

AR TARGET SHEET

The following document was too large to scan as one unit, therefore, it has been broken down into sections.

EDMC#: 0058328

SECTION: 1 of 2

DOCUMENT #: BHI-00720, Rev 006

TITLE: Performance Evaluation Report for
Soil Vapor Extraction Operations at
Carbon Tetrachloride Site February
1992 – September 2001

0058328

BHI-00720

Rev. 6

Performance Evaluation Report for Soil Vapor Extraction Operations at the Carbon Tetrachloride Site, February 1992 – September 2001

RECEIVED
NOV 14 2002

EDMC

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

Submitted by: Bechtel Hanford, Inc.

TRADEMARK DISCLAIMER

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

This report has been reproduced from the best available copy.
Available in paper copy and microfiche.

Available for a processing fee to U.S. Department of Energy
and its contractors from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
(865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov
online ordering: <http://www.doe.gov/bridge>

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(800) 553-6847
fax: (703) 605.6900
email: orders@ntis.fedworld.gov
online ordering: <http://www.ntis.gov/ordering.htm>

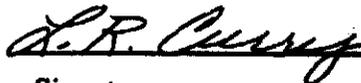
Printed in the United States of America

DISCLM-5.CHP (11/99)

APPROVAL PAGE

Title: Performance Evaluation Report for Soil Vapor Extraction Operations at the Carbon Tetrachloride Site, February 1992 - September 2001

Approval: L. R. Curry, Acting Project Manager / Project Engineer,
Groundwater/Vadose Zone Integration Project

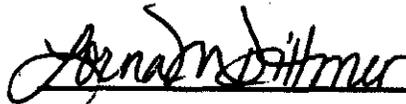


Signature



Date

L. M. Dittmer, Project Environmental Lead,
Groundwater/Vadose Zone Integration Project



Signature



Date

G. A. Day, Groundwater Operations Task Lead,
Groundwater/Vadose Zone Integration Project

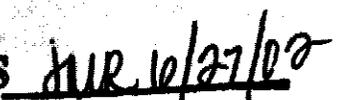


Signature



Date

The approval signatures on this page indicate that this document has been authorized for information release to the public through appropriate channels. No other forms or signatures are required to document this information release.

BHI-DIS 

BHI-00720
Rev. 6

Performance Evaluation Report for Soil Vapor Extraction Operations at the Carbon Tetrachloride Site, February 1992 – September 2001

Author

V. J. Rohay
CH2M HILL Hanford, Inc.

Date Published

June 2002

EXECUTIVE SUMMARY

Soil vapor extraction (SVE) is being used to remove carbon tetrachloride from the vadose zone at the 200-PW-1 Operable Unit (formerly designated as the 200-ZP-2 Operable Unit). The purpose of this report is to evaluate the SVE system operating data and the effectiveness of SVE in remediating the carbon tetrachloride contamination based on the existing remedial design. This report has been revised to cover the operating period from February 25, 1992 through September 30, 2001. The scope of the report includes the history of SVE operations at 200-PW-1, the efficiency of those operations over time, the volume of vapor processed per extraction system, the change in carbon tetrachloride concentrations with time, the mass of carbon tetrachloride removed per site, and recommendations for future operations and evaluations. This revision includes an update to the carbon tetrachloride conceptual model.

Carbon tetrachloride was found in the unconfined aquifer beneath the 200 West Area at the Hanford Site in the mid-1980's. Groundwater monitoring indicated that the carbon tetrachloride plume was widespread and that concentrations were increasing. In response to this contamination, removal of carbon tetrachloride from the vadose zone in the 200 West Area was initiated in 1992 using SVE followed by aboveground vapor treatment on granular activated carbon. By March 1993, three SVE systems, located near the three primary carbon tetrachloride disposal sites, were in operation with a total capacity of 85 m³/min. The three primary carbon tetrachloride disposal sites were the 216-Z-9, 216-Z-1A, and 216-Z-18 subsurface infiltration facilities used from 1955 through 1973 for soil column disposal of aqueous and organic liquid wastes.

Carbon tetrachloride concentrations in the extracted soil vapor have decreased significantly at all three sites during operation of the SVE systems. Initial carbon tetrachloride concentrations in extracted soil vapor were approximately 30,000 parts per million by volume (ppmv) at the 216-Z-9 wellfield and 1,500 ppmv at the 216-Z-1A/Z-18 wellfield. Concentrations in extracted soil vapor were approximately 40 ppmv at the 216-Z-9 wellfield and 25 ppmv at the 216-Z-1A/Z-18 wellfield when active SVE was last used at these sites in 2001.

Executive Summary

Operation of all three SVE systems was temporarily suspended during fiscal year (FY) 1997 (from November 1996 through June 1997) to evaluate the magnitude and rate of carbon tetrachloride concentration rebound following temporary cessation of operations. Soil vapor concentrations were measured in samples collected from 90 probes and wells throughout the SVE sites. The observed rebound in vapor concentrations indicates that additional carbon tetrachloride is available for removal using SVE.

The primary source of this remaining available carbon tetrachloride appears to be the relatively low-permeability zone from approximately 38 to 45 m depth. As carbon tetrachloride from this lower permeability zone migrates into the overlying and underlying higher permeability zones, it can be removed using SVE. However, the rate of removal will be controlled by the rates of carbon tetrachloride desorption and diffusion. At many monitoring locations, including ones within the higher permeability zones, the relatively low carbon tetrachloride rebound concentrations indicate that the readily accessible mass (carbon tetrachloride already in the vapor phase or volatilizing directly from residual nonaqueous-phase liquid) has been removed. At these locations, the availability of additional mass for removal using SVE is controlled by desorption and diffusion kinetics of carbon tetrachloride adsorbed within soil particle micropores and dissolved in soil moisture.

Based on the results of the FY 1997 rebound study and the declining rate of carbon tetrachloride removal during continuous extraction operations, the operating strategy was modified from that of FY 1997 and previous years. Rather than operating all three SVE systems continuously, only the 14.2-m³/min system was used for carbon tetrachloride removal during FY 1998, FY 1999, and FY 2001. During each of these fiscal years, the 14.2-m³/min system was operated from April through September; operation was temporarily suspended each fiscal year from October through March. Operation was temporarily suspended during the entire year in FY 2000. The 28.3-m³/min and 42.5-m³/min SVE systems were maintained in standby mode during FY 1998, FY 1999, and FY 2001. All three systems were maintained in standby mode during FY 2000. Carbon tetrachloride concentrations were monitored at each wellfield during each period of nonoperation.

Executive Summary

Between April 1991 (when the pilot test was conducted) and September 2001, approximately 77,154 kg of carbon tetrachloride were removed from the vadose zone using these three SVE systems. Of this total, 53,318 kg were removed from the 216-Z-9 wellfield and 23,836 kg were removed from the 216-Z-1A/Z-18 wellfield.

Passive SVE systems were installed on eight wells in FY 1999 and operated throughout FY 2000 and FY 2001 to remove carbon tetrachloride from the vadose zone. Passive SVE is a naturally occurring process driven by barometric pressure fluctuations and is often referred to as "barometric pumping." The eight wells are located in the 216-Z-1A/Z-18 wellfield. Between October 1999 and September 2001, approximately 30 kg of carbon tetrachloride were removed from the vadose zone using passive SVE.

The total mass of carbon tetrachloride removed between 1991 and 2001 using SVE represents an estimated 10% of the original carbon tetrachloride inventory (approximately 750,000 kg) discharged to the soil column. Approximately 0.1% of the original inventory was removed each year in FY 1998, FY 1999, and FY 2001 (782 kg, 811 kg, and 710 kg, respectively). Between 1955 and 1990, an estimated 21% of the original inventory was lost to the atmosphere, 2% was dissolved in groundwater, and 1% was biodegraded. The remaining 66% of the original inventory is believed to be primarily in residual saturation, soil moisture, and nonequilibrium sorption sites within the vadose zone and groundwater and possibly as a dense nonaqueous-phase liquid in groundwater.

Recommendations for FY 2002 SVE operations include continuing cyclic SVE operations with potential modifications to the system location and/or to the schedule to allow more efficient extraction, continuing operation of the passive SVE systems with potential modifications to the design and locations of the systems, and continuing carbon tetrachloride vapor concentration monitoring during periods of nonoperation of the SVE system. It is recommended that an evaluation be conducted to determine the frequency and type of SVE operations and monitoring to be implemented in FY 2003.

TABLE OF CONTENTS

1.0	PURPOSE	1-1
2.0	BACKGROUND	2-1
2.1	CARBON TETRACHLORIDE WASTE DISPOSAL	2-2
2.2	CARBON TETRACHLORIDE WELLFIELD	2-2
3.0	SOIL VAPOR EXTRACTION SYSTEM DESIGN	3-1
4.0	HISTORY OF SOIL VAPOR EXTRACTION SYSTEM OPERATIONS	4-1
5.0	SOIL VAPOR EXTRACTION SYSTEM OPERATING DATA	5-1
5.1	SOIL VAPOR EXTRACTION SYSTEM AVAILABILITY	5-2
5.2	VOLUME OF SOIL VAPOR PROCESSED.....	5-3
5.3	VOLUME OF KNOCKOUT WATER DRAINED FROM SVE SYSTEMS	5-5
5.4	CHANGE IN CARBON TETRACHLORIDE CONCENTRATIONS	5-8
5.4.1	Fiscal Years 1997 and 1998	5-9
5.4.2	Fiscal Year 1999.....	5-9
5.4.3	Fiscal Years 2000 and 2001	5-10
5.4.4	Rebound Following Nonoperation of Soil Vapor Extraction Systems ..	5-11
5.4.5	Estimate of Future Concentration Decline	5-12
5.4.6	Concentration Data for Individual Extraction Wells.....	5-13
5.5	MASS OF CARBON TETRACHLORIDE REMOVED	5-15
5.6	IMPACT OF 200-ZP-1 PHASE III PUMP-AND-TREAT OPERATIONS.....	5-17
5.7	PASSIVE SOIL VAPOR EXTRACTION.....	5-18
5.7.1	Mass of Carbon Tetrachloride Removed by Passive Soil Vapor Extraction Systems	5-19
5.7.2	Carbon Tetrachloride Concentrations, Flow Rates, and Differential Pressures Measured at Passive Soil Vapor Extraction Systems.....	5-22
5.7.3	Performance of Passive Soil Vapor Extraction Systems.....	5-23
6.0	NONOPERATIONAL SOIL VAPOR MONITORING DATA	6-1
6.1	SUMMARY OF FISCAL YEAR 1997 REBOUND STUDY	6-1

6.2	FISCAL YEAR 1998 SOIL VAPOR MONITORING	6-3
6.3	FISCAL YEAR 1999 SOIL VAPOR MONITORING	6-5
6.4	FISCAL YEAR 2000 SOIL VAPOR MONITORING	6-6
6.5	FISCAL YEAR 2001 SOIL VAPOR MONITORING	6-7
6.6	COMPARISON OF SOIL VAPOR MONITORING BEFORE AND AFTER SOIL VAPOR EXTRACTION REMEDIATION.....	6-9
7.0	2001 CARBON TETRACHLORIDE CONCEPTUAL MODEL UPDATE	7-1
7.1	CONTAMINANT INVENTORY	7-2
7.2	ENVIRONMENTAL SETTING.....	7-2
7.3	CONTAMINANT DISTRIBUTION	7-2
7.3.1	Vadose Zone Concentrations.....	7-3
7.3.2	Groundwater Concentrations.....	7-3
7.4	CONTAMINANT TRANSPORT	7-4
7.4.1	Vadose Zone.....	7-4
7.4.2	Capillary Fringe.....	7-5
7.4.3	Groundwater Hydraulics	7-6
7.4.4	Groundwater.....	7-6
7.5	DATA GAPS.....	7-7
8.0	CONCLUSIONS.....	8-1
9.0	RECOMMENDATIONS	9-1
9.1	STATUS OF FISCAL YEAR 1997 RECOMMENDATIONS FOR FISCAL YEAR 1998	9-1
9.2	STATUS OF FISCAL YEAR 1998 RECOMMENDATIONS FOR FISCAL YEAR 1999	9-2
9.3	STATUS OF FISCAL YEAR 1999 RECOMMENDATIONS FOR FISCAL YEAR 2000 AND FISCAL YEAR 2001	9-4
9.4	STATUS OF FISCAL YEAR 2000 RECOMMENDATIONS FOR FISCAL YEAR 2001 AND FISCAL YEAR 2002.....	9-6
9.5	FISCAL YEAR 2001 RECOMMENDATIONS FOR FISCAL YEAR 2002	9-8

Table of Contents

9.6	RECOMMENDATIONS FOR FISCAL YEAR 2003.....	9-9
10.0	REFERENCES.....	10-1

APPENDICES

A	200-PW-1 FLOW RATE ESTIMATION METHODOLOGY.....	A-i
B	SOIL VAPOR EXTRACTION WELL CHARACTERIZATION DATA	B-i
C	PASSIVE SOIL VAPOR EXTRACTION DATA.....	C-i
D	FISCAL YEAR 1998 SOIL VAPOR MONITORING DATA	D-i
E	FISCAL YEAR 1999 SOIL VAPOR MONITORING DATA	E-i
F	FISCAL YEAR 2000 SOIL VAPOR MONITORING DATA.....	F-i
G	FISCAL YEAR 2001 SOIL VAPOR MONITORING DATA.....	G-i
H	2001 CARBON TETRACHLORIDE CONCEPTUAL MODEL UPDATE.....	H-i

FIGURES

2-1.	Location of Extraction and Monitoring Wells and Deep (>2 m) Soil Vapor Probes at the Carbon Tetrachloride Soil Vapor Extraction Sites.....	2-5
2-2a.	Cross Section Through the 216-Z-18/Z-12 Wellfield.....	2-7
2-2b.	Cross Section Through the 216-Z-1A Wellfield.....	2-9
2-2c.	Cross Section Through the 216-Z-9 Wellfield.....	2-11
2-3.	Location of Shallow (1.2 to 1.8 m) Soil Vapor Probes at the Carbon Tetrachloride Site.	2-13
3-1.	Soil Vapor Extraction System Process Flow Diagram.....	3-3
3-2.	Configuration of Instrumentation Monitoring Volatile Organic Compounds at the Soil Vapor Extraction System.....	3-4
3-3.	Passive Soil Vapor Extraction System.....	3-5
5-1.	Combined Monthly Availability of the Three Soil Vapor Extraction Systems, November 1994 - September 2001.....	5-25
5-2.	Monthly Availability of the 14.2-m ³ /min Soil Vapor Extraction System, January 1994 - September 2001.....	5-26
5-3.	Monthly Availability of the 28.3-m ³ /min Soil Vapor Extraction System, January 1994 - September 2001.....	5-27
5-4.	Monthly Availability of the 42.5-m ³ /min Soil Vapor Extraction System, January 1994 - September 2001.....	5-28
5-5.	Number of Hours the Three Soil Vapor Extraction Systems Operated, February 1992 - September 2001.....	5-29
5-6.	Daily Average Flow Rate Measured at the 14.2-m ³ /min Soil Vapor Extraction System During 24-hr/day, 7-days/week Operations, August 1994 - September 2001.....	5-30
5-7.	Daily Average Flow Rate Measured at the 28.3-m ³ /min Soil Vapor Extraction System During 24-hr/day, 7-days/week Operations, July 1994 - September 2001.....	5-31
5-8.	Daily Average Flow Rate Measured at the 42.5-m ³ /min Soil Vapor Extraction System During 24-hr/day, 7-days/week Operations, October 1994 - September 2001.....	5-32
5-9.	Volume of Vapor Processed by the 14.2-m ³ /min Soil Vapor Extraction System, June 1994 - September 2001.....	5-33
5-10.	Volume of Vapor Processed by the 28.3-m ³ /min Soil Vapor Extraction System, February 1992 - September 2001.....	5-34
5-11.	Volume of Vapor Processed by the 42.5-m ³ /min Soil Vapor Extraction System, March 1993 - September 2001.....	5-35
5-12.	Weekly Volume of Knockout Water Drained from Soil Vapor Extraction Systems, October 1994 - September 1997.....	5-36
5-13.	Ratio of Cumulative Volume of Knockout Water Drained to Cumulative Volume of Vapor Extracted for Each Soil Vapor Extraction System, October 1994 - April 1995; October 1995 - June 1996; and October 1996.....	5-37
5-14.	Comparison of Carbon Tetrachloride Concentrations Measured at the Soil Vapor Extraction System Inlet to Volume of Vapor Extracted at the 216-Z-1A/Z-18/Z-12 Wellfield, February 1992 - September 2001.....	5-38

Table of Contents

5-15.	Comparison of Carbon Tetrachloride Concentrations Measured at the Soil Vapor Extraction System Inlet to Volume of Vapor Extracted at the 216-Z-9 Wellfield, March 1993 - September 2001.	5-39
5-16.	Carbon Tetrachloride Concentrations Measured at the Soil Vapor Extraction System Inlet During Extraction at the 216-Z-9 Wellfield During 24-hr/day Operations, October 1994 - September 2001.	5-40
5-17.	Carbon Tetrachloride Concentrations Measured at the 14.2-m ³ /min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-1A/Z-18/Z-12 Wellfield, April 1998 - June 1998.	5-41
5-18.	Carbon Tetrachloride Concentrations Measured at the 14.2-m ³ /min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-9 Wellfield, July 1998 - September 1998.	5-42
5-19.	Comparison of Carbon Tetrachloride Concentrations and Mass Removal Rates Using the 14.2-m ³ /min Soil Vapor Extraction System, April 1998 - September 1998.	5-43
5-20.	Carbon Tetrachloride Concentrations Measured at the 14.2-m ³ /min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-9 Wellfield, April 1999 - June 1999.	5-44
5-21.	Carbon Tetrachloride Concentrations Measured at the 14.2-m ³ /min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-1A/Z-18/Z-12 Wellfield, July 1999 - September 1999.	5-45
5-22.	Comparison of Carbon Tetrachloride Concentrations and Mass Removal Rates Using the 14.2-m ³ /min Soil Vapor Extraction System, April 1999 - September 1999.	5-46
5-23.	Carbon Tetrachloride Concentrations Measured at the 14.2-m ³ /min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-1A/Z-18/Z-12 Wellfield, April 2001 - July 2001.	5-47
5-24.	Carbon Tetrachloride Concentrations Measured During Initial Soil Vapor Extraction Tests at New Screened Intervals in Wells 299-W15-84L and 299-W15-95L, July 2001.	5-48
5-25a.	Comparison of Carbon Tetrachloride Concentrations in Soil Vapor Sampled During Drilling and Soil Vapor Extracted Using the Soil Vapor Extraction System at Well 299-W15-95L.	5-49
5-25b.	Comparison of Carbon Tetrachloride Concentrations in Soil Vapor Sampled During Drilling and Soil Vapor Extracted Using the Soil Vapor Extraction System at Well 299-W15-84L.	5-49
5-26.	Carbon Tetrachloride Concentrations Measured at the 14.2-m ³ /min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-9 Wellfield, July 2001 - September 2001.	5-50
5-27.	Comparison of Carbon Tetrachloride Concentrations and Mass Removal Rates Using the 14.2-m ³ /min Soil Vapor Extraction System, April 2001 - September 2001.	5-51
5-28.	Carbon Tetrachloride Concentrations in Vapor Extracted from the 216-Z-9 Site, July 1997 - September 1997, July 1998 - September 1998, April 1999 - June 1999, and July 2001 - September 2001.	5-52
5-29.	Carbon Tetrachloride Concentrations in Vapor Extracted from the 216-Z-18 Site, July 1997 - September 1997 and April 1998 - May 1998.	5-53

Table of Contents

5-30.	Carbon Tetrachloride Concentrations in Vapor Extracted from the 216-Z-1A Site, July 1997 – September 1997, May 1998 – June 1998, July 1999 – September 1999, and April 2001 - July 2001.....	5-54
5-31.	Exponential Decay of Carbon Tetrachloride Concentrations, October 1995 Through November 1996.	5-55
5-32.	Exponential Decay of Carbon Tetrachloride Concentrations, October 1995 Through September 1998.....	5-56
5-33.	Carbon Tetrachloride Concentrations Measured at Extraction Wells in the 216-Z-1A/Z-18 Wellfield, April 1992 - September 2001.	5-57
5-34.	Carbon Tetrachloride Concentrations Measured at Extraction Wells in the 216-Z-9 Wellfield, March 1993 - September 2001.....	5-58
5-35.	Relationship Between Concentrations of Carbon Tetrachloride and Chloroform Measured at Extraction Wells in the 216-Z-9 Wellfield.....	5-59
5-36.	Relationship Between Concentrations of Carbon Tetrachloride Less Than 1,000 ppmv and Chloroform Measured at Extraction Wells in the 216-Z-9 Wellfield.	5-60
5-37.	Relationship Between Concentrations of Carbon Tetrachloride and Chloroform Measured at Two 216-Z-9 Wells, 299-W15-82 and 299-W15-217.....	5-61
5-38.	Relationship Between Concentrations of Carbon Tetrachloride and Chloroform Measured at Extraction Wells in the 216-Z-1A/Z-18/Z-12 Wellfield.	5-62
5-39.	Total Mass of Carbon Tetrachloride Removed, February 1992 – September 2001.....	5-63
5-40.	Carbon Tetrachloride Concentrations Monitored at 216-Z-9 Well 299-W15-218.	5-64
5-41.	Mass of Carbon Tetrachloride Removed from the 216-Z-1A/Z-18/Z-12 Wellfield, February 1992 – September 2001.	5-65
5-42.	Mass of Carbon Tetrachloride Removed from the 216-Z-9 Wellfield, March 1993 – September 2001.....	5-66
5-43.	Decline in Total Carbon Tetrachloride Mass Removal Rate Between October 1994 and September 2001.....	5-67
5-44.	Comparison of Mass Removed Using the 14.2-m ³ /min Soil Vapor Extraction System During Cyclic Operations at the 216-Z-9 Wellfield to the Projected Mass Removed During Continuous Operations.....	5-68
5-45.	Carbon Tetrachloride Concentrations Monitored at the 216-Z-9 Wellfield, Wells 299-W15-6L and 299-W15-9L.	5-69
5-46.	Location of Passive Soil Vapor Extraction Wells.....	5-70
5-47.	Correlation Between Total Carbon Tetrachloride Mass Removed Based on GAC Cartridge Analytical Data and Wellhead Hourly Measurements.....	5-71
5-48.	Monthly Amount of Carbon Tetrachloride Removed from Each Passive Soil Vapor Extraction Well, Based on GAC Cartridge Data.....	5-72
5-49.	Carbon Tetrachloride Concentrations and Flow Rates Measured Hourly at Well 299-W18-6L, October 1999 – September 2001.	5-73
5-50.	Carbon Tetrachloride Concentrations and Flow Rates Measured Hourly at Well 299-W18-247L, October 1999 – September 2001.	5-74
5-51.	Carbon Tetrachloride Concentrations and Flow Rates Measured Hourly at Well 299-W18-252L, October 1999 – September 2001.	5-75
5-52.	Comparison of Carbon Tetrachloride Concentrations Measured Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, July 2000.	5-76

Table of Contents

5-53.	Average Positive Differential Pressures Measured at Passive Soil Vapor Extraction Wells.....	5-77
5-54.	Carbon Tetrachloride Concentrations, Flow Rates, and Differential Pressures Measured Hourly at Well 299-W18-247L, May 2000.....	5-78
6-1.	Vertical Profile of Maximum Carbon Tetrachloride Rebound Concentrations, November 1996 – July 1997.	6-11
6-2.	Vertical Profile of Maximum Chloroform Rebound Concentrations, November 1996 – July 1997.	6-12
6-3.	Relationship Between Concentrations of Carbon Tetrachloride and Chloroform Measured at Rebound Study Monitoring Locations in the 216-Z-9 Wellfield.	6-13
6-4.	Relationship Between Concentrations of Carbon Tetrachloride and Chloroform Measured at Rebound Study Monitoring Locations in the 216-Z-1A/Z-18/Z-12 Wellfield.	6-14
6-5.	Vertical Profile of Maximum Carbon Tetrachloride Rebound Concentrations, November 1996 – July 1997, October 1997 – September 1998, July 1998 – September 1999, and July 1999 – September 2001.	6-15
6-6.	Carbon Tetrachloride Rebound Concentrations Measured at 216-Z-9 Well 299-W15-217, November 1996 – June 2001.....	6-16
6-7.	Vertical Profile of Maximum Carbon Tetrachloride Baseline Concentrations, December 1991 – December 1993.....	6-17
6-8a.	Maximum Carbon Tetrachloride Baseline Concentrations Recorded at Wells and Deep Soil Vapor Probes Open Above the Plio-Pleistocene Unit, December 1991 – December 1993 (from Fancher 1994).	6-18
6-8b.	Maximum Carbon Tetrachloride Baseline Concentrations Recorded at Wells Open Below the Plio-Pleistocene Unit, December 1991 - December 1993 (from Fancher 1994)	6-19
6-9a.	Maximum Carbon Tetrachloride Rebound Concentrations Recorded at Wells and Deep Soil Vapor Probes Open Above the Plio-Pleistocene Unit, November 1996 – July 1997.	6-20
6-9b.	Maximum Carbon Tetrachloride Rebound Concentrations Recorded at Wells Open Below the Plio-Pleistocene Unit, November 1996 - 1997.	6-21
7-1.	Schematic Illustration of Carbon Tetrachloride and Wastewater Migration Beneath the 216-Z-9 Trench in the Higher Concentration Portion of the Plume.....	7-10

TABLES

2-1.	Contaminant Inventory Discharged to Carbon Tetrachloride Disposal Sites.	2-14
4-1.	Mass of Carbon Tetrachloride Removed Using Soil Vapor Extraction.....	4-4
5-1.	Planned Operating Times for the Soil Vapor Extraction Systems.	5-79
5-2.	Monthly Availability Data for the Soil Vapor Extraction Systems, January 1994 – September 2001.....	5-80
5-3.	Number of Hours Each Soil Vapor Extraction System Has Operated.	5-82
5-4a.	Volume of Vapor Processed by Each Soil Vapor Extraction System.....	5-82
5-4b.	Volume of Vapor Extracted from Each Soil Vapor Extraction Wellfield.	5-82
5-5.	Volume of Vapor Extracted from Each Extraction Well Between April 1991 and September 2001.....	5-83

Table of Contents

5-6.	Weekly Volume of Knockout Water Drained from Soil Vapor Extraction Systems, October 1994 – September 2001.....	5-84
5-7.	Analyses of Soil Vapor Extraction System Knockout Water.....	5-87
5-8.	Initial Carbon Tetrachloride Concentrations Measured at Individual Extraction Wells.....	5-89
5-9a.	Hourly Data Availability for Passive Soil Vapor Extraction Wells During FY 2000. .	5-91
5-9b.	Hourly Data Availability for Passive Soil Vapor Extraction Wells During FY 2001. .	5-91
5-10a.	Carbon Tetrachloride Removed by Passive Soil Vapor Extraction Systems During FY 2000.....	5-92
5-10b.	Carbon Tetrachloride Removed by Passive Soil Vapor Extraction Systems During FY 2001.....	5-93
5-11a.	Number of Days Hourly Data are Available During Each GAC Cartridge Sampling Interval in FY 2000.	5-94
5-11b.	Number of Days Hourly Data are Available During Each GAC Cartridge Sampling Interval in FY 2001	5-95
5-12.	Estimate of Total Carbon Tetrachloride Removed from Each Passive Soil Vapor Extraction Well in FY 2000 Based on Linear Trend Between Monthly GAC Cartridge Analytical Data and Hourly Wellhead Measurement Data.	5-95
5-13.	Estimate of Potential Total Carbon Tetrachloride Removed from Each Passive Soil Vapor Extraction Well in FY 2001.	5-96
5-14a.	Comparison of Carbon Tetrachloride Removed in FY 2000 Based on Selected Flow Rates.	5-97
5-14b.	Comparison of Carbon Tetrachloride Removed in FY 2001 Based on Selected Flow Rates	5-98
6-1.	Comparison of Maximum Carbon Tetrachloride Rebound Concentrations Monitored at the 200-PW-1 Soil Vapor Extraction Site, FY 1997 – FY 2001.....	6-22
7-1.	Disposition of Carbon Tetrachloride Inventory Discharged to the Soil Column.....	7-11
7-2.	Carbon Tetrachloride Concentrations Measured in the Vadose Zone.	7-12

ACRONYMS

B&K	Brüel & Kjaer
bgs	below ground surface
DBBP	dibutyl butyl phosphonate
DNAPL	dense nonaqueous-phase liquid
DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERA	expedited response action
FY	fiscal year
GAC	granular activated carbon
HEPA	high-efficiency particulate air
PLC	programmable logic controller
PID	photoionization detector
RL	U.S. Department of Energy, Richland Operations Office
SVE	soil vapor extraction
TBP	tributyl phosphate
VOC	volatile organic compound

METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
<i>If You Know</i>	<i>Multiply By</i>	<i>To Get</i>	<i>If You Know</i>	<i>Multiply By</i>	<i>To Get</i>
Length			Length		
inches	25.4	millimeters	millimeters	0.039	inches
inches	2.54	centimeters	centimeters	0.394	inches
feet	0.305	meters	meters	3.281	feet
yards	0.914	meters	meters	1.094	yards
miles	1.609	kilometers	kilometers	0.621	miles
Area			Area		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.093	sq. meters	sq. meters	10.76	sq. feet
sq. yards	0.0836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.6	sq. kilometers	sq. kilometers	0.4	sq. miles
acres	0.405	hectares	hectares	2.47	acres
Mass (weight)			Mass (weight)		
ounces	28.35	grams	grams	0.035	ounces
pounds	0.454	kilograms	kilograms	2.205	pounds
ton	0.907	metric ton	metric ton	1.102	ton
Volume			Volume		
teaspoons	5	milliliters	milliliters	0.033	fluid ounces
tablespoons	15	milliliters	liters	2.1	pints
fluid ounces	30	milliliters	liters	1.057	quarts
cups	0.24	liters	liters	0.264	gallons
pints	0.47	liters	cubic meters	35.315	cubic feet
quarts	0.95	liters	cubic meters	1.308	cubic yards
gallons	3.8	liters			
cubic feet	0.028	cubic meters			
cubic yards	0.765	cubic meters			
Temperature			Temperature		
Fahrenheit	subtract 32, then multiply by 5/9	Celsius	Celsius	multiply by 9/5, then add 32	Fahrenheit
Radioactivity			Radioactivity		
picocuries	37	millibecquerel	millibecquerel	0.027	picocuries
Pressure			Pressure		
inches (water)	249.07	pascals	pascals	0.0040149	inches (water)

1.0 PURPOSE

Soil vapor extraction (SVE) is being used to remove carbon tetrachloride from the vadose zone at the 200-PW-1 Operable Unit (formerly designated as the 200-ZP-2 Operable Unit). The purpose of this report is to evaluate the SVE system operating data and the effectiveness of SVE in remediating the carbon tetrachloride contamination based on the existing remedial design. This report has been revised to cover the operating period from February 25, 1992 through September 30, 2001. The previous versions of the report covered the operating periods from February 25, 1992 through September 30, 2000 (Rev. 5), February 25, 1992 through September 30, 1999 (Rev. 4); February 25, 1992 through September 30, 1998 (Rev. 3); February 25, 1992 through September 30, 1997 (Rev. 2); February 25, 1992 through June 30, 1996 (Rev. 1); and from February 25, 1992 through June 30, 1995 (Rev. 0). The scope of the report includes the history of SVE operations at 200-PW-1, the efficiency of those operations over time, the volume of vapor processed per system, the change in carbon tetrachloride concentrations with time, the mass of carbon tetrachloride removed per site, and recommendations for future operations and data evaluation. This revision includes an update to the 1994 carbon tetrachloride conceptual model (Rohay et al. 1994).

2.0 BACKGROUND

Carbon tetrachloride was found in the unconfined aquifer beneath the 200 West Area at the Hanford Site in the mid-1980's. Groundwater monitoring indicated that the carbon tetrachloride plume was widespread and that concentrations were increasing. On December 20, 1990, the U.S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (Ecology) requested the U.S. Department of Energy (DOE), Richland Operations Office (RL), to proceed with the detailed planning, including nonintrusive field work, required to implement an Expedited Response Action (ERA) for removing carbon tetrachloride contamination from the unsaturated soils in the 200 West Area. The request was based on concerns that the carbon tetrachloride residing in the soils was continuing to spread to the groundwater and, if left unchecked, would significantly increase the areal extent of groundwater contamination. The purpose of this ERA is to minimize carbon tetrachloride migration within the vadose zone beneath and away from the carbon tetrachloride disposal sites in the 200 West Area.

The first site evaluations were conducted from January through April 1991 to refine the preliminary conceptual model and to collect data in support of the selection and design of an initial remedial action (Hagood and Rohay 1991). These initial site evaluations included a pilot test of a SVE system. Results of the initial ERA site evaluations were summarized in September 1991 (DOE-RL 1991).

Based on the initial investigations and on the engineering evaluation and cost analysis (EE/CA), the preferred alternative for removal of the carbon tetrachloride from the vadose zone was SVE followed by aboveground vapor treatment on granular activated carbon (GAC) (DOE-RL 1991). In January 1992, the EPA and Ecology issued an Action Memorandum authorizing the DOE to initiate SVE for cleanup of the carbon tetrachloride (EPA 1992). The first SVE system began operating in February 1992.

The objective of the ERA, as stated in the Action Memorandum, is to mitigate the threat to site workers, public health, and the environment caused by the migration of carbon tetrachloride vapors through the soil column and into the groundwater. The ERA is an interim action taken to reduce the mass of carbon tetrachloride in the soil column beneath the 200 West Area pending the final cleanup activities.

The final cleanup activities will be determined as part of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* remedial investigation/feasibility study process for the 200-PW-1 Operable Unit. The remedial investigation of the carbon tetrachloride vadose zone plume was initiated in fiscal year (FY) 2002 (DOE-RL 2002a).

Background

2.1 CARBON TETRACHLORIDE WASTE DISPOSAL

Carbon tetrachloride, contained in aqueous and organic wastes generated during the Recuplex and Plutonium Reclamation Facility plutonium processing operations at Z Plant (currently called the Plutonium Finishing Plant), was discharged primarily to three subsurface infiltration facilities: the 216-Z-9 Trench from 1955 to 1962, the 216-Z-1A Tile Field (and the associated 216-Z-1 and 216-Z-2 Cribs) from 1964 to 1969, and the 216-Z-18 Crib from 1969 to 1973 (Figure 2-1). The Recuplex operation was discontinued after a criticality incident in April 1962, and it was replaced in May 1964 by the Plutonium Reclamation Facility; no liquid organic waste associated with these operations was discharged to cribs in the intervening years. No liquid organic waste was discharged to cribs after 1973. A total of 570,000 to 920,000 kg (360,000 to 580,000 L) of carbon tetrachloride is estimated to have been discharged to the soil column during this time (Table 2-1) (DOE-RL 1991).

Three other sites in the vicinity of Z Plant also received some carbon tetrachloride wastes: the 216-Z-12 Crib, the 216-Z-19 Ditch, and the 216-T-19 Crib (Figure 2-1). The 216-Z-12 Crib received analytical and development laboratory waste from Z Plant from 1959 to 1973 and is estimated to have received a small volume of organics, which included carbon tetrachloride (Kasper 1982). The 216-Z-19 Ditch was used to convey process cooling water and steam condensate from Z Plant from 1971 to 1981; apparently, carbon tetrachloride was also occasionally and/or accidentally released to this ditch because heavy organic was noted in the outfall (Rohay and Johnson 1991). Between 1973 and 1976, aqueous waste saturated with carbon tetrachloride was sent to the 242-T Evaporator; during that time, the 216-T-19 Crib received approximately 1,400 kg (880 L) of carbon tetrachloride in the overhead condensate discharged from this evaporator (Rohay et al. 1993).

2.2 CARBON TETRACHLORIDE WELLFIELD

The vadose zone underlying the carbon tetrachloride area consists of approximately 66 m of relatively permeable sand and gravel interrupted by a relatively less permeable interval composed of 4 m of silt and sand and 3 m of carbonate-rich silt and sand. Because it constitutes a relatively low flow zone, this less permeable interval from approximately 38 to 45 m depth effectively divides the wellfield into two zones: an upper zone from the ground surface to the top of the less permeable layer and a lower zone from the bottom of the less permeable layer to the water table. Because of its higher concentration of calcium carbonate, the less permeable Plio-Pleistocene layer is informally referred to as the "caliche layer."

There are currently 46 drilled wells available for on-line extraction (Figure 2-1). Thirteen of these wells were drilled during 1992 and 1993 and completed as vapor extraction wells with stainless steel casing and screens; one well was drilled at a 45° incline. Existing wells, drilled between 1954 and 1978 and completed with carbon steel casing, were adapted for vapor extraction by perforating the well casing using mechanical or jet perforators. Two of these wells were deepened in 2001 and completed with stainless steel screens and casing that extend below the perforated intervals (BHI 2001). Seventeen wells have two screened or perforated open

Background

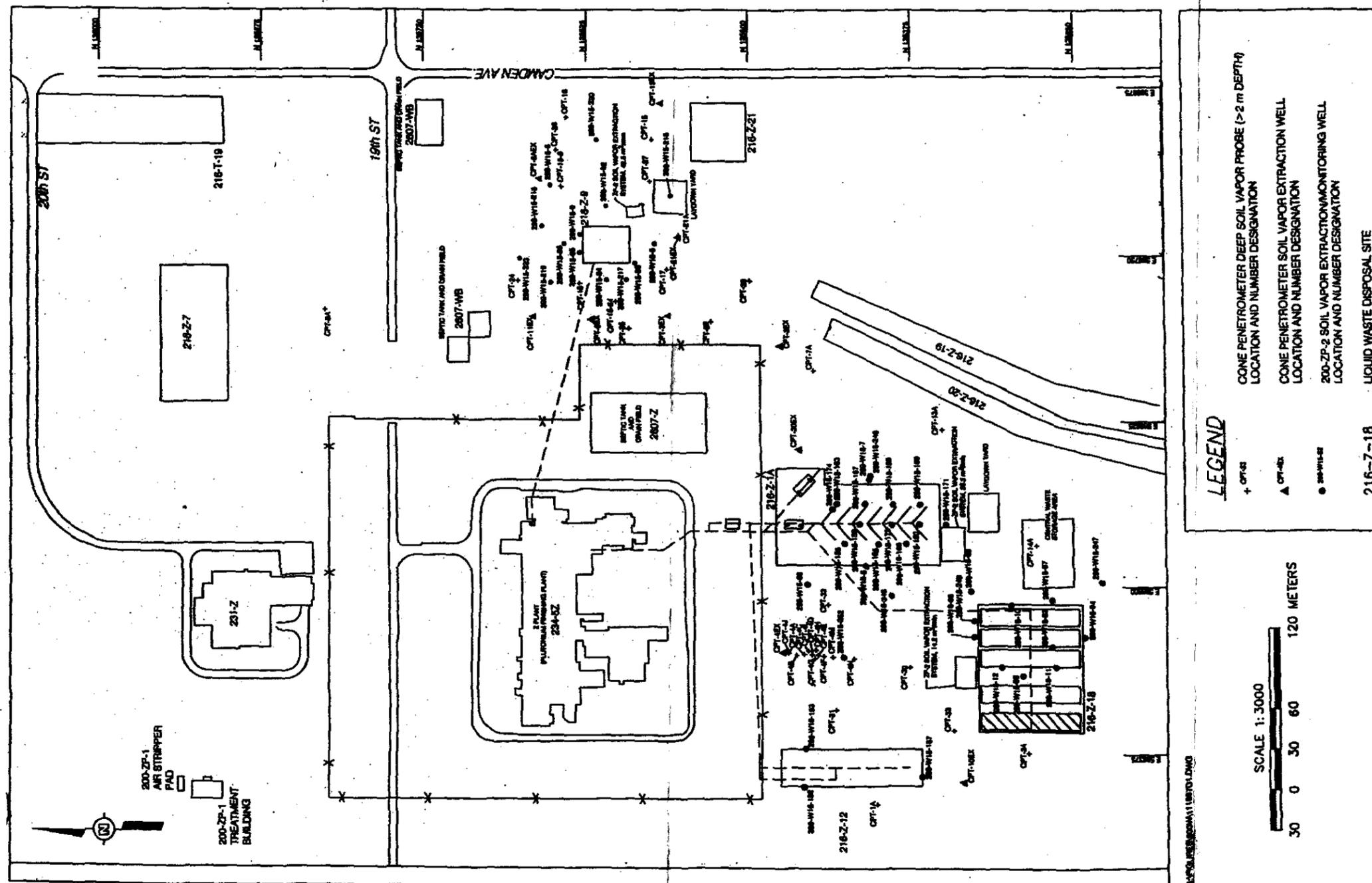
intervals isolated during operations by downhole packers. The two open intervals in the two wells deepened in 2001 are isolated by cement grout placed in the annulus between the two casings. Twenty-one well intervals are available at each of the 2 wellfields, 216-Z-18/Z-12 and 216-Z-1A; 23 well intervals are available at the 216-Z-9 wellfield. Seventeen of these 65 intervals are open below the Plio-Pleistocene layer (6 at 216-Z-18/Z-12, 2 at 216-Z-1A, and 9 at 216-Z-9). Well diameters range from 5 to 20 cm (2 to 8 in.). Each SVE system extracts simultaneously from multiple wells open either above and/or below the Plio-Pleistocene layer. Cross sections through the 216-Z-18/Z-12, 216-Z-1A, and 216-Z-9 wellfields are shown in Figures 2-2a, 2-2b, and 2-2c, respectively.

There are 126 subsurface monitoring probes installed at >2-m depth (Figure 2-1) as follows:

- A cone penetrometer was used in 1993 to install 11 extraction or monitoring wells constructed of 2.54-cm- (1-in.) diameter hollow stainless steel rod. The open interval, located at the bottom of each well, consists of 4 m of rod machined with 33 0.64-cm- (0.25-in.) diameter holes per each 1-m interval. The deepest open interval ends 34 m below ground surface (bgs). One of these wells was decommissioned in April 1997.
- A cone penetrometer was used to install 106 subsurface monitoring probes at 35 locations at the carbon tetrachloride site between 1991 and 1994. Up to five monitoring probes were installed at each location at various depths. Each subsurface monitoring probe consists of a sintered metal monitoring screen (12.7 cm long with an outside diameter of 1.27 cm) attached to a 0.64-cm- (0.25-in.) diameter teflon tube that runs to the surface. The deepest monitoring probe installed at the vapor extraction sites using the cone penetrometer is 36 m bgs.
- Ten stainless steel tubes were strapped to the outside of the casing of four wells during installation in 1993 to enable monitoring above and below the screened intervals.

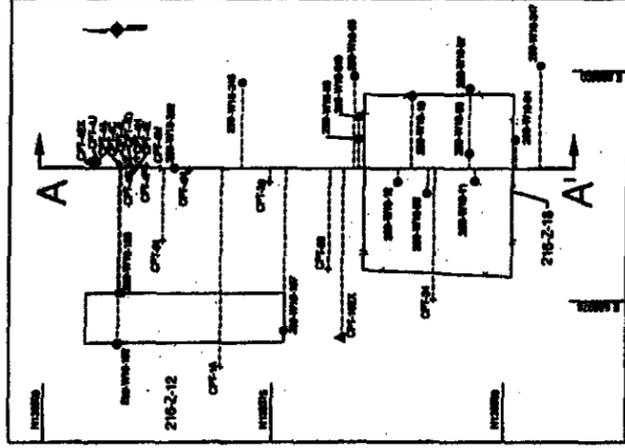
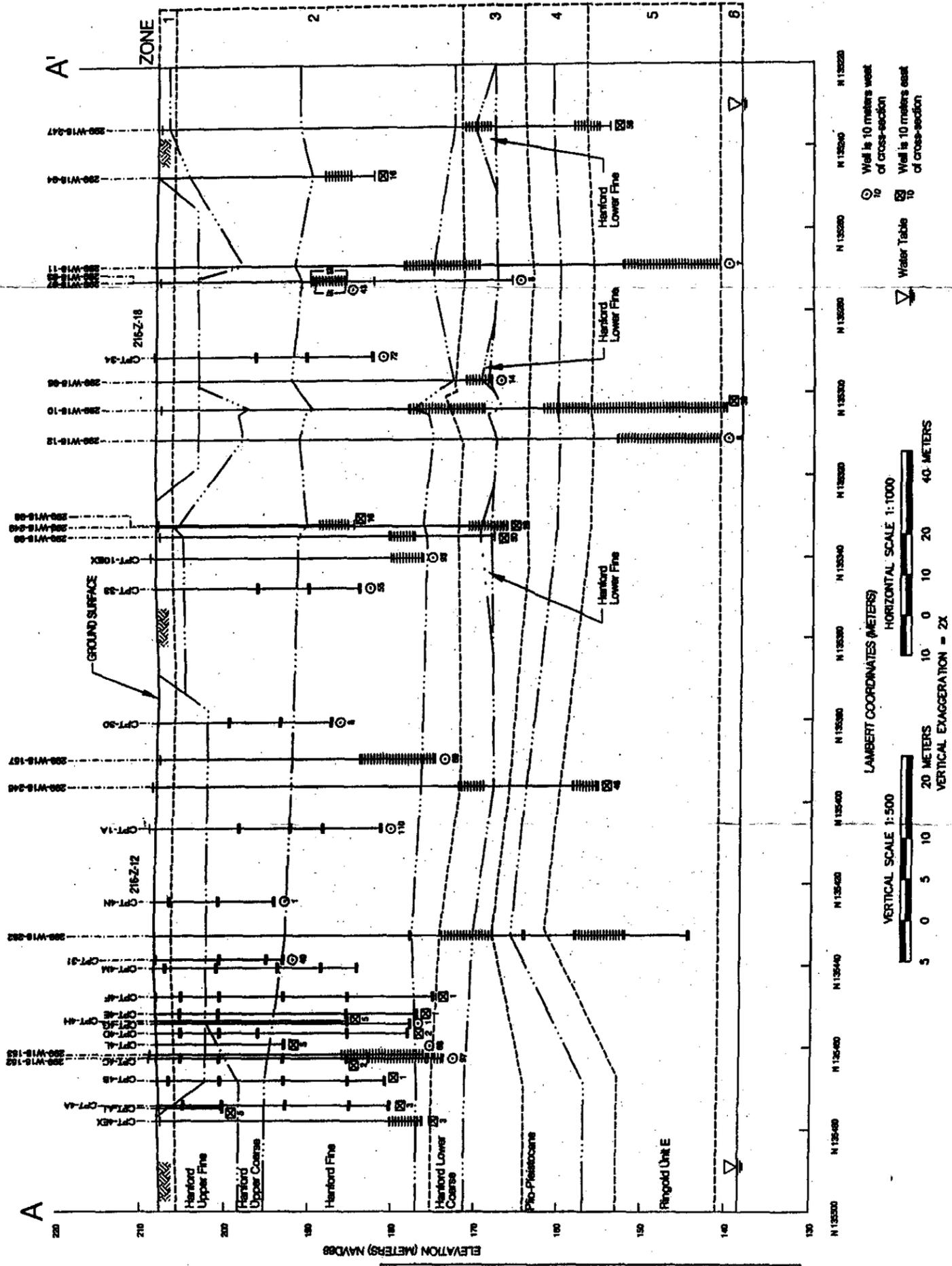
There are up to 87 shallow soil vapor probes at depths ranging from 1.2 to 1.8 m bgs (Figure 2-3). The network was installed between 1991 and 1995. The total number of existing probes is uncertain because some of the probes have since been destroyed, primarily as a result of other near-surface construction activities or prolonged exposure to weather conditions.

Figure 2-1. Location of Extraction and Monitoring Wells and Deep (>2 m) Soil Vapor Probes at the Carbon Tetrachloride Soil Vapor Extraction Sites.



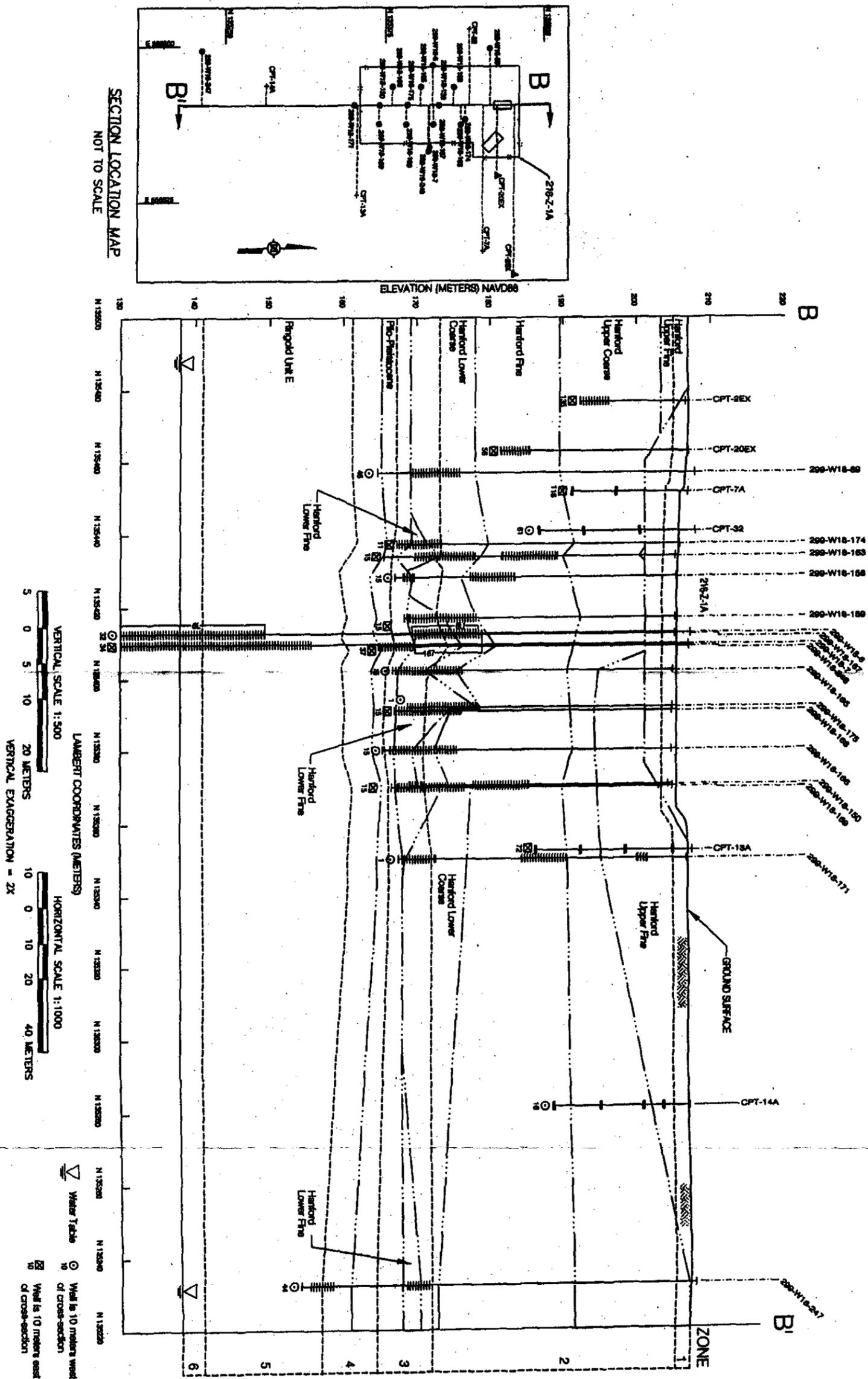
Background

Figure 2-2a. Cross Section Through the 216-Z-18/Z-12 Wellfield.



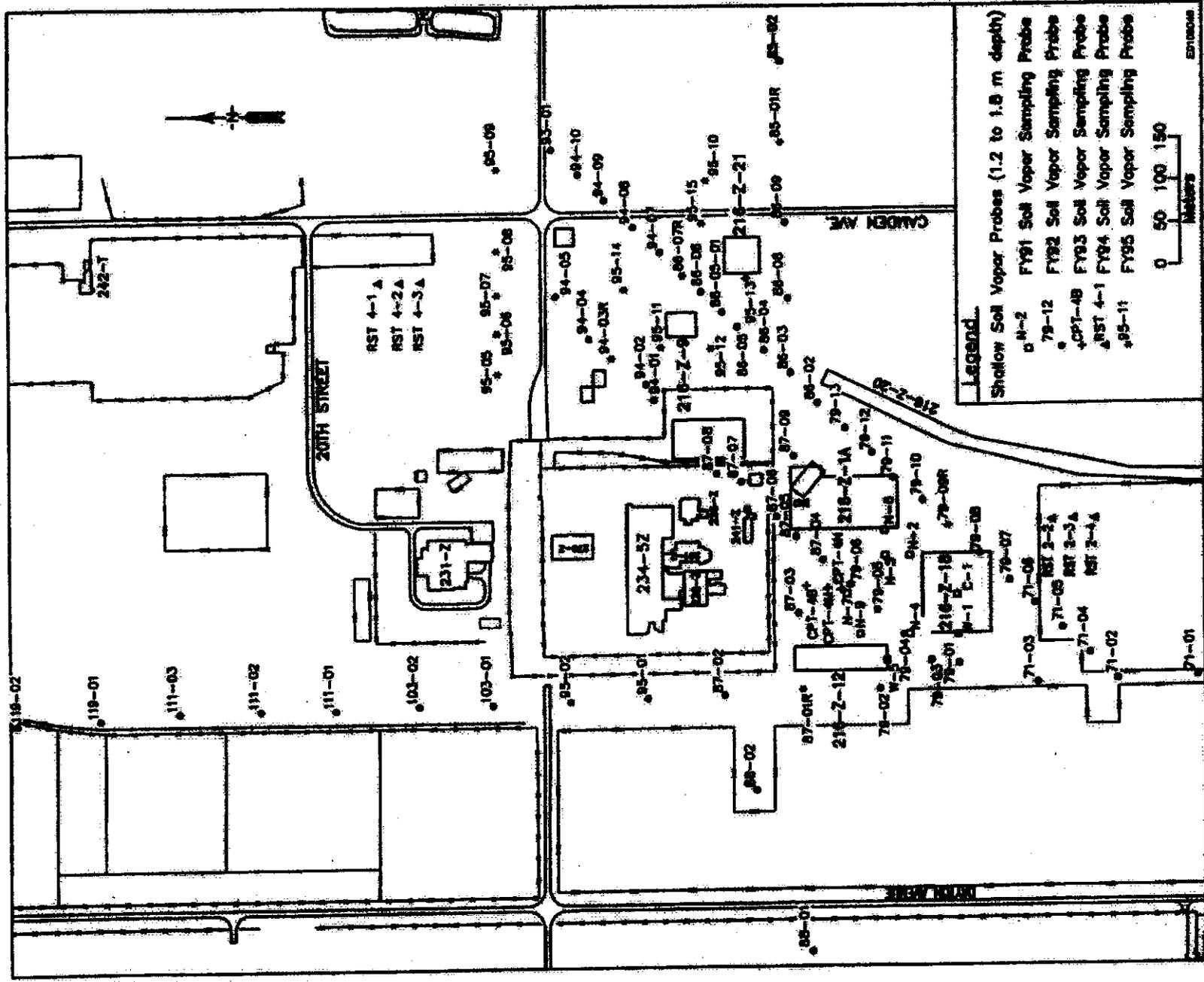
SECTION LOCATION MAP
NOT TO SCALE

Figure 2-2b. Cross Section Through the 216-Z-1A Wellfield.



Background

Figure 2-3. Location of Shallow (1.2 to 1.8 m) Soil Vapor Probes at the Carbon Tetrachloride Site.



**Table 2-1. Contaminant Inventory Discharged to
Carbon Tetrachloride Disposal Sites.**

Site	Carbon Tetrachloride (kg)	Plutonium (kg)	Americium (kg)	Carbon Tetrachloride (L)	Total Liquid (Aqueous and Organic) (L)	Operating Dates
216-Z-9	130,000-480,000	106 ^a	2.5	83,000-300,000	4.09E+06	1955-1962
216-Z-1A	270,000	57	1	170,000	5.20E+06	1964-1969
216-Z-18	170,000	23	0.4	110,000	3.86E+06	1969-1973
Total	570,000-920,000	186	3.9	363,000-580,000	13.15E+06	1955-1973

^a58 kg was later removed.

3.0 SOIL VAPOR EXTRACTION SYSTEM DESIGN

To meet the accelerated ERA startup schedule, constrain costs, and fulfill the requirements for working in a radiologically controlled area, the initial approach to the ERA maximized the use of field screening-level data, existing boreholes, and off-the-shelf technology. During subsequent phases, additional characterization data collected during SVE system operations were used to upgrade the remediation design and performance objectives.

The initial SVE system, purchased for the pilot test, was upgraded to expedite initiation of extraction operations. It consisted of a water knockout tank to remove entrained water droplets that would otherwise damage downstream equipment; a high-efficiency particulate air (HEPA) filter to remove entrained particulate matter, including radionuclides; a blower to extract the soil vapor; GAC-filled canisters in series for adsorbing carbon tetrachloride; and a stack for venting the treated vapor to the atmosphere (Figure 3-1). A chiller to cool the vapor was added later between the blower and the GAC-filled canisters. Two other SVE system units purchased later had a similar design.

The SVE systems were designed for completely automated operations monitoring, requiring only routine checks to ensure that the systems were functioning properly. The pilot-scale SVE test unit was designed with continuous air monitoring instruments for detection of volatile organic compounds (VOCs) and alpha and beta radiation. The output from these instruments, along with other system parameters such as vapor flow rate and system vacuum, was connected to a personal computer-based data logging system. During the test period, however, it was discovered that the instrumentation required almost constant operator attention to maintain extraction operations. VOC sampling was performed using an on-line flame ionization detector that proved unable to specifically target detection of carbon tetrachloride and required frequent calibration and maintenance. Instruments for monitoring alpha and beta radiation and radon gas (added in 1992) were removed in 1994 once baseline operating data were accumulated.

To support an improved design for the first production-mode SVE system, an alternative VOC monitoring instrument was investigated. A new technology was pursued that used a solid-state VOC-sensing device. Testing indicated that the instrument produced both accurate and repeatable measurements of carbon tetrachloride concentrations. During the first year of operations, however, it was discovered that carbon tetrachloride degraded the solid-state sensor, causing unpredictable instrument failures. Following the overheating of a GAC canister in June 1993, revised operating procedures required that concentrations of other, more readily reactive VOCs, such as methyl ethyl ketone, be routinely measured during operations. For these reasons, another VOC monitoring technology using a photoacoustic infrared detector, the Brüel & Kjaer Type 1302 multi-gas monitor (B&K, a trademark of Brüel & Kjaer, DK-2850), was purchased. During its initial use, manual sampling every 2 hours was performed during 8-hr/day operating periods to test the performance of the instrument. The B&K instrument proved to be accurate and reliable, and had the added feature of being able to measure several other targeted VOCs, in addition to being readily adaptable to automated operation. The B&K instrument is currently being used to support 24-hr/day SVE system operations providing

automated sampling and analysis at the SVE system inlet, between GAC canisters, and at the vent stack (Figure 3-2).

Passive SVE uses naturally induced pressure gradients between the subsurface and the surface to drive soil vapor to the surface. The presence of a borehole screened in the vadose zone provides a preferential pathway for flow. In general, falling atmospheric pressure causes subsurface vapor to move to the atmosphere through wells, while rising atmospheric pressure causes atmospheric air to move into the subsurface. At the carbon tetrachloride site, passive SVE systems are installed on selected wells.

The minimum component for a passive SVE system is a well to provide the preferential pathway from the subsurface zone to the surface. On the systems designed for use at the carbon tetrachloride site, additional components include an aboveground canister of GAC to collect the venting carbon tetrachloride; hoses to connect the well to the canister; and a one-way, flow-activated valve that lets soil vapor flow out through the well but prevents atmospheric air from flowing in through the well (Figure 3-3). Each system also has an in-line, replaceable cartridge of GAC for sampling upstream of the canister of GAC. Analysis of the GAC in the cartridge provides a time-integrated estimate of the mass removed while the GAC was in-line. Three of the passive systems are also instrumented to measure and record the flow rate and carbon tetrachloride vapor concentration on an hourly basis; these data can be used to calculate an estimate of the amount of mass removed.

Figure 3-2. Configuration of Instrumentation Monitoring Volatile Organic Compounds at the Soil Vapor Extraction System.

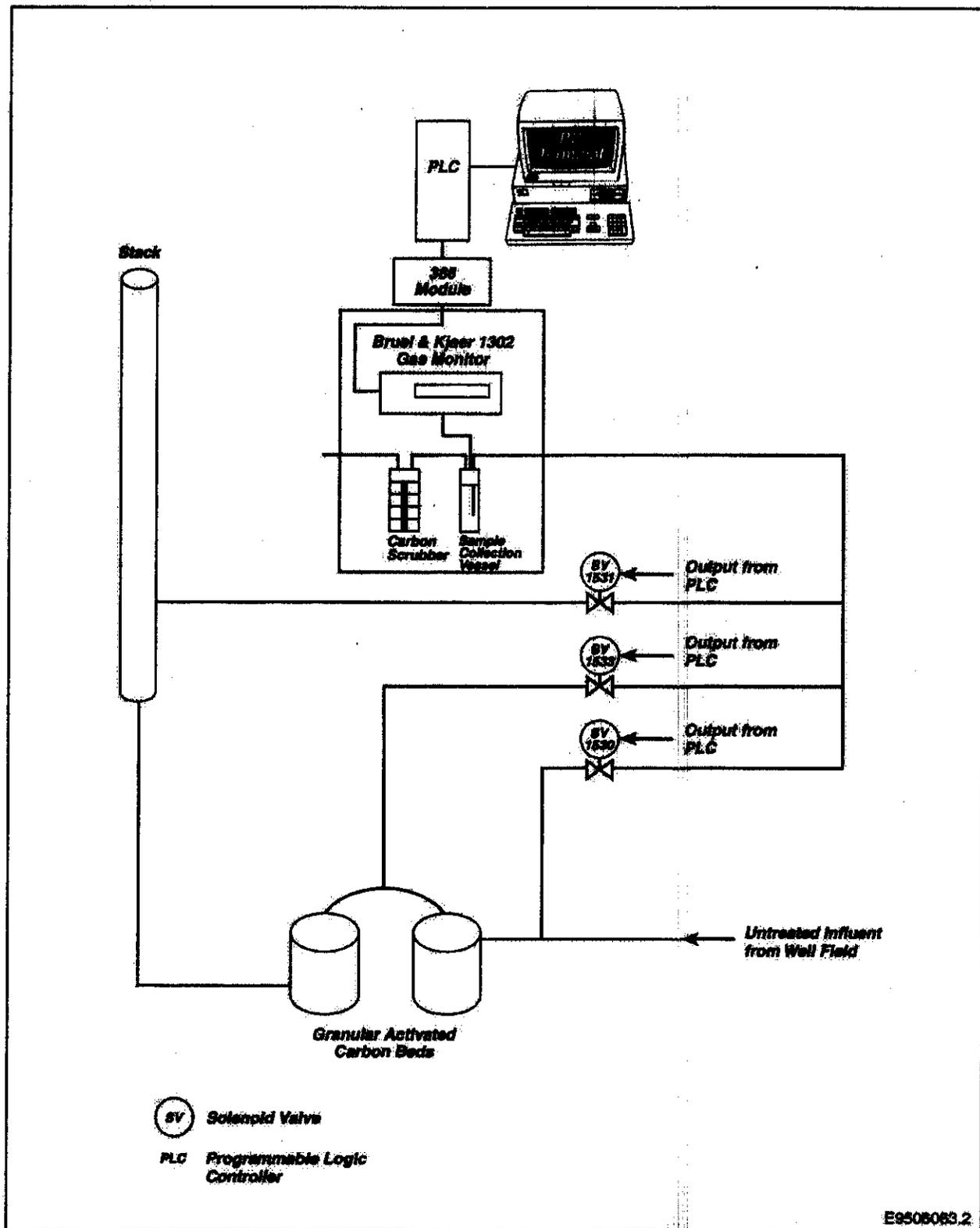
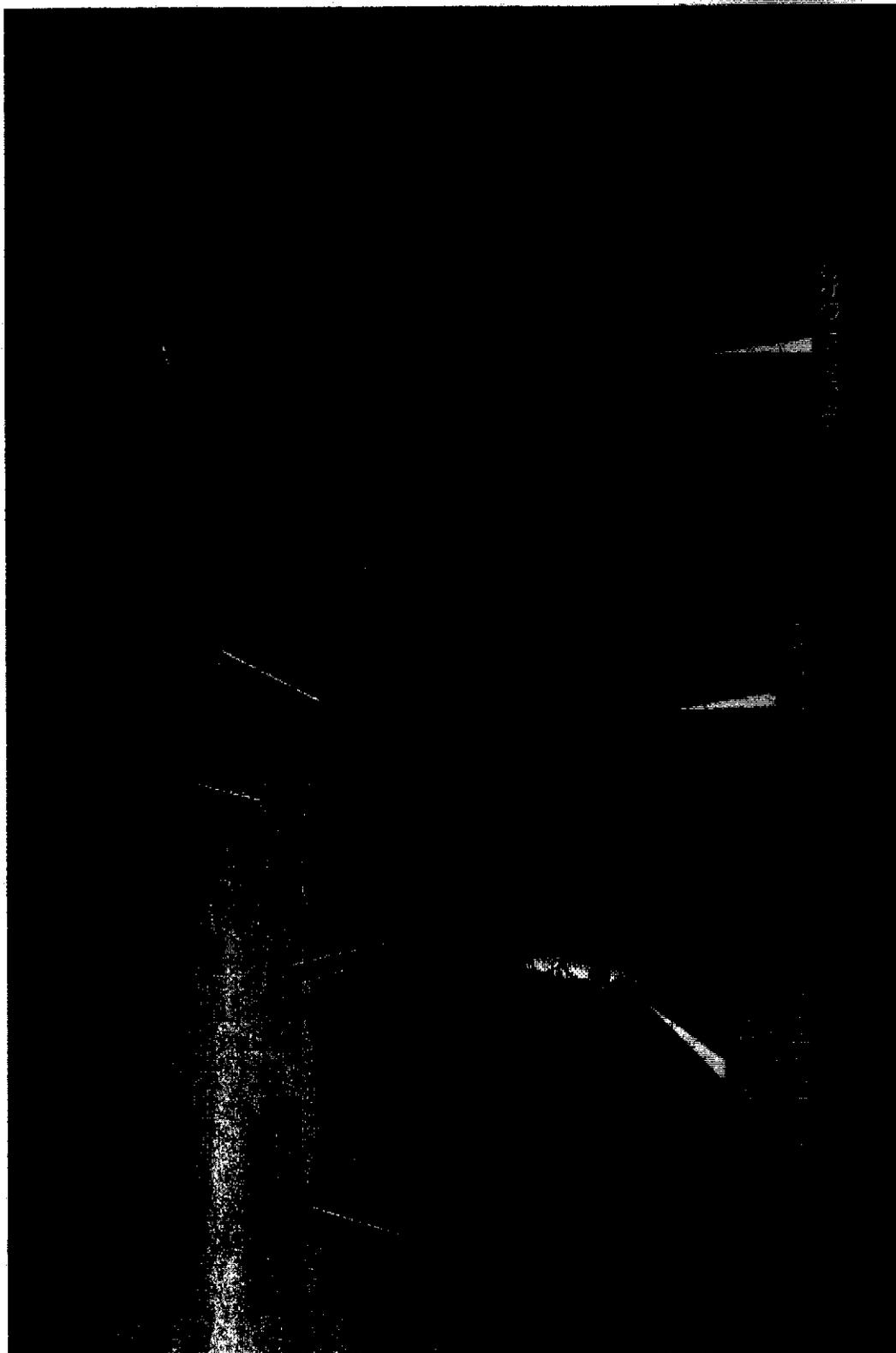


Figure 3-3. Passive Soil Vapor Extraction System.



4.0 HISTORY OF SOIL VAPOR EXTRACTION SYSTEM OPERATIONS

A pilot SVE system was tested at the 216-Z-1A Tile Field in April 1991 (DOE-RL 1991). Based on the results of this testing and as part of the ERA, a full-scale SVE system was installed and began extracting from wells at the tile field on February 25, 1992. Two of the 216-Z-18 Crib wells were added to the same system in May 1992. This system originally had a design capacity of 14.2 m³/min (500 ft³/min), but was upgraded to 28.3 m³/min (1,000 ft³/min) in March 1993. Two additional SVE systems, one with 42.5-m³/min (1,500-ft³/min) capacity and the other with 14.2-m³/min (500-ft³/min) capacity, began operating in March 1993 at the 216-Z-9 Trench. These three areas, the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-18 Crib, were selected for initial SVE operations because they were the primary known disposal sites for carbon tetrachloride.

Extracted carbon tetrachloride is collected on GAC contained in 2.4-m- (8-ft) tall, 1.2-m- (4-ft) diameter carbon steel canisters. Operation of all three systems was temporarily suspended on June 3, 1993, because of a GAC canister overheating incident at 216-Z-9 (Driggers 1994). The 28.3-m³/min system resumed operation at the 216-Z-1A/Z-18 wellfield on November 12, 1993; the 42.5-m³/min system resumed operation at the 216-Z-9 wellfield on February 23, 1994; and the 14.2-m³/min system, which was moved to the 216-Z-18 wellfield, resumed operation on June 30, 1994.

Upon initial startup and restart following the overheating incident, each system was operated during the regular work shift only, Monday through Friday. This schedule was necessary to allow manual sampling of the VOC monitors to ensure compliance with operating limits. With the incorporation of a reliable, automated VOC monitor (the B&K instrument), the SVE systems began continuous operations. The 28.3-m³/min SVE system began operating 24 hr/day, 7 days/week on July 11, 1994; the 14.2-m³/min SVE system began on August 3, 1994; and the 42.5-m³/min SVE system began on October 19, 1994.

On August 15, 1995, SVE operations using the 14.2-m³/min SVE system were expanded to include the 216-Z-12 site. This disposal site was known to have received some carbon tetrachloride, and ERA characterization activities indicated significant concentrations of carbon tetrachloride in the subsurface soil vapor.

A rebound study was conducted throughout the carbon tetrachloride SVE sites from November 1996 through July 1997 (Rohay 1997). The purpose of the study was to determine the increase in carbon tetrachloride vapor concentrations following temporary cessation of operations. Operation of all three SVE systems was temporarily suspended on November 4, 1996 and restarted on July 18, 1997. The results of the 1997 study are summarized in Section 6.1 of this report. All three SVE systems continued to operate until September 30, 1997.

Based on the results of the FY 1997 rebound study and the declining rate of carbon tetrachloride removal during continuous extraction operations (Rohay 1997), the operating strategy was modified. Rather than operating all three SVE systems continuously, only the 14.2-m³/min

History of Soil Vapor Extraction System Operations

system was used for carbon tetrachloride removal during FY 1998, FY 1999, and FY 2001. The 14.2-m³/min system was modified so that it could be moved between the 216-Z-1A/Z-18/Z-12 and 216-Z-9 wellfields. The 28.3- and 42.5-m³/min SVE systems were maintained in standby mode during FY 1998, FY 1999, and FY 2001. All three SVE systems were maintained in standby mode during FY 2000.

The 14.2-m³/min SVE system was operated from March 30 through June 30, 1998 at the combined 216-Z-1A/Z-18/Z-12 wellfield and from July 7 through September 30, 1998 at the 216-Z-9 wellfield. Operation of the system was temporarily suspended during the winter from October 1, 1997 through March 29, 1998.

The 14.2-m³/min SVE system was operated from March 29 through June 28, 1999 at the 216-Z-9 wellfield and from June 30 through September 30, 1999 at the combined 216-Z-1A/Z-18/Z-12 wellfield. Operation of the system was temporarily suspended during the winter from October 1, 1998 through March 28, 1999.

Operation of the 14.2-m³/min SVE system was temporarily suspended in FY 2000 from October 1, 1999 through September 30, 2000 as a result of higher priority remediation activities competing for the limited funding.

The 14.2-m³/min SVE system was operated from April 4 through July 18, 2001 at the combined 216-Z-1A/Z-18/Z-12 wellfield and from July 20 through September 30, 2001 at the 216-Z-9 wellfield. Operation of the system was temporarily suspended during the winter from October 1, 2000 through April 3, 2001.

For the 6 months that the system was not operated in FY 1998, FY 1999, and FY 2001, and the 12 months the system was not operated in FY 2000, the rebound in carbon tetrachloride concentrations was monitored at wells and probes covering both wellfields. For the 3 months that the system was operated at 216-Z-1A/Z-18/Z-12, carbon tetrachloride concentrations were monitored at nonoperational wells and probes primarily at the 216-Z-9 wellfield; and for the 3 months that the system was operated at the 216-Z-9 wellfield, carbon tetrachloride concentrations were monitored at nonoperational wells and probes primarily at the 216-Z-1A/Z-18/Z-12 wellfield. Results of the FY 1998, FY 1999, FY 2000, and FY 2001 rebound measurements are summarized in Sections 6.2, 6.3, 6.4, and 6.5 of this report, respectively.

Between April 1991 (when the pilot test was conducted) and September 2001, 77,154 kg of carbon tetrachloride was removed from the vadose zone using these three SVE systems (Table 4-1). The mass of carbon tetrachloride removed from the 216-Z-1A, 216-Z-18, and 216-Z-12 sites is reported as a combined value because wells from the 216-Z-1A and 216-Z-18 sites were undergoing extraction simultaneously using the 28.3-m³/min SVE system in 1992 and 1993; wells from the 216-Z-18 and 216-Z-12 sites were undergoing extraction simultaneously using the 14.2-m³/min SVE system from 1995 to 1997; and wells from the 216-Z-1A, 216-Z-18, and 216-Z-12 sites have been undergoing extraction simultaneously using the 14.2-m³/min SVE system since 1998. The wellfields at these sites overlap.

History of Soil Vapor Extraction System Operations

Passive SVE systems were installed on eight wells in FY 1999 and operated throughout FY 2000 and FY 2001 to remove carbon tetrachloride from the vadose zone. The eight wells are located in the 216-Z-1A/Z-18 wellfield. Between October 1999 and September 2001, approximately 30 kg of carbon tetrachloride were removed from the vadose zone using passive SVE.

Table 4-1. Mass of Carbon Tetrachloride Removed Using Soil Vapor Extraction.

Site	Carbon Tetrachloride Removed Each Calendar Year (kg)											
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
216-Z-18/Z-12	140	959	2,541	8,757	7,307	2,581	583	258	375	0	335	23,836
216-Z-1A												
216-Z-9	--	--	1,065	35,029	11,500	3,150	1,239	524	436	0	375	53,318
Total	140	959	3,606	43,786	18,807	5,731	1,822	782	811	0	710	77,154

5.0 SOIL VAPOR EXTRACTION SYSTEM OPERATING DATA

Soil vapor extraction system operating data that are routinely recorded include carbon tetrachloride concentrations, applied vacuums, system flow rates, and hours of operation. All instruments (e.g., flowmeters, vacuum gauges, and volatile organic monitors) are calibrated. All calibration data on each instrument are retained and available for review. The VOC monitoring instruments are checked frequently and periodically challenged with calibrated gas standards. The detection limit for carbon tetrachloride is 1 part per million by volume (ppmv).

As part of operations, the SVE system technicians complete daily, weekly, and monthly surveillance checklists on which they verify system startup, shutdown, and compliance monitoring. These records are stored by Document and Information Services and are available for review.

When operations began in 1992, the system data were automatically recorded, first on a datalogger and then using the Strawberry Tree software program (a trademark of Strawberry Tree Incorporated, Computer Instrumentation and Controls, Sunnyvale, California), in binary format. These recording systems sampled the SVE system parameters every 15 minutes without distinguishing between ongoing operations, calibration checks, etc. As a result, these data are essentially raw instrument data and require careful evaluation for validity prior to use for determining SVE system performance. These data were not used in this report.

Field activities, including operation of the SVE systems, are recorded daily by the SVE system technicians in field logbooks. The technicians carefully reviewed the logbooks to reconstruct the operating history for each SVE system, including flow rate, vacuum, carbon tetrachloride concentration, and operating hours. These data were used in preparation of this report, particularly for the 1992-1993 operating period.

As an upgrade to the Strawberry Tree software, a programmable logic controller (PLC) was installed to control the SVE process. The Interact (a registered trademark of Computer Technology Corporation, Milford, Ohio) software was implemented as an operator interface to the PLC. A PLC was incorporated into the 28.3-m³/min SVE system in March 1993 and into the 14.2-m³/min system upon restart in 1994. The 42.5-m³/min system was equipped with an Allen-Bradley (Milwaukee, Wisconsin) PLC and operator interface software when it was purchased. Each PLC records flow and vacuum data every 15 minutes and concentration data every 2 hours; the SVE system technicians use these data to establish daily records of representative system variables. For example, at the 14.2-m³/min system, four data points (6:00 a.m., noon, 6:00 p.m., and midnight) are averaged to establish the loading data for a given day.

Following the GAC overheating incident in 1993, revised operating procedures required a more structured format for recording representative system data. Therefore, beginning in 1994, the representative daily data were recorded on spreadsheets created by the technicians. That same year, a more reliable automated VOC monitor (the B&K instrument) was used at all three SVE systems to collect concentration data. Data for the 14.2- and 28.3-m³/min SVE systems were entered onto spreadsheets manually until December 1995 when the system was automated; data for the 42.5-m³/min system were always recorded automatically. These spreadsheets were the

source of the 1994-1997 data used in this report. Representative daily data provided weekly by the SVE technician were the source of the 1998-2001 data used in this report.

5.1 SOIL VAPOR EXTRACTION SYSTEM AVAILABILITY

The availability of each SVE system is evaluated by comparing the amount of time it was operating to the amount of time it was planned to be operating. This comparison is summarized as "percent availability." Availability data are provided for 1994, 1995, 1996, 1997, 1998, 1999, and 2001.

The amount of time each SVE system was planned to be operating changed as operations became more routine (Table 5-1). In addition, for 16 days during November and December 1994 and 14 days during November and December 1995, the systems were not expected to be operational. Using only the planned operating time to define the maximum possible system availability directly reflects the impacts that GAC changeouts, system malfunctions, and scheduled maintenance have on system operations.

The operating efficiency of all three systems since November 1994, the first full month of 24-hr/day, 7-days/week operations for all three systems, is illustrated in Figure 5-1. Between November 1994 and September 2001, the monthly availability for all three systems averaged 93%. During 1998, 1999, and 2001, the monthly availability for the 14.2-m³/min SVE system averaged 99%, 98%, and 91%, respectively, exceeding the goal of achieving 90% availability.

With the following exceptions, each system was operated at greater than 65% availability, selected as a minimum reference value, during 1994, 1995, 1996, 1997, 1998, 1999, and 2001 (Table 5-2). The 14.2-m³/min SVE system operated at less than 65% availability during July 1994, its initial startup month, and January and February 1995 (Figure 5-2). For 5 weeks during January and February 1995, extraction operations at the 14.2-m³/min SVE system were limited to 9 hr/day, 5 days/week because malfunction of the automated sampling system necessitated manual sampling of VOC concentrations. The 28.3-m³/min SVE system, which was restarted in November 1993, dropped to 65% availability in November 1994, when extraction operations were limited to 9 hr/day, 5 days/week for 1 week because of malfunction of the automated VOC sampling system (Figure 5-3). The 42.5-m³/min SVE system operated at less than 65% availability only during March and April 1994, its initial restart months (Figure 5-4).

In general, operation of the systems is most difficult to maintain during the winter months, as illustrated by comparing the combined monthly availability of the three systems from November 1994 through June 1996 (Figure 5-1). This reflects in part the time needed for draining water from the extraction hoses and water knockout tanks during cold weather. The increased volume of water in the hoses and knockout tanks during the winter months results from condensation of moisture in the extracted soil vapor when it encounters colder temperatures. In addition, when the water in the hoses freezes before it can be drained, operation of the extraction system is limited or impossible, which also contributes to lower availability. These cold weather

Soil Vapor Extraction System Operating Data

operational difficulties were the basis of the decision to temporarily suspend operation of the SVE system during the winter rather than the summer months in 1998, 1999, and 2001.

Significant changes in the rate at which each SVE system was operated are reflected in the changes in slope of the cumulative hours plotted with time (Figure 5-5). For example, the loss of operating time during January and February 1995 at the 14.2-m³/min system is reflected by the decrease in slope; the change from 7-hr/day operations to 24-hr/day operations in October 1994 at the 42.5-m³/min system is reflected by the increase in slope. Between April 1991 (when the pilot test was conducted) and September 2001, the three SVE systems together have operated 72,470 hours: the 14.2-m³/min system has operated a total of 30,799 hours; the 28.3-m³/min system has operated a total of 23,568 hours; and the 42.5-m³/min system has operated a total of 18,103 hours (Table 5-3).

5.2 VOLUME OF SOIL VAPOR PROCESSED

For each SVE system, the volume of soil vapor processed was calculated using the hours the system operated and the measured flow rate of soil vapor exiting the system (FM6, Figure 3-1). The average daily flow rates measured at each system since 24-hr/day operations began are shown in Figures 5-6 through 5-8.

The flow rate measured at the SVE system represents the combined flow from all the on-line wells and may change as the selection of on-line wells changes. For a given applied vacuum, the flow produced from each well is a function of the air permeability of the soil, the open area of the screened or perforated interval, the well diameter, and the radius of influence of the well.

The flow rate at each SVE system may also be adjusted by the SVE system technicians to meet varying conditions and requirements. For example, during the winter months, flow rates were reduced by the technicians to minimize the volume of knockout water generated. Ice blockages within the vapor extraction hoses occasionally also limited the flow to the extraction system. During the warmer months, flow rates are generally established at approximately 90% to 95% of blower capacity (e.g., 14.2 m³/min) to avoid exceeding the operating limits. A well with an open interval in a lower permeability soil layer that produces vapor at a lower flow rate may be placed on line because it has higher contaminant concentrations; typically, the flow rate will increase as extraction continues and airflow pathways are established.

With the exception of the winter months, the flow rate at the 14.2-m³/min SVE system was generally maintained between 11 and 14.2 m³/min between July 1994 and August 1996 (Figure 5-6). The flows were reduced for two separate weeks in April and May 1995 during testing at a single extraction well. Between September 1996 and September 1999, the flow rate was often between 14 and 16 m³/min (Figure 5-6). The flows were lower in August 1997 during testing associated with the rebound study. The initial extraction wells selected for SVE restart operations at the 216-Z-9 site in July 1998, in March 1999, and in July 2001 produced flows that were lower than 14.2 m³/min.

From July 1994 through mid-April 1995, the flow rate at the 28.3-m³/min SVE system varied between 14.2 and 22.7 m³/min (Figure 5-7). In March and April 1995, flow rates were significantly improved by jet perforating 10 of these extraction wells, which previously had been mechanically perforated. Since then, flow rates at the 28.3-m³/min SVE system generally have varied from 22.7 to 28.3 m³/min. The improved flow rates allow the 28.3-m³/min SVE system to operate at lower vacuums, which reduces the heat generated at the blower motor. Prior to jet perforating, the system vacuum had to be reduced during hot weather to avoid overheating the blower motor, which resulted in lower flow rates. The flows were reduced for a week in August 1997 for a low-flow test to estimate the impact of low SVE flow on carbon tetrachloride removal rates.

From mid-February through June 1995, the flow rate at the 42.5-m³/min SVE system tended to be either 36.8 to 39.6 m³/min or 28.3 to 33.9 m³/min (Figure 5-8). During this time, an off-gas treatment system was being tested that frequently temporarily suspended operations. Between July 1995 and January 1996, the flow rate using all three blowers varied from 34 to 42.5 m³/min. From February through August 1996, the system operated on only two blowers at flow rates ranging between 28.3 and 34 m³/min.

Between April 1991 (when the pilot test was conducted) and September 2001, 89 million m³ of soil vapor was extracted and processed using the three SVE systems (Table 5-4a). Of this volume, 40 million m³ was extracted from the 216-Z-9 wellfield and 49 million m³ was extracted from the 216-Z-1A/Z-18/Z-12 wellfield (Table 5-4b). The volume of vapor extracted daily by each system is shown in Figures 5-9 through 5-11.

The flow rates at individual extraction wells were estimated by apportioning the flow rates measured at the SVE systems among the on-line wells (Appendix A). For each well, the system flow rate was multiplied by the ratio of that well's open area to the sum of the open areas for all the wells in operation on that system on that particular day. These daily flow rates and the number of operating hours were then used to estimate the cumulative flow from each extraction well. At the 216-Z-9 wellfield, an estimated 27 million m³ of soil vapor was extracted from wells open above the Plio-Pleistocene layer and 13 million m³ was extracted from wells open below the Plio-Pleistocene layer (Table 5-5). For the 216-Z-1A/Z-18/Z-12 wellfield, an estimated 30 million m³ of soil vapor was extracted from wells open above the Plio-Pleistocene layer, and 19 million m³ was extracted from wells open below the Plio-Pleistocene layer.

Based on an average areal zone of influence of 55,000 m² above the Plio-Pleistocene layer in the 216-Z-9 area, an average Hanford formation thickness of 38 m, an average porosity of 20%, and assuming a uniform distribution of flow, 65 pore volumes of soil vapor have been extracted by the 42.5- and 14.2-m³/min SVE systems above the Plio-Pleistocene layer. Similarly, for the 216-Z-1A/Z-18/Z-12 area, based on an average areal zone of influence of 155,000 m², 25 pore volumes of soil vapor have been extracted by the 28.3- and 14.2-m³/min SVE systems above the Plio-Pleistocene layer.

Based on an average areal zone of influence of 40,000 m² below the Plio-Pleistocene layer in the 216-Z-9 area, an average Ringold Unit E thickness of 21 m in the unsaturated zone, an average

porosity of 20%, and assuming a uniform distribution of flow, 75 pore volumes of soil vapor have been extracted by the 42.5- and 14.2-m³/min SVE systems below the Plio-Pleistocene layer. Similarly, for the 216-Z-1A/Z-18/Z-12 area, based on an average areal zone of influence of 100,000 m², 45 pore volumes of soil vapor have been extracted by the 28.3- and 14.2-m³/min SVE systems below the Plio-Pleistocene layer.

The areal zones of influence at the 216-Z-9 and 216-Z-1A/Z-18/Z-12 wellfields were estimated using numerical airflow modeling (Rohay and McMahon 1996). Two sets of wellfield flow and monitoring data were used to calibrate the model; each set produced a different estimate of the zones of influence above and below the Plio-Pleistocene layer. In this report, the results were averaged to estimate the pore volumes of soil vapor that have been extracted since 1992.

Approximately 1,128,000 kg of water was removed from the subsurface in the 88,510,000 m³ of soil vapor extracted between February 1992 and September 2001. An equal volume of ambient air drawn into the subsurface added 532,000 kg of water over the same time period. These estimates were made by updating the calculations provided by Cameron (1997) for the period February 1992 through June 1996. The calculations are based on an average temperature of 15 °C and a relative humidity of 100% for the extracted soil vapor and an average temperature of 12 °C and a relative humidity of 59% for the ambient air. When the additional water added to the subsurface through natural recharge is factored into the water balance, the impact of SVE on soil moisture content in the vadose zone becomes negligible (Cameron 1997). However, as Cameron (1997) points out, the higher flow zones may have been more dried out than the average subsurface volume.

5.3 VOLUME OF KNOCKOUT WATER DRAINED FROM SVE SYSTEMS

Water condensate was first noticed in the water knockout tank on the 28.3-m³/min SVE system on October 20, 1992. Between October 20, 1992 and February 9, 1994, approximately 1,022 L of knockout water was collected from the 28.3-m³/min SVE system from operations at the 216-Z-1A and 216-Z-18 sites (Table 5-6). This water was sent to the purgewater storage facility using purgewater trucks. After February 9, 1994 (approximately March 1), the carbon tetrachloride was designated as a listed waste, and shipments of the condensate as purgewater ceased.

Since February 9, 1994, SVE knockout water has been transferred to the 200-ZP-1 pump-and-treat operation for treatment. The first transfer, in January 1995, consisted of 92 drums of condensate water stored in 208-L (55-gal) drums with 90-mil liners. The SVE technicians recall that these drums were nearly full. Assuming that each drum held 170 L (45 gal) of water, this transfer represents an additional 15,700 L of knockout water. Approximately 3,500 L of this water is assumed to have been collected during the 1993-1994 winter after February 9, 1994 (15,700 L minus the October-December 1994 volumes listed in Table 5-6).

Between October 1994 and April 1995, 27,290 L of water was drained from the SVE systems (Table 5-6). Significant amounts of water did not accumulate after April 1995 during the

Soil Vapor Extraction System Operating Data

1994-1995 winter season (Figure 5-12). Between October 1995 and June 1996, 66,741 L of water was drained from the SVE systems. Although most of the water had accumulated by the end of April 1996, additional water was drained as late as June (Figure 5-12). During October 1996, 5,564 L of water was drained from the SVE systems. Operation of the systems was temporarily suspended for the rest of the 1996-1997 winter on November 4, 1996; the rebound study was conducted during this planned temporary shutdown. In April 1998, approximately 189 L of water was drained from the SVE hoses when SVE operations resumed after the 1997-1998 winter. In April 1999, approximately 379 L of water was drained from the SVE hoses when SVE operations resumed after the 1998-1999 winter. In April 2001, approximately 757 L of water was drained from the SVE hoses when SVE operations resumed after FY 2000 and the 2000-2001 winter.

More than twice as much water was drained from the SVE systems during the 1995-1996 winter season as during the 1994-1995 winter season. This increase is partly a result of the increased volume of vapor extracted during 1995-1996. During the 6 months of the 1994-1995 winter (October 20, 1994-April 19, 1995), 10 million m³ of vapor was extracted, producing 26,000 L of water. During the same 6 months of the 1995-1996 winter (October 19, 1995-April 17, 1996), 15 million m³ of vapor was extracted, producing 62,000 L of water.

The cumulative liters of water drained per million cubic meters of vapor extracted are compared for the three SVE systems during the 1994-1995, 1995-1996, and 1996-1997 seasons in Figure 5-13. During 1994-1995, the 28.3-m³/min SVE system produced a significantly higher volume of water per million cubic meters of vapor extracted than either the 14.2- or 42.5-m³/min systems (Figure 5-13). Between October 20, 1994 and April 26, 1995, the 28.3-m³/min SVE system produced an average of 3,600 L of water per million cubic meters of vapor extracted. During this same period, the 14.2-m³/min SVE system produced an average of 2,300 L of water per million cubic meters of vapor, and the 42.5-m³/min SVE system produced an average of 2,200 L of water per million cubic meters of vapor. The maximum water production rate was also higher for the 28.3-m³/min SVE system (5,400 L of water per million cubic meters of vapor) than for the 14.2- and 42.5-m³/min systems (2,800 and 3,300 L of water per million cubic meters of vapor, respectively). Unlike the water knockout tanks on the 14.2- and 42.5-m³/min systems, one of the two water knockout tanks on the 28.3-m³/min system was not insulated during this time. The cooler temperature of the knockout tank on the 28.3-m³/min SVE system is the most likely explanation for its higher water accumulation rate.

During 1995-1996, however, the 14.2-m³/min SVE system produced a slightly higher volume of water per million cubic meters of vapor extracted than the other two SVE systems. Between October 19, 1995 and April 17, 1996, the 14.2-m³/min SVE system produced an average of 5,100 L of water per million cubic meters of vapor extracted. During this same period, the 28.3-m³/min SVE system produced an average of 4,500 L of water per million cubic meters of vapor, and the 42.5-m³/min SVE system produced an average of 3,500 L of water per million cubic meters of vapor. The maximum water production rate was also higher for the 14.2-m³/min system (6,200 L of water per million cubic meters vapor) than for the 28.3- and 42.5-m³/min systems (4,700 and 4,100 L of water per million cubic meters of vapor, respectively). Use of the 14.2-m³/min SVE system to extract from the 216-Z-12 Crib beginning in August 1995 added a

long hose run to the system, which may be responsible for the increased water production from September 1995 through January 1996 by allowing more cooling to take place. Decreased flow rates at the 14.2-m³/min SVE system during the 1995-1996 winter (Figure 5-6) also lengthened the travel time through the extraction hoses, potentially increasing the volume of water generated for a given volume of vapor extracted. The second water knockout tank on the 28.3-m³/min SVE system was insulated in October 1995.

Other factors that may have caused increased water production in 1995-1996 include differences in the mix of on-line wells and the depths of their open intervals, differences in the daily temperature fluctuations, and/or changes in the method of measuring the volumes.

The water production rates for the three SVE systems appear to be similar during October 1996. However, the data are insufficient to allow detailed evaluation.

Eight composite samples from the 60 drums of knockout water present in November 1994 were analyzed for radionuclide activity prior to being released for processing in the 200-ZP-1 treatment system. The samples were below minimum detectable activity for both alpha and beta-gamma contamination. These data, plus analyses of a sample collected June 30, 1994 and a sample collected February 22, 1993, indicate that there is no activity above natural background in the SVE condensate water.

Four samples of SVE knockout water have been analyzed for VOCs. On June 30, 1994, a composite condensate water sample was collected and analyzed by an offsite laboratory; the volatile organic analyses followed the EPA protocol except that the sample was not preserved. A sample collected on January 26, 1995 was analyzed the following day on site. The sample was not preserved, did not maintain zero headspace, and was not stored on ice.

Two samples were collected on December 12, 1995 and analyzed using the 200-ZP-1 pump-and-treat process equipment. Analytical results for carbon tetrachloride, chloroform, tetrachloroethylene, and trichloroethylene are summarized in Table 5-7.

The mass of carbon tetrachloride removed in the SVE knockout water is estimated as 1 to 40 g, based on the total volume of water, 104,677 L (Table 5-6), and the range of carbon tetrachloride concentrations, 10 µg/L to 380 µg/L (Table 5-7).

5.4 CHANGE IN CARBON TETRACHLORIDE CONCENTRATIONS

Carbon tetrachloride concentrations in the extracted soil vapor have decreased significantly at both the 216-Z-1A/Z-18/Z-12 and 216-Z-9 wellfields during operation of the SVE systems. This is typical of SVE operations and represents removal of the volatile contaminant readily available in the pore spaces swept out by extracted vapor. Extracted contaminant concentrations approach an asymptotic level as the supply of volatile contaminant to the high-flow zone becomes limited by desorption and diffusion of the contaminant from the sediment particles and soil moisture. Diffusion also controls contaminant migration from the pore spaces between sediment particles in the lower permeability, lower flow zones to pore spaces in the higher permeability, higher flow zones.

Measurements made at the inlet to the extraction system represent the combined soil vapor concentrations from all on-line wells connected to the system.

Carbon tetrachloride concentrations in soil vapor extracted from the 216-Z-1A/Z-18/Z-12 wellfield using the 28.3- and 14.2-m³/min SVE systems have declined from approximately 1,500 ppmv at startup in 1992 to 25 ppmv in September 2001 (Figure 5-14). The increase in August 1995 was caused by addition of an extraction well in the 216-Z-12 wellfield.

The most dramatic decline in carbon tetrachloride concentrations has been at the 216-Z-9 wellfield using the 42.5- and 14.2-m³/min SVE systems. Carbon tetrachloride concentrations in extracted soil vapor have declined from approximately 30,000 ppmv at startup in 1993 to 40 ppmv in September 2001 (Figures 5-15 and 5-16).

The trend of the 1992 to 2001 concentration data is compared to the volume of soil vapor extracted in Figures 5-14 and 5-15. As expected, concentrations decrease with increasing volume of soil vapor extracted. The data also indicate that concentrations rebound during periods of nonoperation as a result of carbon tetrachloride accumulating in the pore spaces after apparently diffusing from sediment micropores, soil moisture, residual dense nonaqueous-phase liquid (DNAPL), and/or low-permeability zones. When SVE operations resume, the initial extracted contaminant concentrations are higher. This concentration rebound can be seen at both wellfields in July 1997 following the 8-month temporary shutdown for the rebound study and in 1998, 1999, and 2001 following the temporary shutdowns during those years (Figures 5-14 and 5-15). The increase in concentrations can also be detected for shorter duration shutdowns. For example, during 12 days in December 1994 and 10 days in December 1995, the systems did not operate, and when operations resumed the following January, concentrations were slightly higher (e.g., Figure 5-15). This shorter duration rebound phenomenon is more apparent in Figure 5-16, which shows the carbon tetrachloride concentration data for the 216-Z-9 site since 24-hr/day operations began in October 1994. The rebound was apparently faster and of greater magnitude in January 1995 when concentrations were still relatively high, indicating a more accessible and extensive contaminant source.

Soil Vapor Extraction System Operating Data

5.4.1 Fiscal Years 1997 and 1998

In FY 1997, operation of all three SVE systems was temporarily suspended from November 1996 through July 1997 for the rebound study. All of the 216-Z-9 and 216-Z-1A wells were placed on line on July 18, 1997. Extraction using all three systems continued through September 30, 1997 (Rohay 1997).

In FY 1998, SVE resumed on March 30, 1998 at the 216-Z-1A/Z-18/Z-12 wellfield using the 14.2-m³/min SVE system, which was on the northern side of the 216-Z-18 Crib (Figure 5-17). Fifteen extraction wells distributed throughout the wellfield were selected to optimize both protection of groundwater and mass removal of contaminant. Initial characterization of the 15 on-line wells indicated that the system was extracting soil vapor effectively from only the closest wells and that the applied vacuum at the distant wells was insufficient to produce flow. Tests showed that the SVE system could, however, extract soil vapor effectively from isolated, distant wells. Therefore, the mix of on-line extraction wells was periodically switched among one set of seven relatively nearby wells and various sets of four relatively distant wells (Figure 5-17). Each set included wells open near the groundwater and wells open near the lower permeability Plio-Pleistocene unit. As a result, the SVE system was extracting from wells primarily associated with the 216-Z-18 site for the first 7 weeks (March 30 through May 17) and from wells primarily associated with the 216-Z-1A site for the following 6 weeks (May 18 through June 30). Comparison of the changes in inlet concentrations to the changes in the sets of on-line wells indicated that the higher concentrations observed from May 18 through June 30 tended to be associated with the 216-Z-1A wells (Figure 5-17).

Soil vapor extraction resumed July 7, 1998 at the 216-Z-9 wellfield using the 14.2-m³/min SVE system. Initial on-line wells were selected close to the 216-Z-9 Trench (Figure 5-18). As extraction continued, wells farther away from the crib were brought on line. Each selection of on-line wells included wells open near the groundwater and wells open near the lower permeability Plio-Pleistocene unit.

The daily mass removal rate from the 216-Z-9 wellfield increased significantly twice during the 3 months of extraction as a result of changes in extraction wells (Figure 5-19):

- Two additional wells were brought on line on July 29, 1998. (A third additional well added on July 29 was removed on July 31.) The mass removal rate increased, despite a continued decline in concentrations, because the flow rate increased (flow rate is shown in Figure 5-6).
- The mix of on-line wells was changed again on September 1, 1998. The mass removal rate increased, despite a constant flow rate, because the inlet concentrations increased.

5.4.2 Fiscal Year 1999

In FY 1999, SVE resumed on March 29, 1999 at the 216-Z-9 wellfield using the 14.2-m³/min SVE system. Following an extraction strategy similar to that used in FY 1998, initial on-line wells were selected close to the 216-Z-9 Trench and wells farther away from the trench were

Soil Vapor Extraction System Operating Data

brought on line as extraction continued (Figure 5-20). Each selection of on-line wells included wells open near the groundwater and wells open near the lower permeability Plio-Pleistocene unit.

On April 20, 1999, the B&K multi-gas monitor used to analyze carbon tetrachloride concentrations in the SVE inlet vapor was discovered to be out of calibration and was replaced. All of the SVE inlet concentrations recorded between March 29 and April 20 were multiplied by a factor of 1.5 as a correction. This factor was selected so that the original concentration recorded on April 20, 2000 (35 ppmv) would match the concentration recorded with the replacement B&K on April 21, 2000 (52 ppmv). (Note: This correction was applied to the data only to illustrate concentration trends. The original data were used to calculate the mass removed.)

Soil vapor extraction resumed on June 30, 1999 at the 216-Z-1A/Z-18/Z-12 wellfield. Extraction wells open near the Plio-Pleistocene unit, primarily within the 216-Z-1A Tile Field, were selected to optimize mass removal of contaminant (Figure 5-21). Because passive SVE systems were being installed on the wells open near the groundwater in the 216-Z-1A/Z-18 wellfield, these wells were not selected for active SVE using the 14.2-m³/min SVE system in FY 1999.

The daily mass-removal rate increased significantly twice during the 3 months of extraction at each wellfield as a result of adjustments in the mix of on-line wells and the flow rate (Figure 5-22).

5.4.3 Fiscal Years 2000 and 2001

In FY 2000, operation of all three SVE systems was temporarily suspended from October 1999 through September 2000.

In FY 2001, SVE resumed on April 4, 2001 at the 216-Z-1A/Z-18/Z-12 wellfield using the 14.2-m³/min SVE system. Following an extraction strategy similar to that used in FY 1999, extraction wells open near the Plio-Pleistocene unit, primarily within the 216-Z-1A Tile Field, were selected to optimize mass removal (Figure 5-23). Although passive SVE systems were installed on wells open near the groundwater in the 216-Z-1A/Z-18 wellfield, two of these wells were selected for active SVE using the 14.2-m³/min SVE system in FY 2001.

Before full-scale operations were initiated at the 216-Z-9 wellfield in July 2001, tests were conducted to characterize the initial carbon tetrachloride concentrations at the new extraction intervals completed in each of the two wells deepened in 2001 (BHI 2001). During each test, only the one test well was placed on line to the SVE system. Extracted soil vapor was monitored 5 minutes after SVE start to obtain a representative sample of the concentration adjacent to the well. Soil vapor was then monitored hourly for 2 to 3 hours to determine the carbon tetrachloride concentration at progressive distances from the well.

Well 299-W15-95L was tested on July 20, 2001. Carbon tetrachloride concentrations in extracted soil vapor increased from 34.7 ppmv to 62.4 ppmv during the 3-hour test (Figure 5-24).

Soil Vapor Extraction System Operating Data

This well is screened from 39.3 to 48.5 m bgs. Carbon tetrachloride vapor concentrations observed during drilling near this interval in May 2001 ranged from 174 ppmv at 37.2 m bgs (base of Plio-Pleistocene) to 46.1 ppmv at 44.7 m to <1 at 50.1 m (Figure 5-25a).

Well 299-W15-84L was tested on July 23, 2001. Carbon tetrachloride concentrations in extracted soil vapor increased from 27.3 ppmv to 29.1 ppmv during the 2-hour test (Figure 5-24). This well is screened from 50.5 to 59.7 m bgs. Carbon tetrachloride vapor concentrations observed during drilling near this interval in June 2001 ranged from 34.9 ppmv at 51.8 m to 37.7 ppmv at 55.1 m to 1.5 ppmv at 58.8 m (Figure 5-25b).

Full-scale SVE operations resumed at the 216-Z-9 wellfield on July 23, 2001. Following an extraction strategy similar to that used in FY 1998 and FY 1999, initial on-line wells were selected close to the 216-Z-9 Trench and wells farther away from the trench were brought on line as extraction continued (Figure 5-26). Each selection of on-line wells included wells open near the groundwater and wells open near the lower permeability Plio-Pleistocene unit.

The daily mass removal rate changed during the 3 months of extraction at each wellfield as a result of adjustments in the mix of on-line wells and the flow rate (Figure 5-27).

5.4.4 Rebound Following Nonoperation of Soil Vapor Extraction Systems

Carbon tetrachloride concentrations measured in extracted soil vapor at the 216-Z-9 site following the 8-month shutdown in 1997 were lower than concentrations measured following the 9-month shutdown in 1998 (Figure 5-28). The slightly longer time for rebound in 1998 would typically produce higher initial concentrations. However, the 1998 concentrations are higher than the 1997 concentrations throughout most of the 3-month extraction period. This concentration difference most likely reflects the mix of on-line wells: in 1997, all wells were placed on line as part of the rebound test, whereas in 1998 only the higher concentration wells were selected to optimize mass removal. In addition, the lower flow 14.2-m³/min SVE system used in 1998 might have resulted in less dilution of the soil vapor.

The higher concentration wells were also selected in 1999 and 2001 to optimize mass removal. Although the initial 1998 concentrations following 9 months of rebound were higher than the initial 1999 concentrations following 6 months of rebound, the 1998 and 1999 concentrations were the same after the first 4 to 5 weeks of extraction (Figure 5-28). The initial 2001 concentrations following 24 months of rebound were nearly twice as high as the initial 1998 concentrations, but were the same as the 1998 concentrations after 8 weeks of extraction (Figure 5-28).

In all 4 years, the initial rebound concentrations were three to six times higher than concentrations after 3 months of extraction. The relative rates of concentration decrease in 1998, 1999, and 2001 were similar to that observed during the 1997 rebound study: carbon tetrachloride concentrations decreased most rapidly in the first 5 weeks following SVE restart, after which they continued decreasing more slowly with continued SVE operations (Rohay 1997).

Soil Vapor Extraction System Operating Data

Initial carbon tetrachloride concentrations measured in extracted soil vapor at the 216-Z-18 site following the 8-month shutdown in 1997 were higher than initial concentrations measured following the 6-month shutdown in 1998 (Figure 5-29). This may reflect the longer period for rebound in 1997. After 1 week of extraction, the 1998 concentrations were equal to the 1997 concentrations. (After approximately 25 days of operations in 1997, selected 216-Z-18 wells were taken off line to support additional rebound study testing, and the concentrations in soil vapor extracted from the remaining on-line wells decreased significantly.)

Initial carbon tetrachloride concentrations measured in extracted soil vapor at the 216-Z-1A site following the 8-month shutdown in 1997 were slightly lower than the initial concentrations measured following the 12-month shutdown in 1999 and the 18-month shutdown in 2001. (Figure 5-30). This may reflect the longer time for rebound in 1999 and 2001 and/or the preferential selection of high-concentration 216-Z-1A wells in 1999 and 2001 to optimize removal. Concentrations decreased more rapidly in 1997 than in 1999 and 2001, probably because in 1997 all 216-Z-1A wells were placed on line as part of the rebound test. Despite the longer period of rebound, the initial concentrations in 2001 were slightly lower than the initial concentrations in 1999, possibly reflecting an overall decline in concentrations with continued remediation.

In 1998, extraction was primarily from the 216-Z-1A wellfield during the last 6 weeks of SVE operations, but limited extraction from 216-Z-1A also occurred during the preceding 7 weeks of operations when extraction was primarily from the 216-Z-18 wellfield. In Figure 5-30, the 1998 concentrations extracted from the 216-Z-1A site are shown as beginning on day 50 of SVE operations rather than on day 1 to indicate that limited extraction from 216-Z-1A had already occurred. The concentrations during the last 6 weeks of SVE operations in 1998 are similar to the concentrations during the last 6 weeks of operations during 1999 and 2001. During 1998, 1999, and 2001, higher concentration wells were selected to optimize removal.

5.4.5 Estimate of Future Concentration Decline

As an initial approach to estimating the future decline in carbon tetrachloride inlet concentrations, exponential curves were used to model the carbon tetrachloride concentration data measured at each SVE system from October 1995 through November 1996 (Figure 5-31). October 1995 was selected as the beginning of the interval because it occurs after the decline of the last major increase in inlet concentrations (the August 1995 concentration spike at the 14.2-m³/min SVE system caused by addition of the 216-Z-12 wellfield, Figure 5-14). The interval of October 1995 through November 1996 thus represents the last continuous operating run that illustrates the decline in SVE inlet concentrations simultaneously at all three systems. In addition, for the purpose of predicting future concentrations, the emphasis was placed on the concentration data more representative of the later, tailing phase of operations rather than of the initial, rapid removal phase. Two or more different equations may be needed to describe the entire curve of concentration decline if two or more different carbon tetrachloride removal mechanisms were operating over the life of the SVE remediation.

Soil Vapor Extraction System Operating Data

The exponential decay curves, fitted to the data through November 1996, were projected to March 1999 in order to evaluate their relationship to the concentration data following the 1997 rebound study and the 1998 winter shutdown (Figure 5-32). The equation values as of November 4, 1996 were held constant until July 18, 1997 and then allowed to resume the exponential decline until September 30, 1997. The equation values as of September 30, 1997 were held constant until March 30, 1998 for the 216-Z-1A and Z-18 wellfields and until July 7, 1998 for the 216-Z-9 wellfield and then allowed to resume the exponential decline. Relative to the exponential decay curves, both the 1997 and 1998 rebound data are initially elevated, as expected. The carbon tetrachloride concentrations decline to concentrations that approach the exponential decay curves in September 1997 but do not appear to approach the exponential decay curves in 1998. In 1997, all the available wells were on line continuously; in 1998, the mix of on-line wells was periodically changed to optimize mass removal.

This preliminary evaluation suggests that these decay curves can be used to provide a reasonable estimate of future concentration decline only under similar operating conditions and similar carbon tetrachloride removal mechanisms. For example, the physical and chemical processes that control carbon tetrachloride removal in the near term may be different than those that determine the removal rate in the long term.

5.4.6 Concentration Data for Individual Extraction Wells

The characterization data routinely measured for individual extraction wells include vacuum, flow, and carbon tetrachloride concentration (Tables B-1 through B-3, Appendix B). To monitor concentrations at individual extraction wells, a sampling apparatus is placed in-line at the wellhead to collect a soil-gas sample in a Tedlar™ (E. I. du Pont de Nemours & Company, Wilmington, Delaware) bag. Concentrations are typically monitored monthly at individual on-line extraction wells and quarterly at individual off-line monitoring wells. One "snap-shot" sample is collected at each on-line extraction well. Three samples are collected during an hour of continuous extraction at wells that have been off line during the month in which quarterly sampling is conducted; only the last of the three samples is included in Tables B-1 through B-3.

Carbon tetrachloride concentrations measured at individual extraction wells have also been decreasing with continued vapor extraction operations (Figures 5-33 and 5-34). At the 216-Z-1A/Z-18 wellfield, concentrations measured in wells with perforated or screened intervals open above the Plio-Pleistocene layer have been the same order of magnitude as those measured in wells open below the Plio-Pleistocene layer throughout extraction operations (Figure 5-33). At the 216-Z-9 wellfield, concentrations measured above the Plio-Pleistocene layer during initial operations (i.e., before April 1994) were generally an order of magnitude higher than those measured below; after approximately 6 months of operations, concentrations measured above and below the Plio-Pleistocene layer had reached comparable levels (Figure 5-34).

In general, initial carbon tetrachloride concentrations measured at individual 216-Z-1A wells when SVE operations resumed in 1997 after the rebound study appear to be slightly higher than concentrations measured at the same wells when operations resumed in 1998 after the winter shutdown (Table 5-8). Higher concentrations in 1997 would be consistent with the longer time

available for rebound in 1997 (8 months) than in 1998 (6 months). Similarly, initial concentrations measured when SVE operations resumed in 1999 appear to be higher than the corresponding 1998 concentrations, consistent with the longer time available for rebound in 1999 (12 months) than in 1998 (6 months). However, the initial lack of flow from 216-Z-1A wells in 1998 makes these comparisons difficult. Initial concentrations measured when SVE operations resumed in 2001, after 18 months of rebound, were slightly less, in general, than concentrations measured in 1999.

At the 216-Z-9 site, three of the wells monitored 3 days after operations resumed in 1997 were also monitored 3 days after operations resumed in 1998. Carbon tetrachloride concentrations were higher in 1998 in two of these three wells (Table 5-8). The slightly longer time available for rebound in 1998 (9 months) than in 1997 (8 months) would typically favor higher concentrations. Comparison of the initial 1999 and 2001 concentrations to the initial 1998 concentrations at the same three wells indicates that the 1999 concentrations were lower in all three wells and that the 2001 concentrations were higher in two of the wells. The lower concentrations in 1999 could reflect the shorter time available for rebound in 1999 (6 months) than in 1998 (9 months); the higher concentrations in 2001 could reflect the longer time available for rebound in 2001 (24 months).

The concentrations of chloroform measured at individual extraction wells have been proportional to the concentrations of carbon tetrachloride measured at individual extraction wells. The chloroform is assumed to have been produced primarily through biodegradation of carbon tetrachloride during the early phases of soil column disposal and migration. The linear relationship suggests that the fate and transport of the chloroform has been similar to that of the carbon tetrachloride. For concentrations measured at 216-Z-9 wells, the ratio between carbon tetrachloride and chloroform is relatively constant for carbon tetrachloride concentrations between 25,000 and 1,000 ppmv (Figure 5-35). At carbon tetrachloride concentrations less than 1,000 ppmv, two different linear trends between carbon tetrachloride and chloroform are apparent (Figure 5-35). These two linear trends are still apparent when the same data are plotted at a finer scale (Figure 5-36). (The data shown in Figure 5-36 are the same as those shown in Figure 5-35 for carbon tetrachloride concentrations less than 1,000 ppmv.) Each trend includes data from above and below the Plio-Pleistocene layer. The reason for the two trends is unknown. Data from two individual wells suggest that the contaminant ratios may decrease more rapidly at relatively low carbon tetrachloride concentrations (Figure 5-37).

The concentration data measured at 216-Z-1A/Z-18/Z-12 wells also suggest two different chloroform-to-carbon tetrachloride trends for carbon tetrachloride concentrations less than 1,000 ppmv, although the trends are not as well defined as at 216-Z-9 (Figure 5-38). Based on the apparent trends, the chloroform-to-carbon tetrachloride ratios at 216-Z-9 wells appear to be higher than at 216-Z-1A/Z-18/Z-12 wells. If the chloroform is a degradation product of the carbon tetrachloride under anaerobic conditions, higher ratios would be expected at 216-Z-9, where aqueous soil column disposal might have been sufficient to create saturated conditions under the disposal site and induce anaerobic conditions.

Soil Vapor Extraction System Operating Data

All of the data used to construct Figures 5-33 through 5-38 were measured using the B&K instrument. Because the minimum detection limit for carbon tetrachloride on the B&K instrument is 1 ppmv, only carbon tetrachloride and chloroform data recorded as greater than 1 ppmv were used in this evaluation.

5.5 MASS OF CARBON TETRACHLORIDE REMOVED

The mass of carbon tetrachloride removed from each wellfield was calculated using the measured flow, concentration, and hours of operation data. Between April 1991 (when the pilot test was conducted) and September 2001, approximately 23,836 kg of carbon tetrachloride was removed from the 216-Z-1A and 216-Z-18/Z-12 wellfields (Table 4-1). Between March 1993 and September 2001, approximately 53,318 kg of carbon tetrachloride was removed from the 216-Z-9 wellfield (Table 4-1). The total mass of carbon tetrachloride removed (77,154 kg) represents an estimated 10% of the original carbon tetrachloride inventory (approximately 750,000 kg) discharged to the soil column (Table 2-1). Approximately 0.1% of the original carbon tetrachloride inventory was removed each year in 1998, 1999, and 2001 (782 kg, 811 kg, and 710 kg, respectively) (Figure 5-39).

Based on the following assumptions, the total mass of carbon tetrachloride removed represents an average of 13% of the residual mass potentially available in the vadose zone. An estimated 440,000 kg of carbon tetrachloride was initially discharged to the 216-Z-1A and 216-Z-18 Cribs, and 310,000 kg was initially discharged to the 216-Z-9 Crib (Table 2-1). (The mass of carbon tetrachloride discharged to the 216-Z-12 Crib is unknown and therefore not included in this calculation.) Of this original inventory, an estimated 21% had been lost to the atmosphere by 1990, 1% to 2% had been dissolved in the upper 10 m of the unconfined aquifer, and 1% had biodegraded (WHC 1993, Rohay and Johnson 1991, Hooker et al. 1996). (These calculations and the 1990 inventory estimates both use the average of the estimated range of carbon tetrachloride discharged to 216-Z-9, Table 2-1.) For the purpose of these calculations, all of the mass that has not been lost to atmosphere, dissolved in groundwater, or biodegraded is assumed to remain as residual mass in the vadose zone. Assuming that 330,000 kg of carbon tetrachloride remained as residual mass in the vadose zone beneath the 216-Z-1A and 216-Z-18 sites, 7% (24,000 kg + 330,000 kg) of the residual mass potentially available at 216-Z-1A and 216-Z-18 has been removed using SVE. Similarly, assuming that 240,000 kg remained as residual mass in the vadose zone beneath the 216-Z-9 site, 22% (53,000 kg + 240,000 kg) of the available mass potentially available at 216-Z-9 has been removed using SVE.

These estimates of the percent of residual mass removed at each site cannot be correlated to the estimate made by Yonge et al. (1996) that SVE can remove only 10% to 15% of the initial mass in contaminated zones through which flow is passing directly. Yonge et al. established known initial conditions for their laboratory experiments in order to compare the amount they removed to the amount they loaded into the soil. At the carbon tetrachloride site, the corresponding initial conditions are unknown, and the data are not available to determine what percent of the "initial" mass has been removed by SVE. In addition, no DNAPL carbon tetrachloride was included in this particular experiment by Yonge et al., but concentrations observed at the 216-Z-9 site in

Soil Vapor Extraction System Operating Data

1993 and 1994 suggest that some carbon tetrachloride was present in the vadose zone as a DNAPL at that time (Rohay et al. 1994).

One indication that DNAPL was present in the vadose zone beneath 216-Z-9 is based on the inlet SVE concentrations. If a major fraction of the carbon tetrachloride originally discharged to the 216-Z-9 site were still present in the soil column as a nonaqueous-phase liquid, a relatively high soil vapor concentration would be expected. For example, a pure, nonaqueous carbon tetrachloride liquid phase in the soil pore space should result in a maximum soil vapor concentration of 120,000 ppmv at 20°C (DOE-RL 1991). As a rule-of-thumb, for soils saturated with an organic contaminant, standard SVE will produce a vapor stream containing one-tenth to one-half the expected concentration (EPA 1993). Therefore, vapor extraction concentrations greater than 12,000 ppmv of carbon tetrachloride may indicate that the soil near the extraction well is saturated with a nonaqueous-phase liquid. During initial SVE operations at the 216-Z-9 site, soil vapor concentrations extracted from wells open above the Plio-Pleistocene layer were in excess of 12,000 ppmv, suggesting the presence of a nonaqueous carbon tetrachloride phase (Figure 5-15). In situ soil vapor samples collected during drilling prior to initiation of SVE remediation also exceeded 12,000 ppmv in one well above the Plio-Pleistocene layer at the 216-Z-9 site (Figure 5-40).

Another indication that DNAPL might have been present in the vadose zone beneath 216-Z-9 prior to SVE remediation is based on comparison of the mass removed to the predicted mass present. Approximately 17% (53,000 kg + 310,000 kg) of the original inventory at the 216-Z-9 site has been removed since 1993. Using available carbon tetrachloride soil vapor concentrations (primarily baseline monitoring of naturally venting boreholes) and equilibrium partitioning relationships, it was estimated that in 1990 12% of the original carbon tetrachloride inventory was present in the vadose zone as vapor, dissolved in soil moisture, or adsorbed to soil particles (WHC 1993). It was not possible to calculate a mass of DNAPL carbon tetrachloride using the equilibrium partitioning relationships, and thus a large fraction (65%) of the inventory was termed "unaccounted." The removal of more than 12% of the original inventory from this site suggests that additional mass was present in the vadose zone as residual liquid saturation and/or in nonequilibrium sorption sites.

The mass of carbon tetrachloride removed daily is compared to the cumulative total for each wellfield in Figures 5-41 and 5-42. The rate of mass removal has decreased with decreasing carbon tetrachloride concentrations. The decline in the total mass removal rate from both wellfields since 24-hr/day, 7-days/week operation began is shown in Figure 5-43. Despite this decline, in September 1997 the three SVE systems were still removing an average of approximately 15 kg of carbon tetrachloride every day (6 kg from the 216-Z-1A/18 wellfield and 9 kg from the 216-Z-9 wellfield). In October 1996, prior to the rebound study, the three SVE systems were removing an average of 15 kg of carbon tetrachloride every day. At the close of operations at the 216-Z-1A wellfield in 2001, the 14.2-m³/min SVE system was removing an average of 3 kg of carbon tetrachloride every day; at the close of operations at the 216-Z-9 wellfield in 2001, the system was removing an average of 5 kg of carbon tetrachloride every day.

Soil Vapor Extraction System Operating Data

The mass of carbon tetrachloride removed during cyclic SVE operations in FY 1997, FY 1998, and FY 1999 can be compared to the estimated mass projected to have been removed if SVE had been continued at the asymptotic concentration level. (Because the SVE system shutdown throughout FY 2000 was not related to cyclic operations, this comparison is only continued through FY 1999.) The mass removed following the rebound study in FY 1997 was compared to the projected mass removed had the SVE systems continued to operate throughout FY 1997 (Rohay 1997). Those comparisons suggested that continuous operation of the SVE systems would have removed three to four times more carbon tetrachloride than was removed in the 2.5 months of operations following the 8-month rebound period.

The mass of carbon tetrachloride removed at the 216-Z-9 wellfield is compared to the projected mass removed had the 14.2-m³/min SVE system continued to operate throughout FY 1998 and FY 1999 in Figure 5-44. Continuous operations would have removed 1657 kg, which is one to two times more carbon tetrachloride than was removed during cyclic operations (966 kg). (If continuous operations had begun at 216-Z-9 in March 1998 rather than July 1998, the projected amount would be higher.) The estimate of the projected mass removed during continuous operations is based on the average of the daily concentrations during the last week of operation in FY 1998 (24 ppmv) and continuous operation of the 14.2-m³/min SVE system at its full capacity. During actual operations, the daily concentrations probably would have continued to slowly decrease and the availability of the system might have been less than 100% during the winter months. Even if the daily concentrations are maintained at half the concentration assumed in Figure 5-44 (i.e., 12 ppmv rather than 24 ppmv), slightly more carbon tetrachloride is removed by continuous operations (1,085 kg). These comparisons suggest that the highest mass removal is achieved by continuous operations. An additional advantage to continuous operations is that a maximum concentration gradient would be maintained between the source of the carbon tetrachloride and the high-flow zone into which it is diffusing.

The 14.2-m³/min SVE system actually removed 966 kg of carbon tetrachloride from the 216-Z-9 wellfield during FY 1998-FY 1999, compared to a projected 1,657 kg, or 60% of the mass in 40% of the time. Thus, once the readily accessible mass of contaminant has been removed during early stages of SVE, mass removal is more efficient (in terms of mass removed per hour of operation) if SVE operations are intermittent rather than continuous. An additional advantage to cyclic operations is that waste minimization is achieved if the SVE system is operated only during warm months. During operations in warm months, water condensate is not generated by the SVE system. In addition, the higher carbon tetrachloride concentrations extracted during cyclic operations require less GAC per unit mass of carbon tetrachloride extracted because the GAC adsorption of the carbon tetrachloride is more efficient at higher concentrations (Cameron 1997).

5.6 IMPACT OF 200-ZP-1 PHASE III PUMP-AND-TREAT OPERATIONS

The 200-ZP-1 groundwater pump-and-treat system has been in operation since August 1994 (DOE-RL 2000). Phase III of the remediation operations was initiated in August 1997 to include extraction wells in the vicinity of the 216-Z-9 wellfield. In particular, Phase III groundwater

Soil Vapor Extraction System Operating Data

extraction well 299-W15-32 is 11 m northeast of SVE well 299-W15-9 and 34 m southwest of SVE well 299-W15-6. Full-scale groundwater extraction from well 299-W15-32 began on August 27, 1997. Drawdown of the water table at this well was only 1.5 m below pre-operational levels. Lowering of the water table in the vicinity of this well has the potential to volatilize additional carbon tetrachloride, either from the introduction of soil vapor in previously saturated pores and/or from the additional agitation of the groundwater. However, the carbon tetrachloride concentration in vapor samples collected from nearby wells 299-W15-9L and 299-W15-6L has not measurably increased (Figure 5-45). During CY 1999, groundwater extraction well 299-W15-32 was off line for approximately 200 days (from June 29, 1999 until February 2, 2000) (DOE-RL 2000). Soil vapor concentrations measured at well 299-W15-9L appear unaffected by the shutdown and subsequent restart of groundwater pumping from well 299-W15-32. As of September 30, 2001, groundwater extraction operations have had no detectable impact on carbon tetrachloride concentrations in vapor extracted from multiple wells and measured at the inlet to either the 42.5- or 14.2-m³/min SVE system (Figure 5-26).

Measurement of groundwater extraction effects may be hampered because of differences in the completion/configuration of the groundwater and vapor extraction wells. The screened interval in well 299-W15-32 is 59 to 72 m bgs. The SVE interval in well 299-W15-6L extends from 47 m bgs to the current water table at 64 m bgs (the well is perforated to 109 m bgs), and the SVE interval in well 299-W15-9L is 49 to 58 m bgs.

The slight increase in carbon tetrachloride concentrations measured at well 299-W15-9L at the start of each period of SVE operations suggests a nearby carbon tetrachloride source (Figure 5-45).

5.7 PASSIVE SOIL VAPOR EXTRACTION

Passive SVE systems began operating on eight wells in the 216-Z-1A/Z-18 wellfield in October 1999. The eight passive SVE systems are installed on wells 299-W18-6L, 299-W18-7, 299-W18-10L, 299-W18-11L, 299-W18-12, 299-W18-246L, 299-W18-247L, and 299-W18-252L (Figure 5-46). All eight passive SVE systems are installed on well intervals open below the Plio-Pleistocene layer. The systems are described in Section 3.0. The passive SVE data are provided in Appendix C.

All eight passive SVE systems include a removable cartridge of GAC that is replaced monthly. Samples of the GAC that was removed from the wells are then sent to an off-site laboratory for analysis of carbon tetrachloride concentrations. In addition, three of the wells (299-W18-6L, 299-W18-247L, and 299-W18-252L) are instrumented to record flow, differential pressure, temperatures, and carbon tetrachloride concentrations hourly. In these three wells, differential pressures are also monitored hourly in the well intervals open above the Plio-Pleistocene (299-W18-6U, 299-W18-247U, and 299-W18-252U). The upper intervals are sealed to atmosphere. A ninth well, 299-W18-9, has an interval open below the Plio-Pleistocene layer, is sealed to atmosphere, and serves as a control well. It is instrumented to record differential pressure and temperatures hourly. Differential pressures are also monitored hourly at three stainless steel

Soil Vapor Extraction System Operating Data

tubes open at depths above, between, and below the two screens on well 299-W18-252 and at five soil vapor probes installed above the Plio-Pleistocene layer at CPT-4F (Figure 5-46).

5.7.1 Mass of Carbon Tetrachloride Removed by Passive Soil Vapor Extraction Systems

Analysis of the GAC in the cartridges was intended to provide a passive, time-integrated measure of the amount of mass removed through the well each month. Analysis of the flow and concentration instrument data was intended to allow calculation of the hourly amount of mass removed, which could then be summed and compared to the time-integrated monthly amount. Because the sampling and analysis of the GAC cartridges was an innovative addition to the passive SVE systems, the hourly flow and concentration measurements were intended to help evaluate whether the cartridge results are representative of the mass removed by barometric pumping. Availability of hourly data is presented in Table 5-9. Sampling, analytical, and calculation methods are provided in Appendix C.1 for GAC cartridges and Appendix C.2 for hourly wellhead data.

The mass removed from the passive wells during FY 2000 based on the GAC cartridge results is at least an order of magnitude lower than the mass removed based on the hourly data (Table 5-10a). The discrepancy is even more significant considering that hourly data were typically not available for the entire sample interval that the GAC cartridges were on the wells (Table 5-11a). Based on the GAC cartridge data, a total of 59 g of carbon tetrachloride were removed from the three instrumented wells; based on the hourly measurements, a total of 1,953 g of carbon tetrachloride were removed from the three instrumented wells during FY 2000. Based on the GAC cartridge data, a total of 252 g of carbon tetrachloride were removed from all eight passive wells during FY 2000. As discussed in Section 5.7.1.1, the eight passive systems are estimated to have removed at least 10 kg of carbon tetrachloride in FY 2000.

In FY 2001, hourly data to calculate the mass removed from the three instrumented wells are limited; the carbon tetrachloride mass could only be calculated for 3 months at well 299-W18-252L (Table 5-10b). For this well, the mass removed in 12 months, based on the GAC cartridge data, was 41 g; the mass removed in 3 months, based on the hourly measurements, was 219 g. As in FY 2000, the hourly data are typically not available for the entire sample interval during which the GAC cartridges were on the wells (Table 5-11b). Based on the GAC cartridge data, a total of 216 g of carbon tetrachloride were removed from all eight passive wells during FY 2001. As discussed in Section 5.7.1.2, the eight passive systems are estimated to have removed approximately 20 kg of carbon tetrachloride in FY 2001.

5.7.1.1 Estimate of Carbon Tetrachloride Mass Removed in FY 2000. Although the GAC cartridge analytical data and hourly wellhead calculations do not agree in magnitude, they do reflect the same pattern of relative total mass removed. For the three wells with both GAC cartridge data and hourly wellhead data, the highest total carbon tetrachloride mass removed based on either data set was at well 299-W18-252L and the lowest total carbon tetrachloride mass removed based on either data set was at well 299-W18-247L (Table 5-10a). (Note: this pattern based on relative total mass removed is not consistent in each monthly sampling interval.)

Because the GAC cartridge data and the wellhead data both show the same pattern of relative total carbon tetrachloride mass removed for the three wells, a linear correlation was established between the two data sets to provide a basis for correcting the GAC-based estimate of total mass removed at all eight passive SVE wells (Figure 5-47). Use of this correlation assumes that the GAC data under-represent the amount of mass removed at each well, relative to the hourly measurement data. The equation describing the linear trend was then applied to the GAC cartridge data to estimate the total amount of carbon tetrachloride removed from each well (Table 5-12). Using this approach, a total of 10 kg (9,827 g) of carbon tetrachloride were removed from the subsurface using the eight passive SVE systems in FY 2000.

For the purposes of establishing the correlation, the total amount of carbon tetrachloride removed at each well was based only on months for which data both from the GAC cartridges and from the wellhead instruments were available at that well (Table 5-10a, Figure 5-47). However, for any given month that the GAC cartridges were in place, the hourly wellhead data were typically not available for the entire month (Table 5-11a). As a result, using the total mass removed based on hourly data calculations to correct the total mass removed based on GAC data provides only a minimum value of total carbon tetrachloride removed from each well (Table 5-12).

5.7.1.2 Estimate of Carbon Tetrachloride Mass Removed in FY 2001. In FY 2001, the hourly data are insufficient to allow a correlation to be established with the GAC cartridge data. Because the total mass removed, based on the GAC cartridge data, is similar in FY 2000 (252 g) and FY 2001 (216 g), it might be expected that the corrected minimum estimate for FY 2000 (9,827 g) would be a reasonable minimum estimate for FY 2001.

In FY 2001, the carbon tetrachloride concentrations at seven of the eight passive wells were monitored on June 1, 2001 using a sampling method similar to that used during the rebound study (Rohay 1996). The eighth passive well was on line to the SVE system during the sampling, and its concentration was monitored on May 31, 2001 as part of routine SVE characterization (Table 5-13). These concentration data can be used to estimate the total carbon tetrachloride mass that potentially could have been removed from the passive wells. Flow rates needed for this calculation were measured at the three instrumented wells and assumed at the other five wells (Table 5-13).

Using the June 1, 2001 sample results and the measured and assumed flow rates, a total of 20 kg (19,748 g) of carbon tetrachloride is estimated to have been extracted from the eight passive wells during FY 2001 (Table 5-13). This calculation assumes that (1) the wells exhale 50% of the time; (2) during outflow, the average flow rate is one-half of the maximum flow rate; (3) during outflow, the average concentration is one-half of the maximum concentration; and (4) the concentrations measured on June 1, 2001 were maximum values.

5.7.1.3 Evaluation of Passive Soil Vapor Extraction Data. One explanation for the relatively low values of carbon tetrachloride mass recorded by the GAC cartridge data may be interference by water that condenses from the vapor stream in the passive system hoses and GAC cartridges during cold-weather months; the sampler often noted that the GAC was wet when the cartridges were retrieved in the winter (Table C-25 and, for example, Tables C-4 and C-5). This water

Soil Vapor Extraction System Operating Data

could have impacted the ability of the GAC in the cartridge to absorb the carbon tetrachloride from the vapor stream, thus reducing the concentration of carbon tetrachloride absorbed on the GAC in the cartridges during the winter. Comparison of the amount of carbon tetrachloride removed from each well monthly based on the GAC cartridge data illustrates these seasonal differences (Figure 5-48).

However, the mass removal rates in the summer months based on GAC cartridge analyses are still significantly lower than the rates calculated using the hourly wellhead data. A possible explanation for the relatively low values of carbon tetrachloride on the GAC in the cartridges during the hot-weather months may be desorption of the carbon tetrachloride resulting from solar heating.

Another possible explanation for the relatively low values of carbon tetrachloride on the GAC in the cartridges might be that the GAC in the cartridges becomes saturated with carbon tetrachloride prior to being sampled. However, this explanation seems unlikely. The expected loading efficiency for carbon tetrachloride on GAC is 25%, i.e., 450 g of GAC (the approximate amount in one cartridge) would be expected to absorb 100 to 125 g of carbon tetrachloride. The highest amount of carbon tetrachloride absorbed on any cartridge of GAC in a single month was only 37.5 g (Table 5-10). However, the maximum loading efficiency may have been reduced because concentrations are relatively low and flow is episodic.

It is also possible that the GAC cartridge data may over-represent the mass of carbon tetrachloride removed from the passive wells because the clean GAC that was used to fill each cartridge may have already contained some carbon tetrachloride. Analysis of two samples of the clean GAC supply, one collected in October 1999 and one in May 2000, indicate that a cartridge of that GAC initially would have contained 0.6 g and 0.1 g of carbon tetrachloride, respectively (Tables C-1 and C-7). These values were not factored into the above analysis of mass removed because many GAC cartridge samples contained less than 0.6 g of carbon tetrachloride. However, it is acknowledged that the clean GAC analytical results suggest that the GAC cartridge results may reflect an initial mass loading in addition to that added by passive extraction. A third sample of clean GAC, collected in March 2001 after a new supply was obtained, indicated that a cartridge of that GAC initially would have contained 0.0 g of carbon tetrachloride (Table C-17).

The values of carbon tetrachloride mass recorded by the wellhead instruments also under-represent the total mass removed by each instrumented system. As described above, the hourly wellhead data are not available for the entire time that the passive SVE systems were in operation and therefore must under-represent the actual mass removed by each instrumented system. In addition, water in the hoses and in the GAC cartridges would have limited the flow of carbon tetrachloride-laden vapor through the system. As a result, the hourly wellhead data under-represent the potential amount of carbon tetrachloride that could have been removed from each instrumented well had the flow pathways been completely unrestricted.

At each instrumented system, flow should only be associated with positive differential pressure because the one-way valve limits flow into the well when the differential pressure is negative.

Soil Vapor Extraction System Operating Data

(For this project, positive differential pressure is defined as subsurface pressure greater than surface pressure.) However, plots of the flow and differential pressure for each instrumented well indicate that low flows are associated with both positive and negative differential pressure (Figures C-10 through C-15). Therefore, a "threshold flow" was selected for each well for each fiscal year, based on the maximum flow associated with a negative differential pressure. Flows above the threshold flows were used in the mass calculation to represent actual flow out of the passive systems. Comparison of the mass removed using all measured flows to the mass removed using only flows greater than the threshold flows indicates that in these wells 74% to 84% of the mass was removed when flows exceeded the threshold values (Table 5-14).

5.7.2 Carbon Tetrachloride Concentrations, Flow Rates, and Differential Pressures Measured at Passive Soil Vapor Extraction Systems

The trend of the carbon tetrachloride concentrations and the shape of the carbon tetrachloride concentration signal during outflow may indicate the relative location of the source of the contamination. In wells 299-W18-6L and 299-W18-247L, concentrations measured over the 18-month period (October 1999 to April 2001) do not exhibit evident trends (Figures 5-49 and 5-50). In contrast, concentrations measured in well 299-W18-252L show an increasing trend throughout FY 2000 (Figure 5-51). (The drop in concentration in December 2000 may reflect the changeout of the B&K instruments on November 30, 2000.) The increasing trend suggests that a source is being drawn to the well that is not drawn away or diluted during periods of no flow. The shapes of the concentration signals are consistent with the long-term record. During periods of outflow from well 299-W18-252L, carbon tetrachloride vapor concentrations are immediately at a maximum value and maintain that value until flow ceases (Figure 5-52). In wells 299-W18-6L and 299-W18-247L, concentrations increase gradually to maximum values.

During FY 2000 and FY 2001, the highest carbon tetrachloride concentration recorded at the three instrumented wells was 69 ppmv at well 299-W18-6L (Table C-27). This value is almost twice the maximum concentration of 36 ppmv recorded at this well during the 1997 rebound study (Rohay 1997). The highest concentration recorded at well 299-W18-252L was 46 ppmv, which is almost identical to the maximum concentration of 48 ppmv recorded during the rebound study. The highest concentration recorded at well 299-W18-247L was 14 ppmv; the highest concentration recorded during the rebound study was 3 ppmv.

The maximum flow rates measured in wells 299-W18-6L, 299-W18-247L, and 299-W18-252L were 0.4 m³/min, 0.2 m³/min, and 0.3 m³/min, respectively (Table C-28). In all three wells, the average flow rate, for all flows exceeding the individual well threshold flow rate, was 0.1 m³/min in FY 2000. The average flow rate was 0.2 m³/min in wells 299-W18-6L and 299-W18-247L, and 0.1 m³/min in well 299-W18-252L, in FY 2001.

In general, the average positive differential pressure increases with depth (Figure 5-53). At a given location, the differential pressure reflects the cumulative relative impermeability of the overlying material. In the 200 West Area, the differential pressure typically increases dramatically at monitoring locations below the Plio-Pleistocene layer (i.e., deeper than approximately 45 m [150 ft] bgs) (Rohay 1996).

5.7.3 Performance of Passive Soil Vapor Extraction Systems

During the winter months, water condensed from the venting soil vapor into the hoses and onto the GAC in the cartridges. This water potentially blocked the venting of air through the hoses and GAC and/or prevented the absorption of carbon tetrachloride onto the GAC in the cartridges. Any low spot in the system can accumulate the water and reduce or prevent venting from the system. The generation of the water necessitated periodic draining of the hoses, detracting from the low maintenance advantages of the passive SVE systems. If the water in the hoses freezes before it can be drained, the passive venting systems can become completely blocked until warmer weather melts the ice. Reconfiguring the passive systems to be vertical or to drop water out of the hoses would eliminate this source of interference with system operations.

Plots of flow and differential pressure for each of the three instrumented passive systems indicate that an approximately linear relationship between positive differential pressure and flow occurs near the zero differential pressure node (Figures C-10 through C-15). The cracking pressure for the one-way valves used on these wells is approximately 0.04 kPa (Rohay 1996). When the positive differential pressure exceeds this value, the valve should open, allowing flow out of the system. The approximately linear relationship between positive differential pressure and flow appears to originate at the cracking pressure.

The plots of flow and differential pressure also indicate that low flows are associated with both negative and positive differential pressures and appear to occur relatively symmetrically around the zero differential pressure node (Figures C-10 through C-15). The high negative differential pressures (atmospheric pressure greater than subsurface pressure) are expected to develop when the valve is closed, sealing the well to atmosphere. The high positive differential pressures (atmospheric pressure less than subsurface pressure) may be a result of water blocking the passive system, effectively sealing the well to atmosphere and allowing high positive differential pressures to develop. The low flows recorded at these negative and high positive differential pressures may fall below the lower threshold for the flowmeters (i.e., these low flows may be in the range equivalent to zero flow for these instruments). As indicated previously, for the purposes of calculating the mass removed, the threshold flow for each system was defined as a highest flow associated with a negative differential pressure.

At each of these systems, moderate flows are associated with moderate positive differential pressures. These data may indicate an increase in the cracking pressure, possibly caused by moisture condensing on the valve and increasing its weight, and/or a partial restriction in flow caused by water in the hoses or GAC cartridge.

If the low flows reflect actual flow within the passive systems, the low flows associated with negative differential pressures may be a result of minor leaks in the passive systems between the flowmeters and the one-way valves (e.g., cracks in the flexible hoses or loss of seals around the fittings). For example, flow and differential pressure records during a 5-day period in May 2000 at well 299-W18-247L indicate a flow associated with a local minimum in the differential pressure (Figure 5-54). (The maximum flow associated with the pressure minimum in this figure

was used as the threshold flow value for this well for FY 2000.) Carbon tetrachloride concentrations and flow decrease to zero when the differential pressure becomes negative; while the pressure is negative, the flow may actually be negative also (i.e., into the well) through a minor leak. Heating of the above-ground system causing expansion of the vapor in the system may also induce flow in the "negative" direction. (Note: The flowmeter records flow magnitude but not flow direction, i.e., all flow is recorded as a positive value).

During FY 2000, the supply of clean, regenerated GAC that was used to fill each cartridge before placement in line on a passive system was sampled and analyzed twice, once in October 1999, when passive operations started, and again in May 1999, when the supply of clean GAC was replenished. Laboratory analysis indicated that the "clean" GAC contained carbon tetrachloride (Tables C-1 and C-7). Because the mass of carbon tetrachloride extracted by the passive systems is relatively low, compared to the mass extracted by the active SVE systems, this concentration of carbon tetrachloride on the regenerated GAC can be a significant percentage of the total analyzed on the passive GAC cartridge samples.

Factors identified above that may affect the operation of the passive SVE systems will be considered as the passive SVE systems are upgraded in the future.

Figure 5-1. Combined Monthly Availability of the Three Soil Vapor Extraction Systems, November 1994 - September 2001.

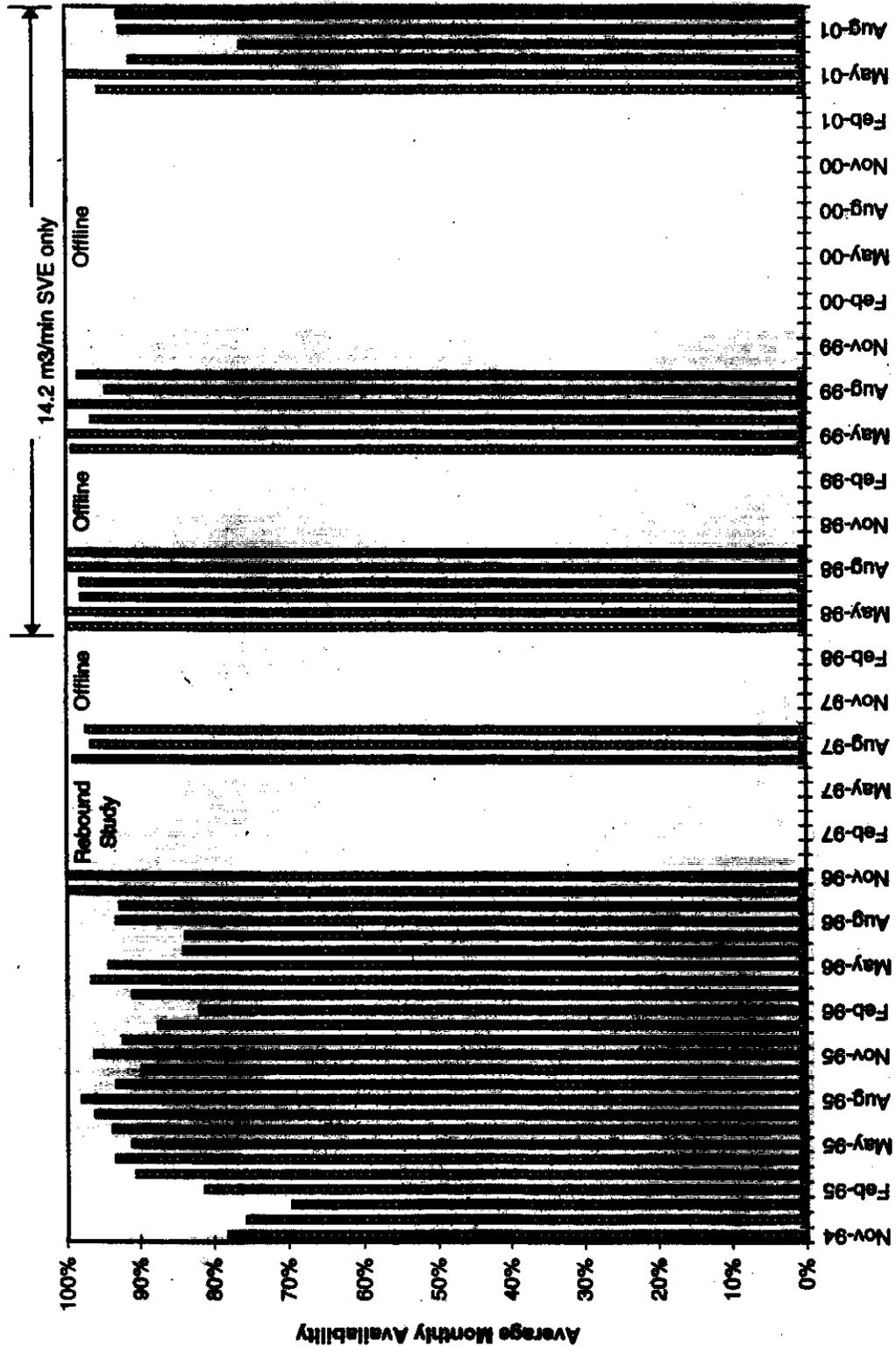


Figure 5-2. Monthly Availability of the 14.2-m³/min Soil Vapor Extraction System, January 1994 - September 2001.

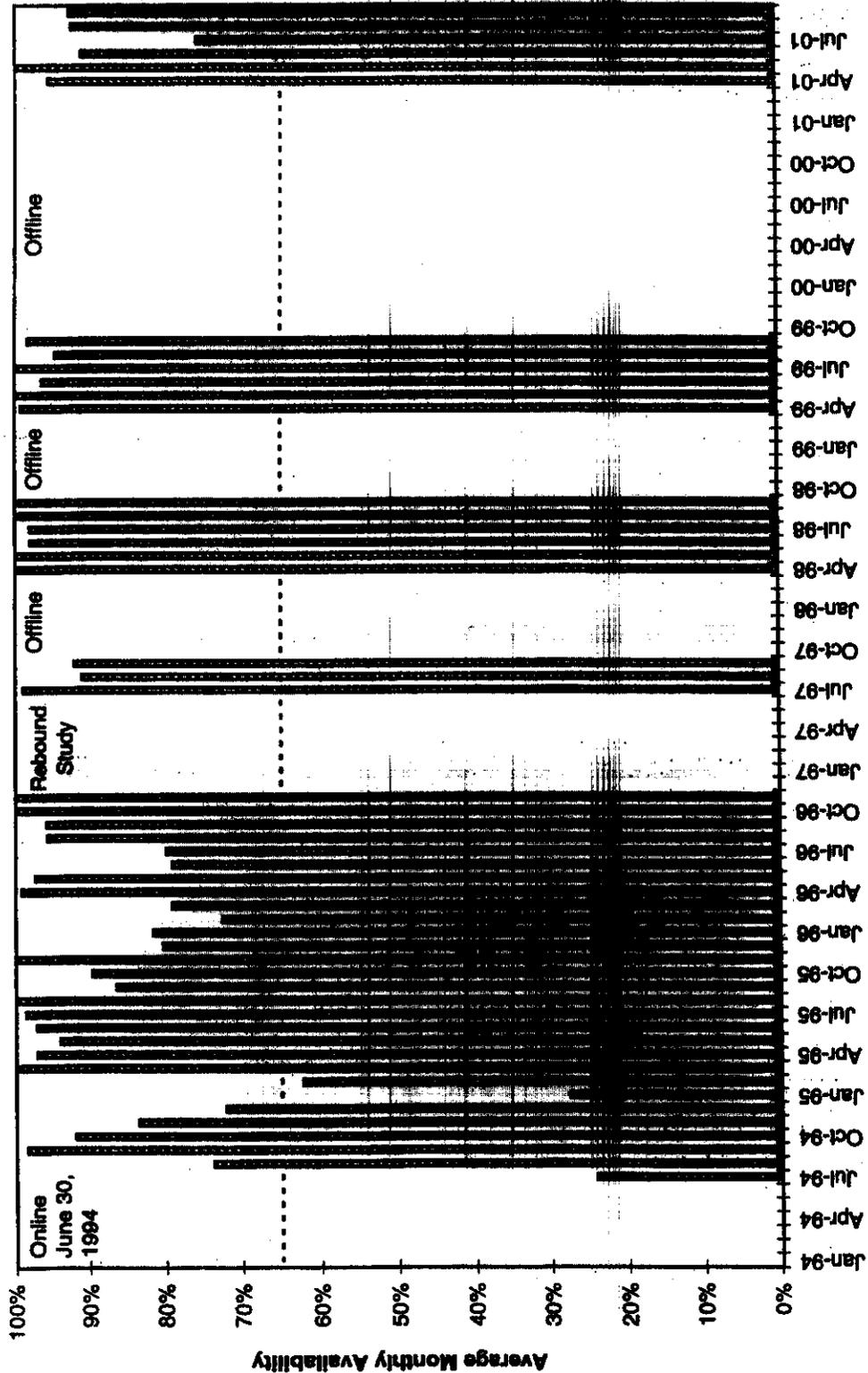


Figure 5-3. Monthly Availability of the 28.3-m³/min Soil Vapor Extraction System, January 1994 - September 2001.

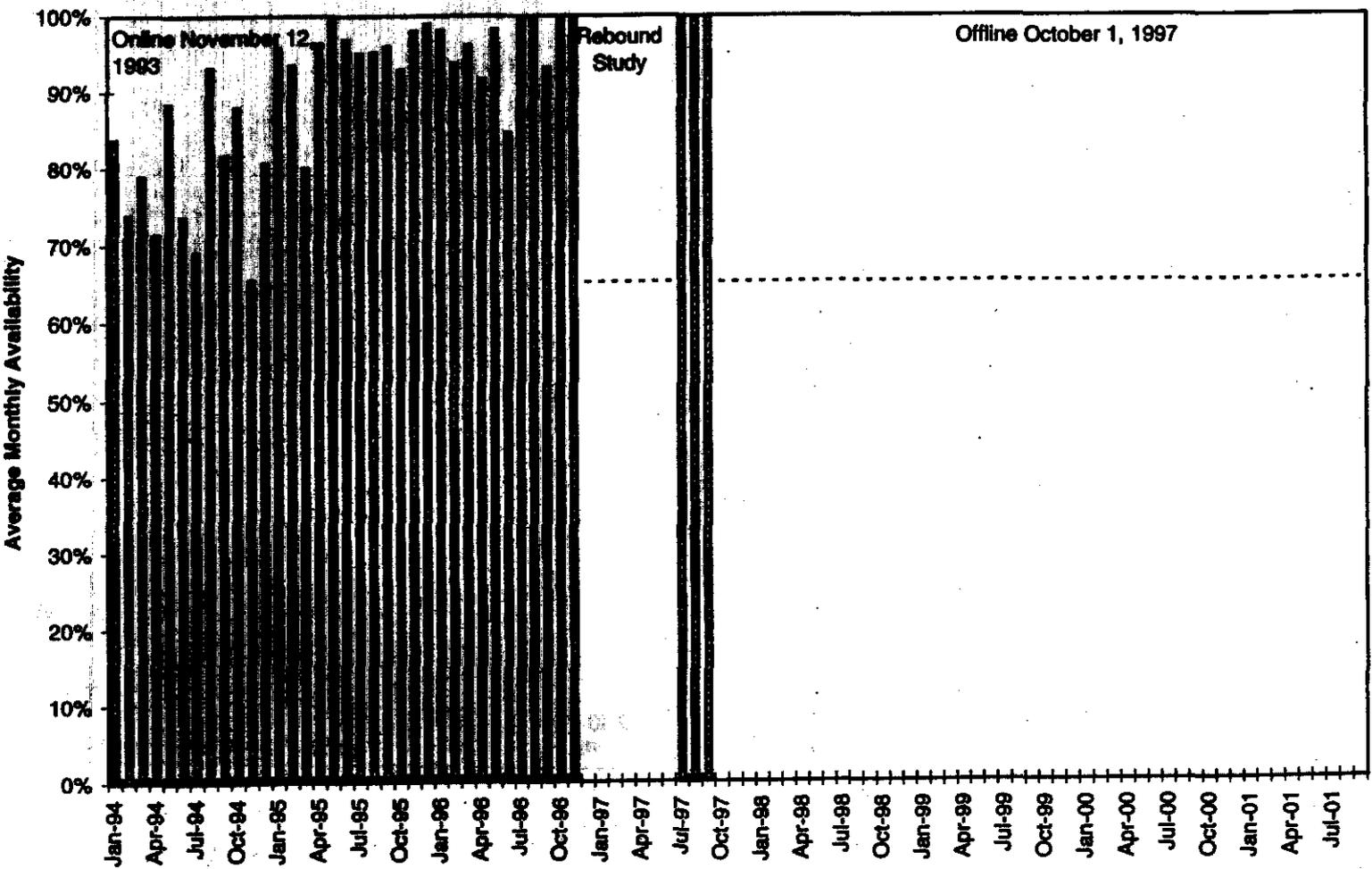
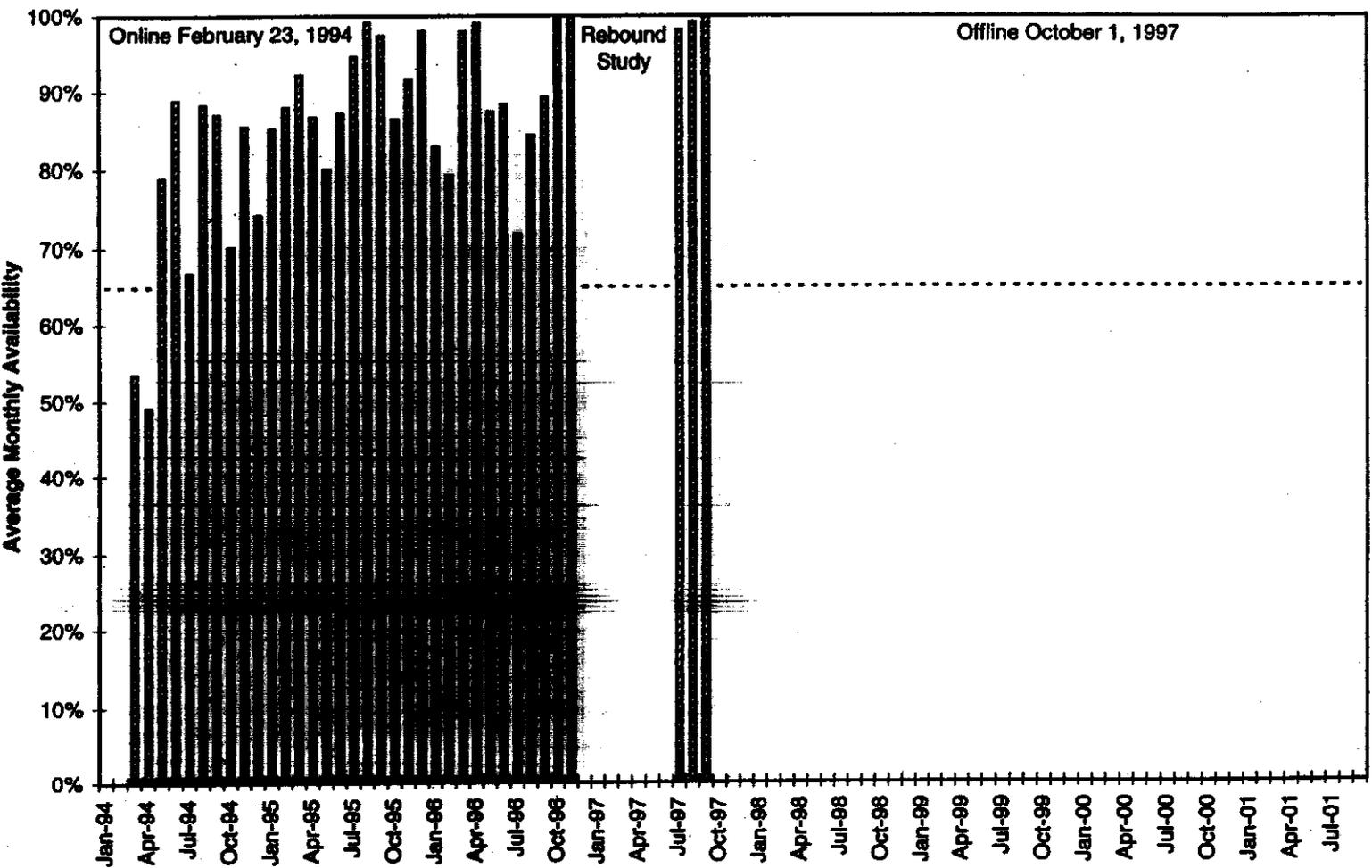


Figure 5-4. Monthly Availability of the 42.5-m³/min Soil Vapor Extraction System, January 1994 - September 2001.



Soil Vapor Extraction System Operating Data

Figure 5-5. Number of Hours the Three Soil Vapor Extraction Systems Operated, February 1992 - September 2001.

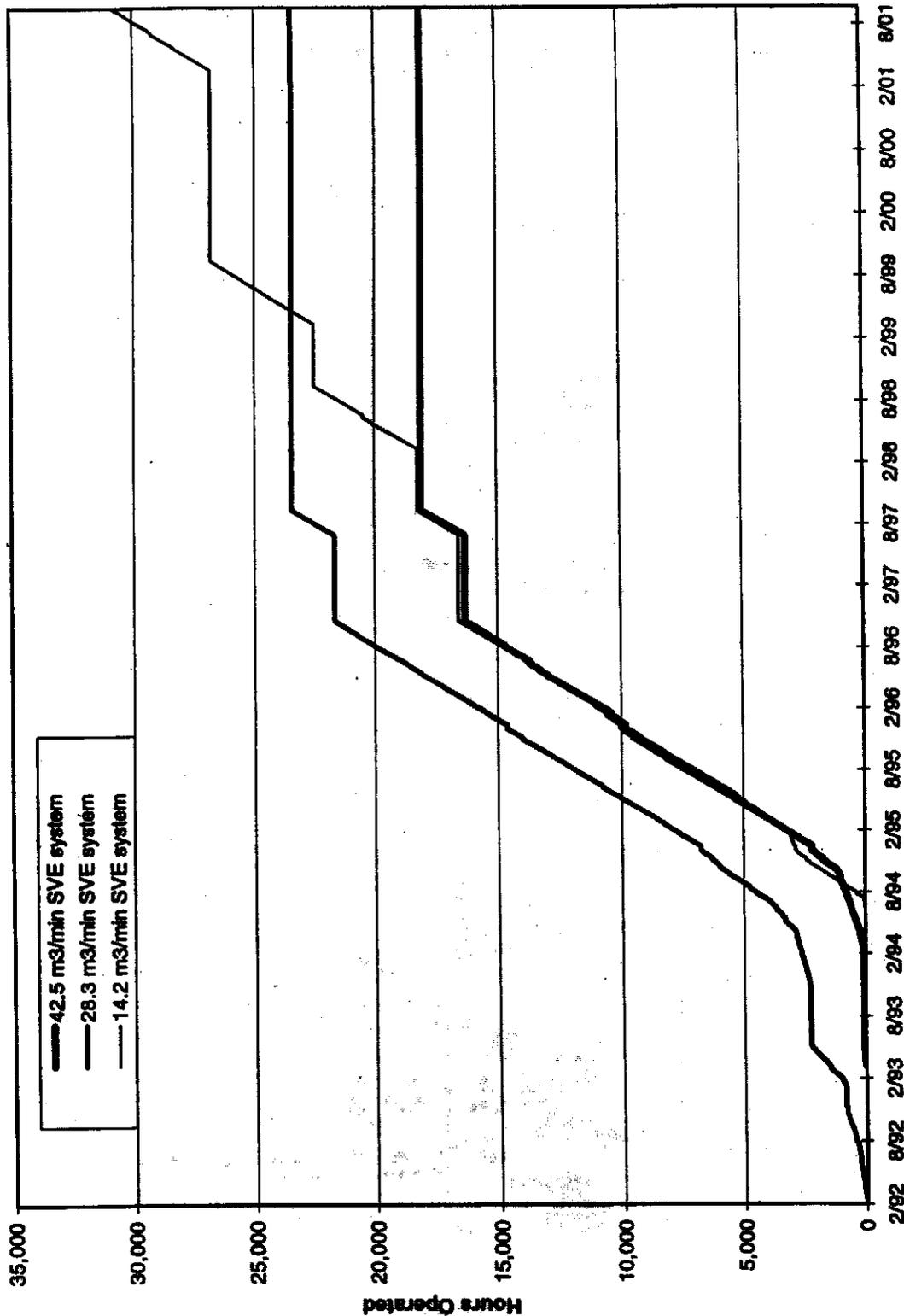


Figure 5-6. Daily Average Flow Rate Measured at the 14.2-m³/min Soil Vapor Extraction System During 24-hr/day, 7-days/week Operations, August 1994 - September 2001.

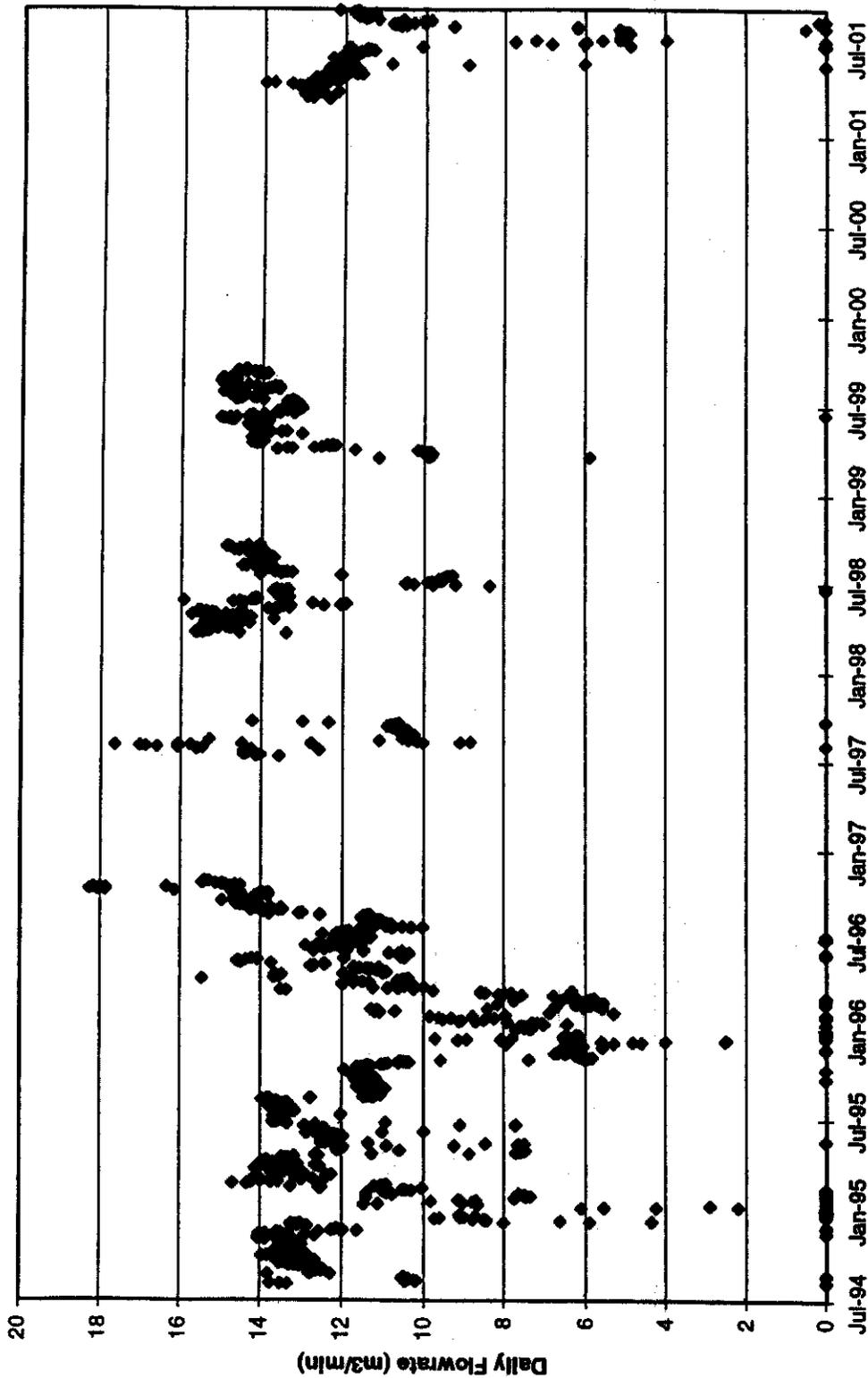


Figure 5-7. Daily Average Flow Rate Measured at the 28.3-m³/min Soil Vapor Extraction System During 24-hr/day, 7-days/week Operations, July 1994 - September 2001.

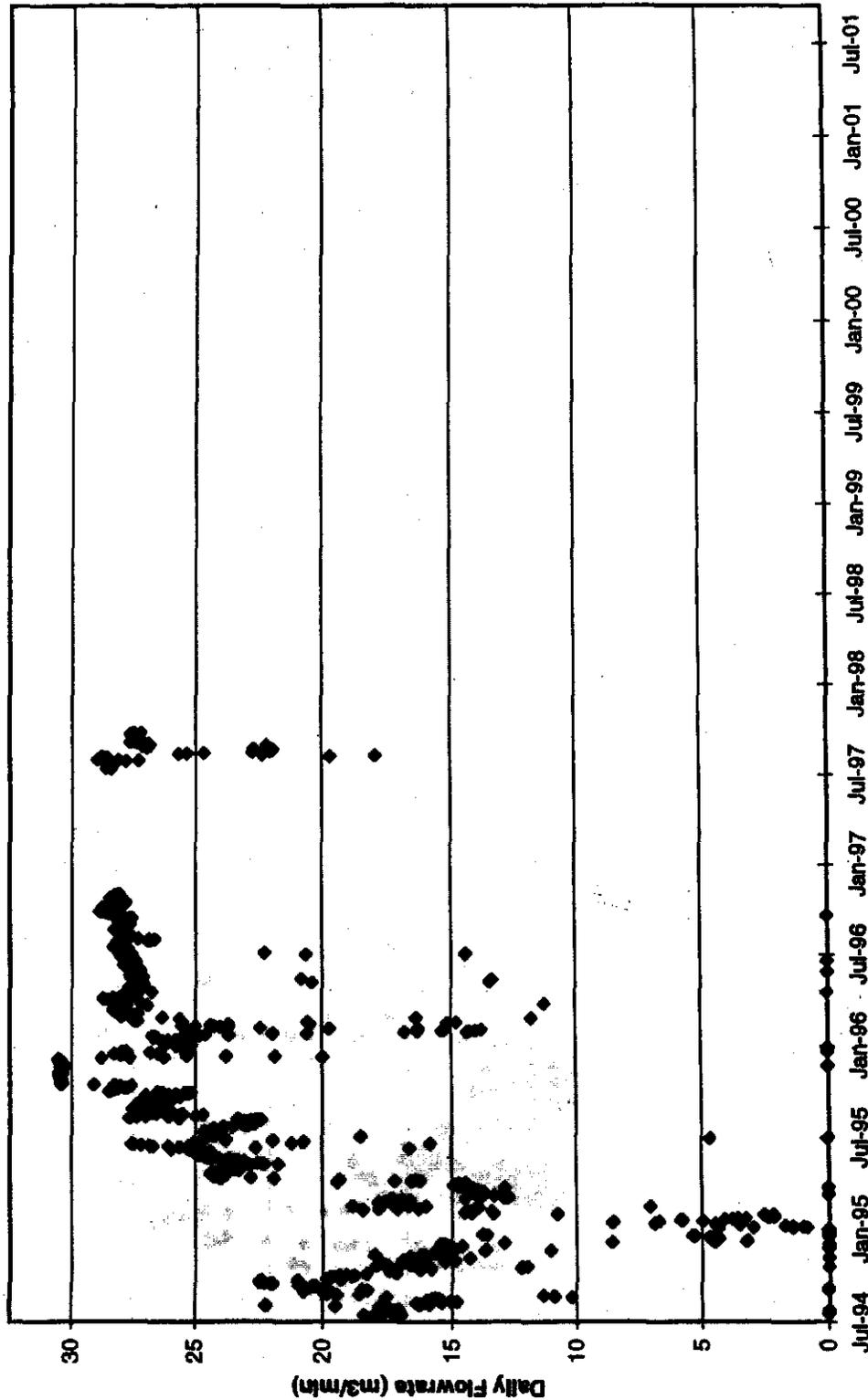


Figure 5-8. Daily Average Flow Rate Measured at the 42.5-m³/min Soil Vapor Extraction System During 24-hr/day, 7-days/week Operations, October 1994 - September 2001.

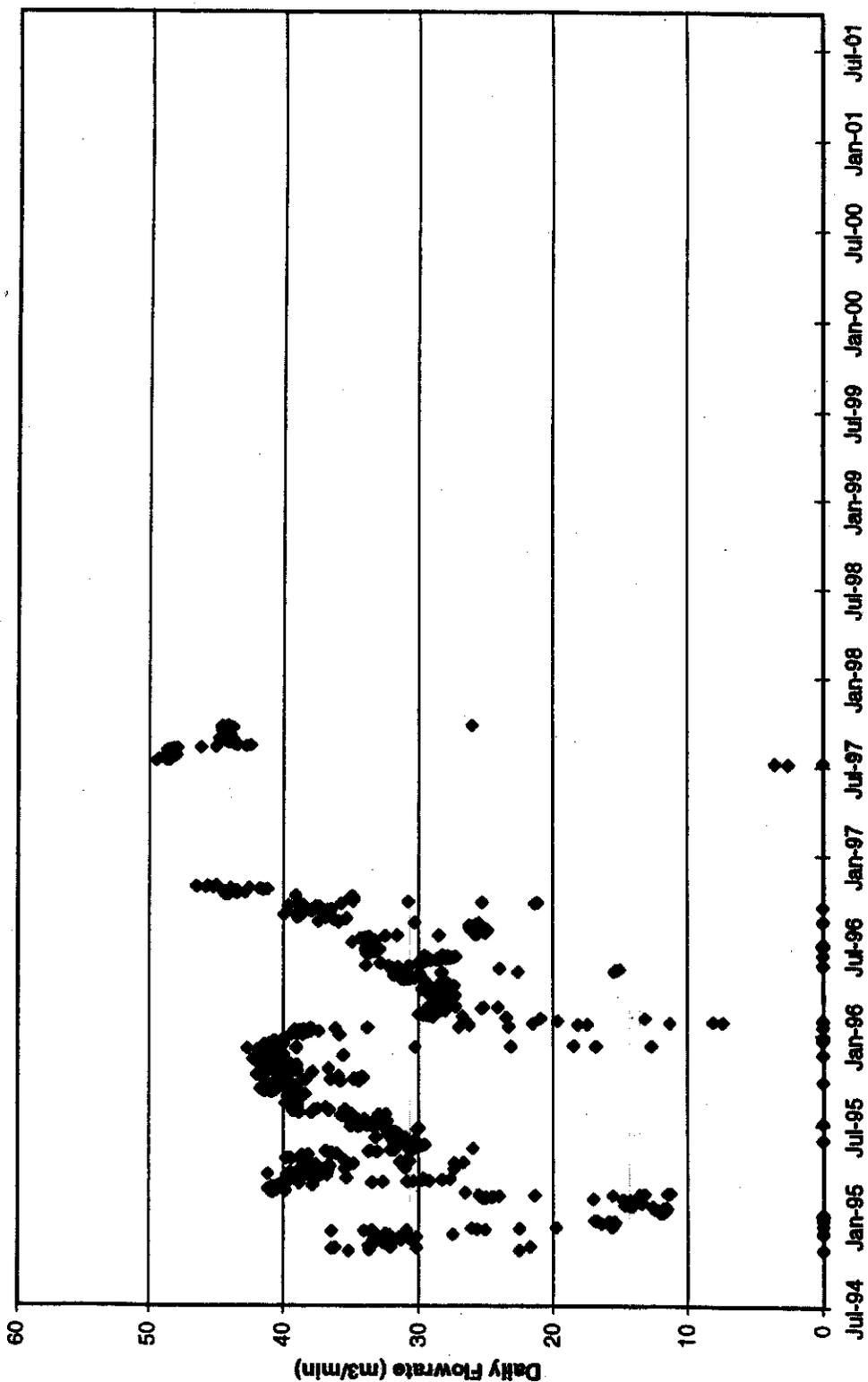


Figure 5-9. Volume of Vapor Processed by the 14.2-m³/min Soil Vapor Extraction System, June 1994 - September 2001.

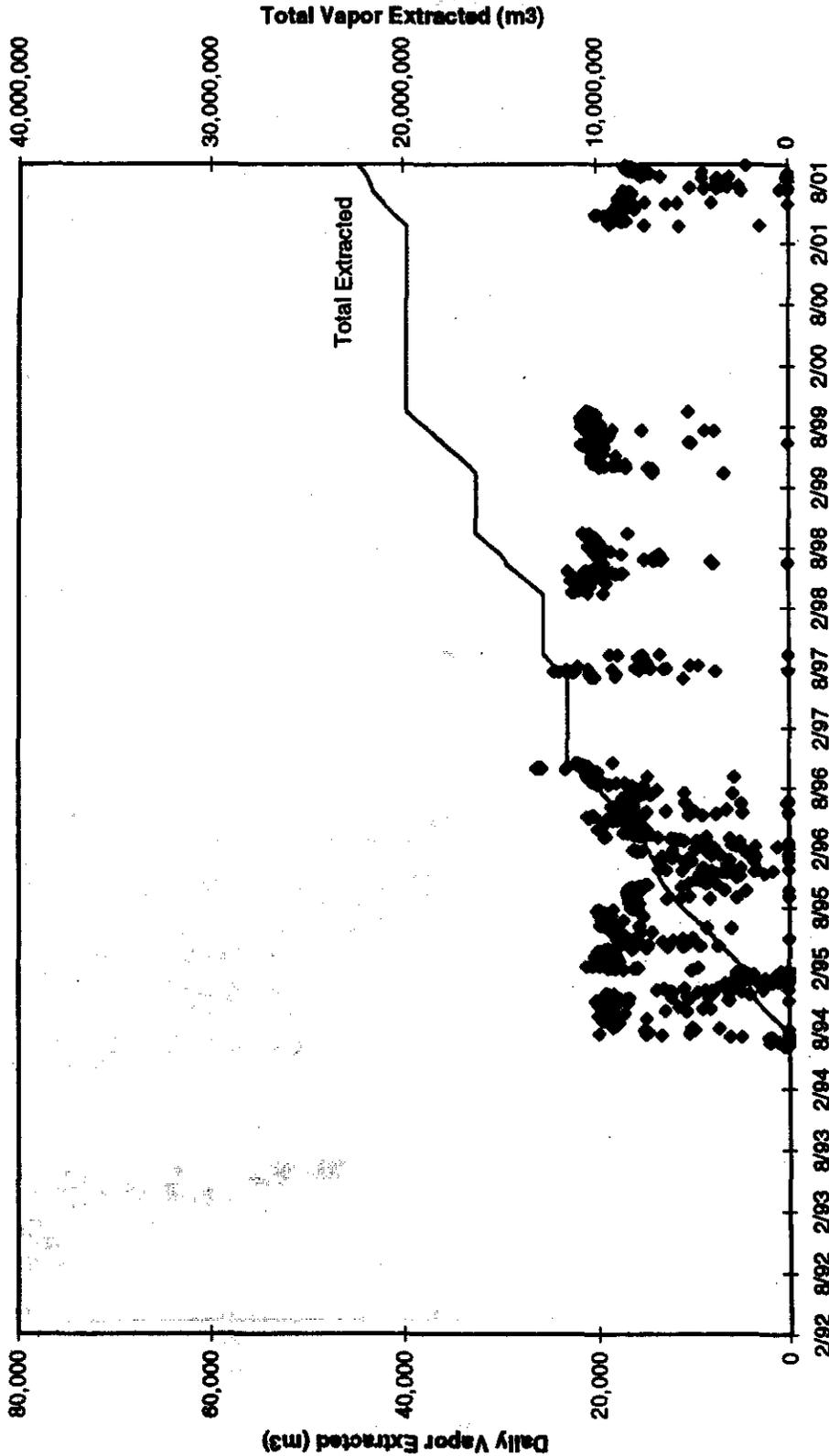
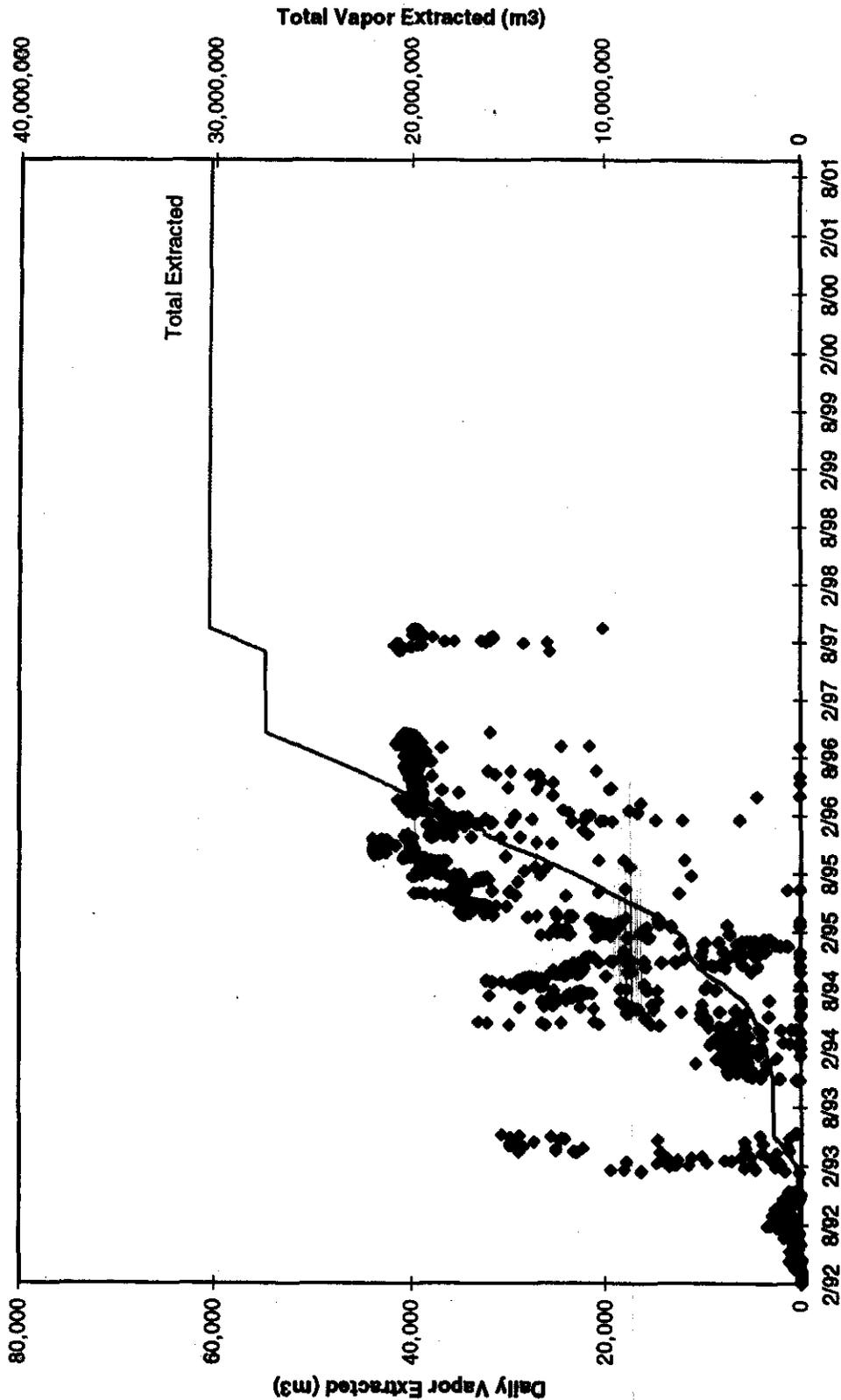


Figure 5-10. Volume of Vapor Processed by the 28.3-m³/min Soil Vapor Extraction System, February 1992 - September 2001.



Soil Vapor Extraction System Operating Data

Figure 5-11. Volume of Vapor Processed by the 42.5-m³/min Soil Vapor Extraction System, March 1993 - September 2001.

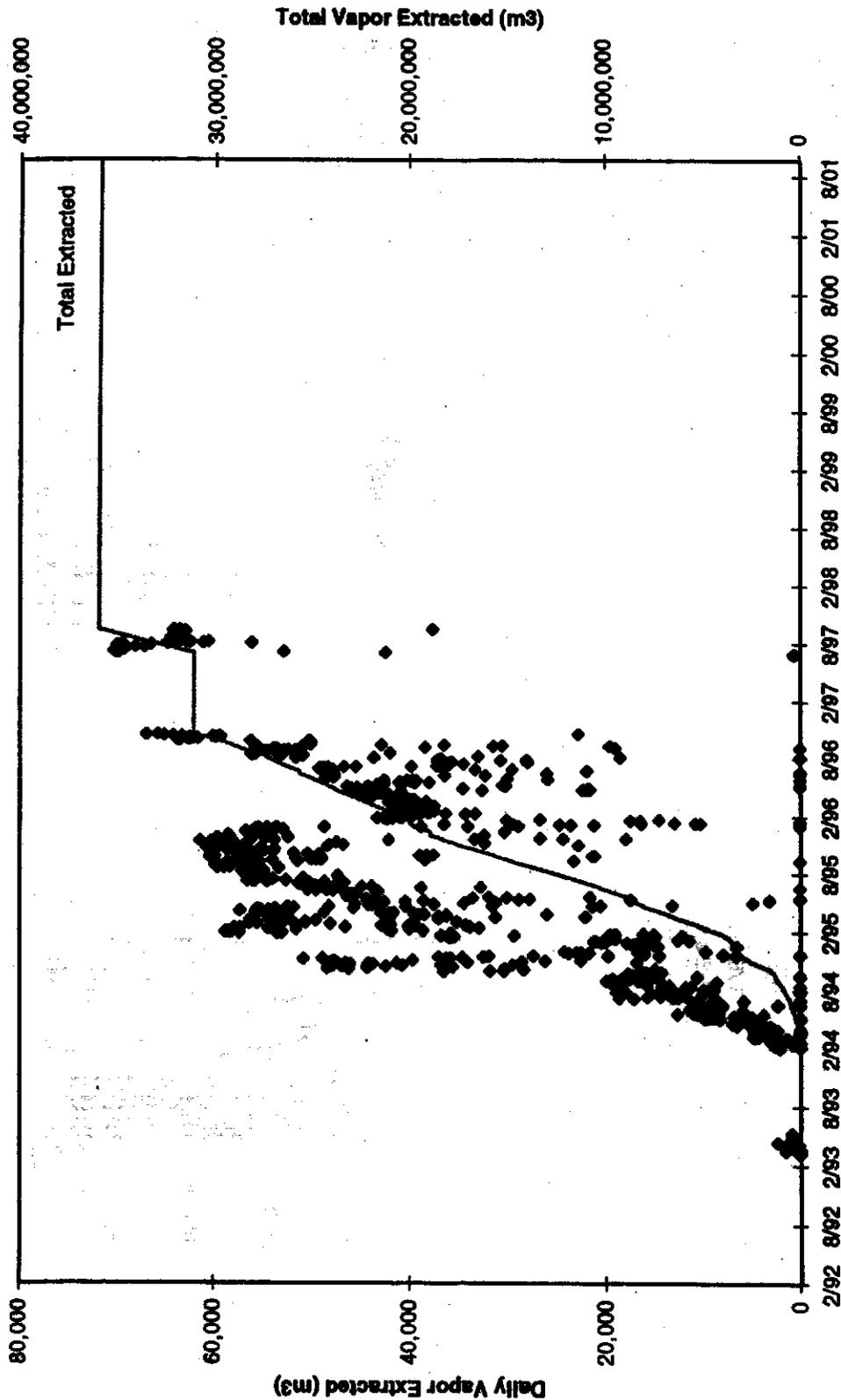
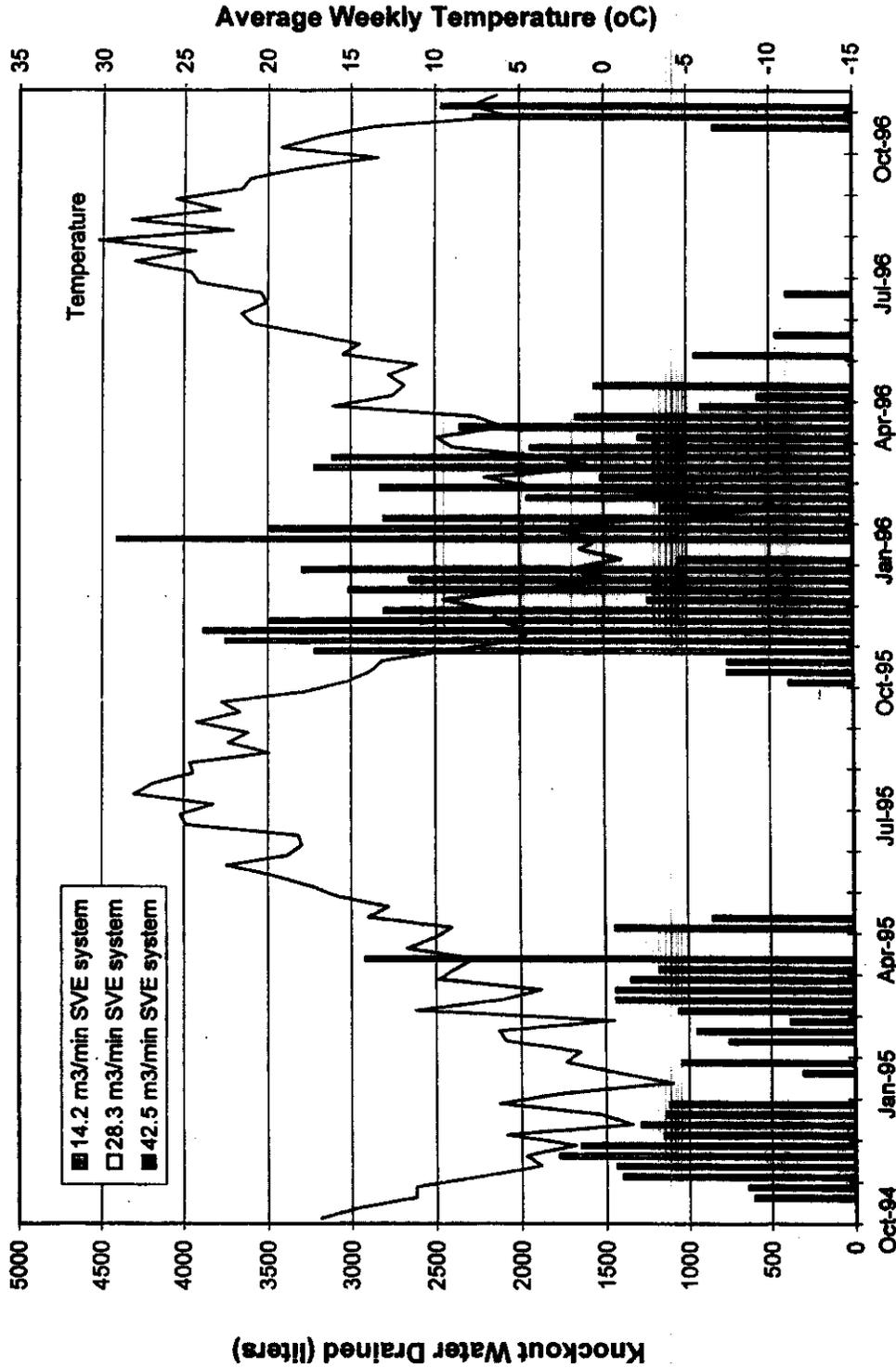


Figure 5-12. Weekly Volume of Knockout Water Drained from Soil Vapor Extraction Systems, October 1994 - September 1997.



Soil Vapor Extraction System Operating Data

Figure 5-13. Ratio of Cumulative Volume of Knockout Water Drained to Cumulative Volume of Vapor Extracted for Each Soil Vapor Extraction System, October 1994 - April 1995; October 1995 - June 1996; and October 1996.

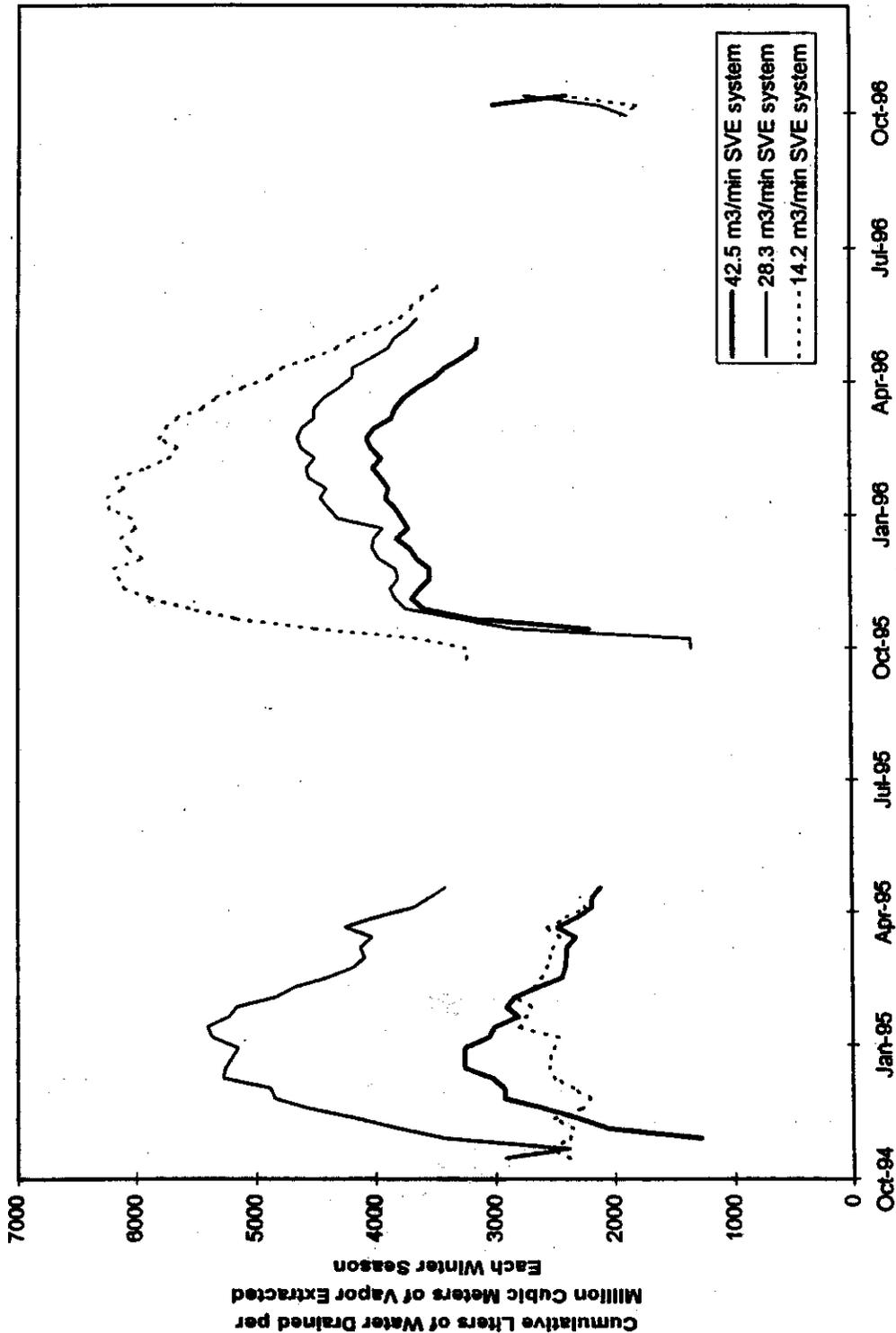


Figure 5-14. Comparison of Carbon Tetrachloride Concentrations Measured at the Soil Vapor Extraction System Inlet to Volume of Vapor Extracted at the 216-Z-1A/Z-18/Z-12 Wellfield, February 1992 - September 2001.

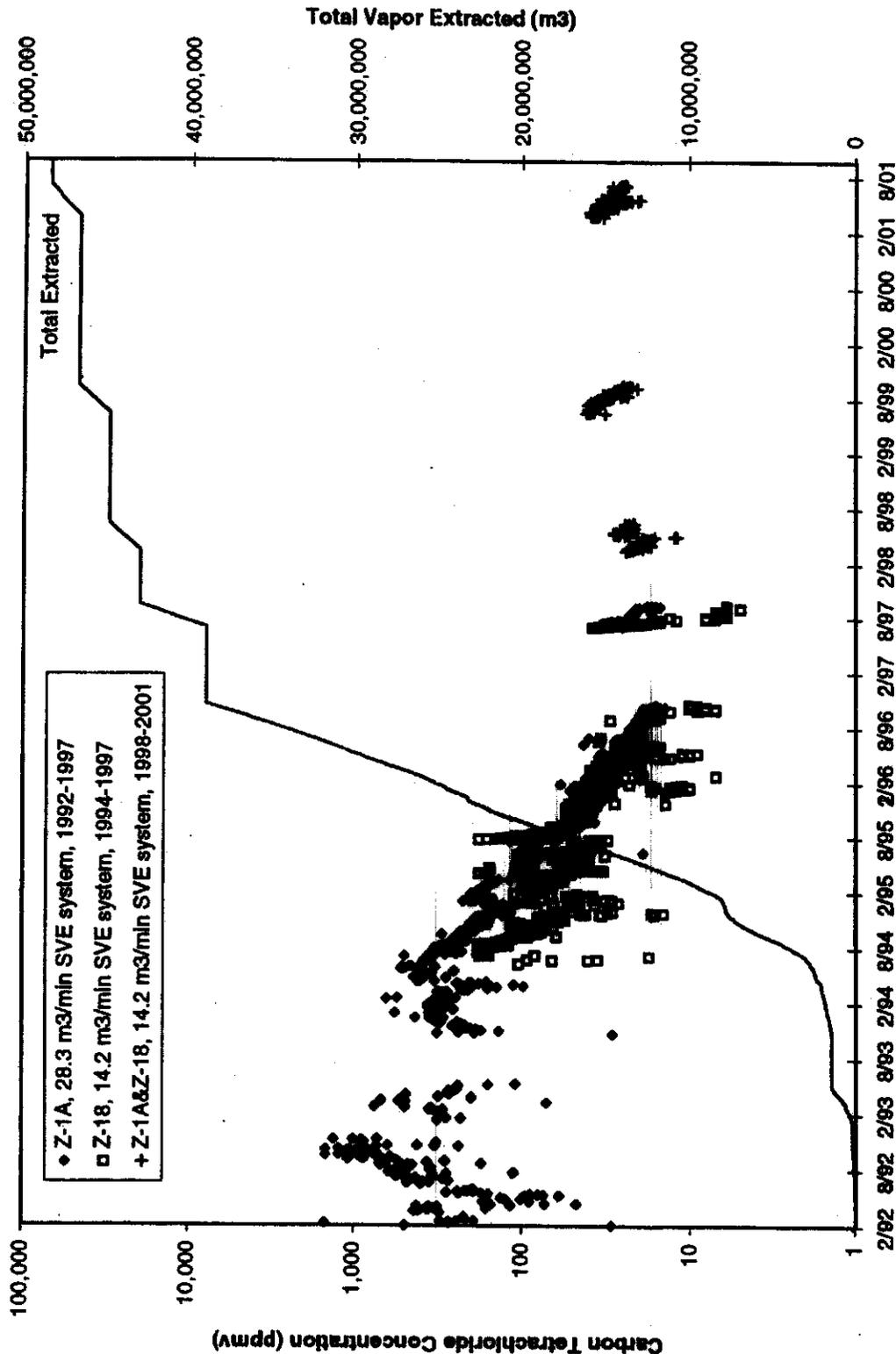


Figure 5-15. Comparison of Carbon Tetrachloride Concentrations Measured at the Soil Vapor Extraction System Inlet to Volume of Vapor Extracted at the 216-Z-9 Wellfield, March 1993 - September 2001.

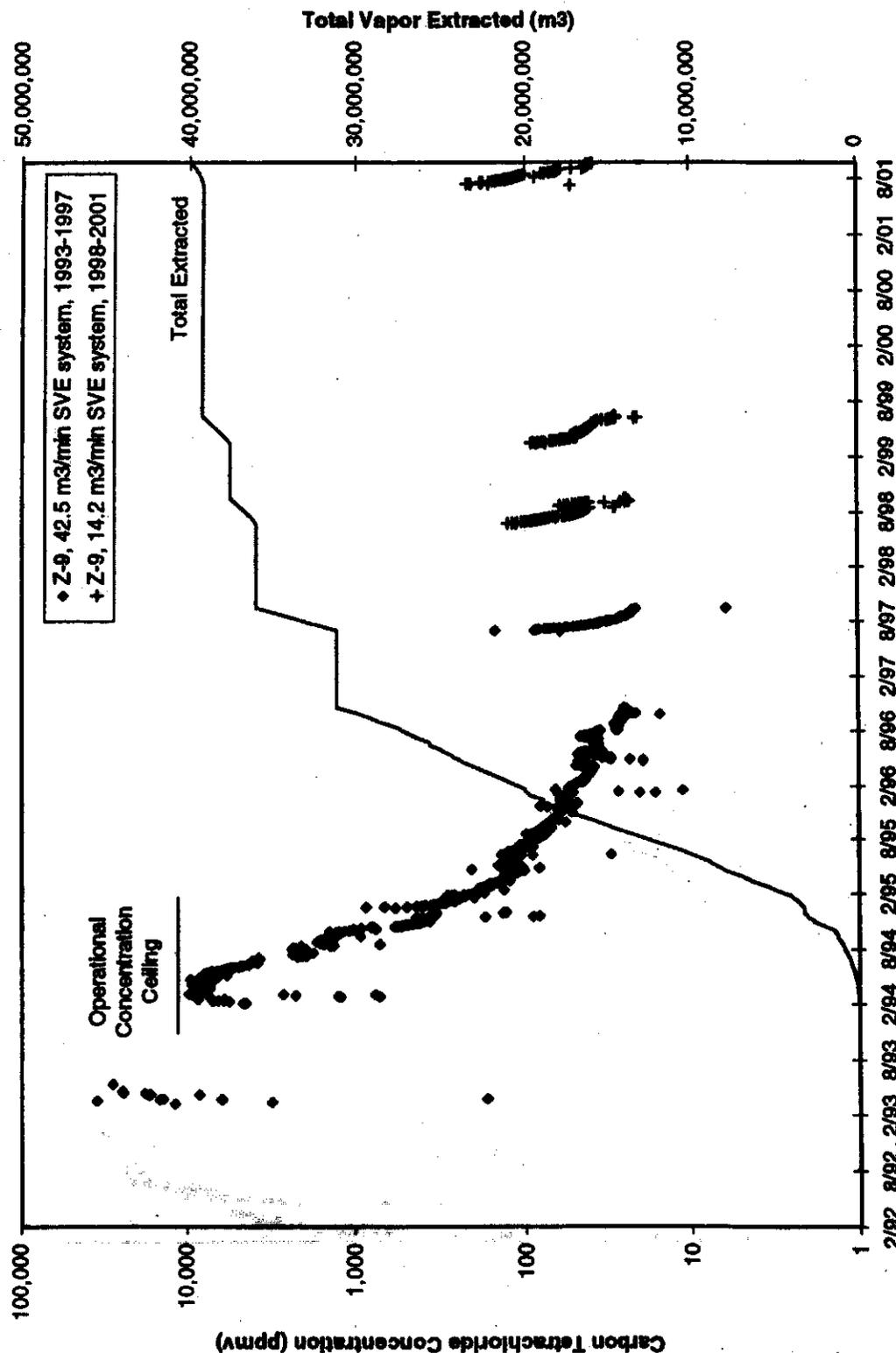
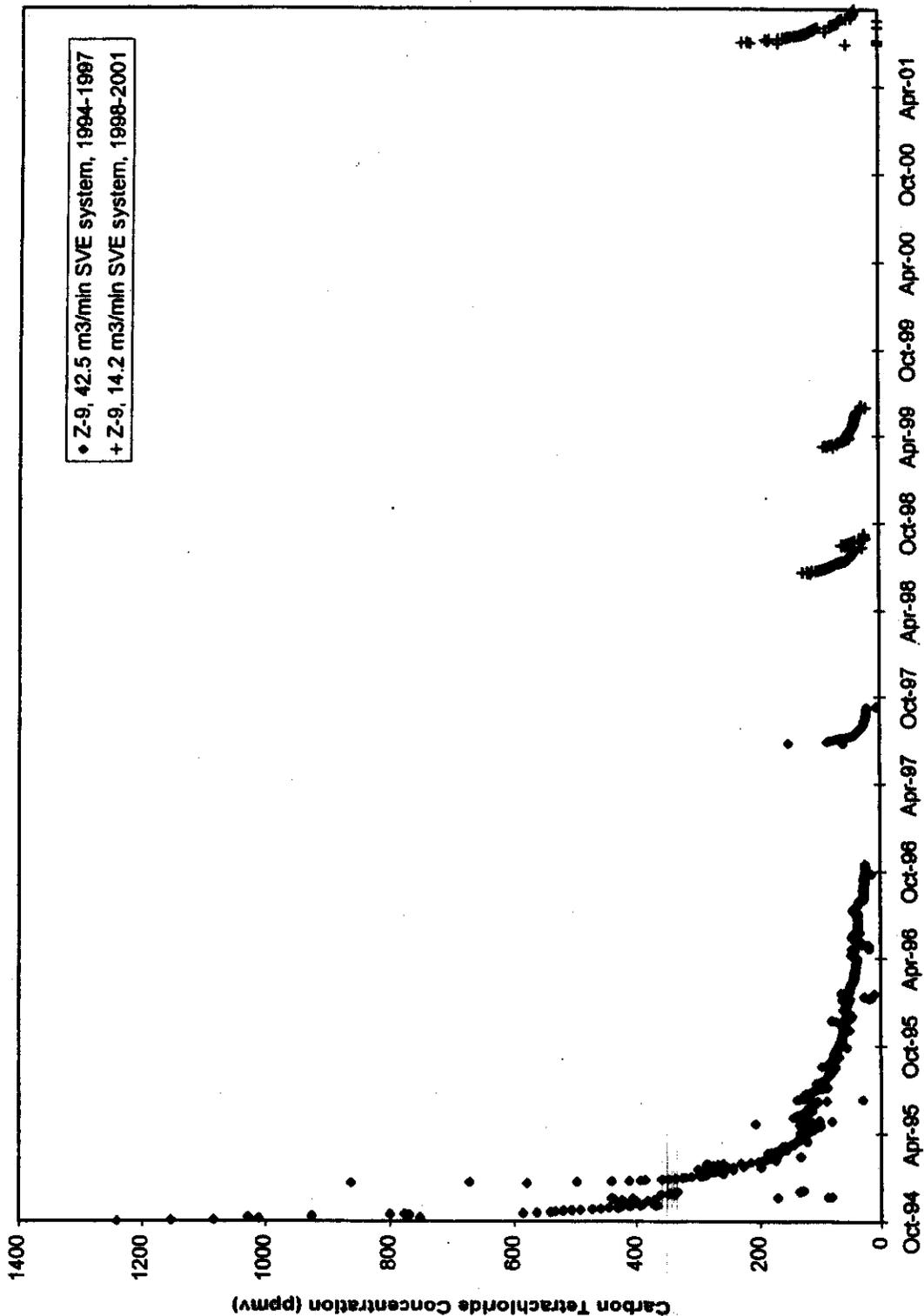


Figure 5-16. Carbon Tetrachloride Concentrations Measured at the Soil Vapor Extraction System Inlet During Extraction at the 216-Z-9 Wellfield During 24-hr/day Operations, October 1994 - September 2001.



Soil Vapor Extraction System Operating Data

Figure 5-17. Carbon Tetrachloride Concentrations Measured at the 14.2-m³/min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-1A/Z-18/Z-12 Wellfield, April 1998 - June 1998.

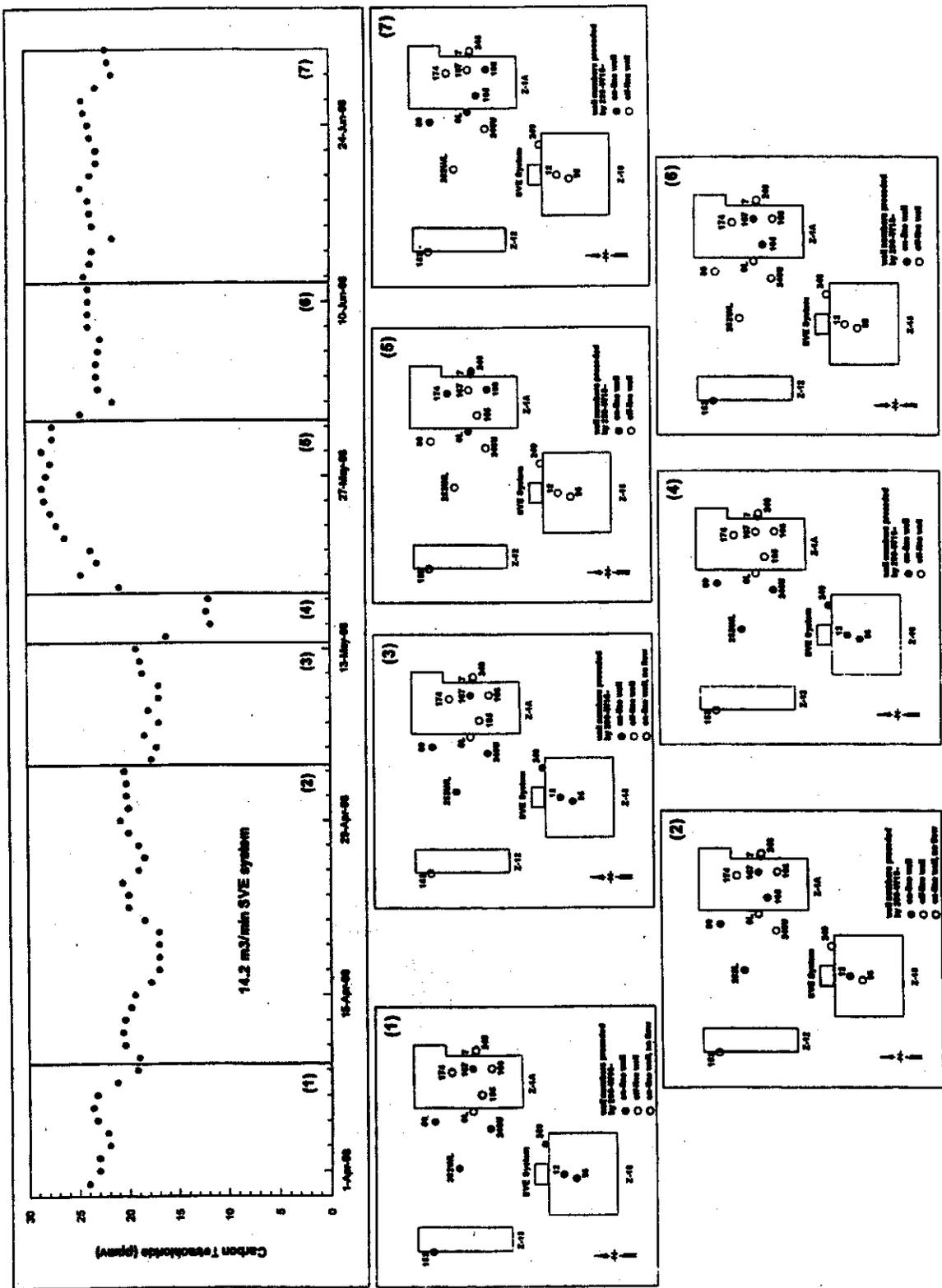


Figure 5-18. Carbon Tetrachloride Concentrations Measured at the 14.2-m³/min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-9 Wellfield, July 1998 – September 1998.

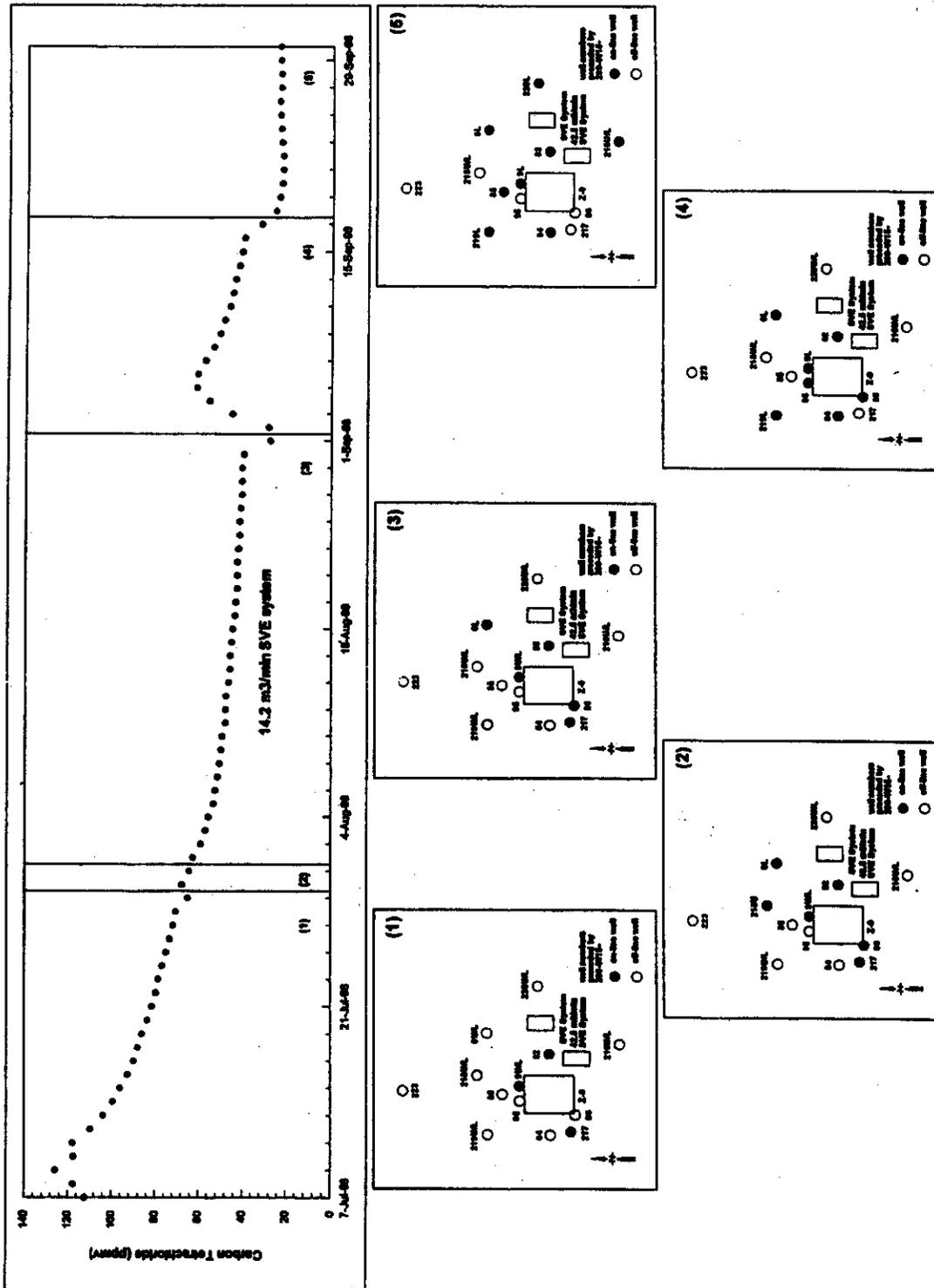


Figure 5-19. Comparison of Carbon Tetrachloride Concentrations and Mass Removal Rates Using the 14.2-m³/min Soil Vapor Extraction System, April 1998 – September 1998.

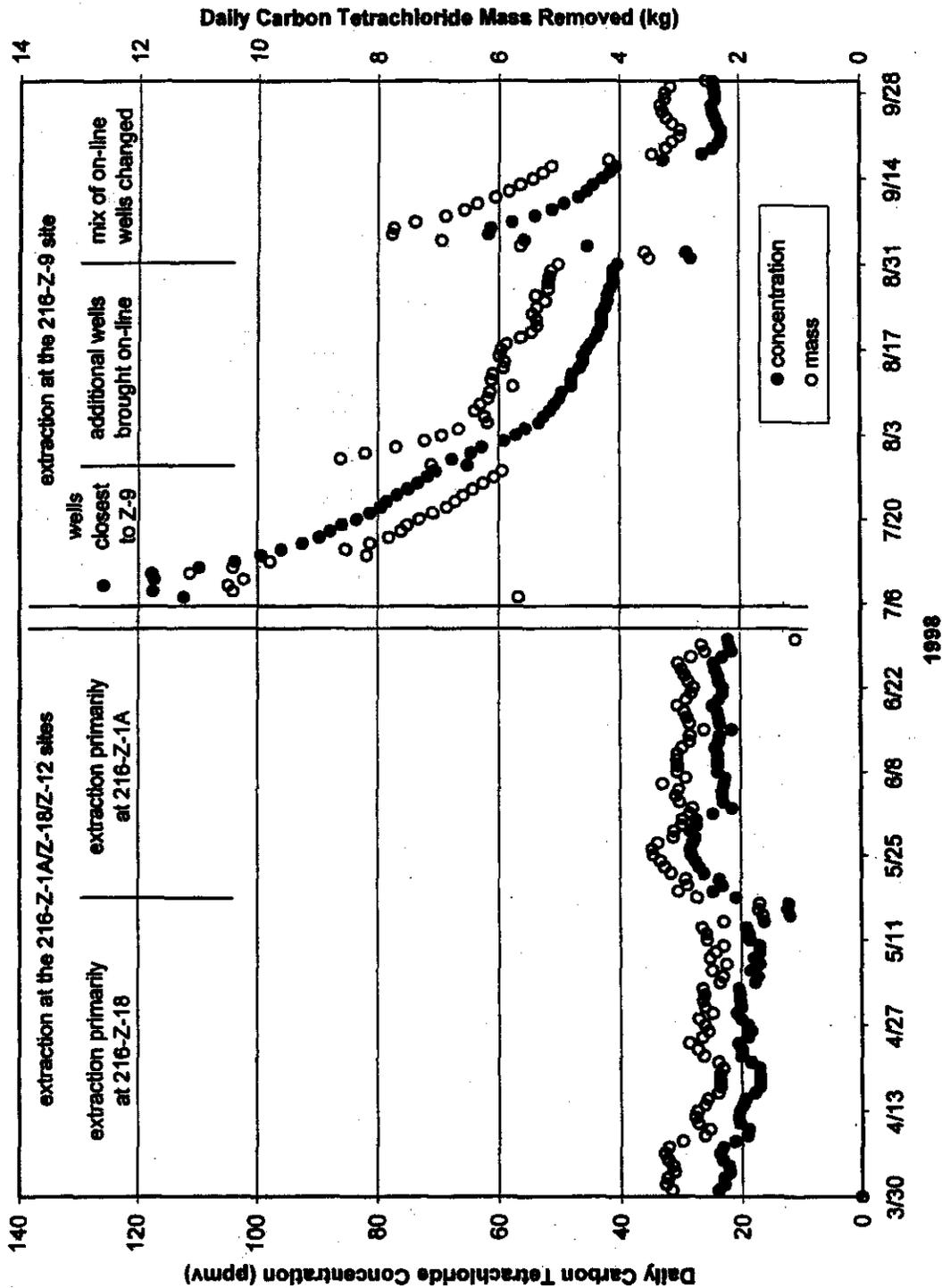
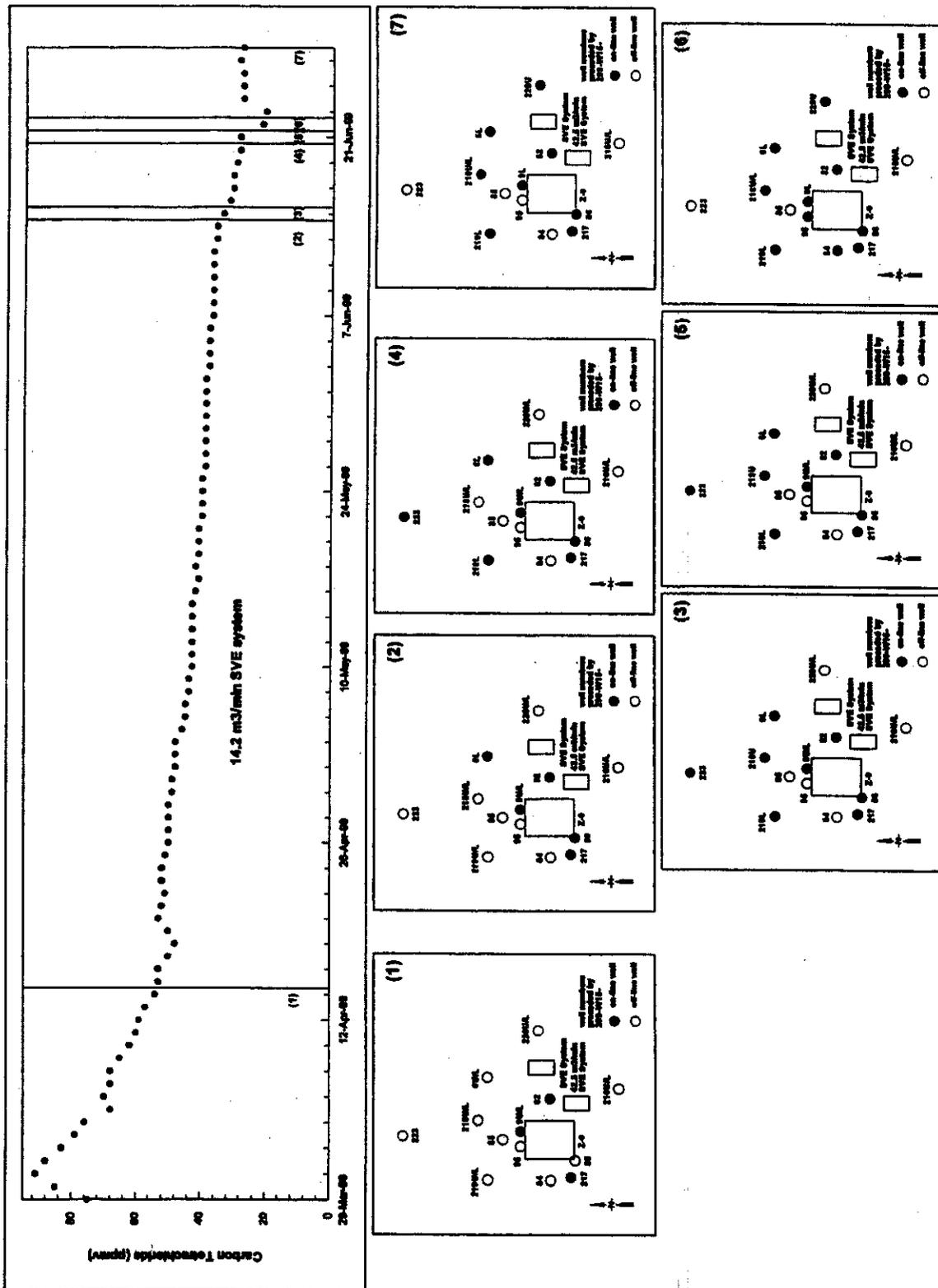


Figure 5-20. Carbon Tetrachloride Concentrations Measured at the 14.2-m³/min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-9 Wellfield, April 1999 – June 1999.



Soil Vapor Extraction System Operating Data

Figure 5-21. Carbon Tetrachloride Concentrations Measured at the 14.2-m³/min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-1A/Z-18/Z-12 Wellfield, July 1999 – September 1999.

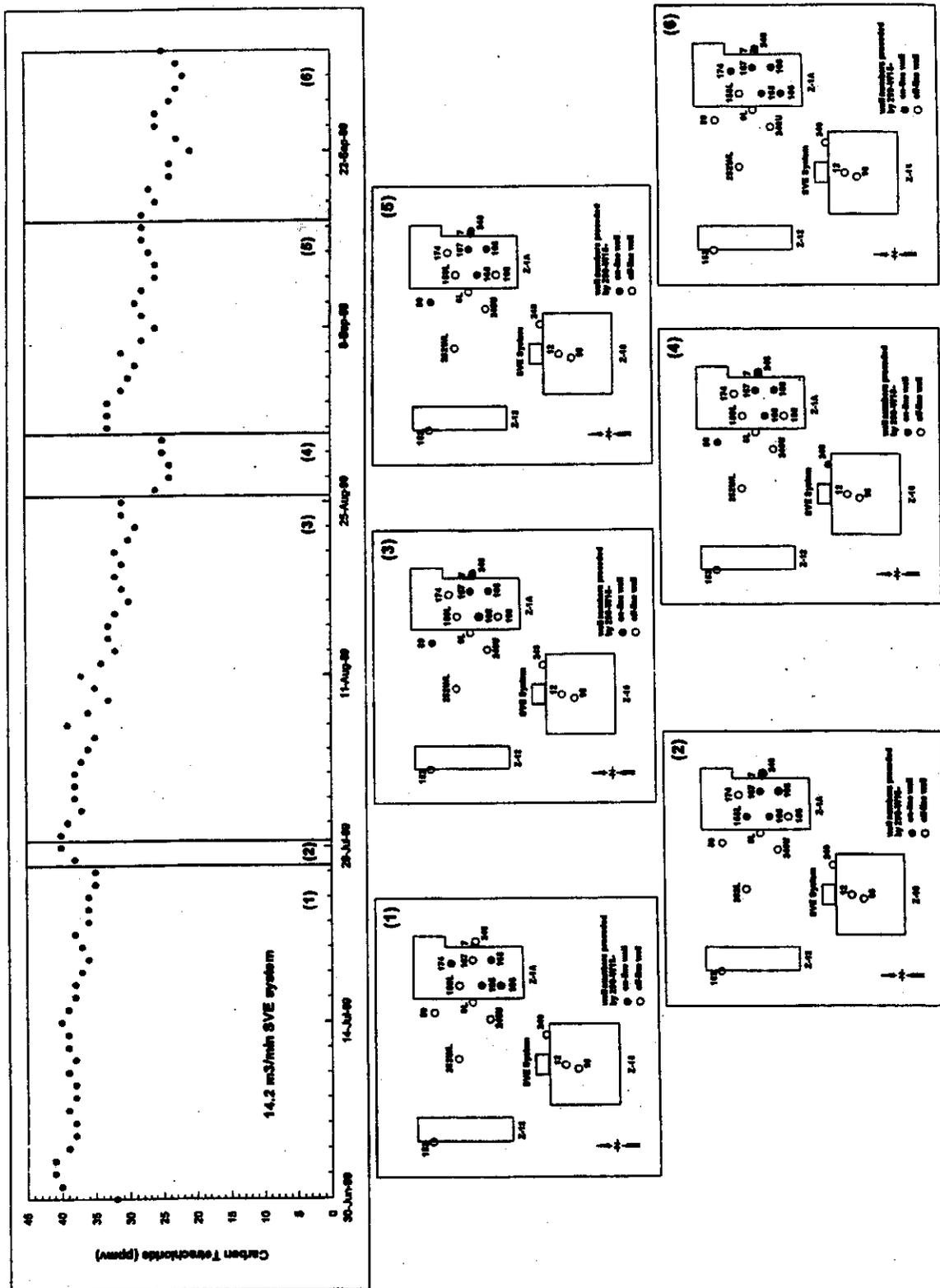
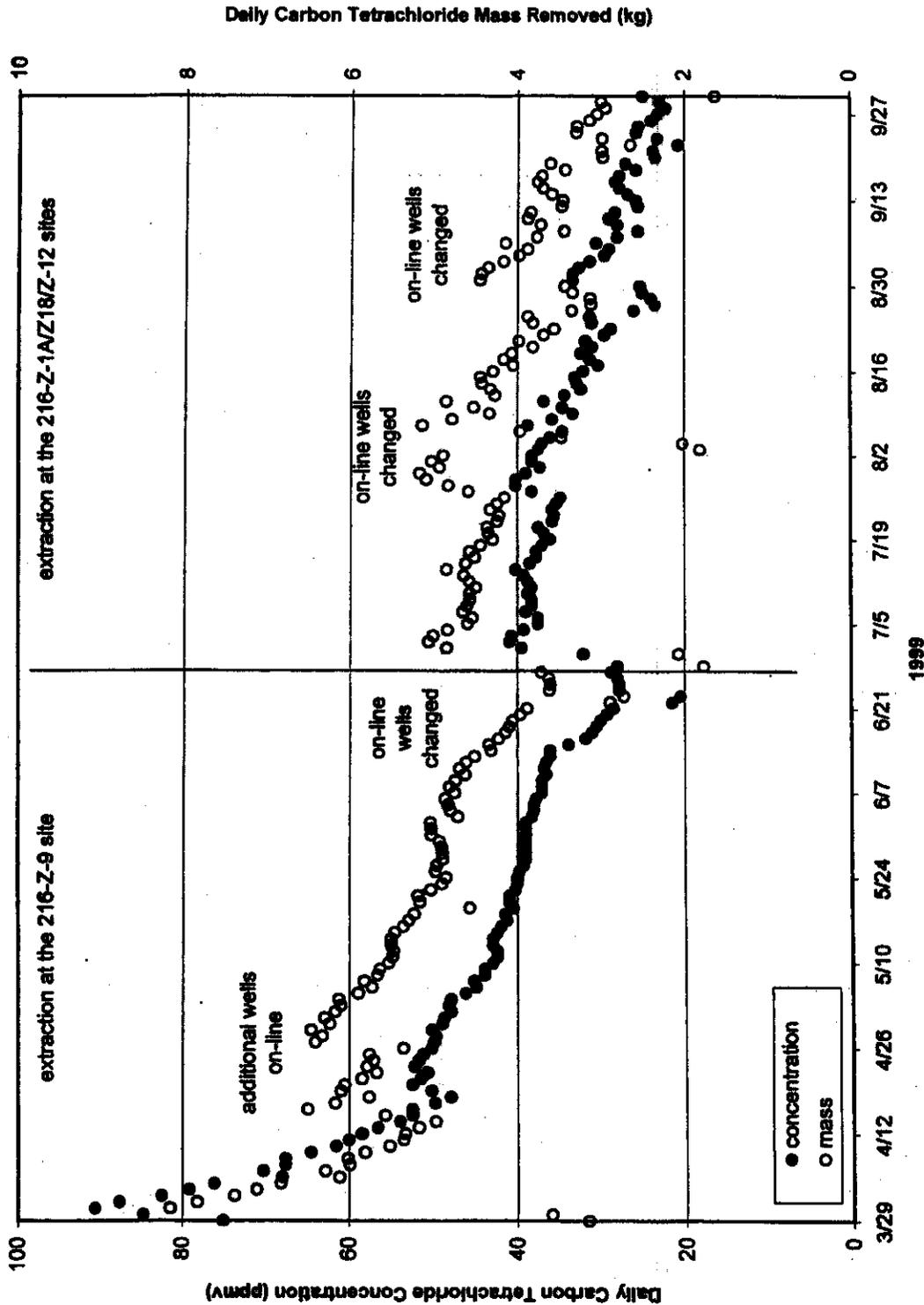


Figure 5-22. Comparison of Carbon Tetrachloride Concentrations and Mass Removal Rates Using the 14.2-m³/min Soil Vapor Extraction System, April 1999 – September 1999.



Soil Vapor Extraction System Operating Data

Figure 5-23. Carbon Tetrachloride Concentrations Measured at the 14.2-m³/min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-1A/Z-18/Z-12 Wellfield, April 2001 – July 2001.

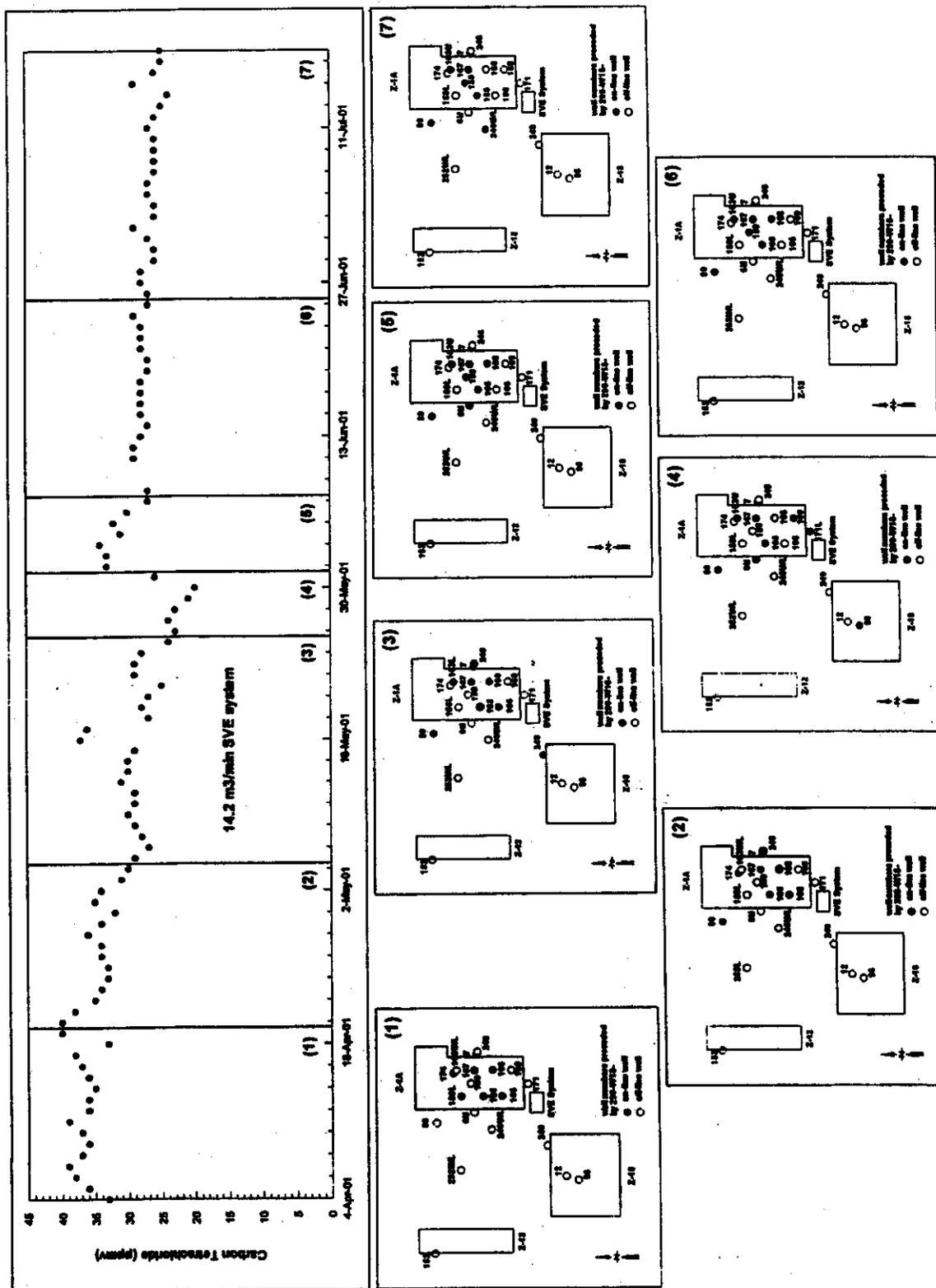
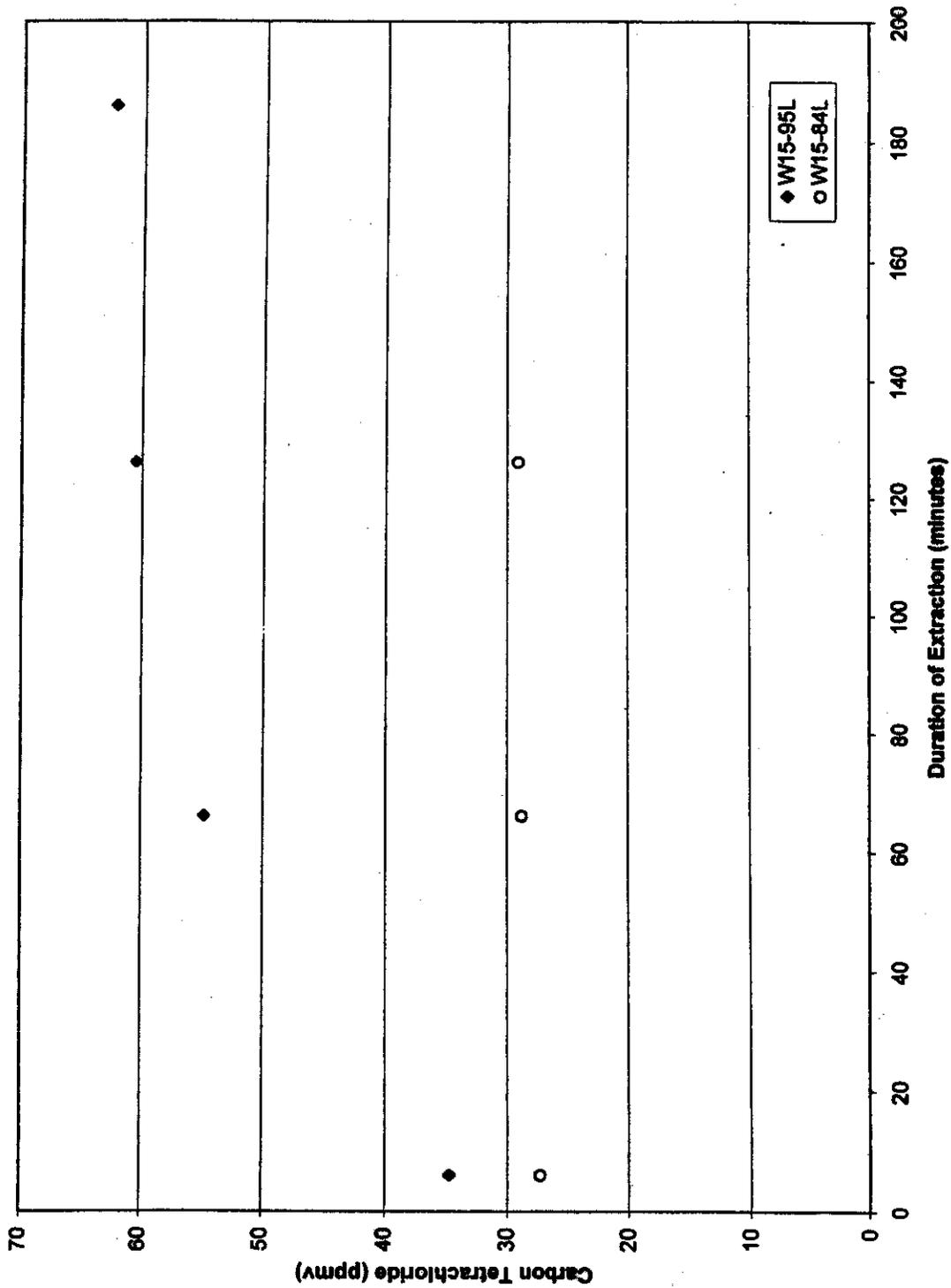


Figure 5-24. Carbon Tetrachloride Concentrations Measured During Initial Soil Vapor Extraction Tests at New Screened Intervals in Wells 299-W15-84L and 299-W15-95L, July 2001.



Soil Vapor Extraction System Operating Data

Figure 5-25a. Comparison of Carbon Tetrachloride Concentrations in Soil Vapor Sampled During Drilling and Soil Vapor Extracted Using the Soil Vapor Extraction System at Well 299-W15-95L.

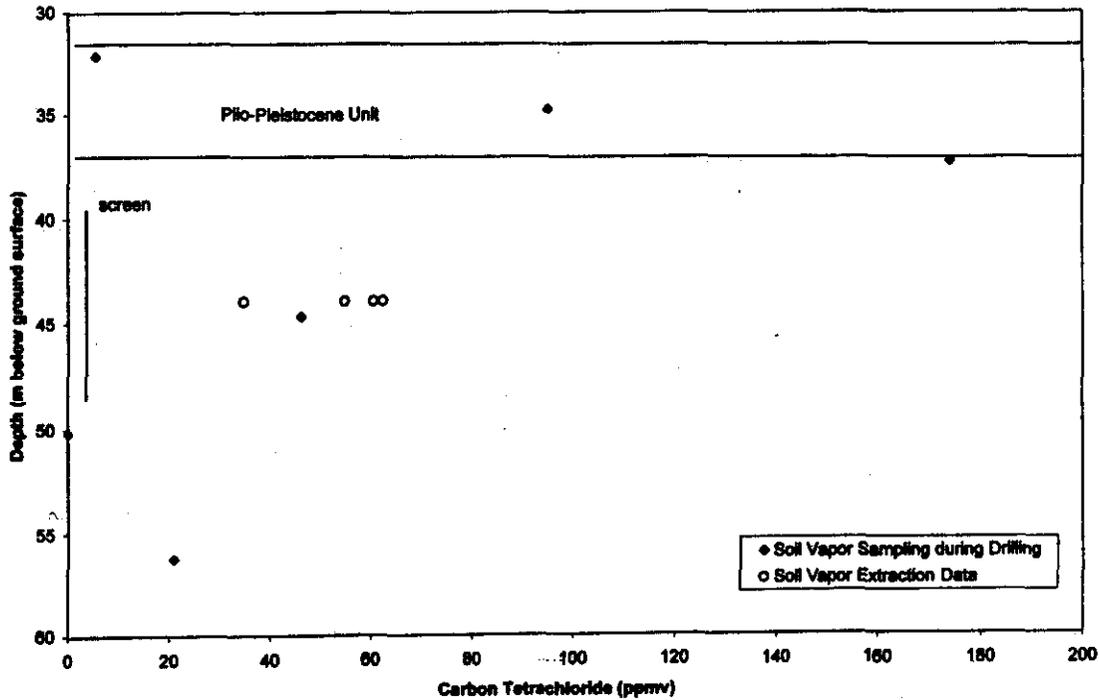


Figure 5-25b. Comparison of Carbon Tetrachloride Concentrations in Soil Vapor Sampled During Drilling and Soil Vapor Extracted Using the Soil Vapor Extraction System at Well 299-W15-84L.

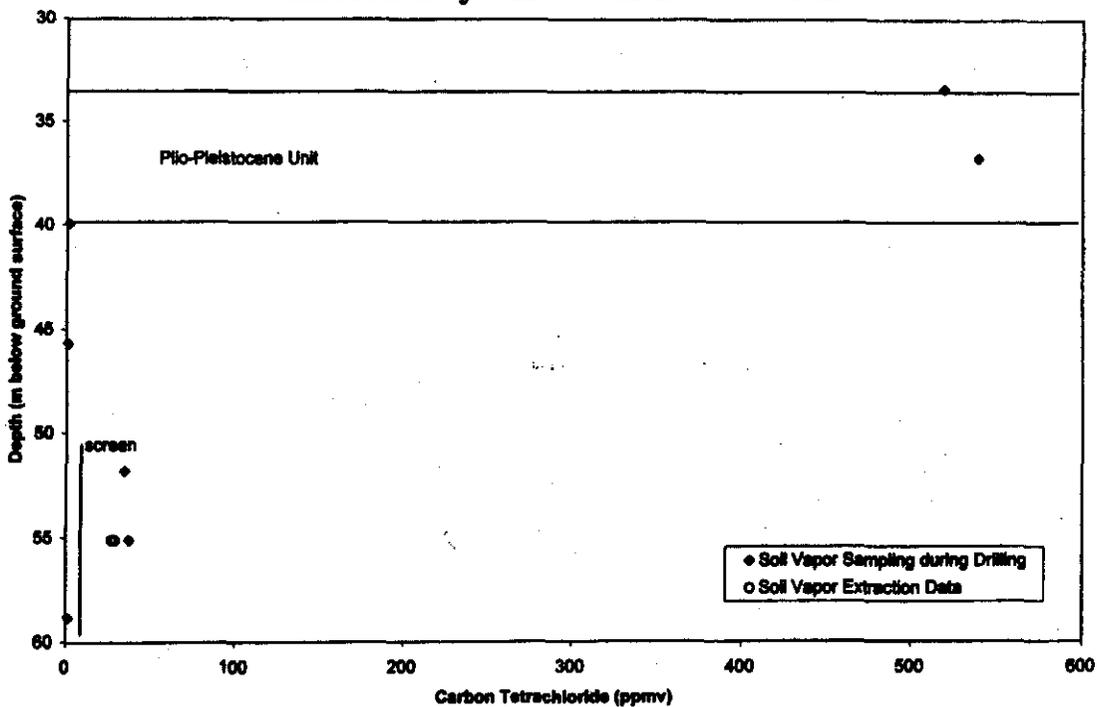


Figure 5-26. Carbon Tetrachloride Concentrations Measured at the 14.2-m³/min Soil Vapor Extraction System Inlet During Extraction at the 216-Z-9 Wellfield, July 2001 – September 2001.

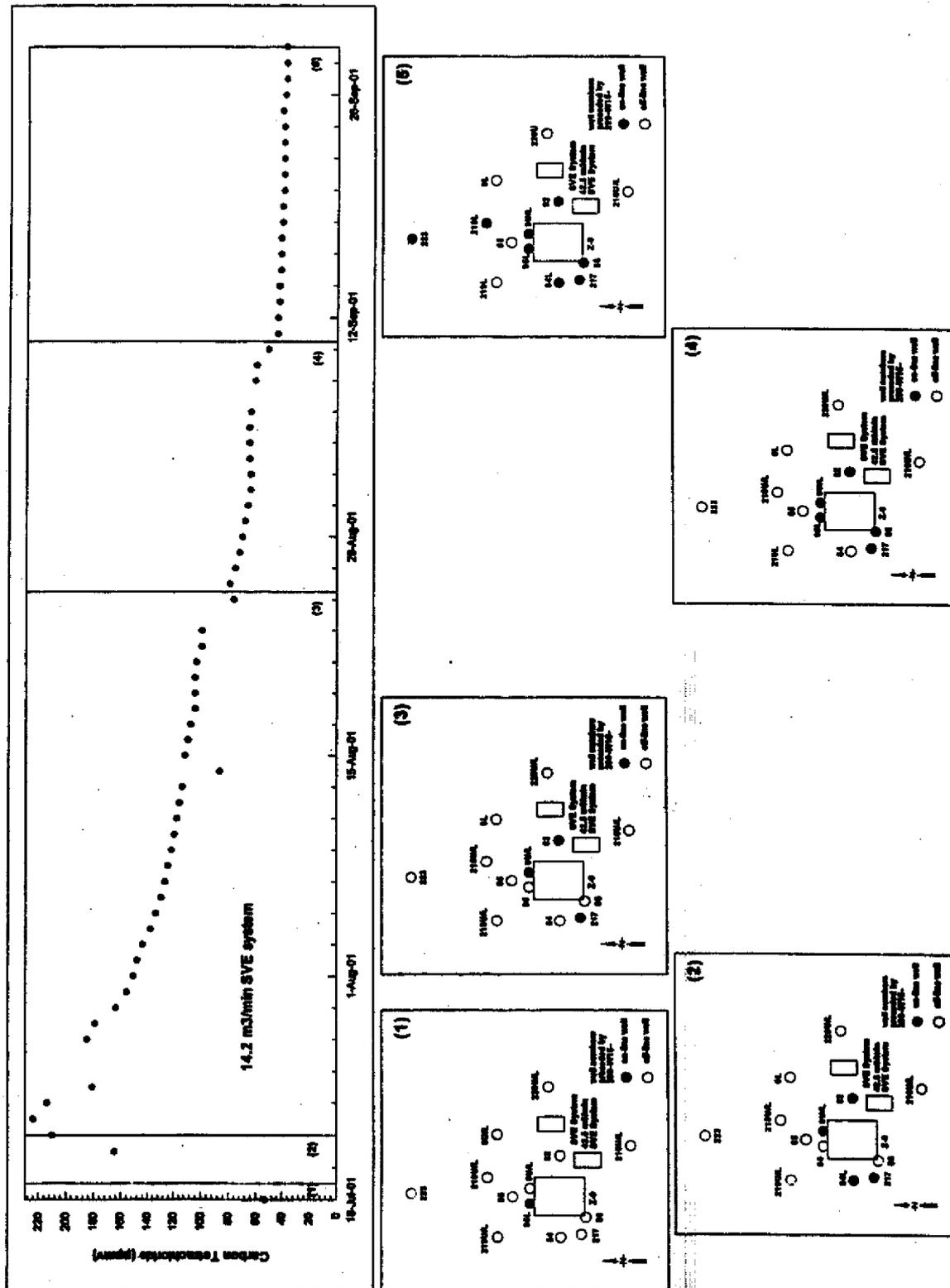


Figure 5-27. Comparison of Carbon Tetrachloride Concentrations and Mass Removal Rates Using the 14.2-m³/min Soil Vapor Extraction System, April 2001 – September 2001.

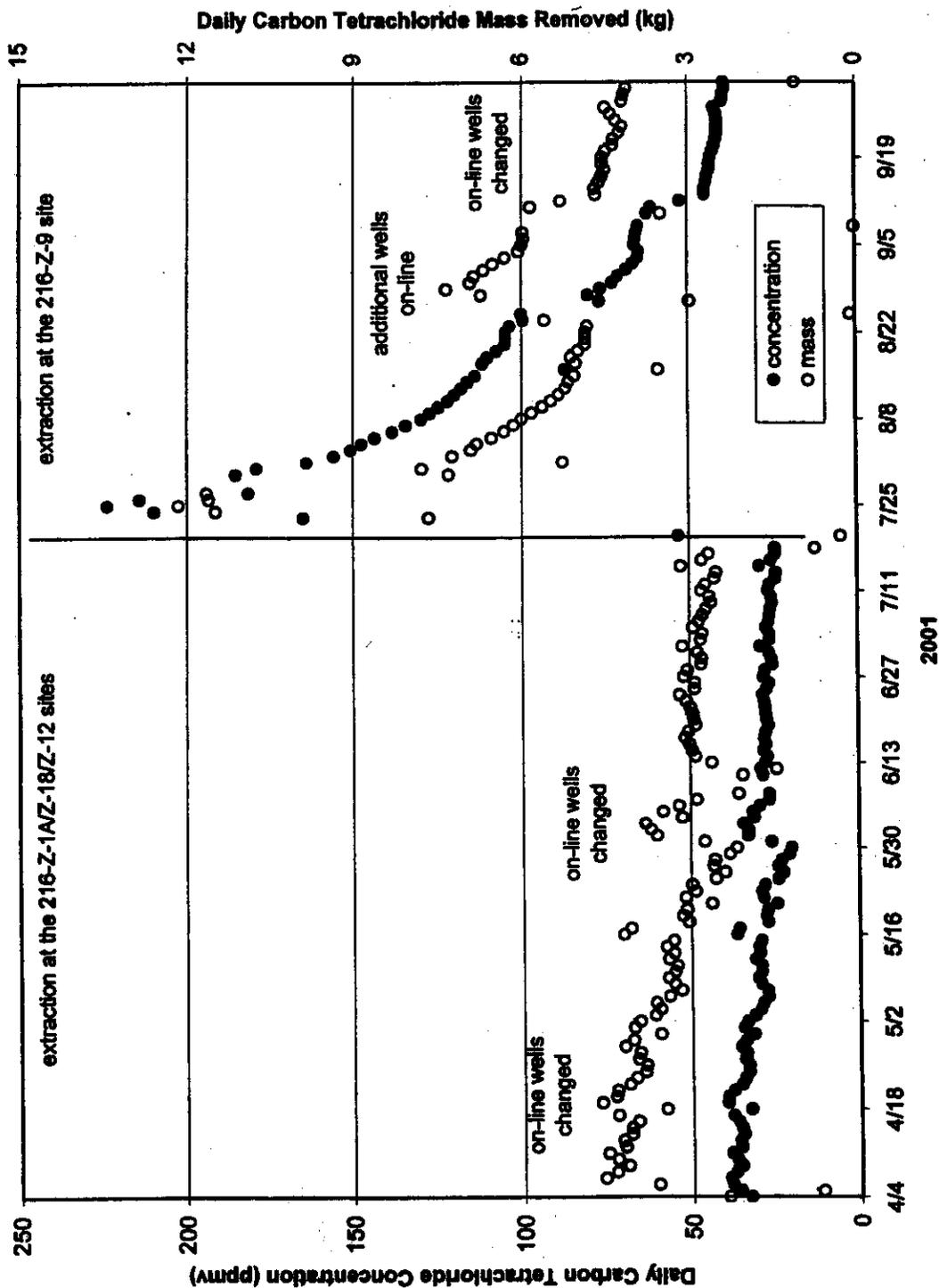


Figure 5-28. Carbon Tetrachloride Concentrations in Vapor Extracted from the 216-Z-9 Site, July 1997 - September 1997, July 1998 - September 1998, April 1999 - June 1999, and July 2001 - September 2001.

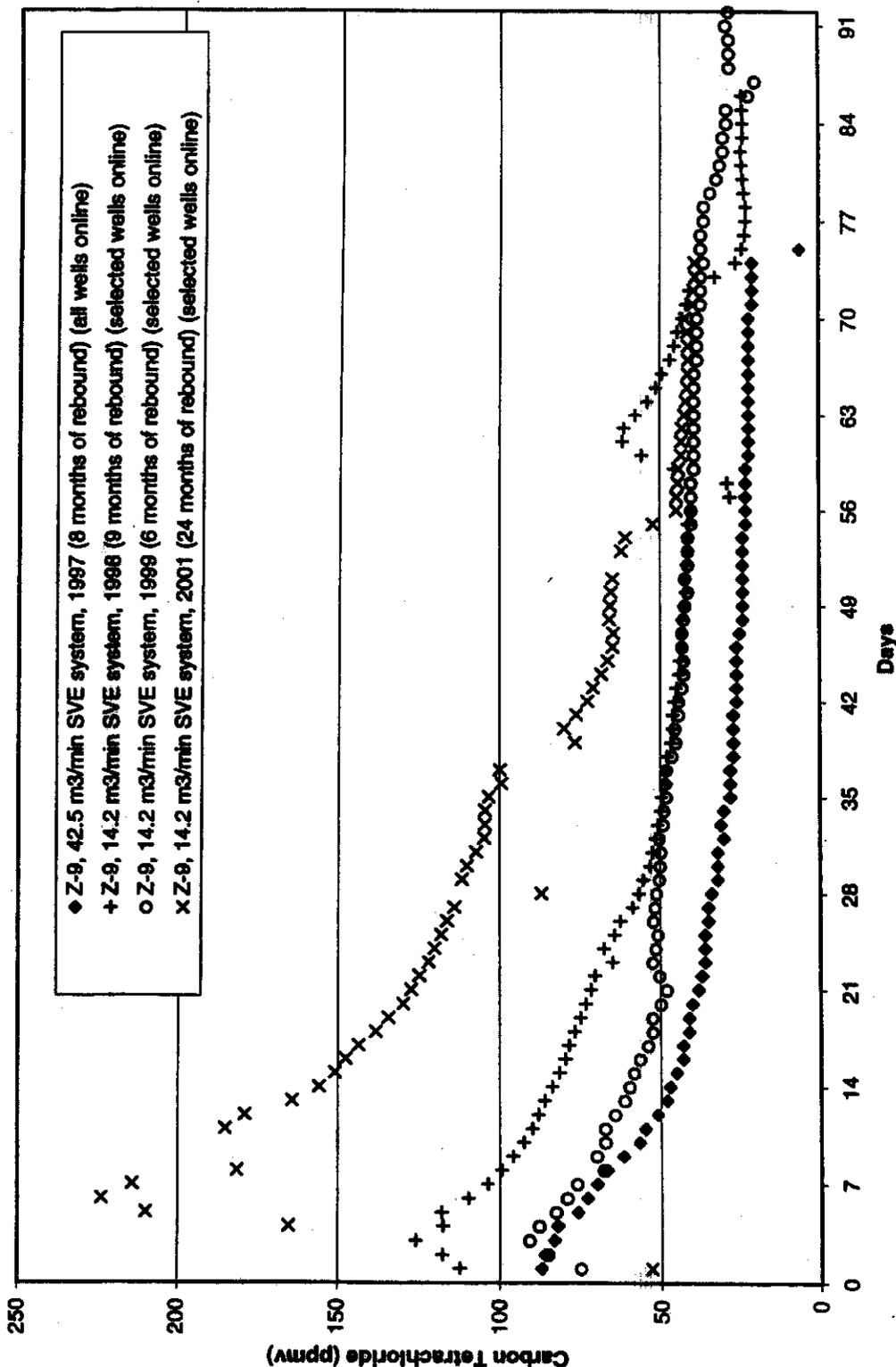


Figure 5-29. Carbon Tetrachloride Concentrations in Vapor Extracted from the 216-Z-18 Site, July 1997 – September 1997 and April 1998 – May 1998.

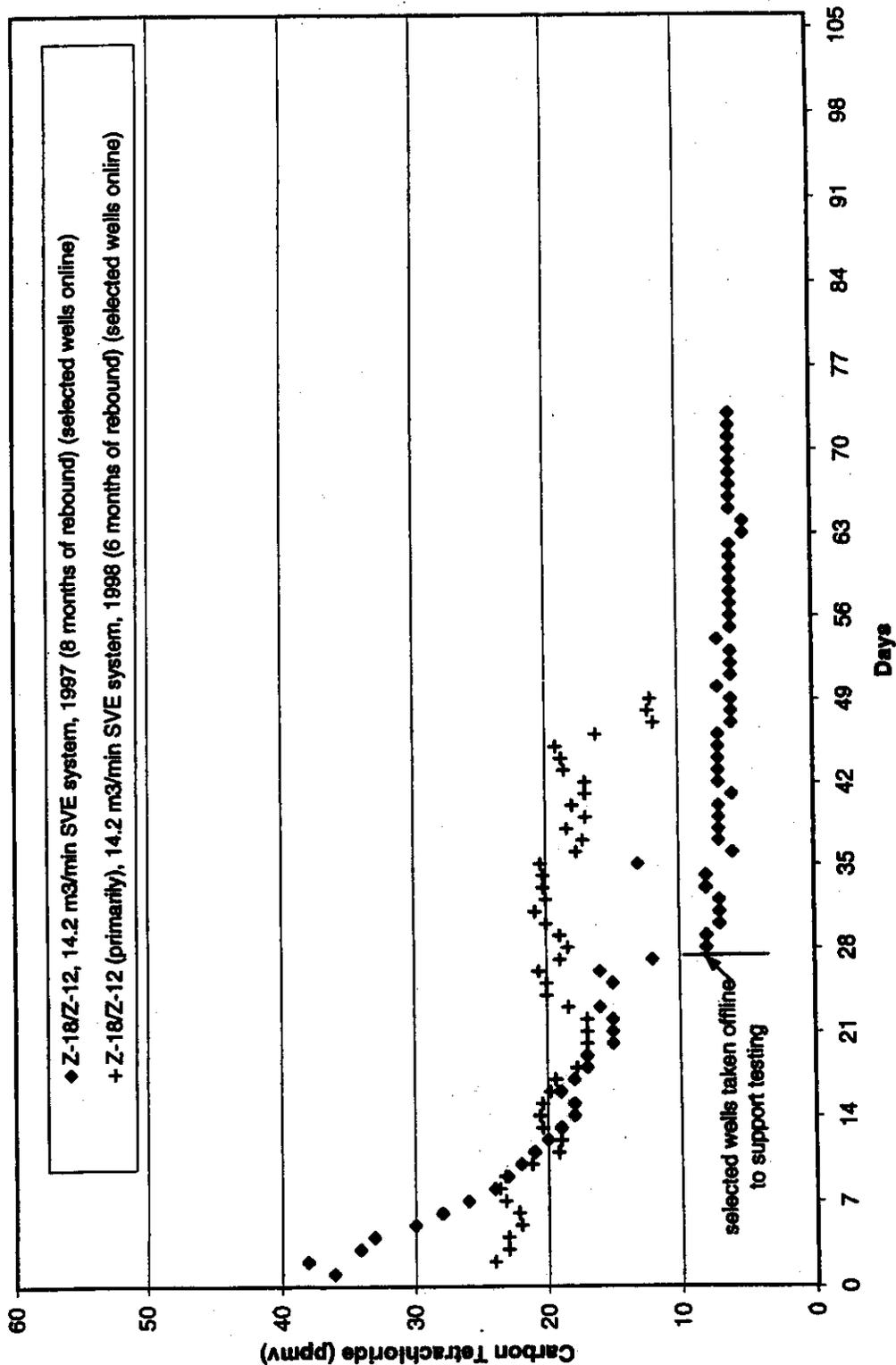


Figure 5-30. Carbon Tetrachloride Concentrations in Vapor Extracted from the 216-Z-1A Site, July 1997 – September 1997, May 1998 – June 1998, July 1999 – September 1999, and April 2001 - July 2001.

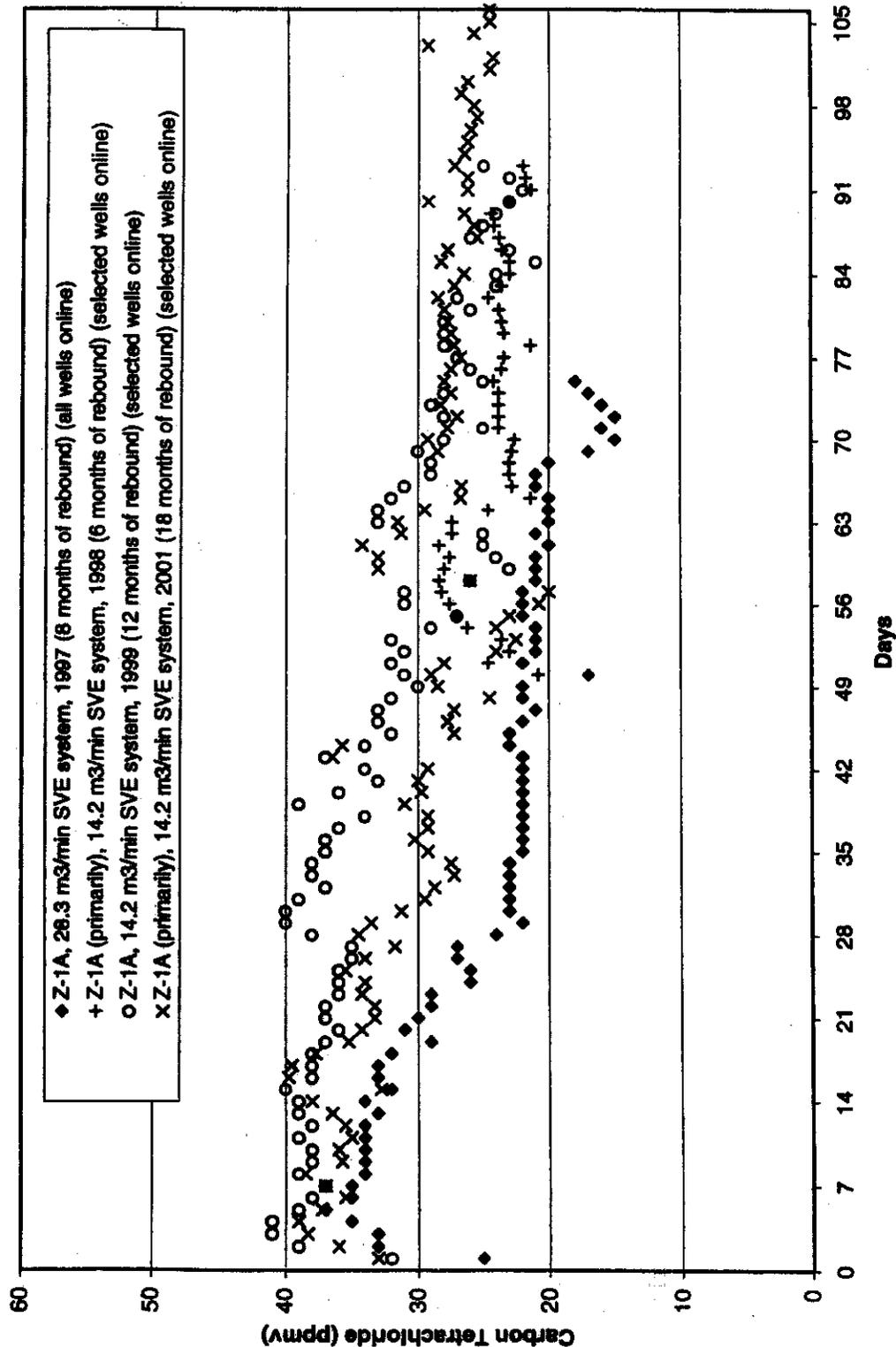


Figure 5-31. Exponential Decay of Carbon Tetrachloride Concentrations, October 1995 Through November 1996.

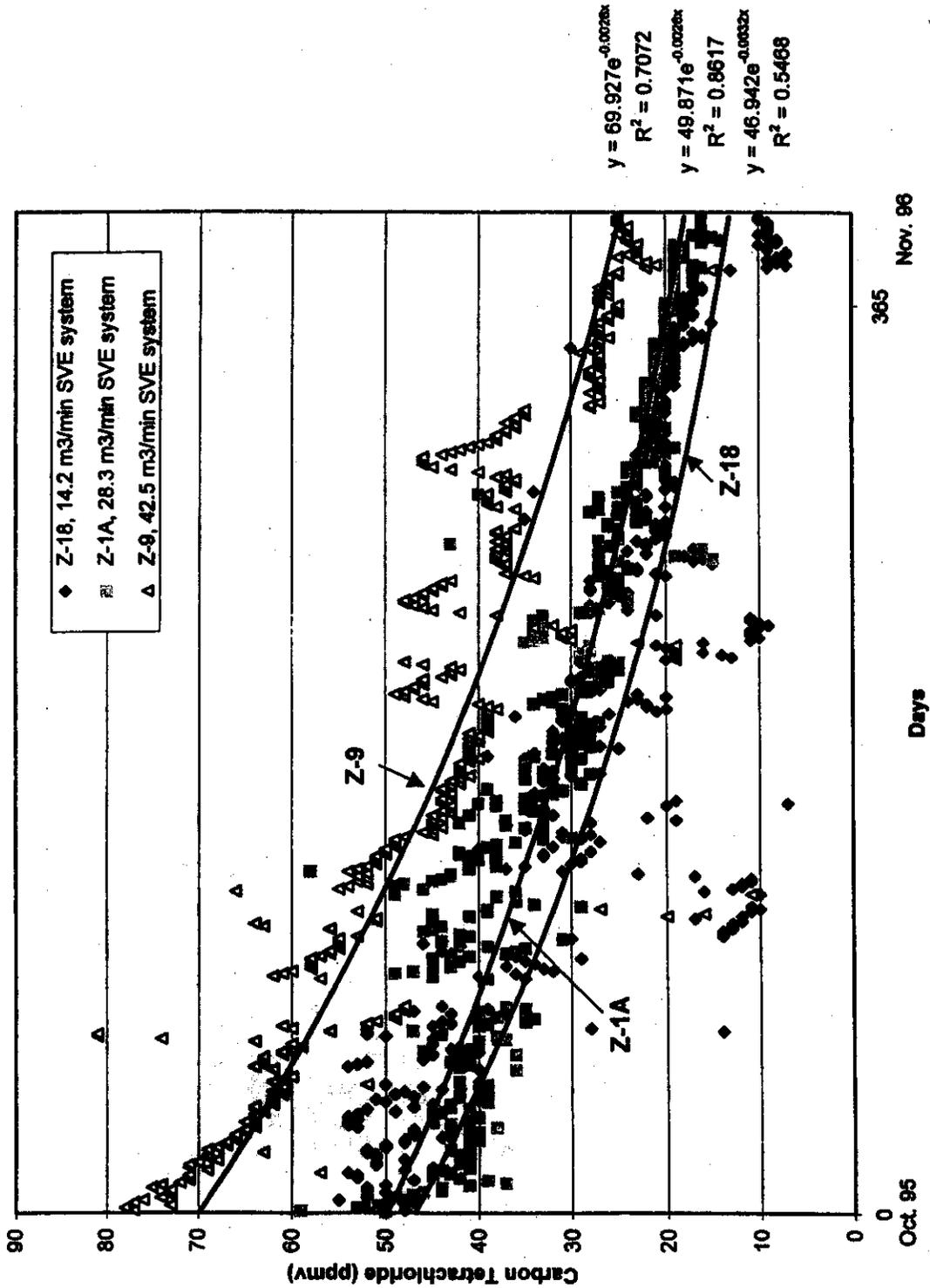


Figure 5-32. Exponential Decay of Carbon Tetrachloride Concentrations, October 1995 Through September 1998.

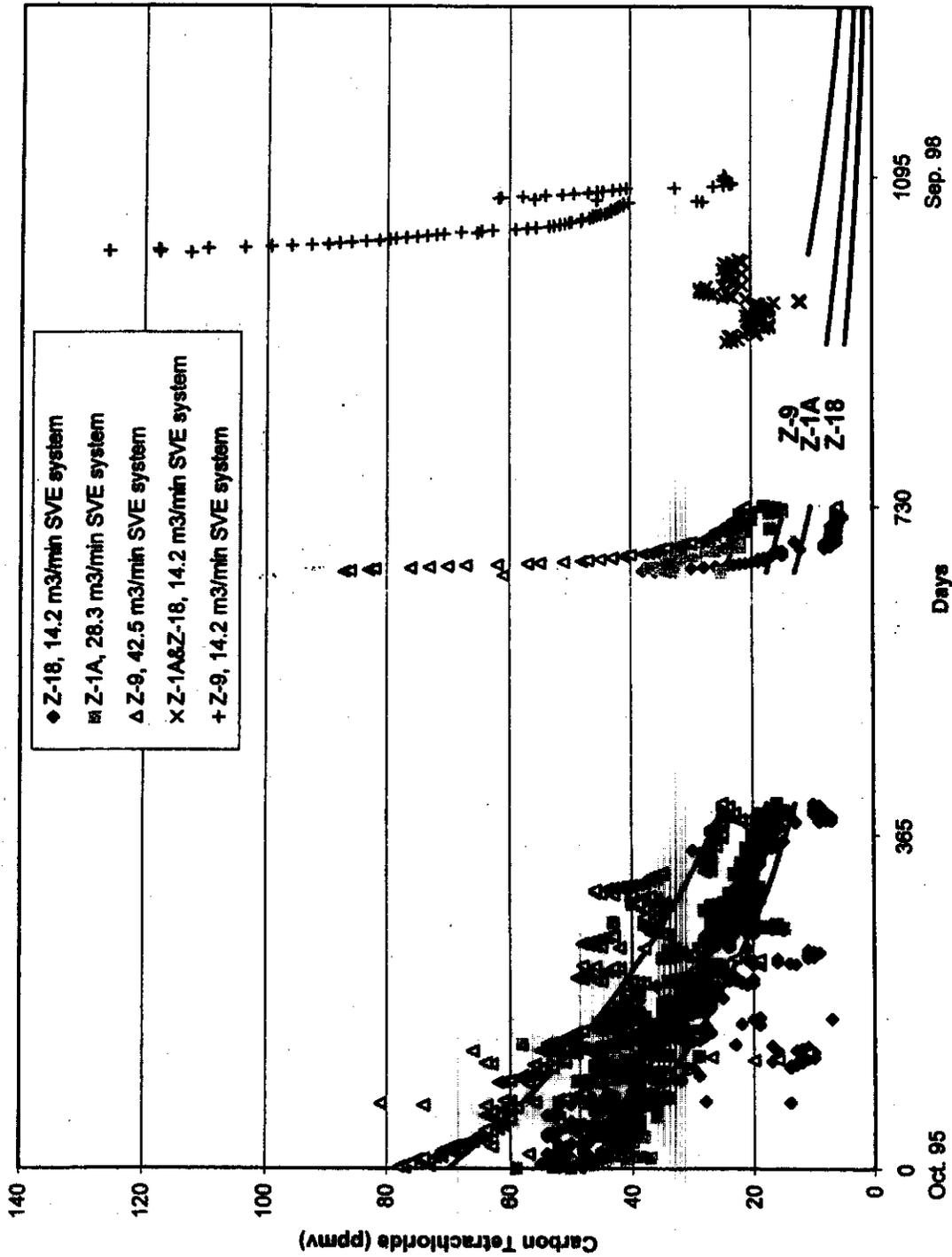


Figure 5-33. Carbon Tetrachloride Concentrations Measured at Extraction Wells in the 216-Z-1A/Z-18 Wellfield, April 1992 - September 2001.

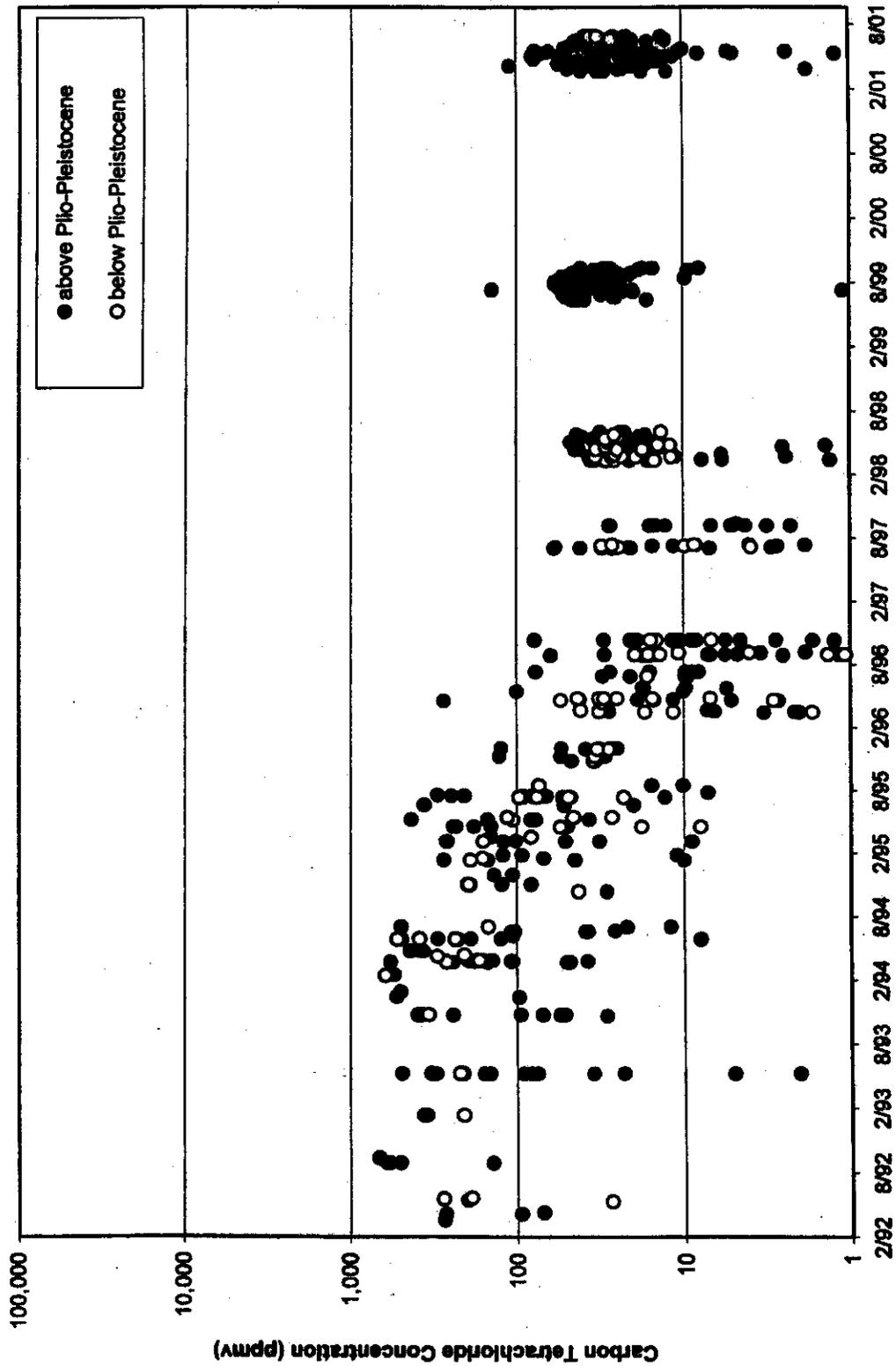


Figure 5-34. Carbon Tetrachloride Concentrations Measured at Extraction Wells in the 216-Z-9 Wellfield, March 1993 - September 2001.

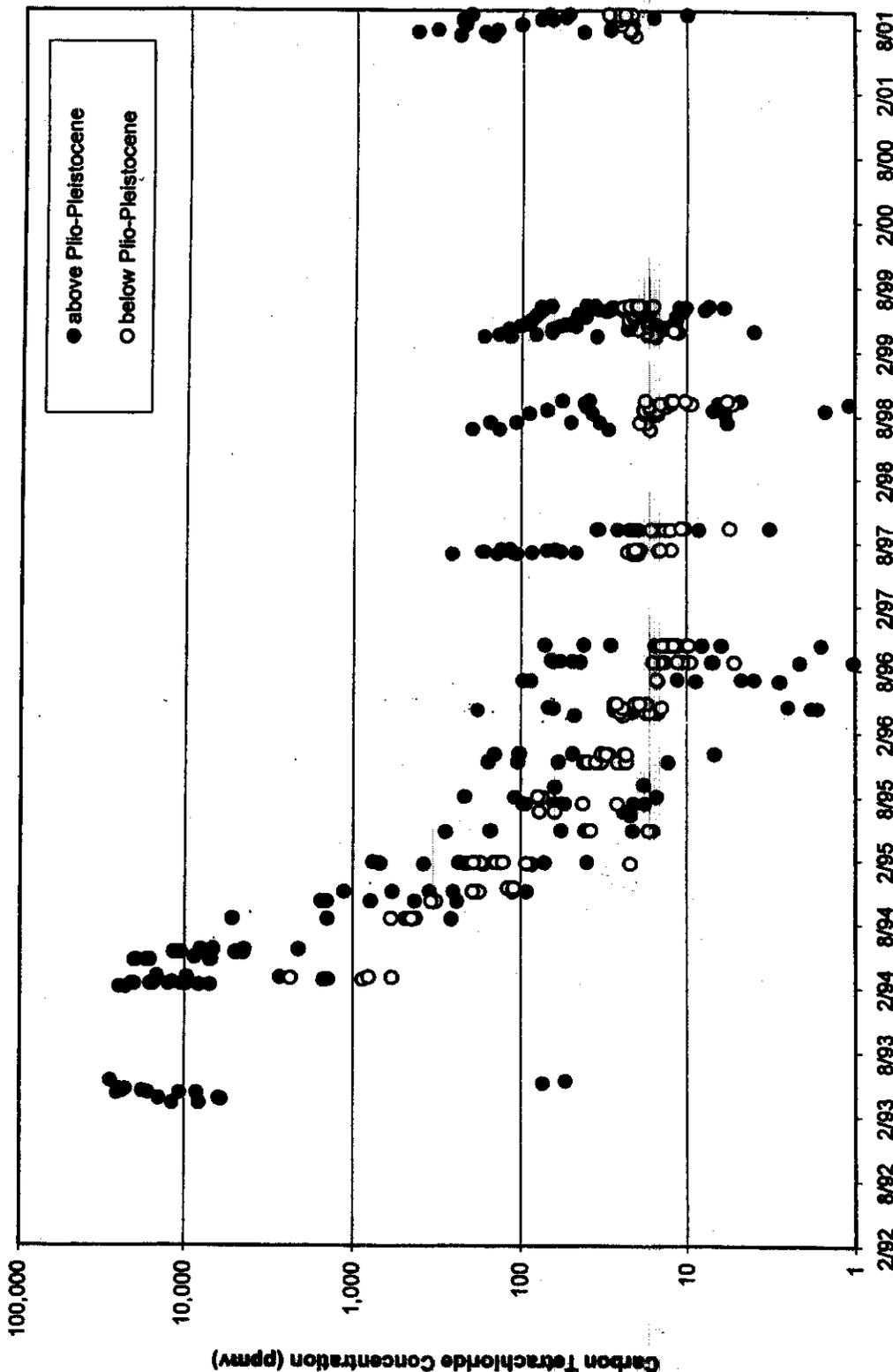


Figure 5-35. Relationship Between Concentrations of Carbon Tetrachloride and Chloroform Measured at Extraction Wells in the 216-Z-9 Wellfield.

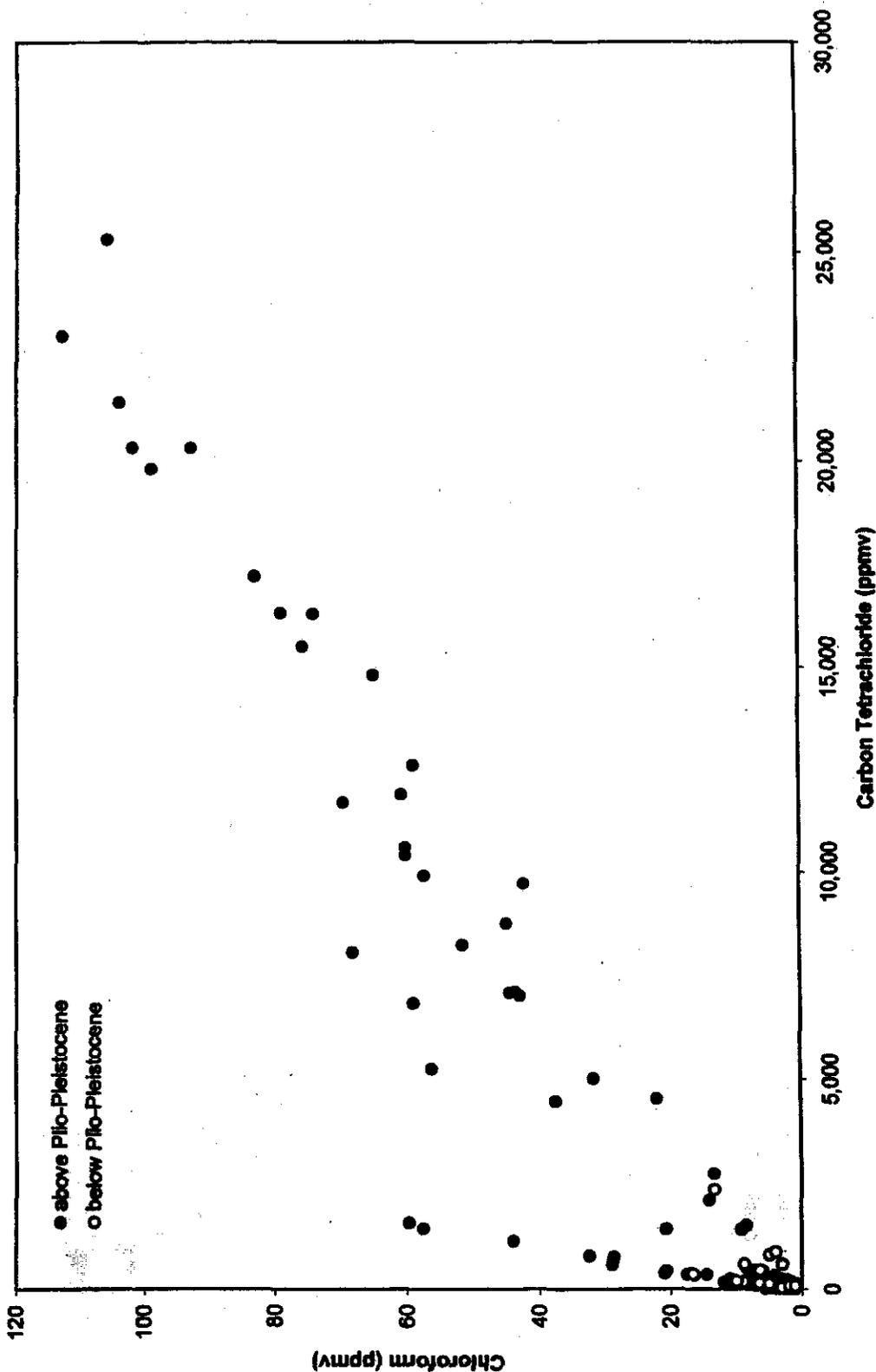


Figure 5-36. Relationship Between Concentrations of Carbon Tetrachloride Less Than 1,000 ppmv and Chloroform Measured at Extraction Wells in the 216-Z-9 Wellfield.

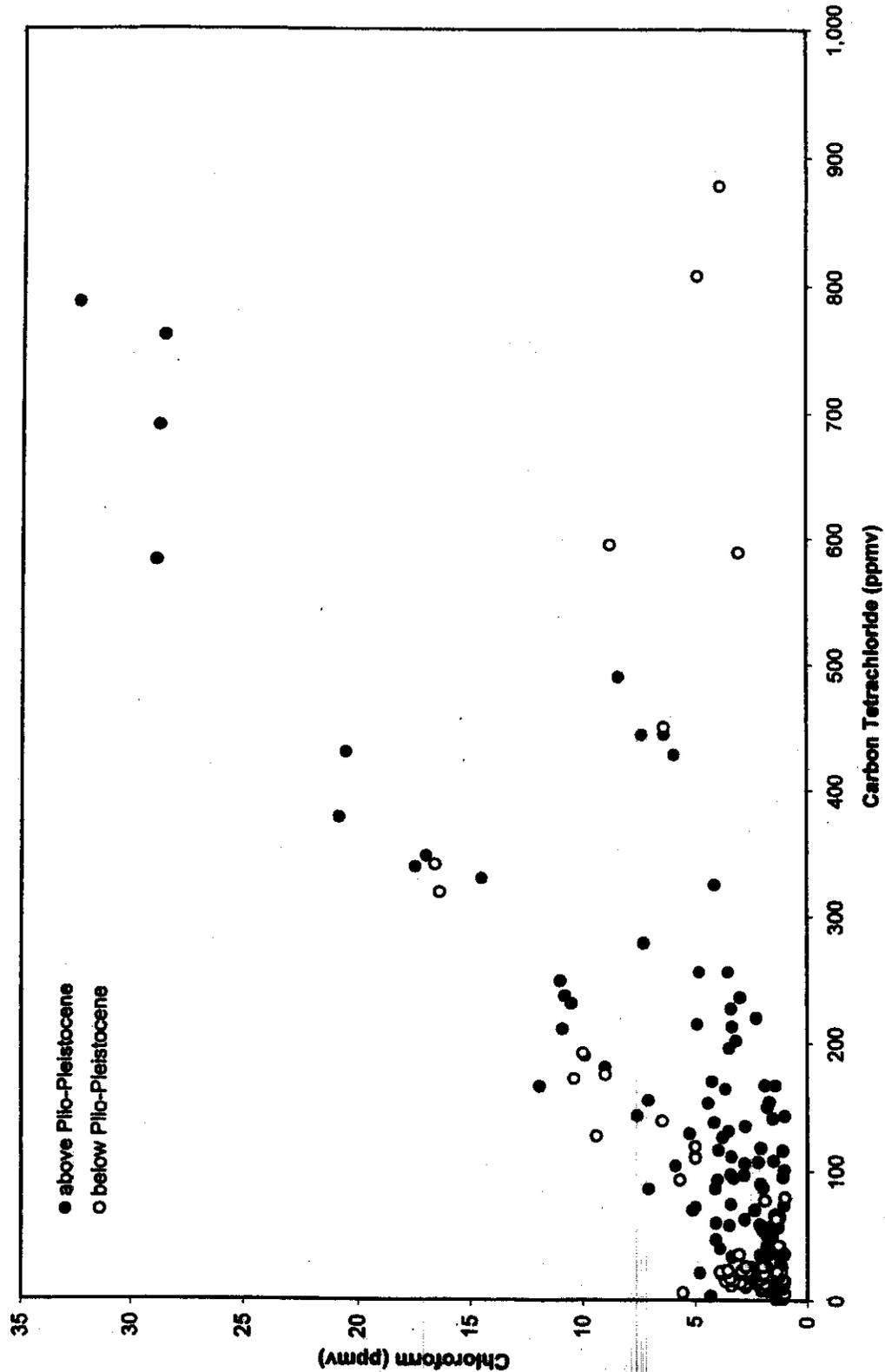


Figure 5-37. Relationship Between Concentrations of Carbon Tetrachloride and Chloroform Measured at Two 216-Z-9 Wells, 299-W15-82 and 299-W15-217.

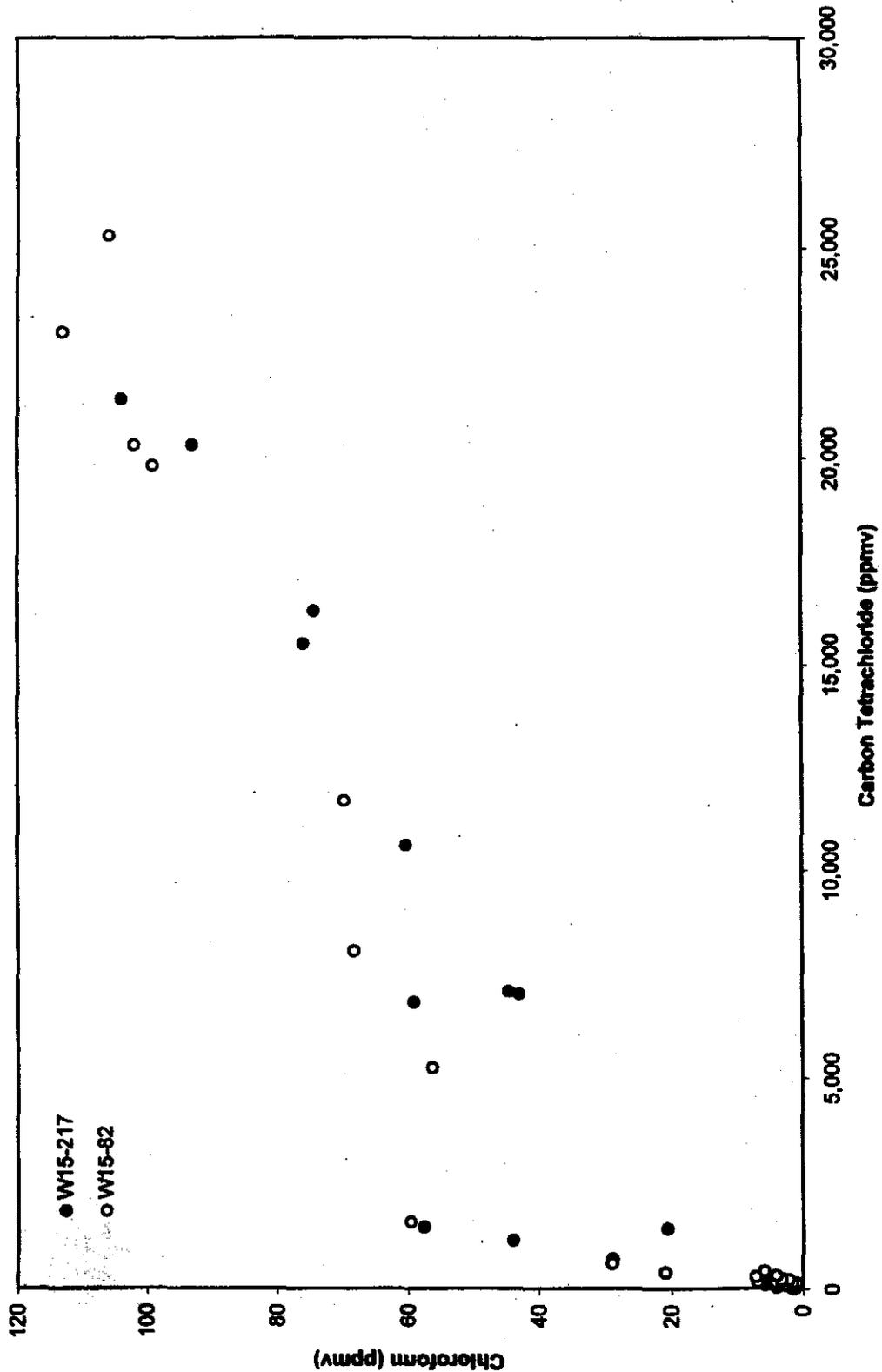


Figure 5-38. Relationship Between Concentrations of Carbon Tetrachloride and Chloroform Measured at Extraction Wells in the 216-Z-1A/Z-18/Z-12 Wellfield.

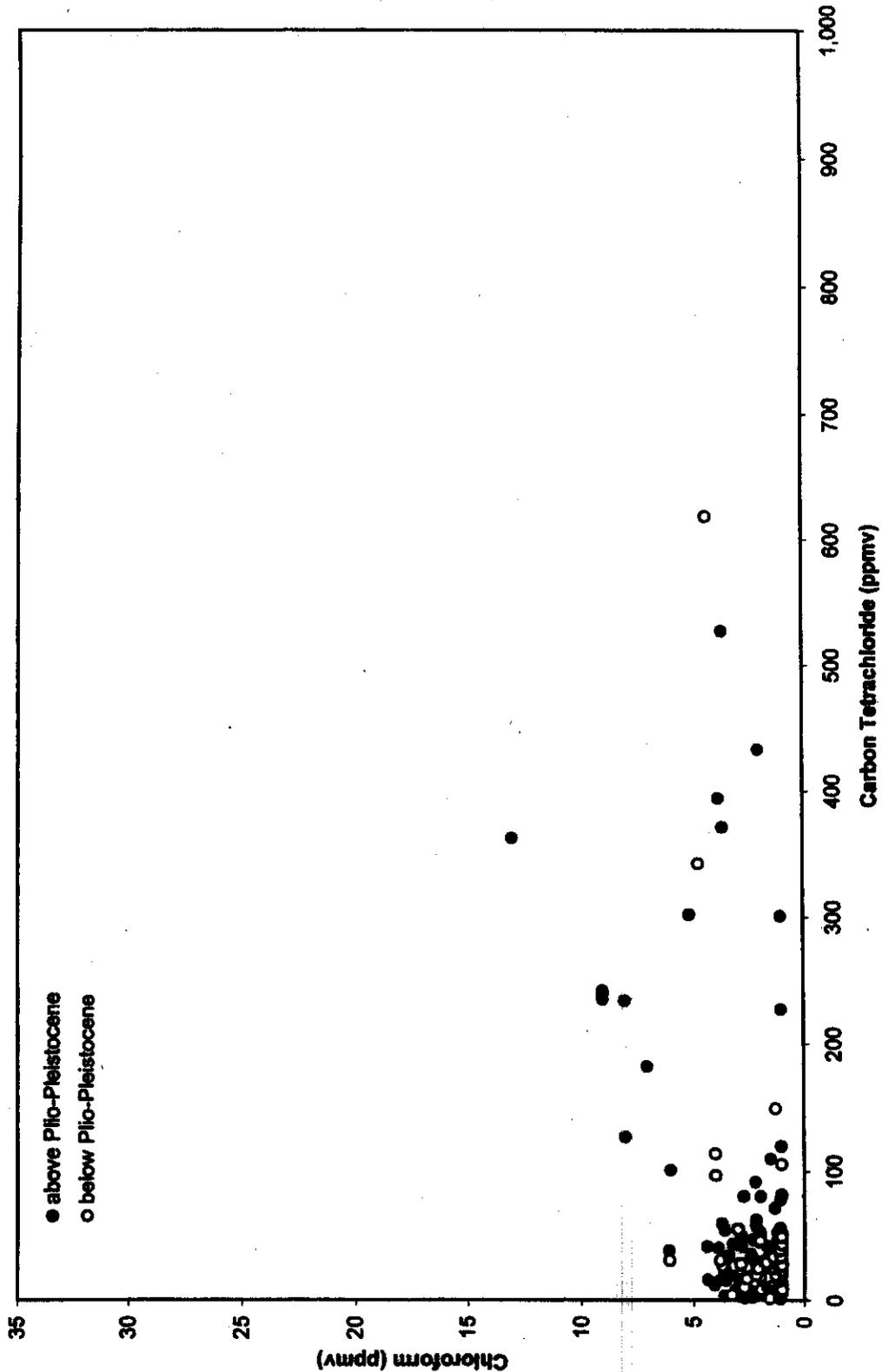


Figure 5-39. Total Mass of Carbon Tetrachloride Removed, February 1992 – September 2001.

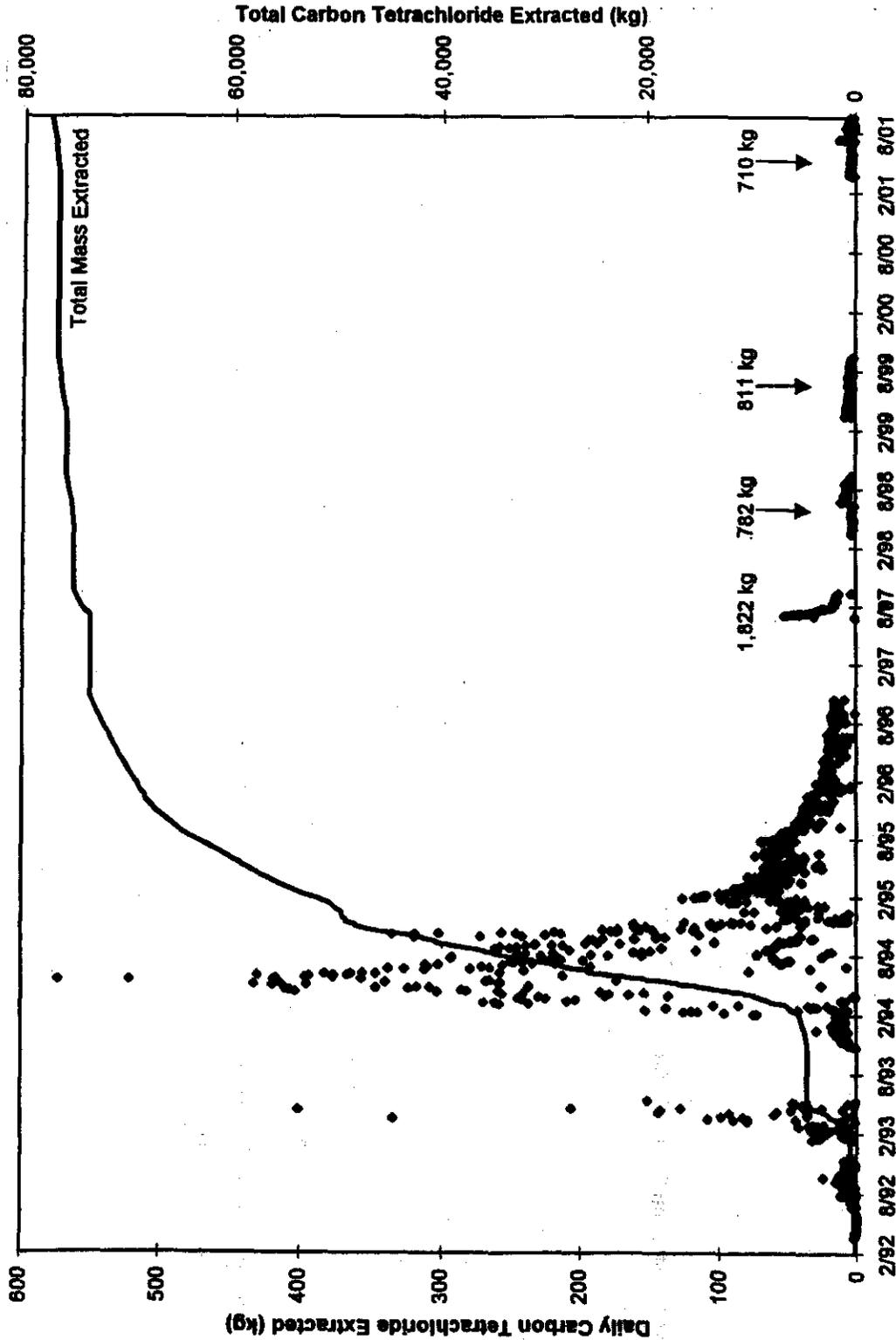


Figure 5-40. Carbon Tetrachloride Concentrations Monitored at 216-Z-9 Well 299-W15-218.

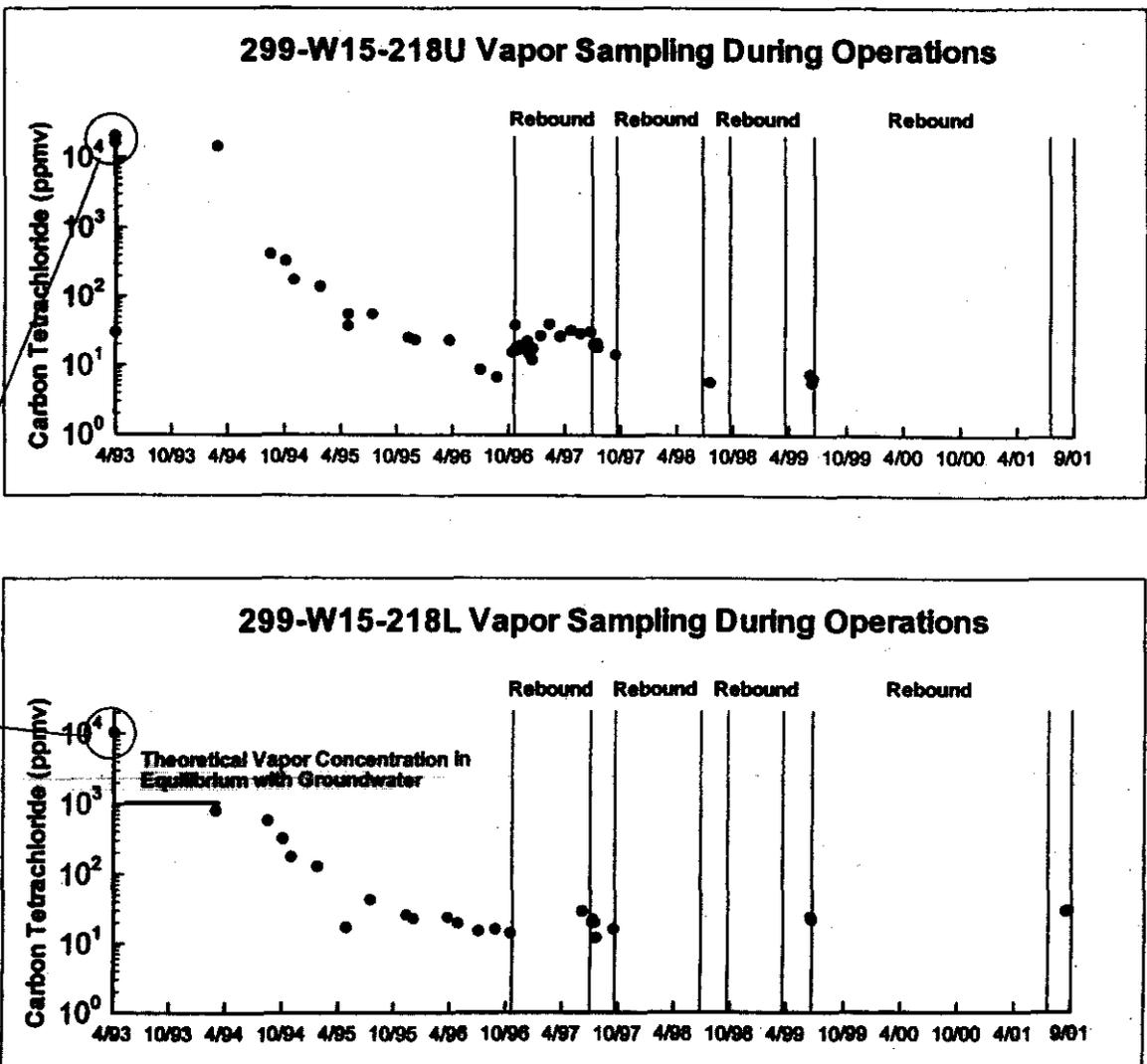


Figure 5-41. Mass of Carbon Tetrachloride Removed from the 216-Z-1A/Z-18/Z-12 Wellfield, February 1992 – September 2001.

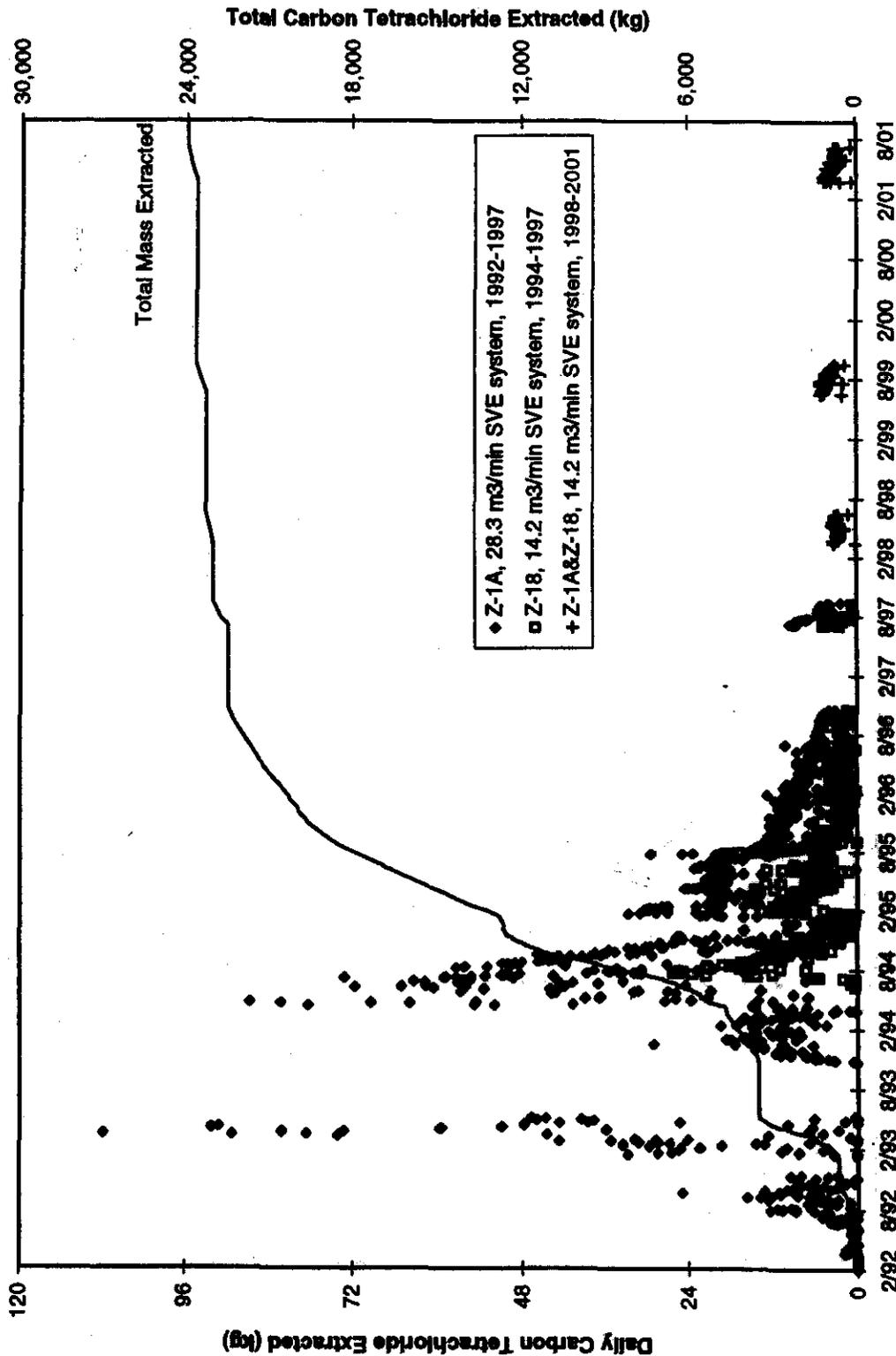


Figure 5-42. Mass of Carbon Tetrachloride Removed from the 216-Z-9 Wellfield, March 1993 – September 2001.

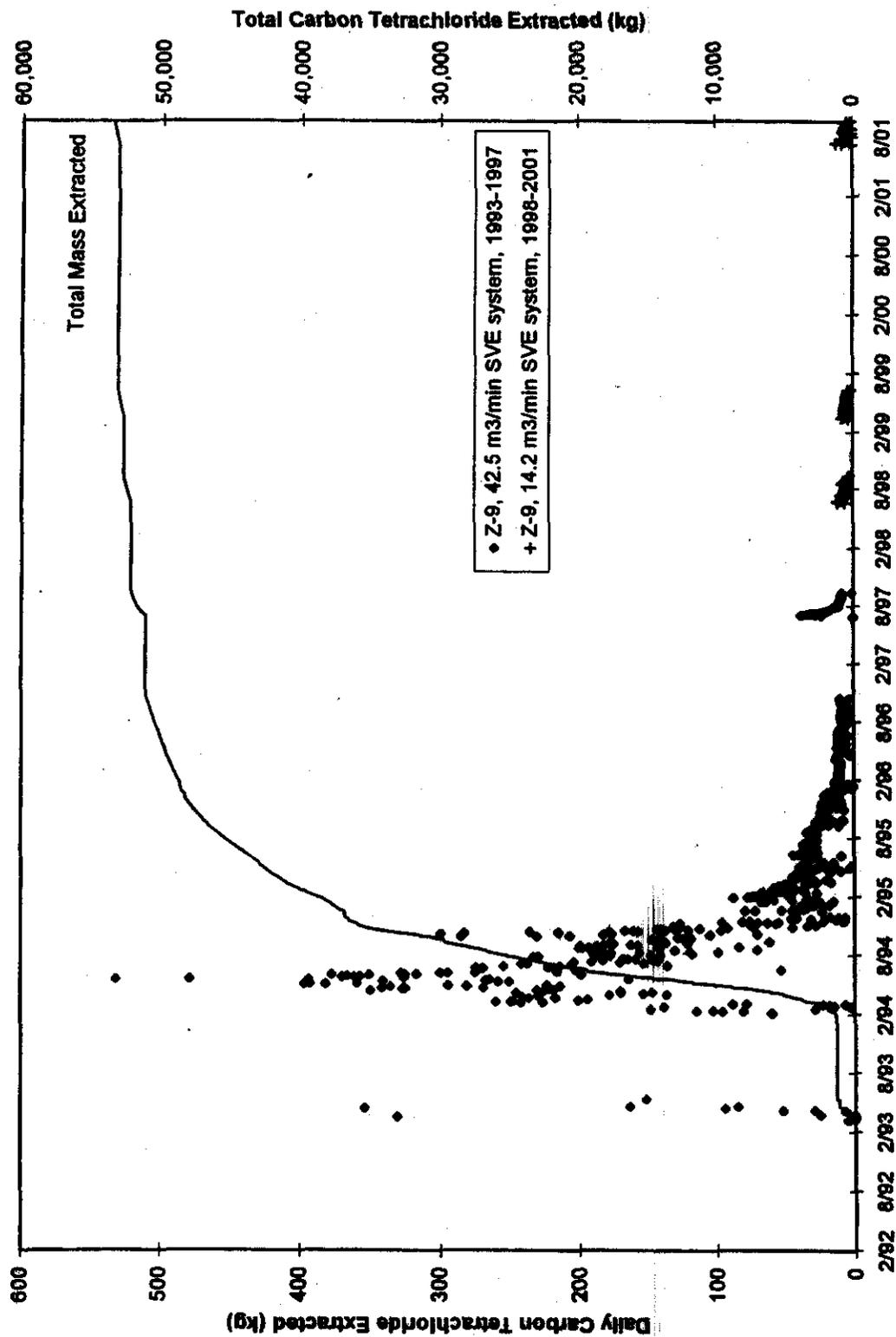


Figure 5-43. Decline in Total Carbon Tetrachloride Mass Removal Rate Between October 1994 and September 2001.

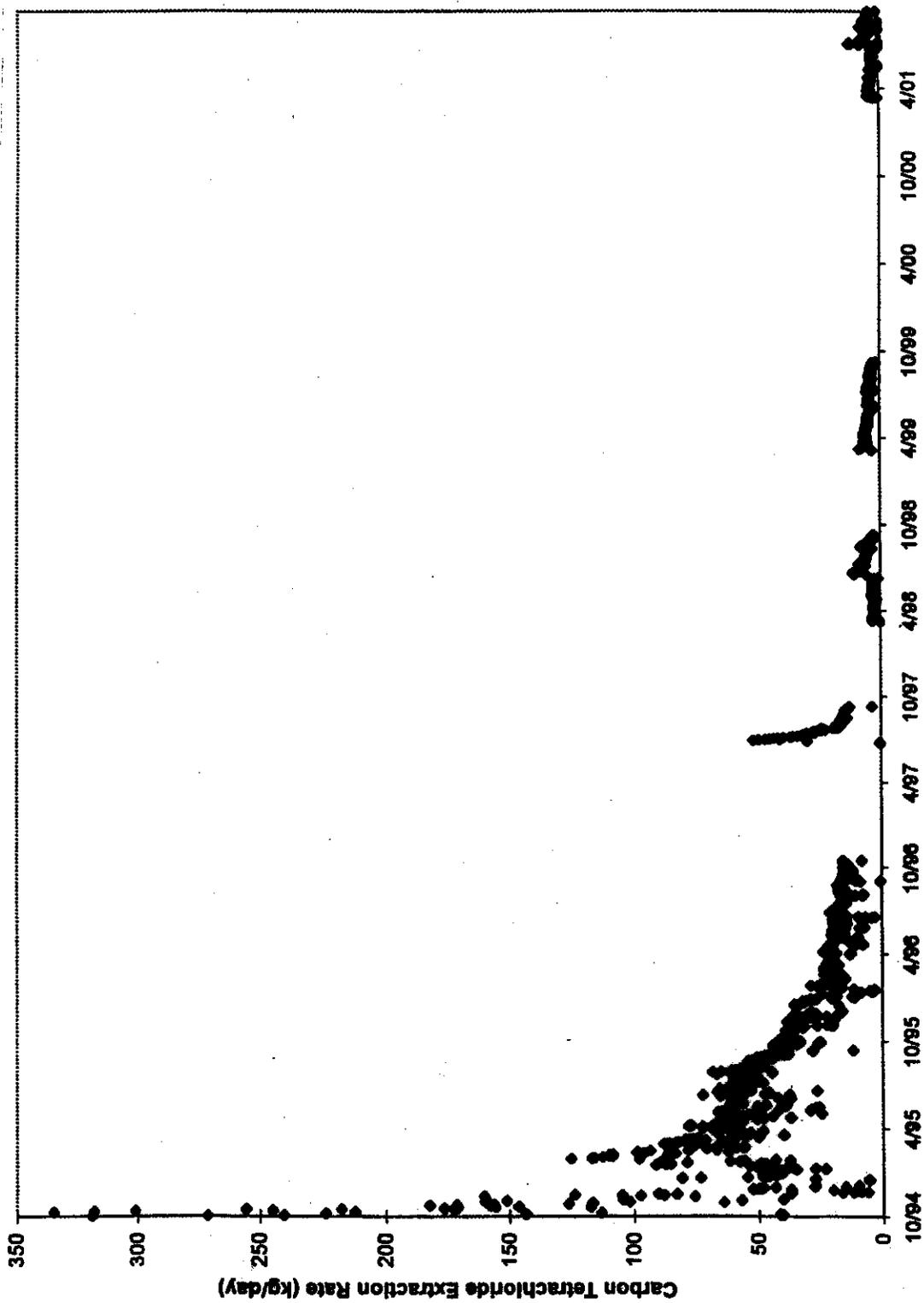


Figure 5-44. Comparison of Mass Removed Using the 14.2-m³/min Soil Vapor Extraction System During Cyclic Operations at the 216-Z-9 Wellfield to the Projected Mass Removed During Continuous Operations.

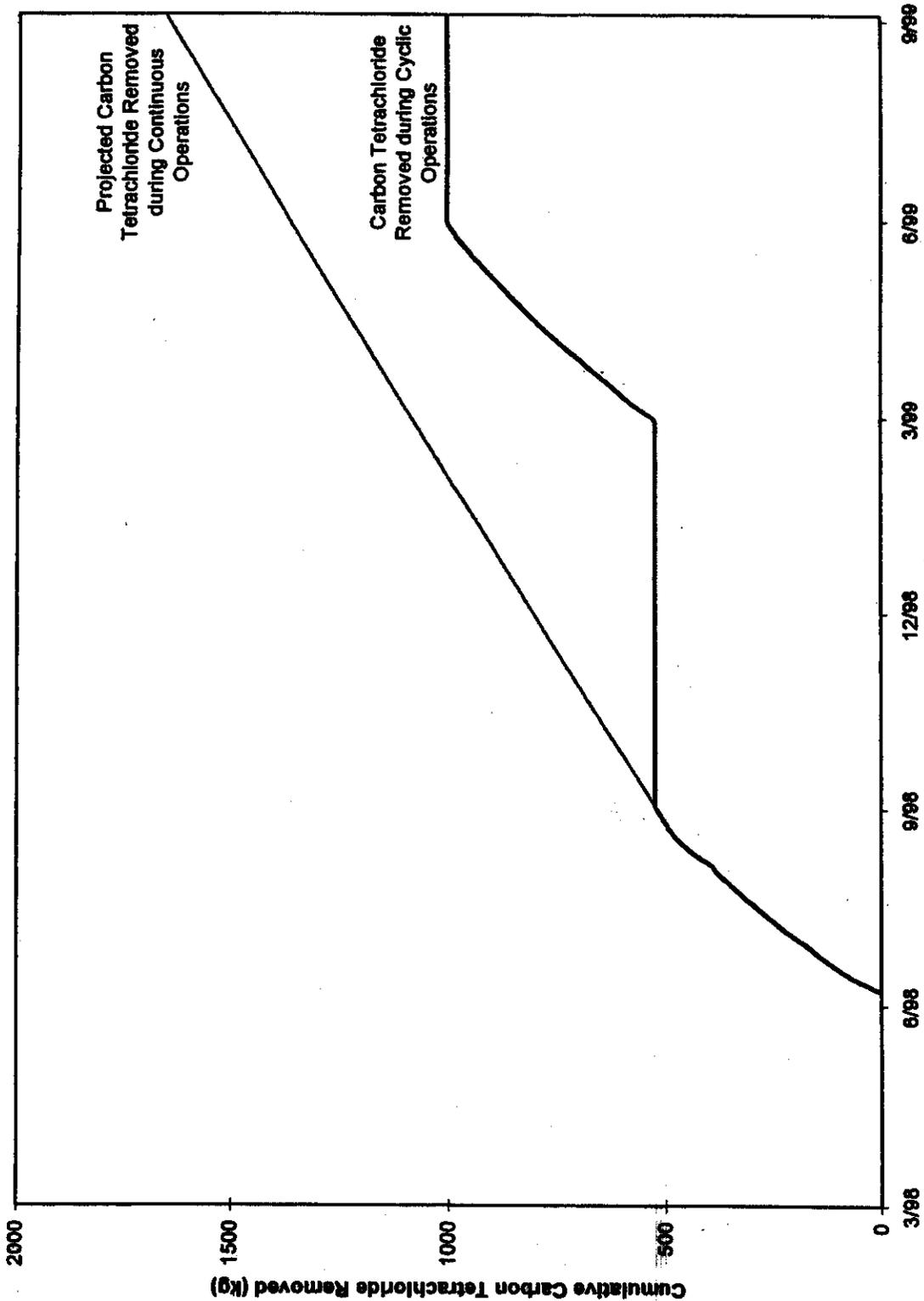


Figure 5-45. Carbon Tetrachloride Concentrations Monitored at the 216-Z-9 Wellfield, Wells 299-W15-6L and 299-W15-9L.

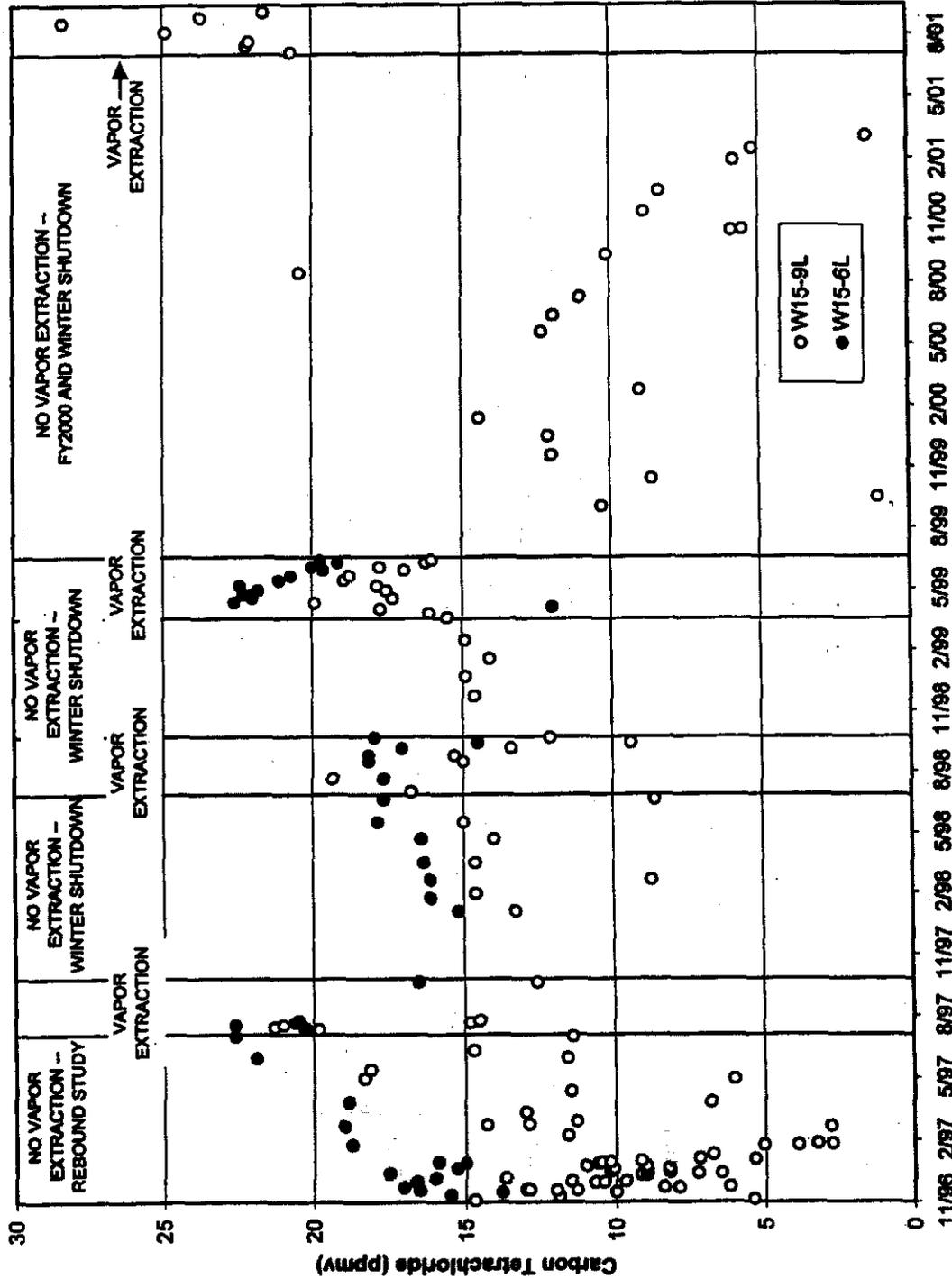


Figure 5-46. Location of Passive Soil Vapor Extraction Wells.

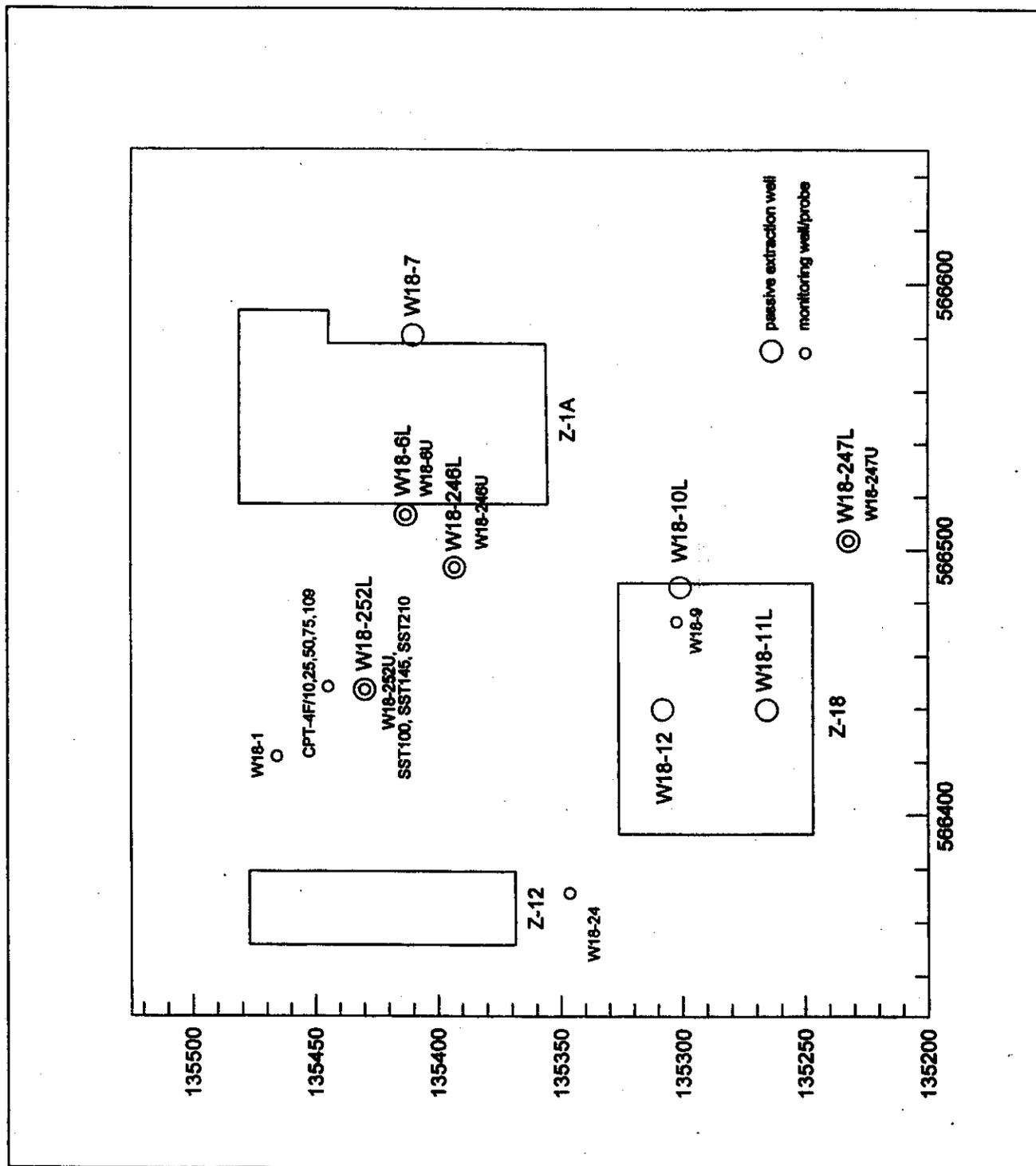


Figure 5-47. Correlation Between Total Carbon Tetrachloride Mass Removed Based on GAC Cartridge Analytical Data and Wellhead Hourly Measurements.

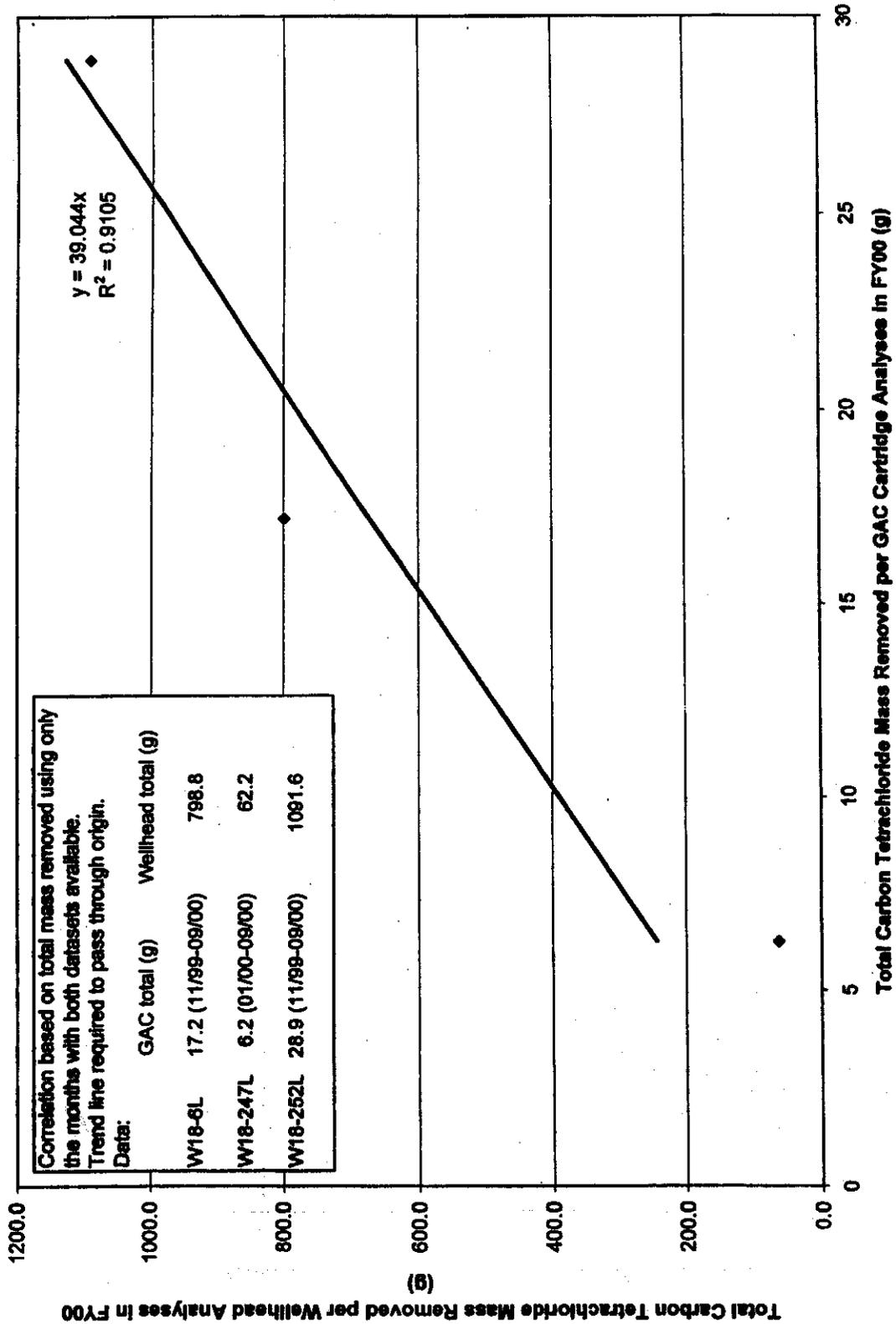


Figure 5-48. Monthly Amount of Carbon Tetrachloride Removed from Each Passive Soil Vapor Extraction Well, Based on GAC Cartridge Data.

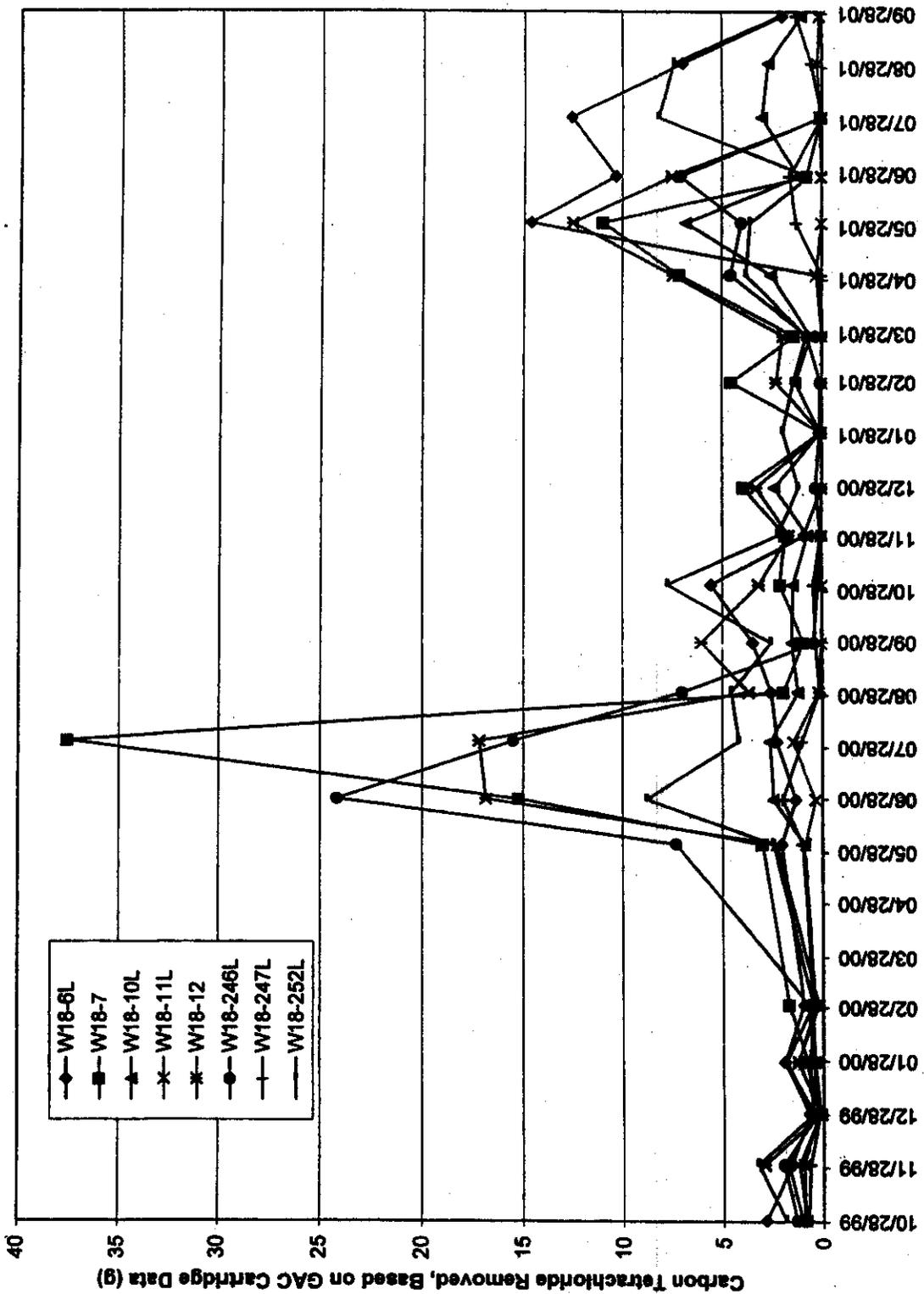


Figure 5-49. Carbon Tetrachloride Concentrations and Flow Rates Measured Hourly at Well 299-W18-6L, October 1999 – September 2001.

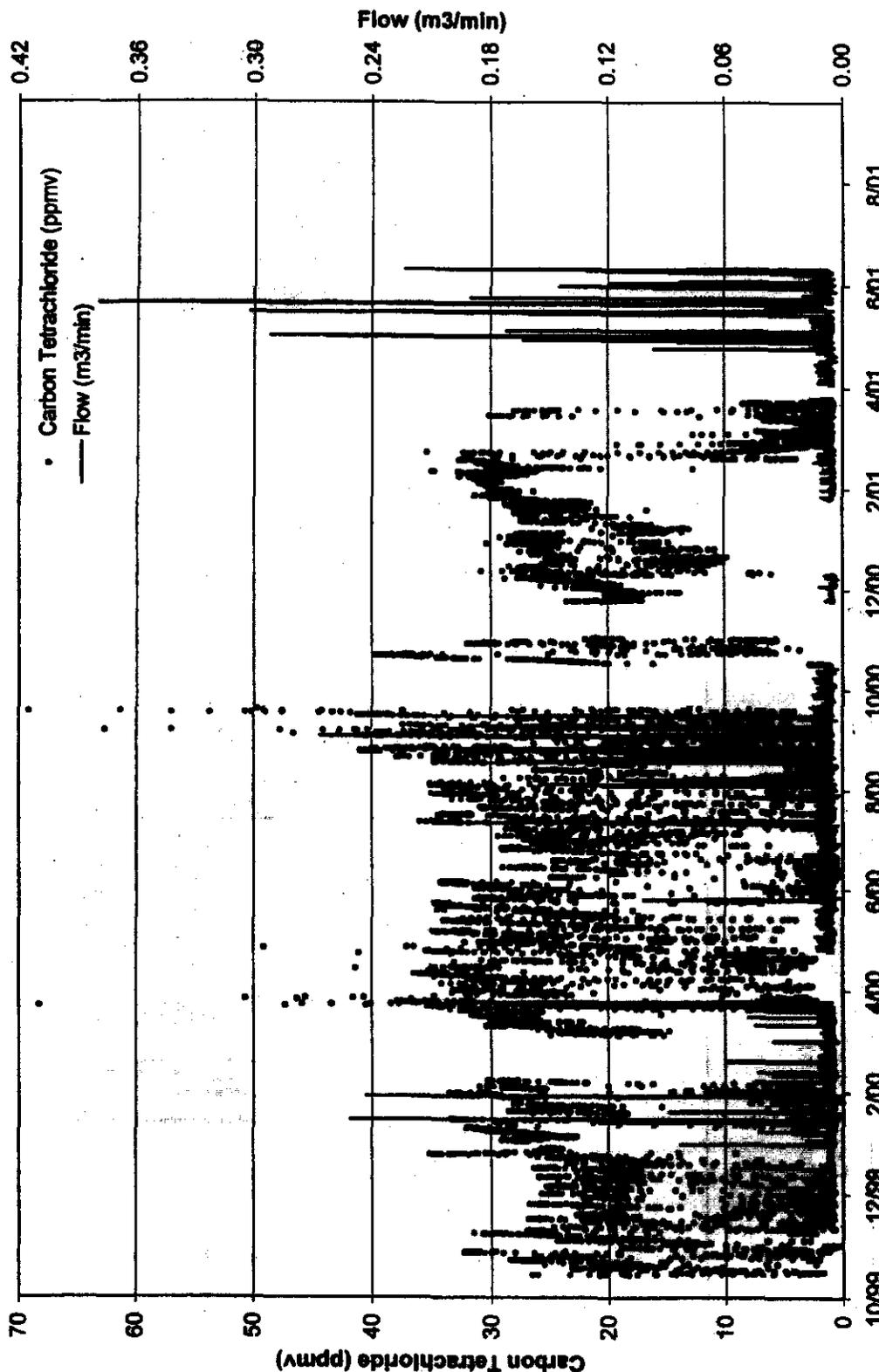


Figure 5-50. Carbon Tetrachloride Concentrations and Flow Rates Measured Hourly at Well 299-W18-247L, October 1999 – September 2001.

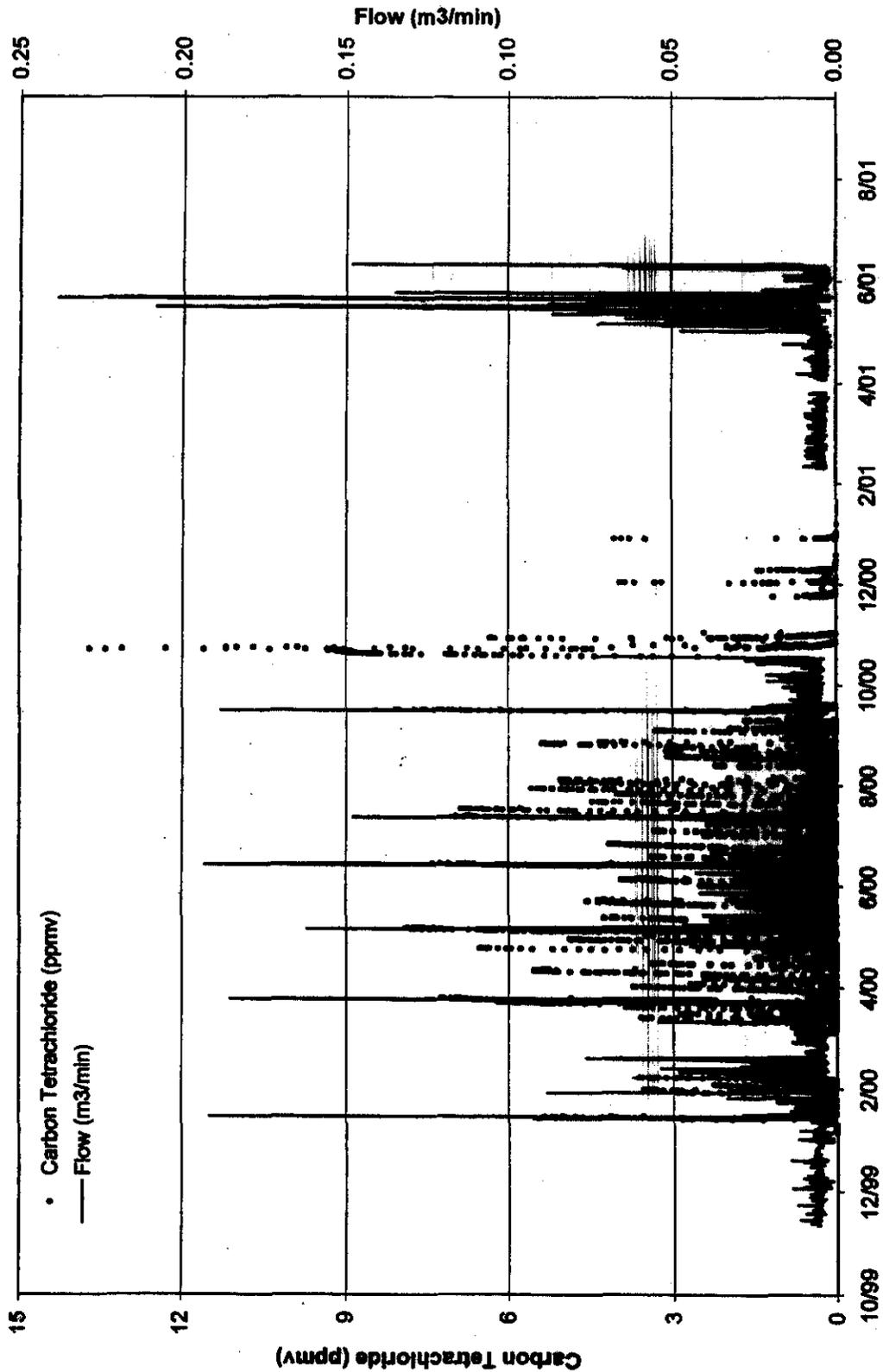


Figure 5-51. Carbon Tetrachloride Concentrations and Flow Rates Measured Hourly at Well 299-W18-252L, October 1999 – September 2001.

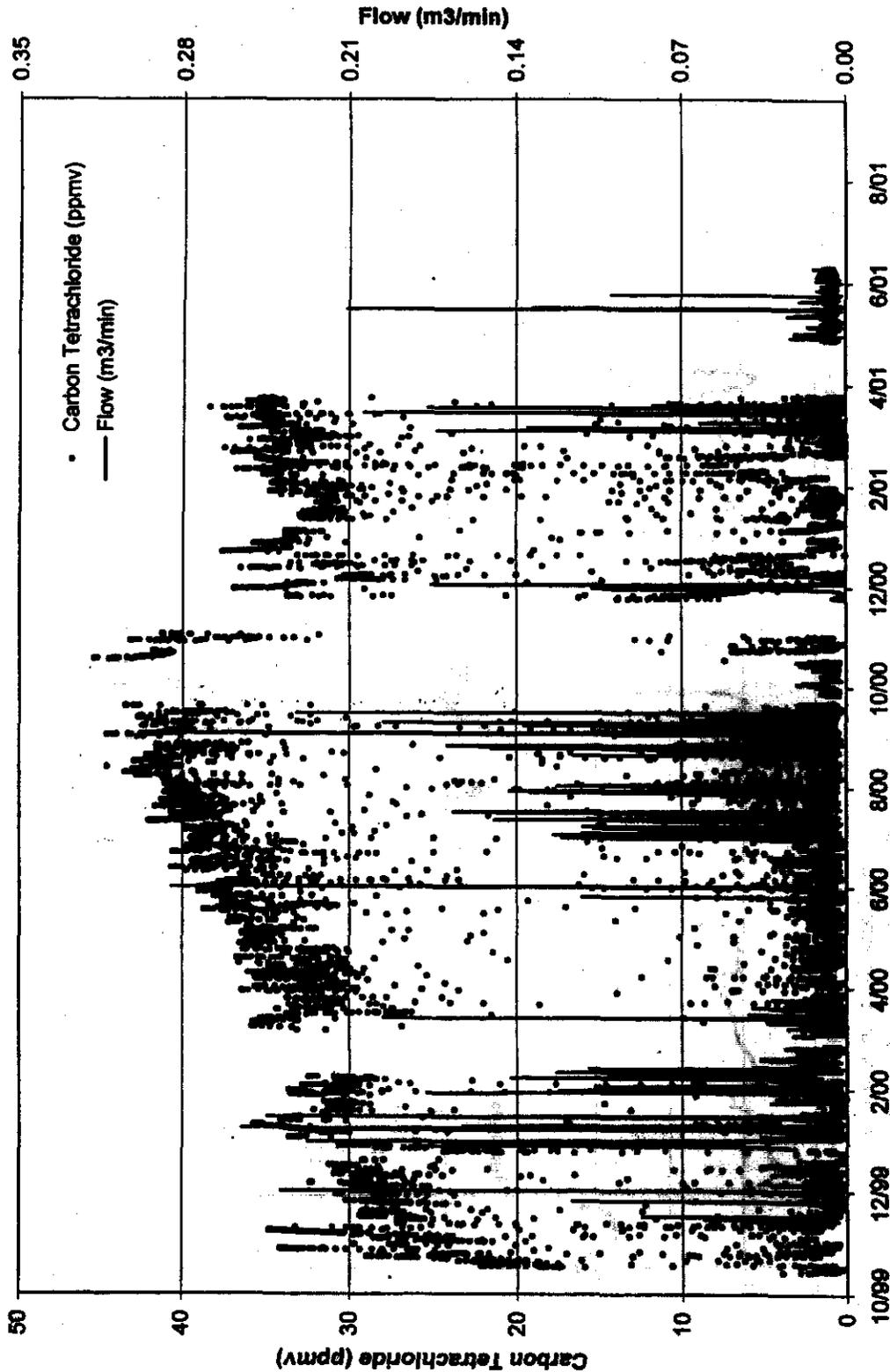


Figure 5-52. Comparison of Carbon Tetrachloride Concentrations Measured Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, July 2000.

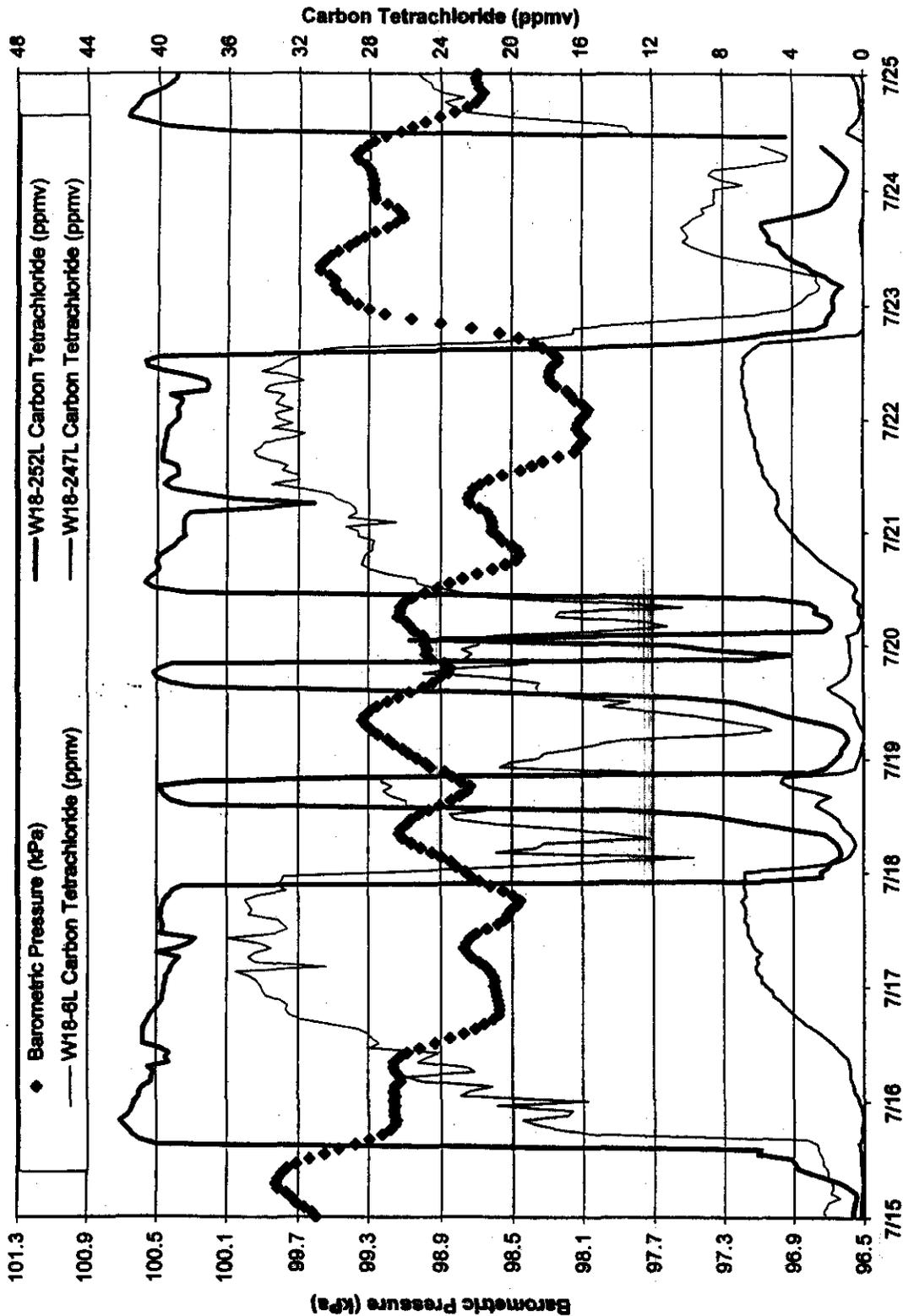


Figure 5-53. Average Positive Differential Pressures Measured at Passive Soil Vapor Extraction Wells.

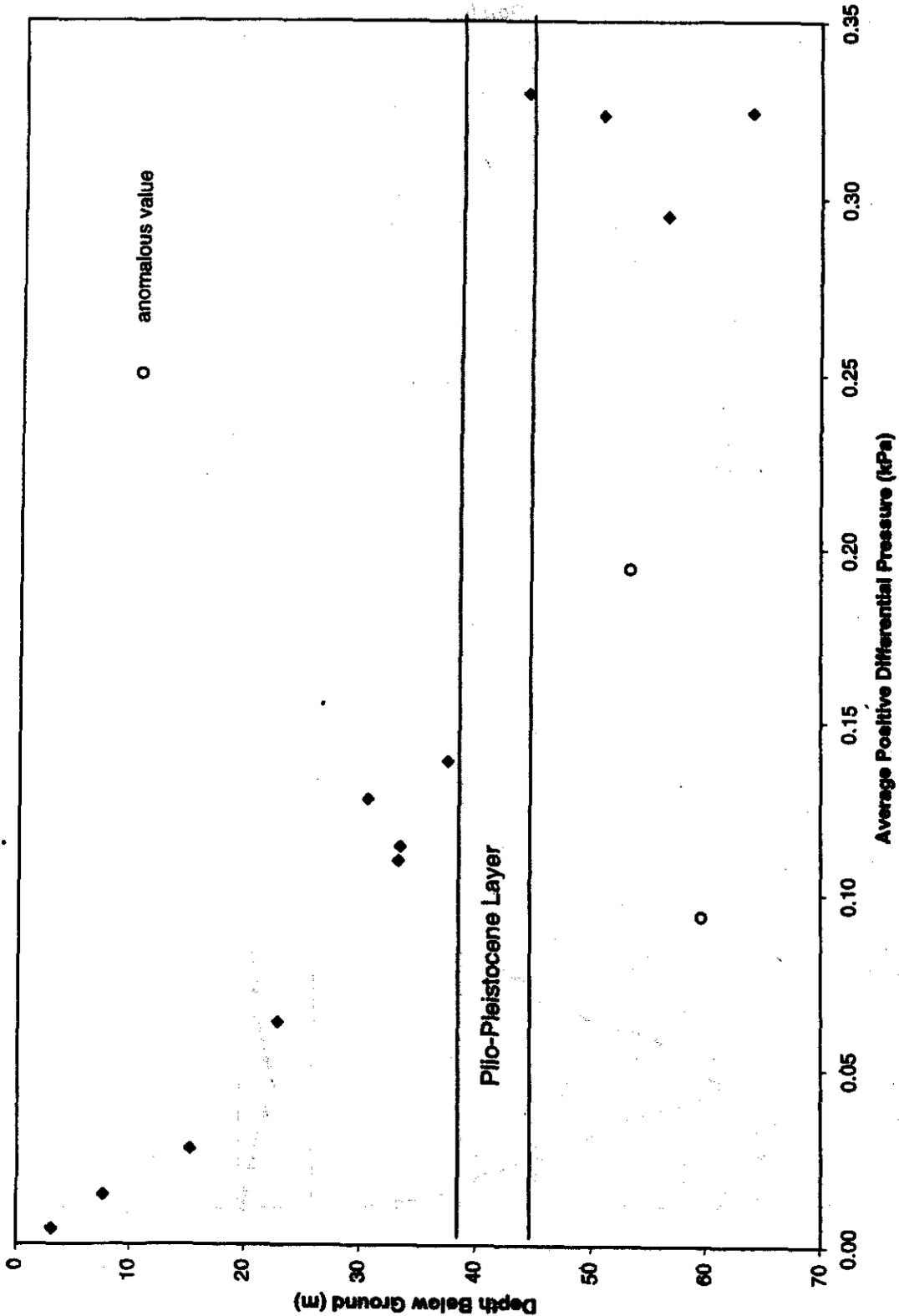
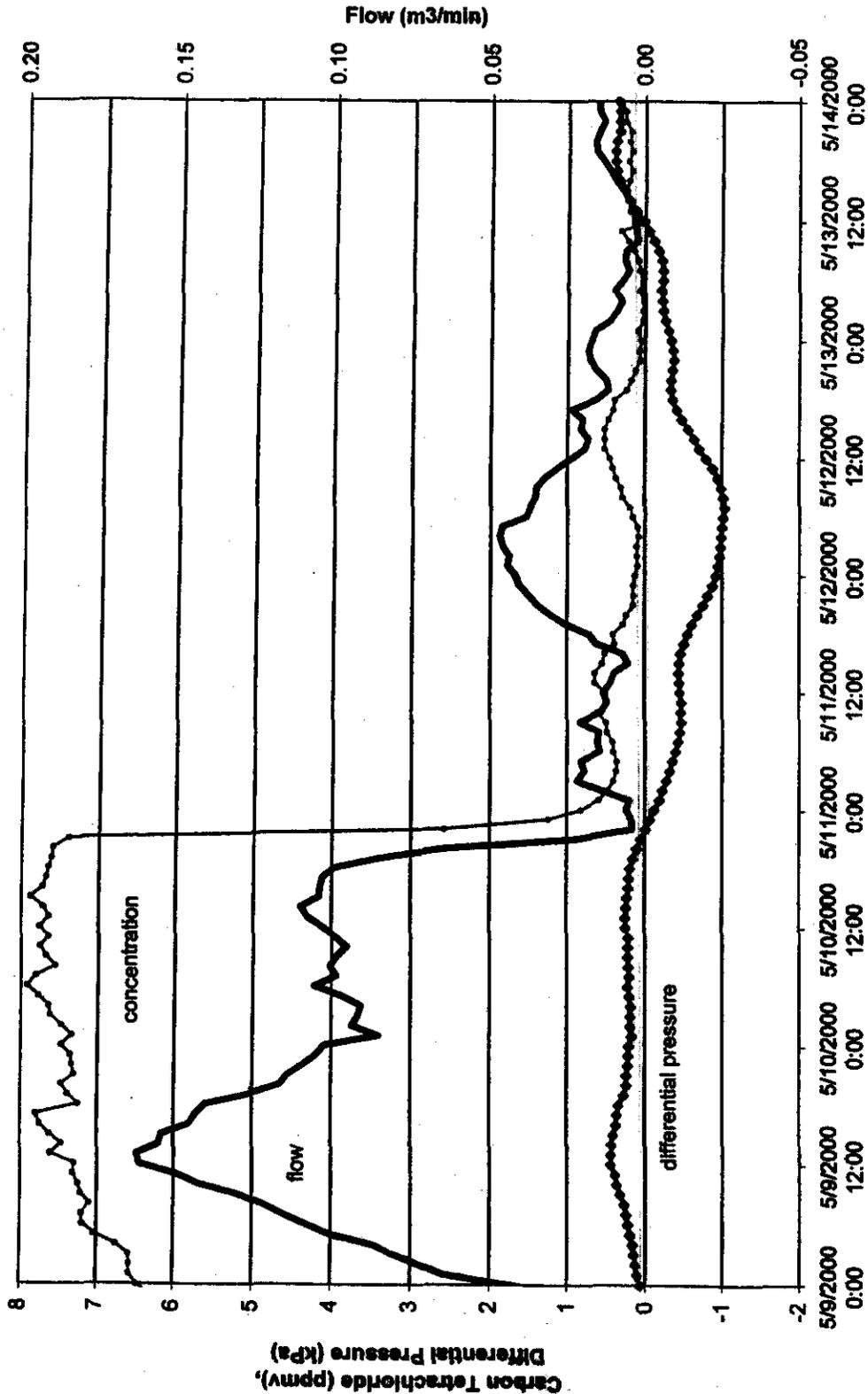


Figure 5-54. Carbon Tetrachloride Concentrations, Flow Rates, and Differential Pressures Measured Hourly at Well 299-W18-247L, May 2000.



Soil Vapor Extraction System Operating Data**Table 5-1. Planned Operating Times for the Soil Vapor Extraction Systems.**

Soil Vapor Extraction System (m ³ /min)	Time Period	Operating Hours/Day	Operating Days/Week
42.5	2/23/94 - 5/9/94	7	5
	5/10/94 - 10/18/94	9	5
	10/19/94 - 11/3/96	24	7
	11/4/96 - 7/17/97	0	0
	7/18/97 - 9/30/97	24	7
	10/1/98 - 9/30/99	0	0
	10/1/99 - 9/30/00	0	0
	10/1/00 - 9/30/01	0	0
28.3	1/3/94 - 4/29/94	7	5
	5/2/94 - 7/10/94	24	5
	7/11/94 - 11/3/96	24	7
	11/4/96 - 7/17/97	0	0
	7/18/97 - 9/30/97	24	7
	10/1/98 - 9/30/99	0	0
	10/1/99 - 9/30/00	0	0
	10/1/00 - 9/30/01	0	0
14.2	6/30/94 - 8/2/94	9	5
	8/3/94 - 11/3/96	24	7
	11/4/96 - 7/17/97	0	0
	7/18/97 - 9/30/97	24	7
	10/1/97 - 3/29/98	0	0
	3/30/98 - 9/30/98	24	7
	10/1/98 - 3/28/99	0	0
	3/29/99 - 9/30/99	24	7
	10/1/99 - 9/30/00	0	0
	10/1/00 - 4/3/01	0	0
	4/4/01 - 9/30/01	24	7

Soil Vapor Extraction System Operating Data

BHI-00720

Rev. 6

Table 5-2. Monthly Availability Data for the Soil Vapor Extraction Systems, January 1994 – September 2001. (2 Pages)

Month	42.5 m ³ /min			28.3 m ³ /min			14.2 m ³ /min			Total		
	Op. Hrs	Avail. Hrs	Avail. ^a	Op. Hrs	Avail. Hrs	Avail. ^a	Op. Hrs	Avail. Hrs	Avail. ^a	Op. Hrs	Avail. Hrs	Avail. ^a
Jan 94	--	--	--	123	147	84%	--	--	--	123	147	84%
Feb 94	--	--	--	103	140	74%	--	--	--	103	140	74%
Mar 94	101	189	53%	127	161	79%	--	--	--	228	350	65%
Apr 94	72	147	49%	105	147	71%	--	--	--	177	294	60%
May 94	144	183	79%	400	452	88%	--	--	--	544	635	86%
Jun 94	175	197	89%	339	460	74%	--	--	--	514	657	78%
Jul 94	111	166	67%	397	575	69%	44	180	24%	551	921	60%
Aug 94	179	203	88%	694	744	93%	522	707	74%	1395	1654	84%
Sep 94	168	193	87%	589	720	82%	709	720	98%	1466	1633	90%
Oct 94	261	372	70%	655	744	88%	684	744	92%	1600	1860	86%
Nov 94	534	624	86%	408	624	65%	521	624	83%	1463	1872	78%
Dec 94	374	504	74%	417	516	81%	364	504	72%	1154	1524	76%
Jan 95	593	696	85%	668	696	96%	192	696	28%	1453	2088	70%
Feb 95	591	672	88%	629	672	94%	419	672	62%	1639	2016	81%
Mar 95	687	744	92%	596	744	80%	741	744	100%	2023	2232	91%
Apr 95	625	720	87%	694	720	96%	699	720	97%	2018	2160	93%
May 95	595	744	80%	741	744	100%	700	744	94%	2035	2232	91%
Jun 95	628	720	87%	698	720	97%	700	720	97%	2026	2160	94%
Jul 95	704	744	95%	639	672	95%	734	744	99%	2077	2160	96%
Aug 95	737	744	99%	709	744	95%	741	744	100%	2188	2232	98%
Sep 95	701	720	97%	691	720	96%	623	720	86%	2015	2160	93%
Oct 95	643	744	86%	692	744	93%	667	744	90%	1994	2208	90%
Nov 95	617	672	92%	593	606	98%	603	605	100%	1813	1883	96%
Dec 95	507	518	98%	512	517	99%	416	517	80%	1434	1552	92%
Jan 96	590	711	83%	697	710	98%	580	710	82%	1866	2131	88%
Feb 96	552	696	79%	653	696	94%	506	696	73%	1710	2088	82%
Mar 96	729	744	98%	715	744	96%	589	744	79%	2034	2232	91%
Apr 96	713	720	99%	661	720	92%	715	720	99%	2088	2160	97%
May 96	651	744	87%	731	744	98%	725	744	97%	2106	2232	94%
Jun 96	637	720	88%	610	720	85%	570	720	79%	1817	2160	84%
Jul 96	533	744	72%	742	744	100%	595	744	80%	1871	2232	84%
Aug 96	628	744	84%	742	744	100%	712	744	96%	2082	2232	93%
Sep 96	644	720	89%	671	720	93%	690	720	96%	2005	2160	93%
Oct 96	741	744	100%	741	744	100%	743	744	100%	2225	2232	100%
Nov 96	80	80	100%	91	91	100%	92	92	100%	263	263	100%
Jul 97	320	326	98%	327	327	100%	322	326	99%	969	979	99%
Aug 97	738	744	99%	741	744	100%	678	744	91%	2157	2232	97%

Soil Vapor Extraction System Operating Data

Rev. 6

**Table 5-2. Monthly Availability Data for the Soil Vapor Extraction Systems,
January 1994 – September 2001. (2 Pages)**

Month	42.5 m ³ /min			28.3 m ³ /min			14.2 m ³ /min			Total		
	Op. Hrs	Avail. Hrs	Avail. ^a	Op. Hrs	Avail. Hrs	Avail. ^a	Op. Hrs	Avail. Hrs	Avail. ^a	Op. Hrs	Avail. Hrs	Avail. ^a
Sep 97	720	720	100%	707	708	100%	663	720	92%	2090	2148	97%
Apr 98	--	--	--	--	--	--	767	768	100%	767	768	100%
May 98	--	--	--	--	--	--	744	744	100%	744	744	100%
Jun 98	--	--	--	--	--	--	706	720	98%	706	720	98%
Jul 98	--	--	--	--	--	--	589	600	98%	589	600	98%
Aug 98	--	--	--	--	--	--	740	744	99%	740	744	99%
Sep 98	--	--	--	--	--	--	716	720	99%	716	720	99%
Apr 99	--	--	--	--	--	--	772	778	99%	772	778	99%
May 99	--	--	--	--	--	--	743	744	100%	743	744	100%
Jun 99	--	--	--	--	--	--	672	696	96%	672	696	96%
Jul 99	--	--	--	--	--	--	743	744	100%	743	744	100%
Aug 99	--	--	--	--	--	--	704	744	95%	704	744	95%
Sep 99	--	--	--	--	--	--	708	720	98%	708	720	98%
Apr 01	--	--	--	--	--	--	611	639	96%	611	639	96%
May 01	--	--	--	--	--	--	743	744	100%	743	744	100%
Jun 01	--	--	--	--	--	--	658	720	91%	658	720	91%
Jul 01	--	--	--	--	--	--	566	744	76%	566	744	76%
Aug 01	--	--	--	--	--	--	689	744	93%	689	744	93%
Sep 01	--	--	--	--	--	--	674	726	93%	674	726	93%

^aMonthly availability = monthly operating hours/monthly available operating hours.

Table 5-3. Number of Hours Each Soil Vapor Extraction System Has Operated.

Soil Vapor Extraction System (m ³ /min)	Number of Hours Operated Each Calendar Year											
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	Total
14.2	--	--	--	2,843	7,235	6,516	1,663	4,261	4,342	0	3,940	30,799
28.3	104	852	1,565	4,357	7,862	7,054	1,775	0	0	0	0	23,568
42.5	--	--	76	2,119	7,628	6,496	1,784	0	0	0	0	18,103
Total	104	852	1,641	9,319	22,725	20,066	5,222	4,261	4,342	0	3,940	72,470

Table 5-4a. Volume of Vapor Processed by Each Soil Vapor Extraction System.

Soil Vapor Extraction System (m ³ /min)	Volume of Vapor Processed Each Calendar Year											
	1991 (m ³)	1992 (m ³)	1993 (m ³)	1994 (m ³)	1995 (m ³)	1996 (m ³)	1997 (m ³)	1998 (m ³)	1999 (m ³)	2000 (m ³)	2001 (m ³)	Total (m ³)
14.2	--	--	--	2,100E+03	4,900E+03	4,550E+03	1,220E+03	3,490E+03	3,550E+03	0	2,520E+03	22,330E+03
28.3	47E+03	150E+03	1,420E+03	4,190E+03	10,470E+03	11,190E+03	2,830E+03	0	0	0	0	30,300E+03
42.5	--	--	10E+03	3,190E+03	15,690E+03	12,180E+03	4,860E+03	0	0	0	0	35,930E+03
Total	47E+03	150E+03	1,430E+03	9,480E+03	31,060E+03	27,920E+03	8,910E+03	3,490E+03	3,550E+03	0	2,520E+03	88,560E+03

Table 5-4b. Volume of Vapor Extracted from Each Soil Vapor Extraction Wellfield.

Site	Volume of Vapor Extracted Each Calendar Year											
	1991 (m ³)	1992 (m ³)	1993 (m ³)	1994 (m ³)	1995 (m ³)	1996 (m ³)	1997 (m ³)	1998 (m ³)	1999 (m ³)	2000 (m ³)	2001 (m ³)	Total (m ³)
216-Z-1A/ Z-18/Z-12	47E+03	150E+03	1,420E+03	6,290E+03	15,370E+03	15,740E+03	4,050E+03	1,910E+03	1,840E+03	0	1,780E+03	48,590E+03
216-Z-9	--	--	10E+03	3,190E+03	15,690E+03	12,180E+03	4,860E+03	1,590E+03	1,720E+03	0	750E+03	39,980E+03
Total	47E+03	150E+03	1,430E+03	9,480E+03	31,060E+03	27,920E+03	8,910E+03	3,490E+03	3,550E+03	0	2,520E+03	88,560E+03

Soil Vapor Extraction System Operating Data

Table 5-5. Volume of Vapor Extracted from Each Extraction Well Between April 1991 and September 2001.

216-Z-9 Wells 3/93-9/01	Vapor Extracted (m ³)	216-Z-18/ 216-Z-12 Wells 2/92-9/01	Vapor Extracted (m ³)	216-Z-1A Wells 4/91-9/01	Vapor Extracted (m ³)
W15-6L	2,390E+03	W18-10L	2,440E+03	W18-6L	1,970E+03
W15-6U	150E+03	W18-10U	660E+03	W18-6U	150E+03
W15-8	0E+03	W18-11L	240E+03	W18-7	8,440E+03
W15-9L	870E+03	W18-12	940E+03	W18-87L	40E+03
W15-9U	840E+03	W18-93	10E+03	W18-87M	20E+03
W15-82	5,040E+03	W18-94	0E+03	W18-87U	40E+03
W15-84L	130E+03	W18-96	440E+03	W18-89	7,340E+03
W15-84U	2,510E+03	W18-97	230E+03	W18-150L	240E+03
W15-85	2,650E+03	W18-98	0E+03	W18-150M	40E+03
W15-86	690E+03	W18-99	160E+03	W18-150U	40E+03
W15-95L	280E+03	W18-152	1,770E+03	W18-158L	230E+03
W15-95U	790E+03	W18-153	480E+03	W18-158M	0E+03
W15-216L	1,160E+03	W18-246L	1,490E+03	W18-158U	820E+03
W15-216U	560E+03	W18-246U	690E+03	W18-159	930E+03
W15-217	4,530E+03	W18-249	670E+03	W18-163L	170E+03
W15-218L	3,530E+03	W18-252L	3,370E+03	W18-163M	10E+03
W15-218U	3,400E+03	W18-252U	1,100E+03	W18-163U	410E+03
W15-219L	2,800E+03			W18-165	1,900E+03
W15-219U	2,770E+03			W18-166	860E+03
W15-220L	1,440E+03			W18-167	1,510E+03
W15-220U	2,010E+03			W18-168	1,600E+03
W15-223	1,420E+03			W18-169	140E+03
				W18-171L	500E+03
				W18-171M	390E+03
				W18-171U	460E+03
				W18-174	2,830E+03
				W18-175	350E+03
				W18-248	2,450E+03
Above Plio-Pleistocene	27,360E+03	Above Plio-Pleistocene	6,220E+03	Above Plio-Pleistocene	23,480E+03
Below Plio-Pleistocene	12,600E+03	Below Plio-Pleistocene	8,480E+03	Below Plio-Pleistocene	10,410E+03
Total	39,950E+03	Total	14,700E+03	Total	33,890E+03

Table 5-6. Weekly Volume of Knockout Water Drained from Soil Vapor Extraction Systems, October 1994 – September 2001. (3 Pages)

Week Start	Week End	SVE System			Total (L)
		42.5 m ³ /min (L)	28.3 m ³ /min (L)	14.2 m ³ /min (L)	
10/20/92	2/9/94	0	1,022	0	1,022
2/10/94	6/30/94	1,747	1,747	0	3,493
1992-1994 Total ^a		1,747	2,769	0	4,515
10/13/94	10/19/94	0	303	303	606
10/20/94	10/26/94	0	341	303	643
10/27/94	11/2/94	379	757	265	1,400
11/3/94	11/9/94	833	303	303	1,438
11/10/94	11/16/94	833	643	303	1,779
11/17/94	11/23/94	795	757	98	1,650
11/24/94	11/30/94	643	454	53	1,151
12/1/94	12/7/94	530	454	303	1,287
12/8/94	12/14/94	303	530	303	1,136
12/15/94	12/21/94	738	227	151	1,117
12/22/94	12/28/94	0	0	0	0
12/29/94	1/4/95	0	0	0	0
1/5/95	1/11/95	0	303	0	303
1/12/95	1/18/95	284	379	379	1,041
1/19/95	1/25/95	0	0	0	0
1/26/95	2/1/95	568	189	0	757
2/2/95	2/8/95	379	379	189	946
2/9/95	2/15/95	0	379	0	379
2/16/95	2/22/95	454	379	227	1,060
2/23/95	3/1/95	757	379	303	1,438
3/2/95	3/8/95	757	379	303	1,438
3/9/95	3/15/95	662	379	303	1,344
3/16/95	3/22/95	568	379	227	1,173
3/23/95	3/29/95	1,514	871	530	2,914
3/30/95	4/5/95	0	0	0	0
4/6/95	4/12/95	0	0	0	0
4/13/95	4/19/95	568	492	379	1,438
4/20/95	4/26/95	379	473	0	852

Soil Vapor Extraction System Operating Data

Table 5-6. Weekly Volume of Knockout Water Drained from Soil Vapor Extraction Systems, October 1994 – September 2001. (3 Pages)

Week Start	Week End	SVE System			Total (L)
		42.5 m ³ /min (L)	28.3 m ³ /min (L)	14.2 m ³ /min (L)	
1994-1995 Total		11,942	10,125	5,223	27,290
9/28/95	10/4/95	0	0	379	379
10/5/95	10/11/95	0	379	379	757
10/12/95	10/18/95	0	379	379	757
10/19/95	10/25/95	757	1,703	757	3,217
10/26/95	11/1/95	1,571	1,419	757	3,747
11/2/95	11/8/95	1,722	1,628	530	3,880
11/9/95	11/15/95	1,628	1,287	568	3,482
11/16/95	11/22/95	1,136	1,154	511	2,801
11/23/95	11/29/95	757	303	170	1,230
11/30/95	12/6/95	1,457	1,211	341	3,009
12/7/95	12/13/95	1,192	1,363	95	2,650
12/14/95	12/20/95	1,646	1,230	416	3,293
12/21/95	12/27/95	700	208	132	1,041
12/28/95	1/3/96	0	0	0	0
1/4/96	1/10/96	1,609	2,309	492	4,410
1/11/96	1/17/96	1,609	1,382	492	3,482
1/18/96	1/24/96	852	1,400	549	2,801
1/25/96	1/31/96	341	662	151	1,154
2/1/96	2/7/96	530	1,173	246	1,949
2/8/96	2/14/96	1,325	1,173	322	2,820
2/15/96	2/21/96	795	568	151	1,514
2/22/96	2/28/96	1,514	1,628	76	3,217
2/29/96	3/6/96	1,325	1,363	416	3,104
3/7/96	3/13/96	757	1,022	151	1,930
3/14/96	3/20/96	246	700	341	1,287
3/21/96	3/27/96	908	1,249	189	2,347
3/28/96	4/3/96	606	681	379	1,665
4/4/96	4/10/96	303	397	208	908
4/11/96	4/17/96	0	454	114	568
4/18/96	4/24/96	341	757	454	1,552

Table 5-6. Weekly Volume of Knockout Water Drained from Soil Vapor Extraction Systems, October 1994 – September 2001. (3 Pages)

Week Start	Week End	SVE System			Total (L)
		42.5 m ³ /min (L)	28.3 m ³ /min (L)	14.2 m ³ /min (L)	
4/25/96	5/1/96	0	0	0	0
5/2/96	5/8/96	0	0	0	0
5/9/96	5/15/96	454	265	227	946
5/16/96	5/22/96	0	0	0	0
5/23/96	5/29/96	0	454	0	454
5/30/96	6/5/96	0	0	0	0
6/6/96	6/12/96	0	0	0	0
6/13/96	6/19/96	0	0	0	0
6/20/96	6/26/96	0	0	390	390
1995-1996 Total		26,079	29,902	10,761	66,741
10/10/96	10/16/96	0	530	303	833
10/17/96	10/23/96	1,325	662	284	2,271
10/24/96	10/30/96	757	1,136	568	2,460
1996-1997 Total ^b		2,082	2,328	1,154	5,564
1997-1998 Total ^c		0	0	189	189
1998-1999 Total ^d		0	0	379	379
2000-2001 Total ^e		0	0	757	757
1992-2001 Total		41,849	45,123	18,463	105,434

^aNo SVE June 4, 1993 through November 11, 1993 following the GAC overheating incident on June 3, 1993; volume February 10, 1994 through June 30, 1994 divided equally between the 28.3- and 42.5-m³/min SVE systems.

^bNo SVE November 4, 1996 through July 17, 1997 during the rebound study.

^cNo SVE October 1, 1997 through March 29, 1998 during the planned winter shutdown. The 14.2-m³/min SVE system operated March 30, 1998 through September 30, 1998.

^dNo SVE October 1, 1998 through March 28, 1999 during the planned winter shutdown. The 14.2-m³/min SVE system operated March 29, 1999 through September 30, 1999.

^eNo SVE October 1, 1999 through September 30, 2000. No SVE October 1, 2000 through April 3, 2001 during planned winter shutdown. 14.2 m³/min SVE system operated April 4, 2001 through September 30, 2001.

Soil Vapor Extraction System Operating Data

BHI-00720

Rev. 6

Table 5-7. Analyses of Soil Vapor Extraction System Knockout Water.

Volatile Organic Compound	6/30/94		1/26/95		12/12/95		
	Result (µg/L)	Detection Limit (µg/L)	Result (µg/L)	Detection Limit (µg/L)	Result (µg/L)	Result (µg/L)	Detection Limit (µg/L)
Carbon tetrachloride	10 J	10	380	N/A	130	140	N/A
Chloroform	130	10	19	N/A	<10	<10	N/A
Tetrachloroethylene	10 U	10	0.7 J	2.0	<5	<5	N/A
Trichloroethylene	10 U	10	<1	N/A	<5	<5	N/A

J = estimated value

N/A = not available

U = analyzed for but not detected

Table 5-8. Initial Carbon Tetrachloride Concentrations Measured at Individual Extraction Wells.

Z-1A Well/ Interval	Restart 7/18/97								Restart 3/30/98				Restart 6/30/99				Restart 4/4/01				
	Date	Well Vacuum (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	Date	Well Vacuum (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	Date	Well Vacuum (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	Date	Well Vacuum (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	Date	Well Vacuum (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	
W18-6L					7/21/97	1	1	27	3/30/98	6	0	26	--	--	--	--	--	--	--	--	--
W18-7					7/21/97	2	3	31	3/30/98	1	1	15	--	--	--	--	--	--	--	--	--
W18-167					7/21/97	2	5	21	4/1/98	0	1	27	--	--	--	--	4/4/01	2	7	33	
W18-174					7/21/97	2	0	7	4/1/98	0	0	8	6/30/99	9	2	39	4/4/01	6	1	30	
W18-248					7/21/97	3	0	59	3/30/98	2	0	1	--	--	--	--	--	--	--	--	--
W18-252U					7/21/97	4	4	42	3/30/98	9	2	36	--	--	--	--	--	--	--	--	--
W18-152					--	--	--	--	3/30/98	6	0	21	--	--	--	--	--	--	--	--	--
W18-96					--	--	--	--	3/30/98	9	2	16	--	--	--	--	--	--	--	--	--
W18-12					--	--	--	--	3/30/98	9	0	29	--	--	--	--	--	--	--	--	--
W18-89					--	--	--	--	3/30/98	1	0	28	--	--	--	--	--	--	--	--	--
W18-246U					--	--	--	--	3/30/98	9	1	30	--	--	--	--	--	--	--	--	--
W18-252L					--	--	--	--	3/30/98	12	1	29	--	--	--	--	--	--	--	--	--
W18-249					--	--	--	--	3/30/98	7	3	33	--	--	--	--	--	--	--	--	--
W18-168					--	--	--	--	4/1/98	0	0	1	6/30/99	8	3	46	4/4/01	3	1	18	
W18-165					--	--	--	--	4/1/98	0	0	6	6/30/99	7	4	16	4/4/01	3	2	41	
W18-166					--	--	--	--	--	--	--	--	6/30/99	8	3	42	4/4/01	3	2	12	
--					--	--	--	--	--	--	--	--	--	--	--	--	4/4/01	3	0	0	
Z-9 Well/ Interval	Restart 7/18/97								Restart 7/7/98				Restart 3/29/99				Restart 7/23/01				
	Date	Well Vacuum (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	Date	Well Vacuum (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	Date	Well Vacuum (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	Date	Well Vacuum (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	Date	Well Vacuum (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	
W15-9L	7/18/97	16	2	20	7/21/97	19	2	21	7/10/98	19	2	17	3/30/99	23	3	16	7/23/01	27	2	21	
W15-82	7/18/97	16	2	106	7/21/97	14	2	47	7/10/98	17	2	196	3/30/99	20	2	167	7/23/01	24	2	154	
W15-217	7/18/97	16	5	256	7/21/97	12	6	86	7/10/98	15	4	135	3/30/99	19	4	116	7/23/01	22	5	236	
W15-6L	7/18/97	10	3	20	7/21/97	8	2	20	7/30/98	9	2	18	--	--	--	--	--	--	--	--	
W15-86	7/18/97	15	5	138	7/21/97	12	5	111	7/30/98	13	4	107	--	--	--	--	--	--	--	--	
W15-218L	7/18/97	20	3	20	7/21/97	13	2	22	--	--	--	--	--	--	--	--	--	--	--	--	
W15-218U	7/18/97	17	6	21	7/21/97	11	5	22	7/30/98	12	2	6	--	--	--	--	--	--	--	--	
W15-9U	--	--	--	--	--	--	--	--	7/10/98	20	2	30	3/30/99	24	2	35	7/23/01	29	1	150	

-- = no data
 CCl₄ = carbon tetrachloride
 ppmv = parts per million by volume

Soil Vapor Extraction System Operating Data

Table 5-9a. Hourly Data Availability for Passive Soil Vapor Extraction Wells During FY 2000.

Well	Carbon Tetrachloride Concentration Data Available	Flow Rate Data Available	Concentration and Flow Rate Data Available
299-W18-6L	10/14/99-12/30/99 01/03/00-02/09/00 03/07/00-09/25/00	11/11/99-03/28/00 04/28/00-09/30/00	11/11/99-12/30/99 01/03/00-02/09/00 03/07/00-03/28/00 04/28/00-09/25/00
299-W18-247L ^a	11/15/99-12/30/99 01/03/00-02/09/00 03/07/00-09/25/00	11/11/99-03/28/00 04/28/00-09/30/00	01/05/00-02/09/00 03/07/00-03/28/00 04/28/00-09/25/00
299-W18-252L	10/14/99-12/30/99 01/03/00-02/09/00 03/07/00-09/25/00	11/11/99-12/21/99 12/28/99-01/20/00 01/24/00-02/29/00 03/05/00-03/28/00 05/22/00-06/14/00 06/27/00-08/09/00 08/20/00-09/28/00	11/11/99-12/21/99 12/28/99-12/30/99 01/03/00-01/20/00 01/24/00-02/09/00 03/07/00-03/28/00 05/22/00-06/14/00 06/27/00-08/09/00 08/20/00-09/25/00

^aConcentration data collected prior to 01/05/00 at this well are not representative.

Table 5-9b. Hourly Data Availability for Passive Soil Vapor Extraction Wells During FY 2001.

Well	Carbon Tetrachloride Concentration Data Available	Flow Rate Data Available	Concentration and Flow Rate Data Available
299-W18-6L	10/23/00 - 11/08/00 11/30/00 - 04/04/01	10/01/00 - 10/24/00 11/30/00 - 12/18/00 02/01/01 - 04/05/01 04/13/01 - 06/22/01	10/23/00 - 10/24/00 11/30/00 - 12/18/00 02/01/01 - 04/04/01
299-W18-247L ^a	10/24/00 - 11/08/00 11/30/00 - 04/04/01	10/01/00 - 10/24/00 11/30/00 - 12/18/00 02/17/01 - 04/05/01 04/13/01 - 06/22/01	10/24/00 - 10/24/00 11/30/00 - 12/18/00
299-W18-252L	10/23/00 - 11/08/00 11/30/00 - 04/04/01	10/01/00 - 10/24/00 11/30/00 - 12/18/00 02/25/01 - 04/05/01 05/07/01 - 06/22/01	10/23/00 - 10/24/00 11/30/00 - 12/18/00 02/25/01 - 04/04/01

^aConcentration data collected after 01/15/01 at this well are not representative.

Table 5-10a. Carbon Tetrachloride Removed by Passive Soil Vapor Extraction Systems During FY 2000.

Well	10/14/1999 10/28/1999 (g)	10/28/1999 11/29/1999 (g)	11/29/1999 12/28/1999 (g)	12/28/1999 1/27/2000 (g)	1/27/2000 2/29/2000 (g)	2/29/2000 6/1/2000 (g)	6/1/2000 6/27/2000 (g)	6/27/2000 7/31/2000 (g)	7/31/2000 8/29/2000 (g)	8/29/2000 9/27/2000 (g)	FY 2000 Total (g)
GAC cartridge monthly analytical data											
299-W18-6L	2.9	1.6	0.7	2.0	1.0	2.1	1.4	2.3	2.6	3.5	20.1
299-W18-7	1.1	1.8	0.5	0.8	1.7	3.1	15.2	37.5	2.0	1.0	64.6
299-W18-10L	0.9	1.2	0.1	0.4	0.5	0.9	2.5	2.7	1.2	1.6	12.1
299-W18-11L	0.9	1.0	0.3	0.7	0.4	0.9	0.4	1.5	0.2	0.1	6.2
299-W18-12		3.0	0.1	1.3	0.2	2.3	16.9	17.2	3.7	6.0	50.8
299-W18-246L	1.4	2.0	0.3	0.5	0.7	7.3	24.2	15.5	7.0	0.4	59.2
299-W18-247L	0.8	0.7	0.2	1.2	0.4	1.0	2.0	1.0	0.2	0.3	7.8
299-W18-252L	1.9	3.3	0.5	1.9	0.5	2.5	8.8	4.2	4.6	2.6	30.8
Total	9.7	14.6	2.6	8.7	5.5	20.1	71.3	82.0	21.5	15.6	251.7
Wellhead hourly measurement data^a											
299-W18-6L	N/A	0.3	4.5	62.4	63.0	109.6	0.0	79.3	128.4	351.2	798.8
299-W18-247L	N/A	N/A	N/A	3.7	0.5	29.3	12.3	7.5	0.0	8.9	62.2
299-W18-252L	N/A	26.2	26.2	188.1	94.0	38.3	85.1	192.0	112.8	328.9	1091.6
Total	N/A	26.5	30.7	254.2	157.5	177.2	97.4	278.8	241.2	689.1	1952.6

^aBased on flows above the following threshold flows: 299-W18-6L = 0.03 m³/min; 299-W18-247L = 0.05 m³/min; 299-W18-252L = 0.04 m³/min.

Table 5-10b. Carbon Tetrachloride Removed by Passive Soil Vapor Extraction Systems During FY 2001.

Well	9/27/2000 10/31/2000 0 (g)	10/31/2000 11/29/2000 (g)	11/29/2000 12/27/2000 (g)	12/27/2000 1/29/2001 (g)	1/29/2001 2/27/2001 (g)	2/27/2001 3/26/2001 (g)	3/26/2001 4/30/2001 (g)	4/30/2001 5/30/2001 (g)	5/30/2001 6/26/2001 (g)	6/26/2001 7/30/2001 (g)	7/30/2001 8/30/2001 (g)	8/30/2001 9/26/2001 (g)	FY 2001 Total (g)
GAC cartridge monthly analytical data													
299-W18-6L	5.6	0.9	0.0	0.0	0.0	0.0	0.2	14.6	10.3	12.6	6.9	2.0	53.2
299-W18-7	2.2	1.9	4.0	0.1	4.6	1.4	7.1	11.0	0.8	0.0			33.1
299-W18-10	1.5	0.8	2.4	0.1	1.4	0.6	2.6	6.8	1.2	3.1	2.7	1.0	24.1
299-W18-11	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.1	0.2	0.1	0.9
299-W18-12	3.2	1.7	3.3	0.0	2.3	2.0	7.4	12.5	7.5	0.0			40.1
299-W18-246L	0.2	0.1	0.3	0.1	0.1	0.8	4.6	4.1	7.0	0.1			17.4
299-W18-247L	0.5	0.1	0.0	0.0	0.0	0.0	0.0	1.3	1.7	0.0	0.5	1.3	5.5
299-W18-252L	7.7	2.3	1.2	2.0	1.5	0.8	3.8	3.6	0.7	8.2	7.4	2.1	41.4
Total	20.9	7.8	11.4	2.3	9.9	5.5	26.0	54.0	29.3	24.1	17.8	6.6	215.6
Wellhead hourly measurement data^a													
299-W18-6L	0.0	N/A	0.0	N/A	0.0	0.0	0.0	N/A	N/A	N/A	N/A	N/A	0.0
299-W18-247L	0.0	N/A	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0
299-W18-252L	0.0	N/A	75.2	N/A	0.0	104.7	39.3	N/A	N/A	N/A	N/A	N/A	219.2
Total	0.0	N/A	75.2	N/A	0.0	104.7	39.3	N/A	N/A	N/A	N/A	N/A	219.2

^aBased on flows above the following threshold flows: 299-W18-6L = 0.04 m³/min; 299-W18-247L = 0.09 m³/min; 299-W18-252L = 0.02 m³/min.

Table 5-11a. Number of Days Hourly Data are Available During Each GAC Cartridge Sampling Interval in FY 2000.

GAC Sample Intervals	10/14/99 10/28/99	10/28/99 11/29/99	11/29/99 12/28/99	12/28/99 1/27/00	1/27/00 2/29/00	2/29/00 6/1/00	6/1/00 6/27/00	6/27/00 7/31/00	7/31/00 8/29/00	8/29/00 9/27/00	Total
Number of days in GAC sample interval	14	31	29	30	33	94	26	34	29	29	349
Number of days hourly data available for calculating mass removal at 299-W18-6L	0	18	29	26	13	55	26	34	29	27	257
Number of days hourly data available for calculating mass removal at 299-W18-247L	0	0	0	22	13	55	26	34	29	27	206
Number of days hourly data available for calculating mass removal at 299-W18-252L	0	18	22	22	13	31	13	34	18	27	198

Table 5-11b. Number of Days Hourly Data are Available During Each GAC Cartridge Sampling Interval in FY 2001.

GAC sample intervals	9/27/00 10/31/00	10/31/00 11/29/00	11/29/00 12/27/00	12/27/00 1/29/01	1/29/01 2/27/01	2/27/01 3/26/01	3/26/01 4/30/01	4/30/01 5/30/01	5/30/01 6/26/01	6/26/01 7/30/01	7/30/01 8/30/01	8/30/01 9/26/01	Total
Number of days in GAC sample interval	34	29	28	33	29	27	35	30	27	34	31	27	364
Number of days hourly data available for calculating mass removal at 299-W18-6L	1	0	18	0	26	27	9	0	0	0	0	0	81
Number of days hourly data available for calculating mass removal at 299-W18-247L	1	0	18	0	0	0	0	0	0	0	0	0	19
Number of days hourly data available for calculating mass removal at 299-W18-252L	1	0	18	0	2	27	9	0	0	0	0	0	57

Table 5-12. Estimate of Total Carbon Tetrachloride Removed from Each Passive Soil Vapor Extraction Well in FY 2000 Based on Linear Trend Between Monthly GAC Cartridge Analytical Data and Hourly Wellhead Measurement Data.

Well	Total Carbon Tetrachloride Mass Removed in FY 2000 (g)		
	Based on Hourly Wellhead Measurement Data	Based on Monthly GAC Analytical Data	Based on Linear Trend Between GAC and Hourly Data Total = 39.044* GAC Total
299-W18-6L	798.8	20.1	785.43
299-W18-7		64.6	2,523.21
299-W18-10L		12.1	473.78
299-W18-11L		6.2	240.95
299-W18-12		50.8	1,982.76
299-W18-246L		59.2	2,313.10
299-W18-247L	62.2	7.8	305.27
299-W18-252L	1,091.6	30.8	1,202.32
Total	1,952.6	251.7	9,826.82

Soil Vapor Extraction System Operating Data

Table 5-13. Estimate of Potential Total Carbon Tetrachloride Removed from Each Passive Soil Vapor Extraction Well in FY 2001.

Well	Maximum Carbon Tetrachloride Concentration	Maximum Flow		Number of Days in Operation	Mass Removed (g)
	06/01/01 Sampling (ppmv)	Hourly Measurements (m ³ /min)	Assumed (m ³ /min)		
299-W18-6L	47.4	0.4		365	7,545.9
299-W18-7	38.5 ^a		0.4 ^b	151 ^{e,f}	2,535.6
299-W18-10L	12.8		0.2 ^c	274 ^f	944.8
299-W18-11L	11.4		0.2 ^c	365	1,120.9
299-W18-12	30.5		0.4 ^b	186 ^{g,h}	2,467.6
299-W18-246L	40.9		0.2 ^d	172 ^{h,i}	1,664.6
299-W18-247L	7.2	0.2		365	710.9
299-W18-252L	38.1	0.2		305 ^j	2,757.8
Total					19,748.1

^a On line to SVE system during June 1, 2001 sampling; concentration measured during characterization of individual on-line extraction wells on May 31, 2001 (Table B-1).

^b Assumed to be the same as 299-W18-6L.

^c Assumed to be the same as 299-W18-247L.

^d Assumed to be the same as 299-W18-252L.

^e Taken off line to passive system on May 31, 2001.

^f Assumed to be blocked 50% of October through March by water in system (Tables C-12 through C-17).

^g Taken off line to passive system on June 5, 2001.

^h Assumed to be blocked 50% of October through January by water in system (Tables C-12 through C-15).

ⁱ Assumed to be blocked 50% of October through February by water in system (Tables C-12 through C-16).

^j Assumed to be blocked 50% of November through February by water in system (Tables C-13 through C-16).

**Table 5-14a. Comparison of Carbon Tetrachloride Removed in FY 2000
Based on Selected Flow Rates.**

Well	Total Carbon Tetrachloride Mass Removed Based on All Flows Recorded (g)	Total Carbon Tetrachloride Mass Removed Based on All Flows Above Threshold Flow ^a (g)	Carbon Tetrachloride Mass Removed, Maximum Hourly Rate (g/hr)
W18-6L	1083.0	798.8	4.1
W18-247L	75.1	62.2	0.5
W18-252L	1366.6	1091.6	4.4

^aThreshold flows are as follows: W18-6L = 0.03 m³/min; W18-247L = 0.05 m³/min; W18-252L = 0.04 m³/min.

**Table 5-14b. Comparison of Carbon Tetrachloride Removed in FY 2001
Based on Selected Flow Rates.**

Well	Total Carbon Tetrachloride Mass Removed Based on All Flows Recorded (g)	Total Carbon Tetrachloride Mass Removed Based on All Flows Above Threshold Flow ^a (g)	Carbon Tetrachloride Mass Removed, Maximum Hourly Rate (g/hr)
W18-6L	72.7	0.0	0.2
W18-247L	1.8	0.0	0.0
W18-252L	261.7	219.1	2.7

^aThreshold flows are as follows: W18-6L = 0.04 m³/min; W18-247L = 0.09 m³/min; W18-252L = 0.02 m³/min.

6.0 NONOPERATIONAL SOIL VAPOR MONITORING DATA

Nonoperational soil vapor monitoring data are collected at wells and probes that are not on line to the SVE system. The objectives of monitoring the nonoperational wells and probes are (1) to measure carbon tetrachloride concentrations and trends near the vadose-atmosphere and vadose-groundwater interfaces to evaluate whether nonoperation of the SVE system is negatively impacting the atmosphere or groundwater; and (2) to be cognizant of carbon tetrachloride concentrations and trends near the lower permeability Plio-Pleistocene layer to provide an indication of concentrations that can be expected during restart of SVE operations and to support selection of on-line wells. The maximum carbon tetrachloride concentrations measured during each period of rebound are provided in Table 6-1. For each wellfield, the period of rebound begins when SVE operations are temporarily suspended.

6.1 SUMMARY OF FISCAL YEAR 1997 REBOUND STUDY

A rebound study was conducted at the carbon tetrachloride SVE sites from November 1996 through July 1997 (Rohay 1997). The purpose of the study was to determine the increase in carbon tetrachloride vapor concentrations following shutdown of the extraction systems. During the time when the systems were off line, carbon tetrachloride concentrations were monitored at 90 subsurface monitoring locations, ranging in depth from 2 to 64 m.

The magnitude and rate of rebound can be used to indicate the distribution of remaining carbon tetrachloride sources and the transfer of additional carbon tetrachloride to the vapor phase that can be remediated using SVE. However, based on the results of a bench-scale experimental study conducted by Yonge et al. (1996), the mass of carbon tetrachloride remaining in the soil at the vapor extraction sites cannot be reliably determined using the rebound study vapor-phase data. Yonge et al. conducted experiments using pure carbon tetrachloride and clean site-specific soils and concluded that calculation of carbon tetrachloride soil concentrations using measured vapor-phase concentrations and either empirical relationships or adsorption isotherms to estimate the soil-partitioning coefficient can lead to significant error (Yonge et al. 1996). This conclusion was based on comparison of calculated and measured soil concentrations using data generated during the experiments. The predictive equations generally assume equilibrium partitioning between phases. However, these relationships do not account for the nonequilibrium partitioning of carbon tetrachloride within the soil particles (the apparent "irreversible" adsorption).

The maximum carbon tetrachloride concentration measured at each individual sampling location is plotted with depth in Figure 6-1. The highest concentration detected was 797 ppmv at well 299-W15-217 (35 m deep) in the 216-Z-9 wellfield. This vertical profile indicates that the remaining carbon tetrachloride available for removal using SVE is primarily associated with the silt and underlying Plio-Pleistocene caliche layers (zones 3 and 4, Figure 2-2). Remaining carbon tetrachloride sources are located in these layers as a result of (1) the initial accumulation of carbon tetrachloride in these finer grained, lower permeability layers, observed during characterization in 1991-1993 (Rohay et al. 1994); and (2) the relative inability of the extraction

Nonoperational Soil Vapor Monitoring Data

systems to induce airflow through this lower permeability zone to effectively remove the carbon tetrachloride.

The maximum chloroform concentration measured at each sampling location is plotted with depth in Figure 6-2. The results are similar to those of carbon tetrachloride with two exceptions: maximum chloroform concentrations tend to be relatively high near the ground surface (zone 1, Figure 2-2) and also near the water table (zone 6, Figure 2-2). Two shallow soil vapor probes, one approximately 30 m west of 216-Z-12 and one approximately 270 m northeast of 216-Z-9, had relatively high maximum chloroform concentrations (20 to 30 ppmv), represented by one data point at 2 m depth in Figure 6-2. The maximum chloroform concentration at the other shallow probes in the 216-Z-1A/Z-18/Z-12 area was 4.3 ppmv and in the 216-Z-9 area was 8.7 ppmv, represented by the other data point at 2 m depth in Figure 6-2. At the monitoring locations near the groundwater (zone 6), the maximum chloroform concentration in the 216-Z-1A area was 8.1 ppmv and in the 216-Z-9 area was 7.5 ppmv. The cause of the apparently elevated chloroform is undetermined.

The concentrations of carbon tetrachloride and chloroform are compared for the 216-Z-9 site in Figure 6-3 and for the 216-Z-1A/Z-18/Z-12 site in Figure 6-4. These data are plotted at the same scales as in Figures 5-36 and 5-38 for ease of comparison. The chloroform to carbon tetrachloride trends for the rebound data at the 216-Z-9 and 216-Z-1A/Z-18/Z-12 monitoring locations appear to be similar. For carbon tetrachloride rebound concentrations greater than approximately 100 ppmv, the trends of the chloroform to carbon tetrachloride ratios follow the shallower of the two trends identified in the extracted soil vapor (Figures 5-36 and 5-38). The data in Figures 6-3 and 6-4 include all the rebound data for zones 2 through 6 (not just the maximum values).

Carbon tetrachloride concentrations rebounded significantly (i.e., by an order of magnitude) at only five locations monitored during the study, indicating that in many areas the readily accessible mass has been removed. The continuing rebound at many locations indicates that the supply of additional carbon tetrachloride to the high flow zone pore spaces affected by SVE is limited by diffusion of the contaminant from soil moisture and micropores and/or from the lower permeability zones. These data also indicate that the distribution of carbon tetrachloride sources is not uniform. During the first 3 weeks of SVE operations in July 1997 following rebound, the three SVE systems combined were extracting an average of 178 kg/week, compared to 102 kg/week in November 1996 and in September 1997. These comparisons indicate that carbon tetrachloride is still available for extraction using SVE.

Carbon tetrachloride concentrations rebounded most rapidly in the 8 to 16 weeks following SVE shutdown but continued rebounding (at the same rate or more slowly) for 8 months and presumably would continue for years. Carbon tetrachloride concentrations decreased most rapidly in the first 5 weeks following SVE restart, after which they continued decreasing more slowly with continued SVE operations. Therefore, to optimize the carbon tetrachloride mass removal efficiency (in terms of mass of carbon tetrachloride removed per volume of soil vapor extracted), the minimum operating cycle recommended in 1997 was 4 to 8 weeks of SVE operation followed by 8 to 16 weeks of rebound.

Nonoperational Soil Vapor Monitoring Data

Carbon tetrachloride concentrations near the water table remained relatively constant or increased slowly, suggesting that volatilization of carbon tetrachloride from the dissolved source in the groundwater into the unsaturated zone is occurring slowly relative to the 8-month-long rebound study period. Based on comparison of measured vapor concentrations to theoretical vapor concentrations that would be in equilibrium with measured groundwater concentrations, the groundwater and vapor do not appear to be in equilibrium. The expected direction of carbon tetrachloride migration is from the groundwater to the vadose zone, based on the comparison of measured to theoretical vapor concentrations.

Numerical model simulations were conducted to evaluate the location of potential sources of residual carbon tetrachloride in the vicinity of the 216-Z-9 Trench (Riley 1998). Carbon tetrachloride concentrations diffusing from assumed source zones of varying configurations and depths in the model were compared to the rebound field data. Model simulations suggested that a horizontal zone of residual DNAPL contamination at a depth of 21 to 47 m was most consistent with the field data. The simulations suggested that a vertical zone of residual contamination directly below the 216-Z-9 Trench would not produce the rebound concentrations observed during the field study. The numerical model also suggested that rebound at other depths may be caused by more localized, diffuse sources.

6.2 FISCAL YEAR 1998 SOIL VAPOR MONITORING

Soil vapor monitoring at off-line wells and probes was conducted in FY 1998 using the sampling methods developed for the rebound study conducted in FY 1997 (Rohay 1997). A low-flow (0.8 L/min) sampling pump was used to draw soil vapor samples from wells and probes into a 1-L Tedlar bag for analysis using a B&K multi-gas monitor. Two purge volumes were drawn before the sample was collected. For most of the wells in which the sampling pump was used, a tube was lowered to the target depth where the casing is perforated (i.e., open to the sediment and its pores) to minimize the volume of air to be purged. A metal filter attached to the end of the tube also served as a weight. Each sampling tube remained in the well for the duration of the monitoring period. Each well equipped with a sampling tube remained sealed at the wellhead throughout the monitoring period. As a test, at a limited number of wells the sampling pump was used to collect a sample at the wellhead without use of a sampling tube extended to the perforated interval. These wells were purged for either 3 minutes or 10 minutes using the sampling pump. The wells remained sealed, and the sample pump was used to collect samples in 1-L Tedlar bags for analysis using the B&K.

Soil vapor samples were collected from approximately 25 off-line wells and probes once per month. All of the FY 1998 soil vapor monitoring data are included in Appendix D.

Soil vapor samples were analyzed primarily to monitor for carbon tetrachloride. However, the samples collected from off-line wells and probes were also analyzed for chloroform, methylene chloride, methyl ethyl ketone, and water vapor because the B&K multi-gas monitor had been configured to analyze for all four contaminants plus water vapor to support routine monitoring during extraction operations.

Nonoperational Soil Vapor Monitoring Data

During October 1997 through March 1998, soil vapor concentrations were monitored near the groundwater and near the ground surface to assess whether nonoperation of the SVE system was allowing carbon tetrachloride to migrate out of the vadose zone to the atmosphere and/or to the groundwater. The maximum concentration detected between depths of 2 and 5 m bgs was 1 ppmv; the maximum concentration detected between depths of 8 and 18 m was 43 ppmv. Near the groundwater, at depths ranging from 54 to 63 m bgs, maximum concentrations ranged from 14.6 to 31.3 ppmv. These results, obtained during 6 months of rebound, are similar to those obtained during the 8-month rebound study conducted in FY 1997 (Rohay 1997).

During April through June 1998, soil vapor monitoring was continued at the shallow and deep locations at the 216-Z-9 site. Monitoring locations were added near the lower permeability Plio-Pleistocene unit at the 216-Z-9 site to provide an indication of concentrations that could be expected during restart of SVE in July 1998. Concentrations detected in the near-surface and near-groundwater zones during these three additional months of rebound were similar to those observed during the previous 6 months. Nearer the Plio-Pleistocene layer, at depths ranging from 18 to 35 m bgs, maximum concentrations ranged from 0 to 630 ppmv. The highest concentration was detected at well 299-W15-217 (35 m deep), the well at which the highest concentration was detected during the FY 1997 rebound study. These results were obtained during 9 months of rebound and are similar to those obtained during the 8-month rebound study conducted in FY 1997 (Rohay 1997).

During July through September 1998, soil vapor monitoring was resumed at the 216-Z-1A and 216-Z-18 sites. Monitoring was conducted in the near-surface, near-Plio-Pleistocene, and near-groundwater zones. The maximum concentration detected was 143 ppmv at well 299-W18-158L (36 m deep) in the 216-Z-1A Tile Field. These results were obtained during only 3 months of rebound.

The maximum carbon tetrachloride concentration measured at each sampling location in FY 1998 is plotted with depth in Figure 6-5. The maximum concentrations measured during the rebound study (Figure 6-1) are included for comparison.

Samples were collected initially from well 299-W15-217 at the wellhead before the downhole sampling tube was installed to evaluate the effect of the sampling tube. In March and April 1998, these wellhead samples contained 65 and 25 ppmv of carbon tetrachloride, respectively. Samples collected in May and June 1998 using the downhole sampling tube contained 630 and 504 ppmv of carbon tetrachloride, respectively. Other wells sampled without the sampling tube had anomalously low to nondetectable carbon tetrachloride concentrations. Based on these results, samples collected at the wellhead when the wells are not venting are not representative of in situ concentrations. These results were not used in evaluation of the monitoring data.

Because carbon tetrachloride concentrations did not increase significantly at the shallow probes monitored in FY 1998, temporarily suspending operation of the SVE system for 6 to 9 months appears to have caused minimal detectable vertical transport of carbon tetrachloride through the

Nonoperational Soil Vapor Monitoring Data

soil surface to the atmosphere. Because carbon tetrachloride concentrations did not increase significantly near the water table during this time, temporarily suspending operation of the SVE systems appears to have had no negative impact on groundwater quality. The results of the FY 1998 soil vapor monitoring again suggest that the silt and underlying Plio-Pleistocene caliche layers are the most likely source of carbon tetrachloride available for removal using SVE.

6.3 FISCAL YEAR 1999 SOIL VAPOR MONITORING

Soil vapor monitoring at off-line wells and probes was also conducted in FY 1999 using the sampling methods developed for the rebound study conducted in FY 1997 (Rohay 1997). Soil vapor samples were collected from 30 off-line wells and probes once per month. All of the FY 1999 soil vapor monitoring data are included in Appendix E. As in FY 1998, soil vapor samples were analyzed primarily to monitor for carbon tetrachloride. However, the samples collected from off-line wells and probes were also analyzed for chloroform, methylene chloride, methyl ethyl ketone, and water vapor because the B&K multi-gas monitor had been configured to analyze for all four contaminants plus water vapor to support routine monitoring during extraction operations.

Soil vapor concentrations were monitored near the groundwater and near the ground surface to assess whether nonoperation of the SVE system was allowing carbon tetrachloride to migrate out of the vadose zone to the atmosphere and/or to the groundwater. Monitoring was also conducted at locations near the lower permeability Plio-Pleistocene unit to provide an indication of concentrations that could be expected during restart of SVE.

Both the 216-Z-1A/Z-18/Z-12 and 216-Z-9 wellfields were monitored between October 1998 and March 1999 while operation of the SVE system was temporarily suspended for the winter. The 216-Z-1A/Z-18/Z-12 wellfield was monitored during SVE operations at 216-Z-9 from April through June 1999, and the 216-Z-9 wellfield was monitoring during SVE operations at 216-Z-1A/Z-18/Z-12 from July through September 1999.

The maximum concentration detected between depths of 2 and 5 m bgs was 5 ppmv; the maximum concentration detected between depths of 8 and 18 m was 57 ppmv (Figure 6-5). Near the groundwater, at depths ranging from 54 to 63 m bgs, maximum concentrations ranged from 13 to 29 ppmv. Nearer the Plio-Pleistocene layer, at depths ranging from 21 and 47 m bgs, maximum concentrations ranged from 0 to 561 ppmv (Figure 6-5). These results, obtained during 3 to 12 months of rebound, are similar to those obtained during the 8-month rebound study conducted in FY 1997 (Rohay 1997).

The highest concentration was detected at the 216-Z-9 wellfield at well 299-W15-217 (35 m deep), the well at which the highest concentrations were detected during the FY 1997 rebound study and the FY 1998 monitoring. This result was obtained during 6 months of rebound. At the 216-Z-1A/Z-18 wellfield, the maximum concentration detected was 492 ppmv at well 299-W18-158L (36 m deep), the well at which the highest concentrations were detected during FY 1998 monitoring. This result was obtained during 12 months of rebound.

Nonoperational Soil Vapor Monitoring Data

Because carbon tetrachloride concentrations did not increase significantly at the shallow probes monitored in FY 1999, temporarily suspending operation of the SVE system for 6 to 12 months appears to have caused minimal detectable vertical transport of carbon tetrachloride through the soil surface to the atmosphere. Because carbon tetrachloride concentrations did not increase significantly near the water table during this time, temporarily suspending operation of the SVE system appears to have had no negative impact on groundwater quality. As in FY 1997 and FY 1998, soil vapor monitoring results in FY 1999 suggest that the silt and underlying Plio-Pleistocene caliche layer are the most likely source zone for the observed carbon tetrachloride vapor.

6.4 FISCAL YEAR 2000 SOIL VAPOR MONITORING

Soil vapor monitoring at off-line wells and probes was also conducted in FY 2000 using the sampling methods developed for the rebound study conducted in FY 1997 (Rohay 1997). Soil vapor samples were collected from 22 off-line wells and probes once per month. All of the FY 2000 soil vapor monitoring data are included in Appendix F. As in previous years, soil vapor samples were analyzed primarily to monitor for carbon tetrachloride. However, the samples collected from off-line wells and probes were also analyzed for chloroform, methylene chloride, methyl ethyl ketone, and water vapor because the B&K multi-gas monitor had been configured to analyze for all four contaminants plus water vapor to support routine monitoring during extraction operations.

During FY 2000, soil vapor was sampled hourly at three of the passive SVE wells and analyzed for carbon tetrachloride, chloroform, methylene chloride, methyl ethyl ketone, and water vapor using a B&K multi-gas monitor. These data are included in the evaluation of the FY 2000 rebound data.

Soil vapor concentrations were monitored near the groundwater and near the ground surface to assess whether nonoperation of the SVE system was allowing carbon tetrachloride to migrate out of the vadose zone to the atmosphere and/or to the groundwater. Monitoring was also conducted at locations near the lower permeability Plio-Pleistocene unit to provide an indication of concentrations that could be expected during restart of SVE. During FY 1998 and FY 1999, carbon tetrachloride concentrations were also monitored at shallow soil vapor probes (2 m deep). In light of the sporadic and low concentrations detected at these shallow soil vapor probes, shallow monitoring was not conducted during FY 2000.

Both the 216-Z-1A/Z-18/Z-12 and 216-Z-9 wellfields were monitored between October 1999 and September 2000 while operation of the SVE system was temporarily suspended for the year.

The maximum concentration detected near the ground surface (between 2 and 10 m bgs) was 9.4 ppmv. Near the groundwater, the maximum concentration was 20.4 ppmv in monthly samples collected from a depth of 54 m bgs at the 216-Z-9 site using the rebound study sampling methods. The maximum concentration was 69.2 ppmv in hourly samples collected from depths ranging from 51 to 63 m bgs at the three passive extraction wells at the 216-Z-1A/Z-18 site.

Nonoperational Soil Vapor Monitoring Data

Near the Plio-Pleistocene layer, at depths ranging from 25 and 40 m bgs, the maximum concentration detected was 442 ppmv (Figure 6-5). These results, obtained during 12 to 15 months of rebound, are similar to those obtained during the 8-month rebound study conducted in FY 1997 (Rohay 1997).

During FY 2000 monitoring, the highest concentration (442 ppmv) was detected at the 216-Z-9 wellfield at well 299-W15-217 (35 m deep), the well at which the highest concentrations were detected during FY 1997, FY 1998, and FY 1999 monitoring. This result was obtained during 15 months of rebound. At the 216-Z-1A/Z-18 wellfield, the maximum concentration detected was 248 ppmv at well 299-W18-167 (32 m deep) in the 216-Z-1A Tile Field, the well at which the highest concentrations were detected during FY 1997 monitoring in this area. The well at which the highest concentrations were detected during FY 1998 and FY 1999 monitoring at the 216-Z-1A/Z-18 site is also in the tile field. This result was obtained during 12 months of rebound.

Because carbon tetrachloride concentrations did not increase significantly at the near-surface probes monitored in FY 2000, temporarily suspending operation of the SVE system for 12 to 15 months appears to have caused minimal detectable vertical transport of carbon tetrachloride through the soil surface to the atmosphere. Because carbon tetrachloride concentrations did not increase significantly near the water table during this time, temporarily suspending operation of the SVE systems appears to have had no negative impact on groundwater quality. As in FY 1997, FY 1998, and FY 1999, soil vapor monitoring results in FY 2000 suggest that the silt and underlying Plio-Pleistocene caliche layer are the most likely source zone for the observed carbon tetrachloride vapor.

6.5 FISCAL YEAR 2001 SOIL VAPOR MONITORING

Soil vapor monitoring at off-line wells and probes was also conducted in FY 2001 using the sampling methods developed for the rebound study conducted in FY 1997 (Rohay 1997). Soil vapor samples were collected from 22 off-line wells and probes once per month. All of the FY 2001 soil vapor monitoring data are included in Appendix G. As in previous years, soil vapor samples were analyzed primarily to monitor for carbon tetrachloride. However, the samples collected from off-line wells and probes were also analyzed for chloroform, methylene chloride, methyl ethyl ketone, and water vapor because the B&K multi-gas monitor had been configured to analyze for all four contaminants plus water vapor to support routine monitoring during extraction operations.

During FY 2001, soil vapor was sampled hourly at three of the passive SVE wells and analyzed for carbon tetrachloride, chloroform, methylene chloride, methyl ethyl ketone, and water vapor using a B&K multi-gas monitor. These data are included in the evaluation of the FY 2001 rebound data.

Soil vapor concentrations were monitored near the groundwater and near the ground surface to assess whether nonoperation of the SVE system was allowing carbon tetrachloride to migrate out

Nonoperational Soil Vapor Monitoring Data

of the vadose zone to the atmosphere and/or to the groundwater. Monitoring was also conducted at locations near the lower permeability Plio-Pleistocene unit to provide an indication of concentrations that could be expected during restart of SVE. During FY 1998 and FY 1999, carbon tetrachloride concentrations were also monitored at shallow soil vapor probes (2 m deep). In light of the sporadic and low concentrations detected at these shallow soil vapor probes, shallow monitoring was not conducted during FY 2000 or FY 2001.

Because the SVE systems were not operated during FY 2000, the concentrations measured during FY 2001 represent a continuation of the rebound that began following SVE in FY 1999. The monitoring at both the 216-Z-1A/Z-18/Z-12 and 216-Z-9 wellfields that was conducted between October 1999 and September 2000 was continued through March 2001 while operation of the SVE system was temporarily suspended.

The maximum concentration detected near the ground surface (between 2 and 10 m bgs) was 16.5 ppmv (Figure 6-5). Near the groundwater, the maximum concentration was 20.4 ppmv in monthly samples collected from a depth of 54 m bgs at the 216-Z-9 site using the rebound study sampling methods. The maximum concentration was 69.2 ppmv in hourly samples collected from depths ranging from 51 to 63 m bgs at the three passive extraction wells at the 216-Z-1A/Z-18 site. Near the Plio-Pleistocene layer, at depths ranging from 25 and 40 m bgs, the maximum concentration detected was 442 ppmv (Figure 6-5). These results, obtained during 18 to 24 months of rebound, are similar to those obtained during the 8-month rebound study conducted in FY 1997 (Rohay 1997).

During FY 2000 and 2001 monitoring, the highest concentration (442 ppmv) was detected at the 216-Z-9 wellfield at well 299-W15-217 (35 m deep), the well at which the highest concentrations were detected during FY 1997, FY 1998, and FY 1999 monitoring. This result was obtained during 21 months of rebound. At the 216-Z-1A/Z-18 wellfield, the maximum concentration detected was 284 ppmv at well 299-W18-158L (36 m deep) in the 216-Z-1A Tile Field, the well at which the highest concentrations were detected during FY 1998 and FY 1999 monitoring. This result was obtained during 18 months of rebound.

Carbon tetrachloride rebound concentrations measured at well 299-W15-217 during four different periods of nonoperation of the SVE system are shown in Figure 6-6. Although the lengths of time available for rebound ranged from 6 to 21 months, the maximum carbon tetrachloride concentration decreased with each successive monitoring period. This decline in maximum concentrations may indicate that the remaining carbon tetrachloride is becoming less accessible and/or diffusing from increasingly greater distances.

Because carbon tetrachloride concentrations did not increase significantly at the near-surface probes monitored in FY 2001, temporarily suspending operation of the SVE system for 18 to 21 months appears to have caused minimal detectable vertical transport of carbon tetrachloride through the soil surface to the atmosphere. Because carbon tetrachloride concentrations did not increase significantly near the water table during this time, temporarily suspending operation of the SVE systems appears to have had no negative impact on groundwater quality. As in FY 1997, FY 1998, FY 1999, and FY 2000, soil vapor monitoring results in FY 2001 suggest

Nonoperational Soil Vapor Monitoring Data

that the silt and underlying Plio-Pleistocene caliche layer are the most likely source zone for the observed carbon tetrachloride vapor.

6.6 COMPARISON OF SOIL VAPOR MONITORING BEFORE AND AFTER SOIL VAPOR EXTRACTION REMEDIATION

Baseline monitoring was conducted to estimate the magnitude of carbon tetrachloride subsurface vapor concentrations prior to initiation of SVE operations to remove carbon tetrachloride from the vadose zone. The baseline monitoring program for the vapor extraction system consisted of 116 selected wells and deep soil vapor probes that were monitored twice per week from December 1991 through December 1993 (Fancher 1994).

The wells and deep soil vapor probes were monitored using a total organic vapor monitor (a photoionization detector [PID] equipped with an 11.8-eV lamp). The range for the instrument was 0.1 to 2,000 ppmv. The total VOC measurement was assumed to consist solely of carbon tetrachloride, based on confirmation at selected sample stations using carbon tetrachloride-specific colorimetric tubes and the predominance of carbon tetrachloride in other samples analyzed using gas chromatography (Fancher 1994, Rohay et al. 1994).

The wells were sampled at the wellhead by inserting the PID probe a few centimeters into the well and allowing air to be drawn through the instrument for at least 10 seconds before a reading was taken. At soil vapor probes, the PID was directly coupled to the sample tube leading from the subsurface probe to the surface. At least two purge volumes were extracted from the tube before the vapor was monitored. At both wells and probes, the vapor was monitored while readings increased; once the readings peaked, the maximum value was recorded (Fancher 1994).

Observed carbon tetrachloride concentrations (measured as total organic vapor) ranged from 0 to over 2,000 ppmv; in this report, readings above 2,000 ppmv (observed at five locations in the 216-Z-9 wellfield) were set equal to 2,000 ppmv (the maximum calibration value). Because the contaminant concentrations fluctuate in response to barometric pressure, the maximum baseline monitoring value for each well or probe was judged to have the greatest likelihood of representing equilibrium conditions.

Although the highest concentrations for the baseline monitoring network measured between December 1991 and December 1993 appear to be associated with the lower permeability Plio-Pleistocene layer, relatively high concentrations are observed throughout the vadose zone (Figure 6-7). (Although SVE was initiated at the 216-Z-1A and 216-Z-18 sites in 1992, operations were limited to 7 hr/day, 5 days/week using up to 11 wells. The baseline monitoring data set presented here is considered generally representative of pre-remediation conditions.) Vertical profiles for carbon tetrachloride concentrations monitored at wells and deep soil vapor probes after remediation in 1996, 1997, 1998, and 1999 (Figure 6-5) suggest that SVE has been relatively successful in remediating the higher permeability, higher flow zones in the sands and gravels above and below the Plio-Pleistocene unit.

Nonoperational Soil Vapor Monitoring Data

The maximum carbon tetrachloride values measured between December 1991 and December 1993 at wells and deep soil vapor probes with open areas above the Plio-Pleistocene unit are shown in Figure 6-8a; the maximum values for wells with open areas below the Plio-Pleistocene unit are shown in Figure 6-8b. In constructing these figures, it was assumed that the results collected at various monitoring points are comparable to each other despite the differing ages, locations, depths, and completions of individual wells and probes. Open intervals in the boreholes range from approximately 23 to 48 m bgs. The deep soil vapor probes range in depth from 3 to 33 m. In addition, the distributions of vapor shown in Figure 6-8 are limited by the extent of the monitoring network. Laterally, the highest concentrations were observed at the 216-Z-9 wellfield. Concentrations observed at the 216-Z-12 Crib wells were comparable in magnitude to those observed at the 216-Z-1A Tile Field.

The maximum values observed during the 1997 rebound monitoring are shown in Figures 6-9a and 6-9b.

Figure 6-1. Vertical Profile of Maximum Carbon Tetrachloride Rebound Concentrations, November 1996 – July 1997.

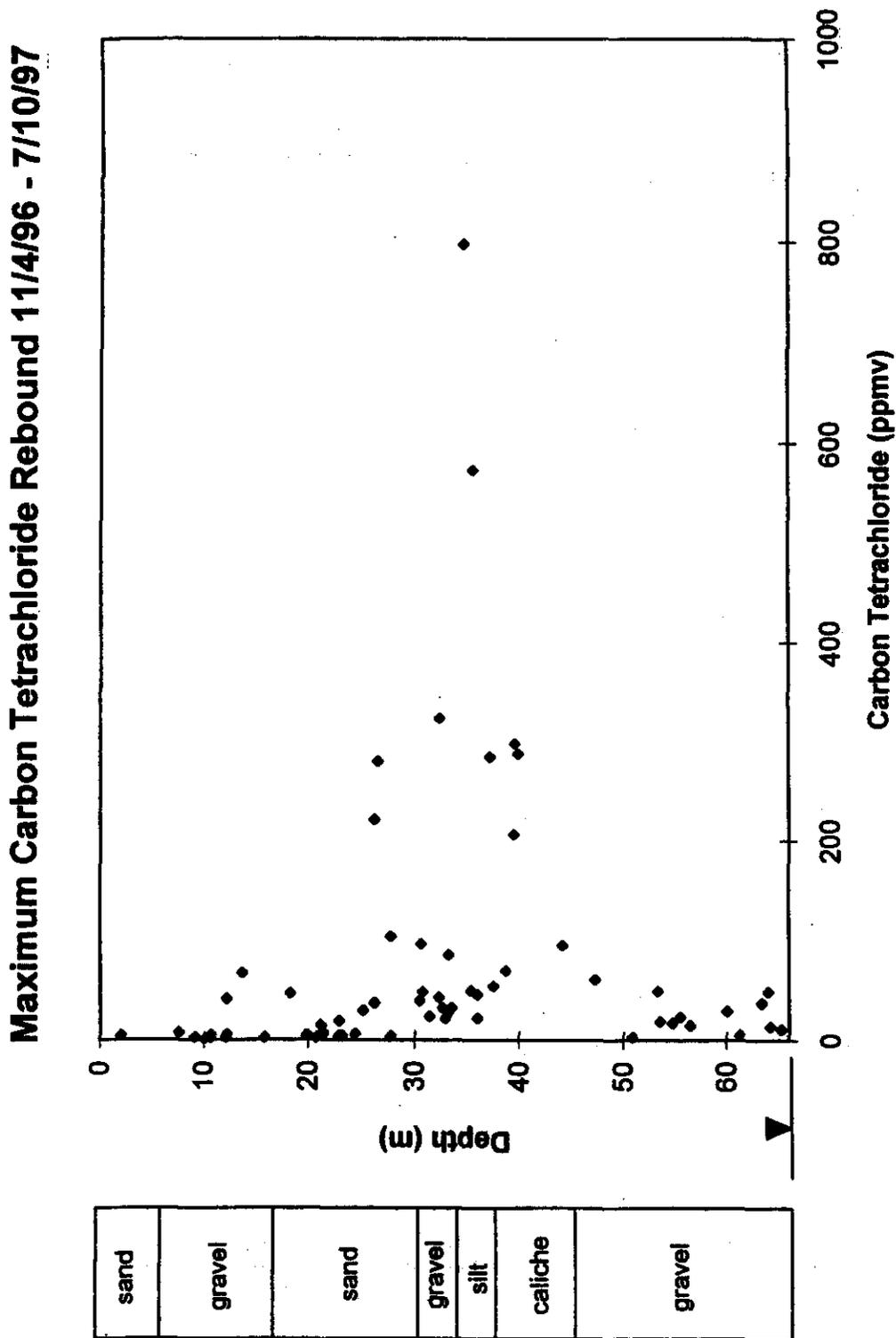
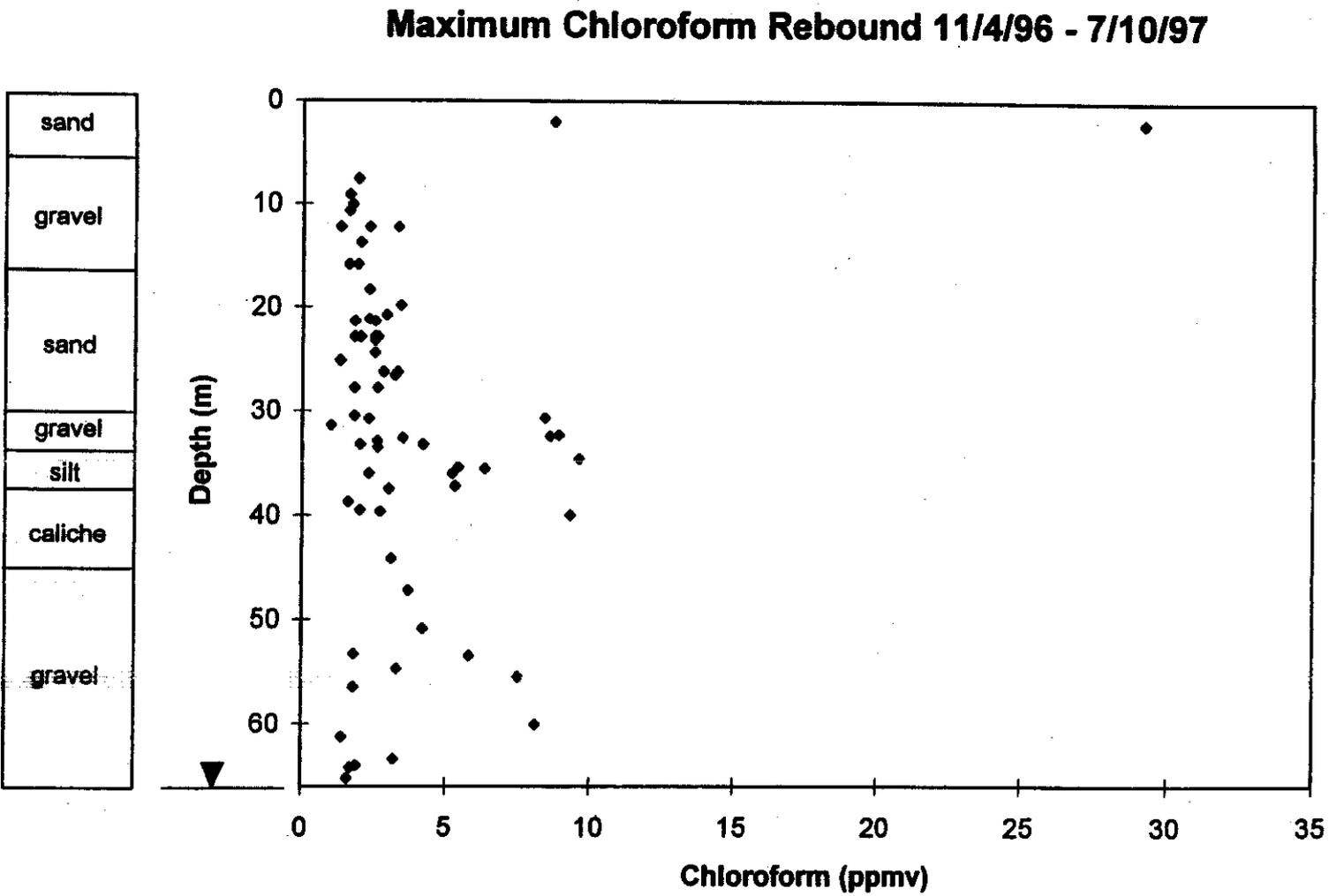


Figure 6-2. Vertical Profile of Maximum Chloroform Rebound Concentrations, November 1996 – July 1997.



Nonoperational Soil Vapor Monitoring Data

Figure 6-3. Relationship Between Concentrations of Carbon Tetrachloride and Chloroform Measured at Rebound Study Monitoring Locations in the 216-Z-9 Wellfield.

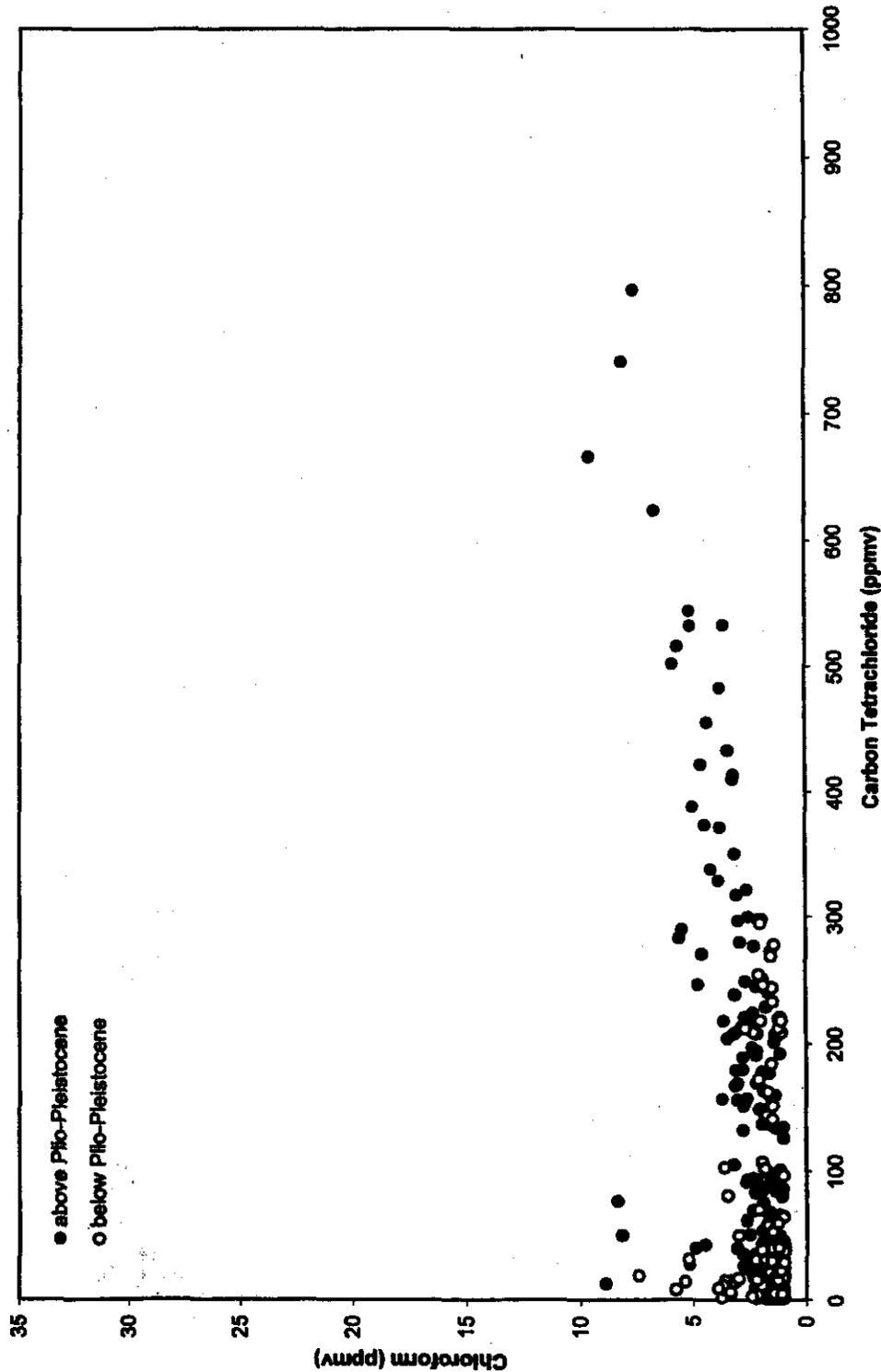


Figure 6-4. Relationship Between Concentrations of Carbon Tetrachloride and Chloroform Measured at Rebound Study Monitoring Locations in the 216-Z-1A/Z-18/Z-12 Wellfield.

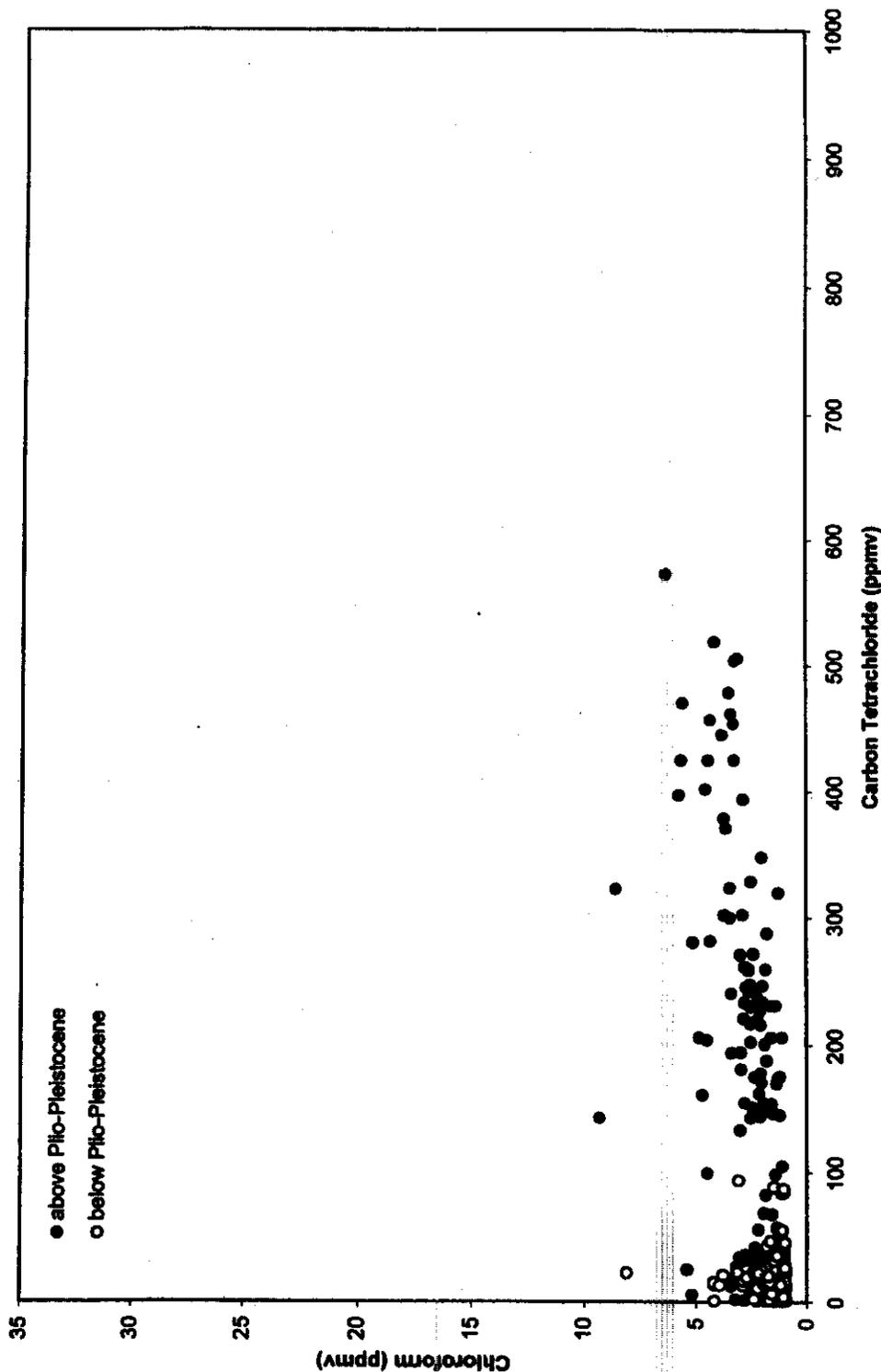


Figure 6-5. Vertical Profile of Maximum Carbon Tetrachloride Rebound Concentrations, November 1996 – July 1997, October 1997 – September 1998, July 1998 – September 1999, and July 1999 – September 2001.

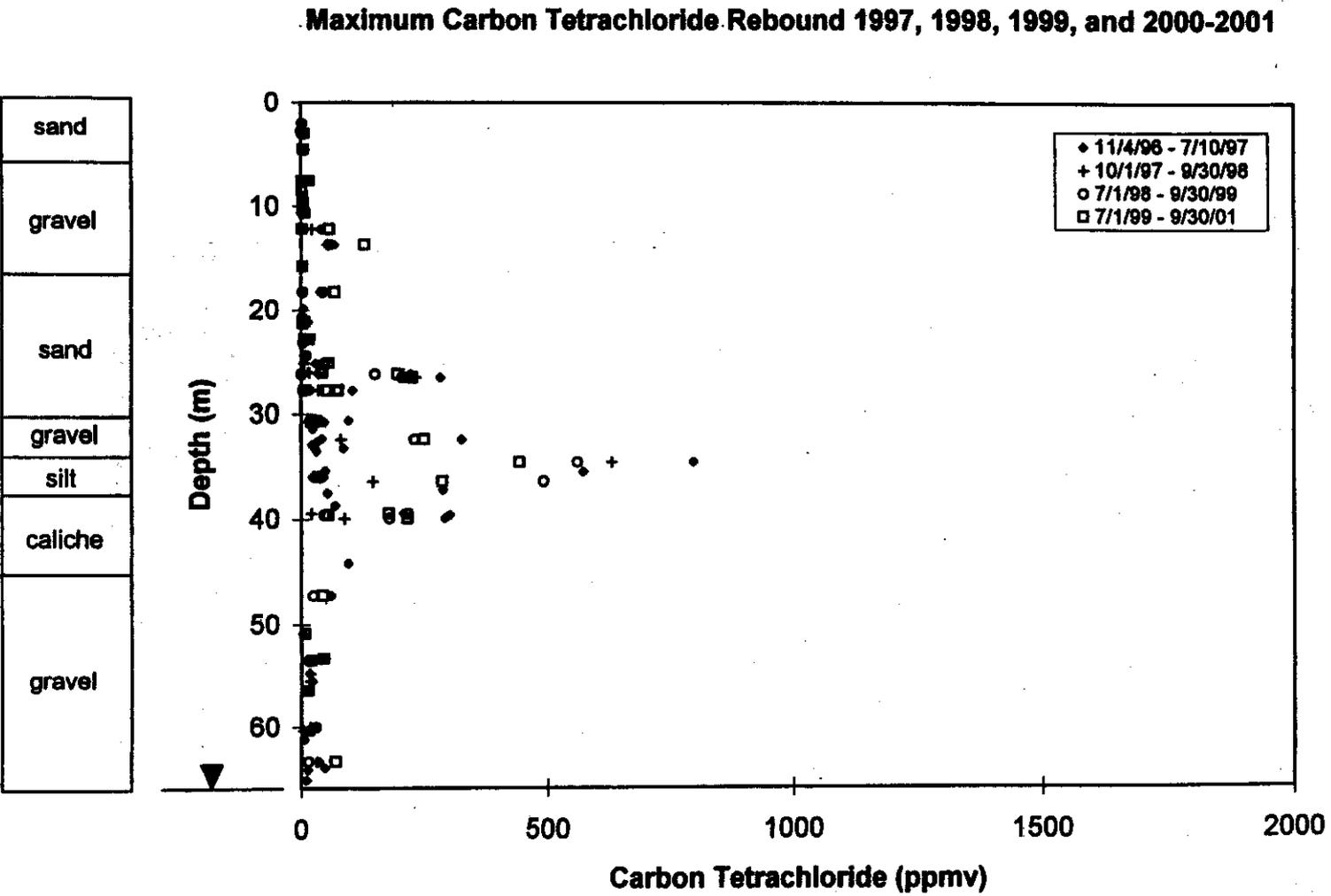


Figure 6-6. Carbon Tetrachloride Rebound Concentrations Measured at 216-Z-9 Well 299-W15-217, November 1996 – June 2001.

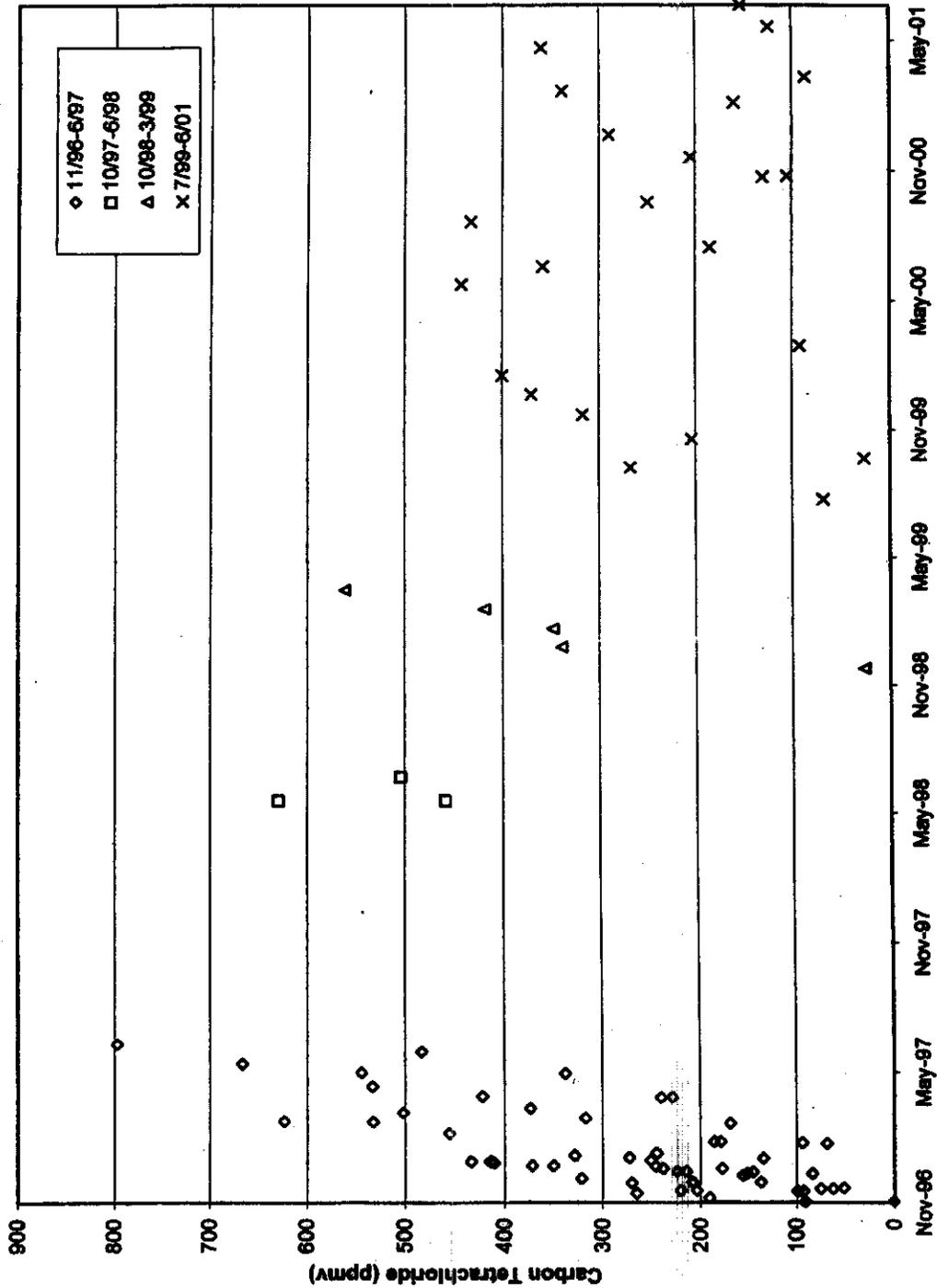


Figure 6-7. Vertical Profile of Maximum Carbon Tetrachloride Baseline Concentrations, December 1991 – December 1993.

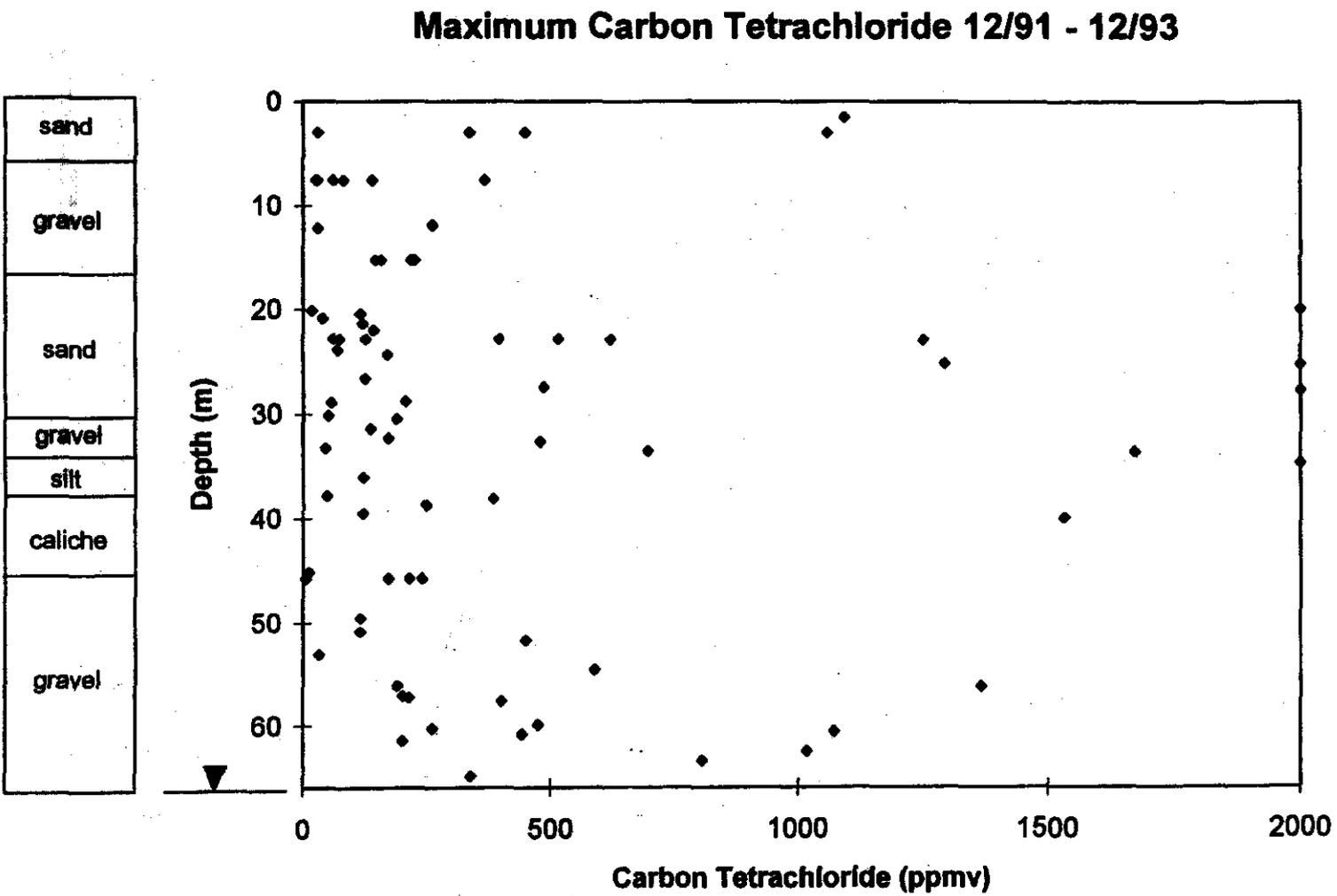
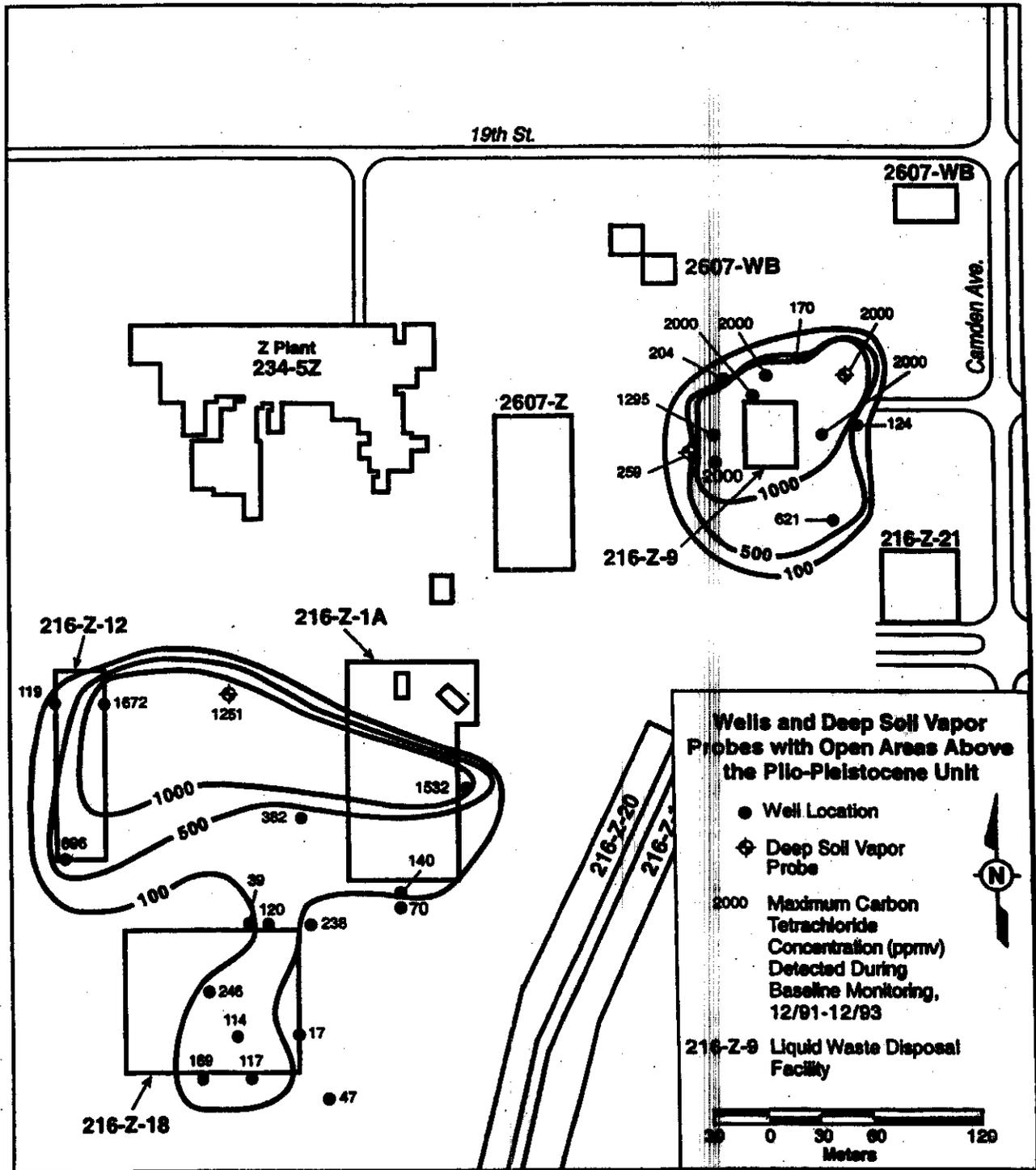


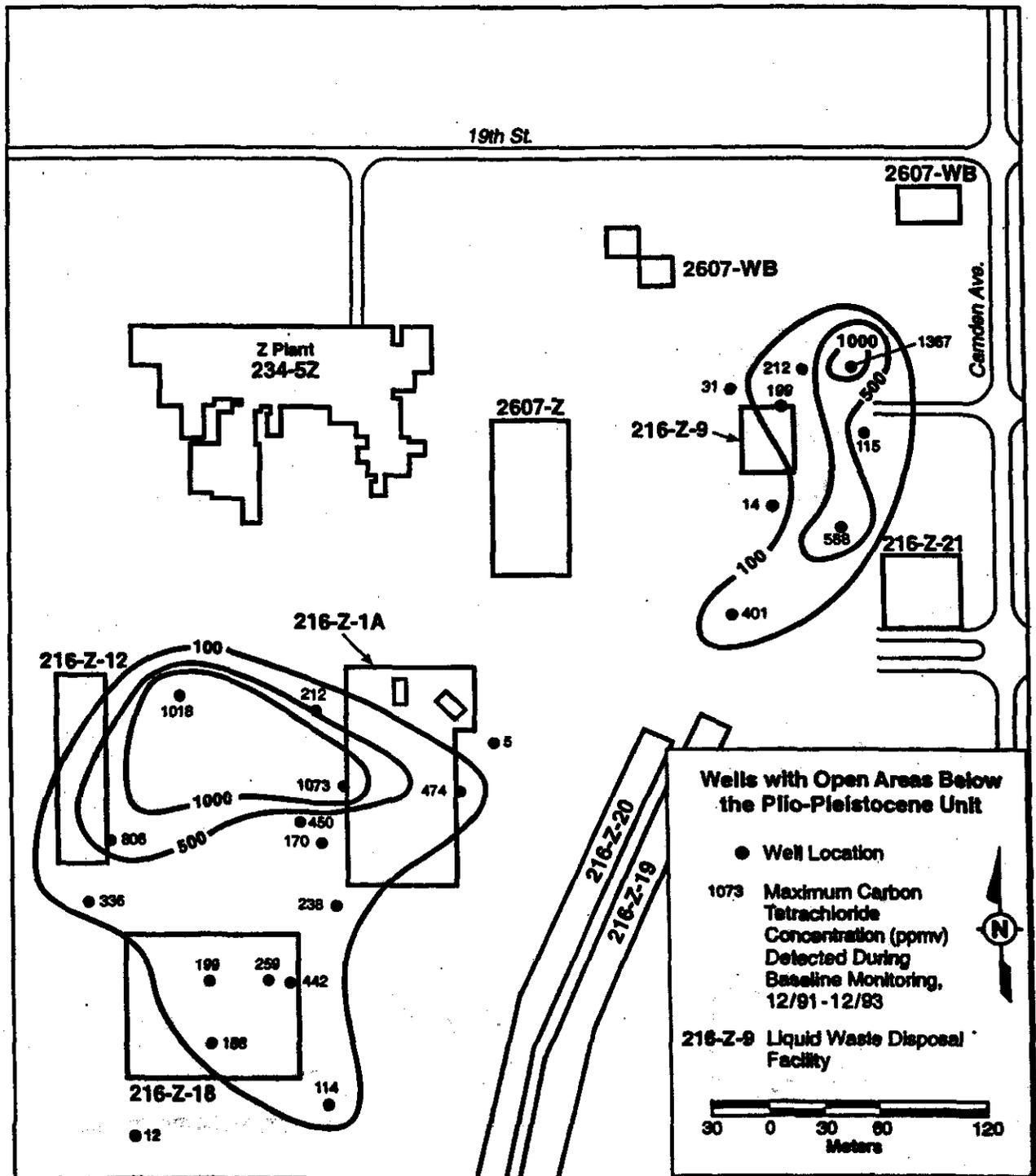
Figure 6-8a. Maximum Carbon Tetrachloride Baseline Concentrations Recorded at Wells and Deep Soil Vapor Probes Open Above the Plio-Pleistocene Unit, December 1991 – December 1993 (from Fancher 1994).



E9905121_3.918

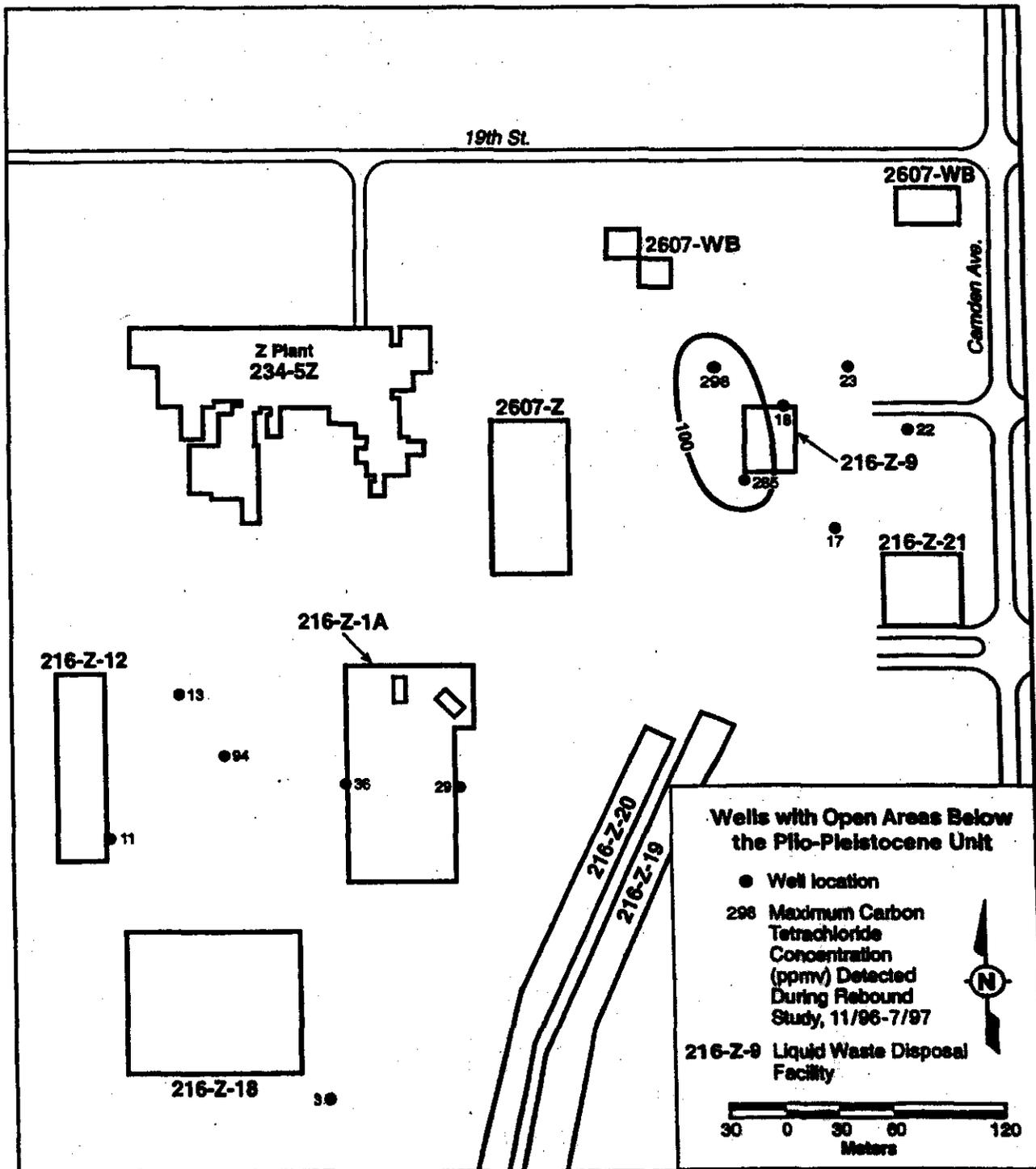
Nonoperational Soil Vapor Monitoring Data

Figure 6-8b. Maximum Carbon Tetrachloride Baseline Concentrations Recorded at Wells Open Below the Plio-Pleistocene Unit, December 1991 – December 1993 (from Fancher 1994).



ED906121_4.9b

Figure 6-9b. Maximum Carbon Tetrachloride Rebound Concentrations Recorded at Wells Open Below the Plio-Pleistocene Unit, November 1996 – July 1997.



E0905121_2.mxd

Table 6-1. Comparison of Maximum Carbon Tetrachloride Rebound Concentrations Monitored at the 200-PW-1 Soil Vapor Extraction Site, FY 1997 - FY 2001. (5 Pages)

Location (Well or Probe)	Site	Depth (m)	November 1996 - July 1997		October 1997 - September 1998		July 1998 - September 1999		July 1999 - June 2001		July 2001 - September 2001	
			Maximum Rebound Carbon Tetrachloride (ppmv)	Months of Rebound ^a								
79-03/ 5 ft	Z-18	2	0	8	0	3	0	12	--	--	--	--
79-06/ 5 ft	Z-1A	2	--	--	--	--	1.4	12	--	--	--	--
79-11/ 5 ft	Z-1A	2	0	8	0	6	2.9	12	--	--	--	--
86-05/ 5 ft	Z-9	2	--	--	--	--	0	3	--	--	--	--
86-05-01/ 5 ft	Z-9	2	--	--	--	--	0	3	--	--	--	--
86-06/ 5 ft	Z-9	2	1.3	8	0	9	1.9	6	--	--	--	--
87-05/ 5 ft	Z-1A	2	--	--	0	3	1.0	12	--	--	--	--
87-09/ 5 ft	Z-1A	2	--	--	1.5	3	2.6	12	--	--	--	--
94-02/ 5 ft	Z-9	2	0	8	--	--	1.4	3	--	--	--	--
95-11/ 5 ft	Z-9	2	0	8	2.1	9	2.5	6	--	--	--	--
95-12/ 5 ft	Z-9	2	1.1	8	1.5	9	1.3	6	--	--	--	--
95-14/ 5 ft	Z-9	2	--	--	--	--	0	3	--	--	--	--
CPT-13A/ 9 ft	Z-1A	3	--	--	0	6	1.0	12	--	--	--	--
CPT-16/ 10 ft	Z-9	3	--	--	0	9	1.5	6	--	--	--	--
CPT-17/ 10 ft	Z-9	3	--	--	4.2	9	5.1	6	6.6	24	--	--
CPT-18/ 15 ft	Z-9	5	--	--	6.5	9	5.0	6	5.2	24	--	--
CPT-31/25 ft	Z-1A	8	--	--	0	6	0	12	--	--	--	--
CPT-16/ 25 ft	Z-9	8	--	--	--	--	--	--	1.8	24	--	--
CPT-32/ 25 ft	Z-1A	8	--	--	9.1	6	10.0	12	16.5	18	0	3

Table 6-1. Comparison of Maximum Carbon Tetrachloride Rebound Concentrations Monitored at the 200-PW-1 Soil Vapor Extraction Site, FY 1997 - FY 2001. (5 Pages)

Location (Well or Probe)	Site	Depth (m)	November 1996 - July 1997		October 1997 - September 1998		July 1998 - September 1999		July 1999 - June 2001		July 2001 - September 2001	
			Maximum Rebound Carbon Tetrachloride (ppmv)	Months of Rebound ^a								
CPT-4A/ 25 ft	Z-1A	8	--	--	--	--	--	--	3.5	0	0	3
CPT-30/ 28 ft	Z-18	9	--	--	--	--	3.2	12	1.4	18	0	3
CPT-13A/ 30 ft	Z-1A	9	2.2	8	--	--	--	--	3.6	18	1.9	3
CPT-7A/ 32 ft	Z-1A	10	--	--	2.3	6	5.4	12	6.2	18	4.2	3
CPT-27/ 33 ft	Z-9	10	1.2	8	--	--	--	--	2.6	24	--	--
CPT-1A/ 35 ft	Z-18	11	2.0	8	1.4	3	3.0	12	7.7	18	11.3	3
CPT-28/ 40 ft	Z-9	12	40.1	8	--	--	--	--	--	--	56.5	0
CPT-33/ 40 ft	Z-1A	12	--	--	2.0	3	2.6	12	--	--	1.6	3
CPT-34/ 40 ft	Z-18	12	2.3	8	--	--	1.7	12	1.9	0	2.2	3
CPT-21A/ 45 ft	Z-9	14	65.6	8	52.7	9	56.6	3	127	24	133	0
W15-220ST/ 52 ft	Z-9	16	2.0	8	--	--	1.6	3	2.5	24	--	--
CPT-28/ 60 ft	Z-9	18	--	--	1.5	0	3.7	3	--	--	--	--
CPT-9A/ 60 ft	Z-9	18	45.5	8	41.1	0	44	3	67.6	24	45.3	0
CPT-30/ 68 ft	Z-18	21	1.7	8	--	--	3.0	12	--	--	--	--
CPT-32/ 70 ft	Z-1A	21	7.4	8	--	--	--	--	--	--	4.3	3
CPT-13A/ 70 ft	Z-1A	21	5.2	8	--	--	5.6	12	--	--	--	--
CPT-24/70 ft	Z-9	21	--	--	3.2	9	3.6	3	--	--	--	--
W15-219SST/ 70 ft	Z-9	21	14.6	8	--	--	7.6	3	7.8	24	--	--

Table 6-1. Comparison of Maximum Carbon Tetrachloride Rebound Concentrations Monitored at the 200-PW-1 Soil Vapor Extraction Site, FY 1997 - FY 2001. (5 Pages)

Location (Well or Probe)	Site	Depth (m)	November 1996 - July 1997		October 1997 - September 1998		July 1998 - September 1999		July 1999 - June 2001		July 2001 - September 2001	
			Maximum Rebound Carbon Tetrachloride (ppmv)	Months of Rebound ^a								
CPT-18/ 75 ft	Z-9	23	--	--	--	--	--	--	17.7	24	--	--
CPT-4A/ 75 ft	Z-1A	23	--	--	--	--	--	--	--	--	7.1	3
CPT-31/ 76 ft	Z-1A	23	4.0	8	--	--	4.2	12	--	--	--	--
CPT-33/ 80 ft	Z-1A	24	5.8	8	--	--	9.2	12	--	--	--	--
W15-82/ 83 ft	Z-9	25	28.9	8	5.5	9	46.4	6	55.0	24	--	--
CPT-21A/ 86 ft	Z-9	26	221	8	206	9	148	6	195	24	186	0
CPT-34/ 86 ft	Z-18	26	36.3	8	5.9	3	0	12	--	--	--	--
W15-95U/ 86 ft	Z-9	26	--	--	15.3	9	39.4	6	42.8	21	--	--
W15-218SST/ 86 ft	Z-9	26	--	--	--	--	0	3	--	--	--	--
CPT-28/ 87 ft	Z-9	27	280	8	230	9	203	6	224	24	225	0
CPT-1A/ 91 ft	Z-18	28	3.9	8	--	--	4.2	12	--	--	8.3	3
CPT-4A/ 91 ft	Z-1A	28	--	--	7.7	3	14.4	12	--	--	7.3	3
CPT-9A/ 91 ft	Z-9	28	103	8	34.5	9	72.3	3	--	--	74.3	0
W15-85/ 91 ft	Z-9	28	--	--	--	--	--	--	51.3	24	--	--
W18-252SST/ 100 ft	Z-1A	30	38.2	8	17.8	3	24.0	12	--	--	--	--
W18-152/ 101 ft	Z-12	31	46.8	8	11.1	3	33.3	12	24.7	18	25.7	3
W18-167/ 106 ft	Z-1A	32	322.8	8	79.7	3	228	12	248	18	283	3

Table 6-1. Comparison of Maximum Carbon Tetrachloride Rebound Concentrations Monitored at the 200-PW-1 Soil Vapor Extraction Site, FY 1997 - FY 2001. (5 Pages)

Location (Well or Probe)	Site	Depth (m)	November 1996 - July 1997		October 1997 - September 1998		July 1998 - September 1999		July 1999 - June 2001		July 2001 - September 2001	
			Maximum Rebound Carbon Tetrachloride (ppmv)	Months of Rebound ^a								
W18-165/ 109 ft	Z-1A	33	--	--	--	--	--	--	--	--	--	--
W15-217/ 114 ft	Z-9	35	797	8	630	9	561	6	442	24	--	--
CPT-24/ 118 ft	Z-9	36	44.6	8	37.7	9	37.3	6	35.2	24	--	--
W15-220SST/ 118 ft	Z-9	36	21.9	8	--	--	35.9	3	34.0	24	--	--
W18-158L/ 120 ft	Z-1A	37	--	--	143	3	492	12	284	18	163	3
W15-219SST/ 130 ft	Z-9	40	298	8	--	--	46.5	3	54.4	24	--	--
W18-249/ 130 ft	Z-18	40	206	8	20.4	3	215	12	176	18	196	3
W18-248/ 131 ft	Z-1A	40	288	8	86.3	3	177	12	214	18	306	3
W15-95L/ 144 ft	Z-9	44	--	--	--	--	--	--	--	--	--	--
W15-219SST/ 155 ft	Z-9	47	59.6	8	--	--	24.2	3	43.6	24	--	--
W15-9L/ 176 ft	Z-9	54	18.3	8	15.0	9	14.9	6	20.4	21	--	--
W15-6L/ 182 ft	Z-9	55	22.6	8	17.8	9	1.3	6	--	--	--	--
W15-220SST/ 185 ft	Z-9	56	14.5	8	--	--	13.4	3	14.5	24	--	--

Table 6-1. Comparison of Maximum Carbon Tetrachloride Rebound Concentrations Monitored at the 200-PW-1 Soil Vapor Extraction Site, FY 1997 - FY 2001. (5 Pages)

Location (Well or Probe)	Site	Depth (m)	November 1996 - July 1997		October 1997 - September 1998		July 1998 - September 1999		July 1999 - June 2001		July 2001 - September 2001	
			Maximum Rebound Carbon Tetrachloride (ppmv)	Months of Rebound ^a								
W18-7/ 197 ft	Z-1A	60	28.5	8	17.3	3	29.0	12	--	--	--	--
W18-12/ 198 ft	Z-18	60	--	--	3.8	3	18.5	12	--	--	--	--
W18-6L/ 208 ft	Z-1A	63	36.0	8	31.3	6	14.5	12	--	--	--	--

216-Z-18 and 216-Z-12 wells off line October 1996-April 1998.

CPT-1A, CPT-9A, and possibly CPT-7A appeared to be beyond the SVE zone of influence in October 1996 based on differential pressure (Rohay 1997).

CPT-9A, CPT-21A, and CPT-28 were beyond the SVE zone of influence in May 1996 based on carbon tetrachloride concentrations and airflow modeling based on measured vacuums (Rohay 1997).

^a Based on location (216-Z-1A/18/12 or 216-Z-9) of monitoring point; specific points may be beyond the SVE zone of influence during particular operating configurations.

-- = not measured

7.0 2001 CARBON TETRACHLORIDE CONCEPTUAL MODEL UPDATE

This section summarizes the current conceptual model as well as working hypotheses concerning the source term, environmental setting, vadose zone and groundwater contaminant distribution, and vadose zone and groundwater transport of carbon tetrachloride and associated contaminants in the 200 West Area. Additional details are provided in Appendix H. The conceptual model of the 200 West Area carbon tetrachloride plume has been continuously refined as additional site-specific data have been collected and as the understanding of DNAPL behavior in the subsurface has been developed by the scientific community. The conceptual model presented in this report provides an update to the conceptual models presented in Rohay and Johnson (1991), Last and Rohay (1991, 1993), Last et al. (1991), Rohay et al. (1994), and Swanson et al. (1999).

Carbon tetrachloride contamination is present in multiple phases and at varying concentrations throughout the vadose zone and groundwater systems. Near the disposal sites, the soil vapor concentrations are much higher and are found throughout the vadose zone; the highest concentrations are associated with the Plio-Pleistocene layer. Farther away from the disposal sites, vapor concentrations are much lower and are usually found at the capillary zone or immediately beneath the Plio-Pleistocene layer. This implies that the farfield diffuse vapor plume may be the result of aquifer outgassing. Based on these observations, carbon tetrachloride contamination can be divided geographically into three main areas:

1. A higher concentration vadose zone plume at the three primary disposal facilities: 216-Z-9, 216-Z-1A, and 216-Z-18 (approximately 0.2 km²)
2. A higher concentration groundwater plume with the centroid located north-northwest of the three primary disposal facilities (although, because of recent pump-and-treat remediation efforts, the centroid is being displaced and the northern edge is moving toward the groundwater extraction wells) (Appendix H, Figure H-6) (DOE-RL 2002b) (approximately 0.6 km²)
3. A geographically large dissolved and diffuse groundwater plume (<1,000 µg/L) and vapor plume (approximately 11 km²). The lateral extent of the vapor plume is not defined but, based on volatilization from groundwater, could be at a minimum coincident with the dissolved groundwater plume.

Possible transport mechanisms and distributions of contaminant phases for the high-concentration zone of the plume, which may also contain DNAPL/residual carbon tetrachloride, are depicted in Figure 7-1. Because of the differences in the sizes of the three primary disposal sites and the quantities of waste received at these disposal sites, one transport mechanism and resulting contaminant distribution (e.g., vapor-phase and aqueous-phase migration to groundwater) may be more appropriate for one or two disposal sites, and another transport mechanism and contaminant distribution (e.g., DNAPL, vapor-phase, and aqueous-phase migration to groundwater) may be more appropriate for the other(s).

7.1 CONTAMINANT INVENTORY

A total of 570,000 to 920,000 kg (average of approximately 750,000 kg) of carbon tetrachloride were discharged to the soil column from 1955 through 1973 (Table 2-1). Estimates of the current distribution of the original inventory are based on historical information, equilibrium partitioning calculations, site-specific characterization measurements, and remediation operating data (Table 7-1).

7.2 ENVIRONMENTAL SETTING

The 66-m-thick vadose zone can be broadly divided into an upper gravel and sand interval (Hanford formation) and a lower gravel and sand interval (Ringold Formation Unit E) separated by a finer grained, carbonate-cemented Plio-Pleistocene unit 38 m below land surface (7 m thick). The Plio-Pleistocene unit appears to have been an accumulation area for carbon tetrachloride. Disposed liquid wastes would have been impeded by this unit during movement through the vadose zone to the water table (Piepho 1996) and later during post-disposal drainage. Other fine-grained zones in both the upper and lower gravel and sand intervals may also be minor accumulation and spreading zones. Carbon tetrachloride may be in nonequilibrium sorption sites within intraparticle sediment pore spaces in these fine-grained units (Yonge et al. 1996).

Migration of fluids, both liquid and vapor, are influenced by the natural stratification and variability in these sediments. The surface of the Plio-Pleistocene unit generally slopes toward the south from the primary carbon tetrachloride disposal sites (Rohay et al. 1994). Areally, the character of the Plio-Pleistocene layer varies across the 200 West Area and includes locally less cemented, more permeable areas and fractures that allow more rapid fluid flow (Slate 1996).

The groundwater system in the area of the disposal sites can be broadly divided into three dominant hydrostratigraphic units: an upper, 66-m-thick unconfined (water table) aquifer (Ringold Formation Unit E); a confining unit/aquitard (Ringold lower mud); and a confined aquifer (from the lower mud to the top of basalt bedrock). This system is more complicated, however, when considered at a site-specific scale (tens of meters), because of spatial heterogeneities including lateral and vertical changes in grain size, changes in degree of cementation, and variably interbedded gravels, sands, silts and clays. Hydrologic properties within the same hydrostratigraphic unit vary spatially and directionally in the unconfined aquifer (Thorne and Newcomer 1992).

7.3 CONTAMINANT DISTRIBUTION

Carbon tetrachloride in the subsurface can exist as a vapor phase, as a dissolved aqueous phase, as an adsorbed phase on solid matrices, and as a separate organic phase (DNAPL). Carbon tetrachloride as a DNAPL has never been observed directly in the vadose zone or in groundwater in the 200 West Area.

2001 Carbon Tetrachloride Conceptual Model Update

7.3.1 Vadose Zone Concentrations

Carbon tetrachloride is found throughout the vadose zone within the 0.2-km² source area. Laterally, the highest concentrations historically have been consistently located in the vicinity of the 216-Z-9 Trench. Vertically, the highest concentrations are associated with the finer grained, relatively less permeable units (e.g., the Plio-Pleistocene unit). The highest vapor and soil concentrations measured before and after SVE operations are summarized in Table 7-2.

Higher vapor concentrations (>12,000 ppmv) of carbon tetrachloride measured prior to SVE operations suggested the presence of DNAPL/residual carbon tetrachloride in the vadose zone (Appendix H). The 1997 rebound study and 1998, 1999, 2000, and 2001 monitoring results now indicate that at most locations within the influence of the SVE systems, much of the readily available carbon tetrachloride has been removed. The lower permeability Plio-Pleistocene layer appears to be the most significant continuing source of carbon tetrachloride soil vapor (Rohay 1997).

In addition to the carbon tetrachloride contamination, plutonium and americium co-contaminants are distributed within the upper 30 m of the vadose zone (Price et al. 1979). The transuranic contamination at these sites may have been carried downward by a combination of acidic waste liquids and organic-complexant mixtures.

7.3.2 Groundwater Concentrations

The zone of highest groundwater concentrations (~3,700 to ~5,500 µg/L) no longer includes the 216-Z-9 Trench, but has shifted in response to 200-ZP-1 pump-and-treat operations to the area of the three northernmost extraction wells (299-W15-33, 299-W15-34, and 299-W15-35). This suggests that carbon tetrachloride discharged to the 216-Z-9 Trench may no longer be providing a continuous or significant source of contamination to the groundwater. The relatively low soil vapor concentrations monitored deep within the vadose zone from 1997 through 2001 supports this conclusion. Based on dissolved phase concentrations in the upper 10 m of the unconfined aquifer in 1990, prior to pump-and-treat remediation, nearly 60% of the mass of carbon tetrachloride was estimated to be contained within about 10% of the area of the plume (Rohay and Johnson 1991).

Although the magnitude and extent of contamination in the deep unconfined aquifer and confined aquifer are not well defined, recent data indicate that contamination is more extensive than previously thought. Contamination has been detected throughout the unconfined aquifer at the 216-Z-9 disposal site, west and north of Z Plant, near U Plant, and near T Plant (Appendix H). Dissolved carbon tetrachloride has also been observed within the deeper confined aquifer system at wells south and east of the 216-Z-9 disposal site and on the perimeter of the T-TY-TX Tank Farms (Appendix H).

In addition to disposal at the Z cribs and trenches, carbon tetrachloride may also have been disposed in the T Plant area and reached groundwater. Carbon tetrachloride concentrations in the T Plant area exceed 1,000 µg/L (Hartman et al. 2002).

If DNAPL is present in the groundwater, the most likely location would be near the 216-Z-9 Trench. Numerical modeling of vadose zone flow and transport indicates that both dissolved and nonaqueous-phase liquid carbon tetrachloride migrated through the vadose zone and reached the unconfined aquifer below the 216-Z-9 Trench (Piepho 1996).

7.4 CONTAMINANT TRANSPORT

7.4.1 Vadose Zone

Contaminated vapors can move downward and laterally by molecular diffusion and by advective flow. Vapors will diffuse along a chemical gradient from high-concentration areas to low-concentration areas in any direction (including upgradient with respect to the groundwater flow direction). The presence of a relatively low-permeability zone, such as a building foundation or soil horizon, can also enhance the lateral extent of diffusion. This might be significant in the soils underlying the Plio-Pleistocene layer or in the area of Z Plant, where surface facilities could act as a barrier and promote lateral expansion of the vapor plume.

The density of soil vapor contaminated with carbon tetrachloride is greater than uncontaminated soil vapor. This contrast in densities can result in density-driven advective flow of vapors in the vadose zone. Within the vadose zone, carbon tetrachloride vapor may also flow in any direction along pressure gradients caused by barometric pressure fluctuations. Atmospheric pressure fluctuations appear to constitute a significant release mechanism for carbon tetrachloride vapor out of the vadose zone both through the soil surface and through boreholes (Table 7-1).

As nonaqueous-phase liquid carbon tetrachloride moves down through the soil column, some of the DNAPL will become discontinuous and will be held in the soil pores as residual contamination. Numerical modeling of vadose zone flow and transport indicates that 66% to 90% of the carbon tetrachloride discharged to the 216-Z-9 site was retained in the vadose zone (Piepho 1996). It should be noted, however, that DNAPL characteristically moves nonuniformly downward through the vadose zone (Cohen et al. 1993). The numerical modeling, therefore, may have overestimated the volume retained in the vadose zone.

Boreholes are also potential preferential pathways for movement of carbon tetrachloride vapor and liquid (both dissolved and DNAPL liquids and vapor). Most boreholes in the 200 West Area are capped but unsealed at the surface and therefore have the potential to draw carbon tetrachloride vapors horizontally along barometrically induced pressure gradients from the source area toward their open intervals. In addition, because most 200 West Area boreholes have no annular seal, the potential for vapor communication and transport of liquid also exists along the outside of the casing.

The presence of locally saturated or near-saturated vadose zone sediments underlying other aqueous waste disposal sites can inhibit the lateral extent of diffusion. The movement of vapor-phase contamination or DNAPL would be away from the hydraulic barrier.

As aqueous liquids from natural recharge or from artificial discharge to nearby disposal facilities migrate downward through the vadose zone, they may dissolve and transport carbon tetrachloride vapor and/or residual liquid phases.

The carbon tetrachloride was not discharged as a pure liquid but as a mixture with other organics (tributyl phosphate [TBP], dibutyl butyl phosphonate [DBBP], and lard oil). The organic composites (even the carbon tetrachloride:lard oil mixture) were found to be denser and more viscous than water (Last and Rohay 1993). Vapor pressures of the carbon tetrachloride:DBBP and carbon tetrachloride:lard oil mixtures are only half that of the pure carbon tetrachloride and the carbon tetrachloride:TBP mixture. The interfacial tension between the 50:50 carbon tetrachloride:lard oil mixture and a 5 M sodium nitrate solution was found to be low, suggesting that the fluids may be somewhat miscible, allowing them to mix and behave more as an aqueous fluid (Last and Rohay 1993, Appendix H).

7.4.2 Capillary Fringe

The capillary fringe forms the interface between the vadose and groundwater zones. Carbon tetrachloride in an aqueous or DNAPL phase can migrate through the capillary fringe. The primary mechanisms for aqueous contaminant migration through the capillary fringe are diffusion and dispersion, advection due to infiltrating water, and water-table fluctuations (Pankow and Cherry 1996). These processes of aqueous phase transport would produce a shallow plume in the aquifer (Pankow and Cherry 1996). Once present in the groundwater, carbon tetrachloride might move deeper into the aquifer because of a continuing downward hydraulic gradient created by past surface liquid discharges. However, the downward gradient is becoming less significant as a result of pump-and-treat operations. Transport and partitioning of carbon tetrachloride vapor between the vadose zone and groundwater may contribute to the large "low concentration halo" surrounding the high-concentration core of the groundwater plume (Appendix H).

Lateral spreading of DNAPL may occur at the capillary fringe until sufficient hydraulic head builds up to displace water and allow the organic liquid to move into the groundwater (Pankow and Cherry 1996). Residual DNAPL would remain at this interface even after the main body of DNAPL contamination moved through. Water-level fluctuations at this interface could increase or decrease the amount of contamination dissolving from the residual mass. A relatively high water table occurred from 1965 to 1984 and may have resulted in carbon tetrachloride dissolving from any residual mass into the groundwater (Appendix H). The water table is now declining at a rate of about 0.40 m/yr in the area of the disposal sites, extending the depth of the vadose zone vapor plume (DOE-RL 2002b). DNAPL has not been detected at the capillary fringe, but high soil vapor concentrations were detected at this depth at the 216-Z-9 site prior to SVE remediation (Table 7-2). The declining water table and the relatively low soil vapor concentrations detected near the water table following SVE remediation suggest that significant residual DNAPL is not now present at the capillary fringe.

7.4.3 Groundwater Hydraulics

The hydraulic flow field during and after carbon tetrachloride waste disposal was characterized by an increase in the water table elevation by 2 m (1965 to 1977). After discharges to the U Pond were discontinued in 1984, the water table began declining in the area of the disposal sites.

The U Pond produced a groundwater mound in the area of the disposal sites, creating a radial flow pattern in this area. Formerly, the flow direction was from west to east (Zimmerman et al. 1986, Newcomer 1990). This radial (up- or cross-gradient) flow direction probably pushed the high-concentration portion of the groundwater plume to the north/northwest. However, several hypotheses might account for the location of the plume center (centroid) to the northwest of the known disposal sites, including the following:

- Mounding of groundwater locally in the region of the carbon tetrachloride disposal sites, with a significant northwest trending hydraulic gradient.
- A continuous fine-grained stratigraphic unit dipping to the northwest that could have laterally diverted disposed liquids in this direction. The primary unit potentially affecting horizontal contaminant movement would be the Plio-Pleistocene unit, but this unit is thought to dip to the south in the area of the disposal sites based on regional geologic information. However, recent surface geophysics work suggests that DNAPL discharged to the 216-Z-9 Trench would flow to the north and northeast (Temples et al. 2001). This latest information supports the idea that carbon tetrachloride may have moved to the north of the 216-Z-9 Trench.
- Other undocumented sources of carbon tetrachloride from soil column disposal near the centroid.
- A vertical hydraulic barrier in the vadose zone from wastewater disposal at other facilities (e.g., the 216-Z-20 Trench) to the south, driving contaminant migration locally to the north and west.

It should also be noted that limited vadose zone data or groundwater data are available beneath the large area that the Z Plant surface facilities cover. Because of this, the plume center may not be positioned as far northwest of the 216-Z-9 Trench as previously thought. Plume contouring may be biased toward the higher well density to the northwest.

7.4.4 Groundwater

Numerical modeling of carbon tetrachloride flow and transport in the vadose zone indicates that the depth of penetration of carbon tetrachloride (dissolved and nonaqueous liquid phases) into the aquifer primarily depends on the residual saturation in the vadose zone (Piepho 1996). Dissolved groundwater contamination may have reached 50 m below the water table and nonaqueous-phase liquid carbon tetrachloride about 25 m below the water table based on this modeling study.

Preliminary sitewide numerical modeling of carbon tetrachloride transport indicates that under nonretarded flow conditions contamination in excess of 5 $\mu\text{g/L}$ will move significantly past the 200 East Area perimeter in 200 years (Chiaramonte et al. 1997). However, if a small retardation factor is included in the analysis, the movement of carbon tetrachloride will be significantly slowed. The extent of contamination is very sensitive to the carbon tetrachloride partitioning coefficient between the aquifer sediments and groundwater. However, values for the partitioning coefficient on Hanford Site sediments are not well defined. Other important factors that this modeling effort did not take into account were biodegradation, abiotic degradation, and volatilization of carbon tetrachloride during transport. These factors may reduce the extent of contamination over any comparable period of time.

The higher concentration portion of the carbon tetrachloride plume for FY 2001 (Figure H-6) has a similar shape as the FY 2000 plume, but the overall concentration distribution has changed. High concentrations of carbon tetrachloride present beneath the PFP complex are being drawn toward the extraction wells. In the area of the injection wells, concentrations continue to decline from the injection of treated groundwater into the aquifer, and as hydraulic mounding drives groundwater toward the extraction wells. The high-concentration area of the plume appears to be shrinking in size, evidenced by decreasing concentrations in monitoring and extraction wells, the smaller area of the 4,000 $\mu\text{g/L}$ contour intervals, and decreasing concentrations in the 200-ZP-1 influent tank from 4,041 $\mu\text{g/L}$ in FY 2000 to 3,600 $\mu\text{g/L}$ in FY 2001. In addition, the groundwater data no longer support a 6,000 $\mu\text{g/L}$ contour (DOE-RL 2002b).

7.5 DATA GAPS

The nature and extent of the carbon tetrachloride plume have been partially defined, but several key data gaps currently exist. The data gaps are identified in this report to help describe some uncertainties in the existing database being used to formulate the conceptual model.

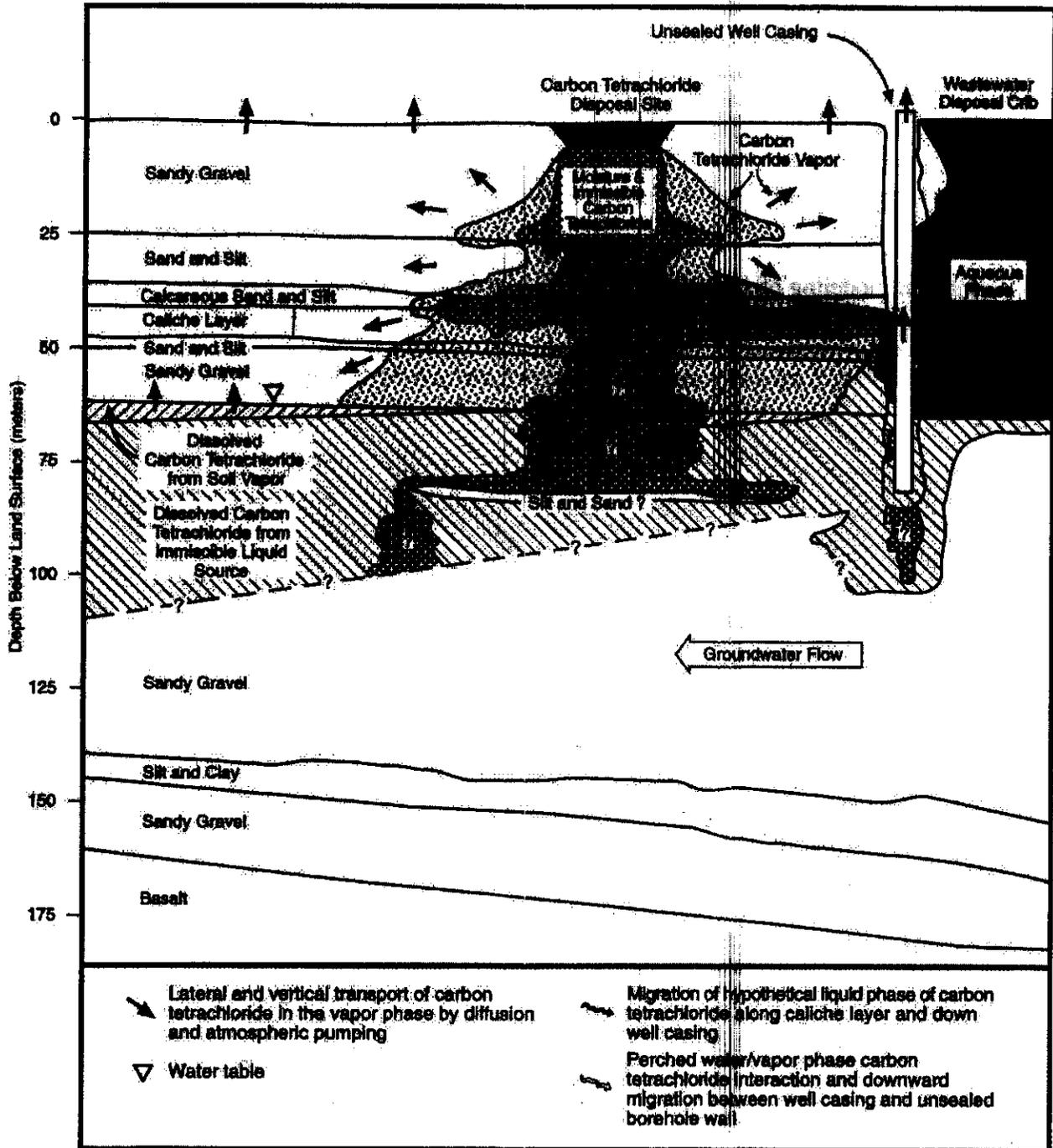
1. The nature and magnitude of the exchange of carbon tetrachloride between the vadose zone and groundwater needs to be investigated. This information will be required in the future to address the interdependency of the vadose zone-groundwater system in achieving remediation of the 200 West Area subsurface carbon tetrachloride contamination. The study, including field measurements near the groundwater-vadose zone interface, should be undertaken to quantify the volatilization process.
2. The lateral extent of the carbon tetrachloride plume in the vadose zone and vertical extent of the carbon tetrachloride plume in the groundwater need to be better defined. These data would help define the extent of the contamination and therefore the expected magnitude of the remediation efforts.
3. The location, amount, and properties of DNAPL carbon tetrachloride within the subsurface need to be quantified. This information would help focus and define the remediation needs.

2001 Carbon Tetrachloride Conceptual Model Update

4. The residual saturation of carbon tetrachloride (i.e., the carbon tetrachloride held in vadose zone sediments that is no longer mobile except through partitioning to porewater that is still migrating) needs to be quantified. This information would help account for inventory between the vadose and groundwater zones, help refine the estimates of flux from the vadose zone to the groundwater, and help refine the numerical modeling estimates of the depth of carbon tetrachloride in the aquifer. Because SVE operations have modified the distribution of subsurface carbon tetrachloride and possibly soil moisture beneath the disposal sites, part of this task would be identification of suitable locations for data collection and measurements.
5. Data are needed to determine the extent of the nonequilibrium sorption in the vadose zone and groundwater. This information would help account for the inventory and help define remediation needs.
6. The partitioning coefficient (K_d) for carbon tetrachloride on site sediments and its variation across the site needs to be quantified. This information would help refine the predictions of carbon tetrachloride transport rates using numerical models.
7. The interaction between carbon tetrachloride and calcium carbonate needs to be quantified. This information would help determine carbon tetrachloride transport mechanisms and rates through the Plio-Pleistocene unit.
8. The abiotic half-life of carbon tetrachloride under site conditions needs to be quantified. The potential degradation of carbon tetrachloride may contribute to natural attenuation of the plume and could be a significant term in the assessment of the carbon tetrachloride mass balance.
9. The inventory mass balance should be reevaluated based on more recent studies and data from current remedial actions in the groundwater and the vadose zone. The existing evaluation of the mass balance was based on 1990 groundwater plume data for the upper 10 m of the aquifer and limited soil vapor data. This information would help define the source term.
10. The hydraulic flow fields during and after the carbon tetrachloride disposal should be reevaluated to determine if the distribution of the relatively high concentrations of carbon tetrachloride to the northwest, the low-concentration lobes of carbon tetrachloride to the south, and the concentrations of carbon tetrachloride near T Plant are reasonable based on the hydraulics alone. Results of this evaluation potentially may identify other contributing carbon tetrachloride disposal areas.

11. A systematic study of the carbon tetrachloride/chloroform relationship in both the vadose zone and groundwater should be conducted using existing data. Understanding the cause and significance of the variation in the ratio of carbon tetrachloride to chloroform could potentially yield insights on contaminant source, inventory, distribution, and persistence of the chloroform plume. This study could be extended to include the full carbon tetrachloride degradation chain to support evaluation of natural attenuation.
12. A predictive modeling effort needs to be performed that considers the fate and transport of carbon tetrachloride over the next several hundred years. Such a model is needed to account for all of the significant factors that affect the migration and concentration of carbon tetrachloride and ultimately will be needed to support final remediation decisions.
13. Numerical modeling of carbon tetrachloride migration in the vadose zone is needed that incorporates the effects of three-dimensional stratigraphy and heterogeneities, multi-phase flow, and co-contaminants. This model could help guide characterization and remediation efforts in vadose zone and groundwater and support selection of remedial alternatives.

Figure 7-1. Schematic Illustration of Carbon Tetrachloride and Wastewater Migration Beneath the 216-Z-9 Trench in the Higher Concentration Portion of the Plume.



E9908104.4

Table 7-1. Disposition of Carbon Tetrachloride Inventory Discharged to the Soil Column.

Carbon Tetrachloride Disposition	Percent of Estimated Original Carbon Tetrachloride Inventory (Average 750,000 kg)	Estimated Mass of Carbon Tetrachloride (kg)	Reference
Estimated using pre-remediation data			
Equilibrium partitioning within vadose zone into vapor, dissolved, and adsorbed phases	12	91,000	WHC 1993
Lost to atmosphere	21	159,000	WHC 1993
Biodegraded	1	8,000 (4,385 for Z-9 only)	Hooker et al. 1996
Dissolved in upper 10 m of unconfined aquifer (assuming 30% porosity and no partitioning to aquifer solids)	1-2	5,250 – 15,740	Rohay and Johnson 1991
DNAPL/residual in vadose and/or unconfined aquifer	65	484,000	WHC 1993
Measured using remediation data			
Removed from vadose zone using soil vapor extraction (FY 1991-FY 2001)	10	77,150	Table 4-1
Removed from unconfined aquifer using pump and treat (200-ZP-1 and 200-UP-1 operations) (FY 1994-FY 2001)	0.8	5,820	DOE-RL 2002b

Table 7-2. Carbon Tetrachloride Concentrations Measured in the Vadose Zone.

Location/Type	Facility	Geologic Unit	Year	Maximum Carbon Tetrachloride Concentration
Shallow soil vapor survey	All three sites	Near surface	1991	72 ppmv
Wellheads/deep soil vapor probes	216-Z-9	Above PP	1991-93	>10,000 ppmv (estimated)
Wellheads/deep soil vapor probes	216-Z-1A/Z-18	Above PP	1991-93	1,000 ppmv
Wellheads	All three sites	Below PP	1991-93	1,000 ppmv
Sediment samples	216-Z-9	PP	1992-93	37.8 ppm
Sediment samples	216-Z-1A/Z-18	PP	1992-93	6.6 ppm
In situ soil vapor	216-Z-9	PP	1993	21,000 ppmv
In situ soil vapor	216-Z-9	Capillary fringe	1993	10,000 ppmv
In situ soil vapor	216-Z-1A/Z-18	PP	1993	1,400 ppmv
SVE inlet	216-Z-9	Above PP	1993	30,000 ppmv
SVE inlet	216-Z-1A/Z-18	Above PP	1992	1,500 ppmv
Wellheads/deep soil vapor probes	216-Z-9	Above PP	1997	797 ppmv
Wellheads/deep soil vapor probes	216-Z-1A	Above PP	1997	573 ppmv
Wellheads	216-Z-9	Below PP	1997	298 ppmv
Wellheads	216-Z-1A	Below PP	1997	94 ppmv

PP = Plio-Pleistocene

8.0 CONCLUSIONS

Operation of SVE between 1991 and 2001 has removed 77,154 kg of carbon tetrachloride (approximately 10% of the estimated original inventory) from the vadose zone underlying the primary carbon tetrachloride disposal sites. This mass removal has contributed to achieving the ERA objective of mitigating the threat to site workers, public health, and the environment caused by the migration of carbon tetrachloride vapors through the soil column and into the groundwater. Monitoring data indicate that, in the area of the disposal sites, the expected direction of the chemical gradient between the vadose and groundwater zones has been reversed since SVE operations began; the expected direction of carbon tetrachloride migration is currently from the groundwater to the vadose zone. However, monitoring data near the vadose zone-groundwater interface are sparse.

Although SVE is being used successfully to reduce the mass of carbon tetrachloride in the soil column, the ERA was implemented as an interim action pending the final cleanup activities associated with the 200-PW-1 Operable Unit. The final cleanup activities will be determined as part of the CERCLA remedial investigation/feasibility study process for the 200-PW-1 Operable Unit. The remedial investigation of the carbon tetrachloride vadose zone plume was initiated in FY 2002 (DOE-RL 2002a).

9.0 RECOMMENDATIONS

9.1 STATUS OF FISCAL YEAR 1997 RECOMMENDATIONS FOR FISCAL YEAR 1998

The status of recommendations regarding future SVE operations that were based on the FY 1997 rebound study, operating experience, and data evaluation (Rohay 1997) is as follows:

1. **FY 1997 Recommendation:** Implement cyclic operations of the SVE systems using a minimum of 4 to 8 weeks of operation followed by 8 to 16 weeks of rebound to optimize the carbon tetrachloride mass removal efficiency (in terms of mass of carbon tetrachloride removed per volume of soil vapor extracted).

Status: At the conclusion of the rebound study, the three SVE systems were operated for 11 weeks (July 1997-September 1997). During FY 1998, one SVE system was operated for 12 weeks (April 1998-June 1998) at the 216-Z-1A/Z-18/Z-12 site following 26 weeks of rebound (October 1997-March 1998), and then operated for 12 weeks (July 1998-September 1998) at the 216-Z-9 site following 39 weeks of rebound (October 1997-June 1998).

2. **FY 1997 Recommendation:** Implement carbon tetrachloride vapor monitoring during future periods of nonoperation of the SVE systems to confirm that groundwater quality and atmospheric emissions are not being negatively impacted.

Status: Carbon tetrachloride vapor monitoring was conducted at both the 216-Z-1A/Z-18/Z-12 site and the 216-Z-9 site from October 1997 through March 1998 during the 26 weeks of nonoperation of the SVE system. While the SVE system was operated at 216-Z-1A/Z-18/Z-12 from April 1998 through June 1998, vapor monitoring was focused at 216-Z-9, and while the SVE system was operated at 216-Z-9 from July 1998 through September 1998, vapor monitoring was focused at 216-Z-1A/Z-18/Z-12. Based on the available monitoring, nonoperation of the SVE system appears to have caused no additional degradation of groundwater quality and minimal detectable vertical transport of carbon tetrachloride through the soil surface to atmosphere.

3. **FY 1997 Recommendation:** Repeat the measurement of carbon tetrachloride rebound in the first 4 to 8 weeks following SVE operations at 216-Z-1A planned from April through June 1998 and following SVE operations at 216-Z-9 planned from July through September 1998.

Status: The first carbon tetrachloride rebound measurements were made at the 216-Z-1A site 6.5 weeks (August 1998) after SVE operations ceased at that site (June 1998). The first carbon tetrachloride rebound measurements were made at the 216-Z-9 site 5 weeks (November 1998) after SVE operations ceased at that site (September 1998). Rebound measurements were continued monthly at both sites.

Recommendations

4. **FY 1997 Recommendation:** Consider implementation of passive SVE, also known as barometric pumping, as an alternative to active SVE operations.

Status: Passive SVE systems were installed on eight wells during FY 1999. The passive SVE systems began operation in FY 2000.

5. **FY 1997 Recommendation:** Update the carbon tetrachloride site conceptual model, including the estimate of the current distribution of the original carbon tetrachloride inventory and the nature and magnitude of the exchange of carbon tetrachloride between the vadose zone and groundwater.

Status: Plans to update the carbon tetrachloride site conceptual model were included in the detailed planning for FY 1998. The 1998 update to the site conceptual model was included in Revision 3 of this performance evaluation report; the 1999 update was included in Revision 4 of the report; the 2000 update was included in Rev. 5 of the report; and the 2001 update is included in this revision of the report. The University of Washington is evaluating the estimate of the current distribution of the original carbon tetrachloride inventory. Results are anticipated in 2002. Investigation of the exchange of carbon tetrachloride between the vadose zone and groundwater was not implemented in FY 1998 and was carried forward as a FY 1998 recommendation in this report (Section 9.2).

9.2 STATUS OF FISCAL YEAR 1998 RECOMMENDATIONS FOR FISCAL YEAR 1999

1. **FY 1998 Recommendation:** Investigate the nature and magnitude of the exchange of carbon tetrachloride between the vadose zone and groundwater. This information will be required in the future to address the interdependency of the vadose zone-groundwater system in achieving remediation of the 200 West Area subsurface carbon tetrachloride contamination.

Status: A study to specifically investigate the exchange of carbon tetrachloride between the vadose zone and groundwater did not occur in FY 1999.

2. **FY 1998 Recommendation:** Continue cyclic SVE operations. However, consider one or more of the following modifications:
- In FY 1999, return the 14.2-m³/min SVE system to a position closer to the 216-Z-1A Tile Field, where carbon tetrachloride concentrations are higher, to improve extraction efficiency from that site by allowing more wells to be on line simultaneously. From its position in FY 1998 at the 216-Z-18 Crib, the 14.2-m³/min SVE system could not extract from all 216-Z-1A/Z-18/Z-12 wells simultaneously.
 - Extend the length of the operating period at the 216-Z-1A/Z-18/Z-12 site to allow additional time to cycle between sets of wells.

Recommendations

Status: Cyclic SVE operations were continued during FY 1999. One SVE system operated for 12 weeks (April through June 1999) at the 216-Z-9 site following 26 weeks of rebound (October 1998 through March 1999) and then operated for 12 weeks (July through September 1999) at the 216-Z-1A/Z-18/Z-12 site following 52 weeks of rebound (July 1998 through June 1999). The modifications recommended in FY 1998 were not implemented during FY 1999.

- FY 1998 Recommendation:** Continue carbon tetrachloride vapor monitoring during future periods of nonoperation of the SVE systems to confirm that groundwater quality is not being negatively impacted. Consider discontinuing the near-surface (1.5-m depth) monitoring for atmospheric emissions based on sporadic and low concentrations detected in FY 1997 and FY 1998.

Status: Carbon tetrachloride vapor monitoring was conducted at both the 216-Z-1A/Z-18/Z-12 site and the 216-Z-9 site from October 1998 through March 1999 during the 26 weeks of nonoperation of the SVE system. While the SVE system was operated at 216-Z-9 from April through June 1999, vapor monitoring was focused at 216-Z-1A/Z-18/Z-12, and while the SVE system was operated at 216-Z-1A/Z-18/Z-12 from July through September 1999, vapor monitoring was focused at 216-Z-9. Based on the available monitoring, nonoperation of the SVE system appears to have caused no additional degradation of groundwater quality and minimal detectable vertical transport of carbon tetrachloride through the soil surface to atmosphere. The near-surface monitoring was discontinued, as recommended, in FY 2000.

- FY 1998 Recommendation:** Repeat the measurement of carbon tetrachloride rebound in the first 4 to 8 weeks following SVE operations at 216-Z-9 planned from April through June 1999 and following SVE operations at 216-Z-1A planned from July through September 1999.

Status: The first carbon tetrachloride rebound measurements were made at the 216-Z-9 site 4.5 weeks (July 1999) after SVE operations ceased at that site (June 1999). The first carbon tetrachloride rebound measurements were made at the 216-Z-1A site 4 weeks (October 1999) after SVE operations ceased at that site (September 1999). Rebound measurements were continued monthly at both sites.

- FY 1998 Recommendation:** Consider application of one or more innovative technologies to significantly enhance characterization and/or remediation of carbon tetrachloride in the vadose zone and/or groundwater. An Innovative Treatment Remediation Demonstration program, funded by the DOE Office of Environmental Restoration, has been implemented to evaluate appropriate technologies to address the Hanford Site 200 Area carbon tetrachloride plume. Treatability testing of the characterization and/or remediation technology recommended by the Innovative Treatment Remediation Demonstration program is scheduled to begin in January 2000 and implementation is scheduled for September 2000.

Recommendations

Status: During FY 1999, the Innovative Treatment Remediation Demonstration program focused on the need for additional characterization and recommended conducting a Partitioning Interwell Tracer Test under the 216-Z-9 site to evaluate the presence of DNAPL (i.e., carbon tetrachloride as a separate organic phase) in the vadose and groundwater zones. Possible test configurations and cost estimates were evaluated during FY 1999 and FY 2000. Because of other priorities, this recommendation was not adopted by the project.

9.3 STATUS OF FISCAL YEAR 1999 RECOMMENDATIONS FOR FISCAL YEAR 2000 AND FISCAL YEAR 2001

1. **FY 1999 Recommendation:** Continue cyclic SVE operations using the 14.2-m³/min SVE system to remove carbon tetrachloride mass.

Comparison of the mass of carbon tetrachloride removed during cyclic operations to the mass projected to be removed during continuous operations indicates that greater mass removal is achieved using continuous operations. However, waste minimization is achieved using cyclic operations in which the SVE system is operated during warm months. In addition, available soil vapor monitoring indicates that nonoperation of the SVE system for 6 to 12 months does not appear to have a negative impact on groundwater quality.

Consider one or more of the following modifications to cyclic SVE operations:

- a. During extraction from the 216-Z-1A/Z-18/Z-12 wellfield, move the 14.2-m³/min SVE system to a position closer to the 216-Z-1A Tile Field, where carbon tetrachloride concentrations are higher, to improve extraction efficiency from that site by allowing more wells to be on line simultaneously. From its position in FY 1998 and FY 1999 at the 216-Z-18 Crib, the 14.2-m³/min SVE system could not extract from all 216-Z-1A/Z-18/Z-12 wells simultaneously.
- b. Move the SVE system between the 216-Z-9 and 216-Z-1A/Z-18/Z-12 wellfields after 4 to 8 weeks of operation, or when concentrations return to an asymptotic decline.
- c. Use the SVE system to apply a vacuum at wells open below (or above) the Plio-Pleistocene unit and monitor pressures at wells open above (or below) the Plio-Pleistocene unit. The pressure response in the monitoring wells can be used to help evaluate the continuity and relative permeability of the Plio-Pleistocene unit. This evaluation, in turn, supports understanding of vertical pathways for contaminant migration and remediation strategies using SVE.

Status: Soil vapor extraction using the 14.2-m³/min SVE system was not conducted during FY 2000. The suggested modifications were carried forward.

Recommendations

2. **FY 1999 Recommendation:** Continue operation of the eight passive SVE systems to obtain a long-term record of performance.

Passive SVE systems were installed on eight wells in the 216-Z-1A/Z-18 area in FY 1999 and began operation in FY 2000. These eight wells were selected because they are open below the Plio-Pleistocene unit. Differential pressures between the subsurface and surface drive passive venting ("barometric pumping") and are higher below the Plio-Pleistocene unit than above it (Section 3.0).

Consider the following modifications to operation of the passive SVE systems:

- a. Use virgin GAC rather than regenerated GAC in the passive systems. Analytical results of passive SVE GAC cartridge samples indicate that the regenerated GAC placed in the cartridges contains carbon tetrachloride.
- b. Reconfigure the passive systems to be vertical or to drop water out of the hoses (e.g., through a series of baffles). During the winter months, water condensed from the venting soil vapor into the hoses and onto the GAC in the cartridges, potentially interfering with operation of the systems.

Status: The eight passive SVE systems were operated during FY 2000. Modifications to the systems were not made during FY 2000. The recommended changes were carried forward.

3. **FY 1999 Recommendation:** Consider further implementation of passive SVE systems as the rate of carbon tetrachloride delivery to the high flow zones becomes diffusion-limited. Very few additional wells are available below the Plio-Pleistocene unit in the active SVE wellfields. The differential pressure in wells open above the Plio-Pleistocene will be lower but should still be sufficient to drive barometric pumping. In addition, impermeable surface barriers that artificially increase the differential pressure in the zone between the surface and the Plio-Pleistocene layer can be considered in implementation of passive systems on shallower wells.

Status: Additional passive SVE systems were not installed in FY 2000. The recommendations were carried forward.

4. **FY 1999 Recommendation:** Repeat the measurement of carbon tetrachloride rebound in the first 4 to 8 weeks following SVE operations. Consider monitoring selected wells (e.g., 299-W15-217, 299-W18-158L) more frequently to confirm the rate of concentration rebound immediately following cessation of SVE operations. During the rebound study in 1997, the initial rapid increase appeared to take place during the first 6 to 8 weeks of rebound (Rohay 1997).

Status: SVE operations were not conducted during FY 2000.

Recommendations

5. **FY 1999 Recommendation:** Continue carbon tetrachloride vapor monitoring during future periods of nonoperation of the SVE systems to confirm that groundwater quality is not being negatively impacted.

Status: Carbon tetrachloride vapor monitoring was conducted at both the 216-Z-1A/Z-18/Z-12 site and the 216-Z-9 site from October 1999 through September 2000 during nonoperation of the SVE system. Based on the available monitoring, nonoperation of the SVE system appears to have caused no additional degradation of groundwater quality and minimal detectable vertical transport of carbon tetrachloride through the soil surface to atmosphere.

9.4 STATUS OF FISCAL YEAR 2000 RECOMMENDATIONS FOR FISCAL YEAR 2001 AND FISCAL YEAR 2002

1. **FY 2000 Recommendation:** Resume cyclic SVE operations using the 14.2-m³/min SVE system to remove carbon tetrachloride mass.

Consider one or more of the modifications to cyclic SVE operations recommended in FY 1999 (Section 9.3, Recommendation 1).

Status: Cyclic SVE operations were conducted during FY 2001. One SVE operated for 15 weeks (April through July 2001) at the 216-Z-1A/Z-18/Z-12 site following 78 weeks of rebound (October 1999 through March 2001) and then operated for 10 weeks (July 2001 through September 2001) at the 216-Z-9 site following 104 weeks of rebound (July 1999 through June 2001). During extraction from the 216-Z-1A/Z-18/Z-12 wellfield, the SVE system was moved to a position closer to the 216-Z-1A tile field, as recommended in FY 1999 (Section 9.3, Recommendation 1).

2. **FY 2000 Recommendation:** Continue operation of the eight passive SVE systems to obtain a long-term record of performance.

Consider one or more of the modifications to operation of the passive SVE systems recommended in FY 1999 (Section 9.3, Recommendation 2). Also, consider the following new recommendations:

- a. Use longer GAC cartridges, or two in series, to test whether the current GAC cartridges are becoming saturated prior to being sampled for analysis.
- b. Obtain backup power supplies for the dataloggers to prevent data loss during power outages.
- c. Move the wellhead instrumentation to different wells each quarter to obtain hourly flow and concentrations at each well by the end of the year.

Recommendations

- d. Discontinue the differential pressure monitoring above the Plio-Pleistocene layer at the CPT-F soil vapor probes. Additional data are not needed to characterize this location.
- e. Discontinue the differential pressure monitoring at the control well, 299-W18-9. This well could be used for passive SVE.
- f. Evaluate each passive SVE system for minor leaks and replace component parts (e.g., hoses) as needed.

Status: The eight passive SVE systems were operated during FY 2001.

- 3. **FY 2000 Recommendation:** Consider further implementation of passive SVE systems on wells open below or above the Plio-Pleistocene unit in the active SVE wellfields. Wells open below the Plio-Pleistocene are available in the 216-Z-9 wellfield. The differential pressure data recorded above the Plio-Pleistocene unit during FY 1996 testing and during FY 2000 implementation indicate that although the driving force will be lower in wells open above the Plio-Pleistocene (compared to wells open below the Plio-Pleistocene), the differential pressure should be sufficient to drive barometric pumping (Section 9.3, Recommendation 3).

Status: Additional passive SVE systems were not installed in FY 2001.

- 4. **FY 2000 Recommendation:** Repeat the measurement of carbon tetrachloride rebound in the first 4 to 8 weeks following SVE operations.

Status: The first carbon tetrachloride rebound measurements were made at the 216-Z-1A/Z-18/Z-12 site two weeks (July 2001) after SVE operations ceased at that site (July 2001). The first carbon tetrachloride rebound measurements were made at the 216-Z-9 site five weeks (November 2001) after SVE operations ceased at that site (September 2001). Rebound measurements were continued monthly at both sites.

- 5. **FY 2000 Recommendation:** Continue carbon tetrachloride vapor monitoring during future periods of nonoperation of the SVE systems to confirm that groundwater quality is not being negatively impacted.

Status: Carbon tetrachloride vapor monitoring was conducted at the 216-Z-1A/Z-18/Z-12 and the 216-Z-9 sites from October 2000 through September 2001 during periods of nonoperation of the SVE system. Based on the available monitoring, nonoperation of the SVE system appears to have caused no additional degradation of groundwater quality and minimal detectable vertical transport of carbon tetrachloride through the soil surface to atmosphere.

- 6. **FY 2000 Recommendation:** Inventory the network of shallow soil vapor probes and CPT-emplaced soil vapor probes and rods. Consider decommissioning those probes/rods no longer needed to support SVE operations or field characterization activities for the 200-PW-1 Operable Unit.

Status: An inventory of the vapor probe network was not conducted during FY 2001.

9.5 FISCAL YEAR 2001 RECOMMENDATIONS FOR FISCAL YEAR 2002

- 1. Resume cyclic SVE operations using the 14.2-m³/min SVE system to remove carbon tetrachloride mass.**

Consider moving the SVE system between the 216-Z-9 and 216-Z-1A/Z-18/Z-12 wellfields after 4 to 8 weeks of operation, or when concentrations return to an asymptotic decline (Section 9.3, Recommendation 1).

- 2. Continue operation of the eight passive SVE systems.**

Consider one or more of the following modifications to operation of the passive SVE systems:

- a. Reconfigure the passive systems to be vertical or to drop water out of the hoses (e.g., through a series of baffles). During the winter months, water condensed from the venting soil vapor into the hoses, potentially interfering with operation of the systems (Section 9.3, Recommendation 2).**
- b. Discontinue sampling using in-line, replaceable cartridges of GAC. These sample results were found to be unrepresentative of the mass extracted through each well (Section 5.7).**
- c. Discontinue automated hourly measurements of flow rate and carbon tetrachloride vapor concentrations at individual wells using the instrumentation installed in FY 1999. Conduct future automated monitoring of flow rate and carbon tetrachloride vapor concentrations at individual wells using an instrumentation package that can be moved from well to well relatively easily. Move the wellhead instrumentation to different wells each quarter to obtain hourly flow and concentrations at each well by the end of the year (Section 9.4, Recommendation 2).**
- d. Monitor passive extraction wells monthly using the sampling method used for the nonoperational wells. Monitor the vapor concentration both upstream and downstream of the GAC canister. The measured vapor concentrations can be used to estimate the amount of carbon tetrachloride extracted through each well during the month (Section 5.7.1.2).**
- e. Discontinue the differential pressure monitoring above the Mio-Pleistocene layer at the CPT-F soil vapor probes. Additional data are not needed to characterize this location (Section 9.4, Recommendation 2).**
- f. Discontinue the differential pressure monitoring at the control well, 299-W18-9. This well could be used for passive SVE (Section 9.4, Recommendation 2).**

Recommendations

- g. Evaluate each passive SVE system for minor leaks and replace component parts (e.g., hoses) as needed (Section 9.4, Recommendation 2).
3. Consider further implementation of passive SVE systems on wells open below or above the Plio-Pleistocene unit in the active SVE wellfields. Wells open below the Plio-Pleistocene are available in the 216-Z-9 wellfield. The differential pressure data recorded above the Plio-Pleistocene unit during FY 1996 testing and during FY 2000 implementation indicate that although the driving force will be lower in wells open above the Plio-Pleistocene (compared to wells open below the Plio-Pleistocene), the differential pressure should be sufficient to drive barometric pumping (Section 9.3, Recommendation 3; Section 9.4, Recommendation 3).
4. Repeat the measurement of carbon tetrachloride rebound in the first 4 to 8 weeks following SVE operations.
5. Continue carbon tetrachloride vapor monitoring during future periods of nonoperation of the SVE systems to confirm that groundwater quality is not being negatively impacted.
6. Inventory the network of shallow soil vapor probes and CPT-emplaced soil vapor probes and rods. Consider decommissioning those probes/rods no longer needed to support SVE operations or field characterization activities for the 200-PW-1 Operable Unit (Section 9.4, Recommendation 6).
7. Evaluate the condition of the wells currently included in the SVE well network. Identify and prioritize those wells recommended for decommissioning.

9.6 RECOMMENDATIONS FOR FISCAL YEAR 2003

It is recommended that an evaluation be conducted to determine the frequency and type of SVE operations and monitoring to be implemented in FY 2003. During cyclic operations in FY 1998, FY 1999, and FY 2001, only approximately 0.1% of the original inventory was removed each year. Although the mass removed each year during cyclic operations is low compared to the total mass removed during early stages of SVE, each year of cyclic operations does remove approximately 0.75 metric tons of carbon tetrachloride from the vadose zone. Based on the existing remedial design, the following components could be considered for an operating strategy over the next few years:

- **Continuing cyclic SVE operations using one or more SVE systems.** Now that the readily accessible carbon tetrachloride has been removed, mass removal is more efficient (in terms of mass removed per hour of operation) if SVE operations are intermittent, allowing the carbon tetrachloride vapor concentrations to rebound during periods of temporary shutdown. An additional advantage to cyclic operations is that waste minimization is achieved if the SVE system is operated only during warm months, when water condensate is not generated by the SVE system.

Recommendations

- **Resuming continuous SVE operations using one or more SVE systems.** Comparison of the mass removed during cyclic operations to the projected mass removed had the SVE system continued to operate throughout the year suggests that the highest amount of mass removal is achieved by continuous operations. An additional advantage to continuous operations is that a maximum concentration gradient is maintained between the source of the carbon tetrachloride and the high-flow zone into which it is diffusing.
- **Continuing use of passive SVE systems.** Passive SVE systems have low operation and maintenance costs because they are designed to use only renewable energy resources and to operate unattended for long periods of time. However, the amount of mass removed each year by the existing passive systems is significantly lower than the amount removed using the active system. The driving force for barometric pumping is greater if the well is screened below a low permeability layer such as the Plio-Pleistocene unit, but the differential pressure should also be sufficient to drive barometric pumping in wells above the Plio-Pleistocene unit.
- **Continuing monitoring of rebound concentrations.** Rebound concentrations are monitored during periods of nonoperation of the SVE system. One objective of monitoring the nonoperational wells and probes is to measure carbon tetrachloride concentrations and trends near the vadose-atmosphere and vadose-groundwater interfaces to evaluate whether nonoperation of the SVE system is negatively impacting atmosphere or groundwater. Monitoring is also conducted near the Plio-Pleistocene unit to support SVE operations. Monitoring is conducted monthly at approximately 30 locations. Considerations could be given to changing the monitoring frequency and/or locations.
- **Implementing enhancements to the SVE system(s).** The Innovative Treatment and Remediation Demonstration program reviewed the available technologies to enhance remediation using the SVE system(s). Feasibility testing of one or more of these or other enhancements could be conducted to determine their cost and performance effectiveness.
- **Revising the existing SVE extraction well network.** The existing well network consists of 46 vertical wells that provide 48 perforated or screened intervals open above the Plio-Pleistocene unit and 17 perforated or screened intervals open below the Plio-Pleistocene unit. Some wells in the current well network may need to be decommissioned, and additional wells may need to be added to provide complete coverage of the vadose zone in the source term area. Consideration could be given to installing horizontal wells for enhancing the carbon tetrachloride remediation.

10.0 REFERENCES

- BHI, 1998, *Fiscal Year 1997 Annual Report for the 100-NR-2, 200-UP-1, and 200-ZP-1 Pump and Treat Operations and Operable Units*, BHI-01126, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.
- BHI, 2001, *Borehole Completion Report - 216-Z-9 Trench Vadose Well Deepening and Characterization*, BHI-01552, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.
- Cameron, R. J., 1997, *An Assessment of Field and Laboratory Studies of the Hanford Carbon Tetrachloride Soil Vapor Extraction Site*, M.S. Thesis, Washington State University, Pullman, Washington, 110 pp.
- Chiaramonte, G. R., C. W. Denslow, A. J. Knepp, R. D. Landon, and S. Panday, 1997, *Hanford Sitewide Groundwater Remediation Strategy - Groundwater Contaminant Predictions*, BHI-00469, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.
- Cohen, R. M., J. W. Mercer, and J. Matthews, 1993, *DNAPL Site Evaluation*, CRC Press, Inc., Boca Raton, Florida.
- Comprehensive Environmental Response, Compensation, and Liability Act of 1980*, 42 U.S.C. 601, et seq.
- DOE-RL, 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 Operations Office, Richland, Washington.
- DOE-RL, 2000, *Fiscal Year 1999 Annual Summary Report for the 200-UP-1, 200-ZP-1, and 100-NR-2 Pump-and-Treat Operations and Operable Units*, DOE/RL-99-79, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- DOE-RL, 2002a, *200-PW-1 Operable Unit Dispersed Carbon Tetrachloride Vadose Zone Plume Sampling and Analysis Plan - Step I*, DOE/RL-2001-67, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- DOE-RL, 2002b, *Fiscal Year 2001 Annual Summary Report for the 200-UP-1 and 200-ZP-1 Pump-and-Treat Operations*, DOE/RL-2001-53, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- Driggers, S. A., 1994, *Summary of Canister Overheating Incident at the Carbon Tetrachloride Expedited Response Action Site*, WHC-SD-EN-TI-203, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

References

- EPA, 1992, *Action Memorandum: Expedited Response Action Proposal for 200 West Area Carbon Tetrachloride Plume* (Letter, R. F. Smith, U.S. Environmental Protection Agency Region 10, and R. Stanley, Washington State Department of Ecology, to R. D. Izatt, U.S. Department of Energy, Richland Operations Office, Incoming CCN 9200423, dated January 21, 1992).
- EPA, 1993, *HyperVentilate Users Manual: A Software Guidance System Created for Vapor Extraction Applications*, EPA 510-R-93-001, U.S. Environmental Protection Agency, Solid Waste and Emergency Response, Washington, D.C.
- EPA, 2001, *USDOE Hanford Site First Five-Year Review Report*, U.S. Environmental Protection Agency, Region 10, Seattle, Washington.
- Fancher, J. D., 1994, *Carbon Tetrachloride ERA Soil-Gas Baseline Monitoring*, WHC-SD-EN-TI-265, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- Hagood, M. C. and V. J. Rohay, 1991, *200 West Area Carbon Tetrachloride Expedited Response Action Project Plan*, WHC-EP-EN-AP-046, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- Hartman, M. J., L. F. Morasch, and W. D. Webber, 2001, *Hanford Site Groundwater Monitoring for Fiscal Year 2000*, PNNL-13404, Pacific Northwest National Laboratory, Richland, Washington.
- Hooker, B. S., M. J. Truex, T. P. Clement, and R. S. Skeen, 1996, "Preliminary Validation of Intrinsic Remediation of Carbon Tetrachloride at the Hanford Site," presented at the Intrinsic Remediation Conference, Salt Lake City, Utah, April 1996.
- Kasper, R. B., 1982, *216-Z-12 Transuranic Crib Characterization: Operational History and Distribution of Plutonium and Americium*, RHO-ST-44, Rockwell Hanford Operations, 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. and V. J. Rohay, 1993, *Refined Conceptual Model for the Volatile Organic Compounds - Arid Integrated Demonstration and 200 West Area Carbon Tetrachloride Expedited Response Action*, PNL-8597, 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.

References

- Newcomer, D. R., 1990, *Evaluation of Hanford Site Water-Table Changes—1980 to 1990*, PNL-7498, Pacific Northwest National Laboratory, Richland, Washington.
- Pankow, J. F. and J. A. Cherry, 1996, *Dense Chlorinated Solvents and Other DNAPLs in Groundwater: History, Behavior, and Remediation*, Waterloo Press, Portland, Oregon.
- Piepho, M. G., 1996, *Numerical Analysis of Carbon Tetrachloride Movement in the Saturated and Unsaturated Zones in the 200 West Area, Hanford Site*, BHI-00459, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.
- 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.
- Riley, G. J., 1998, *Residual DNAPL Source Evaluation Using Concentration Rebound Data*, MS Thesis, University of Washington, Seattle, Washington, 154 pages.
- Rohay, V. J., 1996, *Field Tests of Passive Soil Vapor Extraction Systems at the Hanford Site, Washington*, BHI-00766, Bechtel Hanford, Inc., Richland, Washington.
- Rohay, V. J., 1997, *Rebound Study Report for the Carbon Tetrachloride Soil Vapor Extraction Site, Fiscal Year 1997*, BHI-01105, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.
- Rohay, V. J. and V. G. Johnson, 1991, "Site Evaluation," in *Expedited Response Action Proposal (EE/CA & EA) for 200 West Area Carbon Tetrachloride Plume*, Appendix B, DOE/RL-91-32, Draft B, U.S. Department of Energy, Richland Operations Office, Richland, Washington.
- Rohay, V. J. and W. J. McMahon, 1996, *Airflow Modeling Report for Vapor Extraction Operations at the 200-ZP-2 Operable Unit (Carbon Tetrachloride Expedited Response Action)*, BHI-00882, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.
- Rohay, V. J., K. J. Swett, V. M. Johnson, G. V. Last, D. C. Lanigan, and L. A. Doremus, 1993, *FY93 Site Characterization Status Report and Data Package for the Carbon Tetrachloride Site*, WHC-SD-EN-TI-202, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- Rohay, V. J., K. J. Swett, and G. V. Last, 1994, *1994 Conceptual Model of the Carbon Tetrachloride Contamination in the 200 West Area at the Hanford Site*, WHC-SD-EN-TI-248, Rev. 0, Westinghouse Hanford Company, Richland, Washington.
- Slate, J. L., 1996, "Buried Carbonate Paleosols Developed in Pliocene-Pleistocene Deposits of the Pasco Basin, South-Central Washington, U.S.A.," *Quaternary International*, Vol. 34-36, p. 191-196.

References

- Swanson, L. C., V. J. Rohay, and J. M. Faurote, 1999, *Hydrogeologic Conceptual Model for the Carbon Tetrachloride and Uranium/Technetium Plumes in the 200 West Area: 1994 Through 1999 Update*, BHI-01311, Bechtel Hanford, Inc., Richland, Washington.
- Temples, T. J., M. G. Domoracki, W. J. Waddell, and J. Eyer, 2001, "Noninvasive Determination of the Location and Distribution of DNAPL Using Advanced Seismic Reflection Techniques," *Ground Water*, Vol. 39, No. 3: 465-474.
- Thorne, P. D. and D. R. Newcomer, 1992, *Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System*, PNL-8337, Pacific Northwest Laboratory, 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.
- Yonge, D., A. Hossain, R. Cameron, H. Ford, and C. Storey, 1996, *Hanford Soil Partitioning and Vapor Extraction Study*, BHI-00861, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.
- Zimmerman, D. A., A. E. Reisenauer, G. D. Black, and M. A. Young, 1986, *Hanford Site Water Table Changes 1950 Through 1980 – Data Observations and Evaluation*, PNL-5506, Pacific Northwest Laboratory, Richland, Washington.

APPENDIX A
200-PW-1 FLOW RATE ESTIMATION METHODOLOGY

APPENDIX A

200-PW-1 FLOW RATE ESTIMATION METHODOLOGY

The memorandum included in this appendix describes the methodology used to estimate the flow rates and cumulative volume of vapor extracted from each individual extraction well. The memorandum was prepared in July 1996 to support preparation of Revision 1 of this report, and the results it presents are now out-of-date. The results have been updated using the same methodology to support preparation of Revisions 2 through 6 and are presented in Table 5-5 of this report.



Memorandum

To: Rhett Tranbarger, Virginia Rohay

Date: July 16, 1996

From: Kirk W. Hudson

KWH

MEMO:0021-96

Subject: 200-ZP-2 Flow Rate Estimation Methodology and Results

This letter report documents the review of the Soil Vapor Extraction (SVE) system data and flow rate estimates for the 200-ZP-2 system. The purpose of this work was to: 1) develop a spreadsheet that estimates the flow rates at extraction wells based on the flow rates at the header; and 2) estimate cumulative flow from each extraction well to date; and 3) plot estimated flow rates and carbon tetrachloride concentrations versus time for selected wells for comparison. This report documents the methodology used to estimate the flow rates and the results.

The 200-ZP-2 SVE system consists of three separate well fields (Z-18, Z-1A, and Z-9) with respective 500 cubic feet per minute (cfm), 1,000 cfm, and 1,500 cfm flow rate capacities. The systems are configured in such a manner that real-time flow rates, cumulative volume removed, and vacuums are indicated at a common header. The individual extraction wells are not equipped with vacuum gauges or flow meters. However, a truck-mounted flow meter and vacuum gauge are used periodically (scheduled once per quarter) to record vacuum and flow meter readings at individual extraction wells during system operation.

METHODOLOGY

Three methods were identified to estimate the flow rates from each extraction well based on the vacuum and flow measurements at the headers.

METHOD 1:

Using the Johnson Equation [Johnson 1990]:

$$Q = H \times \pi \times \left(\frac{k}{\mu}\right) \times P_w \times \frac{1 - \left(\frac{P_{atm}}{P_w}\right)^2}{\ln\left(\frac{R_w}{R_j}\right)}$$

44-8-85

Kirk W. Hudson
Page 2
July 16, 1996

MEMO:0021-96

Where: Q = vapor flow rate (scfs)
P_{atm} = absolute atmospheric pressure (psf)
P_w = absolute wellhead vacuum (P_{atm} - wellhead vacuum) (psf)
H = length of screened interval in vadose zone (ft)
k = soil permeability (sq. ft.)
μ = viscosity of air (lb-sec/sq. ft.)
R_w = radius of the well screen (in.)
R_i = vapor radius of influence (assumed 20 meters) (in.)

If P_{atm}, μ, and R_i are assumed constant throughout the site, and P_w, H, and R_w are given for each well, then the only missing factor is k. If all the variables are the same for two given wells (i.e., upper and lower nested wells) then k can be estimated (proportionally). Therefore, a factor can be developed for each well to proportion the flow contribution from each well to the total flow measured at the header. The permeability and the factor can then be adjusted accordingly to calibrate to the characterization data.

Use of this equation is based on the following assumptions:

- Radial flow and equal velocity distribution throughout screened interval
- Radius of influence is consistent from well to well at the site (assumed 20 meters)
- Viscosity of air (temperature) is the same from well to well
- Wells are screened in the vadose zone

METHOD 2:

Using a ratio of the open area (screened or jet perforated) of the wells.

For example:

Wells A, B, and C have ten, twenty, and thirty square inches of open area, respectively and are being used as extraction wells with a flow rate at the system header of 1000 cfm. The flow rates are proportioned out as follows:

$$\text{Well A flow rate} = 1000 \times \frac{10}{10 + 20 + 30} = 1000 \times \frac{10}{60} = 167 \text{ cfm}$$

$$\text{Well B flow rate} = 1000 \times \frac{20}{60} = 333 \text{ cfm}$$

Kirk W. Hudson
Page 3
July 16, 1996

MEMO:0021-96

$$\text{Well C flow rate} = 1000 \times \frac{30}{60} = 500 \text{ cfm}$$

Use of this method is based on the following assumptions:

- The flow rates from individual wells are directly proportional to the open areas of the well screens.
- The soil permeabilities are the same for every well.
- Friction losses from the well head to the system are the same for every well.
- Well losses are the same for each well.

METHOD 3:

Using a ratio of estimated permeabilities for different lithologic layers where wells are screened to proportion flow rates amongst wells.

For example:

System header flow rate = 500 cfm and,

Well A is screened in the Hanford Lower Coarse layer from 50 - 60 feet below grade.

Well B is screened in the Plio-Pleistocene layer from 125 - 140 feet below grade.

If the permeability in the Hanford Lower Coarse layer is estimated to be two times that in the Plio-Pleistocene layer then the flow rate from Well A is twice that of Well B.

$$\text{Well A flow rate} = 500 \times \frac{2}{2+1} = 500 \times \frac{2}{3} = 333 \text{ cfm}$$

$$\text{Well B flow rate} = 500 \times \frac{1}{2+1} = 500 \times \frac{1}{3} = 167 \text{ cfm}$$

The permeabilities for different lithologies are estimated based on the flow rate ratio (from characterization data) from wells screened in different zones.

Use of this method is based on the following assumption:

- The screen length, well vacuum, radius of well, and radius of influence in the Johnson Equation (Method 1) combine to form a constant. This constant does not change significantly from well to well with the variations in screen length, well

Kirk W. Hudson
Page 4
July 16, 1996

MEMO:0021-96

vacuum, radius of well, and radius of influence. Therefore, the most significant parameter is the variation in soil permeability from well to well.

EVALUATION OF METHODOLOGY

Characterization data was used to evaluate the three methods. Characterization data was used for comparison purposes only if it was more recent than June 1995. Prior to June 1995, wells were characterized on an individual basis as opposed to on a system basis where all wells in operation are characterized. Based on this criterion, two characterization data events were determined to be useable from the Z-18 system. One characterization data event was determined to be useable from the Z-1A system. Two characterization data events were determined to be useable from the Z-9 system. Table 1 presents a summary of the characterization data events that were determined to be useable.

SYSTEM	DATE	WELLS	WELLS	WELLS	WELLS
Z-18	8/3/95	12, 246U, 246L, 252U, 252L, 96	17	474	1,158
Z-18	11/16/95	152, 252L	17	227	210
Z-1A	8/4/95 - 8/7/95	7, 89, 248, 165, 174	34	801	773
Z-9	8/1/95 - 8/2/95	82, 9U, 84, 85, 217, 218L, 218U, 219L, 219U	20	1314	1328
Z-9	11/28/95 - 11/29/95	6L, 9U, 216L, 218L, 218U, 220L, 220U, 82, 86, 217, 219L, 219U	20	1448	1171

Based on the characterization data, Z-9 appeared to be the system with the most complete data as there was characterization data for 14 out of 20 wells and the summations of the individual flow rates were somewhat consistent with the header flow rate. Therefore, the three methods were used on both useable characterization data sets for Z-9 (Attachment 1).

The results of the estimated flow rates using each method are summarized in Table 2. Method 1 flow rate estimates are summarized by presenting the adjusted flow rates resulting from the average adjusted k values from both characterization data sets for Z-9.

**Appendix A – 200-ZP-2 Flow
Rate Estimation Methodology**

BHI-00720

Rev. 6

Kirk W. Hudson
Page 5
July 16, 1996

MEMO:0021-96

SUMMARY OF METHOD RESULTS							
WELL	MEASURED	METHOD	ERROR	METHOD	ERROR	MEASURED	ERROR
Characterization Data Set # 1							
82	172	146	-18%	167	-3%	164	-5%
9U	79	66	-20%	54	-46%	164	108%
84	420	226	-86%	167	-151%	164	-156%
85	166	105	-58%	167	1%	164	-1%
217	67	148	120%	152	126%	164	145%
218L	95	168	77%	152	60%	82	-16%
218U	175	272	56%	152	-15%	164	-7%
219L	71	73	3%	152	114%	82	16%
219U	83	111	34%	152	83%	164	98%
TOTAL	1,328						
Characterization Data Set #2							
6L	91	100	10%	121	33%	96	5%
9U	39	44	12%	50	27%	138	255%
216L	23	31	35%	93	303%	96	316%
218L	103	111	8%	139	35%	96	-8%
218U	194	181	-7%	139	-40%	138	-40%
220L	98	157	60%	139	42%	138	41%
220U	135	201	49%	139	3%	96	-41%
82	95	97	2%	153	61%	138	46%
86	190	306	61%	59	-220%	138	-37%
217	103	98	-5%	139	35%	138	34%
219L	35	49	39%	139	297%	96	173%
219U	65	74	13%	139	114%	138	113%
TOTAL	1,171						

Kirk W. Hudson
Page 6
July 16, 1996

MEMO:0021-96

The results of an error analysis for each well on each characterization data set are summarized in Table 3.

METHOD	PERCENTAGE	PERCENTAGE
1	-86% to 120%	-7% to 61%
2	-151% to 126%	-220% to 303%
3	-156% to 145%	-41% to 316%

At first glance, it would appear that Method 1 is the most accurate approach. However, the accuracy of Method 1 depends heavily on the amount of characterization data in order to estimate and adjust the permeability to calibrate with the characterization data. In the absence of characterization data, it can be shown (Attachment 2) that the error range increases significantly (-185% to 260%) when estimated permeability values are used. This also holds true for Method 3 which relies heavily on characterization data to estimate relative permeabilities of different lithologies.

In conclusion, with the limited characterization data, Methods 1 and 3 do not appear to be any more accurate than Method 2 which does not rely on characterization data whatsoever. Furthermore, discrepancies in cumulative flow measurements (between the header flow rates and the total measured flow rates) from the characterization data (Table 1) present further questions about the confidence in the characterization data that were determined to be useable. Therefore, method 2 was used to estimate flow rates and cumulative flow from the wells.

SPREADSHEET DEVELOPMENT

One spreadsheet was developed for each well field. Each spreadsheet was set up so that each well in the well field has five columns associated with it. These columns consist of the following:

- Operation - ("on" is entered in this cell if this well was used as an extraction well on a particular date). Cell was left blank if the well was not being used as an extraction well.
- Flow - estimated flow rates are calculated for all wells with "on" entered in the operation column by multiplying the system flow rate by the ratio of that well's

Kirk W. Hudson
Page 7
July 16, 1996

MEMO:0021-96

open area to the sum of the open areas for all the wells in operation for that particular day.

- Volume Removed - estimated by multiplying the estimated well flow rate by the estimated duration of operation for that particular day.
- Cumulative Volume Removed - summation of the Volume Removed cells for individual wells.
- Carbon Tetrachloride Concentration - Individual well carbon tetrachloride concentrations are entered corresponding to the day monitored. These concentrations can be used for comparison with flow rates, cumulative flow, and time.

The only other individual well data entered was the estimated open areas (provided) of each well screen. Some of the wells have open areas which changed due to jet perforating. Therefore, the open areas of some wells may vary depending on the date with which the well was in operation. The dates of operation, duration of operation, and system flow rate columns were used as the reference to which all data were input and estimates were linked.

The assumptions and notes associated with these flow rate estimates are as follows:

- The flow rates of individual wells are directly proportional to the open areas of individual well screens.
- Wells that were used as part of other well fields were included in each system's spreadsheet. Flow rates, however, were only estimated in the system spreadsheet for the system which was extracting vapors from that well on a particular date.
- The screened areas for wells W15-223 and W18-167 were modified to reflect actual operating conditions. The flow rates based on the provided open areas were grossly over-estimated. The open area for well W15-223 was modified by using an estimated open area of 3.67 in²/ft of well screen. At 20 feet of well screen, the open area was estimated at 73.4 in². The open area of well W18-167 was modified by ignoring the open bottom of the well. Therefore, an open area of 8.438 in² was used when operated on 4/22/94 and 4/26/94 and 23.562 in² was used for this well when operated from 8/10/95 to 4/24/96.

As a quality check on the spreadsheets, the system header flow rates were multiplied by the estimated duration of operation and summed. This estimated total system volume removed was compared and confirmed to be equivalent to the summation of the individual well cumulative volumes removed.

Appendix A - 200-ZP-2 Flow Rate Estimation Methodology

BHI-00720

Rev. 6

Kirk W. Hudson

Page 8

July 16, 1996

MEMO:0021-96

RESULTS

The results of the cumulative volume estimates are summarized in Attachment 3 for each well and corresponding system from the period 2/25/92 to 4/24/96. It should be noted that there are errors associated with this calculation as discussed in the Evaluation of Methodology section.

Two sample plots generated from the spreadsheets are included in Attachment 4. These plots include: 1) well W15-82 cumulative volume removed and carbon tetrachloride concentrations versus time; and 2) well W15-223 flow rate and carbon tetrachloride concentrations versus time. The well W15-82 plot indicates decreasing carbon tetrachloride concentrations with increasing cumulative volume removed. The well W15-223 plot indicates carbon tetrachloride concentrations' response to well operation (decreasing carbon tetrachloride concentrations with well operation and minor rebounding concentrations while well is not in operation).

SUMMARY AND CONCLUSIONS

The flow rate and cumulative volume estimates presented in this report were developed using methodologies presented in this report. The estimates are based on measured flow rates at each system header and proportioned to individual wells based on a ratio of open areas of the operating extraction wells' screened interval. This report acknowledges that there are several sources of error associated with these estimates. Nonetheless, these estimates do provide useful information with respect to analyzing operating conditions of the system (estimated flow rates, operational periods for individual wells and well combinations, and carbon tetrachloride concentration trends with respect to well operation).

REFERENCES

Johnson, P.C., M.W. Kemblowald, and J.D. Colthart, 1990, "Quantitative Analysis for the Cleanup of Hydrocarbon-Contaminated Soils by In-Situ Soil Venting", Groundwater, pp. 413-429.

KWH:mmz

attachment

ATTACHMENT 1

1900

SYSTEM FLOW RATE = 1314 gpm									
AIR VISCOSITY = 3.7E-07 lb-mass/ft-s									
ATMOSPHERIC PRESSURE = 2116 mb									
RADIUS OF INFLUENCE = 787 ft									
METHOD 1 - CHARACTERIZATION DATA SET #1									
WELL	DIAM (in)	SCREEN LENGTH (ft)	AIR K (mb)	AIR K ADJ (Per ft. water)	FACTOR	FACTOR ADJ	Q ESTIMATED	Q ADJ	% ERROR
162	8	15	0.38	7.74	10573	258159	8	152	-13%
163	4	25	4.15	2.28	201133	156076	145	83	18%
164	8	15	0.38	15.12	14353	64243	10	402	-5%
165	8	15	4.15	7.03	138030	240508	98	154	-6%
217	4	15	4.15	2.73	141329	118203	102	70	5%
219L	4	15	21.74	4.74	603291	180348	436	98	5%
218U	4	70	4.15	8.07	124360	310486	90	152	4%
218L	4	15	21.74	4.31	488008	129482	358	74	5%
218U	4	15	4.15	5.07	84788	146578	68	87	5%
							1314	1314	
METHOD 1 - CHARACTERIZATION DATA SET #2 USING ADJUSTED FACTORS FOR REPEATED WELLS IN CALIBRATION CASE #1									
WELL	DIAM (in)	SCREEN LENGTH (ft)	AIR K (mb)	AIR K ADJ (Per ft. water)	FACTOR	FACTOR ADJ	Q ESTIMATED	Q ADJ	% ERROR
162	8	15	0.38	7.74	10573	626657	456	179	87%
163	4	25	4.15	2.28	271898	213748	81	82	5%
164	8	15	0.38	15.12	14353	146782	68	40	74%
165	8	15	4.15	7.03	138030	240508	128	23	-20%
217	4	15	4.15	2.73	141329	118203	102	84	-18%
219L	4	15	21.74	4.74	603291	180348	28	185	86%
218U	4	70	4.15	8.07	124360	643226	136	259	87%
218L	4	15	21.74	4.31	488008	877288	28	86	-17%
218U	4	15	4.15	5.07	84788	233597	3	314	107%
217	4	15	4.15	2.73	141329	118203	28	25	-10%
219L	4	15	21.74	4.74	603291	180348	139	42	20%
218U	4	15	4.15	5.07	84788	116822	28	81	-77%
							1448	1448	
METHOD 1 - CHARACTERIZATION DATA SET #2 USING ADJUSTED FACTORS FOR REPEATED WELLS IN CALIBRATION CASE #1									
WELL	DIAM (in)	SCREEN LENGTH (ft)	AIR K (mb)	AIR K ADJ (Per ft. water)	FACTOR	FACTOR ADJ	Q ESTIMATED	Q ADJ	% ERROR
162	8	15	0.38	7.74	10573	626657	456	179	87%
163	4	25	4.15	2.28	271898	213748	81	82	5%
164	8	15	0.38	15.12	14353	146782	68	40	74%
165	8	15	4.15	7.03	138030	240508	128	23	-20%
217	4	15	4.15	2.73	141329	118203	102	84	-18%
219L	4	15	21.74	4.74	603291	180348	28	185	86%
218U	4	70	4.15	8.07	124360	643226	136	259	87%
218L	4	15	21.74	4.31	488008	877288	28	86	-17%
218U	4	15	4.15	5.07	84788	233597	3	314	107%
217	4	15	4.15	2.73	141329	118203	28	25	-10%
219L	4	15	21.74	4.74	603291	180348	139	42	20%
218U	4	15	4.15	5.07	84788	116822	28	81	-77%
							1448	1448	

Appendix A - 200-ZP-2 Flow Rate Estimation Methodology

BHI-00720

Rev. 6

1900

METHOD 1 - CHARACTERIZATION DATA SET #2 (READJUSTING ALL FACTORS)											
SYSTEM FLOW RATE = 1448 m ³ /day											
WELL	DIAM (in)	SCREEN LENGTH (ft)	AIR K (m ² /d)	AIR K ADJ	Pw (in. water)	FACTOR	FACTOR ADJ	Q ESTIMATED	Q ADJ	% ERROR	
8L	6	30	21.74	4.51	55	167780	501808	459	118	27%	
8U	4	26	4.16	2.46	54	271994	232483	66	54	37%	
20U	4	10	21.74	5.12	75	403377	66	86	26	17%	
210L	4	16	21.74	17.73	66	622026	644881	126	126	22%	
210U	4	16	4.16	26.35	74	117218	1029662	28	237	22%	
220L	4	15	21.74	15.80	61	557175	520056	135	120	22%	
220U	4	15	4.15	20.33	78	113917	718408	28	165	22%	
82	6	16	0.36	11.78	71	13821	448664	3	103	6%	
88	6	30	21.74	13.14	75	128712	1104356	314	254	34%	
217	4	16	4.16	17.66	65	163864	644891	25	128	22%	
218L	4	16	21.74	6.43	70	674339	166736	139	45	22%	
218U	4	16	4.16	9.78	78	113817	344838	28	79	22%	
219U	4	16	4.16	9.78	665		6266191	1448	1448		
WELL SUMMARY (WITH AVERAGE K VALUES)											
WELL	DIAM (in)	SCREEN LENGTH (ft)	AIR K (m ² /d)	AIR K ADJ	Pw (in. water)	FACTOR	FACTOR ADJ	Q ESTIMATED	Q ADJ	% ERROR	
8L	6	15	0.36	9.73	80	16378	325185				
8U	4	15	0.36	15.12	60	14353	694243				
84	6	15	4.15	7.63	72	158336	263006				
86	6	15	21.74	13.14	75	128712	1104356				
88	6	30	21.74	11.52	62	141329	432465				
217	4	15	4.15	5.12	75	403377	112272				
218L	4	15	21.74	11.23	75	605391	401542				
218U	4	15	4.15	16.23	70	124360	701371				
218U	4	15	21.74	4.90	90	698026	143768				
218U	4	15	4.15	7.43	90	84798	217810				
219U	4	15	21.74	15.80	81	557175	520056				
220L	4	15	4.15	20.33	76	113917	718408				
220U	4	15	21.74	4.51	65	166780	501808				
85	6	25	4.15	2.36	72	201183	165004				
METHOD 1 AND 2 TEST ON CHARACTERIZATION DATA SET #1 (WITH AVERAGE K VALUES)											
METHOD 2											
WELL	DIAM (in)	SCREEN LENGTH (ft)	AIR K (m ² /d)	AIR K ADJ	Pw (in. water)	FACTOR	FACTOR ADJ	Q ESTIMATED	Q ADJ	% ERROR	AREA
82	6	15	0.36	9.73	75	11411	350754	6	146	-15%	187.178108
8U	4	25	4.15	2.36	75	163804	154678	133	69	-20%	54.0866544
84	6	15	0.36	15.12	75	11411	544000	8	226	-66%	187.178108
86	6	15	4.15	7.63	75	131542	252016	80	105	-58%	187.178108
88	6	15	21.74	13.14	75	118263	355040	80	146	120%	187.178108
217	4	15	4.15	5.12	75	605391	401123	418	168	77%	151.672928
218L	4	15	21.74	11.23	75	118263	655316	80	272	50%	151.672928
218U	4	15	4.15	16.23	75	605391	176367	418	73	3%	151.672928
219U	4	15	21.74	4.90	75	118263	267173	80	111	34%	151.672928
218U	4	15	4.15	7.43	75	118263	267173	1314	1314		478.918

Appendix A - 200-ZP-2 Flow Rate Estimation Methodology

BHI-00720
Rev. 6

1800

METHOD 1 AND 2 TEST ON CHARACTERIZATION DATA SET #2 (WITH AVERAGE K VALUES)												
SHELL	DIAM (in)	SCREEN LENGTH (in)	METHOD 1			FACTOR	FACTOR ADJ	Q ESTIMATED	Q ADJ	METHOD 2		
			Q (m ³ /hr)	FACTOR	Q ADJ					% ERROR	Q AREA	% ERROR
54	8	4	21.74	4.51	162301	483076	362	100	10%	121.17287	33%	41.63
54	8	4	21.74	2.36	168148	215108	33	44	12%	49.5380788	27%	18.633
60	4	4	21.74	6.12	140887	153245	107	31	35%	62.3484433	303%	38.7
218	4	4	21.74	11.23	134545	147018	160	111	6%	138.1838885	35%	93.05
218	4	4	21.74	4.15	187288	867116	31	181	-7%	138.1838885	-40%	64.05
218	4	4	21.74	15.00	152548	769317	160	157	60%	138.1838885	42%	55.05
220	4	4	4.15	20.33	152388	862888	31	201	46%	138.1838885	3%	58.05
220	4	4	0.36	9.75	15448	474788	3	87	2%	153.081282	61%	60.473
84	6	6	21.74	13.14	1789141	1504387	343	308	81%	36.7453843	-220%	23.882
217	4	4	4.15	9.88	151388	481588	31	58	-5%	138.1838885	33%	55.05
218	4	4	21.74	4.00	154848	238787	160	49	39%	138.1838885	297%	55.05
218	4	4	4.15	7.43	157388	381844	31	74	15%	138.1838885	114%	55.05
218	4	4					148	148				57.888

Solid values are taken from the Characterization Data Set #1

1500

METHOD 3 TEST ON CHARACTERIZATION DATA SET #1			
WELL	FLOW (cc/min)	LITHOLOGY	% ERROR
		EST C	
13	172 IN	184.25	-5%
19	79 IN	184.25	105%
24	420 IN	184.25	-150%
25	180 IN	184.25	-1%
217	67 IN	184.25	145%
218L	85 R/P	82.125	-16%
218U	175 IN	184.25	-7%
218L	71 R/P	82.125	18%
218U	83 IN	184.25	96%
Ave	R/P	83	
	IN	186	
RATIO	2		
CHARACTERIZATION DATA SET #1 ERROR ANALYSIS			
WELL	METHOD	METHOD	METHOD
	1	2	3
13	-18%	-3%	-5%
19	-50%	-4%	100%
24	-60%	-151%	-150%
25	-50%	1%	-1%
217	120%	120%	145%
218L	77%	60%	-16%
218U	50%	-15%	-7%
218L	3%	114%	16%
218U	34%	87%	96%
Ave	17%	19%	20%
STD. DE	0.05543	0.8700917	0.8900225

1900

METHOD 3 TEST ON CHARACTERIZATION DATA SET #2			
WELL	FLOW (cc/hr)	LITHOLOGY	% ERROR
01	81 Rep	8L SB	8%
02	30 IN	138.300877	265%
216L	23 Rep	8L SB	316%
216R	103 Rep	8L SB	-8%
218A	194 IN	138.300877	-40%
220L	85 IN	138.300877	41%
220R	133 Rep	8L SB	-41%
03	95 IN	138.300877	46%
04	180 IN	138.300877	-37%
217	103 IN	138.300877	34%
218L	38 Rep	8L SB	173%
218R	85 IN	138.300877	115%
AVE	Rep	77.4	144%
	IN	112	
SAF70	1.4000		
CHARACTERIZATION DATA SET #2 ERROR ANALYSIS			
WELL	METHOD 1	METHOD 2	METHOD 3
01	10%	35%	5%
02	12%	27%	267%
216L	35%	30%	316%
216R	8%	35%	-8%
218A	2%	40%	38%
220L	1%	3%	-41%
220R	4%	2%	46%
03	2%	61%	46%
04	61%	-220%	-37%
217	-6%	35%	34%
218L	38%	287%	173%
218R	15%	114%	115%
AVE	26%	57%	71%
STD. DE	0.2813	1.33823821	1.18038081

ATTACHMENT 2

1900

METHOD 1 CHARACTERIZATION DATA SET #2 (USING ADJUSTED K VALUES FOR REPEATED WELLS IN CHARACTERIZATION DATA SET #1 AND SIMILAR K VALUES FOR WELLS SCREENED AT SIMILAR DEPTHS) SYSTEM FLOW RATE = 1448 acfm										
WELL	DIAM (in)	SCREEN LENGTH (ft)	JAR K (mD-ft)	JAR K ADJ	Pw (in. water)	FACTOR	FACTOR ADJ	Q ESTIMATED	Q ADJ	% ERROR
6L	6	30	21.74	4.74	65	1667700	551870	459	320	280%
6U	4	25	4.18	2.35	64	274896	213748	84	127	225%
216L	4	19	21.74	4.74	75	403327	103918	96	82	186%
216U	4	16	21.74	4.74	86	623028	144853	128	87	-18%
218U	4	16	4.98	8.97	74	117158	282868	28	178	-12%
220L	4	15	21.74	4.74	81	621178	155583	135	83	-6%
220U	4	15	4.18	2.28	78	113817	78658	28	47	-185%
82	8	19	8.38	7.24	71	13821	283357	3	174	83%
88	6	30	21.74	2.38	75	1288712	168977	314	113	-6%
217	4	16	4.18	3.73	83	932864	87887	25	82	-69%
219L	4	16	21.74	3.31	70	872829	148792	188	87	-14%
219U	4	16	4.18	8.97	78	113817	178451	28	188	578
					683			1448	1448	

ATTACHMENT 3

**Appendix A – 200-ZP-2 Flow
Rate Estimation Methodology**

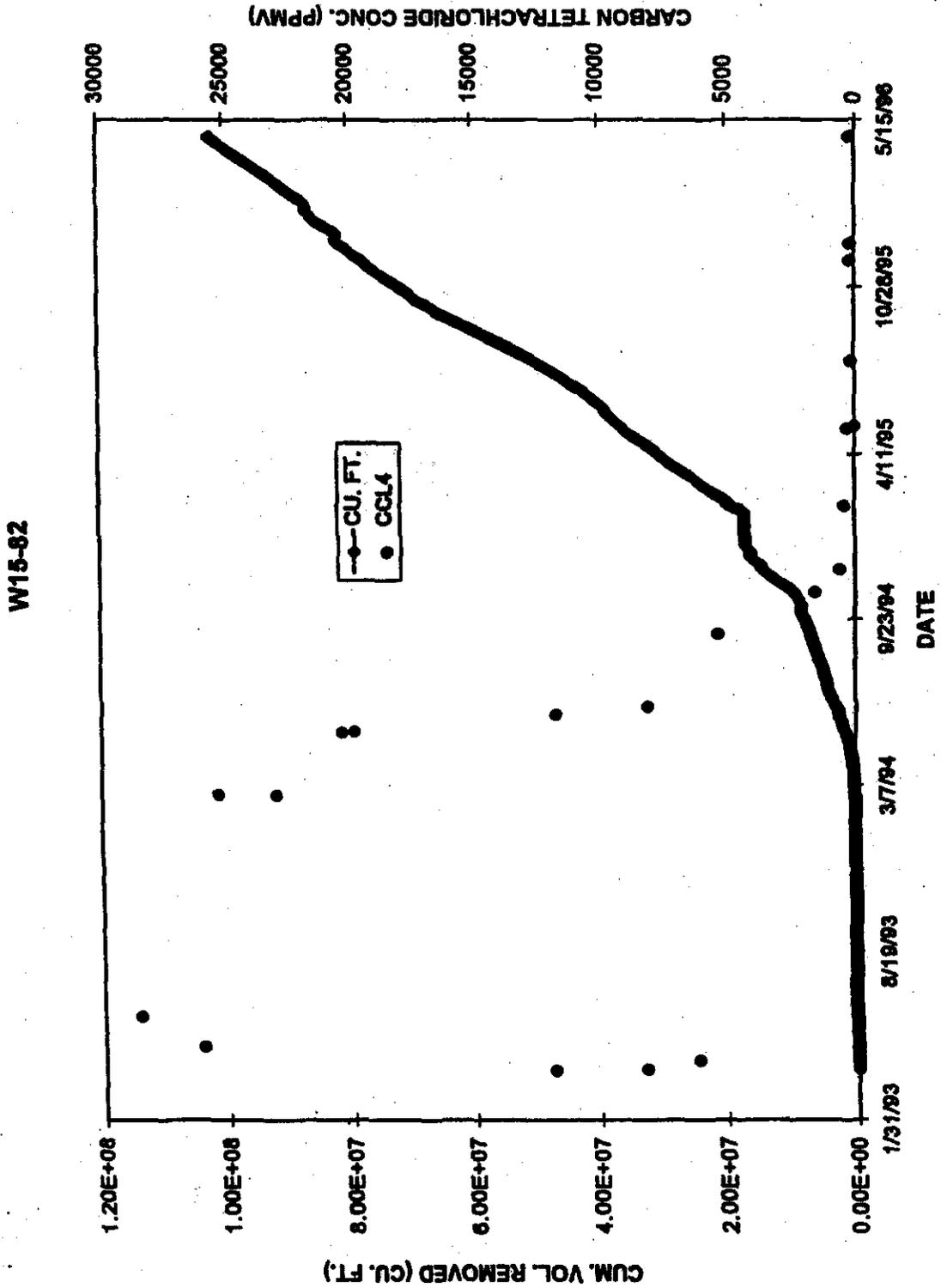
BHI-00720

Rev. 6

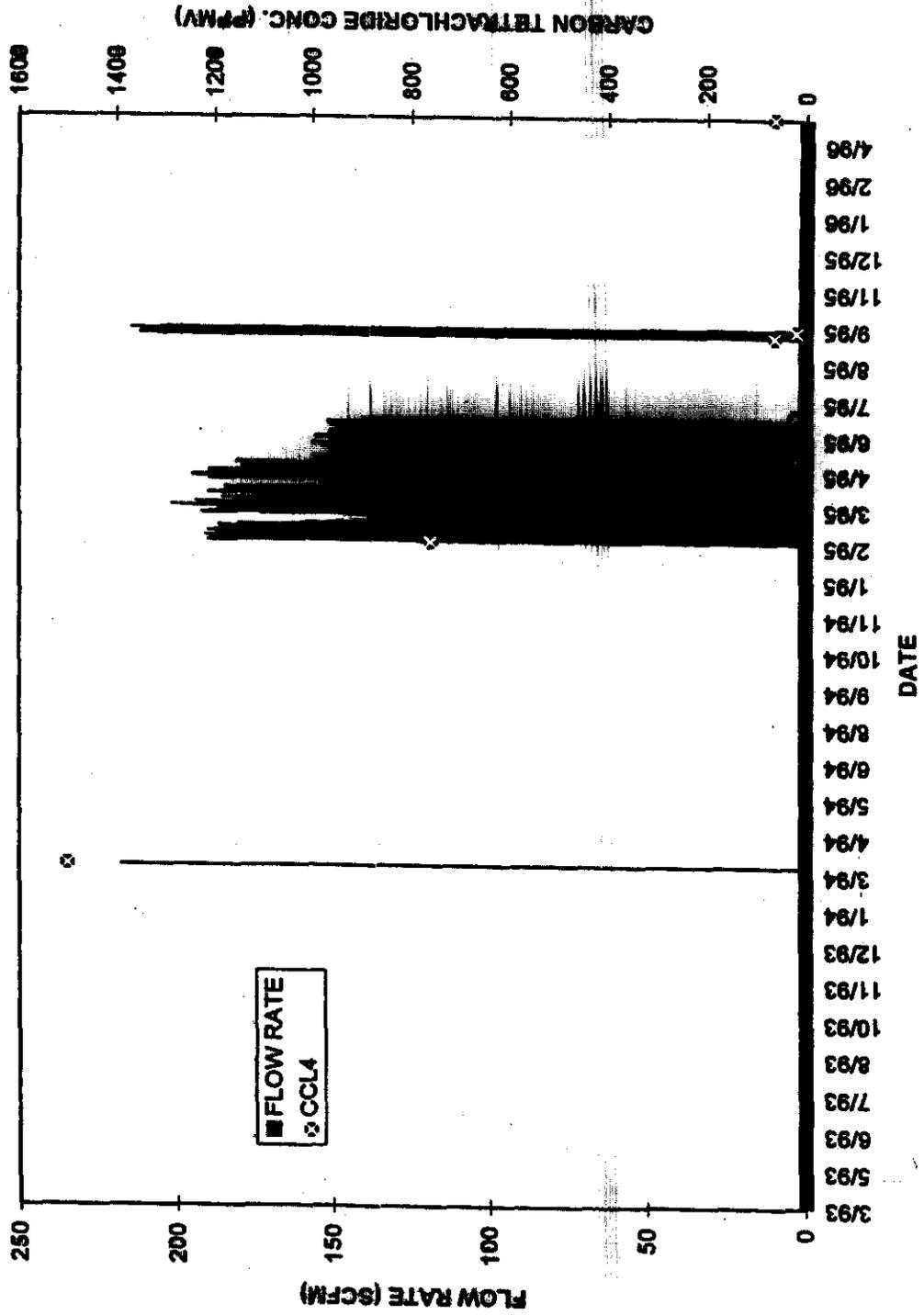
CUMULATIVE VOLUME REMOVED (IN CUBIC FT.)										
Z-1A	1.42E+08 CU.FT.REMOVED FROM 2/25/92 TO 4/24/96									
WELLS	W18-150L	W18-150M	W18-150U	W18-175	W18-185L	W18-189M	W18-189U	W18-07	W18-10L	W18-10U
CU.FT.	7.46E+06	1.02E+06	1.02E+06	1.14E+07	2.26E+06	1.06E+06	1.77E+07	5.61E+06	1.26E+07	1.52E+07
	W18-171U	W18-165	W18-166	W18-252L	W18-252U	W18-249	W18-246L	W18-246U	W18-6L	W18-6U
	1.04E+07	3.70E+07	8.56E+06	2.11E+06	7.40E+06	3.50E+07	1.82E+06	2.36E+06	2.84E+07	7.34E+06
Z-9	8.15E+06 CU.FT.REMOVED FROM 3/31/93 TO 4/24/96									
WELLS	W15-82	W15-84	W15-85	W15-85	W15-217	W15-223	W15-216L	W15-216U	W15-218L	W15-219U
CU.FT.	1.02E+06	7.09E+07	5.12E+07	8.60E+06	9.93E+07	3.05E+07	2.04E+07	6.50E+04	6.89E+07	6.90E+07
Z-18	2.91E+06 CU.FT.REMOVED FROM 6/30/94 TO 4/24/96									
WELLS	W18-10L	W18-10U	W18-11L	W18-12	W18-246L	W18-246U	W18-249	W18-252L	W18-252U	W18-152
CU.FT.	6.22E+07	2.34E+07	7.36E+06	2.42E+07	2.91E+07	1.06E+07	1.82E+07	5.38E+07	1.92E+07	2.24E+07

CUMULATIVE VOLUME REMOVED (IN CUBIC FT.)										
Z-1A										
WELLS	W18-163L	W18-163M	W18-163U	W18-159	W18-169	W18-67L	W18-67M	W18-67U	W18-171L	W18-171M
CU.FT.	8.17E+06	3.19E+05	4.55E+05	2.09E+07	2.80E+07	8.07E+05	5.65E+06	8.87E+05	5.27E+06	9.24E+06
	W18-7	W18-174	W18-167	W18-69						
	2.09E+06	6.31E+07	2.66E+07	1.34E+06						
Z-9										
WELLS	W15-220L	W15-220U	W15-218L	W15-218U	W15-8	W15-9	W15-9L	W15-9U	W15-88	W15-8L
CU.FT.	3.06E+07	3.08E+07	6.51E+07	8.66E+07	0.00E+00	1.26E+04	8.42E+06	1.36E+07	9.97E+06	3.09E+07
Z-18										
WELLS	W18-93	W18-94	W18-95	W18-97	W18-98	W18-99				
CU.FT.	1.36E+04	7.55E+04	1.45E+07	7.15E+03	6.70E+04	5.53E+06				

ATTACHMENT 4



W15-223



APPENDIX B
SOIL VAPOR EXTRACTION WELL CHARACTERIZATION DATA

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
05/02/1994	299-W18-6L	22.2	10.5	304.0	28.9	0.0	4.0	0.0
06/20/1994	299-W18-6L	21.4	11.0	525.0	52.2	0.0	7.0	0.0
11/22/1994	299-W18-6L	26.7	9.7	199.0	17.5	0.0	0.0	0.0
02/07/1995	299-W18-6L	24.9	11.8	161.0	17.2	0.0	1.0	0.0
09/06/1995	299-W18-6L	5.7	1.2	73.5	0.8	0.0	1.3	0.0
05/09/1996	299-W18-6L	5.2	0.9	54.4	0.4	0.0	0.0	0.0
05/14/1996	299-W18-6L	11.2	2.5	30.0	0.7	0.0	0.0	0.0
09/18/1996	299-W18-6L	3.2	1.4	19.6	0.3	2.2	0.0	0.0
10/29/1996	299-W18-6L	3.5	2.4	15.8	0.3	0.0	0.0	0.0
07/21/1997	299-W18-6L	1.5	0.5	26.8	0.1	3.7	0.0	0.0
07/24/1997	299-W18-6L	2.0	0.5	24.4	0.1	2.9	0.0	0.0
07/28/1997	299-W18-6L	1.9	0.4	30.9	0.1	3.8	0.0	0.0
07/31/1997	299-W18-6L	2.1	0.5	8.6	0.0	2.0	0.0	0.0
03/30/1998	299-W18-6L	6.0	0.0	25.6	0.0	0.6	0.0	0.0
04/08/1998	299-W18-6L	0.8	0.0	0.1	0.0	0.4	0.0	0.0
04/10/1998	299-W18-6L	0.0	0.0	33.4	0.0	1.1	0.0	0.0
04/16/1998	299-W18-6L	1.5	0.1	0.1	0.0	0.6	0.0	0.0
04/29/1998	299-W18-6L(f)	21.7	2.9	17.6	0.5	0.9	0.0	1.2
04/30/1998	299-W18-6L	0.6	0.0	33.2	0.0	1.4	0.0	0.0
05/21/1998	299-W18-6L	11.0	2.7	28.1	0.7	2.9	0.0	0.0
05/29/1998	299-W18-6L	11.2	2.9	29.1	0.8	1.6	0.0	0.0
06/19/1998	299-W18-6L	2.1	0.8	13.5	0.1	1.6	0.0	0.0
09/06/1995	299-W18-6U	4.5	2.4	10.1	0.2	0.0	0.3	0.0
05/09/1996	299-W18-6U	4.5	2.3	15.1	0.3	0.0	0.0	0.0
09/18/1996	299-W18-6U	2.2	2.4	6.9	0.1	1.1	0.0	0.0
10/29/1996	299-W18-6U	3.2	2.5	1.2	0.0	1.1	0.0	0.0
09/24/1997	299-W18-6U	2.1	1.2	6.8	0.1	2.3	0.0	0.0
05/25/2001	299-W18-6U	1.0	0.8	32.3	0.2	0.5	1.0	0.3
05/30/2001	299-W18-6U	1.2	0.7	23.4	0.1	0.2	0.0	0.1
06/06/2001	299-W18-6U	1.8	1.1	16.2	0.2	0.1	0.0	0.1
05/06/1994	299-W18-7	23.9	6.1	209.0	11.6	0.0	3.0	0.0
06/21/1994	299-W18-7	21.2	6.3	388.0	22.1	0.0	6.0	0.0
11/22/1994	299-W18-7	24.4	5.1	197.0	9.2	0.0	0.0	0.0
02/01/1995	299-W18-7	26.2	7.8	192.0	13.6	0.0	4.0	0.0
03/28/1995	299-W18-7(e)	23.2	12.4	160.0	18.0	0.0	29.0	3.0
05/31/1995	299-W18-7(e)	23.9	11.9	106.0	11.4	1.0	2.0	0.0
08/04/1995	299-W18-7(e)	5.0	7.1	75.6	4.9	0.5	2.5	0.4
11/28/1995	299-W18-7(e)	4.7	6.5	34.2	2.0	0.9	0.1	0.0
12/20/1995	299-W18-7(e)	3.5	--	33.0	--	0.7	1.4	--
05/02/1996	299-W18-7(e)	5.0	6.6	31.0	1.9	0.0	0.0	0.0

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
05/14/1996	299-W18-7(e)	6.5	9.9	43.2	3.9	0.0	0.0	0.0
07/17/1996	299-W18-7(e)	2.5	5.4	16.5	0.8	2.6	0.0	0.0
09/16/1996	299-W18-7(e)	3.7	5.9	17.7	1.0	1.7	0.0	0.0
10/29/1996	299-W18-7(e)	3.0	2.8	0.0	0.0	0.0	0.0	0.0
07/21/1997	299-W18-7(e)	2.5	2.8	30.8	0.8	6.1	0.0	0.0
07/24/1997	299-W18-7(e)	2.0	3.5	3.9	0.1	3.3	0.0	0.0
07/28/1997	299-W18-7(e)	2.0	3.5	9.8	0.3	2.7	0.0	0.0
07/31/1997	299-W18-7(e)	2.5	3.6	26.6	0.9	3.2	0.0	0.0
03/30/1998	299-W18-7(e)	1.2	0.7	14.8	0.1	0.7	0.1	0.0
04/09/1998	299-W18-7(e)	0.6	0.7	0.9	0.0	0.0	0.1	0.0
04/10/1998	299-W18-7(e)	0.4	1.7	26.8	0.4	1.2	0.0	0.0
04/16/1998	299-W18-7(e)	1.0	0.0	0.0	0.0	1.1	0.0	0.0
04/30/1998	299-W18-7(e)	0.5	0.0	0.3	0.0	0.1	0.1	0.0
06/05/1998	299-W18-7(e)	2.0	3.5	24.6	0.8	2.1	0.0	0.0
06/11/1998	299-W18-7(e)	1.8	3.1	25.7	0.7	2.6	0.0	0.0
05/31/2001	299-W18-7(e)	1.4	2.4	38.5	0.8	1.1	0.8	0.3
06/06/2001	299-W18-7(e)	2.5	2.4	36.2	0.8	0.6	0.7	0.3
06/13/2001	299-W18-7(e)	1.1	1.1	37.4	0.4	0.8	1.0	0.3
06/20/2001	299-W18-7(e)	2.1	2.4	36.5	0.8	0.8	0.6	0.2
06/27/2001	299-W18-7(e)	2.0	2.4	36.1	0.8	0.8	1.1	0.2
07/03/2001	299-W18-7(e)	1.8	2.4	36.7	0.8	0.6	0.7	0.2
07/11/2001	299-W18-7(e)	2.1	2.4	35.8	0.8	0.6	0.6	0.3
02/03/1993	299-W18-87	24.9	2.3	365.0	7.5	--	--	--
06/02/1993	299-W18-87	32.4	3.4	75.0	2.3	--	--	--
11/16/1993	299-W18-87	31.6	2.2	55.0	1.1	0.1	0.3	0.0
03/03/1995	299-W18-87	offline	--	--	--	--	--	--
07/26/1994	299-W18-89	24.2	10.4	496.0	46.7	0.0	6.0	0.0
11/22/1994	299-W18-89	25.4	9.9	123.0	11.1	0.0	0.0	0.0
08/04/1995	299-W18-89	3.7	7.3	92.0	6.1	0.2	3.6	0.7
11/16/1995	299-W18-89	5.0	8.2	34.0	2.5	0.5	0.0	0.0
12/20/1995	299-W18-89	4.2	--	32.0	--	0.3	1.3	--
05/01/1996	299-W18-89	4.5	6.9	28.1	1.8	0.0	0.0	0.0
07/17/1996	299-W18-89	2.5	4.9	30.6	1.4	1.5	0.0	0.0
09/18/1996	299-W18-89	4.5	6.2	14.3	0.8	1.7	0.0	0.0
10/29/1996	299-W18-89	3.2	3.4	20.8	0.6	0.0	0.0	1.1
09/24/1997	299-W18-89	1.9	3.1	15.5	0.4	3.9	0.0	0.0
03/30/1998	299-W18-89	1.2	0.4	28.1	0.1	0.7	0.2	0.0
04/08/1998	299-W18-89	0.6	0.5	0.8	0.0	0.2	0.1	0.0
04/10/1998	299-W18-89	0.5	1.6	25.9	0.4	0.7	1.0	0.0
04/16/1998	299-W18-89	0.9	2.0	5.9	0.1	1.1	0.0	0.0

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
04/18/1994	299-W18-158L	29.9	1.4	192.0	2.5	0.9	--	0.5
02/01/1995	299-W18-158L	26.2	0.4	45.0	0.2	2.0	3.0	0.0
08/08/1995	299-W18-158L	10.0	0.0	--	--	--	--	--
07/30/1996	299-W18-158L	3.7	1.2	76.5	0.8	0.0	9.4	0.0
09/16/1996	299-W18-158L	8.2	0.0	0.2	0.0	0.4	0.0	0.0
10/29/1996	299-W18-158L	3.5	0.0	77.6	0.0	0.0	0.0	6.5
09/24/1997	299-W18-158L	3.7	0.0	0.0	0.0	2.4	0.0	0.0
07/27/1999	299-W18-158L	6.5	0.3	1.1	0.0	0.0	2.8	0.7
07/28/1999	299-W18-158L	6.0	0.3	0.1	0.0	1.3	4.7	1.5
04/04/2001	299-W18-158L	3.2	0.2	0.3	0.0	0.1	0.8	0.1
04/06/2001	299-W18-158L	3.5	0.2	1.0	0.0	0.0	0.0	0.0
04/11/2001	299-W18-158L	3.5	0.2	1.8	0.0	0.0	0.0	0.1
06/01/1993	299-W18-158M	32.6	1.1	91.0	0.9	--	--	--
04/18/1994	299-W18-158M(c)	31.1	0.8	106.0	0.7	0.6	--	0.8
06/01/1993	299-W18-158U(c)	7.7	1.8	2.0	0.0	--	--	--
04/18/1994	299-W18-158U(c)	30.9	2.2	38.0	0.8	0.4	--	0.5
08/08/1995	299-W18-158U(e)	7.5	1.8	248.0	4.0	0.0	10.8	0.0
11/29/1995	299-W18-158U(e)	4.7	0.4	127.0	0.5	8.0	18.0	1.0
12/22/1995	299-W18-158U(e)	3.7	--	124.0	--	0.0	12.0	--
06/03/1996	299-W18-158U(e)	5.0	1.9	99.8	1.7	0.0	7.8	0.0
09/16/1996	299-W18-158U(e)	6.2	2.8	2.5	0.1	0.6	0.2	0.0
10/29/1996	299-W18-158U(e)	2.5	1.4	0.0	0.0	1.3	0.0	0.0
09/24/1997	299-W18-158U(e)	3.0	0.9	0.0	0.0	3.7	0.0	0.0
09/22/1992	299-W18-159(a)	24.9	1.6	580.0	8.5	--	--	--
06/01/1993	299-W18-159	32.9	2.0	307.0	5.7	--	--	--
04/15/1994	299-W18-159	31.6	1.1	243.0	2.4	0.7	--	0.4
06/20/1994	299-W18-159	24.2	1.1	238.0	2.4	--	--	--
11/22/1994	299-W18-159	--	0.0	--	--	--	--	--
02/01/1995	299-W18-159	26.2	0.8	150.0	1.1	0.0	7.0	0.0
05/31/1995	299-W18-159(e)	24.9	11.1	77.0	7.7	0.0	3.0	0.0
06/13/1996	299-W18-159(e)	6.2	3.8	9.7	0.3	2.5	1.3	0.0
07/30/1996	299-W18-159(e)	3.0	3.9	8.1	0.3	3.1	0.0	0.0
09/18/1996	299-W18-159(e)	3.7	3.1	5.6	0.2	1.4	1.4	0.0
10/29/1996	299-W18-159(e)	3.5	3.1	11.7	0.3	0.0	0.0	2.1
09/24/1997	299-W18-159(e)	2.5	0.8	3.1	0.0	3.6	0.0	0.0
05/31/2001	299-W18-159(e)	1.3	1.9	22.7	0.4	0.3	0.4	0.2
06/06/2001	299-W18-159(e)	2.7	2.4	20.8	0.5	0.2	0.3	0.2
06/13/2001	299-W18-159(e)	1.0	1.3	21.1	0.3	0.1	0.0	0.2
06/20/2001	299-W18-159(e)	2.0	2.2	20.9	0.4	0.2	0.0	0.1
06/27/2001	299-W18-159(e)	2.0	2.1	23.4	0.4	0.3	0.1	0.1

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
04/30/1998	299-W18-89	0.5	1.9	28.5	0.5	1.3	0.0	0.0
05/08/1998	299-W18-89	0.5	1.0	27.4	0.2	3.1	0.0	0.0
05/13/1998	299-W18-89	0.5	1.0	27.7	0.3	1.7	0.0	0.0
06/19/1998	299-W18-89	1.6	4.2	23.6	0.9	2.1	0.0	0.0
07/29/1999	299-W18-89	2.0	4.5	41.6	1.7	1.7	0.0	0.0
08/06/1999	299-W18-89	1.9	4.9	27.9	1.2	1.1	2.7	0.2
08/13/1999	299-W18-89	1.9	5.0	23.9	1.1	0.7	2.0	0.4
08/19/1999	299-W18-89	1.8	4.4	27.2	1.1	0.8	2.9	0.6
08/26/1999	299-W18-89	2.0	4.7	25.2	1.1	0.7	2.6	0.5
09/03/1999	299-W18-89	2.2	4.8	30.6	1.3	0.7	0.2	0.1
09/08/1999	299-W18-89	2.1	4.5	21.1	0.9	0.5	0.5	0.1
09/13/1999	299-W18-89	2.0	5.0	20.4	0.9	0.7	1.0	0.2
04/19/2001	299-W18-89	2.3	4.2	46.0	1.8	0.3	0.1	0.2
04/26/2001	299-W18-89	2.2	4.4	37.2	1.5	0.3	0.1	0.2
05/02/2001	299-W18-89	2.7	4.5	32.5	1.0	0.3	0.0	0.1
05/09/2001	299-W18-89	1.1	2.5	32.1	0.7	0.2	0.5	0.2
05/16/2001	299-W18-89	1.6	2.4	23.7	0.5	0.1	1.0	0.2
05/23/2001	299-W18-89	1.0	2.6	32.4	0.8	0.5	0.2	0.3
05/30/2001	299-W18-89	1.1	2.2	21.2	0.4	0.2	0.0	0.2
06/06/2001	299-W18-89	1.5	2.6	27.5	0.7	0.2	0.0	0.2
06/13/2001	299-W18-89	0.7	1.7	23.7	0.4	0.3	0.0	0.1
06/20/2001	299-W18-89	1.5	3.3	21.5	0.6	0.1	0.0	0.2
06/27/2001	299-W18-89	1.3	2.5	21.8	0.5	0.2	0.1	0.2
07/03/2001	299-W18-89	1.1	2.7	21.2	0.5	0.3	0.0	0.2
07/11/2001	299-W18-89	1.3	2.5	21.5	0.5	0.2	0.0	0.1
06/01/1993	299-W18-150L	32.9	2.4	219.0	4.7	--	--	--
11/15/1993	299-W18-150L	32.1	1.4	243.0	3.1	0.1	2.7	1.1
11/15/1993	299-W18-150L(b)	32.1	1.4	--	--	0.6	6.7	--
04/15/1994	299-W18-150L	31.6	1.5	150.0	2.9	0.4	--	0.2
11/22/1994	299-W18-150L	25.9	1.1	82.0	0.8	0.0	0.0	0.0
02/01/1995	299-W18-150L	24.4	1.2	10.0	0.1	0.0	1.0	0.0
06/01/1993	299-W18-150M	32.9	0.8	157.0	1.1	--	--	--
04/18/1994	299-W18-150M	28.9	0.5	180.0	0.8	0.0	--	0.9
06/01/1993	299-W18-150U	32.6	0.9	35.0	0.9	--	--	--
04/18/1994	299-W18-150U	30.1	0.6	181.0	0.9	0.0	--	1.3
05/25/1995	299-W18-150	alpha	--	--	--	--	--	--
04/30/1992	299-W18-158L(a)	27.4	1.7	270.0	4.2	--	--	--
09/22/1992	299-W18-158L(a)	22.7	1.3	500.0	5.8	--	--	--
06/01/1993	299-W18-158L	32.6	1.1	144.0	1.5	--	--	--
11/15/1993	299-W18-158L	30.9	0.7	394.0	2.6	3.8	3.6	0.8

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
07/03/2001	299-W18-159(e)	1.8	2.1	20.0	0.4	0.2	0.0	0.2
07/11/2001	299-W18-159(e)	2.0	2.1	22.1	0.4	0.2	0.0	0.1
09/22/1992	299-W18-163L(a)	19.9	0.7	140.0	0.9	--	--	--
06/01/1993	299-W18-163L	30.9	0.2	5.0	0.0	--	--	--
11/15/1993	299-W18-163L	31.9	0.0	--	--	--	--	--
04/18/1994	299-W18-163L	29.9	0.0	--	--	--	--	--
06/02/1993	299-W18-163M	32.4	0.3	2.0	0.0	--	--	--
04/18/1994	299-W18-163M	29.1	0.0	--	--	--	--	--
08/08/1995	299-W18-163L(e)	7.5	1.8	80.6	1.3	2.0	2.5	0.0
05/10/1996	299-W18-163L(e)	3.0	0.5	31.1	0.2	0.0	0.0	0.0
10/29/1996	299-W18-163L(e)	2.0	0.5	1.7	0.0	0.0	0.0	0.0
09/24/1997	299-W18-163L(e)	1.7	0.0	5.2	0.0	2.6	0.0	0.0
05/04/2001	299-W18-163L(e)	0.7	0.2	16.3	0.0	0.4	0.0	0.1
05/09/2001	299-W18-163L(e)	1.0	0.3	16.0	0.0	0.0	0.1	0.1
05/16/2001	299-W18-163L(e)	1.3	0.2	11.4	0.0	0.0	0.2	0.1
05/23/2001	299-W18-163L(e)	0.8	0.3	18.4	0.0	0.2	0.2	0.2
06/02/1993	299-W18-163U	35.1	0.3	2.0	0.0	--	--	--
04/18/1994	299-W18-163U	29.6	0.0	--	--	--	--	--
08/08/1995	299-W18-163U(e)	6.2	4.0	72.1	2.6	0.1	9.1	0.0
06/13/1996	299-W18-163U(e)	5.0	2.1	17.7	0.3	0.0	13.5	0.0
07/30/1996	299-W18-163U(e)	1.7	2.1	27.5	0.5	0.0	13.9	0.0
10/29/1996	299-W18-163U(e)	1.7	2.4	5.6	0.1	0.0	1.3	8.7
09/24/1997	299-W18-163U(e)	1.5	1.0	14.8	0.1	1.5	2.4	0.0
05/25/2001	299-W18-163U(e)	0.7	0.5	23.2	0.1	0.3	2.3	0.4
05/30/2001	299-W18-163U(e)	0.8	0.7	29.3	0.2	0.6	1.6	0.1
06/06/2001	299-W18-163U(e)	1.0	0.8	24.6	0.2	0.4	1.1	0.2
06/13/2001	299-W18-163U(e)	0.5	0.4	26.8	0.1	0.5	0.0	0.1
06/20/2001	299-W18-163U(e)	1.0	0.9	33.4	0.3	0.5	1.3	0.2
06/27/2001	299-W18-163U(e)	1.1	0.9	20.0	0.2	0.3	1.3	0.1
07/03/2001	299-W18-163U(e)	1.0	0.8	30.4	0.2	0.2	1.6	0.3
07/11/2001	299-W18-163U(e)	1.1	1.0	38.6	0.3	0.4	2.0	0.2
04/20/1994	299-W18-165	30.4	0.1	140.0	0.1	--	--	--
05/31/1995	299-W18-165(e)	24.9	6.7	150.0	9.1	0.0	5.0	0.0
08/07/1995	299-W18-165(e)	14.9	6.2	91.9	5.2	2.2	4.0	0.0
11/29/1995	299-W18-165(e)	5.0	1.4	29.4	0.4	2.0	4.0	0.4
12/22/1995	299-W18-165(e)	3.7	--	25.0	--	0.0	0.0	--
06/03/1996	299-W18-165(e)	6.7	3.8	10.0	0.3	0.0	0.5	0.1
07/30/1996	299-W18-165(e)	6.2	2.2	8.9	0.2	1.8	0.0	0.0
09/16/1996	299-W18-165(e)	5.5	3.3	16.0	0.5	1.6	0.0	0.0
10/29/1996	299-W18-165(e)	3.0	2.7	29.9	0.7	0.0	0.0	1.9

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
09/24/1997	299-W18-165(e)	3.5	1.9	15.5	0.3	2.1	0.0	0.0
04/01/1998	299-W18-165(e)	0.3	0.0	5.8	0.0	1.0	0.0	0.0
04/09/1998	299-W18-165(e)	0.6	0.0	36.7	0.0	0.5	1.8	0.0
04/10/1998	299-W18-165(e)	0.6	0.5	33.6	0.2	1.6	1.0	0.0
04/30/1998	299-W18-165(e)	0.5	0.4	42.0	0.2	2.9	0.0	0.0
05/08/1998	299-W18-165(e)	0.3	0.0	2.5	0.0	0.4	0.0	0.0
05/13/1998	299-W18-165(e)	0.4	0.0	1.4	0.0	0.9	0.0	0.0
06/05/1998	299-W18-165(e)	2.5	1.7	40.3	0.6	3.9	0.0	0.0
06/11/1998	299-W18-165(e)	2.4	1.7	43.2	0.7	3.2	0.0	0.0
06/19/1998	299-W18-165(e)	7.0	3.3	22.3	0.7	2.8	0.0	0.0
06/30/1999	299-W18-165(e)	7.5	3.7	16.4	0.5	0.8	4.2	0.5
07/08/1999	299-W18-165(e)	8.0	3.6	50.2	1.6	1.0	2.5	0.2
07/14/1999	299-W18-165(e)	8.2	3.7	49.4	1.6	2.8	0.0	0.0
07/23/1999	299-W18-165(e)	8.0	3.7	45.3	1.5	1.2	2.7	0.3
07/28/1999	299-W18-165(e)	6.0	3.5	40.6	1.3	1.3	2.4	0.9
08/06/1999	299-W18-165(e)	4.0	2.8	46.3	1.3	0.7	4.3	0.5
08/13/1999	299-W18-165(e)	4.2	2.6	33.4	0.8	0.7	2.4	0.3
08/19/1999	299-W18-165(e)	3.5	2.7	39.7	1.0	0.6	4.1	0.6
08/26/1999	299-W18-165(e)	4.0	2.5	35.8	0.8	0.7	2.8	0.5
09/03/1999	299-W18-165(e)	4.7	2.9	33.8	0.9	0.4	1.0	0.2
09/08/1999	299-W18-165(e)	4.7	2.8	24.8	0.6	0.9	0.9	0.1
09/13/1999	299-W18-165(e)	4.0	2.8	28.3	0.7	0.7	1.1	0.3
09/22/1999	299-W18-165(e)	4.0	2.7	26.6	0.6	0.7	0.9	0.6
09/27/1999	299-W18-165(e)	3.0	2.1	17.5	0.3	0.3	0.3	0.3
04/04/2001	299-W18-165(e)	3.5	1.8	40.7	0.7	1.4	1.3	1.6
04/11/2001	299-W18-165(e)	3.7	2.0	41.6	0.7	1.4	0.0	0.2
04/19/2001	299-W18-165(e)	2.2	1.7	38.2	0.6	6.1	0.9	9.7
04/26/2001	299-W18-165(e)	2.0	1.5	55.8	0.7	1.1	0.6	0.2
05/02/2001	299-W18-165(e)	2.2	1.0	35.4	0.3	0.4	0.0	0.1
05/09/2001	299-W18-165(e)	1.8	1.0	77.8	0.7	1.1	1.0	0.2
05/16/2001	299-W18-165(e)	2.3	1.1	80.3	0.8	1.0	0.9	0.3
05/23/2001	299-W18-165(e)	1.6	1.0	71.5	0.6	1.3	1.0	0.4
05/30/2001	299-W18-165(e)	2.1	1.0	63.7	0.6	0.9	0.8	0.3
06/06/2001	299-W18-165(e)	2.7	1.4	51.1	0.7	0.9	0.4	0.3
06/13/2001	299-W18-165(e)	1.2	0.7	47.2	0.3	0.6	0.0	0.1
06/20/2001	299-W18-165(e)	3.2	1.4	43.1	0.5	0.7	0.0	0.2
06/27/2001	299-W18-165(e)	3.2	1.2	44.0	0.5	0.9	0.3	0.2
07/03/2001	299-W18-165(e)	3.0	1.3	38.4	0.5	0.6	0.1	0.2
07/11/2001	299-W18-165(e)	3.0	1.3	36.0	0.4	0.4	0.0	0.1
06/01/1993	299-W18-166	32.4	0.5	82.0	0.3	--	--	--

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
11/16/1993	299-W18-166	31.9	0.1	70.0	0.1	0.3	0.7	0.0
04/18/1994	299-W18-166	29.9	0.1	148.0	0.2	0.7	--	0.8
05/31/1995	299-W18-166(e)	25.7	6.9	37.0	2.3	1.0	1.0	0.0
08/07/1995	299-W18-166(e)	16.2	5.7	66.6	3.5	0.3	4.0	0.0
06/13/1996	299-W18-166(e)	6.7	2.1	17.4	0.3	1.5	0.0	0.0
07/30/1996	299-W18-166(e)	6.2	1.9	9.7	0.2	0.0	0.0	0.0
09/18/1996	299-W18-166(e)	8.7	4.7	7.0	0.3	1.1	1.7	0.0
10/29/1996	299-W18-166(e)	2.7	2.1	8.4	0.2	0.0	0.0	0.0
09/24/1997	299-W18-166(e)	5.0	2.5	15.9	0.4	4.4	0.0	0.0
06/30/1999	299-W18-166(e)	8.0	3.5	42.3	1.3	0.1	6.6	0.0
07/08/1999	299-W18-166(e)	8.7	3.7	26.0	0.9	0.0	3.0	0.3
07/14/1999	299-W18-166(e)	8.7	3.7	25.9	0.9	1.6	0.6	0.0
07/23/1999	299-W18-166(e)	8.7	3.3	19.8	0.6	1.5	1.5	0.1
09/21/1999	299-W18-166(e)	4.2	2.4	9.3	0.2	0.3	1.5	0.2
09/27/1999	299-W18-166(e)	3.5	1.8	8.0	0.1	0.5	0.4	0.3
04/04/2001	299-W18-166(e)	3.5	1.6	12.4	0.2	0.0	0.1	0.7
04/11/2001	299-W18-166(e)	4.0	1.7	24.4	0.4	0.2	0.5	0.2
04/19/2001	299-W18-166(e)	2.4	1.3	20.3	0.2	0.1	0.4	0.2
04/26/2001	299-W18-166(e)	2.5	1.3	18.0	0.2	0.1	0.3	0.1
05/02/2001	299-W18-166(e)	2.0	0.6	14.3	0.1	0.0	0.0	0.0
05/09/2001	299-W18-166(e)	1.9	0.8	15.2	0.1	0.0	0.0	0.1
05/16/2001	299-W18-166(e)	2.5	0.8	12.5	0.1	0.0	0.1	0.1
05/23/2001	299-W18-166(e)	1.7	0.8	14.7	0.1	0.1	0.0	0.3
04/20/1994	299-W18-167	29.9	1.6	180.0	2.7	--	--	--
06/21/1994	299-W18-167	21.7	0.6	191.0	1.0	0.0	3.0	0.0
03/28/1995	299-W18-167(e)	20.7	12.9	51.0	5.9	1.0	22.0	3.0
08/08/1995	299-W18-167(e)	2.5	6.4	208.0	12.1	0.8	5.8	0.0
11/29/1995	299-W18-167(e)	3.7	7.1	34.4	2.2	3.4	7.0	0.6
12/22/1995	299-W18-167(e)	3.7	--	27.0	--	0.0	3.0	--
05/10/1996	299-W18-167(e)	3.7	8.2	18.9	1.4	0.0	0.5	0.0
07/30/1996	299-W18-167(e)	2.0	5.4	16.0	0.8	1.2	2.9	0.0
10/29/1996	299-W18-167(e)	3.0	3.5	18.9	0.6	0.0	0.0	1.8
07/21/1997	299-W18-167(e)	1.7	4.8	20.6	0.9	3.6	5.5	1.1
07/24/1997	299-W18-167(e)	2.2	4.8	21.2	0.9	3.4	2.2	0.0
07/28/1997	299-W18-167(e)	2.0	4.9	15.3	0.7	3.5	1.8	0.0
07/31/1997	299-W18-167(e)	2.4	4.7	1.8	0.1	2.7	0.0	0.0
09/24/1997	299-W18-167(e)	2.0	5.0	27.9	1.3	2.7	0.0	0.0
04/01/1998	299-W18-167(e)	0.3	1.0	26.9	0.2	2.8	0.0	0.0
04/09/1998	299-W18-167(e)	0.4	1.2	11.7	0.1	0.3	0.3	0.0
04/10/1998	299-W18-167(e)	0.3	1.3	11.1	0.1	1.0	0.4	0.0

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
04/30/1998	299-W18-167(e)	0.4	1.8	19.6	0.3	2.9	0.0	0.0
05/08/1998	299-W18-167(e)	0.4	0.9	30.4	0.2	1.5	0.0	0.0
05/13/1998	299-W18-167(e)	0.5	0.0	0.0	0.0	1.2	0.0	0.0
06/05/1998	299-W18-167(e)	1.3	4.6	25.1	1.0	2.7	0.0	0.0
06/11/1998	299-W18-167(e)	1.2	4.5	23.9	1.0	2.8	0.0	0.0
07/27/1999	299-W18-167(e)	2.7	9.1	141.0	11.6	0.9	2.9	0.5
07/28/1999	299-W18-167(e)	2.7	9.0	37.5	3.1	0.2	5.9	0.7
08/06/1999	299-W18-167(e)	2.0	6.4	34.9	2.0	0.5	6.2	0.7
08/13/1999	299-W18-167(e)	2.1	6.5	28.7	1.7	0.4	5.0	0.4
08/19/1999	299-W18-167(e)	1.9	6.3	33.8	1.9	0.2	7.0	0.9
08/26/1999	299-W18-167(e)	2.0	6.4	31.0	1.8	0.3	5.0	0.7
09/03/1999	299-W18-167(e)	2.3	6.8	27.2	1.7	0.4	2.4	0.3
09/08/1999	299-W18-167(e)	2.2	6.9	24.5	1.5	0.4	2.3	0.2
09/13/1999	299-W18-167(e)	2.1	6.7	24.4	1.5	0.4	2.6	0.4
09/22/1999	299-W18-167(e)	2.4	7.0	26.3	1.7	0.5	1.7	0.6
09/27/1999	299-W18-167(e)	2.7	8.2	27.4	2.0	0.3	1.6	0.2
04/04/2001	299-W18-167(e)	2.5	7.2	32.6	2.1	0.5	0.6	2.1
04/11/2001	299-W18-167(e)	2.5	7.5	41.5	2.8	0.6	1.4	0.2
04/19/2001	299-W18-167(e)	1.9	4.8	37.7	1.6	0.6	1.7	1.3
04/26/2001	299-W18-167(e)	16.9	4.9	29.1	1.3	0.5	0.8	0.2
05/02/2001	299-W18-167(e)	2.4	5.8	38.2	2.0	0.5	0.1	0.1
05/09/2001	299-W18-167(e)	1.0	2.8	34.4	0.9	0.5	1.0	0.2
05/16/2001	299-W18-167(e)	1.4	2.7	35.7	0.9	0.3	1.0	0.2
05/23/2001	299-W18-167(e)	0.8	2.9	33.7	0.9	0.5	0.9	0.4
05/30/2001	299-W18-167(e)	0.8	2.0	27.7	0.5	0.3	0.0	0.2
06/06/2001	299-W18-167(e)	1.1	2.2	27.1	0.5	0.4	0.3	0.2
06/13/2001	299-W18-167(e)	0.6	2.0	27.4	0.5	0.3	0.0	0.2
06/20/2001	299-W18-167(e)	1.0	2.7	24.0	0.5	0.4	0.0	0.1
06/27/2001	299-W18-167(e)	1.0	2.8	24.4	0.6	0.4	0.0	0.1
07/03/2001	299-W18-167(e)	0.9	2.8	24.3	0.6	0.2	0.0	0.1
07/11/2001	299-W18-167(e)	1.1	2.7	25.9	0.6	0.1	0.0	0.2
10/06/1992	299-W18-168(a)	24.9	0.3	670.0	1.7	--	--	--
06/01/1993	299-W18-168	34.6	0.8	212.0	1.5	--	--	--
11/16/1993	299-W18-168	32.1	0.4	371.0	1.2	3.6	5.0	0.3
11/16/1993	299-W18-168(b)	32.1	0.4	--	--	--	1.5	--
04/18/1994	299-W18-168	29.9	0.4	108.0	0.4	0.0	--	0.6
06/20/1994	299-W18-168	22.2	0.2	--	--	--	--	--
03/30/1995	299-W18-168(e)	25.7	7.2	101.0	6.6	6.0	101.0	5.0
08/09/1995	299-W18-168(e)	6.2	2.2	302.0	6.1	5.1	0.0	0.0
11/29/1995	299-W18-168(e)	4.5	0.4	54.6	0.2	3.6	7.0	0.6

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
12/22/1995	299-W18-168(e)	4.7	--	54.0	--	0.0	2.0	--
05/10/1996	299-W18-168(e)	4.7	0.9	42.3	0.3	0.0	0.0	0.0
10/29/1996	299-W18-168(e)	2.5	0.8	2.8	0.0	1.3	0.0	0.0
09/24/1997	299-W18-168(e)	3.7	1.4	27.2	0.4	2.1	0.0	0.0
04/01/1998	299-W18-168(e)	0.4	0.0	1.3	0.0	0.7	0.0	0.0
04/09/1998	299-W18-168(e)	0.5	0.0	0.3	0.0	0.1	0.0	0.0
04/10/1998	299-W18-168(e)	0.4	0.0	2.4	0.0	1.1	0.0	0.0
04/29/1998	299-W18-168(e)(f)	16.4	4.0	44.1	1.6	2.9	0.0	0.0
04/30/1998	299-W18-168(e)	0.5	0.0	11.9	0.0	0.8	0.0	0.0
05/21/1998	299-W18-168(e)	10.0	4.7	28.1	1.2	2.5	0.0	0.0
05/29/1998	299-W18-168(e)	11.0	5.9	35.1	1.9	2.4	0.0	0.0
06/19/1998	299-W18-168(e)	6.2	3.2	31.2	0.9	2.4	0.0	0.0
06/30/1999	299-W18-168(e)	8.0	3.3	46.1	1.4	0.1	4.1	0.5
07/08/1999	299-W18-168(e)	9.0	3.2	46.7	1.4	0.0	4.9	0.3
07/14/1999	299-W18-168(e)	9.0	3.3	52.0	1.6	1.2	2.8	0.1
07/23/1999	299-W18-168(e)	8.7	3.5	49.2	1.5	0.1	5.4	0.4
07/28/1999	299-W18-168(e)	3.2	0.9	53.5	0.4	1.1	4.0	1.0
08/06/1999	299-W18-168(e)	2.5	0.4	55.8	0.2	0.5	4.1	0.4
08/13/1999	299-W18-168(e)	2.5	0.4	58.6	0.2	0.0	2.8	0.2
08/19/1999	299-W18-168(e)	2.3	0.3	58.5	0.2	0.1	4.5	0.7
08/26/1999	299-W18-168(e)	2.5	0.3	55.0	0.2	0.0	4.3	0.6
09/03/1999	299-W18-168(e)	2.7	0.4	52.5	0.2	0.0	1.4	0.2
09/08/1999	299-W18-168(e)	2.7	0.4	47.3	0.2	0.0	1.5	0.2
09/13/1999	299-W18-168(e)	2.7	0.4	45.9	0.2	0.2	1.4	0.2
09/22/1999	299-W18-168(e)	2.7	0.5	41.4	0.2	0.2	1.7	0.4
09/27/1999	299-W18-168(e)	3.5	0.8	40.9	0.3	0.0	1.0	0.2
04/04/2001	299-W18-168(e)	2.7	0.9	17.6	0.1	0.3	0.2	0.3
04/11/2001	299-W18-168(e)	3.0	0.8	48.7	0.3	0.6	1.1	0.2
04/19/2001	299-W18-168(e)	2.4	0.2	44.2	0.1	0.7	0.8	0.2
04/26/2001	299-W18-168(e)	2.2	0.2	44.8	0.1	0.4	0.9	0.2
05/02/2001	299-W18-168(e)	2.5	0.4	50.3	0.2	0.4	0.2	0.1
05/09/2001	299-W18-168(e)	1.2	0.2	53.9	0.1	0.4	1.1	0.2
05/16/2001	299-W18-168(e)	1.6	0.2	51.4	0.1	0.3	0.9	0.2
05/23/2001	299-W18-168(e)	1.0	0.3	52.2	0.1	0.6	0.8	0.4
05/31/2001	299-W18-168(e)	0.7	0.3	77.1	0.2	0.7	1.2	0.4
06/06/2001	299-W18-168(e)	1.5	0.2	10.0	0.0	0.2	0.0	0.1
06/07/2001	299-W18-168(e)	--	0.3	49.7	0.1	0.6	0.2	0.3
06/13/2001	299-W18-168(e)	0.8	0.2	33.8	0.1	0.4	0.0	0.1
06/20/2001	299-W18-168(e)	1.3	0.3	44.8	0.1	0.4	0.1	0.2
06/21/1994	299-W18-169	22.4	0.0	--	--	--	--	--

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
03/28/1995	299-W18-169	23.7	1.2	266.0	2.9	0.0	54.0	6.0
09/06/1995	299-W18-169(e)	3.7	3.7	15.6	0.5	1.4	1.4	0.1
05/10/1996	299-W18-169(e)	3.5	4.1	11.5	0.4	0.0	0.3	0.0
09/25/1996	299-W18-169(e)	5.0	4.4	4.1	0.2	1.6	0.0	0.0
10/29/1996	299-W18-169(e)	3.5	3.7	0.0	0.0	0.0	0.0	0.0
09/24/1997	299-W18-169(e)	2.5	1.8	4.2	0.1	2.2	0.0	0.0
05/25/2001	299-W18-169(e)	1.0	0.8	1.2	0.0	0.0	0.2	0.2
05/30/2001	299-W18-169(e)	1.1	1.1	2.4	0.0	0.0	0.0	0.0
02/03/1993	299-W18-171	24.9	8.5	350.0	27.0	--	--	--
06/02/1993	299-W18-171	32.4	8.4	329.0	25.0	--	--	--
11/12/1993	299-W18-171(d)	32.4	8.2	29.0	2.2	--	--	--
11/16/1993	299-W18-171(d)	26.9	7.1	51.5	3.3	0.0	0.8	0.0
04/15/1994	299-W18-171(d)	30.6	9.2	50.0	4.2	0.0	--	0.1
06/20/1994	299-W18-171(d)	21.9	8.0	8.0	0.6	0.0	1.0	0.0
08/16/1995	299-W18-171L	9.0	4.0	7.2	0.3	0.6	0.0	0.0
04/03/1996	299-W18-171L	7.0	2.9	3.3	0.1	0.0	0.0	0.0
09/25/1996	299-W18-171L	6.2	3.7	1.8	0.1	0.0	0.0	0.0
10/29/1996	299-W18-171L	7.0	4.6	4.6	0.2	1.3	0.0	0.0
09/24/1997	299-W18-171L	4.7	2.4	5.0	0.1	3.1	0.0	0.0
05/25/2001	299-W18-171L	2.5	1.9	5.0	0.1	0.1	0.1	0.3
05/30/2001	299-W18-171L	2.5	1.8	5.4	0.1	0.2	0.0	0.1
08/16/1995	299-W18-171U	7.5	5.6	0.6	0.0	1.3	0.0	0.0
04/03/1996	299-W18-171U	6.0	4.1	0.5	0.0	0.0	0.0	0.0
09/25/1996	299-W18-171U	6.0	5.3	0.0	0.0	1.2	0.0	0.0
10/29/1996	299-W18-171U	6.0	7.8	0.0	0.0	0.0	0.0	1.6
09/24/1997	299-W18-171U	4.0	3.2	0.0	0.0	2.1	0.0	0.0
04/21/1994	299-W18-174	29.9	3.5	199.0	6.3	0.0	4.0	0.0
06/20/1994	299-W18-174	23.4	3.2	227.0	6.5	1.0	4.0	0.0
11/22/1994	299-W18-174	--	0.0	--	--	--	--	--
02/01/1995	299-W18-174	25.4	0.0	--	--	--	--	--
05/31/1995	299-W18-174	24.9	2.9	82.0	2.2	1.0	3.0	0.0
08/07/1995	299-W18-174	7.5	1.1	80.6	0.5	2.7	0.8	0.0
10/29/1996	299-W18-174	1.0	0.0	0.0	0.0	0.0	0.0	0.0
07/21/1997	299-W18-174	2.5	0.4	7.0	0.0	3.1	0.0	0.0
07/24/1997	299-W18-174	2.5	0.4	2.9	0.0	1.4	0.0	0.0
07/28/1997	299-W18-174	2.5	0.4	0.0	0.0	1.8	0.0	0.0
07/31/1997	299-W18-174	3.2	0.4	4.0	0.0	1.9	0.0	0.0
09/24/1997	299-W18-174	4.0	0.8	14.6	0.1	2.8	0.0	0.0
04/01/1998	299-W18-174	0.4	0.0	7.7	0.0	0.8	0.0	0.0
04/09/1998	299-W18-174	0.7	0.0	0.4	0.0	0.0	0.0	0.0

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
05/21/1998	299-W18-174	10.5	2.5	15.2	0.3	2.1	0.0	0.0
05/29/1998	299-W18-174	9.5	2.9	22.4	0.6	1.9	0.0	0.0
06/30/1999	299-W18-174	8.7	1.8	38.8	0.6	0.7	4.6	0.0
07/08/1999	299-W18-174	9.2	2.1	25.2	0.5	0.1	3.9	0.3
07/14/1999	299-W18-174	9.0	2.2	30.9	0.6	1.8	0.9	0.0
07/23/1999	299-W18-174	9.0	2.4	23.1	0.5	0.3	4.7	0.5
09/22/1999	299-W18-174	5.7	0.8	18.5	0.1	0.3	2.5	0.5
09/27/1999	299-W18-174	6.0	1.0	15.2	0.1	0.2	1.5	0.3
04/04/2001	299-W18-174	6.2	1.2	29.5	0.3	0.7	1.0	0.6
04/11/2001	299-W18-174	2.7	0.3	23.2	0.1	0.2	0.6	0.1
04/19/2001	299-W18-174	2.7	0.4	22.1	0.1	0.2	0.4	0.2
04/26/2001	299-W18-174	2.5	0.3	16.4	0.0	0.3	0.2	0.1
05/02/2001	299-W18-174	4.2	0.8	14.5	0.1	0.1	0.0	0.0
04/13/1992	299-W18-175(a)	24.9	2.5	275.0	6.4	--	--	--
09/22/1992	299-W18-175(a)	22.4	1.7	605.0	9.3	--	--	--
06/01/1993	299-W18-175	32.9	1.9	490.0	8.6	--	--	--
04/15/1994	299-W18-175	30.9	0.9	576.0	4.9	0.0	--	1.6
06/20/1994	299-W18-175	21.9	1.1	494.0	5.1	0.0	12.0	1.0
11/22/1994	299-W18-175	25.2	0.8	193.0	1.4	0.0	0.0	0.0
02/01/1995	299-W18-175	26.4	0.9	277.0	2.3	0.0	22.0	0.0
04/24/1995	299-W18-175	alpha	--	--	--	--	--	--
04/21/1994	299-W18-248	29.9	0.8	142.0	1.1	0.0	1.0	0.0
06/21/1994	299-W18-248	22.7	0.8	301.0	2.1	1.0	4.0	1.0
12/20/1994	299-W18-248	26.4	0.7	137.0	0.9	0.0	3.0	0.0
02/07/1995	299-W18-248	25.9	0.6	69.0	0.4	0.0	0.0	0.0
03/28/1995	299-W18-248	24.7	2.0	263.0	4.7	0.0	37.0	4.0
05/31/1995	299-W18-248	24.9	0.7	433.0	2.6	2.0	2.0	0.0
08/04/1995	299-W18-248	0.0	0.1	--	--	--	--	--
05/07/1996	299-W18-248	12.5	0.5	277.0	1.1	0.0	0.0	0.0
07/17/1996	299-W18-248	2.5	0.1	9.5	0.0	0.0	0.0	0.0
09/16/1996	299-W18-248	8.7	0.6	62.3	0.3	2.2	0.0	0.0
10/29/1996	299-W18-248	6.0	0.5	8.4	0.0	0.0	0.0	0.0
07/21/1997	299-W18-248	3.2	0.1	59.3	0.0	3.7	0.0	0.0
07/24/1997	299-W18-248	3.7	0.3	57.9	0.1	2.2	0.0	0.0
07/28/1997	299-W18-248	3.5	0.3	2.7	0.0	2.9	0.0	0.0
07/31/1997	299-W18-248	3.7	0.4	26.4	0.1	2.0	0.0	0.0
09/30/1997	299-W18-248	3.7	0.0	4.8	0.0	2.5	0.0	0.0
03/30/1998	299-W18-248	2.5	0.0	0.7	0.0	0.0	0.5	0.0
04/09/1998	299-W18-248	0.9	0.0	0.0	0.0	0.2	0.0	0.0
04/10/1998	299-W18-248	1.8	0.0	36.4	0.0	1.2	0.0	0.0

Appendix B – Characterization Data

Table B-1. Characterization Data for Individual Extraction Wells in the 216-Z-1A Wellfield, April 1992-September 2001. (12 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
04/16/1998	299-W18-248	1.8	0.0	0.0	0.0	0.6	0.0	0.0
04/30/1998	299-W18-248	1.0	0.0	0.9	0.0	0.3	0.0	0.0
05/21/1998	299-W18-248	11.2	0.5	47.0	0.2	2.3	0.0	0.0
05/29/1998	299-W18-248	12.5	0.8	29.5	0.2	2.1	0.0	0.0
07/27/1999	299-W18-248	7.0	0.3	36.9	0.1	1.1	4.2	1.0
07/28/1999	299-W18-248	6.5	0.3	20.1	0.0	0.6	3.2	0.8
08/06/1999	299-W18-248	4.2	0.3	28.5	0.1	0.6	3.9	0.4
08/13/1999	299-W18-248	4.5	0.3	25.3	0.1	0.1	3.2	0.4
08/19/1999	299-W18-248	3.7	0.3	35.8	0.1	0.6	4.3	0.9
08/26/1999	299-W18-248	4.5	0.3	36.8	0.1	0.1	3.2	0.6
09/03/1999	299-W18-248	5.5	0.3	36.6	0.1	0.3	1.2	0.2
09/08/1999	299-W18-248	5.2	0.3	34.9	0.1	0.2	1.2	0.2
09/13/1999	299-W18-248	4.2	0.3	31.7	0.1	0.0	1.6	0.2
09/22/1999	299-W18-248	6.0	0.3	34.0	0.1	0.4	1.2	0.4
09/27/1999	299-W18-248	5.7	0.3	29.8	0.1	0.4	0.5	0.1
04/19/2001	299-W18-248	2.7	0.2	110.0	0.2	1.5	1.2	0.6
04/26/2001	299-W18-248	2.5	0.2	53.1	0.1	0.9	0.7	0.3
05/02/2001	299-W18-248	7.0	0.2	42.8	0.1	0.6	0.0	0.2
05/09/2001	299-W18-248	2.1	0.2	36.5	0.1	0.5	0.6	0.2
05/16/2001	299-W18-248	2.5	0.3	22.0	0.1	0.2	0.0	0.0
05/23/2001	299-W18-248	1.9	0.3	33.5	0.1	0.6	0.2	0.3

*After 6/15/95, all measurements made at the wellhead.

^aOdysey analysis.

^bGas chromatograph analysis.

^cShort circuiting.

^dPacker broken.

^eAfter jet perforating.

^fOnly well on-line.

CCl₄ = carbon tetrachloride

CHCl₃ = chloroform

CH₂Cl₂ = methylene chloride

MEK = methyl ethyl ketone

Appendix B – Characterization Data

Table B-2. Characterization Data for Individual Extraction Wells in the 216-Z-18/Z-12 Wellfield, May 1992-September 2001. (5 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
06/05/1992	299-W18-10L(a)	25.7	2.4	27.4	0.6	--	--	--
06/09/1992	299-W18-10L(a)	24.9	1.9	200.0	3.4	--	--	--
06/12/1992	299-W18-10L(a)	24.9	0.9	280.0	2.4	--	--	--
06/15/1992	299-W18-10L(a)	24.9	2.6	190.0	4.5	--	--	--
02/03/1993	299-W18-10L	26.9	1.8	210.0	3.5	--	--	--
06/02/1993	299-W18-10L	32.4	2.3	221.0	4.5	--	--	--
11/16/1993	299-W18-10L	32.4	1.3	342.0	4.0	4.7	6.0	0.8
04/15/1994	299-W18-10L	30.9	1.4	267.0	3.4	0.0	--	0.2
07/26/1994	299-W18-10U&L	24.9	2.3	149.0	3.1	1.3	1.0	0.8
11/02/1994	299-W18-10U&L	25.2	2.0	43.0	0.8	1.0	0.0	0.0
05/10/1995	299-W18-10L	24.4	1.5	18.0	0.2	2.0	3.0	0.0
04/04/1996	299-W18-10L	18.7	1.0	11.5	0.1	0.0	0.0	0.0
05/14/1996	299-W18-10L	19.4	0.9	7.0	0.1	0.1	0.0	0.0
09/23/1996	299-W18-10L	--	--	4.0	--	0.0	0.0	0.0
04/04/1996	299-W18-10U	--	0.0	--	--	--	--	--
09/23/1996	299-W18-10U	19.9	0.0	--	--	--	--	--
07/14/1994	299-W18-11U&L	25.2	0.9	54.1	0.5	0.0	1.0	1.8
05/10/1995	299-W18-11L	24.7	0.8	8.0	0.1	1.0	2.0	0.0
06/07/1995	299-W18-11L	24.7	0.8	27.0	0.2	1.0	0.0	0.0
04/04/1996	299-W18-11L	19.2	0.3	1.7	0.0	0.0	0.0	0.0
09/19/1996	299-W18-11L	18.9	0.9	1.1	0.0	0.5	1.4	0.0
04/04/1996	299-W18-11U	17.9	0.8	2.0	0.0	0.0	0.0	0.0
09/19/1996	299-W18-11U	18.2	1.2	1.2	0.0	1.0	0.0	0.0
04/10/1995	299-W18-12(b)	25.7	7.1	82.0	5.3	--	--	--
05/10/1995	299-W18-12(b)	25.4	5.6	55.0	2.8	3.0	4.0	0.0
06/07/1995	299-W18-12(b)	25.2	5.6	46.0	2.3	2.0	2.0	0.0
08/03/1995	299-W18-12(b)	24.7	5.5	23.0	1.1	1.0	0.0	0.0
04/04/1996	299-W18-12(b)	15.7	4.4	17.1	0.7	0.0	0.0	0.0
05/14/1996	299-W18-12(b)	16.9	3.2	15.4	0.5	0.0	0.0	0.0
09/23/1996	299-W18-12(b)	14.9	6.2	10.7	0.6	1.7	0.0	0.0
03/30/1998	299-W18-12(b)	8.7	0.4	28.7	0.1	1.0	0.0	0.0
04/09/1998	299-W18-12(b)	2.1	0.8	19.1	0.1	1.3	0.0	0.0
04/10/1998	299-W18-12(b)	2.5	1.9	0.3	0.0	0.5	0.0	0.0
04/16/1998	299-W18-12(b)	0.4	5.4	0.0	0.0	0.3	0.0	0.0
04/30/1998	299-W18-12(b)	3.0	1.8	17.4	0.3	1.2	0.0	0.0
05/08/1998	299-W18-12(b)	1.3	0.5	14.6	0.1	1.2	0.0	0.0
05/13/1998	299-W18-12(b)	1.4	0.7	14.1	0.1	2.3	0.0	0.0
07/14/1994	299-W18-93	24.9	4.8	25.8	1.1	0.0	1.8	1.0
04/04/1996	299-W18-93	14.9	2.8	0.4	0.0	0.2	0.0	0.2
09/19/1996	299-W18-93	15.9	3.5	0.1	0.0	1.4	0.0	0.0

Appendix B – Characterization Data

Table B-2. Characterization Data for Individual Extraction Wells in the 216-Z-18/Z-12 Wellfield, May 1992-September 2001. (5 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
07/25/1994	299-W18-94	25.4	7.7	22.0	1.5	0.0	1.3	0.8
04/06/1996	299-W18-94	13.2	6.1	0.5	0.0	0.0	0.0	0.0
09/19/1996	299-W18-94	13.4	5.6	0.1	0.0	1.5	0.0	0.0
07/13/1994	299-W18-96	24.9	7.2	103.0	6.8	0.7	--	0.3
11/02/1994	299-W18-96	25.9	8.2	29.0	2.2	1.0	0.0	0.0
02/15/1995	299-W18-96	24.4	9.4	121.0	10.3	--	--	--
03/28/1995	299-W18-96	25.2	9.3	120.0	10.2	1.0	0.0	0.0
04/10/1995	299-W18-96	28.9	9.9	143.0	12.8	--	--	--
05/10/1995	299-W18-96	24.9	7.5	50.0	3.4	2.0	4.0	0.0
08/03/1995	299-W18-96	24.7	7.2	13.0	0.9	1.0	0.0	0.0
04/09/1996	299-W18-96	12.0	6.5	7.2	0.4	0.2	0.0	0.0
09/23/1996	299-W18-96	12.5	8.2	3.4	0.3	0.0	0.0	0.0
03/30/1998	299-W18-96	9.2	1.6	16.2	0.2	0.6	0.0	0.0
04/09/1998	299-W18-96	2.0	2.1	26.5	0.5	1.4	0.0	0.0
05/08/1998	299-W18-96	1.4	1.8	14.2	0.2	0.9	0.0	0.0
05/13/1998	299-W18-96	1.5	1.9	19.9	0.3	2.4	0.0	0.0
05/25/2001	299-W18-96	2.5	2.8	8.0	0.2	0.2	0.1	0.3
05/30/2001	299-W18-96	1.7	2.4	10.5	0.2	0.1	0.0	0.1
05/01/1992	299-W18-97(a)	6.2	2.9	95.0	2.5	--	--	--
05/05/1992	299-W18-97(a)	5.5	3.2	70.0	2.0	--	--	--
02/03/1993	299-W18-97	27.1	7.5	355.0	24.1	--	--	--
06/02/1993	299-W18-97	33.4	8.8	23.0	1.8	--	--	--
11/16/1993	299-W18-97	31.9	--	95.0	--	0.0	0.0	0.0
04/15/1994	299-W18-97	32.1	7.3	48.2	3.2	0.5	--	0.1
07/26/1994	299-W18-97	25.4	8.4	12.0	0.9	0.0	1.9	0.7
04/06/1996	299-W18-97	13.0	6.2	0.3	0.0	0.0	0.0	0.0
09/23/1996	299-W18-97	13.2	7.6	0.0	0.0	1.3	0.0	0.0
07/12/1994	299-W18-98	31.4	9.3	37.6	3.2	1.5	1.7	0.1
07/12/1994	299-W18-98	25.2	7.5	39.0	2.7	0.0	3.8	0.5
04/04/1996	299-W18-98	13.7	5.4	0.3	0.0	0.2	0.0	0.0
09/23/1996	299-W18-98	13.9	7.1	0.0	0.0	1.0	0.0	0.0
06/30/1994	299-W18-99	24.7	6.4	106.0	6.1	0.3	1.6	0.3
02/16/1995	299-W18-99	25.4	7.8	11.0	0.8	0.0	2.0	0.0
03/28/1995	299-W18-99	24.4	7.8	9.0	0.6	0.0	0.0	0.0
04/05/1996	299-W18-99	23.7	5.4	0.7	0.0	0.0	0.0	0.0
09/24/1996	299-W18-99	14.4	6.4	0.0	0.0	1.3	0.0	0.0
07/12/1995	299-W18-152	24.9	6.6	362.0	21.7	13.0	20.0	3.0
11/16/1995	299-W18-152	8.7	3.9	47.0	1.7	0.0	0.0	0.0
12/20/1995	299-W18-152	8.5	--	38.9	--	0.7	0.7	--
05/07/1996	299-W18-152	14.7	6.9	31.7	2.0	0.0	0.0	0.0

Appendix B – Characterization Data

Table B-2. Characterization Data for Individual Extraction Wells in the 216-Z-18/Z-12 Wellfield, May 1992-September 2001. (5 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
07/17/1996	299-W18-152	11.7	6.6	20.9	1.3	3.7	0.0	0.0
10/29/1996	299-W18-152	2.2	1.0	11.4	0.1	1.7	0.0	0.0
09/24/1997	299-W18-152	24.9	3.9	12.7	0.4	2.6	0.0	0.0
03/30/1998	299-W18-152	6.5	0.4	20.8	0.1	0.7	0.0	0.0
04/09/1998	299-W18-152	0.1	0.0	0.3	0.0	1.4	0.0	0.0
06/05/1998	299-W18-152	5.0	4.4	18.3	0.7	2.1	0.0	0.0
06/11/1998	299-W18-152	6.5	3.3	16.8	0.5	2.8	0.0	0.0
07/12/1995	299-W18-153	24.9	10.0	52.0	4.7	2.0	2.0	0.0
05/07/1996	299-W18-153	5.0	9.7	2.7	0.2	0.0	0.0	0.0
09/26/1996	299-W18-153	11.5	10.6	0.7	0.1	1.7	0.0	0.0
10/29/1996	299-W18-153	2.5	3.8	0.0	0.0	0.0	0.0	0.0
09/24/1997	299-W18-153	5.7	0.0	2.2	0.0	2.4	0.0	0.0
07/12/1995	299-W18-157	24.9	10.1	20.0	1.8	1.0	1.0	0.0
04/06/1996	299-W18-157	6.2	8.1	6.5	0.5	0.2	0.0	0.0
09/26/1996	299-W18-157	9.0	8.1	0.6	0.0	0.5	0.2	0.2
04/20/1994	299-W18-246L	30.1	1.7	162.0	2.5	0.7	0.8	0.1
04/20/1994	299-W18-246L	17.7	1.2	169.0	1.9	0.3	0.2	0.0
06/21/1994	299-W18-246L	21.7	1.5	236.0	3.2	0.0	2.0	0.0
11/02/1994	299-W18-246U&L	25.4	8.6	134.0	10.4	1.0	0.0	0.0
06/07/1995	299-W18-246L	24.9	2.1	114.0	2.1	4.0	5.0	0.0
08/03/1995	299-W18-246L	24.7	5.2	49.0	2.3	1.0	2.0	0.0
04/06/1996	299-W18-246L	16.9	1.8	32.2	0.5	0.0	0.0	0.0
05/14/1996	299-W18-246L	17.4	1.5	32.3	0.4	0.0	0.0	0.0
09/18/1996	299-W18-246L	18.7	2.4	16.3	0.4	1.7	0.0	0.0
10/29/1996	299-W18-246L	7.5	1.4	6.9	0.1	2.0	0.0	0.0
06/25/2001	299-W18-246L	1.7	0.2	37.2	0.1	0.5	0.0	0.1
06/27/2001	299-W18-246L	1.8	0.2	34.8	0.1	0.4	0.0	0.1
07/03/2001	299-W18-246L	1.5	0.3	26.8	0.1	0.3	0.0	0.1
07/11/2001	299-W18-246L	1.8	0.2	32.6	0.1	0.3	0.0	0.1
04/19/1994	299-W18-246U	29.1	5.4	271.0	13.4	0.2	--	0.4
06/21/1994	299-W18-246U	22.4	4.4	125.0	5.0	0.0	3.0	0.0
08/03/1995	299-W18-246U	25.2	5.4	48.0	2.3	2.0	2.0	0.0
04/06/1996	299-W18-246U	16.9	4.2	27.9	1.1	0.0	0.0	0.0
07/17/1996	299-W18-246U	14.9	5.2	9.8	0.5	1.2	0.0	0.0
09/18/1996	299-W18-246U	13.9	5.7	29.7	1.5	1.2	0.0	0.0
10/29/1996	299-W18-246U	5.5	11.6	9.0	0.9	0.0	0.0	0.0
03/30/1998	299-W18-246U	8.7	1.2	29.7	0.3	0.8	0.0	0.0
04/08/1998	299-W18-246U	1.8	1.6	15.2	0.2	0.8	1.3	0.0
05/08/1998	299-W18-246U	1.4	1.2	22.4	0.2	1.5	0.0	0.0
05/13/1998	299-W18-246U	1.6	1.1	23.4	0.2	2.0	0.0	0.0

Table B-2. Characterization Data for Individual Extraction Wells in the 216-Z-18/Z-12 Wellfield, May 1992-September 2001. (5 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
06/25/2001	299-W18-246U	1.5	0.4	21.9	0.1	0.4	0.0	0.2
06/27/2001	299-W18-246U	1.6	0.4	16.2	0.1	0.2	0.0	0.1
07/03/2001	299-W18-246U	1.4	0.3	12.6	0.0	0.1	0.0	0.2
07/11/2001	299-W18-246U	1.7	0.4	13.3	0.1	0.0	0.0	0.1
05/08/1996	299-W18-247L	17.9	1.4	2.9	0.0	0.0	0.0	0.0
09/19/1996	299-W18-247L	16.9	2.5	1.4	0.0	1.6	0.0	0.1
05/08/1996	299-W18-247U	20.4	0.4	5.2	0.0	0.0	0.0	0.0
09/19/1996	299-W18-247U	19.9	0.0	4.7	0.0	1.7	0.1	0.0
07/11/1994	299-W18-249	21.2	13.5	108.0	13.2	0.0	1.7	0.5
02/15/1995	299-W18-249	18.4	14.2	93.0	12.0	--	--	--
03/28/1995	299-W18-249	17.4	14.2	32.0	4.1	0.0	0.0	0.0
04/05/1996	299-W18-249	5.7	10.4	2.1	0.2	0.4	0.0	0.0
09/24/1996	299-W18-249	11.5	9.1	15.7	1.3	1.3	0.0	0.0
03/30/1998	299-W18-249	7.0	2.7	33.4	0.8	0.3	0.0	0.0
04/09/1998	299-W18-249	1.1	3.2	20.2	0.6	1.0	0.0	0.0
05/08/1998	299-W18-249	1.0	3.3	13.6	0.4	0.9	0.0	0.0
05/13/1998	299-W18-249	1.1	3.1	15.9	0.4	2.9	0.0	0.0
08/30/1999	299-W18-249	2.7	7.3	9.7	0.6	1.0	0.0	0.1
05/04/2001	299-W18-249	1.9	5.5	19.9	1.0	0.3	0.0	0.1
05/09/2001	299-W18-249	2.0	5.2	17.6	0.8	0.0	0.0	0.0
05/16/2001	299-W18-249	2.5	5.4	16.0	0.8	0.3	0.0	0.0
05/23/2001	299-W18-249	2.0	5.4	17.3	0.8	0.1	0.0	0.2
03/07/1994	299-W18-252L	30.4	2.7	618.0	15.2	4.3	6.0	0.2
08/03/1995	299-W18-252L	25.7	3.0	97.0	2.7	4.0	5.0	0.0
11/16/1995	299-W18-252L	11.2	2.0	35.0	0.6	0.0	0.0	0.0
12/20/1995	299-W18-252L	11.2	--	28.2	--	0.4	0.2	--
04/09/1996	299-W18-252L	12.2	5.9	41.6	2.2	0.0	0.0	0.0
05/14/1996	299-W18-252L	15.9	6.4	25.0	1.4	0.0	0.0	0.0
07/17/1996	299-W18-252L	18.4	0.0	--	--	--	--	--
09/18/1996	299-W18-252L	13.4	4.2	13.9	0.5	1.6	0.0	0.0
10/29/1996	299-W18-252L	9.0	14.2	14.6	1.5	0.0	0.0	0.0
03/30/1998	299-W18-252L	12.0	0.5	28.9	0.1	0.6	0.0	0.0
04/09/1998	299-W18-252L	2.5	0.0	11.7	0.0	1.5	0.0	0.0
04/10/1998	299-W18-252L	2.5	1.2	23.3	0.5	0.7	0.0	0.0
04/16/1998	299-W18-252L	2.5	1.2	25.6	0.5	0.9	0.0	0.0
04/30/1998	299-W18-252L	2.5	1.4	24.7	0.5	1.4	0.0	0.0
05/08/1998	299-W18-252L	1.9	0.7	29.1	0.2	1.7	0.0	0.0
05/13/1998	299-W18-252L	1.7	0.9	11.9	0.1	1.6	0.0	1.0
01/05/1994	299-W18-252U	22.9	4.2	97.0	3.7	0.6	1.2	0.2
01/06/1994	299-W18-252U	31.6	6.7	527.0	31.9	3.6	5.8	0.1

Appendix B – Characterization Data

Table B-2. Characterization Data for Individual Extraction Wells in the 216-Z-18/Z-12 Wellfield, May 1992-September 2001. (5 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
01/20/1994	299-W18-252U	31.6	6.7	500.0	30.2	--	--	--
03/10/1994	299-W18-252U	14.2	5.3	--	--	--	--	--
03/10/1994	299-W18-252U	18.4	5.8	--	--	--	--	--
03/10/1994	299-W18-252U	23.7	6.6	--	--	--	--	--
03/10/1994	299-W18-252U	28.4	7.3	547.0	36.1	--	--	--
03/10/1994	299-W18-252U	32.6	7.6	--	--	--	--	--
05/16/1994	299-W18-252U	24.2	6.7	368.0	22.2	0.0	0.0	0.0
05/17/1994	299-W18-252U	23.9	6.8	440.0	27.0	0.0	4.0	0.0
05/18/1994	299-W18-252U	23.9	6.6	395.0	23.5	0.0	4.0	0.0
05/19/1994	299-W18-252U	23.7	6.7	404.0	24.5	0.0	4.0	0.0
12/20/1994	299-W18-252U	25.2	8.7	106.0	8.3	1.0	--	0.0
05/11/1995	299-W18-252U	6.7	2.6	--	--	--	--	--
05/11/1995	299-W18-252U	8.7	4.0	143.0	5.2	0.0	0.0	--
05/11/1995	299-W18-252U	11.0	5.2	182.0	8.5	7.0	10.0	--
05/11/1995	299-W18-252U	13.7	6.2	239.0	13.4	9.0	13.0	--
05/11/1995	299-W18-252U	17.4	6.6	234.0	14.1	8.0	12.0	--
05/11/1995	299-W18-252U	21.2	7.3	235.0	15.6	9.0	13.0	--
05/11/1995	299-W18-252U	24.4	7.9	242.0	17.3	9.0	14.0	--
05/11/1995	299-W18-252U	28.1	8.4	241.0	18.4	9.0	14.0	--
08/03/1995	299-W18-252U	24.9	6.5	53.0	3.1	2.0	3.0	0.0
06/12/1996	299-W18-252U	11.2	6.6	5.5	0.3	0.0	0.0	0.0
09/18/1996	299-W18-252U	24.2	6.1	7.2	0.4	1.7	0.0	0.0
10/29/1996	299-W18-252U	4.5	10.8	10.4	1.0	0.0	0.0	0.0
07/21/1997	299-W18-252U	3.7	4.2	41.5	1.6	4.4	0.0	0.0
07/24/1997	299-W18-252U	4.7	3.6	25.8	0.8	3.1	0.0	0.0
07/28/1997	299-W18-252U	4.2	3.5	11.4	0.4	4.1	0.0	0.0
07/31/1997	299-W18-252U	5.0	4.0	8.4	0.3	2.6	0.0	0.0
03/30/1998	299-W18-252U	9.0	1.7	35.7	0.5	0.9	0.0	0.0
04/09/1998	299-W18-252U	2.2	1.7	33.2	0.5	1.6	0.0	0.0
05/08/1998	299-W18-252U	2.0	1.1	28.4	0.3	2.0	0.0	0.0
05/13/1998	299-W18-252U	2.0	0.4	27.2	0.1	2.7	0.0	0.0

*After 6/15/95, all measurements made at the wellhead.

*Odyssey analysis.

*After jet perforating.

CCl₄ = carbon tetrachlorideCHCl₃ = chloroformCH₂Cl₂ = methylene chloride

MEK = methyl ethyl ketone

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
08/22/1995	299-W15-6L(d)	21.2	3.5	79.6	2.5	1.0	4.6	0.1
11/28/1995	299-W15-6L(d)	13.7	2.6	35.3	0.8	3.0	5.7	0.0
12/20/1995	299-W15-6L(d)	21.7	--	30.5	--	0.3	4.9	--
05/02/1996	299-W15-6L(d)	16.9	2.8	24.4	0.6	0.0	2.3	0.0
05/14/1996	299-W15-6L(d)	22.9	3.6	26.4	0.9	0.0	2.5	0.0
07/23/1996	299-W15-6L(d)	17.9	3.3	15.3	0.5	1.2	1.1	0.0
09/10/1996	299-W15-6L(d)	19.9	4.8	14.6	0.6	0.0	1.7	0.0
10/29/1996	299-W15-6L(d)	8.7	2.5	14.2	0.3	0.0	2.0	0.0
07/18/1997	299-W15-6L(d)	10.0	2.7	20.2	0.5	3.9	0.0	0.0
07/21/1997	299-W15-6L(d)	8.0	2.4	20.3	0.4	2.9	1.3	0.0
07/24/1997	299-W15-6L(d)	11.0	2.2	22.6	0.5	2.9	0.0	0.0
07/28/1997	299-W15-6L(d)	12.5	3.0	20.6	0.6	3.8	0.0	0.0
07/31/1997	299-W15-6L(d)	10.0	2.9	20.5	0.5	1.9	0.0	0.0
09/26/1997	299-W15-6L(d)	10.5	2.0	16.5	0.5	3.4	0.0	0.0
07/30/1998	299-W15-6L(d)	9.5	2.1	17.6	0.3	1.7	1.8	0.0
08/25/1998	299-W15-6L(d)	10.5	2.9	18.1	0.5	0.9	1.2	0.0
09/03/1998	299-W15-6L(d)	4.5	1.6	18.1	0.3	1.8	1.4	0.0
09/14/1998	299-W15-6L(d)	4.5	1.7	17.0	0.3	0.8	1.5	0.0
09/22/1998	299-W15-6L(d)	3.0	1.3	14.5	0.2	1.4	1.6	0.0
09/30/1998	299-W15-6L(d)	2.5	1.4	17.9	0.2	0.6	2.1	0.0
04/15/1999	299-W15-6L(d)	14.9	3.4	12.0	0.4	0.0	0.0	0.0
04/21/1999	299-W15-6L(d)	11.7	2.8	22.6	0.8	0.0	5.6	0.0
04/28/1999	299-W15-6L(d)	14.9	3.3	22.0	0.6	0.0	4.7	0.0
05/03/1999	299-W15-6L(d)	14.9	3.1	22.3	0.5	1.4	3.9	0.0
05/10/1999	299-W15-6L(d)	13.7	2.8	21.8	0.6	0.0	5.2	0.0
05/17/1999	299-W15-6L(d)	14.4	2.9	22.4	0.6	0.0	6.2	0.0
05/25/1999	299-W15-6L(d)	20.7	3.5	21.1	0.7	0.0	6.1	0.0
06/01/1999	299-W15-6L(d)	20.4	3.8	20.7	0.7	0.0	4.6	0.0
06/10/1999	299-W15-6L(d)	19.7	3.5	19.6	0.6	0.0	5.4	0.0
06/15/1999	299-W15-6L(d)	12.0	2.5	20.0	0.4	0.0	6.3	0.0
06/21/1999	299-W15-6L(d)	13.4	3.0	19.1	0.5	0.0	7.0	0.0
06/25/1999	299-W15-6L(d)	10.0	2.5	19.7	0.4	1.4	4.3	0.0
08/22/1995	299-W15-6U(d)	19.9	4.3	15.3	0.6	0.0	0.0	0.0
05/02/1996	299-W15-6U(d)	16.2	3.2	1.8	0.1	0.0	0.0	0.0
09/12/1996	299-W15-6U(d)	17.9	4.6	0.0	0.0	1.1	0.0	0.0
10/29/1996	299-W15-6U(d)	7.5	2.4	0.0	0.0	0.0	0.0	0.0
12/02/1994	299-W15-8L	24.9	1.5	119.0	1.6	5.0	--	0.0
02/01/1995	299-W15-8L	26.4	0.7	--	--	--	--	--
02/10/1995	299-W15-8L	26.9	1.2	22.0	0.2	3.9	2.7	1.0
03/09/1995	299-W15-8	alpha	--	--	--	--	--	--

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
12/02/1994	299-W15-9L	24.9	1.4	110.0	1.4	5.0	--	0.0
02/01/1995	299-W15-9L	26.4	1.0	--	--	--	--	--
02/10/1995	299-W15-9L	27.6	1.0	93.0	0.9	5.7	4.9	1.0
07/10/1995	299-W15-9L(d)	13.7	1.4	63.0	0.8	1.4	4.0	0.5
05/03/1996	299-W15-9L(d)	17.4	1.6	14.2	0.2	0.0	0.0	0.0
05/14/1996	299-W15-9L(d)	27.4	2.1	19.4	0.4	0.0	0.0	0.0
09/12/1996	299-W15-9L(d)	19.7	2.4	11.4	0.3	1.3	0.0	0.0
10/29/1996	299-W15-9L(d)	10.0	2.0	9.7	0.2	0.0	0.0	0.0
07/18/1997	299-W15-9L(d)	16.2	1.7	19.8	0.3	2.2	0.0	0.0
07/21/1997	299-W15-9L(d)	19.4	1.8	21.3	0.3	3.6	0.0	0.0
07/24/1997	299-W15-9L(d)	21.2	2.1	21.0	0.4	1.4	0.0	0.0
07/28/1997	299-W15-9L(d)	20.9	2.7	14.8	0.4	3.3	0.0	0.0
07/31/1997	299-W15-9L(d)	19.4	2.4	14.5	0.3	3.7	0.0	0.0
09/26/1997	299-W15-9L(d)	18.7	2.5	12.6	0.3	2.8	0.0	0.0
07/10/1998	299-W15-9L(d)	19.4	2.3	16.7	0.4	2.5	0.0	0.0
07/30/1998	299-W15-9L(d)	19.4	1.7	19.3	0.3	1.7	1.0	0.5
08/25/1998	299-W15-9L(d)	17.7	2.0	15.0	0.3	1.5	0.0	0.0
09/03/1998	299-W15-9L(d)	10.0	1.3	15.3	0.2	1.3	0.0	0.0
09/14/1998	299-W15-9L(d)	10.0	1.4	13.4	0.2	1.3	0.0	0.0
09/22/1998	299-W15-9L(d)	5.5	0.9	9.4	0.1	1.1	0.0	0.0
09/30/1998	299-W15-9L(d)	5.5	0.9	12.1	0.1	1.4	0.0	0.0
03/30/1999	299-W15-9L(d)	23.4	2.6	15.5	0.4	0.0	0.0	0.0
04/05/1999	299-W15-9L(d)	23.7	2.4	16.1	0.3	0.0	NA	NA
04/12/1999	299-W15-9L(d)	22.4	2.5	17.7	0.4	0.0	0.0	0.0
04/21/1999	299-W15-9L(d)	18.9	2.0	19.9	0.4	0.0	4.1	0.0
04/28/1999	299-W15-9L(d)	24.7	2.4	17.3	0.4	0.0	2.8	0.0
05/03/1999	299-W15-9L(d)	24.2	2.1	22.0	0.4	1.2	2.7	0.0
05/10/1999	299-W15-9L(d)	23.9	2.4	17.5	0.4	0.0	3.6	0.0
05/17/1999	299-W15-9L(d)	22.7	1.7	17.8	0.3	0.0	4.2	0.0
05/25/1999	299-W15-9L(d)	23.4	2.1	18.9	0.4	0.0	5.0	0.0
06/01/1999	299-W15-9L(d)	22.9	2.2	18.7	0.4	0.0	2.6	0.0
06/10/1999	299-W15-9L(d)	22.7	2.1	16.9	0.3	0.0	3.4	0.0
06/15/1999	299-W15-9L(d)	13.0	1.4	17.7	0.2	0.0	4.1	0.0
06/21/1999	299-W15-9L(d)	14.9	1.9	16.2	0.3	0.0	4.8	0.0
06/25/1999	299-W15-9L(d)	10.5	1.3	16.0	0.2	2.1	1.2	0.0
07/23/2001	299-W15-9L(d)	26.9	1.6	20.7	0.3	0.4	1.7	0.4
08/01/2001	299-W15-9L(d)	14.4	1.4	22.2	0.3	0.4	0.5	0.1
08/08/2001	299-W15-9L(d)	14.9	1.4	22.1	0.3	0.2	1.0	0.2
08/22/2001	299-W15-9L(d)	14.9	1.2	24.9	0.3	0.2	1.6	0.3
09/05/2001	299-W15-9L(d)	19.9	1.4	28.3	0.4	0.3	1.7	0.2

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
09/12/2001	299-W15-9L(d)	8.2	0.8	23.7	0.2	0.4	1.6	0.4
09/20/2001	299-W15-9L(d)	8.7	0.8	21.6	0.1	0.2	0.9	0.2
08/02/1995	299-W15-9U(d)	17.9	2.2	97.2	2.0	3.4	6.7	1.3
11/28/1995	299-W15-9U(d)	13.4	1.1	26.0	0.3	1.1	0.1	0.0
12/22/1995	299-W15-9U(d)	15.2	--	32.5	--	0.0	1.7	--
05/03/1996	299-W15-9U(d)	17.9	1.4	68.2	0.9	0.0	0.0	0.0
09/12/1996	299-W15-9U(d)	21.7	1.6	48.9	0.7	1.6	0.0	0.0
10/29/1996	299-W15-9U(d)	10.7	1.3	8.1	0.1	0.0	1.1	1.1
09/26/1997	299-W15-9U(d)	19.7	1.4	8.4	0.1	1.7	0.0	0.0
07/10/1998	299-W15-9U(d)	19.9	2.0	29.6	0.5	1.9	0.0	0.0
07/30/1998	299-W15-9U(d)	18.4	2.0	33.5	0.5	1.9	0.0	0.5
08/25/1998	299-W15-9U(d)	19.4	1.8	16.3	0.3	1.4	0.0	0.0
03/30/1999	299-W15-9U(d)	23.9	2.5	34.8	0.8	0.0	0.0	0.0
04/05/1999	299-W15-9U(d)	24.9	2.1	17.5	0.3	0.0	NA	NA
04/12/1999	299-W15-9U(d)	23.7	2.1	11.2	0.2	0.0	0.0	0.0
04/21/1999	299-W15-9U(d)	18.9	1.8	14.1	0.2	0.0	2.7	0.0
04/28/1999	299-W15-9U(d)	24.7	2.1	12.8	0.2	0.0	1.2	0.0
05/03/1999	299-W15-9U(d)	24.9	1.7	15.3	0.2	1.3	1.9	0.0
05/10/1999	299-W15-9U(d)	23.7	2.0	11.8	0.2	1.3	1.5	0.0
05/17/1999	299-W15-9U(d)	23.9	1.8	11.5	0.2	0.0	2.7	0.0
05/25/1999	299-W15-9U(d)	22.9	1.6	11.7	0.2	0.0	3.3	0.0
06/01/1999	299-W15-9U(d)	23.7	1.8	11.3	0.2	0.0	1.5	0.0
06/10/1999	299-W15-9U(d)	22.4	1.6	10.5	0.1	0.0	2.1	0.0
06/15/1999	299-W15-9U(d)	13.4	0.9	10.7	0.1	1.1	1.9	0.0
06/21/1999	299-W15-9U(d)	14.9	1.1	11.1	0.1	0.0	3.4	0.0
07/23/2001	299-W15-9U(d)	29.1	1.2	150.0	1.7	1.8	6.4	0.7
08/01/2001	299-W15-9U(d)	14.9	0.8	42.4	0.3	0.7	0.9	0.2
08/08/2001	299-W15-9U(d)	15.2	1.1	29.0	0.3	0.4	0.6	0.2
08/22/2001	299-W15-9U(d)	14.9	0.8	21.4	0.1	0.1	0.7	0.3
09/05/2001	299-W15-9U(d)	20.9	1.1	23.5	0.2	0.2	0.0	0.1
09/12/2001	299-W15-9U(d)	8.5	0.4	27.4	0.1	0.2	0.1	0.3
09/20/2001	299-W15-9U(d)	9.0	0.4	25.8	0.1	0.3	0.0	0.0
03/31/1993	299-W15-82(a)(b)	31.9	0.7	11848.0	70.0	--	--	--
04/01/1993	299-W15-82(a)(c)	--	1.6	8208.0	115.9	--	--	--
04/12/1993	299-W15-82(a)(c)	--	--	6101.0	--	--	--	--
04/28/1993	299-W15-82	6.5	2.0	26000.0	467.2	--	--	--
06/03/1993	299-W15-82	17.2	7.2	28500.0	1851.2	--	--	--
02/23/1994	299-W15-82	3.2	1.4	23000.0	301.1	113.0	114.0	3.9
02/23/1994	299-W15-82(b)	3.2	1.4	--	--	16.1	24.6	--
02/24/1994	299-W15-82	3.2	1.4	25300.0	311.7	106.0	139.0	4.1

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
02/24/1994	299-W15-82(b)	3.2	1.4	--	--	25.0	25.0	--
05/10/1994	299-W15-82	5.0	--	20300.0	--	102.0	115.0	2.4
05/11/1994	299-W15-82	5.2	--	19800.0	--	99.2	118.0	2.8
06/01/1994	299-W15-82	11.5	--	11700.0	--	69.8	74.7	2.0
06/10/1994	299-W15-82	24.9	--	8040.0	--	68.3	61.6	2.0
09/06/1994	299-W15-82	28.9	8.2	5240.0	387.4	56.3	28.8	1.3
10/26/1994	299-W15-82	29.9	10.4	1550.0	145.6	59.7	81.9	5.8
11/22/1994	299-W15-82	30.9	10.3	582.0	54.1	29.0	--	3.0
01/31/1995	299-W15-82	25.7	9.1	--	--	--	--	--
02/08/1995	299-W15-82	25.2	9.1	378.0	31.2	20.9	22.5	3.6
05/12/1995	299-W15-82	24.9	7.6	279.0	19.2	7.3	14.8	1.3
08/01/1995	299-W15-82	19.9	4.9	94.5	4.2	3.3	6.3	1.2
11/29/1995	299-W15-82	17.7	2.7	155.0	3.8	7.1	10.6	0.9
12/20/1995	299-W15-82	19.7	--	143.0	--	1.0	1.2	--
04/25/1996	299-W15-82	23.9	2.3	180.0	3.7	0.0	0.0	0.0
07/19/1996	299-W15-82	20.9	2.2	87.3	1.7	2.0	0.0	0.0
09/10/1996	299-W15-82	24.9	3.2	43.9	1.3	0.0	0.0	0.0
10/29/1996	299-W15-82	13.4	1.9	28.5	0.5	1.2	0.0	0.0
07/18/1997	299-W15-82	15.9	1.6	106.0	1.5	2.8	6.7	0.0
07/21/1997	299-W15-82	13.7	2.1	46.8	0.9	4.1	0.0	0.0
07/24/1997	299-W15-82	16.9	1.9	170.0	2.9	4.2	0.0	0.0
07/28/1997	299-W15-82	16.7	1.8	126.0	2.0	3.8	0.0	0.0
07/31/1997	299-W15-82	18.4	1.8	116.0	1.9	4.0	0.0	0.0
09/26/1997	299-W15-82	14.9	1.5	19.7	0.3	1.6	0.0	0.0
07/10/1998	299-W15-82	17.4	2.1	196.0	3.8	3.5	11.0	0.0
07/30/1998	299-W15-82	12.5	1.6	153.0	2.2	4.4	0.0	0.1
08/25/1998	299-W15-82	12.7	1.6	89.9	1.3	2.1	0.0	0.0
09/03/1998	299-W15-82	6.2	0.8	70.0	0.5	2.4	0.0	0.0
09/14/1998	299-W15-82	6.5	0.9	40.7	0.3	1.7	0.0	0.0
09/22/1998	299-W15-82	4.0	0.5	41.4	0.2	1.8	0.0	0.0
09/30/1998	299-W15-82	3.7	0.5	56.7	0.3	1.3	0.0	0.0
03/30/1999	299-W15-82	20.4	1.8	167.0	2.7	1.4	0.0	0.0
04/05/1999	299-W15-82	21.4	2.2	136.0	2.8	0.0	NA	NA
04/12/1999	299-W15-82	21.2	2.0	118.0	2.2	2.1	0.0	0.0
04/21/1999	299-W15-82	13.7	1.7	119.0	1.8	0.0	0.0	0.0
04/28/1999	299-W15-82	17.9	1.7	102.0	1.6	0.0	0.0	0.0
05/03/1999	299-W15-82	17.2	1.6	95.4	1.3	1.1	0.0	0.0
05/10/1999	299-W15-82	17.4	1.6	91.1	1.4	0.0	0.0	0.0
05/17/1999	299-W15-82	16.9	1.7	86.6	1.3	0.0	0.0	0.0
05/25/1999	299-W15-82	17.2	1.6	83.6	1.2	0.0	1.6	0.0

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
06/01/1999	299-W15-82	17.2	1.6	80.0	1.1	0.0	0.0	0.0
06/10/1999	299-W15-82	15.9	1.6	76.2	1.1	0.0	0.0	0.0
06/15/1999	299-W15-82	10.0	1.0	74.5	0.7	0.0	2.0	0.0
06/21/1999	299-W15-82	11.5	1.1	76.3	0.8	0.0	2.8	0.0
06/25/1999	299-W15-82	10.5	0.8	66.4	0.5	1.4	0.0	0.0
07/23/2001	299-W15-82	24.4	1.9	154.0	2.6	1.7	12.9	0.9
08/01/2001	299-W15-82	13.4	1.0	428.0	3.8	5.9	12.8	1.4
08/08/2001	299-W15-82	13.7	1.1	325.0	3.3	4.1	5.1	1.0
08/22/2001	299-W15-82	13.4	1.2	220.0	2.4	2.3	1.7	0.6
09/05/2001	299-W15-82	16.9	1.4	227.0	3.0	3.4	1.6	0.6
09/12/2001	299-W15-82	7.5	0.5	213.0	1.0	3.3	1.7	0.8
09/20/2001	299-W15-82	8.2	0.5	202.0	1.0	3.1	0.9	0.6
09/12/2001	299-W15-84L	7.7	1.8	23.1	0.4	0.2	0.5	0.3
09/20/2001	299-W15-84L	8.7	1.9	25.9	0.4	0.2	0.3	0.2
04/02/1993	299-W15-84U(a)	31.9	0.0	--	--	--	--	--
04/29/1993	299-W15-84U	5.0	2.1	8475.0	169.2	--	--	--
03/01/1994	299-W15-84U	16.2	9.1	8230.0	682.4	51.7	58.8	1.6
03/01/1994	299-W15-84U(b)	16.2	9.1	--	--	32.8	6.0	--
03/01/1994	299-W15-84U	10.0	2.7	7100.0	176.8	43.6	51.5	1.4
03/01/1994	299-W15-84U(b)	10.0	2.7	--	--	46.7	5.3	--
03/02/1994	299-W15-84U	10.0	5.8	9910.0	524.0	57.4	69.2	2.2
03/02/1994	299-W15-84U(b)	10.0	5.8	--	--	64.8	6.8	--
05/10/1994	299-W15-84U	5.0	--	17200.0	--	83.3	100.0	2.0
05/11/1994	299-W15-84U	5.2	--	16300.0	--	79.3	100.0	3.0
06/01/1994	299-W15-84U	11.5	--	5010.0	--	31.7	37.8	1.9
06/10/1994	299-W15-84U	24.9	--	4470.0	--	37.5	38.7	2.0
09/06/1994	299-W15-84U	25.2	12.5	444.0	50.1	7.4	6.9	0.5
10/26/1994	299-W15-84U	28.1	13.3	787.0	94.7	32.5	45.7	3.3
11/22/1994	299-W15-84U	26.4	13.5	348.0	42.7	17.0	--	1.0
01/31/1995	299-W15-84U	26.7	12.5	--	--	--	--	--
02/08/1995	299-W15-84U	25.9	13.3	166.0	19.9	11.9	13.0	2.2
08/02/1995	299-W15-84U	14.9	11.9	54.7	5.9	2.0	4.5	0.6
04/25/1996	299-W15-84U	11.7	12.9	0.0	0.0	0.0	0.0	0.0
09/12/1996	299-W15-84U	6.7	7.0	0.0	0.0	1.6	0.0	0.0
10/29/1996	299-W15-84U	10.5	10.0	1.6	0.1	0.0	0.0	0.0
09/26/1997	299-W15-84U	18.7	0.7	20.8	0.1	2.4	0.0	0.0
09/03/1998	299-W15-84U	3.0	4.2	15.2	0.6	1.0	0.8	0.0
09/14/1998	299-W15-84U	4.2	4.6	13.3	0.6	1.9	0.0	0.0
09/22/1998	299-W15-84U	3.2	4.1	12.8	0.5	0.7	1.4	0.2
09/30/1998	299-W15-84U	2.2	4.2	39.0	1.5	1.5	5.1	0.0

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
06/22/1999	299-W15-84U	3.5	3.3	0.0	0.0	0.0	16.0	0.0
04/02/1993	299-W15-85(a)	32.4	0.0	--	--	--	--	--
04/05/1993	299-W15-85(a)	30.6	0.0	--	--	--	--	--
04/30/1993	299-W15-85	4.2	2.1	16700.0	321.5	--	--	--
03/03/1994	299-W15-85	22.9	6.5	10400.0	614.0	60.3	55.3	1.3
03/03/1994	299-W15-85(b)	22.9	6.5	--	--	16.1	5.5	--
03/03/1994	299-W15-85	15.4	2.7	12600.0	310.5	59.1	76.6	2.2
03/03/1994	299-W15-85(b)	15.4	2.7	--	--	12.9	6.4	--
09/06/1994	299-W15-85	28.6	6.1	256.0	14.2	4.8	1.0	0.3
10/26/1994	299-W15-85	32.4	7.5	237.0	16.1	10.8	15.3	1.2
11/22/1994	299-W15-85	29.9	7.4	111.0	7.4	5.0	--	0.0
01/31/1995	299-W15-85	25.9	5.5	--	--	--	--	--
02/08/1995	299-W15-85	25.2	6.7	86.0	5.2	7.1	7.4	1.7
05/16/1995	299-W15-85	25.9	8.6	41.1	3.2	0.6	2.7	1.0
08/02/1995	299-W15-85	17.9	4.7	18.0	0.8	1.3	2.1	0.6
04/10/1996	299-W15-85	22.4	8.6	47.5	3.7	0.0	0.0	0.0
07/19/1996	299-W15-85	20.9	5.2	97.0	4.5	2.8	0.0	0.0
09/12/1996	299-W15-85	23.4	6.6	64.4	3.9	1.2	0.0	0.0
10/29/1996	299-W15-85	10.5	2.4	6.2	0.1	0.0	0.0	0.0
09/26/1997	299-W15-85	17.4	5.4	22.0	1.1	2.6	0.0	0.0
09/22/1998	299-W15-85	4.0	2.2	1.1	0.0	1.1	0.0	0.0
09/30/1998	299-W15-85	3.2	3.5	0.8	0.0	1.4	0.0	0.0
08/22/1995	299-W15-86(d)	18.7	8.6	215.0	16.8	4.9	10.9	0.7
11/29/1995	299-W15-86(d)	18.7	5.4	59.7	2.9	4.1	6.8	0.6
12/22/1995	299-W15-86(d)	22.4	--	49.0	--	0.5	2.9	--
05/07/1996	299-W15-86(d)	19.7	4.6	2.5	0.1	0.0	0.0	0.0
09/16/1996	299-W15-86(d)	15.4	6.5	65.9	3.9	1.5	0.0	0.0
10/29/1996	299-W15-86(d)	16.2	8.0	41.8	3.0	1.2	1.7	0.0
07/18/1997	299-W15-86(d)	15.2	4.8	138.0	6.0	4.2	0.0	0.0
07/21/1997	299-W15-86(d)	12.5	5.1	111.0	5.1	3.4	0.0	0.0
07/24/1997	299-W15-86(d)	16.4	4.9	57.8	2.6	3.5	0.0	0.0
07/28/1997	299-W15-86(d)	13.9	4.7	69.6	3.0	5.1	0.0	0.0
07/31/1997	299-W15-86(d)	16.7	4.7	62.5	2.7	2.8	0.0	0.0
09/26/1997	299-W15-86(d)	14.9	4.5	34.9	1.4	2.1	0.0	0.0
07/30/1998	299-W15-86(d)	13.0	4.1	107.0	4.0	2.2	0.0	0.0
08/25/1998	299-W15-86(d)	13.9	4.3	37.2	1.5	1.5	0.0	0.0
09/03/1998	299-W15-86(d)	7.5	0.3	1.5	0.0	0.2	0.0	0.1
09/14/1998	299-W15-86(d)	8.2	0.3	0.1	0.0	0.6	0.0	0.0
04/15/1999	299-W15-86(d)	13.7	3.8	4.0	0.1	1.4	0.0	0.0
04/21/1999	299-W15-86(d)	14.9	3.4	64.3	2.0	0.0	4.4	0.0

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
04/28/1999	299-W15-86(d)	19.9	4.5	59.3	2.4	0.0	3.2	0.0
05/03/1999	299-W15-86(d)	19.9	4.8	54.7	2.4	0.0	3.4	0.0
05/10/1999	299-W15-86(d)	19.9	4.8	48.5	2.1	0.0	3.2	0.0
05/17/1999	299-W15-86(d)	19.2	4.8	46.4	2.0	0.0	5.9	0.0
05/25/1999	299-W15-86(d)	18.9	4.7	45.7	1.9	0.0	4.9	0.0
06/01/1999	299-W15-86(d)	18.7	4.5	43.6	1.8	0.0	4.0	0.0
06/10/1999	299-W15-86(d)	17.9	4.4	41.0	1.6	0.0	4.4	0.0
06/15/1999	299-W15-86(d)	9.0	2.8	38.8	1.0	0.0	5.4	0.0
06/21/1999	299-W15-86(d)	9.5	3.0	39.0	1.1	0.0	6.6	0.0
06/25/1999	299-W15-86(d)	7.5	2.6	35.9	0.8	1.0	3.0	0.0
09/05/2001	299-W15-86(d)	9.7	2.4	77.0	1.7	1.0	1.5	0.3
09/12/2001	299-W15-86(d)	7.5	2.0	73.5	1.3	1.1	1.6	0.5
09/20/2001	299-W15-86(d)	8.5	2.1	68.7	1.3	0.8	1.0	0.3
09/05/2001	299-W15-95L	7.5	3.8	25.7	0.9	0.1	2.4	0.3
09/12/2001	299-W15-95L	5.2	3.2	24.3	0.7	0.4	2.4	0.3
09/20/2001	299-W15-95L	5.7	3.1	23.6	0.7	0.2	2.2	0.2
04/05/1993	299-W15-95U(a)	30.6	0.0	--	--	--	--	--
04/13/1993	299-W15-95U(a)(c)	--	0.6	14320.0	73.5	--	--	--
04/14/1993	299-W15-95U(a)(c)	--	0.6	6240.0	32.0	--	--	--
04/28/1993	299-W15-95U	29.4	1.0	10700.0	93.4	--	--	--
03/08/1994	299-W15-95U	26.2	0.6	11900.0	64.1	60.9	67.3	1.6
03/08/1994	299-W15-95U(b)	26.2	0.6	--	--	12.6	4.6	--
05/18/1994	299-W15-95U	25.7	2.1	8740.0	166.0	44.9	49.6	0.0
06/01/1994	299-W15-95U	11.5	--	4530.0	--	21.9	30.3	0.6
06/10/1994	299-W15-95U	24.9	--	2110.0	--	14.1	18.4	1.3
09/06/1994	299-W15-95U	24.7	1.8	444.0	7.2	6.4	5.3	0.4
10/26/1994	299-W15-95U	28.1	2.3	330.0	6.9	14.5	19.6	1.6
11/22/1994	299-W15-95U	26.9	2.1	249.0	4.7	11.0	--	0.0
01/31/1995	299-W15-95U	27.9	1.5	--	--	--	--	--
02/10/1995	299-W15-95U	29.4	1.6	211.0	3.5	10.9	12.4	1.4
05/02/1996	299-W15-95U(d)	14.9	9.9	1.7	0.1	0.0	0.0	0.0
09/11/1996	299-W15-95U(d)	15.9	9.1	1.0	0.1	1.4	0.0	0.0
10/29/1996	299-W15-95U(d)	9.5	3.3	0.0	0.0	1.6	0.0	0.0
09/26/1997	299-W15-95U(d)	19.9	2.4	33.6	0.7	3.4	0.0	0.0
09/03/1998	299-W15-95U(d)	5.5	5.0	6.9	0.3	1.2	0.0	0.0
09/14/1998	299-W15-95U(d)	6.5	4.8	0.4	0.0	1.3	0.0	0.0
06/22/1999	299-W15-95U(d)	6.0	3.3	0.0	0.0	0.0	13.3	0.0
03/17/1994	299-W15-216L	26.4	2.4	878.0	19.4	3.9	6.9	0.7
03/17/1994	299-W15-216L(b)	26.4	2.4	--	--	0.2	0.1	--
02/02/1995	299-W15-216L	28.1	2.0	--	--	--	--	--

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
02/14/1995	299-W15-216L	27.1	2.0	139.0	2.6	6.5	7.4	1.1
07/10/1995	299-W15-216L	21.2	0.8	77.5	0.5	1.9	3.9	0.7
11/28/1995	299-W15-216L	18.7	0.7	39.7	0.2	0.0	0.9	0.0
12/20/1995	299-W15-216L	19.4	--	32.7	--	0.3	1.2	--
04/19/1996	299-W15-216L	23.2	1.4	17.8	0.2	0.0	0.0	0.0
05/14/1996	299-W15-216L	22.4	0.8	27.3	0.2	0.0	0.0	0.0
09/11/1996	299-W15-216L	18.7	1.6	9.5	0.1	2.0	0.0	0.0
10/29/1996	299-W15-216L	14.4	1.4	11.3	0.1	0.0	0.0	0.0
09/30/1997	299-W15-216L	14.9	1.7	5.5	0.1	5.6	0.0	0.0
09/22/1998	299-W15-216L	4.7	1.1	5.3	0.1	1.0	0.0	0.0
09/30/1998	299-W15-216L	4.5	1.1	5.7	0.1	0.2	0.0	0.0
03/18/1994	299-W15-216U	26.7	5.6	1410.0	70.9	9.2	8.8	0.0
03/18/1994	299-W15-216U(b)	26.7	5.6	--	--	4.4	0.2	--
02/02/1995	299-W15-216U	23.9	7.2	--	--	--	--	--
02/14/1995	299-W15-216U	25.4	7.6	40.0	2.8	3.9	2.5	0.9
07/10/1995	299-W15-216U	19.9	8.1	24.0	1.8	0.1	0.6	0.0
04/19/1996	299-W15-216U	18.4	6.5	14.9	0.9	0.0	0.0	0.0
07/23/1996	299-W15-216U	20.2	6.1	4.7	0.3	1.4	0.0	0.0
09/11/1996	299-W15-216U	16.2	7.0	7.1	0.4	1.7	0.0	0.0
10/29/1996	299-W15-216U	8.7	5.7	12.0	0.6	0.0	0.0	0.0
09/30/1997	299-W15-216U	13.9	1.9	3.2	0.1	4.3	0.0	0.0
09/22/1998	299-W15-216U	3.2	2.7	6.5	0.2	1.2	0.0	0.0
09/30/1998	299-W15-216U	3.0	2.8	4.8	0.1	0.6	0.0	0.0
05/04/1993	299-W15-217	15.4	2.1	18200.0	350.4	--	--	--
05/05/1993	299-W15-217	32.4	4.4	23800.0	959.2	--	--	--
05/10/1993	299-W15-217	29.6	5.3	23000.0	1098.1	--	--	--
05/11/1993	299-W15-217	23.7	5.0	25500.0	1165.1	--	--	--
03/04/1994	299-W15-217	7.0	1.1	15500.0	159.2	76.0	88.9	2.9
03/04/1994	299-W15-217(b)	7.0	1.1	--	--	15.1	3.5	--
03/04/1994	299-W15-217	10.2	2.1	16300.0	313.8	74.4	96.7	3.9
03/04/1994	299-W15-217(b)	10.2	2.1	--	--	24.7	3.7	--
03/04/1994	299-W15-217	15.2	2.7	20300.0	495.0	93.2	112.0	3.9
03/04/1994	299-W15-217(b)	15.2	2.7	--	--	18.5	3.0	--
03/04/1994	299-W15-217	18.2	2.8	21400.0	549.3	104.0	122.0	3.7
03/04/1994	299-W15-217(b)	18.2	2.8	--	--	17.3	2.9	--
05/10/1994	299-W15-217	5.0	--	7070.0	--	44.5	47.1	1.9
05/11/1994	299-W15-217	5.2	--	7000.0	--	42.9	48.4	1.8
06/01/1994	299-W15-217	11.5	--	10600.0	--	60.3	67.1	2.1
06/10/1994	299-W15-217	24.9	--	6800.0	--	59.1	53.5	1.7
09/06/1994	299-W15-217	28.4	4.5	1420.0	57.6	20.6	11.0	0.8

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
10/26/1994	299-W15-217	32.4	5.7	1430.0	74.5	57.6	77.5	5.5
11/22/1994	299-W15-217	30.6	5.2	1131.0	53.4	44.0	--	3.0
01/31/1995	299-W15-217	28.4	5.3	--	--	--	--	--
02/10/1995	299-W15-217	28.9	5.0	690.0	31.4	28.9	36.0	4.3
05/16/1995	299-W15-217	26.2	5.8	150.0	7.9	1.0	4.6	1.0
08/02/1995	299-W15-217	15.4	1.9	63.0	1.1	0.0	0.2	0.1
11/29/1995	299-W15-217	20.7	2.9	104.0	2.7	5.9	10.1	0.8
12/22/1995	299-W15-217	23.4	--	102.0	--	0.9	2.8	--
04/25/1996	299-W15-217	23.9	3.3	27.2	0.8	0.0	0.0	0.0
07/19/1996	299-W15-217	21.7	3.8	2.8	0.1	0.0	0.0	0.0
09/10/1996	299-W15-217	23.7	5.7	2.1	0.1	0.0	0.0	0.0
10/29/1996	299-W15-217	16.9	7.9	71.7	5.1	0.0	2.6	0.0
07/18/1997	299-W15-217	15.7	4.7	256.0	10.9	3.5	0.5	0.0
07/21/1997	299-W15-217	12.5	5.8	86.3	4.5	4.1	0.0	0.0
07/24/1997	299-W15-217	17.4	3.8	164.0	5.6	3.6	2.7	0.0
07/28/1997	299-W15-217	14.7	3.8	129.0	4.4	5.3	0.0	0.0
07/31/1997	299-W15-217	17.4	3.8	131.0	4.5	3.5	0.0	0.0
09/26/1997	299-W15-217	14.9	4.0	26.0	0.9	1.8	0.0	0.0
07/10/1998	299-W15-217	14.9	4.4	135.0	5.4	2.7	5.8	0.0
07/30/1998	299-W15-217	12.5	4.0	50.4	1.8	1.8	1.1	0.2
08/25/1998	299-W15-217	10.5	2.8	5.9	0.1	1.4	0.0	0.0
03/30/1999	299-W15-217	18.7	4.0	116.0	4.2	1.1	0.0	0.0
04/05/1999	299-W15-217	18.2	4.1	82.0	3.1	0.0	NA	NA
04/12/1999	299-W15-217	17.4	4.4	65.6	2.6	1.3	0.0	1.4
04/21/1999	299-W15-217	14.9	3.8	65.2	2.5	0.0	5.8	0.0
04/28/1999	299-W15-217	18.7	5.0	47.0	2.1	0.0	4.5	0.0
05/03/1999	299-W15-217	18.4	4.9	51.4	2.3	0.0	5.3	0.0
05/10/1999	299-W15-217	18.4	4.9	48.5	2.2	0.0	5.8	0.0
05/17/1999	299-W15-217	18.9	5.0	45.7	2.1	0.0	6.8	0.0
05/25/1999	299-W15-217	17.7	4.7	40.9	1.7	0.0	7.3	0.0
06/01/1999	299-W15-217	18.9	4.6	45.6	1.9	0.0	7.3	0.0
06/10/1999	299-W15-217	17.4	4.5	30.5	1.3	0.0	8.0	0.0
06/15/1999	299-W15-217	9.5	2.4	34.5	0.7	0.0	9.2	0.0
06/21/1999	299-W15-217	10.2	2.6	28.0	0.7	0.0	9.5	0.0
06/25/1999	299-W15-217	8.5	2.0	40.8	0.7	0.0	6.7	0.0
07/23/2001	299-W15-217	22.4	4.8	236.0	10.3	3.0	15.1	1.2
08/01/2001	299-W15-217	12.0	2.5	167.0	3.9	1.9	6.7	0.7
08/08/2001	299-W15-217	12.7	2.5	141.0	3.1	1.5	4.4	0.6
08/22/2001	299-W15-217	11.7	2.7	101.0	2.4	1.0	2.7	0.7
09/05/2001	299-W15-217	10.7	2.0	65.5	1.2	0.9	1.7	0.3

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
09/12/2001	299-W15-217	8.0	1.6	54.5	0.8	0.8	1.5	0.4
09/20/2001	299-W15-217	8.7	2.0	52.2	0.9	0.7	1.0	0.3
03/24/1994	299-W15-218L	24.7	4.3	808.0	31.7	4.9	7.4	0.3
03/24/1994	299-W15-218L(b)	24.7	4.3	--	--	1.2	<0.1	--
09/07/1994	299-W15-218L	27.4	2.9	595.0	15.9	8.8	8.8	0.5
10/26/1994	299-W15-218L	30.1	4.4	319.0	12.9	16.4	26.4	1.7
11/22/1994	299-W15-218L	28.9	4.8	175.0	7.7	9.0	--	0.0
02/02/1995	299-W15-218L	26.9	4.2	--	--	--	--	--
02/14/1995	299-W15-218L	27.9	4.2	127.0	4.8	9.4	12.7	1.6
05/16/1995	299-W15-218L	25.7	5.2	17.2	0.8	0.4	3.7	0.9
08/02/1995	299-W15-218L	18.7	2.7	42.5	1.0	1.3	4.8	0.5
11/28/1995	299-W15-218L(e)	21.4	2.9	26.1	0.7	2.8	5.5	0.4
12/20/1995	299-W15-218L(e)	21.9	--	23.4	--	0.5	4.1	--
04/10/1996	299-W15-218L	24.9	3.8	24.2	0.8	0.0	2.5	0.0
05/14/1996	299-W15-218L	23.2	3.7	19.8	0.7	0.0	1.8	0.0
07/19/1996	299-W15-218L	24.4	3.8	15.0	0.5	1.1	1.6	0.0
09/11/1996	299-W15-218L	15.4	4.1	16.1	0.6	1.1	1.6	0.0
10/29/1996	299-W15-218L	8.0	1.6	13.7	0.2	0.0	1.8	0.0
07/18/1997	299-W15-218L	19.9	3.0	20.3	0.6	3.0	0.3	0.0
07/21/1997	299-W15-218L	12.7	2.4	21.9	0.5	2.7	1.6	0.2
07/24/1997	299-W15-218L	15.9	2.4	20.0	0.4	2.5	0.0	0.0
07/28/1997	299-W15-218L	14.9	2.4	20.0	0.4	2.4	0.0	0.0
07/31/1997	299-W15-218L	16.2	--	12.4	--	1.9	0.0	0.0
09/26/1997	299-W15-218L	18.7	2.9	16.2	0.4	2.1	1.9	0.0
06/22/1999	299-W15-218L	7.5	1.4	24.2	0.3	0.0	8.8	0.0
06/25/1999	299-W15-218L	10.2	2.0	22.2	0.4	0.0	6.2	0.0
09/12/2001	299-W15-218L	8.7	1.5	28.6	0.4	0.3	3.6	0.4
09/20/2001	299-W15-218L	10.0	1.6	29.6	0.4	0.2	2.7	0.3
03/25/1994	299-W15-218U	24.7	2.8	14800.0	372.3	65.2	82.7	0.0
03/25/1994	299-W15-218U(b)	24.7	2.8	--	--	12.0	0.7	--
09/07/1994	299-W15-218U	29.1	3.7	424.0	14.0	7.6	4.2	0.1
10/26/1994	299-W15-218U	31.6	6.3	339.0	19.5	17.5	28.5	1.9
11/22/1994	299-W15-218U	29.1	5.0	181.0	8.1	9.0	--	0.0
02/02/1995	299-W15-218U	26.9	4.2	--	--	--	--	--
02/14/1995	299-W15-218U	27.4	4.2	143.0	5.4	7.6	7.8	1.2
05/16/1995	299-W15-218U	24.7	5.1	57.4	2.7	0.4	7.5	1.2
05/16/1995	299-W15-218U(L)	25.9	8.6	37.7	2.9	1.2	5.3	1.3
08/02/1995	299-W15-218U	17.4	5.0	56.8	2.6	1.7	6.6	0.5
11/28/1995	299-W15-218U(e)	18.4	5.5	25.6	1.3	2.4	5.2	0.2
12/20/1995	299-W15-218U(e)	19.2	--	23.8	--	0.2	4.3	--

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
04/10/1996	299-W15-218U	24.9	3.8	24.3	0.3	0.0	2.1	0.0
07/19/1996	299-W15-218U	24.9	2.4	8.8	0.2	2.1	0.0	0.0
09/11/1996	299-W15-218U	17.9	2.4	6.9	0.1	1.1	0.0	0.0
10/29/1996	299-W15-218U	7.0	2.9	15.6	0.4	0.0	2.5	0.0
07/18/1997	299-W15-218U	17.4	6.0	21.1	1.2	1.9	0.9	0.0
07/21/1997	299-W15-218U	11.5	4.6	21.8	0.9	2.0	1.5	0.0
07/24/1997	299-W15-218U	13.7	4.2	21.1	0.8	4.8	0.0	0.0
07/28/1997	299-W15-218U	12.7	4.2	22.0	0.8	2.7	0.0	0.0
07/31/1997	299-W15-218U	16.2	3.3	19.1	0.6	3.4	0.0	0.0
09/26/1997	299-W15-218U	12.5	5.4	15.0	0.7	2.6	0.0	0.0
07/30/1998	299-W15-218U	12.0	2.4	5.7	0.1	1.1	0.0	0.2
06/15/1999	299-W15-218U	10.0	1.3	7.7	0.1	0.0	4.1	0.0
06/21/1999	299-W15-218U	13.9	2.6	6.0	0.1	0.0	4.2	0.0
06/25/1999	299-W15-218U	10.2	2.0	7.3	0.1	2.0	0.0	0.0
03/21/1994	299-W15-219L	27.9	3.8	2360.0	80.6	13.3	20.1	0.3
03/21/1994	299-W15-219L(b)	27.9	3.8	--	--	3.2	0.1	--
09/07/1994	299-W15-219L	27.6	3.5	450.0	14.3	6.4	8.0	0.3
10/26/1994	299-W15-219L	29.9	3.6	341.0	11.0	16.6	26.5	1.7
11/22/1994	299-W15-219L	28.1	4.1	192.0	7.1	10.0	--	0.0
02/02/1995	299-W15-219L	26.2	3.3	--	--	--	--	--
02/13/1995	299-W15-219L	27.6	3.4	172.0	5.3	10.4	15.8	1.5
05/16/1995	299-W15-219L	26.2	3.8	38.0	1.3	0.6	4.4	0.7
08/02/1995	299-W15-219L	22.4	2.0	26.3	0.5	2.0	2.2	0.1
11/29/1995	299-W15-219L	19.7	1.0	23.2	0.2	3.5	5.8	0.7
04/19/1996	299-W15-219L(e)	22.4	2.4	25.1	0.5	0.0	0.1	0.0
05/14/1996	299-W15-219L	23.9	2.5	20.6	0.5	0.0	1.4	0.0
09/11/1996	299-W15-219L	20.2	3.3	5.2	0.2	0.0	0.0	0.0
10/29/1996	299-W15-219L	13.9	2.6	12.8	0.3	0.0	2.9	0.0
09/30/1997	299-W15-219L	15.4	2.4	10.8	0.2	3.4	0.0	0.0
09/03/1998	299-W15-219L	4.7	1.0	18.3	0.2	1.3	1.0	0.1
09/14/1998	299-W15-219L	4.7	1.0	16.8	0.2	1.4	1.5	0.0
09/22/1998	299-W15-219L	3.0	1.0	12.4	0.1	0.8	1.5	0.2
09/30/1998	299-W15-219L	2.7	1.0	12.6	0.1	0.8	0.8	0.0
06/15/1999	299-W15-219L	10.0	1.4	24.6	0.3	0.0	6.8	0.0
06/21/1999	299-W15-219L	11.2	1.5	21.2	0.3	0.0	8.1	0.0
06/25/1999	299-W15-219L	7.0	1.0	20.2	0.2	0.0	4.7	0.0
03/22/1994	299-W15-219U	27.1	4.3	9710.0	381.4	42.2	59.1	0.0
03/22/1994	299-W15-219U(b)	27.1	4.3	--	--	6.8	0.2	--
09/07/1994	299-W15-219U	28.1	3.5	490.0	15.6	8.4	7.0	0.3
10/26/1994	299-W15-219U	30.6	4.2	430.0	16.4	20.6	29.7	2.2

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
11/22/1994	299-W15-219U	27.9	4.2	93.0	3.6	4.0	--	0.0
02/02/1995	299-W15-219U	26.2	4.4	--	--	--	--	--
02/13/1995	299-W15-219U	26.9	4.0	72.0	2.6	5.0	5.4	0.8
05/16/1995	299-W15-219U	26.4	4.7	16.1	0.7	1.1	2.3	0.7
05/16/1995	299-W15-219U,L	25.2	6.8	27.0	1.7	0.8	2.5	0.3
08/02/1995	299-W15-219U	22.4	2.4	21.0	0.4	0.7	2.1	0.4
11/29/1995	299-W15-219U	18.9	1.8	13.0	0.2	2.3	3.4	0.4
12/22/1995	299-W15-219U	21.4	--	6.8	--	0.4	1.6	--
04/24/1996	299-W15-219U(e)	22.4	4.1	24.1	0.9	0.0	1.1	0.0
07/23/1996	299-W15-219U	19.4	2.2	4.0	0.1	0.0	0.0	0.0
09/11/1996	299-W15-219U	22.4	3.0	13.6	0.4	1.1	0.0	0.0
10/29/1996	299-W15-219U	13.7	4.0	0.0	0.0	0.0	0.0	0.0
09/30/1997	299-W15-219U	15.9	2.5	10.2	0.2	2.0	0.0	0.0
03/23/1994	299-W15-220L	25.9	4.2	589.0	22.5	3.0	3.8	0.3
03/23/1994	299-W15-220L(b)	25.9	4.2	--	--	0.3	<0.1	--
02/13/1995	299-W15-220L	27.6	4.2	190.0	7.2	9.9	11.6	1.5
08/21/1995	299-W15-220L	14.9	2.7	74.8	1.8	0.9	2.3	0.2
11/28/1995	299-W15-220L	20.2	2.8	32.6	0.8	0.0	0.7	0.0
12/20/1995	299-W15-220L	22.7	--	23.2	--	0.7	0.8	--
04/19/1996	299-W15-220L(e)	26.2	2.7	16.8	0.4	0.0	0.0	0.0
05/14/1996	299-W15-220L	23.2	3.0	17.4	0.5	0.0	0.0	0.0
09/11/1996	299-W15-220L	19.4	3.9	10.6	0.4	1.2	0.0	0.0
10/29/1996	299-W15-220L	11.2	3.2	12.1	0.3	1.2	0.0	0.0
09/26/1997	299-W15-220L	13.4	2.1	13.5	0.3	3.0	0.0	0.0
09/22/1998	299-W15-220L	2.5	1.1	9.7	0.1	0.9	0.0	0.1
09/30/1998	299-W15-220L	2.5	1.1	10.2	0.1	0.9	0.0	0.0
03/23/1994	299-W15-220U	23.2	4.5	2740.0	111.1	13.3	19.6	0.0
03/23/1994	299-W15-220U(b)	23.2	4.5	--	--	1.0	<0.1	--
02/13/1995	299-W15-220U	26.2	5.1	231.0	10.7	10.5	12.3	1.5
08/21/1995	299-W15-220U	19.9	4.5	108.0	4.4	1.5	3.2	0.1
11/28/1995	299-W15-220U	18.9	3.8	42.1	1.5	0.0	0.6	0.0
12/20/1995	299-W15-220U	20.4	--	29.4	--	0.6	0.5	--
04/19/1996	299-W15-220U(e)	26.4	4.8	21.5	0.9	0.0	0.0	0.0
07/23/1996	299-W15-220U	18.7	3.5	11.4	0.4	1.4	0.0	0.0
09/10/1996	299-W15-220U	18.7	5.8	0.0	0.0	0.0	0.0	0.0
10/29/1996	299-W15-220U	10.0	3.8	8.1	0.3	1.2	0.0	0.0
09/26/1997	299-W15-220U	12.7	2.7	0.0	0.0	2.6	0.0	0.0
06/22/1999	299-W15-220U	4.7	2.8	17.4	0.4	0.0	2.7	0.0
06/25/1999	299-W15-220U	6.7	3.5	19.3	0.6	1.7	0.0	0.0
03/16/1994	299-W15-223	22.7	5.9	1500.0	80.5	8.4	11.3	0.1

Appendix B – Characterization Data

Table B-3. Characterization Data for Individual Extraction Wells in the 216-Z-9 Wellfield, March 1993-September 2001. (13 Pages)

Date	Well and Interval	Vacuum* (kPa)	Flow (m ³ /min)	CCl ₄ (ppmv)	CCl ₄ Flux (kg/day)	CHCl ₃ (ppmv)	CH ₂ Cl ₂ (ppmv)	MEK (ppmv)
03/16/1994	299-W15-223(b)	22.7	5.9	--	--	2.1	0.1	--
02/01/1995	299-W15-223	27.6	8.1	--	--	--	--	--
02/14/1995	299-W15-223	30.1	4.7	761.0	32.6	28.7	35.1	4.1
05/15/1995	299-W15-223	24.7	8.9	21.3	1.7	1.6	0.7	0.9
06/30/1995	299-W15-223	16.2	5.9	21.9	1.2	1.5	4.4	0.8
09/19/1995	299-W15-223	13.0	5.1	62.7	2.9	--	--	--
09/26/1995	299-W15-223	--	--	18.3	--	--	--	--
05/01/1996	299-W15-223	12.5	6.4	64.1	3.7	0.0	0.0	0.0
09/12/1996	299-W15-223	14.4	8.4	58.5	4.5	2.1	0.0	0.0
10/29/1996	299-W15-223	9.0	3.9	10.0	0.4	2.7	0.0	0.0
09/26/1997	299-W15-223	16.2	6.6	0.0	0.0	2.8	0.0	0.0
06/15/1999	299-W15-223	6.7	3.0	28.9	0.8	0.0	3.8	0.0
06/21/1999	299-W15-223	9.0	3.3	10.1	0.3	0.0	4.6	0.0
09/12/2001	299-W15-223	7.5	2.3	15.9	0.3	0.2	0.5	0.2
09/20/2001	299-W15-223	8.5	2.5	9.9	0.2	0.0	0.0	0.1
06/03/1993	CPT-8	23.9	0.3	54	0.2	--	--	--
05/27/1993	CPT-12	25.2	1.8	74.0	1.2	3.4	--	--

*After 6/15/95, all measurements made at the wellhead.

*Before perforating well casing.

^bGas chromatograph analysis.

^cOdyssey analysis.

^dAfter jet perforating.

*Packer deflated.

CCl₄ = carbon tetrachloride

CHCl₃ = chloroform

CH₂Cl₂ = methylene chloride

MEK = methyl ethyl ketone

APPENDIX C
PASSIVE SOIL VAPOR EXTRACTION DATA

PASSIVE SOIL VAPOR EXTRACTION DATA

This appendix contains data collected at passive soil vapor extraction (PSVE) systems operating on eight wells in the 216-Z-1A/Z-18 wellfield between October 1999 and September 2001. The eight PSVE systems are installed on wells 299-W18-6L, 299-W18-7, 299-W18-10L, 299-W18-11L, 299-W18-12, 299-W18-246L, 299-W18-247L, and 299-W18-252L. All eight PSVE systems are installed on wells with intervals open below the Plio-Pleistocene layer. Some well names include an "L" following the number to designate this lower interval (e.g., 299-W18-6L); these wells also have an interval open above the Plio-Pleistocene layer that would be designated by a "U" following the number (e.g., 299-W18-6U). In wells with two open intervals, the intervals are isolated by a downhole packer.

All eight PSVE systems include a removable cartridge of granular activated carbon (GAC) that is replaced monthly; samples of the GAC that was removed from the well are then sent to an offsite laboratory for analysis of carbon tetrachloride concentrations. In addition, three of the wells (299-W18-6L, 299-W18-247L, and 299-W18-252L) are instrumented to record flow, differential pressure, temperature, and carbon tetrachloride concentrations hourly. In these three wells, differential pressures are also monitored hourly in the well intervals open above the Plio-Pleistocene (299-W18-6U, 299-W18-247U, and 299-W18-252U). A ninth well, 299-W18-9, has an interval open below the Plio-Pleistocene layer, is sealed to atmosphere, and serves as a control well. It is instrumented to record differential pressure and temperatures hourly. In wells 299-W18-6L, 299-W18-247L, 299-W18-252L, and 299-W18-9, temperatures are measured at 3 m and 61 m below the top of the well. Differential pressures are also monitored hourly at three stainless steel tubes open at depths above, between, and below the two screens on well 299-W18-252 and at five soil vapor probes installed above the Plio-Pleistocene layer at CPT-4F.

The PSVE systems are described in Section 3.0 of this report. Evaluation of the data is provided in Section 5.7 of this report. The locations of the PSVE systems and associated differential pressure monitoring are shown in Figure 5-46.

The following data are included in this appendix:

- Carbon tetrachloride concentrations monitored hourly at the three instrumented PSVE systems (Figures C-1 through C-3)
- Chloroform concentrations monitored hourly at the three instrumented PSVE systems (Figure C-4 through C-6)
- Methylene chloride concentrations monitored hourly at the three instrumented PSVE systems (Figures C-7 through C-9)
- Comparisons of flows and differential pressures monitored hourly at the three instrumented PSVE systems in FY 2000 (Figures C-10 through C-12) and FY 2001 (Figures C-13 through C-15)

Appendix C – Passive Soil Vapor Extraction Data

- Temperatures monitored hourly at the three instrumented PSVE systems and at the sealed control well (Figures C-16 through C-19)
- Monthly comparisons of carbon tetrachloride concentrations monitored hourly at the three instrumented PSVE systems (Figures C-20 through C-36).
- Sample collection and analysis data for the GAC cartridges at the eight PSVE systems (Tables C-1 through C-24)
- Volume of water drained from GAC cartridges and hoses during sample collection at the eight PSVE systems (Table C-25)
- Passive soil vapor extraction well network parameter and instrumentation (Table C-26)
- Summary of contaminant concentrations, differential pressures, and flowrates measured during passive soil vapor extraction (Tables C-27 and C-28)

C.1 MONTHLY GAC CARTRIDGE SAMPLING AND ANALYSIS

The following method is used to collect samples from the passive GAC sample cartridges:

1. Upon arrival, collect all 8 previously-prepared sample cartridges stored at the site. Each of the cartridges has been assigned to a specific well and labeled accordingly. At each of the passive well sites, replace the in-line cartridge with the corresponding cartridge of clean GAC.
2. Sample each of the removed cartridges by pouring the GAC into a plastic bag. Weigh the used GAC from the cartridge and record the weight. Using a sterile scoop, mix the GAC in the bag thoroughly and fill sample jars with sample media. The sample jar size is 250 mL.
3. Fill the cartridge with approximately 0.45 kg (1 lb) of clean GAC. Weigh the clean GAC used to fill the cartridge and record the weight.
4. Store the re-filled clean cartridges for use during the next sampling event the following month.

The volume of drainable water contained in the used GAC cartridges and/or in the PSVE hoses is estimated and recorded by the sampler. Routine inspection by the soil vapor extraction system operator also resulted in occasional water drainage from the PSVE hoses.

The sampling is performed in accordance with the following procedures:

- BHI-EE-01, Procedure 1.5 "Field Logbooks"

Appendix C – Passive Soil Vapor Extraction Data

- BHI-EE-01, Procedure 3.0 “Chain of Custody”
- BHI-EE-01, Procedure 3.1 “Sample Packaging and Shipping”
- BHI-EE-01, Procedure 4.4 “Container Sampling.”

At the off-site laboratory, a subsample of the GAC sample is used for analysis. Initially, two methods were selected for analysis of carbon tetrachloride on the GAC: bomb combustion to obtain a total volatile organic compound (VOC) concentration (i.e., total chloride concentration) and traditional volatile organic analysis (VOA) (SW-846 method 8260) to obtain individual VOC concentrations. The purpose of selecting two methods was to evaluate whether the traditional method was detecting all of the VOC by comparing the total VOC concentration to the sum of the individual VOC concentrations. The laboratory also provides % moisture for each sample.

Based on initial analytical results, the bomb combustion method was discontinued. Because of the water content on the GAC, the laboratory was unable to get the GAC to burn consistently. In the October 1999 analytical results, low total chloride results correlate to GAC noted to be wet at time of sampling (Tables C-1 and C-2). In addition, the high carbon tetrachloride concentrations detected by the traditional VOA method suggested that the traditional VOA method (which does not have a low detection limit) would be adequate to analyze the samples. Therefore, the bomb combustion method was not retained for analysis of the GAC.

Because of the high carbon tetrachloride concentrations, the VOA method was modified to be “medium level.” In the medium-level method, methanol is used to extract carbon tetrachloride from the GAC. This approach improves the consistency of the laboratory results and avoids overwhelming the gas chromatograph with high concentrations. Although using methanol may result in a more thorough removal of the carbon tetrachloride for analysis, it also results in dilution of the sample. Dilution of the sample may explain the results for chloroform being below the detection limit in later analyses.

The mass of carbon tetrachloride on each cartridge of GAC is calculated according to the following method:

1. Receive laboratory values based on as-received material:
 - a. carbon tetrachloride concentration as (micrograms of carbon tetrachloride)/(kilograms of GAC and water) in aliquot, where the GAC in the aliquot consists of GAC and water;
 - b. percent solids as (kg of dry GAC)/(kilograms of GAC and water) * 100
2. Divide the carbon tetrachloride result by the percent solids, providing (micrograms of carbon tetrachloride)/(kilograms of dry GAC)
3. Multiply by the dry weight of GAC in the cartridge measured by the sampler before the cartridge is placed on the well, providing (micrograms of carbon tetrachloride)

Grams of carbon tetrachloride = $[(\mu\text{g CCl}_4)/(\text{kg GAC}+\text{water})/(\text{percent solids})] * (\text{kg dry GAC}) * (1 \text{ g}) / (1\text{E}+06 \mu\text{g})$.

Appendix C – Passive Soil Vapor Extraction Data

C.2 HOURLY WELLHEAD SAMPLING AND ANALYSIS

Three of the eight wells used for passive extraction (299-W18-6L, 299-W18-247L, 299-W18-252L) are also instrumented to record hourly data (flow, differential pressure, temperature, and carbon tetrachloride concentrations). The flow, pressure, and temperature data are recorded on Campbell dataloggers; the carbon tetrachloride concentrations are stored in the memory of the B&K monitors. The hourly data are downloaded from the dataloggers and from the B&Ks every 2 to 4 weeks. The instruments are powered by line power. The flow meters measure flow in 1.2-m (4-ft) lengths of 10.2-cm (4-in.)-diameter PVC pipe built in-line with the flexible hoses (Figure 3-3). Twelve additional locations in the 216-Z-1A/Z-18 well field are instrumented to measure hourly differential pressure and/or temperature data that is recorded on a datalogger, downloaded every 2 to 4 weeks, and powered by line power. The instrumentation used at these locations is identified in Table C-26.

At each of the three instrumented wells, a sampling pump is used to pull a vapor sample from the wellhead for analysis by the B&K to protect the internal pump in the B&K from pulling against the downhole differential pressure. The sampling pump releases the vapor sample into a buffer jar which has a narrow diameter tube to atmosphere to maintain ambient pressure in the sample chamber. The internal pump on the B&K samples from the buffer jar.

The datalogger is programmed to turn on the sample pump to sample the well at 2 minutes before the hour. The datalogger is programmed to turn off the sample pump at 5 minutes after the hour. After downloading the B&K, the sampler turns on the B&K at a time close to, but after, 5 minutes after the hour (e.g., 6 minutes after the hour). The B&K is programmed to sample every 60 minutes after that (in this example, theoretically always sampling at 6 minutes after the hour). However, the B&K internal clock loses time at a rate of approximately 7 minutes every 2 weeks.

The datalogger is programmed to measure temperature, pressure, and flow every ten seconds and to save the data in an intermediate memory. At the end of each hour, the data are averaged and the result recorded as a single data point for that hour.

To calculate the mass removed using the flow and concentration data, the B&K data must be assigned to the top of the hour to be associated with the corresponding flow data. Because of the drifting B&K clock, the following rule was used to assign B&K data to a particular hour: If the B&K analysis is recorded at a time later than 2 minutes before the hour and earlier than 2 minutes before the following hour, the data is assigned to that hour. For example, data collected between 9:58 and 10:58 is assigned to 10:00.

In January 2000, it was discovered that at well 299-W18-247L, the sample tube length had been entered into the B&K computer program as 0 ft. instead of 10 ft. The sample tube length affects the purge time for the sample loop (the B&K calculates the purge volume/time based in part on sample tube length). Between October 1999 and January 2000, carbon tetrachloride concentrations recorded at this well were very low. After January 2000 concentrations became detectable and followed a typical venting well pattern (rising and falling with barometric

Appendix C – Passive Soil Vapor Extraction Data

pressure fluctuations). Therefore, concentration data collected prior to correcting the parameter in the B&K computer have been disregarded as unrepresentative.

After January 15, 2001, the soil vapor results from well 299-W18-247L are flagged with an "X". The flag is automatically supplied by the B&K instrument and indicates an error message. These data do not appear to be representative of the passive soil vapor extraction process. On April 4, 2001, the sampler noted that the B&K internal sample pump was not working. It is assumed that the error flag is a result of the malfunctioning pump, and these data were not retained for analysis.

The mass of carbon tetrachloride removed is calculated based on the following formula:

$$\text{Grams of carbon tetrachloride} = X \text{ ppmv} * Y \text{ ft}^3/\text{min} * 60 \text{ min/hr} * 1 \text{ hr} * (1/E+06) * 153.84 \text{ g/mol} * 1 \text{ mol}/22.4 \text{ L} (0 \text{ }^\circ\text{C}, 1 \text{ atm}) * 273 \text{ }^\circ\text{K}/298 \text{ }^\circ\text{K} * 28.32 \text{ L/ft}^3.$$

Figure C-1. Carbon Tetrachloride Concentrations Monitored Hourly at Well 299-W18-6L, October 1999 through April 2001.

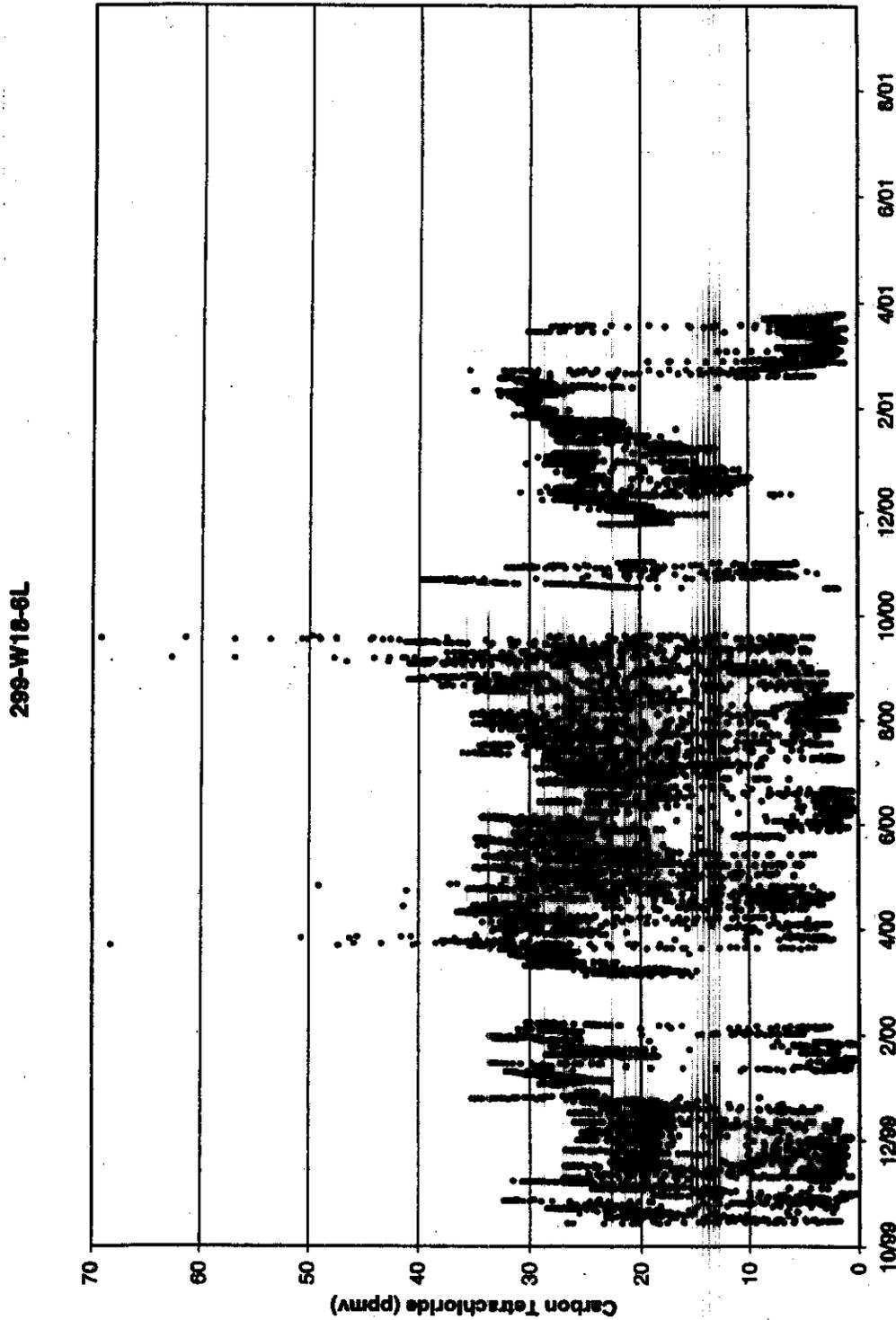


Figure C-2. Carbon Tetrachloride Concentrations Monitored Hourly at Well 299-W18-247L, October 1999 through April 2001.

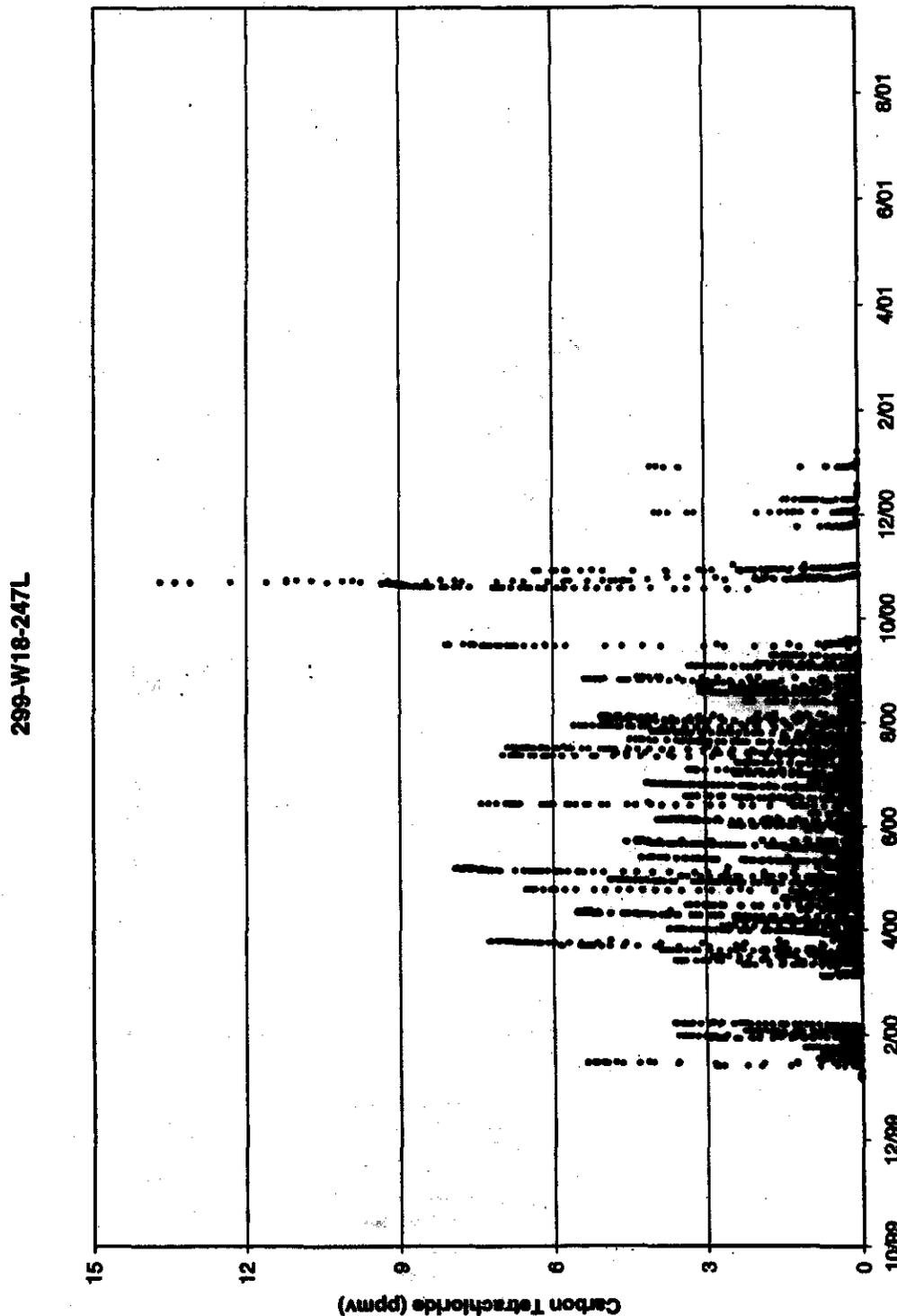


Figure C-3. Carbon Tetrachloride Concentrations Monitored Hourly at Well 299-W18-252L, October 1999 through April 2001.

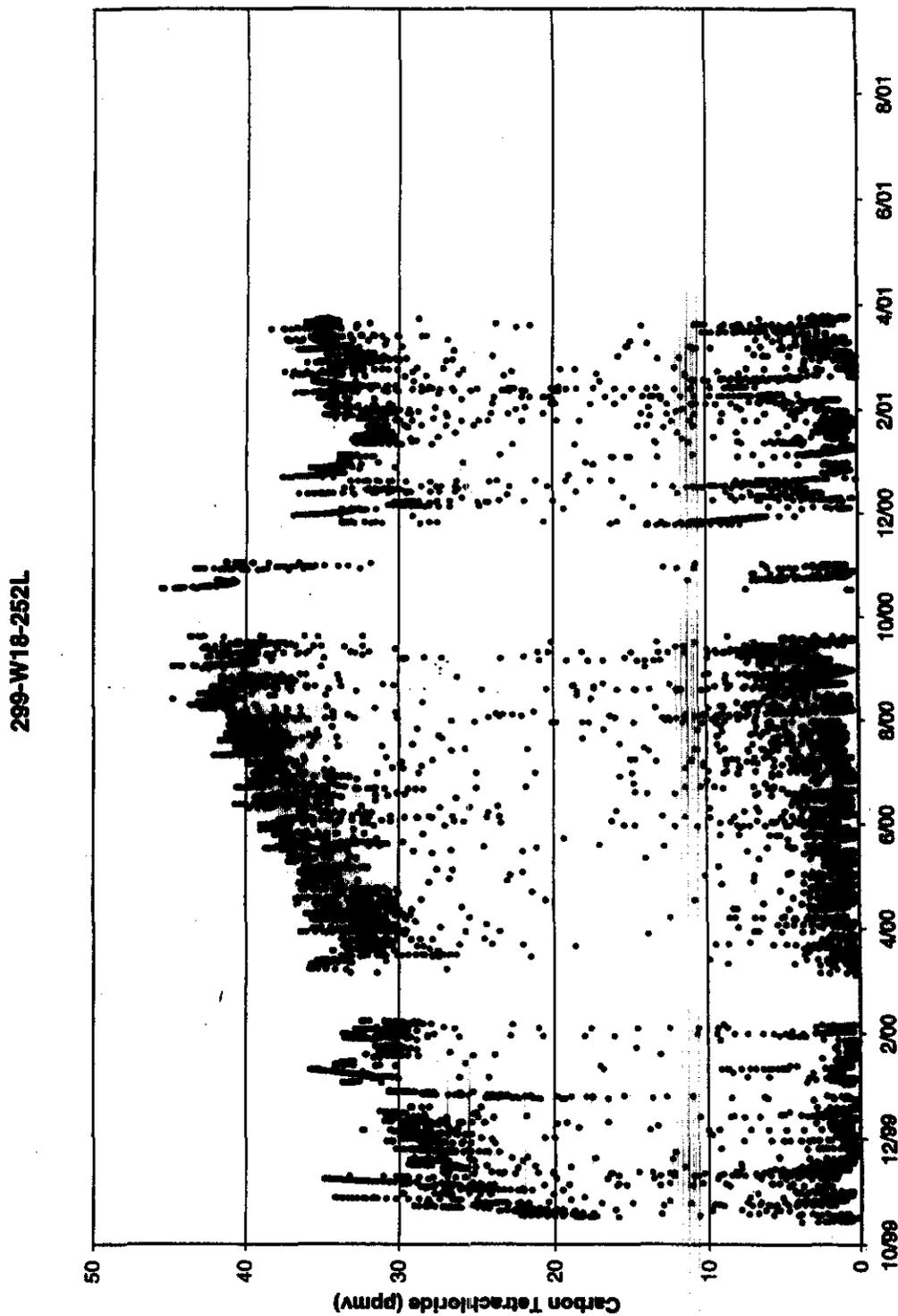


Figure C-4. Chloroform Concentrations Monitored Hourly at Well 299-W18-6L, October 1999 through April 2001.

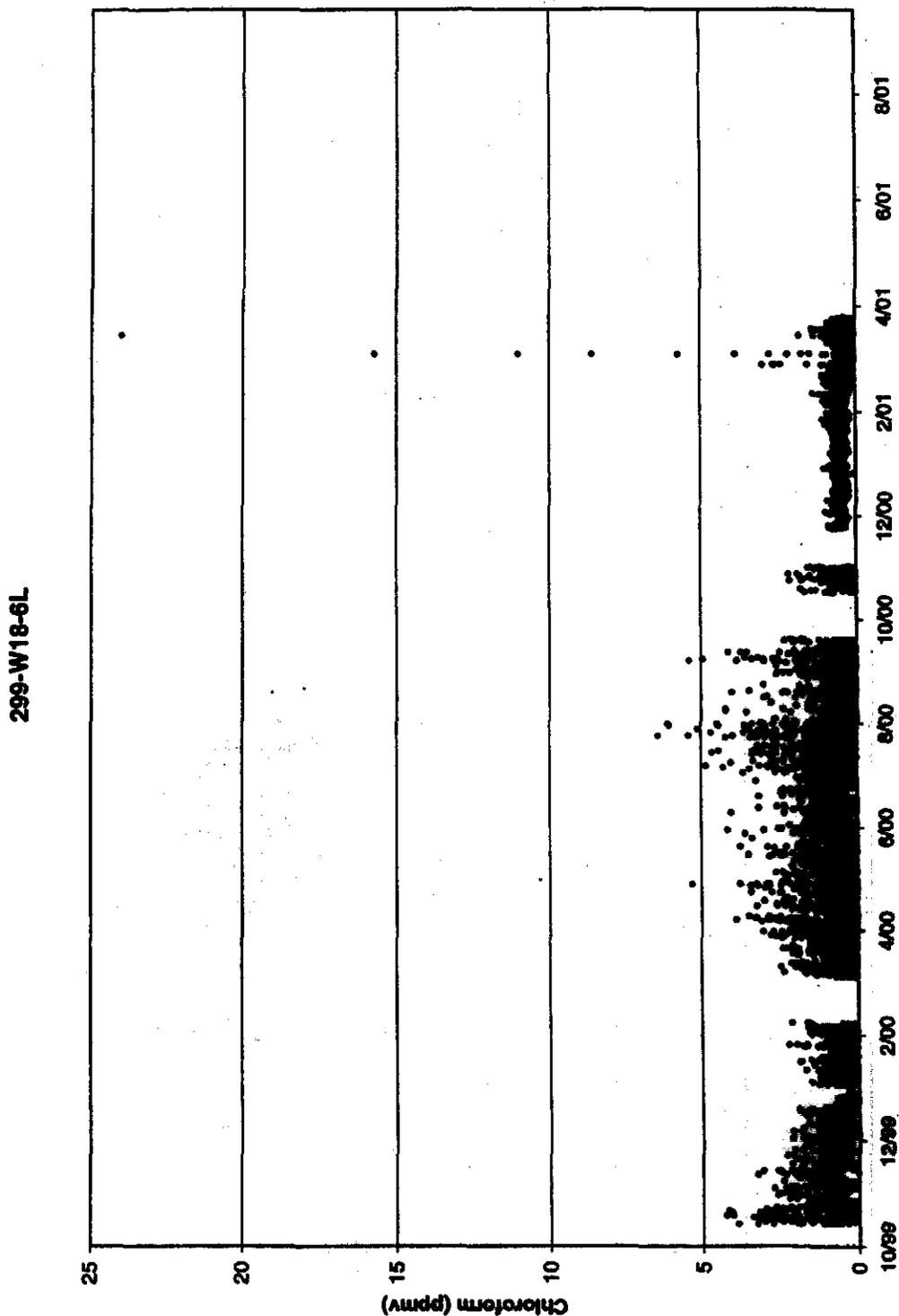


Figure C-5. Chloroform Concentrations Monitored Hourly at Well 299-W18-247L, October 1999 through April 2001.

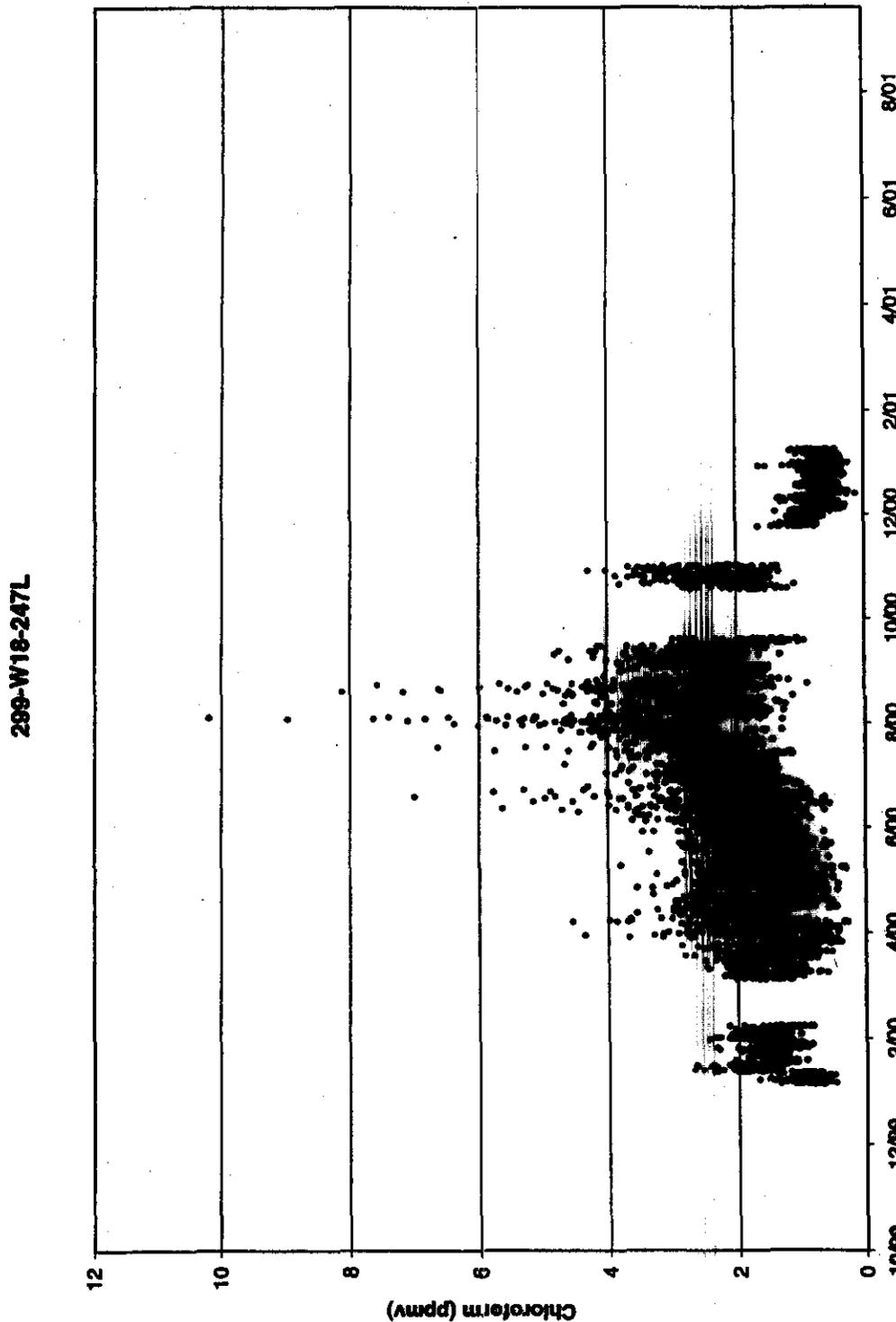


Figure C-6. Chloroform Concentrations Monitored Hourly at Well 299-W18-252L, October 1999 through April 2001.

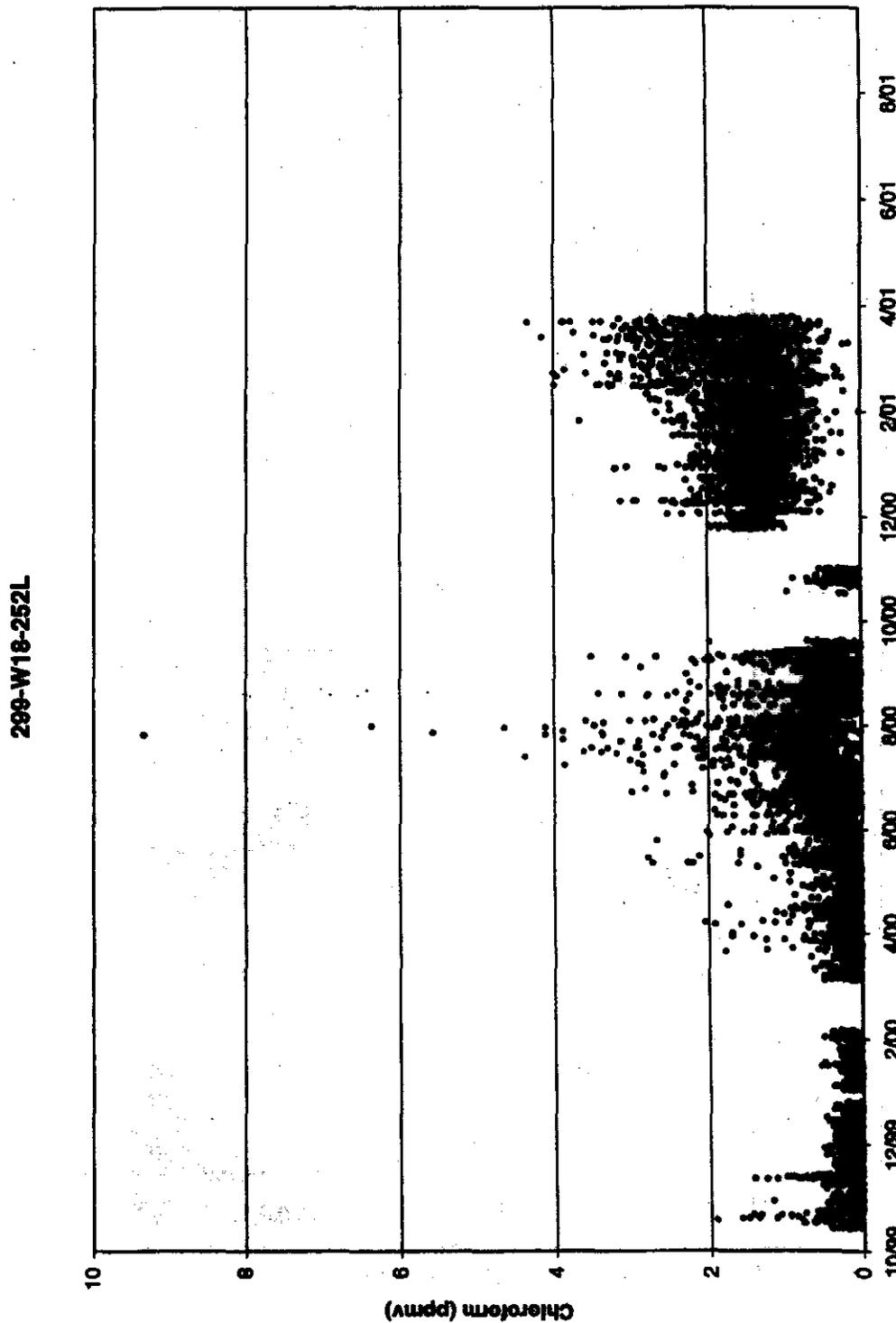
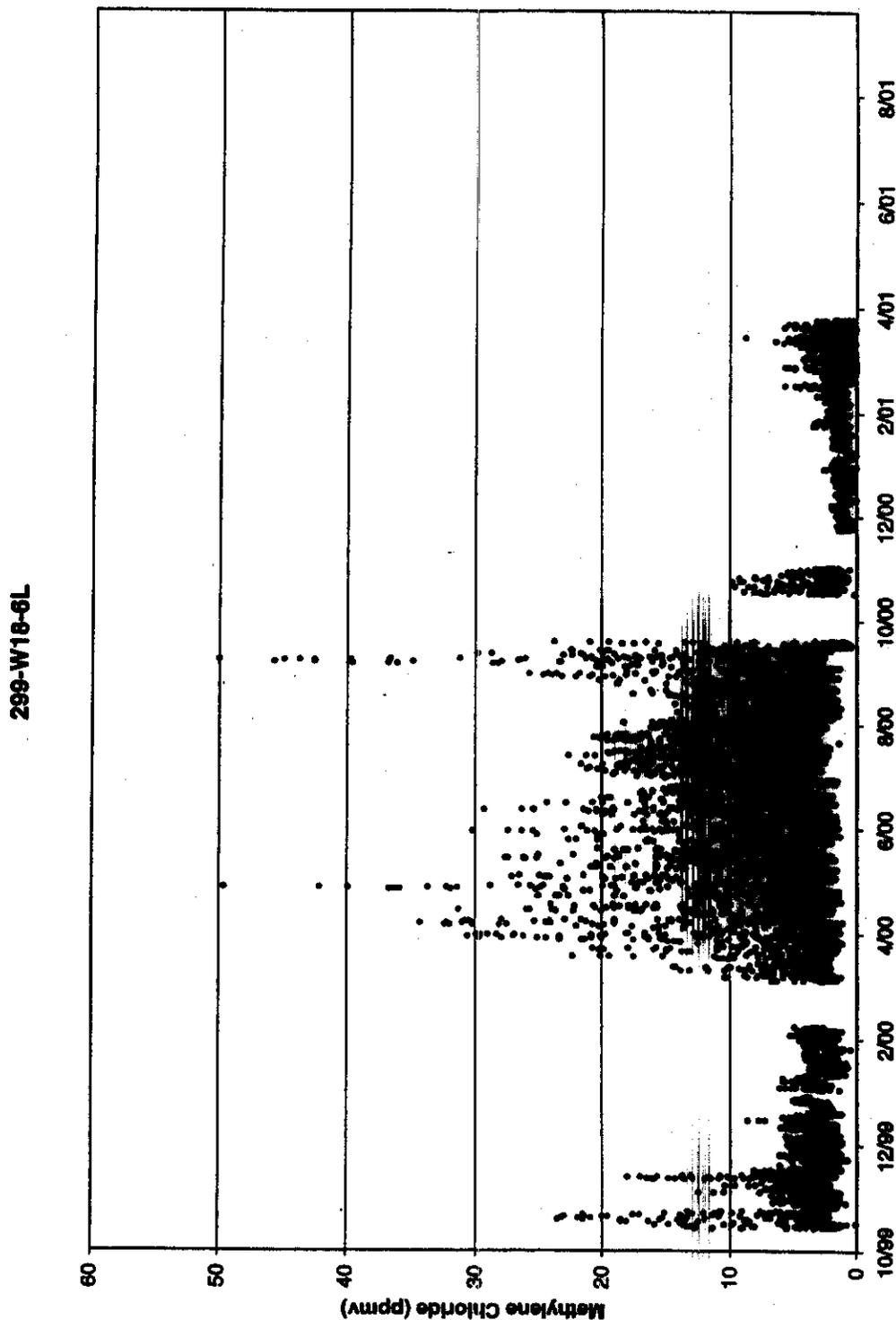


Figure C-7. Methylene Chloride Concentrations Monitored Hourly at Well 299-W18-6L, October 1999 through April 2001.



Appendix C – Passive Soil Vapor Extraction Data

Figure C-8. Methylene Chloride Concentrations Monitored Hourly at Well 299-W18-247L, October 1999 through April 2001.

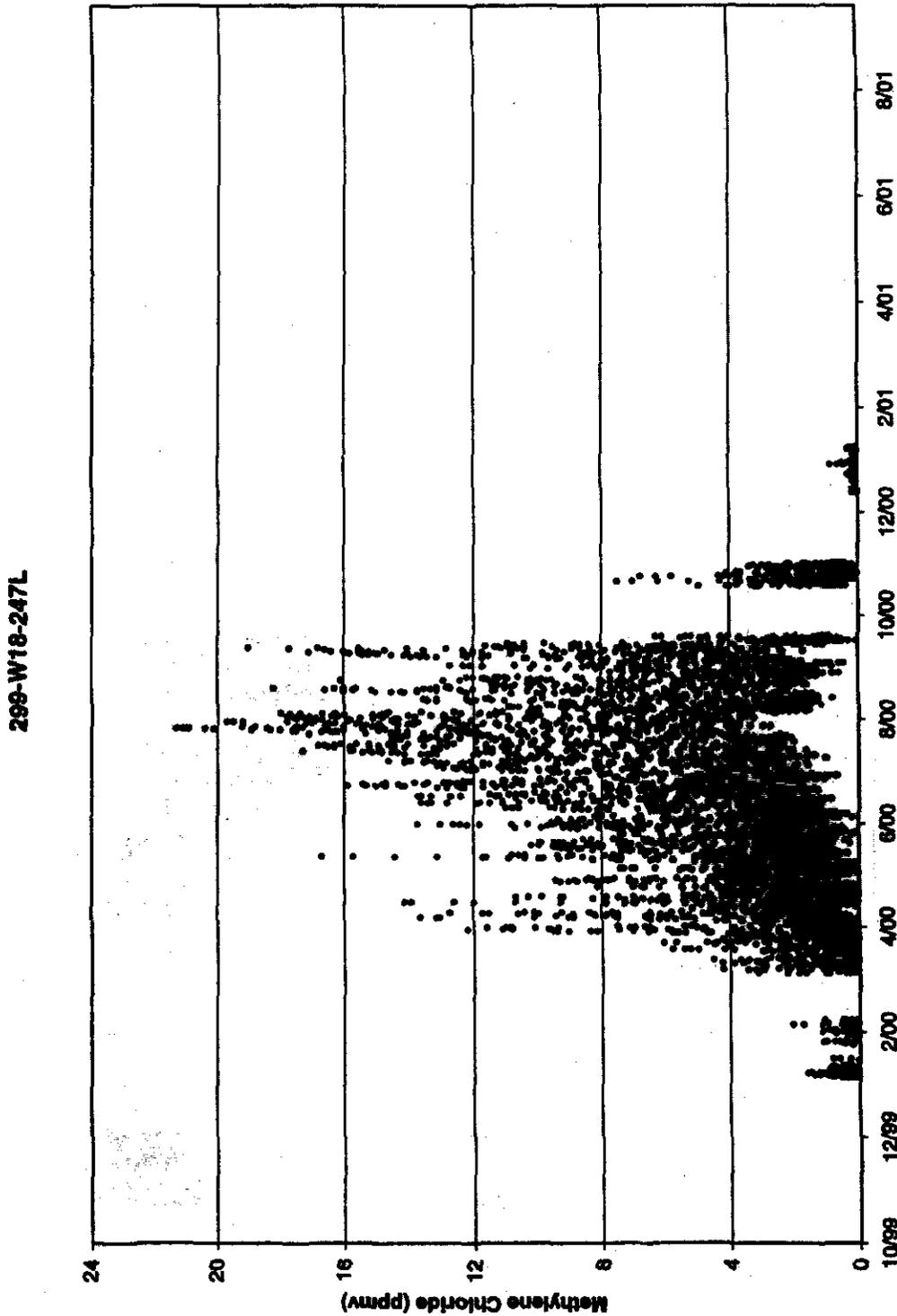


Figure C-9. Methylene Chloride Concentrations Monitored Hourly at Well 299-W18-252L, October 1999 through April 2001.

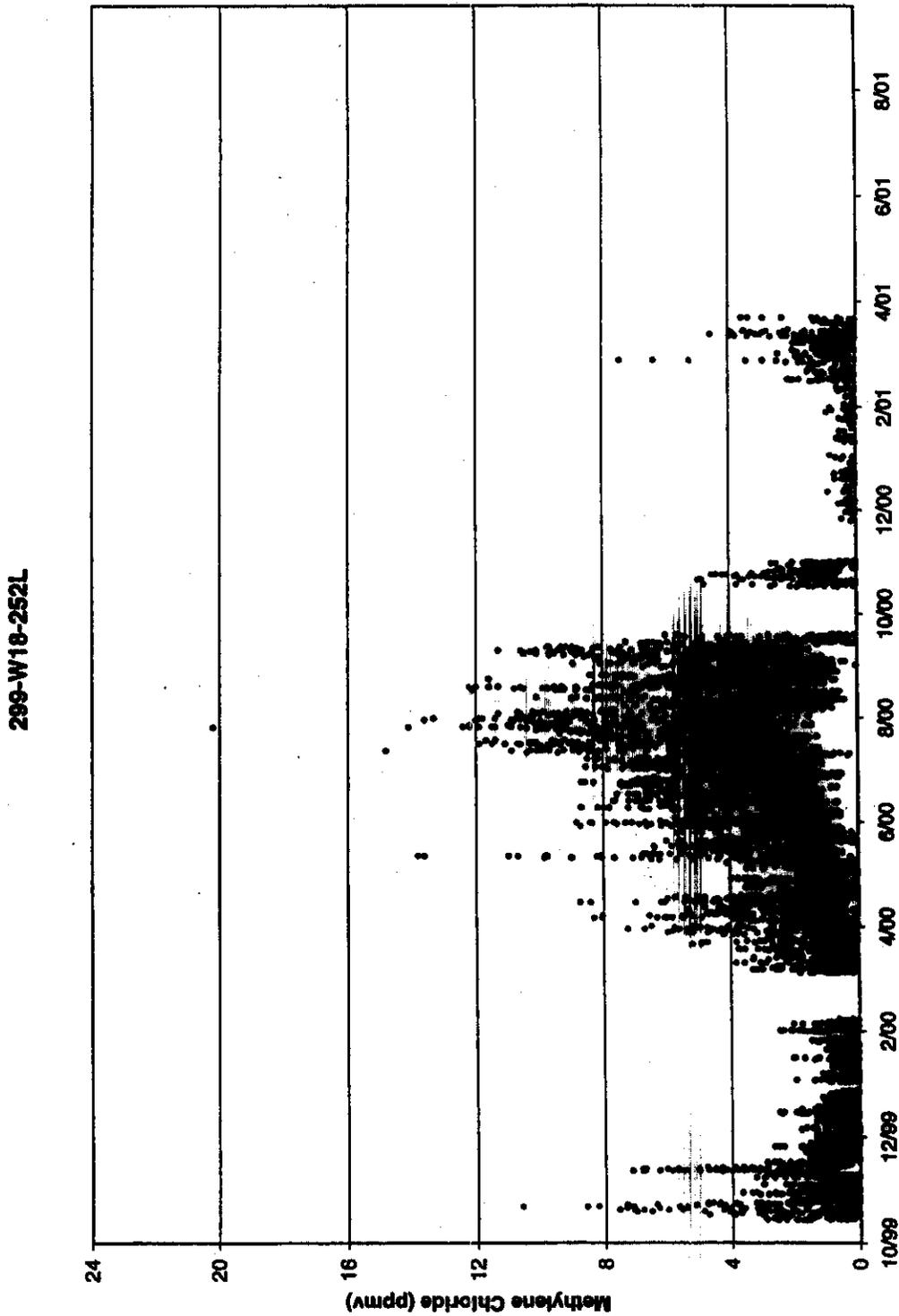


Figure C-10. Comparisons of Flows and Differential Pressures Monitored Hourly at Well 299-W18-6L, October 1999 through September 2000.

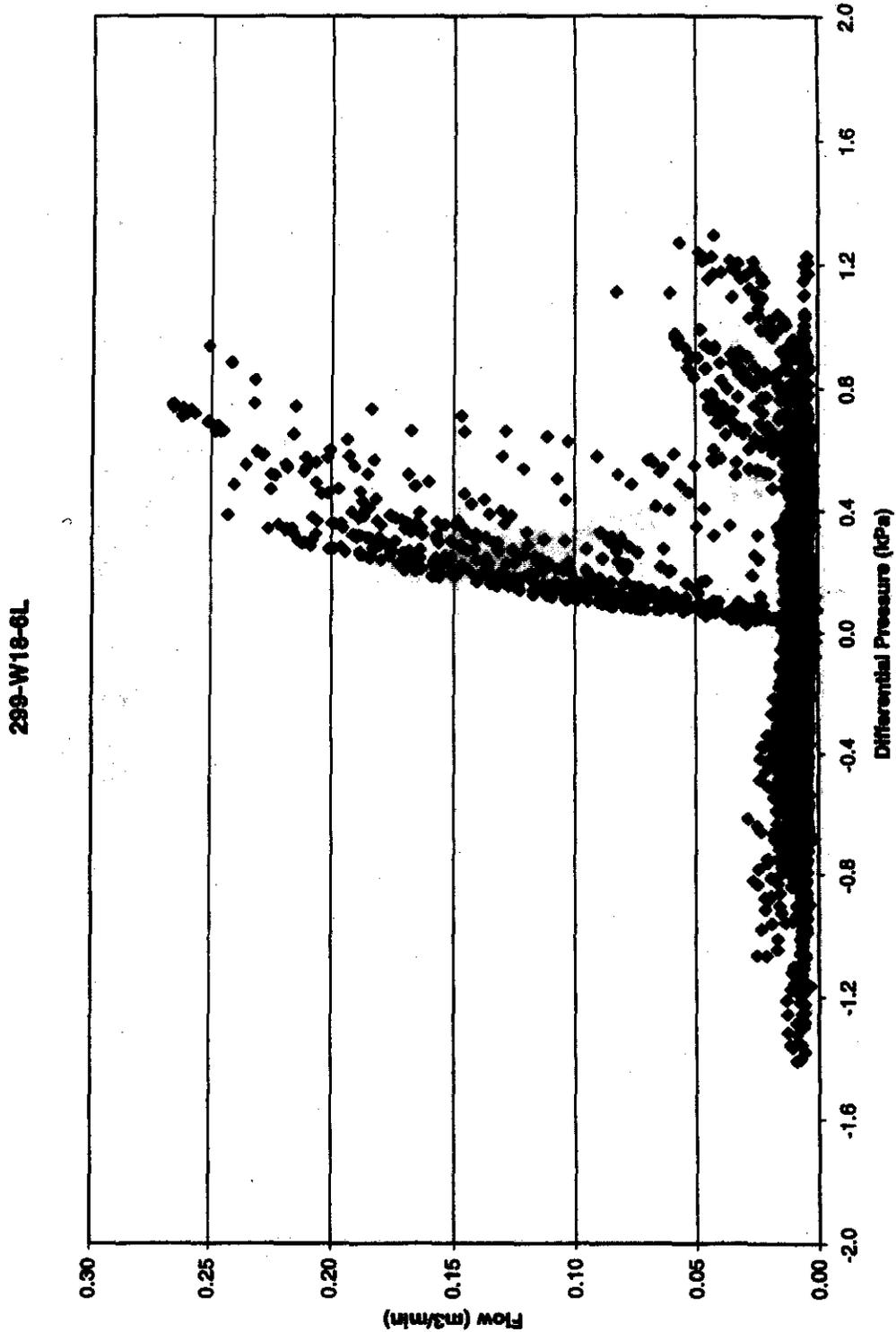


Figure C-11. Comparisons of Flows and Differential Pressures Monitored Hourly at Well 299-W18-247L, October 1999 through September 2000.

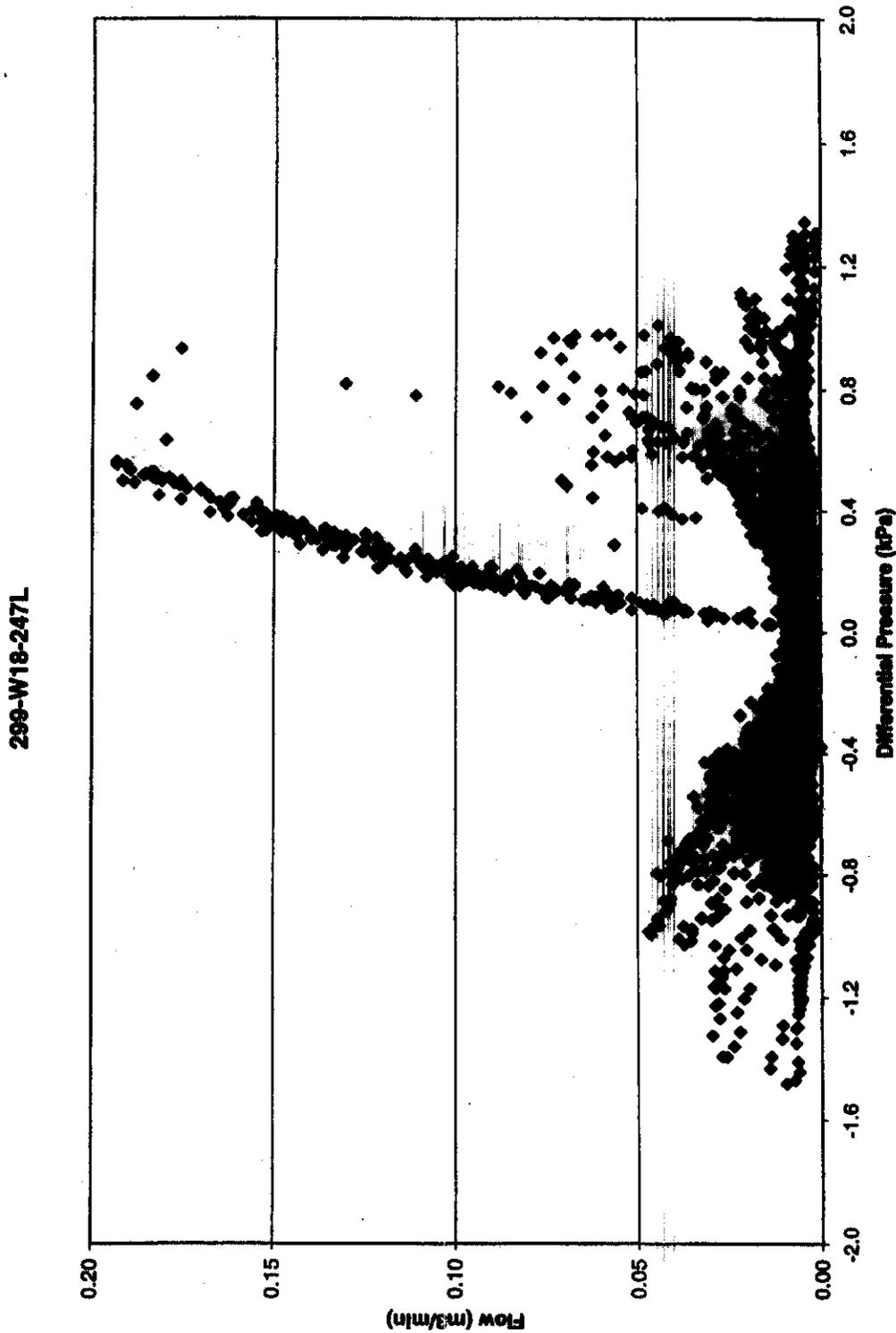


Figure C-12. Comparisons of Flows and Differential Pressures Monitored Hourly at Well 299-W18-252L, October 1999 through September 2000.

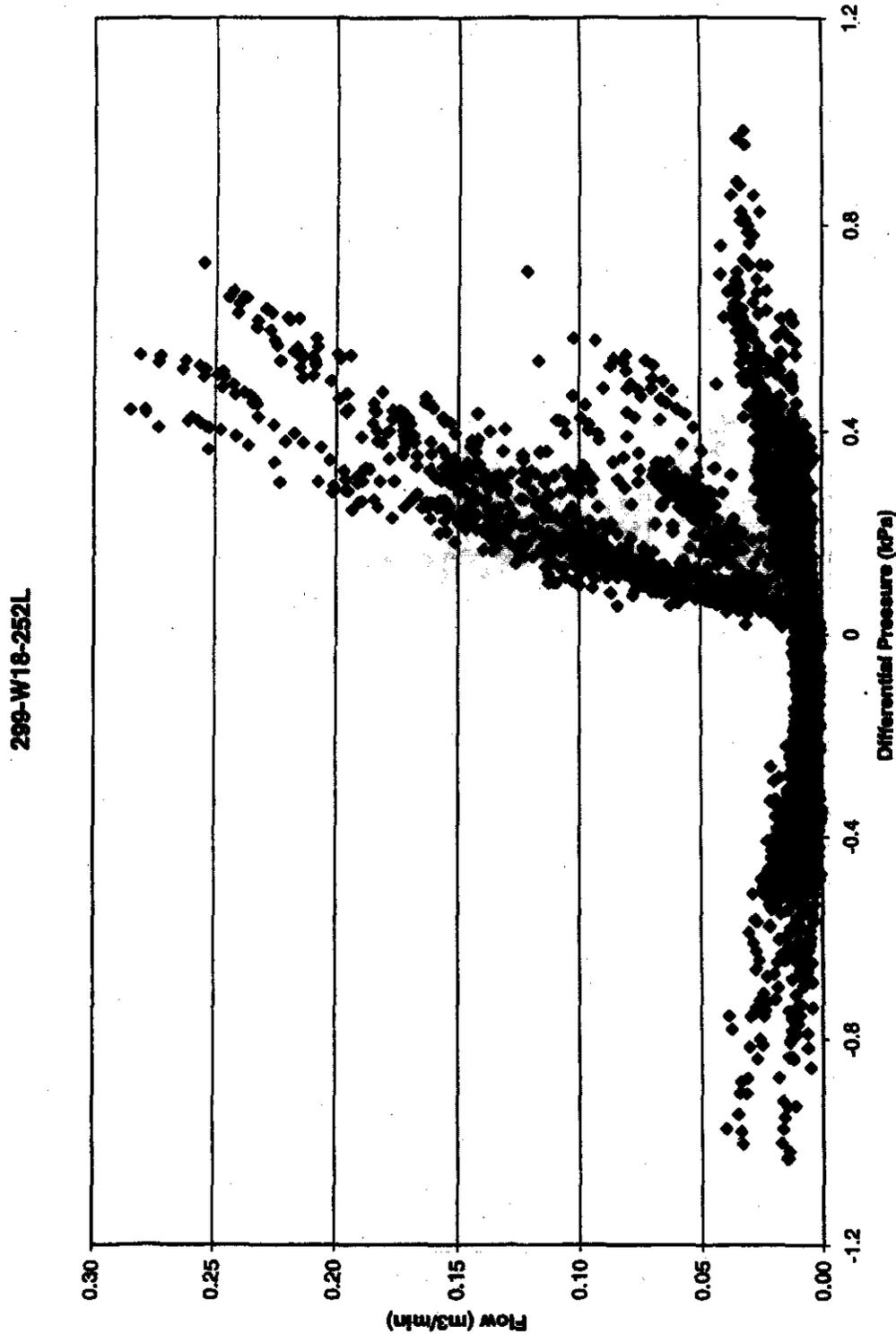


Figure C-13. Comparisons of Flow and Differential Pressures Monitored Hourly at Well 299-W18-6L, October 2000 through June 2001.

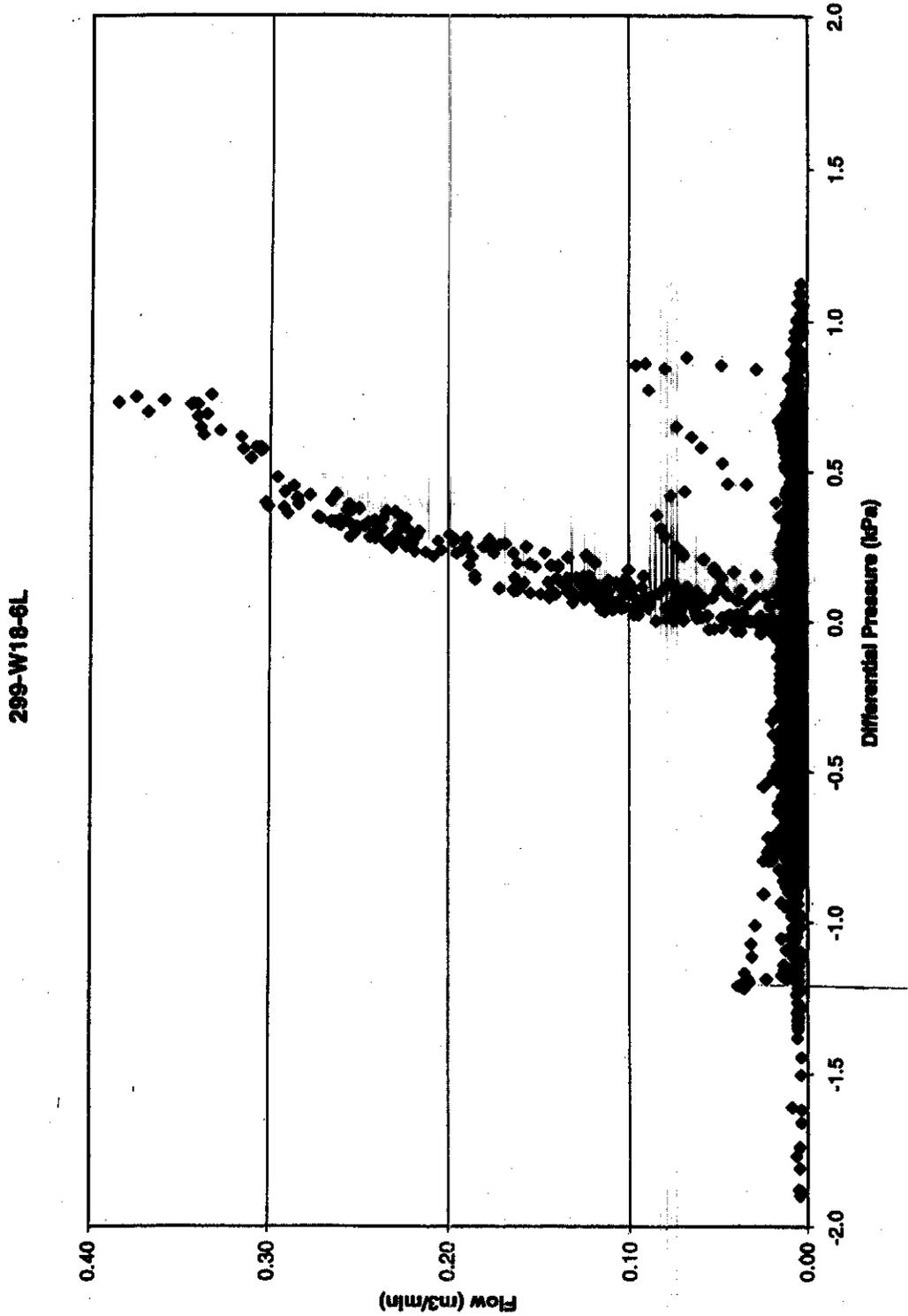


Figure C-14. Comparisons of Flow and Differential Pressures Monitored Hourly at Well 299-W18-247L, October 2000 through June 2001.

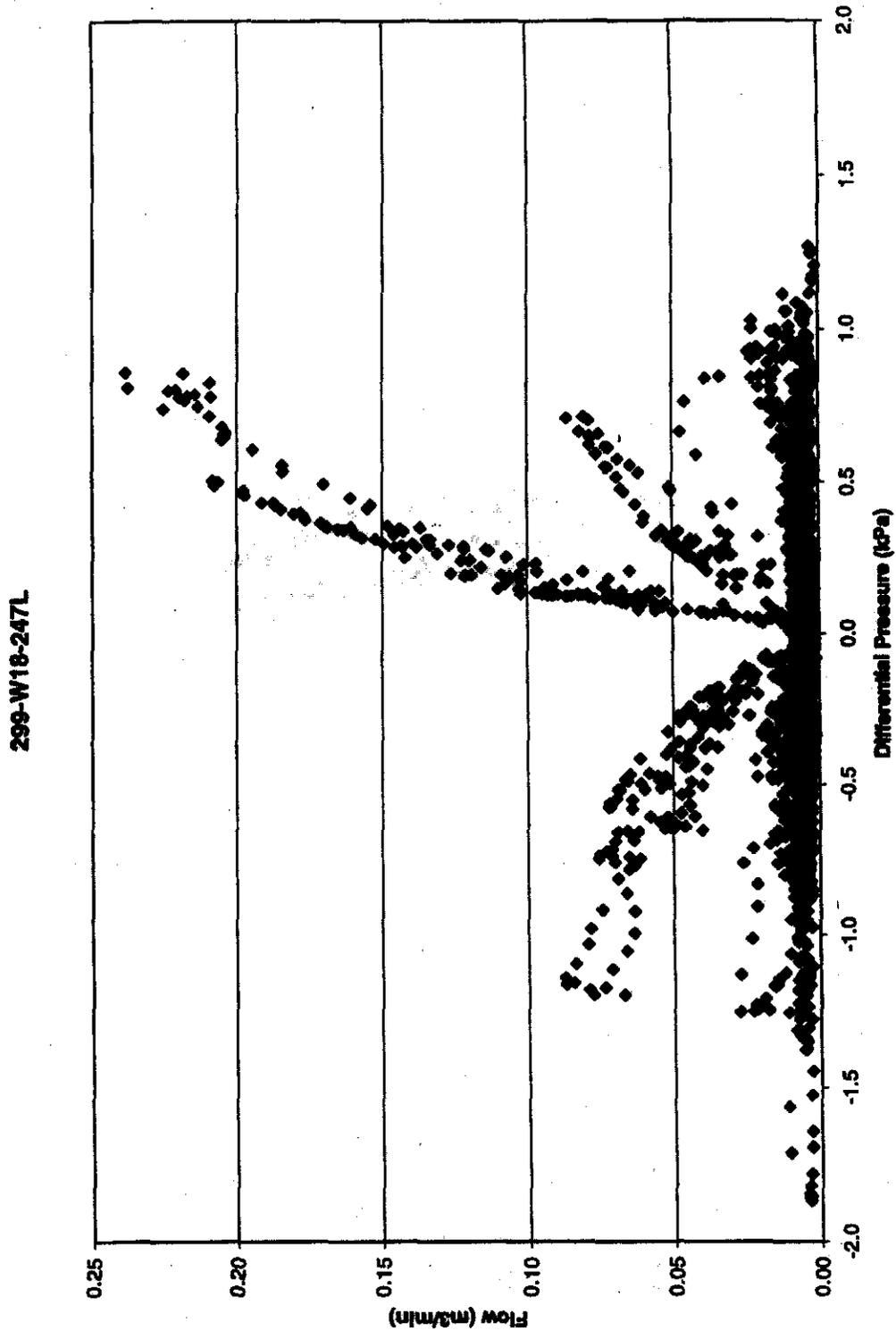


Figure C-15. Comparisons of Flow and Differential Pressures Monitored Hourly at Well 299-W18-252L, October 2000 through June 2001.

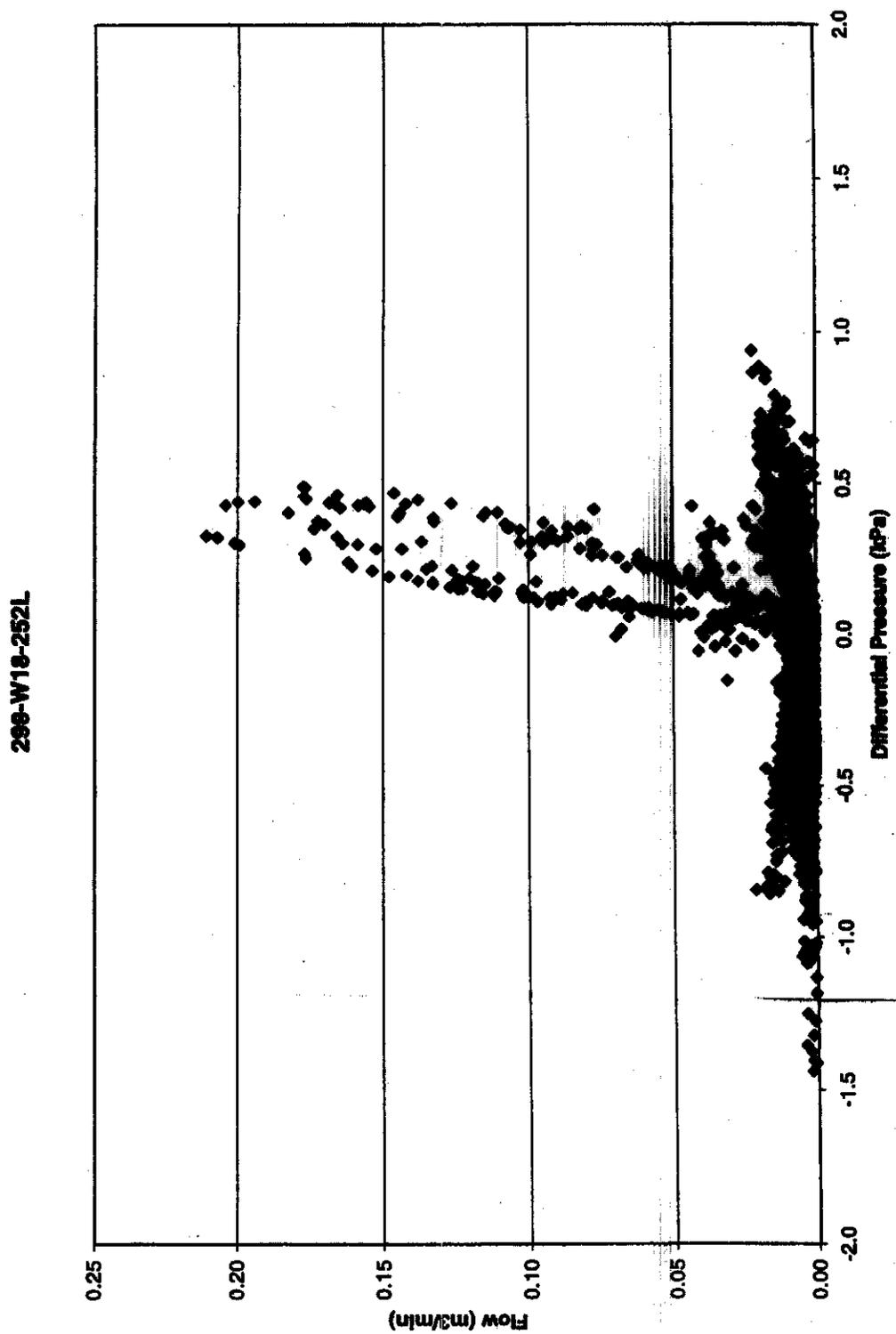


Figure C-16. Temperatures Monitored Hourly at Top and Bottom of Well 299-W18-6L.

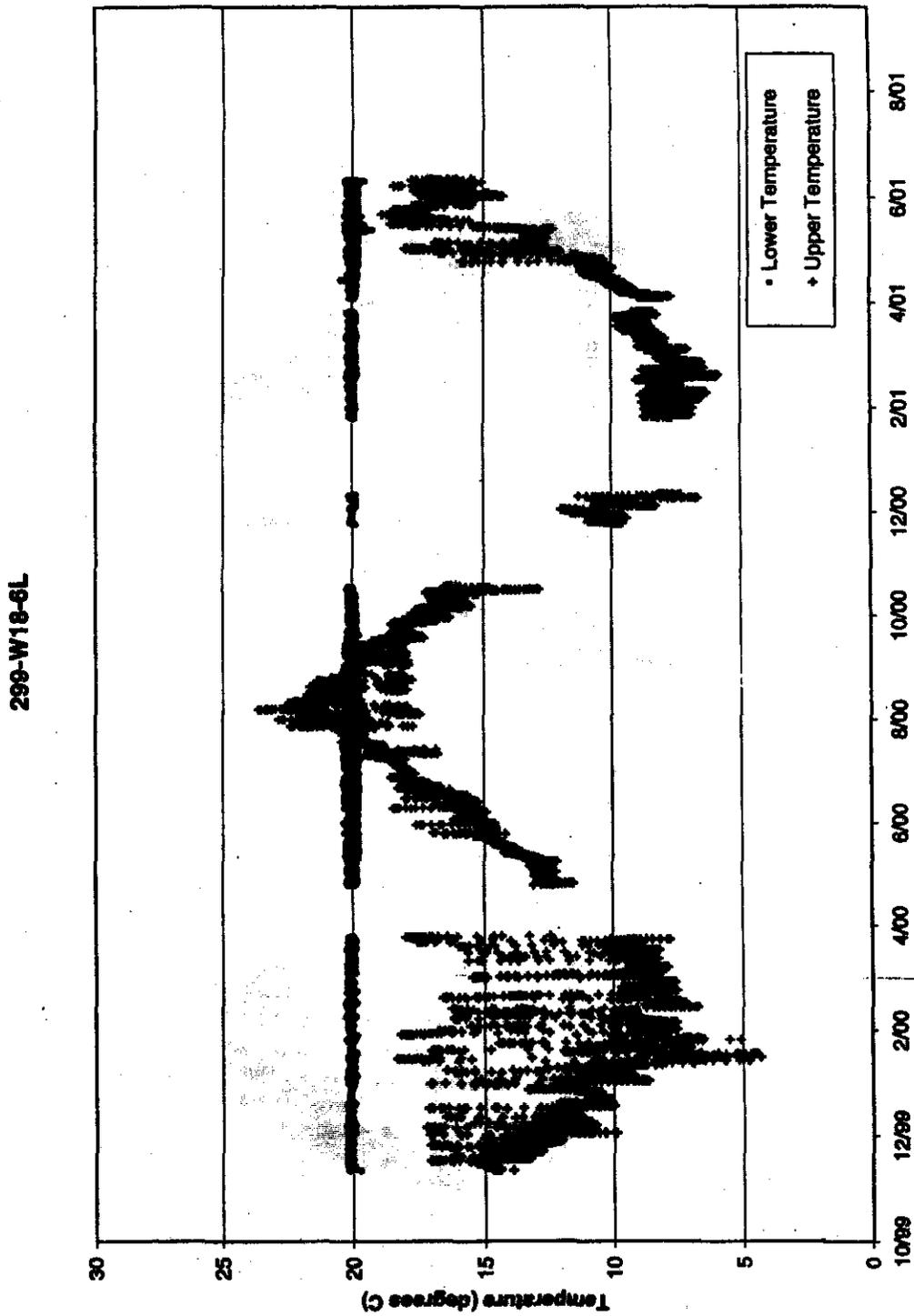


Figure C-17. Temperatures Monitored Hourly at Top and Bottom of Well 299-W18-247L.

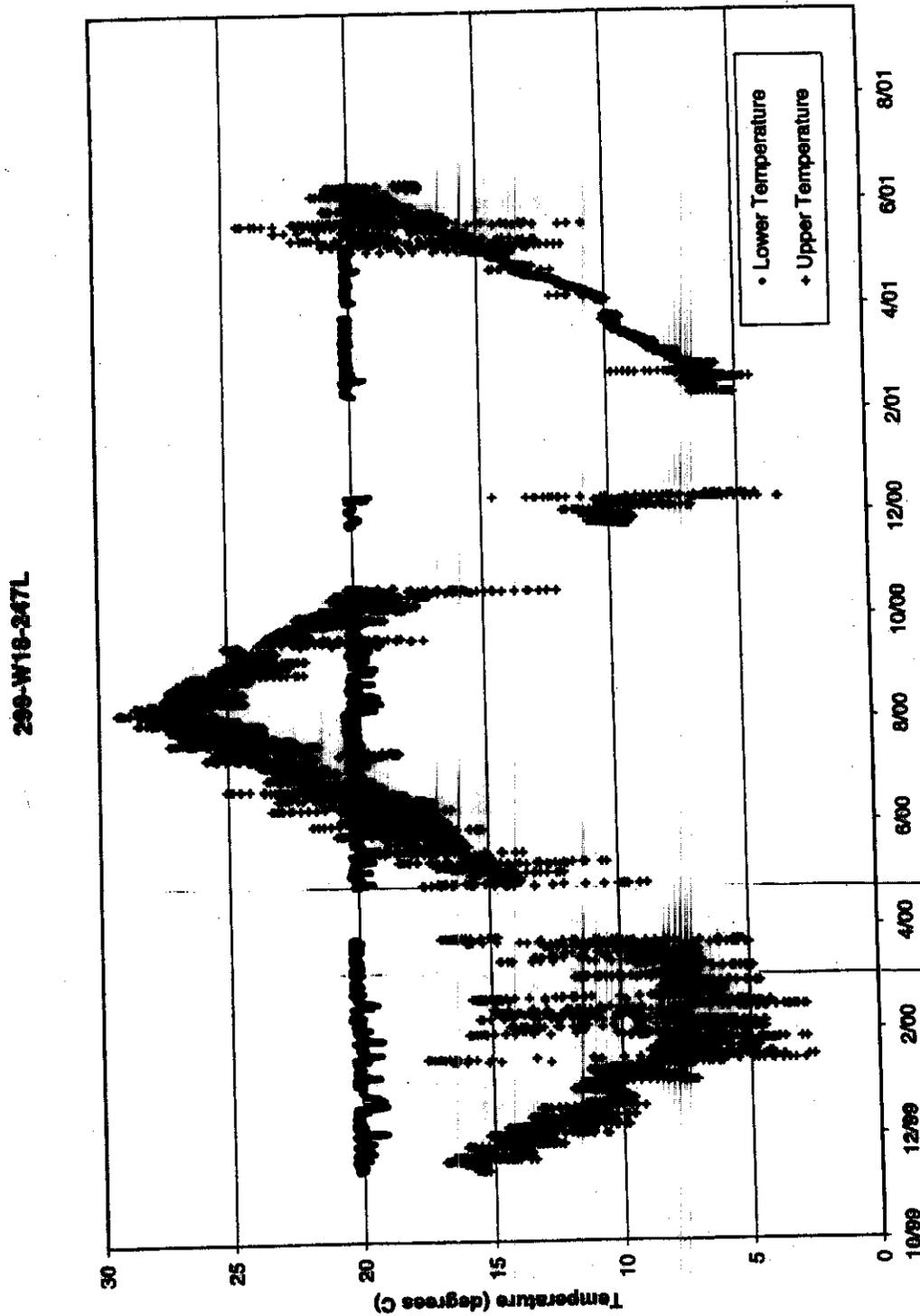


Figure C-22. Comparison of Carbon Tetrachloride Concentrations Monitored Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, December 1999.

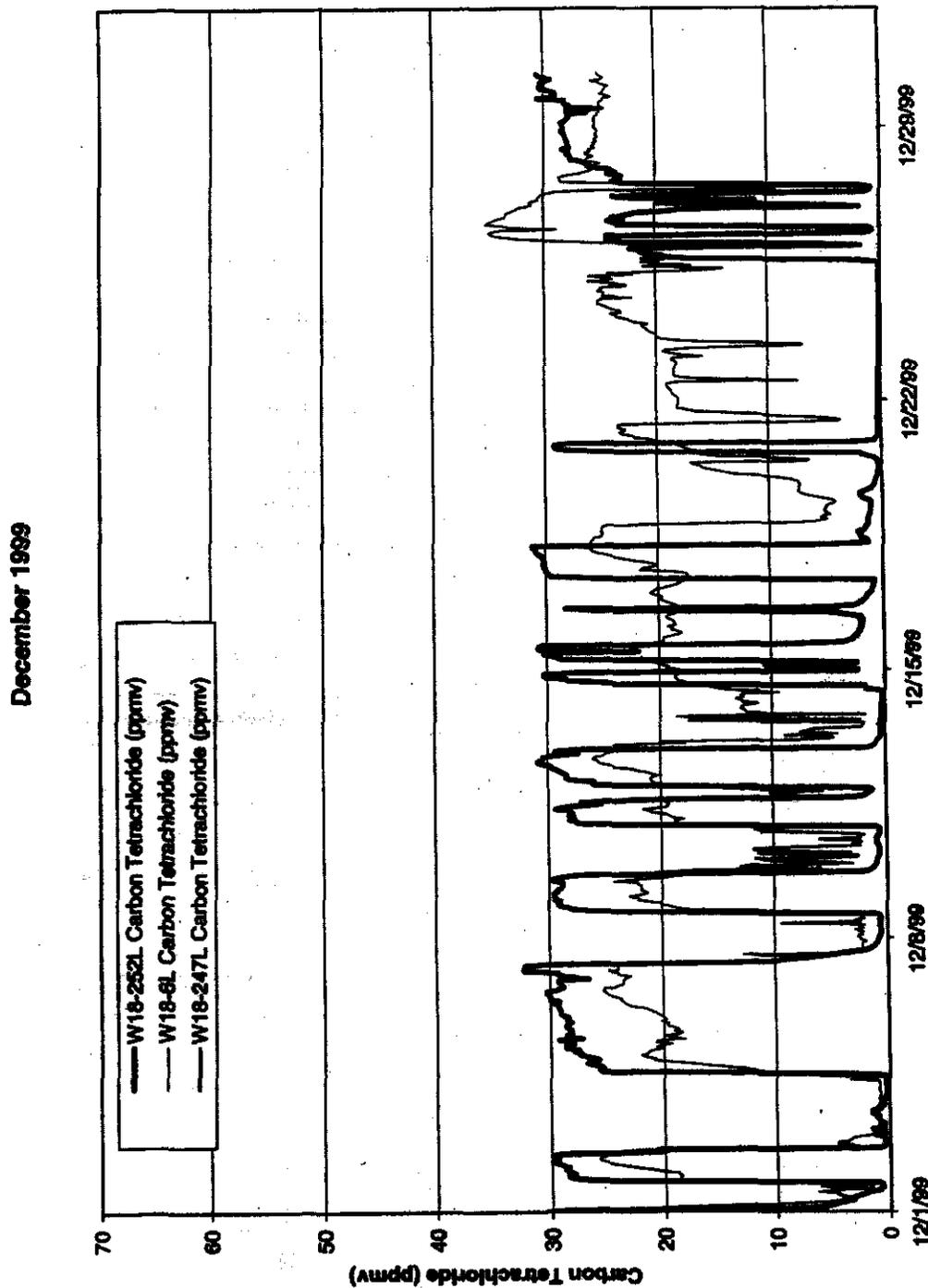


Figure C-23. Comparison of Carbon Tetrachloride Concentrations Monitored Hourly at Wells 299-W18-6L, 299-W18-274L, and 299-W18-252L, January 2000.

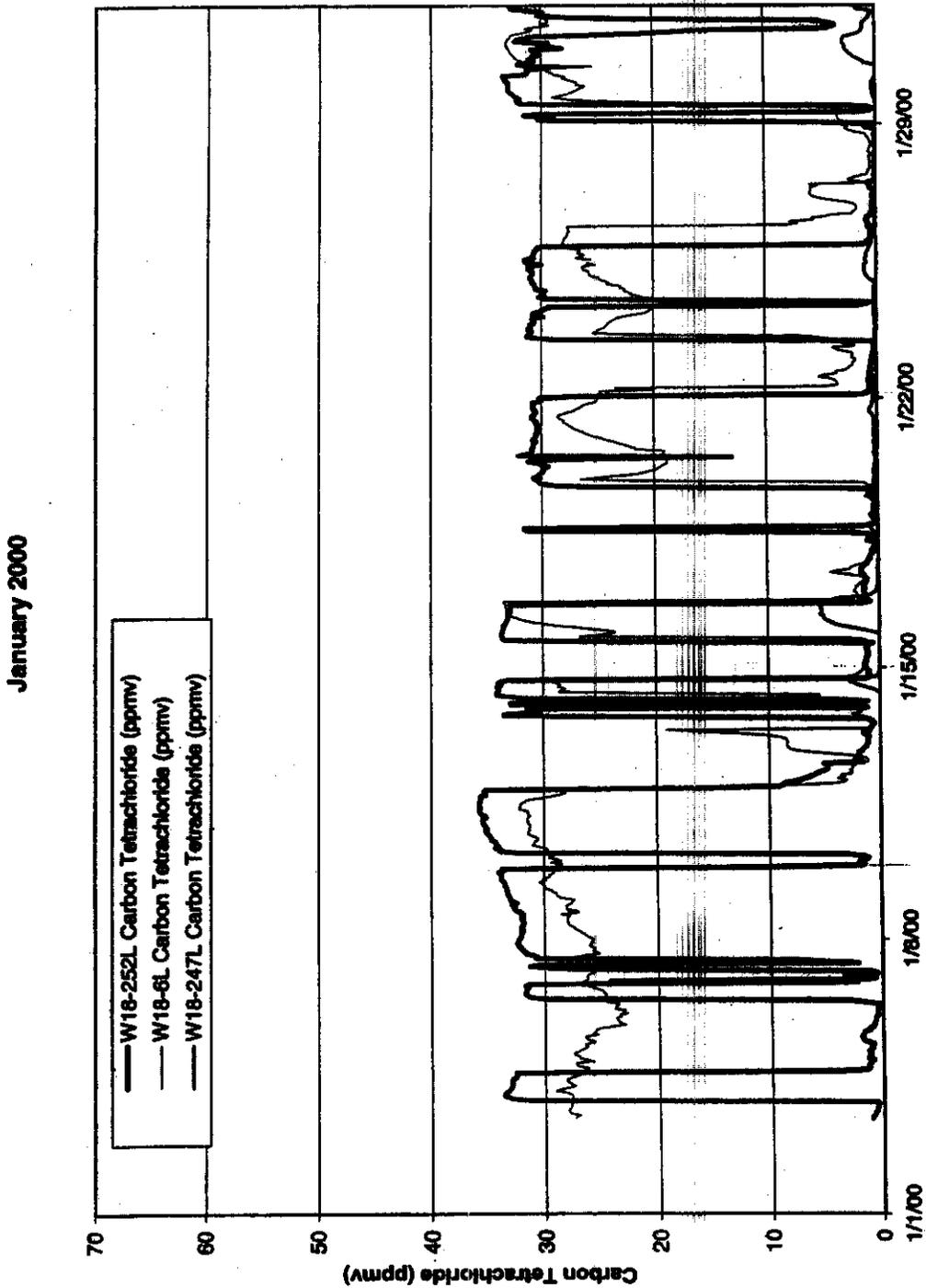


Figure C-24. Comparison of Carbon Tetrachloride Concentrations Monitored Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, February 2000.

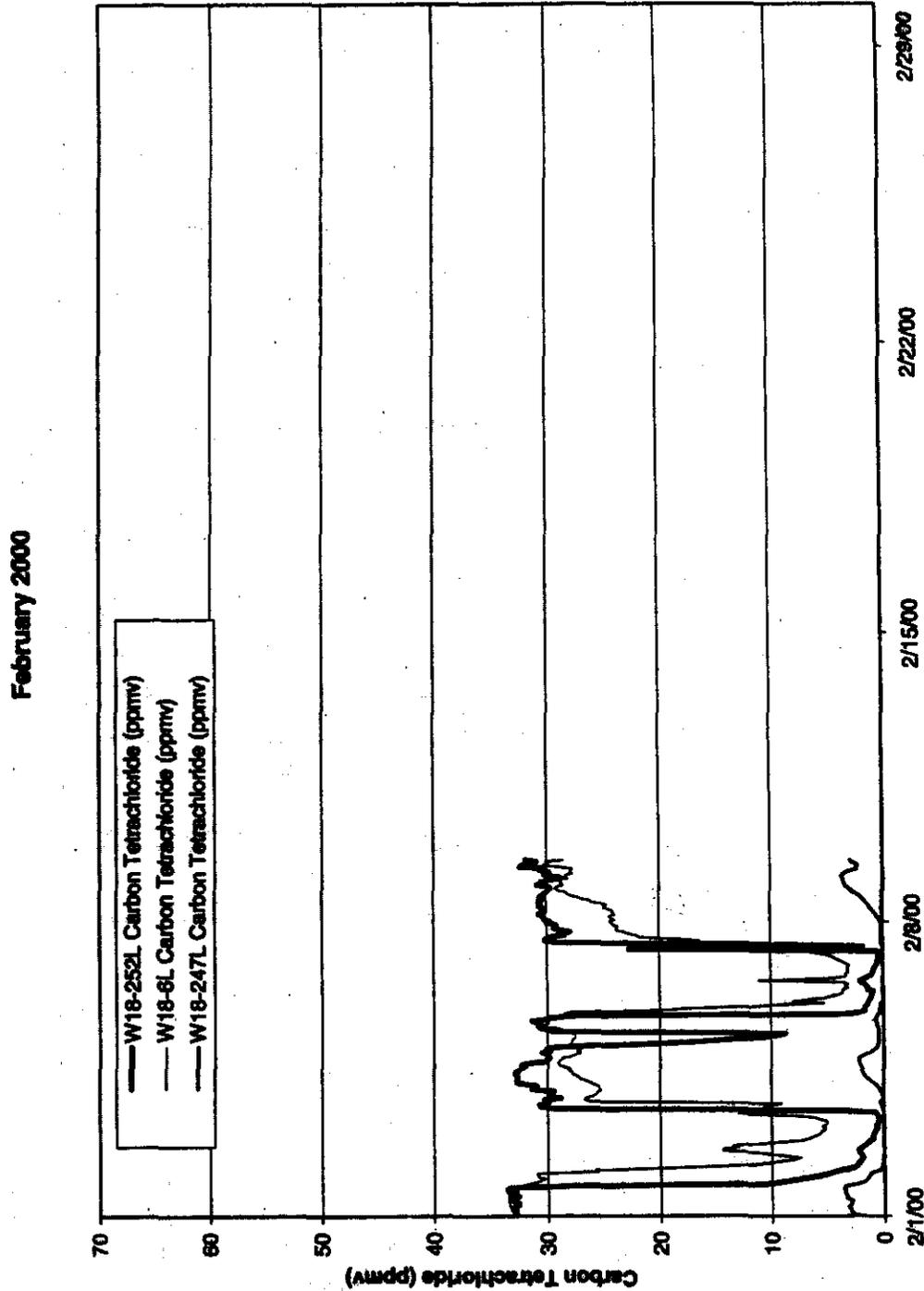


Figure C-25. Comparison of Carbon Tetrachloride Concentrations Monitored Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, March 2000.

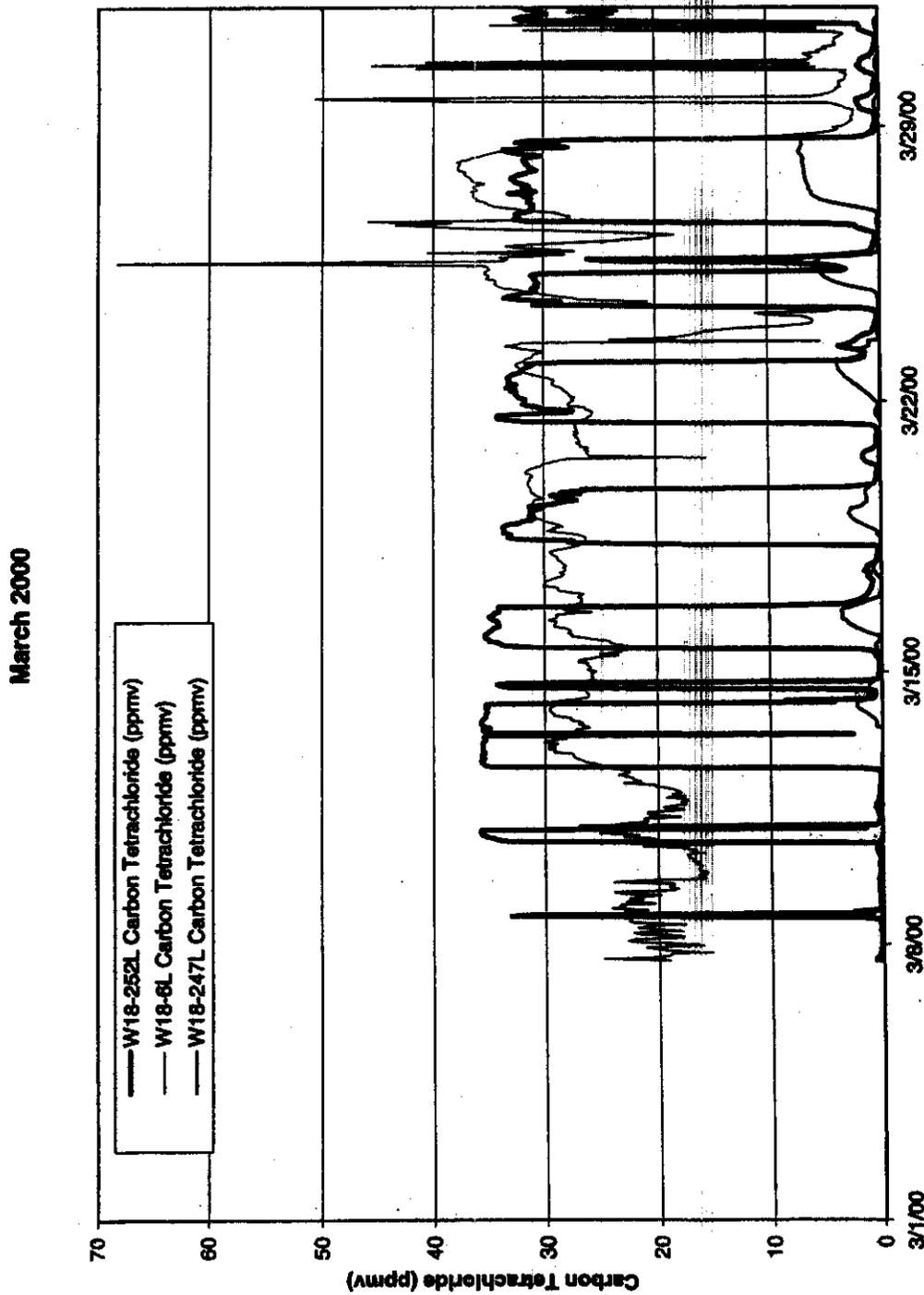


Figure C-26. Comparison of Carbon Tetrachloride Concentrations Monitored Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, April 2000.

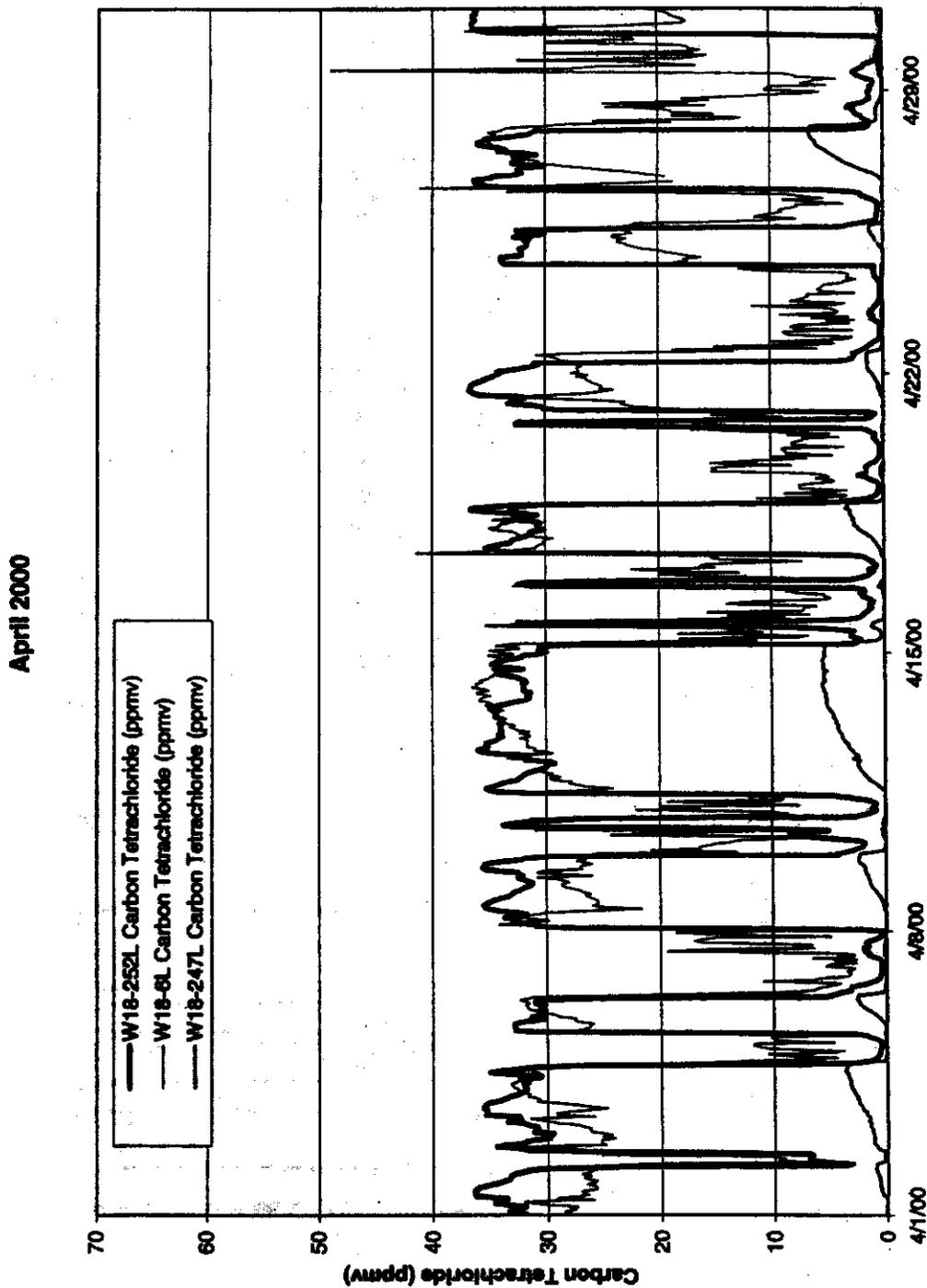


Figure C-27. Comparison of Carbon Tetrachloride Concentrations Monitored Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, May 2000.

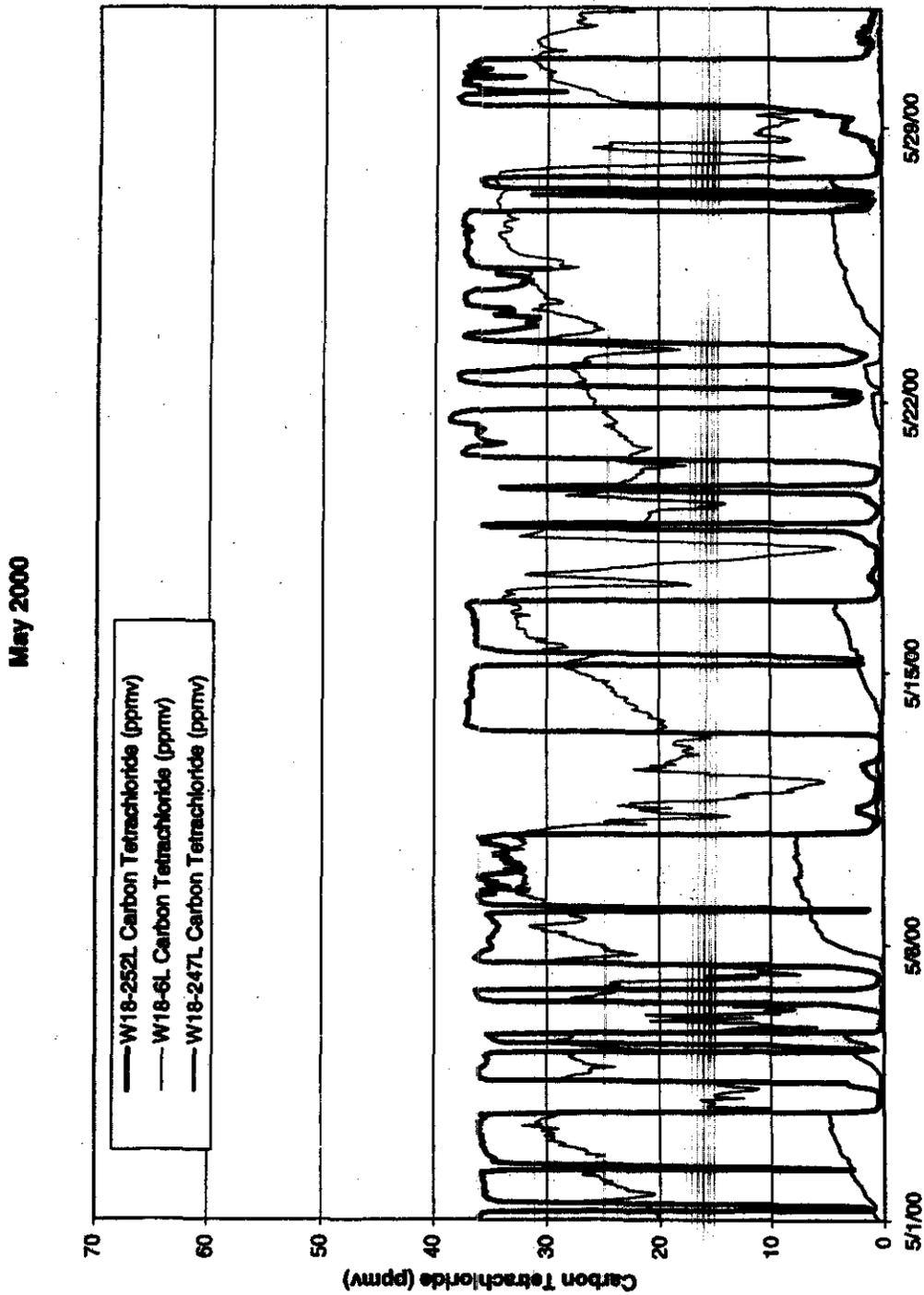


Figure C-28. Comparison of Carbon Tetrachloride Concentrations Monitored Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, June 2000.

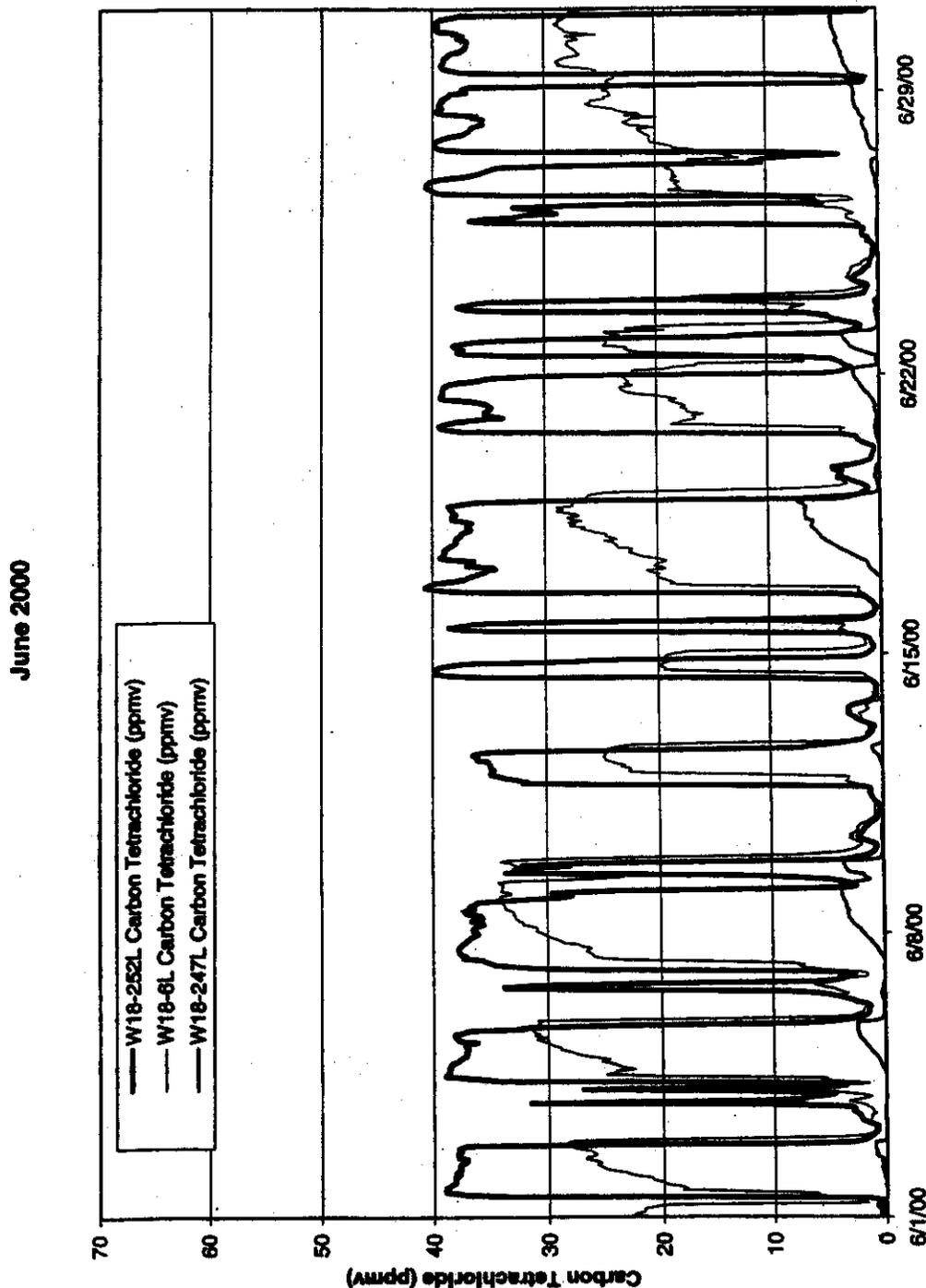


Figure C-29. Comparison of Carbon Tetrachloride Concentrations Monitored Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, July 2000.

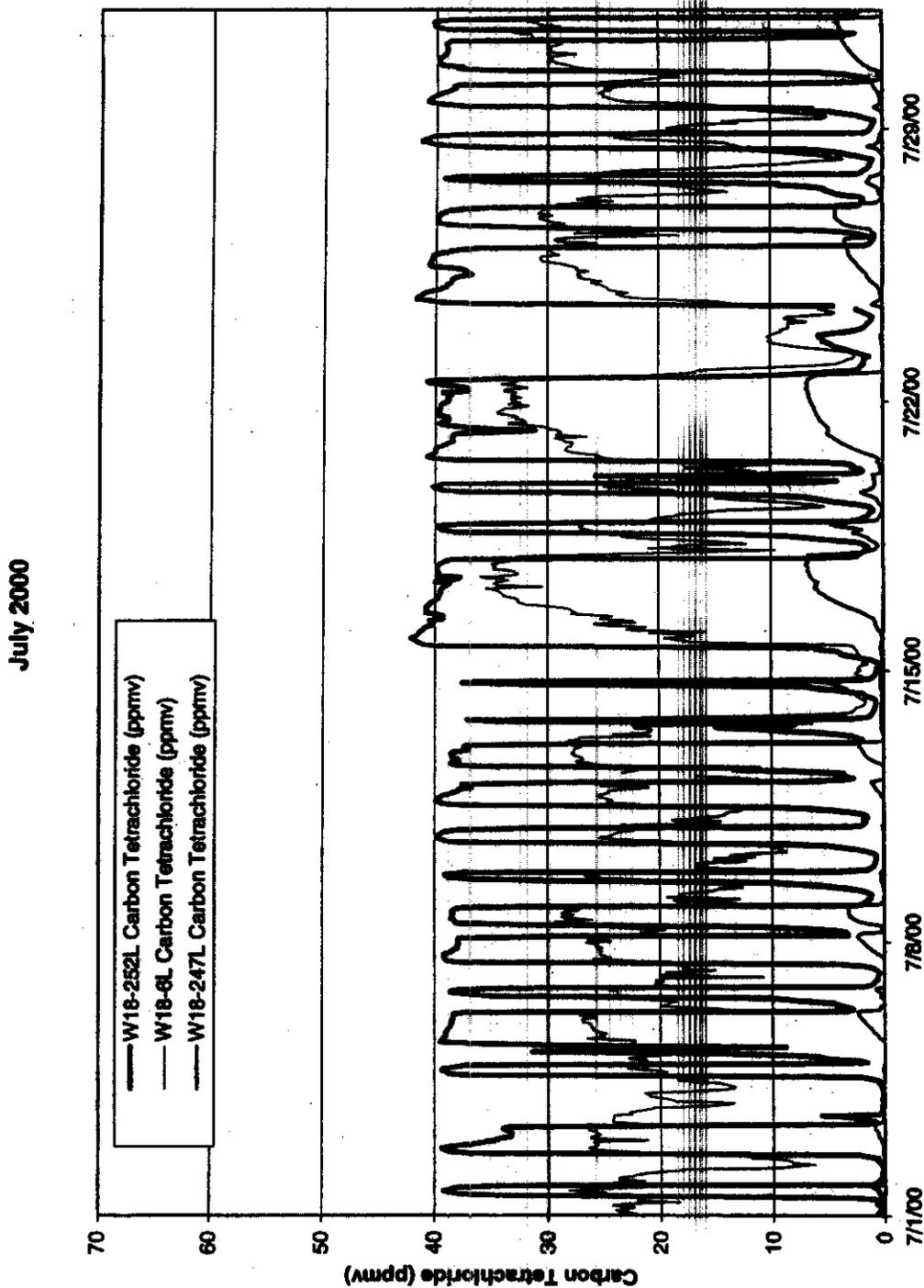


Figure C-30. Comparison of Carbon Tetrachloride Concentrations Monitored Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, August 2000.

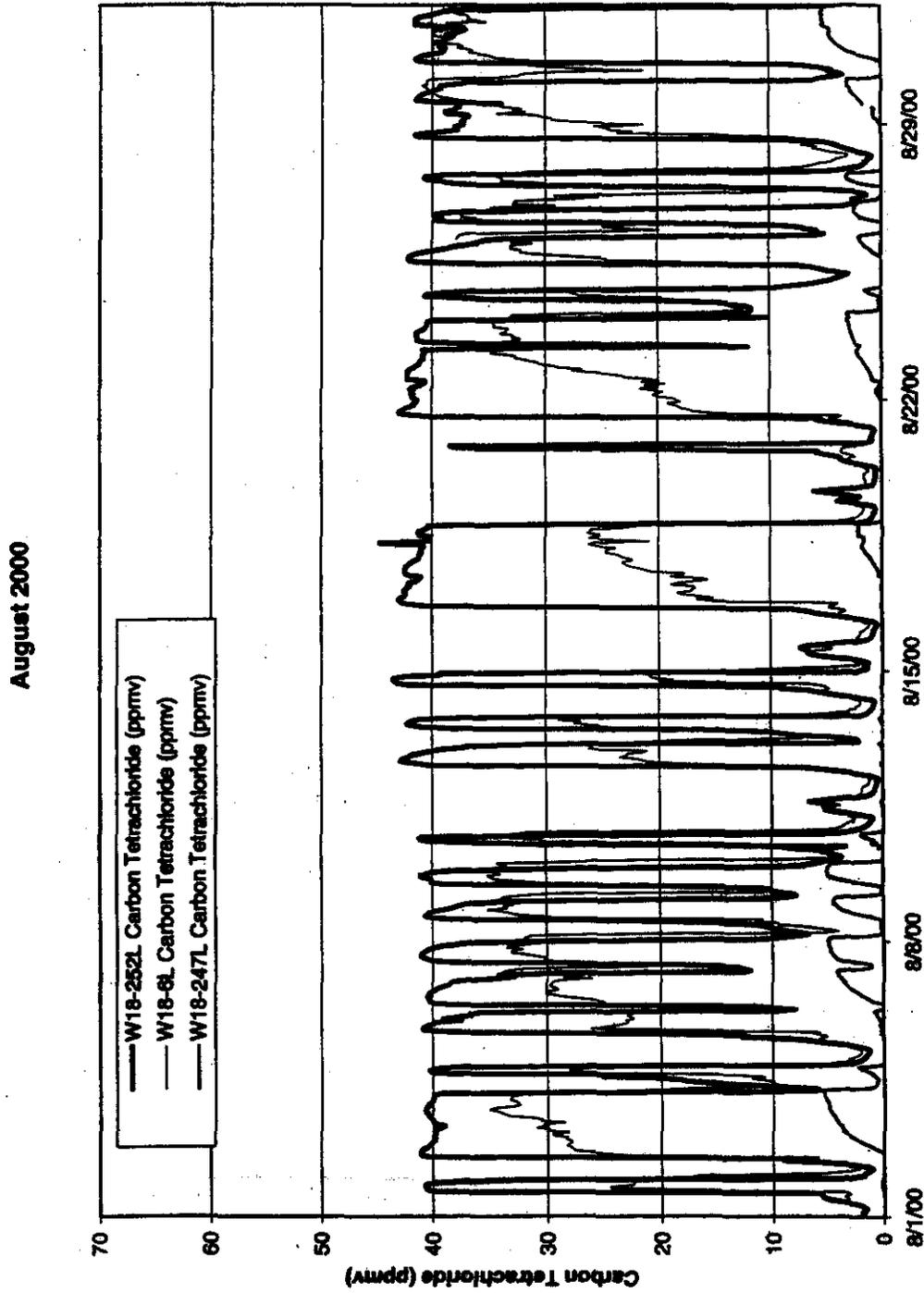


Figure C-31. Comparison of Carbon Tetrachloride Concentrations Monitored Hourly at Wells 299-W18-6L, 299-W18-247L, and 299-W18-252L, September 2000.

