B06JW2	Soil	27.36	5.58	19.5	0.023	-0.215	0.0627	0.0102	0.672	0.597	0.672	0.693
B06JX0	Soil	31.32	13	25.5	0.00295	0.064	0.0428	0.0346	1.11	0.975	0.716	1.14
B06JX7	Soil	37.11	9.77	21.5	-0.041	-0.293	0.0347	0.0307	NR	NR	NR	NR
B06JY4	Soil	38.79	6.9	24.7	0.0245	0.0535	0.0477	-0.0638	NR	NR	NR	NR
B06JZ3	Soil	42.90	18.5	16.8	0.0359	0.115	-0.0163	-0.0565	NR	NR	NR	NR

NR - Not Reported

9 3 1 2 9 7 0 1 2 8 5

Appendix F

Averaged Carbon Tetrachloride Concentrations in Groundwater Beneath the 200 West Area

9 3 1 2 9 0 1 2 8 6

THIS PAGE INTENTIONALLY
LEFT BLANK

Well	Average of Result	L.T.	Constituent	D.L.	Units
2-W10-13	13		Carbon tetrachloride	5	PPB
2-W10-14	5	<	Carbon tetrachloride	5	PPB
2-W10-16	690		Carbon tetrachloride	5	PPB
2-W10-17	170		Carbon tetrachloride	5	PPB
2-W10-18	1100		Carbon tetrachloride	5	PPB
2-W10-4	2663		Carbon tetrachloride	5	PPB
2-W10-8	49		Carbon tetrachloride	5	PPB
2-W10-9	2000		Carbon tetrachloride	5	PPB
2-W11-14	767		Carbon tetrachloride	5	PPB
2-W11-23	10		Carbon tetrachloride	5	PPB
2-W11-7	2290		Carbon tetrachloride	5	PPB
2-W14-10	5	<	Carbon tetrachloride	5	PPB
2-W14-2	858		Carbon tetrachloride	5	PPB
2-W14-5	630		Carbon tetrachloride	5	PPB
2-W14-6	301		Carbon tetrachloride	5	PPB
2-W15-10	3620		Carbon tetrachloride	5	PPB
2-W15-11	4900		Carbon tetrachloride	5	PPB
2-W15-12	1580		Carbon tetrachloride	5	PPB
2-W15-15	655		Carbon tetrachloride	5	PPB
2-W15-16	6573		Carbon tetrachloride	5	PPB
2-W15-17	5	<	Carbon tetrachloride	5	PPB
2-W15-18	1360		Carbon tetrachloride	5	PPB
2-W15-19	1104		Carbon tetrachloride	5	PPB
2-W15-20	201		Carbon tetrachloride	5	PPB
2-W15-22	1230		Carbon tetrachloride	5	PPB
2-W15-23	454		Carbon tetrachloride	5	PPB
2-W15-24	223		Carbon tetrachloride	5	PPB
2-W15-4	1960		Carbon tetrachloride	5	PPB
2-W15-7	2133		Carbon tetrachloride	5	PPB
2-W15-8	620		Carbon tetrachloride	5	PPB
2-W18-15	106		Carbon tetrachloride	5	PPB
2-W18-17	703		Carbon tetrachloride	5	PPB
2-W18-20	62		Carbon tetrachloride	5	PPB
2-W18-21	177		Carbon tetrachloride	5	PPB
2-W18-22	5	<	Carbon tetrachloride	5	PPB
2-W18-23	666		Carbon tetrachloride	5	PPB
2-W18-24	752		Carbon tetrachloride	5	PPB
2-W18-25	6		Carbon tetrachloride	5	PPB
2-W18-26	186		Carbon tetrachloride	5	PPB
2-W18-27	370		Carbon tetrachloride	5	PPB
2-W18-28	53		Carbon tetrachloride	5	PPB
2-W18-4	137		Carbon tetrachloride	5	PPB
2-W18-5	3517		Carbon tetrachloride	5	PPB
2-W18-9	180		Carbon tetrachloride	5	PPB

Note: PPB = $\mu g/L$.

(1/88 THROUGH 10/92)

Well	Average of Result	L.T.	Constituent	D.L.	Units
2-W19-1	5	<	Carbon tetrachloride	5	PPB
2-W19-11	115		Carbon tetrachloride	5	PPB
2-W19-12	20		Carbon tetrachloride	5	PPB
2-W19-13	36		Carbon tetrachloride	5	PPB
2-W19-15	84		Carbon tetrachloride	5	PPB
2-W19-16	175		Carbon tetrachloride	5	PPB
2-W19-18	64		Carbon tetrachloride	5	PPB
2-W19-19	15		Carbon tetrachloride	5	PPB
2-W19-2	22		Carbon tetrachloride	5	PPB
2-W19-20	29		Carbon tetrachloride	5	PPB
2-W19-21	5	<	Carbon tetrachloride	5	PPB
2-W19-23	29		Carbon tetrachloride	5	PPB
2-W19-24	20		Carbon tetrachloride	5	PPB
2-W19-25	26		Carbon tetrachloride	5	PPB
2-W19-26	32		Carbon tetrachloride	5	PPB
2-W19-27	12		Carbon tetrachloride	5	PPB
2-W19-28	66		Carbon tetrachloride	5	PPB
2-W19-29	86		Carbon tetrachloride	5	PPB
2-W19-3	141		Carbon tetrachloride	5	PPB
2-W19-30	18		Carbon tetrachloride	5	PPB
2-W19-31	130		Carbon tetrachloride	5	PPB
2-W19-5	5	<	Carbon tetrachloride	5	PPB
2-W19-9	136		Carbon tetrachloride	5	PPB
2-W22-1	5	<	Carbon tetrachloride	5	PPB
2-W22-12	5	<	Carbon tetrachloride	5	PPB
2-W22-20	10		Carbon tetrachloride	5	PPB
2-W22-21	5	<	Carbon tetrachloride	5	PPB
2-W22-22	5	<	Carbon tetrachloride	5	PPB
2-W22-26	5	<	Carbon tetrachloride	5	PPB
2-W22-39	5	<	Carbon tetrachloride	5	PPB
2-W22-40	8		Carbon tetrachloride	5	PPB
2-W22-41	6		Carbon tetrachloride	5	PPB
2-W22-42	5	<	Carbon tetrachloride	5	PPB
2-W23-10	5	<	Carbon tetrachloride	5	PPB
2-W23-11	5	<	Carbon tetrachloride	5	PPB
2-W23-14	5	<	Carbon tetrachloride	5	PPB
2-W23-9	5	<	Carbon tetrachloride	5	PPB
2-W26-10	5	<	Carbon tetrachloride	5	PPB
2-W26-12	5	<	Carbon tetrachloride	5	PPB
2-W26-6	5	<	Carbon tetrachloride	5	PPB
2-W26-7	5	<	Carbon tetrachloride	5	PPB
2-W26-8	5	<	Carbon tetrachloride	5	PPB
2-W26-9	5	<	Carbon tetrachloride	5	PPB
2-W27-1	5	<	Carbon tetrachloride	5	PPB
2-W6-2	100		Carbon tetrachloride	5	PPB

93129701288

Well	Average of Result	L.T.	Constituent	D.L.	Units
2-W6-4	183		Carbon tetrachloride	5	PPB
2-W6-5	270		Carbon tetrachloride	5	PPB
2-W6-6	5	<	Carbon tetrachloride	5	PPB
2-W6-7	200		Carbon tetrachloride	5	PPB
2-W6-8	5	<	Carbon tetrachloride	5	PPB
2-W7-1	5	<	Carbon tetrachloride	5	PPB
2-W7-10	5	<	Carbon tetrachloride	5	PPB
2-W7-11	5	<	Carbon tetrachloride	5	PPB
2-W7-12	5	<	Carbon tetrachloride	5	PPB
2-W7-2	5	<	Carbon tetrachloride	5	PPB
2-W7-3	5	<	Carbon tetrachloride	5	PPB
2-W7-4	255		Carbon tetrachloride	5	PPB
2-W7-5	40		Carbon tetrachloride	5	PPB
2-W7-6	5	<	Carbon tetrachloride	5	PPB
2-W7-7	5	<	Carbon tetrachloride	5	PPB
2-W7-8	7		Carbon tetrachloride	5	PPB
2-W7-9	5	<	Carbon tetrachloride	5	PPB
2-W8-1	5	<	Carbon tetrachloride	5	PPB
2-W9-1	5	<	Carbon tetrachloride	5	PPB
6-29-78	5	<	Carbon tetrachloride	5	PPB
6-32-70B	5	<	Carbon tetrachloride	5	PPB
6-32-72	5	<	Carbon tetrachloride	5	PPB
6-32-77	5	<	Carbon tetrachloride	5	PPB
6-35-66	5	<	Carbon tetrachloride	5	PPB
6-35-70	5	<	Carbon tetrachloride	5	PPB
6-36-61A	5	<	Carbon tetrachloride	5	PPB
6-37-82A	5	<	Carbon tetrachloride	5	PPB
6-38-70	42		Carbon tetrachloride	5	PPB
6-39-79	779		Carbon tetrachloride	5	PPB
6-40-62	5	<	Carbon tetrachloride	5	PPB
6-44-64	5	<	Carbon tetrachloride	5	PPB
6-45-69A	5	<	Carbon tetrachloride	5	PPB
6-47-60	5	<	Carbon tetrachloride	5	PPB
6-48-71	5	<	Carbon tetrachloride	5	PPB
6-49-79	5	<	Carbon tetrachloride	5	PPB
6-50-85	5	<	Carbon tetrachloride	5	PPB

93129 0128 9

(1/88 THROUGH 10/92)

Well	Average of Result	L.T.	Constituent	D.L.	Units
2-W10-13	5	<	Chloroform	5	PPB
2-W10-14	5	<	Chloroform	5	PPB
2-W10-16	8		Chloroform	5	PPB
2-W10-17	5	<	Chloroform	5	PPB
2-W10-18	9		Chloroform	5	PPB
2-W10-4	19		Chloroform	5	PPB
2-W10-8	5	<	Chloroform	5	PPB
2-W10-9	15		Chloroform	5	PPB
2-W11-14	6		Chloroform	5	PPB
2-W11-23	5	<	Chloroform	5	PPB
2-W11-7	26		Chloroform	5	PPB
2-W14-10	5	<	Chloroform	5	PPB
2-W14-2	8		Chloroform	5	PPB
2-W14-5	7		Chloroform	5	PPB
2-W14-6	5	<	Chloroform	5	PPB
2-W15-10	21		Chloroform	5	PPB
2-W15-11	31		Chloroform	5	PPB
2-W15-12	23		Chloroform	5	PPB
2-W15-15	6		Chloroform	5	PPB
2-W15-16	41		Chloroform	5	PPB
2-W15-17	5	<	Chloroform	5	PPB
2-W15-18	17		Chloroform	5	PPB
2-W15-19	154		Chloroform	5	PPB
2-W15-20	9		Chloroform	5	PPB
2-W15-22	14		Chloroform	5	PPB
2-W15-23	5	<	Chloroform	5	PPB
2-W15-24	41		Chloroform	5	PPB
2-W15-4	18		Chloroform	5	PPB
2-W15-7	16		Chloroform	5	PPB
2-W15-8	1595		Chloroform	5	PPB
2-W18-15	5	<	Chloroform	5	PPB
2-W18-17	101		Chloroform	5	PPB
2-W18-20	24		Chloroform	5	PPB
2-W18-21	5	<	Chloroform	5	PPB
2-W18-22	5	<	Chloroform	5	PPB
2-W18-23	7		Chloroform	5	PPB
2-W18-24	17		Chloroform	5	PPB
2-W18-25	5	<	Chloroform	5	PPB
2-W18-26	21		Chloroform	5	PPB
2-W18-4	521		Chloroform	5	PPB
2-W18-5	25		Chloroform	5	PPB
2-W18-9	14		Chloroform	5	PPB
2-W19-1	5	<	Chloroform	5	PPB
2-W19-11	5	<	Chloroform	5	PPB

9 3 1 2 9 7 0 1 2 9 0

Well	Average of Result	L.T.	Constituent	D.L.	Units
2-W19-12	5	<	Chloroform	5	PPB
2-W19-13	5	<	Chloroform	5	PPB
2-W19-15	5	<	Chloroform	5	PPB
2-W19-16	5	<	Chloroform	5	PPB
2-W19-18	5	<	Chloroform	5	PPB
2-W19-19	5	<	Chloroform	5	PPB
2-W19-2	5	<	Chloroform	5	PPB
2-W19-20	5	<	Chloroform	5	PPB
2-W19-21	5	<	Chloroform	5	PPB
2-W19-23	5	<	Chloroform	5	PPB
2-W19-24	5	<	Chloroform	5	PPB
2-W19-25	5	<	Chloroform	5	PPB
2-W19-26	5	<	Chloroform	5	PPB
2-W19-27	5	<	Chloroform	5	PPB
2-W19-28	7		Chloroform	5	PPB
2-W19-29	6		Chloroform	5	PPB
2-W19-3	5	<	Chloroform	5	PPB
2-W19-30	5	<	Chloroform	5	PPB
2-W19-31	5	<	Chloroform	5	PPB
2-W19-5	5	<	Chloroform	5	PPB
2-W19-9	5	<	Chloroform	5	PPB
2-W22-1	5	<	Chloroform	5	PPB
2-W22-12	5	<	Chloroform	5	PPB
2-W22-20	9		Chloroform	5	PPB
2-W22-21	5	<	Chloroform	5	PPB
2-W22-22	5	<	Chloroform	5	PPB
2-W22-26	5	<	Chloroform	5	PPB
2-W22-39	5	<	Chloroform	5	PPB
2-W22-40	5	<	Chloroform	5	PPB
2-W22-41	5	<	Chloroform	5	PPB
2-W22-42	5	<	Chloroform	5	PPB
2-W23-10	5	<	Chloroform	5	PPB
2-W23-11	5	<	Chloroform	5	PPB
2-W23-14	5	<	Chloroform	5	PPB
2-W23-9	5	<	Chloroform	5	PPB
2-W26-10	5	<	Chloroform	5	PPB
2-W26-12	5	<	Chloroform	5	PPB
2-W26-6	5	<	Chloroform	5	PPB
2-W26-7	5	<	Chloroform	5	PPB
2-W26-8	5	<	Chloroform	5	PPB
2-W26-9	5	<	Chloroform	5	PPB
2-W27-1	9		Chloroform	5	PPB
2-W6-2	5	<	Chloroform	5	PPB
2-W6-4	12		Chloroform	5	PPB
2-W6-5	17		Chloroform	5	PPB

Well	Average of Result	L.T.	Constituent	D.L.	Units
2-W6-6	5	<	Chloroform	5	PPB
2-W6-7	8		Chloroform	5	PPB
2-W6-8	5	<	Chloroform	5	PPB
2-W7-1	5	<	Chloroform	5	PPB
2-W7-10	5	<	Chloroform	5	PPB
2-W7-11	5	<	Chloroform	5	PPB
2-W7-12	5	<	Chloroform	5	PPB
2-W7-2	5	<	Chloroform	5	PPB
2-W7-3	5	<	Chloroform	5	PPB
2-W7-4	6		Chloroform	5	PPB
2-W7-5	5	<	Chloroform	5	PPB
2-W7-6	5	<	Chloroform	5	PPB
2-W7-7	5	<	Chloroform	5	PPB
2-W7-8	5	<	Chloroform	5	PPB
2-W7-9	5	<	Chloroform	5	PPB
2-W8-1	5	<	Chloroform	5	PPB
2-W9-1	5	<	Chloroform	5	PPB
6-29-78	5	<	Chloroform	5	PPB
6-32-70B	5	<	Chloroform	5	PPB
6-32-72	5	<	Chloroform	5	PPB
6-32-77	5	<	Chloroform	5	PPB
6-35-66	5	<	Chloroform	5	PPB
6-35-70	5	<	Chloroform	5	PPB
6-36-61A	5	<	Chloroform	5	PPB
6-37-82A	5	<	Chloroform	5	PPB
6-38-70	5	<	Chloroform	5	PPB
6-39-79	6		Chloroform	5	PPB
6-40-62	5	<	Chloroform	5	PPB
6-44-64	5	<	Chloroform	5	PPB
6-45-69A	5	<	Chloroform	5	PPB
6-47-60	5	<	Chloroform	5	PPB
6-48-71	5	<	Chloroform	5	PPB
6-49-79	5	<	Chloroform	5	PPB
6-50-85	5	<	Chloroform	5	PPB

93129701292

Distribution

No. of
Copies

OFFSITE

12 DOE/Office of Scientific and Technical Information

D. L. Biancosino
U. S. Department of Energy
12800 Middlebrook Road
EM-551, 406/TREV
Germantown, MD 20874

2 M. Angel
K. Langry
Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94550

S. Booth
Los Alamos National Laboratory
Los Alamos, NM 87545

2 L. Bromberg
D. R. Cohn
Plasma Fusion Center
Massachusetts Institute of Technology
167 Albany Street, NW16-140
Cambridge, MA 02139

2 R. J. Cameron
B. B. Peters
Ebasco Services, Inc.
1201 Jadwin, Suite 202
Richland, WA 99352

J. Conca
Washington State University
100 Sprout Road
Tri-Cities, WA 99352

No. of
Copies

G. W. Dawson
ICF Technology, Inc.
601 Williams Blvd.
Richland, WA 99352

D. P. Eyman
Department of Chemistry
University of Iowa
Iowa City, IA 52242

2 G. C. Frye
J. Sprung
Sandia National Laboratories
P. O. Box 5800
Albuquerque, NM 87185

R. Jenkins
Oak Ridge National Laboratory
P.O. Box 2008
Oak Ridge, TN 37831-6273

G. Junk
Iowa State University
Ames, IA 50011

D. R. Sherwood
U. S. Environmental Protection Agency
712 Swift Blvd., Suite 5
Richland, WA 99352

M. F. Wheeler
Department of Mathematical Sciences
Rice Unviersity
Houston, TX 77005

No. of Copies

ONSITE

2 DOE Richland Field Office

P. M. Pak
D. E. Trader

2 Kaiser Engineers Hanford Company

H. A. Dugger
N. M. Hutchins

28 Westinghouse Hanford Company

M. P. Connelly
J. D. Fancher
K. R. Fecht
B. H. Ford
M. C. Hagood
K. M. Hodgson
R. L. Jackson
J. M. Jimenez
V. G. Johnson
W. L. Johnson
G. L. Kasza
C. V. King
A. J. Knepp
K. J. Koegler
O. L. Kruger
A. G. Law
K. A. Lindsay
G. W. McLellan
D. J. Moak
S. M. Narbutovskih
M. G. Piepho
J. A. Rawlins
V. J. Rohay (5)
M. J. Schliebe
K. J. Swett
S. J. Trent
B. W. Volk
J. G. Wollard

No. of Copies

48 Pacific Northwest Laboratory

L. N. Archibald
M. P. Bergeron
T. M. Bergsman
B. N. Bjornstad
J. V. Borghese
T. M. Brouns
M. A. Chamness
D. E. Deonigi
P. G. Doctor
J. C. Evans
R. E. Engelman
M. J. Fayer
G. K. Gerke
W. O. Heath
E. C. Korstad (2)
G. V. Last (5)
R. J. Lenhard
A. M. Lesperance
R. E. Lewis
S. P. Luttrell
G. H. McCabe, BSRC
F. A. Morris
R. G. Riley
K. R. Roberson
M. L. Rockhold
R. Schalla
S. C. Slate
S. L. Stein
E. J. Stenehjem
J. A. Stottlemyre
C. K. Thornhill
S. D. Tomich
M. J. Truex
C. L. Widrig
G. L. Wilfert
S. B. Yabusaki
Publication Coordination (2)
Technical Report Files (5)

9 3 1 2 9 7 0 1 2 9 4

No. of
Copies

Routing

R. M. Ecker
M. J. Graham
P. M. Irving
R. L. Skaggs
C. S. Sloane
P. C. Hays/B. V. Johnston (last)

9 3 1 2 9 0 1 2 9 5

THIS PAGE INTENTIONALLY
LEFT BLANK