

SPARTON

SPARTON CORPORATION

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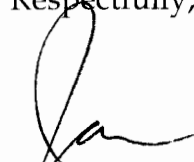
NM ENVIRONMENT DEPARTMENT
OFFICE OF THE SECRETARY

Mr. Mark E. Weidler, Secretary
State of New Mexico
Environment Department
Harold Runnels Building
1190 St. Francis Drive
P. O. Box 26110
Santa Fe, NM 87502

Dear Mark:

In response to your request, enclosed is a copy of the Battelle report for your information. If you have any questions, please feel free to give me a call.

Respectfully,



R. Jan Appel
Vice President and
General Counsel

RJA:jc

Enclosure

cc: Ana Marie Ortiz
Richard Mertz

OGC-002280—

MAY 23 1996



505 King Avenue
Columbus, Ohio 43201-2693
Telephone (614) 424-6424
Facsimile (614) 424-5263

May 22, 1996

Mr. R. Jan Appel
Sparton Corporation
2400 East Ganson Street
Jackson, MI 49202

Dear Jan:

Please find enclosed 5 copies of our final report entitled "Evaluation of Remedial Options for Sparton's Coors Road Site." This concludes our activity on our current contract with you. From discussions with Jim Harris during the preparation of this final document, I am under the assumption that we met the objectives of our statement of work.

It was our pleasure doing business with Sparton, in particular, the discussions that took place during the site visit and working toward the final product with Jim.

If there are future issues which you think Battelle could assist in, please feel free to call me at (614) 424-6344.

Sincerely,

A handwritten signature in black ink, appearing to read "Tom", with a stylized flourish above the name.

Thomas G. Naymik, Ph.D.
Senior Research Leader
Environmental Restoration Department

TGN:bms
Enclosures

cc: Mr. James B. Harris, Esq.
Thompson & Knight
1700 Pacific Avenue, Suite 300
Dallas, TX 75210
(2 copies)

REPORT

FINAL

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NM ENVIRONMENT DEPARTMENT
OFFICE OF THE SECRETARY

EVALUATION OF REMEDIAL OPTIONS FOR SPARTON'S COORS ROAD SITE

To

Sparton Corporation

2400 East Ganson Street

Jackson, Michigan 49202

May 22, 1996



OGC-002281

Evaluation of Remedial Options for Sparton's Coors Road Site
Final Report

to

**Sparton Corporation
2400 East Ganson Street
Jackson, Michigan 49202**

by

**Battelle
505 King Avenue
Columbus, Ohio 43201**

May 22, 1996

TABLE OF CONTENTS

	<u>Page</u>
ABBREVIATIONS AND ACRONYMS	iii
1.0 INTRODUCTION AND REVIEW OF SITE INFORMATION	1
1.1 Introduction	1
1.2 Site History	1
1.3 Site and Contaminant Characteristics	3
1.4 Source Zone Data Review	3
1.5 Dissolved Plume Data Review	10
2.0 STATE OF THE ART FOR REMEDIATION BY PUMPING AND TREATING GROUNDWATER IMPACTED BY CHLORINATED SOLVENTS	18
3.0 STATE OF THE ART FOR NATURAL ATTENUATION OF GROUNDWATER IMPACTED BY CHLORINATED SOLVENTS	20
4.0 ADDITIONAL TECHNOLOGIES DEVELOPED SINCE SUBMISSION OF DRAFT CMS	22
4.1 Source Zone Technologies	22
4.1.1 Soil Flushing	22
4.1.2 Thermal Technologies	22
4.1.3 Soil Vapor Extraction	22
4.1.4 Bioventing	23
4.1.5 Impermeable Barriers	23
4.1.6 Air Sparging	23
4.2 Plume Control/Remediation Technologies	23
4.2.1 Air Sparging	23
4.2.2 In Situ Biodegradation	24
4.2.3 Permeable Barriers	24
5.0 EVALUATION OF APPLICABLE TECHNOLOGIES	25
5.1 Source Zone Technologies	25
5.1.1 Soil Flushing	25
5.1.2 Thermal Technologies	25
5.1.3 Impermeable Barriers	25
5.1.4 Air Sparging	26
5.1.5 Bioventing	26
5.1.6 Soil Vapor Extraction	27
5.1.7 Pump & Treat	27
5.2 Dissolved Plume Control/Remediation Technologies	28
5.2.1 Permeable Barriers	28
5.2.2 In Situ Biodegradation	28
5.2.3 Air Sparging	28
5.2.4 Natural Attenuation	28
5.2.5 Pump & Treat	29
6.0 REFERENCES	30

LIST OF TABLES

TABLE 1. LIST OF DATA SOURCES, SPARTON TECHNOLOGY, INC., ALBUQUERQUE, NEW MEXICO	2
TABLE 2. TCE CONCENTRATIONS IN ON-SITE AND OFF-SITE MONITORING WELLS	4
TABLE 3. CHEMICAL ANALYSIS OF GROUNDWATER CLOSE TO THE SOURCE (MW-16)	9

LIST OF FIGURES

Figure 1. Monitoring Well Locations at Sparton and Vicinity	8
Figure 2. TCE Concentrations in the UFZ Well (MW-16) Closest to the Source	11
Figure 3. Erratic TCE Concentrations in MW-32 (UFZ)	12
Figure 4. Decreasing Concentrations in an On-Site UFZ Well (MW-9)	14
Figure 5. Increasing Concentrations in a UFZ Well (MW-61) Near the Edge of the Plume	15
Figure 6. Increasing Concentrations in a ULFZ Well (MW-60) Near the Edge of the Plume	16
Figure 7. Increasing Concentrations in an LLFZ (MW-55) Near the Edge of the Plume	17

ABBREVIATIONS AND ACRONYMS

CMS	Corrective Measures Study
Cr	chromium
DCE	dichloroethene
DNAPL	dense, nonaqueous-phase liquid
DO	dissolved oxygen
gpm	gallons per minute
LFZ	lower flow zone
LLFZ	lower-lower flow zone
LNAPL	light, nonaqueous-phase liquid
MCL	maximum contaminant level
MECL	methylene chloride
MW	monitoring well
NAPL	nonaqueous-phase liquid
NMED	New Mexico Environment Division
P&T	pump and treat
PCE	perchloroethylene
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SVE	soil vapor extraction
TCA	trichloroethane
TCE	trichloroethylene
TFZ	third flow zone
UFZ	upper flow zone
ULFZ	upper-lower flow zone
U.S. EPA	U.S. Environmental Protection Agency
VC	vinyl chloride
ZORLP	zone of relatively lower permeability

1.0 INTRODUCTION AND REVIEW OF SITE INFORMATION

1.1 Introduction

During January 1996, Battelle was brought under contract by Sparton Corporation to review information regarding their Coors Road Site in Albuquerque, New Mexico; to provide state-of-the-art technology descriptions; and to evaluate the potential for site cleanup based on the current technologies. Specifically, the five scope items were:

1. Review all information provided by Sparton to the U.S. Environmental Protection Agency (U.S. EPA) or the New Mexico Environment Division (NMED) regarding the Coors Road Facility in Corrales, New Mexico (near Albuquerque).
2. Describe the state of the art, as of January 1996, for remediation by pumping and treating of groundwater impacted by chlorinated solvents.
3. Describe the state of the art, as of January 1996, for remediation by natural attenuation or intrinsic bioremediation of groundwater impacted by chlorinated solvents.
4. Identify existing technologies developed since the submission of a draft Corrective Measures Study (CMS), that may have a cost-effective application to the Coors Road Facility.
5. Evaluate, based on the results of items 1 to 4, the technical practicability, cost-effectiveness, and likelihood of success in using (a) pumping and treating, (b) natural attenuation or intrinsic bioremediation, or (c) any technologies identified in item 4, to remediate impacted groundwater at the Coors Road Facility.

Table 1 is a list of documents provided by Sparton and reviewed by Battelle as the basis for the evaluation that follows.

1.2 Site History

Sparton's Coors Road facility is a 12-acre site on the northwest side of Albuquerque, New Mexico. Electronic components were manufactured at this facility from 1961 to 1994. From 1961 to 1980, waste cleaning solvents were placed in an on-site sump for evaporation. In October 1980, the sump was emptied and filled with sand. From 1961 to 1983, plating wastes were stored on site in a variety of impoundments, including the East and West Ponds. In 1987, the impoundments and sump area were capped to prevent infiltration.

In 1983, Sparton installed a groundwater monitoring system at the facility, which detected the presence of contaminants in the groundwater. Elevated levels of trichloroethylene (TCE), trichloroethane (TCA), methylene chloride (MECL), 1,1-dichloroethene (1,1-DCE), perchloroethylene (PCE), toluene, benzene, and chromium (Cr) were found during monitoring. An investigation of soil samples from soil borings in 1986-87 revealed the presence of Cr at elevated levels outside the impoundments. Soil gas surveys conducted in 1984 and 1987 also revealed TCE and TCA across the facility. An Interim Measure was implemented in December 1988. This consists of a pump and treat (P&T) system that extracts and treats approximately 1,300 gpm of water recovered from 8 wells in the upper 10 ft of the aquifer. The treatment system is a 20-gpm packed-bed air stripper that operates

**TABLE 1. LIST OF DATA SOURCES, SPARTON TECHNOLOGY, INC.
ALBUQUERQUE, NEW MEXICO**

-
-
- RCRA Facility Investigation Volume I of II, May 1992
 - RCRA Facility Investigation Volume II of II, May 1992
 - Additional monitoring well data dated 1/29/96
 - Draft Corrective Measures Study dated November 6, 1992
 - Statement of Basis, RCRA Corrective Action, Prepared by EPA, February 1996
 - Reaction to questions raised by EPA dated November 6, 1995
 - Aerial photograph of facility and surrounding areas
 - Geological survey map of Los Griegos Quadrangle
 - Letter to Tom Naymik, Battelle dated January 22, 1996, from James Harris, Thompson & Knight
 - Copy of the Subject Agreement (Sparton/Battelle) dated January 23, 1996
 - Ten maps of the 4th quarter analytical results for December 1993
 - Albuquerque Water Resources Management Strategy San Juan - Chama Diversion Project Options - Summary Report Volume 1 of 3, July 1995
 - Albuquerque Water Resources Management Strategy San Juan - Chama Diversion Project Options - Appendices A, B, and C Volume 2 of 3, July 1995.
 - Albuquerque Water Resources Management Strategy San Juan - Chama Diversion Project Operations - Appendices D and E Volume 3 of 3, July 1995
 - Sparton monitoring results, Fax from Pierce Chandler, Black and Veatch to Tom Naymik, Battelle dated February 27, 1996
 - Final Results for STI-NMED 1st Q 1996 Event. Prepared by John Wakefield, Sparton, February 26, 1996
-
-

at a demonstrated efficiency of 99% for the organic contaminants. The effluent air from the air stripper meets local air emission standards and is vented to the atmosphere.

A Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) was submitted by Sparton in 1992 to determine the nature and extent of the contamination. A draft CMS was also conducted in 1992 as part of a Corrective Action Plan for the Coors Road Site. By 1993,

monitoring showed that the leading edge of the contaminant plume had migrated approximately ½ mile off site.

1.3 Site and Contaminant Characteristics

The site is underlain by clays and sandy clays interbedded with gravelly sands. The gravelly sands predominate in the upper and lower flow zones. Soil borings show that the depositional environment changes vertically as well as horizontally, and both types of sediments are found in every boring. On a linear scale from 1 to 10, with 1 being homogeneous and 10 being completely heterogeneous, this site would rank at about 7½.

Previous reports have described the hydrogeology in terms of three flow zones, i.e., upper flow zone (UFZ), lower flow zone (LFZ), and third flow zone (TFZ), based on stratigraphic and potentiometric differences. On site, between the UFZ and the LFZ, there are continuous fine-grained layers of clay or compacted silty sand that act as barriers between the two zones. Such continuous zones of relatively lower permeability (ZORLPs) were not found off site. The LFZ is further divided into the upper-lower flow zone (ULFZ) and the lower-lower flow zone (LLFZ). All these flow zones are connected and constitute a single groundwater unit.

Groundwater flow direction in the region is generally to the southwest. Locally however, groundwater flow direction underlying the site may be to the southwest whereas off site the flow moves west or northwest. Seasonal water table fluctuations are caused by irrigation and may affect flow direction locally.

Groundwater contaminants identified during the RFI and subsequent monitoring well studies include TCE, TCA, 1,1-DCE, PCE, MECL, benzene, toluene, and Cr. Of these, TCE and TCA are the most prevalent. TCE is the critical component that has been used to delineate the source and plume. Table 2 shows the TCE concentrations over time in the on-site and off-site monitoring wells. The monitoring well locations are shown in Figure 1.

The contaminants are from one of two main categories, either the source zone or the dissolved groundwater contaminant plume emanating from the source zone.

1.4 Source Zone Data Review

The source zone consists of the portion of the contamination that is in the underground vicinity of the historical release (sump, ponds), and which contributes contaminants to the plume. The source includes both the vadose and saturated zones. MW-16 is the monitoring well closest to the source and the dissolved contaminant levels in this well over time are shown in Table 3. In addition, soil gas samples collected near the surface indicate the presence of TCE and TCA contamination in the vadose zone.

There was no indication in the reviewed information of any free-phase solvent being found in the subsurface at the site. However, the data indicate the potential for the presence of dense, nonaqueous-phase liquid (DNAPL) in the source zone. Dissolved groundwater concentrations in the vicinity of the release (MW-16) have been above 1% of the individual aqueous solubilities for both TCE (solubility limit 1,100 mg/L) and TCA (solubility limit 720 mg/L) at various times (see Table 3). Data from MW-16 and MW-21 are both indicative of a DNAPL source. In 1989, following the implementation of the Interim Measure, TCE and TCA concentrations in both wells

TABLE 2. TCE CONCENTRATIONS IN ON-SITE AND OFF-SITE MONITORING WELLS

Well#:	7	9	12	13	14	15	16	17	19	20	21	22	29	30	31
Flow Zone	UFZ	UFZ	UFZ	UFZ	UFZ	UFZ	UFZ	UFZ	ULFZ	LLFZ	UFZ	UFZ	ULFZ	ULFZ	ULFZ
Year	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Oct-83	83	21000													
Oct-84	530	9600	61	6900	12000	4400	37000	4300							
Jul-85		7300													
Jan-86		6100													
Apr-86		8300													
Jul-86		5000					20000								
Oct-86		5000			4900	940	36000		3600	17	2300	230			
Jan-87		4500			5000	630	21000		2700	12	1700	170			
Apr-87		3600			1800	580	23000		2900	32	1400	270			
Jul-87	370	6400	3700	1300	2100	650	25000	4200	4600	35	2100	370			
Oct-87		7100			2700	480	28000		3400	25	2000	240			
Jan-88		5500			6200	370	26000		2900	10	1800	150			
Apr-88		4800			5000	<10	25000		<5	28	1100	230			
Jul-88		3300			5200	380	26000		1800	19	1500	63			
Oct-88		4200			5600	250	22000		3600	15	1300	120			
Jan-89		4000			3300	180	16000		3200	12	900	110			
Feb-89				610	1100	210							5.7	320	120
Mar-89				650	3700	210							5.4	320	120
Apr-89		4400			4900	200	14000		3700	14	520	150			
Aug-89		2500			3000	200	13000		2400	20	460	120			
Aug-89															
Nov-89		2300			2200	260	16000		1500	5	1100	91			
Nov-89															
Jan-90		2800			2100	190	13000		880	17	1000	110			
Jan-90															
Apr-90		2400			1800	160	20000		1000	21	400	130			
Apr-90															
Jun-90															
Aug-90		2200			2100	230	19000		850	15	670	140			
Aug-90															
Sep-90															
Oct-90		1600			1500	140	16000		590	10	850	83			
Oct-90															
Oct-90															
Jan-91		1700			1700	110	16000		680	28	910	75			
Apr-91		1600			1400	5	12000		690	5.4	400	92			
Jun-91		1400			1100	91	17000		570	12	500	110	<5	180	60
Jul-91		1300		330	1400	110	16000		190	12	440	110			
Oct-91		1000			1100	80	12000		170	16	880	93			
Nov-91															
Dec-91															
Jan-92		1200			1300	64	13000		130	5	680	65			
Apr-92		1400			1400	64	12000		230	5	360	90			
Jul-92		930			860	49	15000		140	5	390	72			
Oct-92		1000			1100	66	14000		120	30	460	48			
Jan-93	340	690			850	52	13000		577	3	430	51			
Apr-93		820			850	1.9	12000		110	31	240	55			
Jul-93		730			720	56	11000		62	7	350	47			
Oct-93		680			700	44	13000		45	23	480	41			
Dec-93		680		330	640	39	13000		39	6	490	41	1	47	10
Jan-94		790			680	36	12000		48	1.1	380	60			
Apr-94		740			730		11000		81	0.2	280	62			
Jul-94		750			730	52	11000		61	8	210	44			
Oct-94		750			700	31	11000		47	44	360	45			
Oct-94															
Feb-95		850			690	45	8700		72	5	270	72			
Apr-95		790			1000	45	7100		92	0.2	160	100			
Aug-95		490			470		9100		39	11	200	32			
Oct-95		650			470	21	7400		48	26	280	34			
Jan-96		570	1000	380	290	15	7600	3800	24	1.3	330?	46	0.9	19	2.7

TABLE 2. TCE CONCENTRATIONS IN ON-SITE AND OFF-SITE MONITORING WELLS
(Continued)

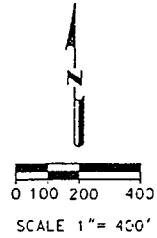
Well#:	32	33	34	35	36	37	38	39	40	41	42	43	44
Flow Zone	LLFZ	UFZ	UFZ	UFZ	UFZ	UFZ	LLFZ	ULFZ	LLFZ	ULFZ	ULFZ	LLFZ	ULFZ
Year	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Oct-83													
Oct-84													
Jul-85													
Jan-86													
Apr-86													
Jul-86													
Oct-86													
Jan-87													
Apr-87													
Jul-87													
Oct-87													
Jan-88													
Apr-88													
Jul-88													
Oct-88													
Jan-89													
Feb-89	4800	7500											
Mar-89	3400	7000											
Apr-89													
Aug-89			<5	<5	7.9	1100							
Aug-89			<5	<5	11	1800							
Nov-89							<5	<5	<5	1100	1100	270	
Nov-89							<5	<5	<5	960	1200	160	
Jan-90													<5
Jan-90													<5
Apr-90													
Apr-90													
Jun-90													
Aug-90													
Aug-90													
Sep-90													
Oct-90													
Oct-90													
Oct-90													
Jan-91													
Apr-91	4900				22	710					880	300	
Jun-91	57	7300	<5	<5.0	22	2000	<5	<5	<5	620	1000	280	<5
Jul-91													
Oct-91	5100			<5.0	19	1400					930	440	
Nov-91	2400												
Dec-91	2400												
Jan-92	5100			<5.0	15	1200					740	260	
Apr-92	6000			<5.0	14	960					690	340	
Jul-92	7500			<5.0	10	800					640	200	
Oct-92	2600			<5.0	8.3	810				510	600	180	
Jan-93	830			<1	7	510					680	200	
Apr-93	1500			<1	4	340					320	130	
Jul-93	4400			<1	25	800				370	620	850	<1
Oct-93	780			<1	3	600					600	160	
Dec-93	490		<1	<1	3	980	<1	<1	<1	350	620	150	<1
Jan-94	580			<1	3	860					570	150	
Apr-94	1700			<1	2	850					490	120	
Jul-94	400			<1	3	370					530	160	
Oct-94	1700			ND	2 J	940				420	510	110	
Oct-94													
Feb-95	2000			<5.0	3 J	770					340	79	
Apr-95	1600			<5.0	3 J	750					340	98	
Aug-95	4200				2 J	750					340	100	
Oct-95	2800				2	750					350	110	
Jan-96	760	2000	<0.3	<0.3	1.9	720	<0.3	<0.3	<0.3	290	470	95	<0.3

**TABLE 2. TCE CONCENTRATIONS IN ON-SITE AND OFF-SITE MONITORING WELLS
(Continued)**

Well#:	45	46	47	48	49	51	52	53	55	56	57	58	59
Flow Zone	ULFZ	ULFZ	UFZ	UFZ	3rd FZ	UFZ	UFZ	UFZ	LLFZ	ULFZ	UFZ	UFZ	ULFZ
Year	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Oct-83													
Oct-84													
Jul-85													
Jan-86													
Apr-86													
Jul-86													
Oct-86													
Jan-87													
Apr-87													
Jul-87													
Oct-87													
Jan-88													
Apr-88													
Jul-88													
Oct-88													
Jan-89													
Feb-89													
Mar-89													
Apr-89													
Aug-89													
Aug-89													
Nov-89													
Nov-89													
Jan-90	1400	4200	310	820	<5								
Jan-90	1400	2300	330	830?	<5								
Apr-90						8.5							
Apr-90						6.2							
Jun-90			220	820		6.7	<1	<1					
Aug-90				600					13	50			
Aug-90				1100					9.2	29			
Sep-90		4800		930					12	98	<1	20	<1
Oct-90													<5
Oct-90												22	
Oct-90												22	
Jan-91													
Apr-91		1200		400		5		<5	31	160		34	
Jun-91	770	1300	120	410	<5	<5?	<5	<5	45	200	<5	29	<5
Jul-91													
Oct-91		5200		220		<5	<5	<5	74	210		31	<5
Nov-91		2600											
Dec-91													
Jan-92		2300		280		11		6.8	96	260		34	
Apr-92		1300		290		<5.0		9.8	120	290		37	
Jul-92		960		340		<5.0		14	130	290		37	
Oct-92		4200		240		<5.0		16	120	240		39	
Jan-93		1200		360		<1		21	190	370		48	
Apr-93		1200		310		<1		23	110	230		43	
Jul-93		1400		330		<1		33	240	320		62	
Oct-93		2100		420		1		30	310	430		64	
Dec-93	160	1800	93	350	<1	2	<1	32	380	410	<1	74	<1
Jan-94		2500		350		<1		38	370	430		85	
Apr-94		2700		340		0.6 J		34	390	370		93	
Jul-94		3200		370		<1		43	550	370		110	
Oct-94		2100		300		<5	<5	40	580	420	<5	97	
Oct-94								38					
Feb-95		2600		253		<5		21	580	340		100	
Apr-95		2400		300		1 J		41	640	370		120	
Aug-95		3000		250		<5		42	680	360	<5	130	
Oct-95		3300		270		<1		48	130	350	<1	140	
Jan-96	59	3200	36	350	<0.3	<0.3	<0.3	100	940	430	<0.3	270	<0.3

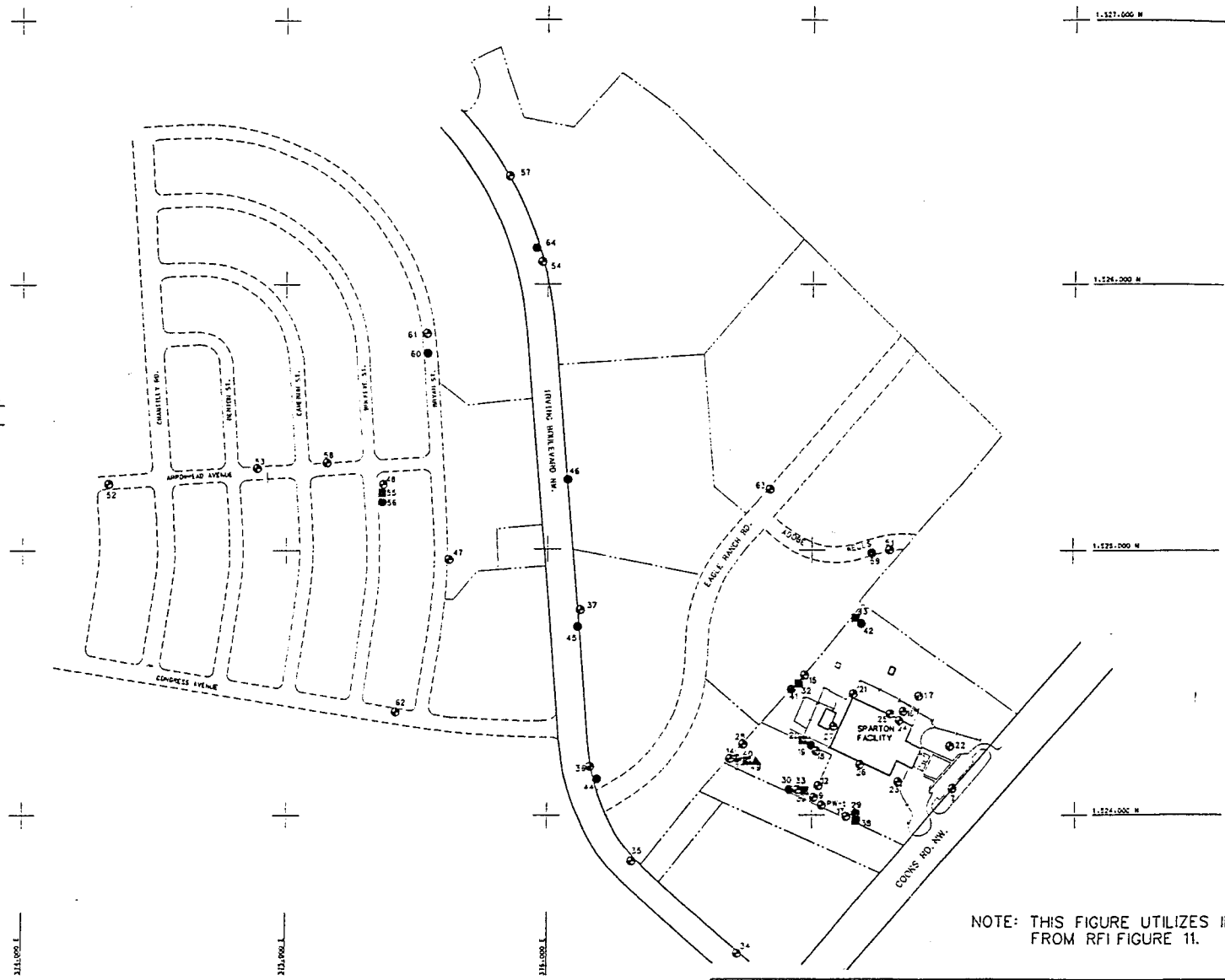
**TABLE 2. TCE CONCENTRATIONS IN ON-SITE AND OFF-SITE MONITORING WELLS
(Continued)**

Year	Well#: 60 Flow Zone ULFZ µg/L	61 UFZ µg/L	62 UFZ µg/L	63 UFZ µg/L	64 ULFZ µg/L
Oct-83					
Oct-84					
Jul-85					
Jan-86					
Apr-86					
Jul-86					
Oct-86					
Jan-87					
Apr-87					
Jul-87					
Oct-87					
Jan-88					
Apr-88					
Jul-88					
Oct-88					
Jan-89					
Feb-89					
Mar-89					
Apr-89					
Aug-89					
Aug-89					
Nov-89					
Nov-89					
Jan-90					
Jan-90					
Apr-90					
Apr-90					
Jun-90					
Aug-90					
Aug-90					
Sep-90					
Oct-90	<1	<1	<5	<1	<5
Oct-90	<5	<5	2.2?	<5	<1
Oct-90	<5	<5	<5?	<5	<5
Jan-91					
Apr-91	<5				
Jun-91	<5	<5	<5	<5	<5
Jul-91					
Oct-91	<5		<5		
Nov-91					
Dec-91					
Jan-92	<5.0		<5.0		
Apr-92	<5.0		<5.0		
Jul-92	<5.0		<5.0		
Oct-92	<5.0		<5.0		
Jan-93	1		2		
Apr-93	<1		2		
Jul-93	4	490	3		
Oct-93	2	500	3		
Dec-93	7	610	3	<1	<1
Jan-94	3	530	2		
Apr-94	6		2		
Jul-94	9	800	3		
Oct-94	24	870	2 J		10
Oct-94					
Feb-95	16	960	2 J		11
Apr-95	44	1400	2 J		18
Aug-95	66	1700	2 J?		17
Oct-95	100	2000	2		8
Jan-96	170	1900	1.8	<0.3	15



LEGEND

- UPPER FLOW ZONE WELL
- UPPER LOWER FLOW ZONE WELL
- LOWER LOWER FLOW ZONE WELL
- ▲ THIRD FLOW ZONE WELL



NOTE: THIS FIGURE UTILIZES INFORMATION FROM RFI FIGURE 11.

HDR
HDR Engineering, Inc.

MONITOR WELL LOCATION PLAN

SPARTON TECHNOLOGY, INC.
COORS ROAD FACILITY
ALBUQUERQUE, NEW MEXICO

Date	OCT '92
Page	FIGURE 8

Figure 1. Monitoring Well Locations at Sparton and Vicinity

**TABLE 3. CHEMICAL ANALYSIS OF GROUNDWATER CLOSE
TO THE SOURCE (MW-16)**

Year	Quarter	TCE μg/L	PCE μg/L	1,1,1 TCA μg/L	1,1 DCE μg/L	1,2 DCE μg/L	Vinyl Chloride μg/L	Toluene μg/L	Benzene μg/L	Total Chromium mg/L	Cr +6 mg/L	Methylene Chloride μg/L
1983	4											
1984	4	37000	140	5500	3100	200	<10	1600	58	0.75		49000
1985	1											
1985	2											
1985	3											
1985	4											
1986	1											
1986	2											
1986	3	20000			2200							
1986	4	36000	<1300	30000	3500	<1300	<2500	<1300	<1300	0.017		16000
1987	1	21000			2200							
1987	2	23000			1900							
1987	3	25000	<1200	21000	2200	<1200	<2500	<1200	<1200	<0.01		<6200
1987	4	28000			1600							
1988	1	26000			1400							
1988	2	25000			1400							
1988	3	26000	<1600	24000	1900	<1600	<3100	<1600	<1600	0.04		<7800
1988	4	22000			1600							
1989	1	16000			1200							
1989	2	14000			1000							
1989	3	13000	<250	10000	960	<250	<500	<250	<250	0.05		1100
1989	4	16000			<1200							
1990	1	13000			<1000							
1990	2	20000	<1000	16000	<1000	<1000	<2000	<1000	<1000	0.041		<1000
1990	3	19000			1200							
1990	4	16000			<1000							
1991	Jan	16000										
1991	Apr	12000										
1991	Jun	17000		13000								
1991	Jul	16000										
1991	Oct	12000										
1992	Jan	13000										
1992	Apr	12000										
1992	Jul	15000										
1992	Oct	14000										
1993	Jan	13000		5900	400							
1993	Apr	12000		5900	470							
1993	Jul	11000		4200	310							
1993	Oct	13000		6200	360							
1993	Dec	13000		5100	360							
1994	Jan	12000		4400	360							
1994	Apr	11000		3200	190							
1994	Jul	11000		3700	230					0.376	0.4	
1994	Oct	11000		4000	280							
1995	Feb	8700		3100	340							
1995	Apr	7100		2100	200							
1995	Aug	9100		2700	280							
1995	Oct	7400		2200	140					0.57	0.52	
1996	Jan	7600		1900	93					0.19		

dropped to a new equilibrium (see Table 3), rather than declining steadily. Similar effects were observed by Rivett (1993) in a field evaluation of a P&T application. The initial drop in concentration is due to dilution from ambient water flowing upgradient into the area or possibly drawn in from outside the plume by the P&T system. A new equilibrium is established as soon as the mass transfer rate (of dissolution) adjusts to the ambient water flux.

The most recent groundwater samples taken from the source zone (MW-16) have shown TCE (Figure 2) and TCA (Table 3) concentrations below the 1% rule-of-thumb level. This type of behavior was predicted by several researchers (Feenstra and Guiguer, 1995; Johnson and Pankow, 1992) who demonstrated that when DNAPL is heterogeneously distributed, the rate of dissolution, and therefore the observed concentrations, decrease with time. This happens because the groundwater flow initially dissolves the more accessible solvent (residual solvent from larger pores). As the more accessible solvent is depleted, the dissolved concentrations are determined by the reduced mass transfer associated with the less accessible solvent (residual solvent in dead-end pores and solvent associated with regions of accumulation). This research has shown that, even with the lower observed concentrations, the chlorinated solvent source can persist for many years and contribute to a plume that exceeds maximum contaminant levels (MCLs).

The on-site monitoring wells in the ULFZ that are closest to the source are MW-19, MW-41, and MW-42. Both TCE and TCA have been found in these wells. The appearance of TCE and TCA in these wells indicates the possibilities that the plume is sinking (density effect), the DNAPL in the source zone has moved into the lower flow zones, or mixing has taken place with the ambient groundwater. The ZORLP underlying the site separates the UFZ from the ULFZ and serves to impede the downward progress of the solvent. The ZORLP could be penetrated through either diffusion of the dissolved phase or migration of the free phase. MW-41 (west of source) and MW-42 (northwest) have higher TCE concentrations than MW-19 (southwest), indicating that the plume may be developing to the west or northwest across the site in the lower flow zones. TCE concentrations found on site in the LLFZ in MW-32 (west) and MW-43 (northwest) are also indicative of this movement. MW-32 in the LLFZ shows erratically fluctuating concentrations of TCE (see Figure 3), which are regarded as another indicator of DNAPL (Cohen and Mercer, 1993). Furthermore, MW-32 is part of a well cluster that shows increasing TCE concentration with depth.

Shallow soil gas surveys conducted in 1984, 1987, and 1991 found soil gas contaminated with TCE and TCA. The overall area of soil gas contamination did not show a reduction between 1987 and 1991. However, on-site soil gas concentrations in the near-surface soils had declined in 1991 compared to the earlier surveys (1984 and 1987). This could be attributed to a number of reasons. First, dense vapors could be settling deeper in the vadose zone (Mendoza and Frind, 1990; Johnson et al., 1992). Second, the solvent itself could be traveling lower into the vadose zone. Third, the solvents could have migrated to below the water table and are now outgassing from the water table back into the vadose zone. A deeper soil gas survey and soil borings (soil samples) would be required to characterize the region.

1.5 Dissolved Plume Data Review

The existing P&T system, installed as an Interim Measure in December 1988, has had a noticeable effect on plume movement in the UFZ.

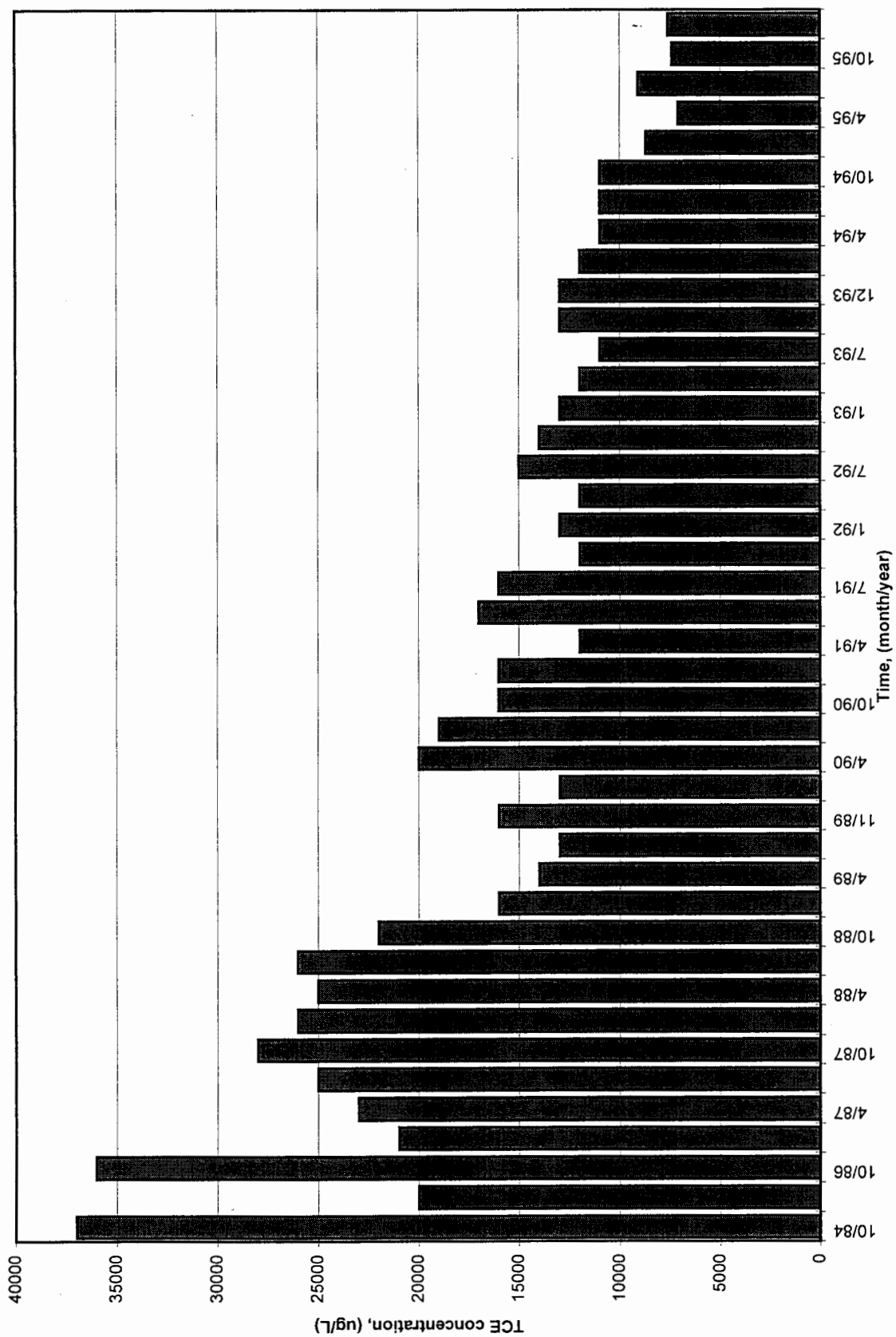


Figure 2. TCE Concentrations in the UFZ Well (MW-16) Closest to the Source

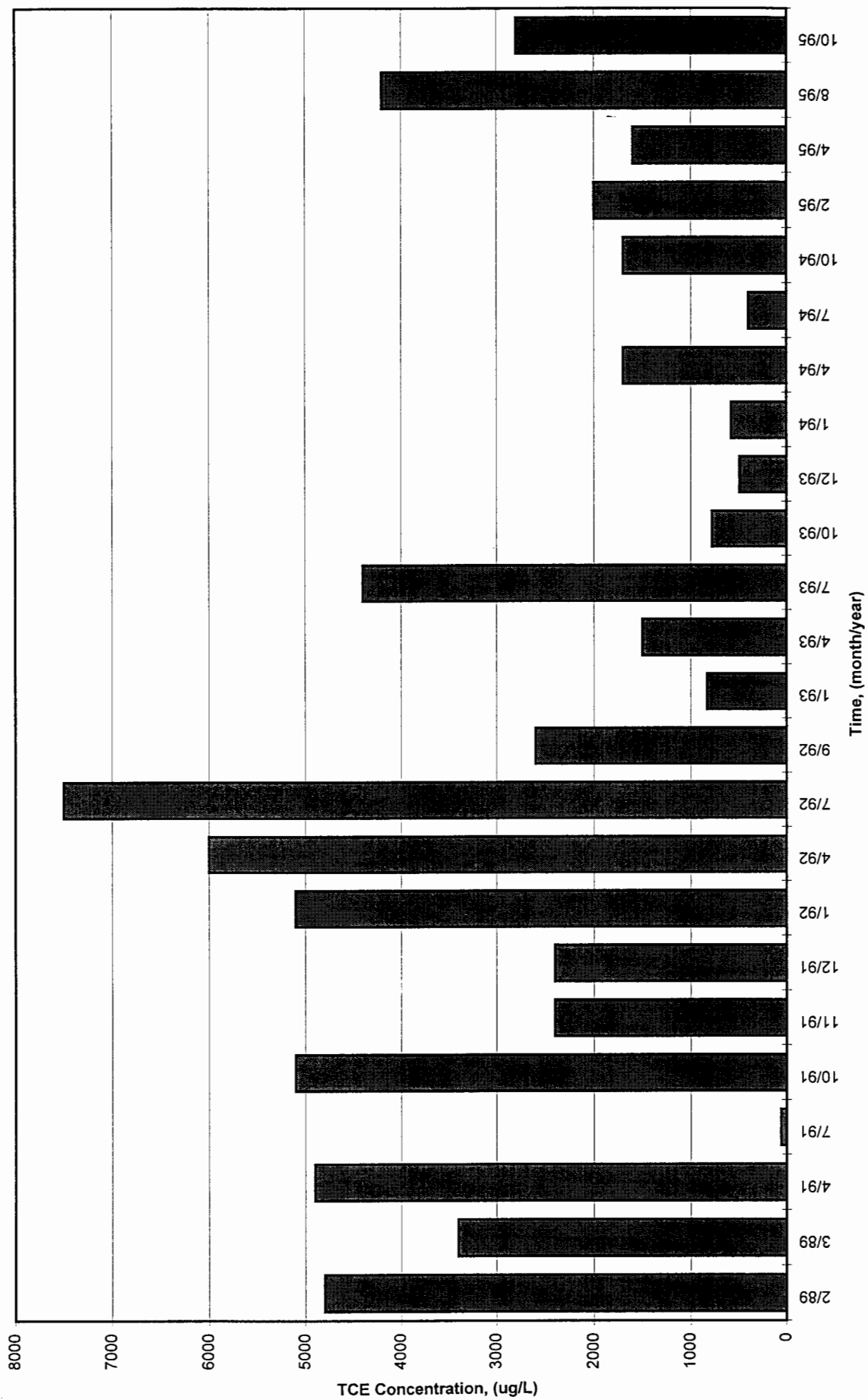


Figure 3. Erratic TCE Concentrations in MW-16 (UFZ)

- TCE concentrations in the UFZ monitoring wells that are relatively close to the source, such as MW-9 (see Figure 4), MW-14, MW-15, MW-21, MW-33, and MW-36, have shown generally declining concentrations over time.
- TCE concentrations in the UFZ monitoring wells that are relatively far from the source — MW-53, MW-58, and MW-61 (see Figure 5) — are increasing with time.

The above trends indicate that the Interim Measure has succeeded in restricting the on-site source from contributing contaminants to the plume in the UFZ. However, the off-site plume itself is continuing to move, as indicated by the appearance of TCE in distant wells and the subsequent rise in concentrations in these wells.

In the lower flow zones (ULFZ and LLFZ), TCE concentrations in the on-site monitoring wells, such as MW-30 and MW-41, have declined with time. In other on-site wells — MW-43, MW-42, MW-41, MW-20, and MW-19 — TCE concentrations have fluctuated over a modest range after showing initial declines. TCE concentrations in MW-32 have been fluctuating erratically over time (see Figure 3). Off site, however, the plume in the LFZ is moving in the direction of the groundwater flow to the north-northwest. This is indicated by increasing concentrations in distant ULFZ monitoring wells MW-46, MW-56, MW-60 (see Figure 6), and distant LLFZ wells MW-55 (see Figure 7) and MW-64.

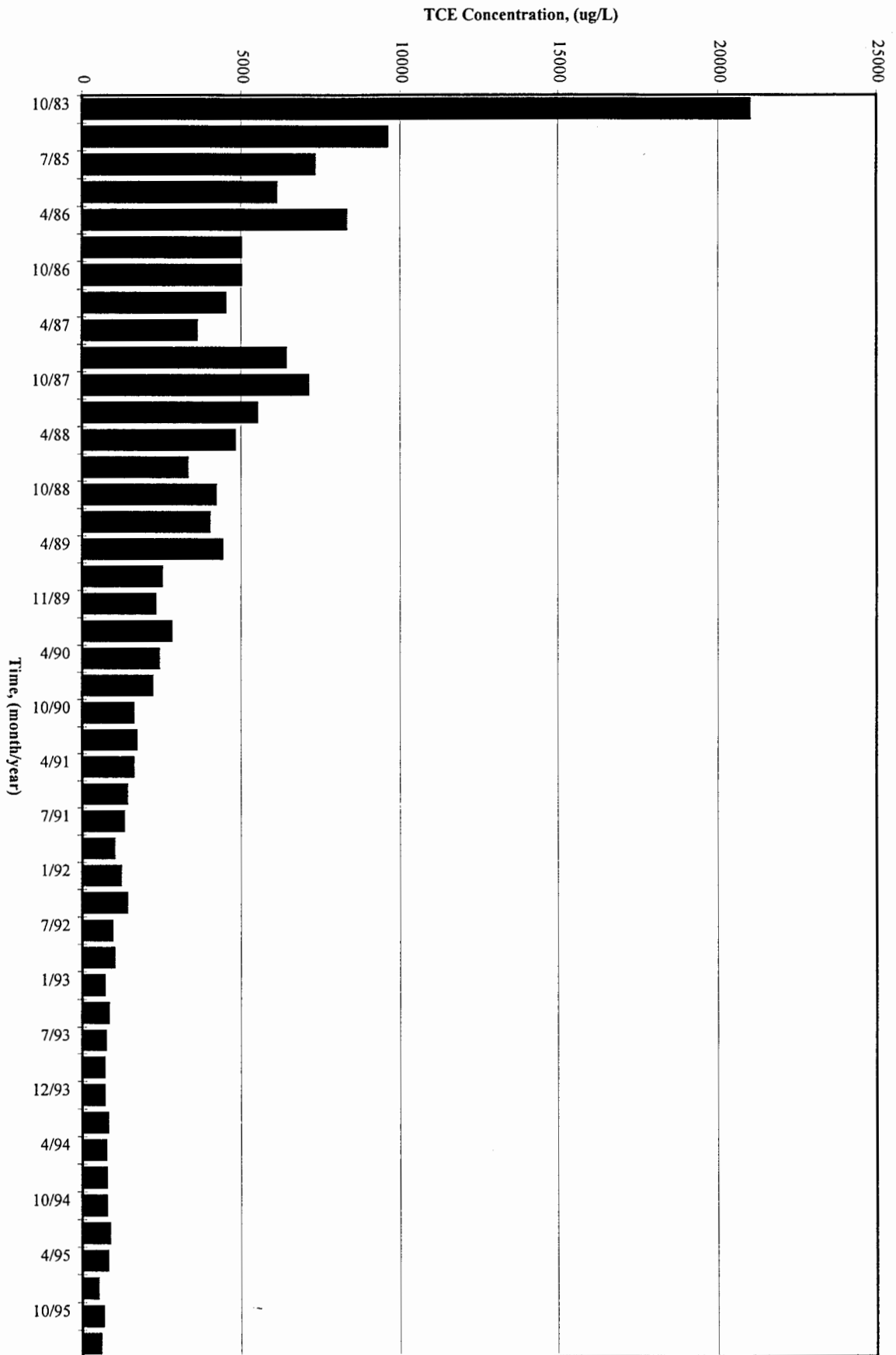


Figure 4. Decreasing Concentrations in an On-Site UFZ Well (MW-9)

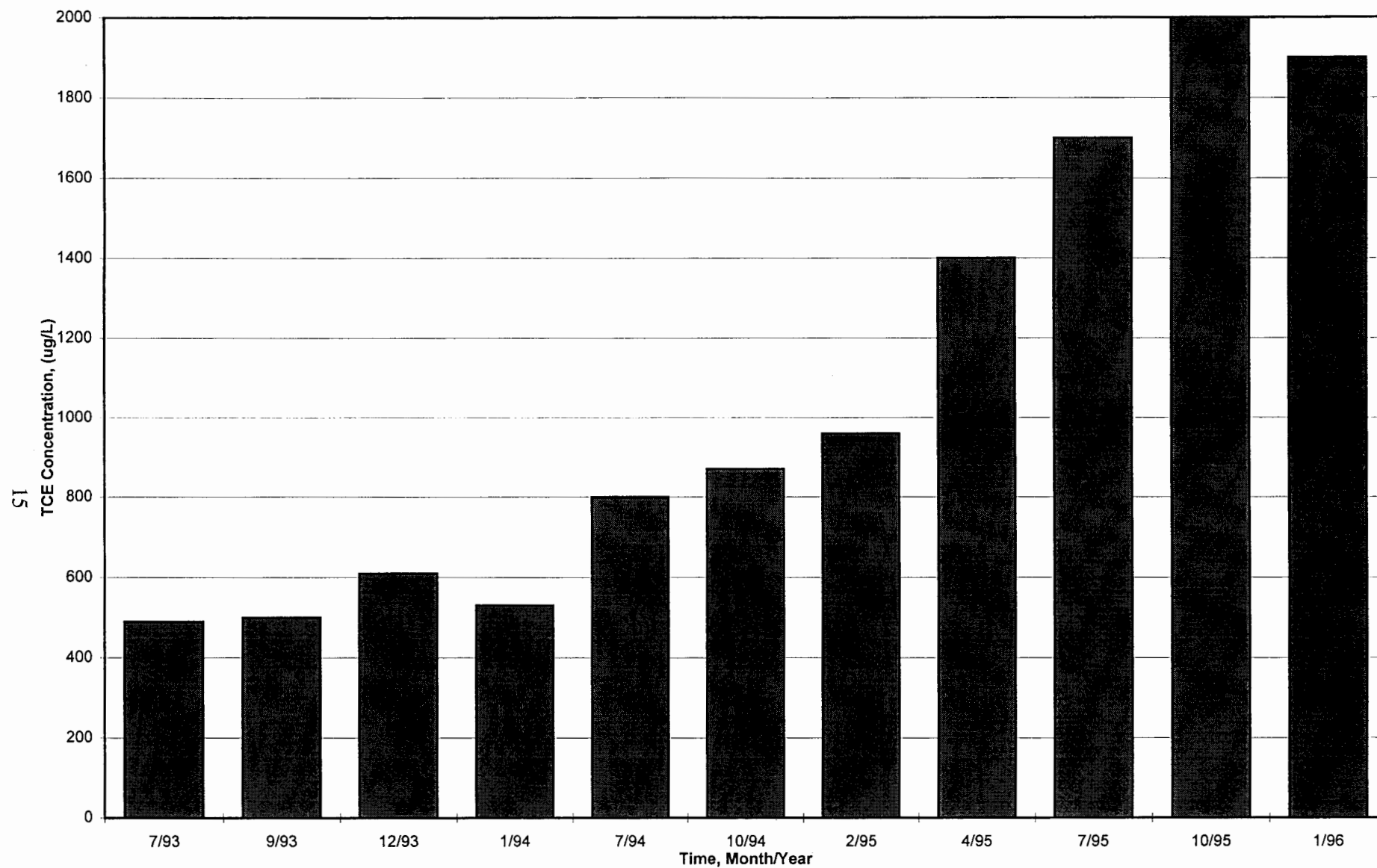


Figure 5. Increasing Concentrations in a UFZ Well (MW-61) Near the Edge of the Plume

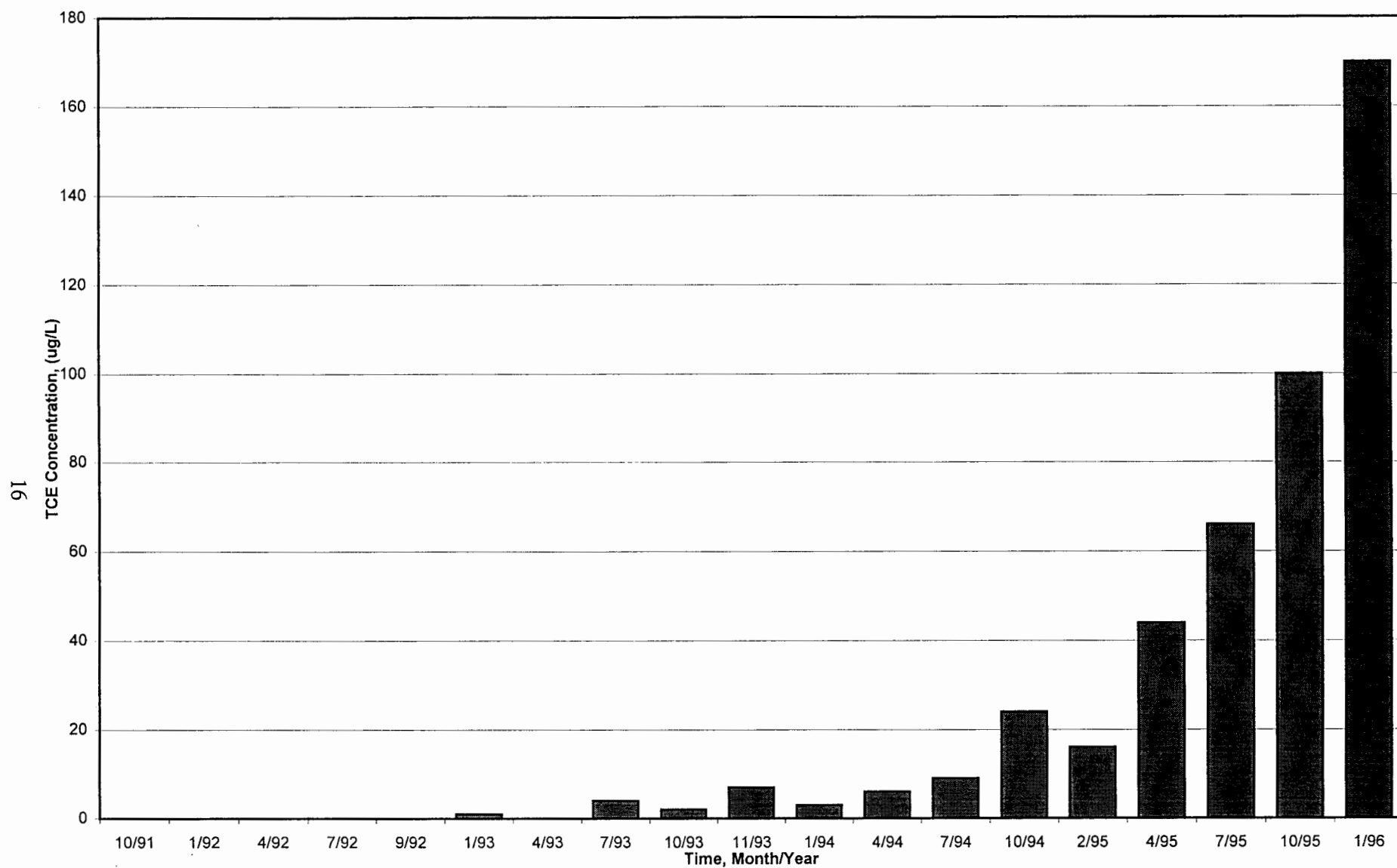


Figure 6. Increasing Concentrations in a ULFZ Well (MW-60) Near the Edge of the Plume

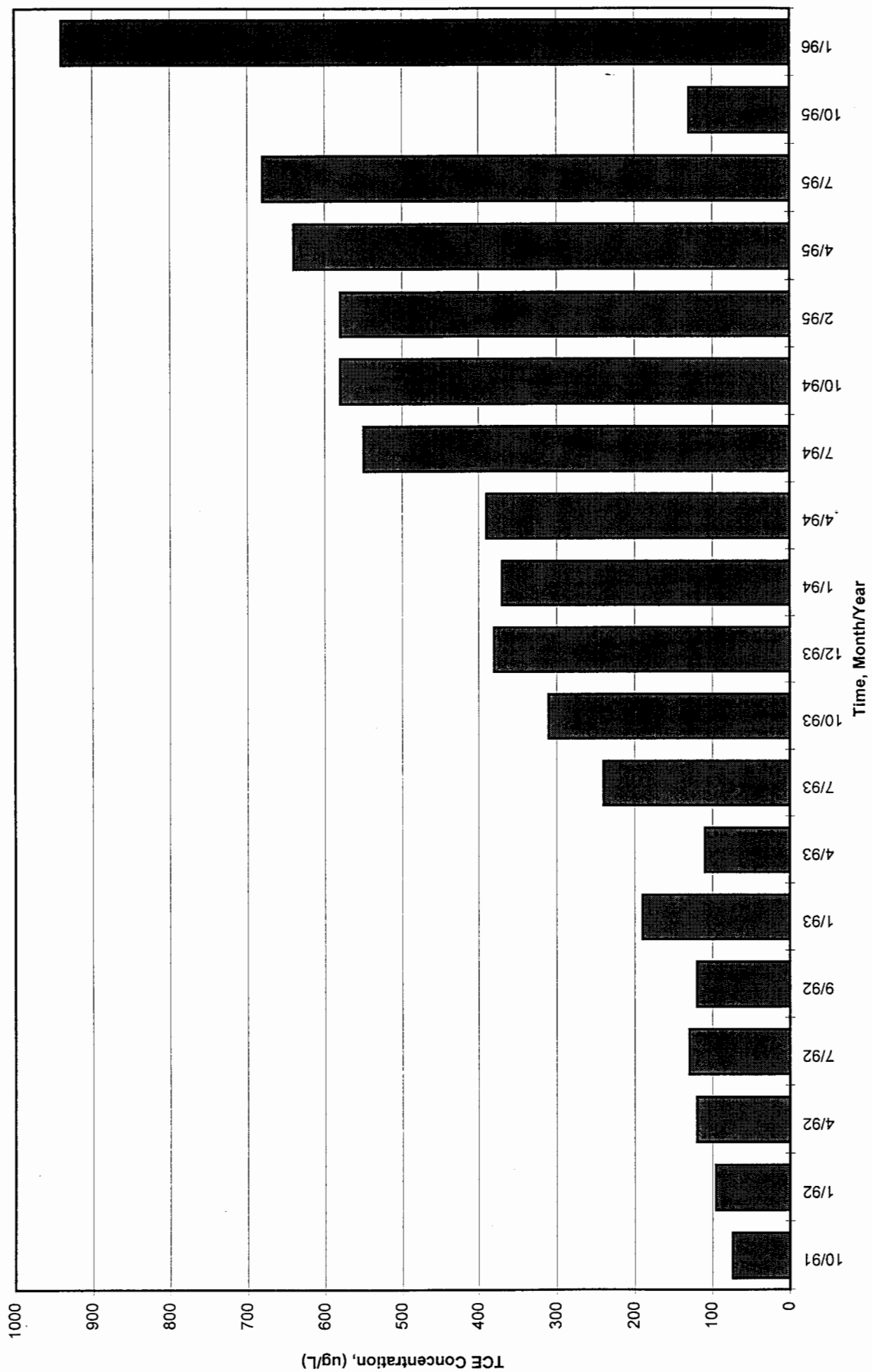


Figure 7. Increasing Concentrations in an LLFZ (MW-55) Near the Edge of the Plume

2.0 STATE OF THE ART FOR REMEDIATION BY PUMPING AND TREATING GROUNDWATER IMPACTED BY CHLORINATED SOLVENTS

Conventional P&T systems have been used for groundwater treatment for several years. Groundwater is extracted from the ground through pumping wells and treated above ground with technologies such as air stripping or activated carbon. The clean water is discharged, reinjected, or used on site. The effluent air from the air stripper may or may not require treatment depending on the contaminant concentrations and the local air discharge limits.

P&T systems can be operated at sites contaminated by chlorinated solvents in either slow mode or aggressive mode (National Research Council, 1994; Cherry et al., 1995). In the slow mode, pumping is carried out at the minimum rate required to stop the spreading of contaminants in the aquifer. To achieve this, pumping wells are usually installed at the leading edge of the plume. In the aggressive mode, pumping is carried out at higher rates so that clean water from surrounding regions can flush out the contaminated zone. P&T in the slow mode generally requires less power, involves the treatment of lower volumes of water above ground, and is expected to be less costly.

Depending on the amount of DNAPL mass in the source zone, P&T systems may have to be operated for decades, centuries, or longer to even approach background levels. Experience has shown that the P&T method for reduction of groundwater contamination by organic chemicals often is not possible when the goal is remediation to background conditions, or even satisfaction of drinking water criteria. Chlorinated solvents dissolve slowly over time for a number of reasons, including low compound solubility limits, effects of co-contaminants, and mass transfer limitations. At many sites, neither the DNAPL mass nor the rate of dissolution can be predicted accurately. Therefore, P&T systems have to be operated for as long as it takes the source to deplete completely.

If operation of the P&T system is stopped before the source has been completely depleted, dissolved contaminant concentrations in the source area will start increasing and a plume will be regenerated. This phenomenon was noticed at an industrial site in Dayton, New Jersey (EPA, 1989) that was involved in the manufacture of printer ink ribbons. At this site, P&T was started in 1978 after PCE was found in on-site and off-site monitoring wells. This P&T system treated water by air stripping after extraction from a network of pumping wells around the source and along the axis of the plume. In 1984, P&T was stopped after state regulatory agencies determined that PCE concentrations throughout the plume zone had declined to low $\mu\text{g/L}$ levels. The PCE concentrations in the monitoring wells around the source also had declined significantly during the same period of time to 300 to 500 $\mu\text{g/L}$. In about 6 months after P&T was stopped, PCE concentrations in the monitoring wells around the source began to rise again. Eventually, concentrations in the wells close to the source rose to levels higher than those observed in 1978. By 1987, the dissolved plume was again several hundred meters long. In 1990, the P&T system was recommissioned with a network of four pumping wells, including one near the source, one in the middle of the plume, and two at the edge of the plume. The goal of this system was to isolate the source and prevent further migration of the plume.

The technical community has come to the following conclusions about the use of P&T systems at chlorinated solvent sites (National Research Council, 1994):

1. At some sites with simple geology and dissolved contaminants, P&T systems can clean up groundwater to drinking water standards in a relatively short period of time. Such simple sites are the exception rather than the rule.

2. Geologic conditions (heterogeneities) can lengthen the time required to achieve cleanup to drinking water standards.
3. If the DNAPL source is not contained or removed, P&T systems will need to be operated over long periods of time (hundreds or thousands of years) where NAPL contaminants remain unless the NAPLs are contained or removed.
4. At sites where cleanup to drinking water standards is infeasible due to heterogeneities or nature of contaminants, P&T systems can prevent the contamination from spreading.
5. Operation of P&T systems varies widely depending on site conditions and pumping rates.
6. Implementation of a P&T system should be viewed as a long-term project (decades or centuries), during which the system is modified as understanding of the site grows.

According to the National Research Council study (1994), restoring the total volume of contaminated groundwater to drinking water standards may be infeasible at some sites. Nevertheless, properly designed P&T systems still provide benefits, including containment of the contamination (source), retraction (remediation) of the dissolved contaminant plume, and removal of some contaminant mass from the subsurface (from the source).

3.0 STATE OF THE ART FOR NATURAL ATTENUATION OF GROUNDWATER IMPACTED BY CHLORINATED SOLVENTS

Natural attenuation is a general term for natural physical, chemical (abiotic), and biochemical (biotic) processes that occur in the environment, and that tend to degrade contaminants. Natural attenuation is not a "no action" alternative in which the site is left undisturbed and unmonitored (Nelson, 1994). It involves careful investigation to confirm the occurrence of natural degradation mechanisms, risk assessment to evaluate the threat to receptors, long-term monitoring to document the progress, and establishment of final confirmatory sampling and closure plans.

The main physical process that tends to retard the movement of contaminants in a plume is adsorption of the contaminant onto the soil matrix. The process of adsorption initially will cause the plume to be attenuated as the adsorption sites are being satisfied. Once the sites are full, attenuation will no longer occur. When the dissolved phase of the plume decreases in concentration, the contaminants will desorb from the soil matrix and contribute again to the dissolved phase of the plume. Adsorption is directly proportional to the amount of organic matter in the soil matrix. Adsorption only retards the movement of the plume but does not eliminate any mass of contaminants.

Abiotic transformations can eliminate contaminant mass. For example, TCA degrades abiotically to 1,1-DCE and acetic acid under most aquifer conditions. The half-life for this degradation is less than 1 year (McCarty, 1994).

Biological transformations can be important mechanisms in the destruction of organic contaminants. Aerobic transformations are common with petroleum hydrocarbons. Generally TCE and especially PCE are recalcitrant to biodegradation under aerobic conditions. However, in the presence of a suitable primary substrate such as benzene or toluene (or other petroleum hydrocarbons), TCE (but not PCE) can degrade due to cometabolic activity (Lu et al., 1995).

Anaerobic degradation is the more common biodegradation mechanism at chlorinated solvent sites. PCE may degrade anaerobically to TCE, TCE to 1,2-DCE, and 1,2-DCE to vinyl chloride (VC). VC is finally degraded to ethene, although at a much slower pace. Although, TCA degrades abiotically to 1,1-DCE, biotic mechanisms are required to further degrade 1,1-DCE to VC. Because the rate of reductive dechlorination slows down with each chlorine atom removed (PCE to TCE to DCE to VC), significant amounts of these byproducts (1,2-DCE and VC) are seen at sites where anaerobic degradation is occurring.

At the DuPont Necco Park Landfill in Niagara Falls, New York, an extensive monitoring program was conducted to determine if intrinsic anaerobic biodegradation was occurring at the site, to determine what factors might limit the degradation activity, and to characterize this activity with depth and distance away from the landfill (Lee et al., 1995). It was determined that anaerobic degradation was going on based on the presence of intermediate products, such as 1,2-DCE and VC, and the presence of final products such as ethene and ethane. The presence of these products was considered key to the determination. Extensive computer-based groundwater modeling efforts during development of a site conceptual model indicated that biological degradation was necessary to account for the downgradient reduction of chlorinated organic compounds, as compared to inorganic chloride.

At another site in St. Joseph, Michigan, intrinsic bioremediation of TCE was determined to be occurring after 1,2-DCE and VC were found in the plume (Rifai et al., 1995). Significant levels of

ethane and methane (products of anaerobic degradation) were also measured to confirm natural attenuation.

4.0 ADDITIONAL TECHNOLOGIES DEVELOPED SINCE SUBMISSION OF DRAFT CMS

Chlorinated solvent contamination is widely recognized as being one of the most difficult types of contamination to remediate. The contamination can be looked upon as consisting of two parts:

1. Contaminant source zone
2. Contaminant plume.

Remediation technologies available to address either of these two categories can be considered either proven or innovative. *Proven* technologies are commercially available technologies with a considerable base of site experience and success, and whose performance is reasonably predictable (Cherry et al., 1995). *Innovative* technologies are technologies that are considered promising, that may or may not be available commercially, but that would require some degree of additional development or demonstration before final site application.

In addition to P&T and natural attenuation, the technologies presented in Sections 4.1 and 4.2 are potentially applicable to chlorinated solvent sites.

4.1 Source Zone Technologies

Both proven and innovative technologies used to treat the source zone are presented in the following paragraphs.

4.1.1 Soil Flushing (discussed in CMS)

Soil flushing is an *innovative* technology for remediation of the *source zone*. This technology involves flushing the source zone with chemical solutions that enhance the recovery of the DNAPL by mobilization (viscosity reduction, interfacial tension reduction) or dissolution. For example, surfactant (detergent) solutions are injected to mobilize the DNAPL. Alcohol solutions can be injected to enhance the dissolution of the DNAPL. The recovered fluids (DNAPL, pore water, alcohol) have to be treated above ground before discharge.

4.1.2 Thermal Technologies

Thermal technologies are *innovative* technologies that are suited for the *source zone*. These technologies involve the application of heat to mobilize, vaporize, or strip off the chlorinated contaminants. Heat may be applied in the form of steam, radio frequency, or electricity. The heated contaminants are driven off to an extraction well, where they are collected as a mixture of contaminants and pore water.

4.1.3 Soil Vapor Extraction (discussed in CMS)

Soil vapor extraction (SVE) is a *proven* technology that draws air through the vadose zone contamination. The airflow is induced through a dry well attached to a vacuum blower. In some cases, air may be injected through some wells and extracted through others. The air evaporates the residual chlorinated solvents. The vapors are collected above ground and may require treatment before discharge to the atmosphere.

4.1.4 Bioventing (discussed in CMS under SVE)

Most conventional SVE systems use high airflow rates to remove volatile contaminants as quickly as possible. Besides requiring blowers with high horsepower, the SVE approach may be inefficient in terms of the large volumes of air that are generated as air is pulled in from surrounding clean areas. These large volumes of air may have to be treated. Bioventing, an *innovative* technology, involves drawing air at much lower rates to remediate soils more efficiently. The objective is not just to evaporate the contaminants but also to supply oxygen and induce biodegradation.

4.1.5 Impermeable Barriers

Placement of impermeable barriers is a *proven* technology for isolating the source from the groundwater flow. Once the source is isolated, the plume can be remediated within a smaller time frame as it receives no more contribution from the source. The barrier or enclosure can be designed as a keyed enclosure or hanging enclosure. The keyed enclosure is a barrier extending all the way down to the bottom of the aquifer. The hanging enclosure is a barrier that extends only part way down the aquifer. The type of enclosure selected depends on the site conditions.

Slurry walls and sheet piling are common types of impermeable barriers. The slurry wall is a vertical trench filled with Portland cement, bentonite, and water. The mixture hardens to form an impermeable barrier. Sheet piling involves pile driving sheets of steel into the ground to create a physical barrier. Recent innovations have involved the injection of grout into the interlocks between the sheets to secure the barrier.

4.1.6 Air Sparging (discussed in CMS for plume remediation)

Air sparging is an *innovative* technology in which air is injected into the aquifer. As the air travels upward, it strips the volatile contaminants and carries them to the vadose zone, where they are collected by an air extraction well. In contrast to its application for plume remediation, air sparging for source removal is expected to involve two mass transfer steps. First, solubilized chlorinated compounds are transferred from the aqueous phase to the air. Then, as mass is lost from the aqueous phase, more DNAPL dissolves in the water. This process continues until all the DNAPL is depleted.

Although conventional vertical wells are often used for air sparging, recent developments have involved the use of horizontal wells to inject and extract air. A single horizontal well can cover a much larger area than a vertical well.

4.2 Plume Control/Remediation Technologies

Innovative technologies used to control and remediate the contaminant plume are presented in the following paragraphs.

4.2.1 Air Sparging (discussed in CMS)

Air sparging may be conducted for plume control/remediation by placing air sparging wells either in the saturated zone at the edge of the plume or along the axis of the plume. Air is withdrawn from the vadose zone and may have to be treated before it is discharged to the ambient.

4.2.2 In Situ Biodegradation (discussed in CMS)

In situ biodegradation is an *innovative* process more suitable for the *plume* than for the source zone, which tends to have toxic levels of the contaminants. However, its applicability generally has to be evaluated on a site-specific basis. Although a number of field demonstrations of this technology to remediate chlorinated compounds have taken place, most full-scale applications have been implemented on petroleum hydrocarbons.

In situ biodegradation can be either aerobic or anaerobic. *Aerobic* biodegradation is stimulated by injecting a primary substrate, nutrients, and oxygen to degrade the chlorinated compound to carbon dioxide, chloride, and water. *Anaerobic* degradation occurs when no dissolved oxygen (DO) is present in the aquifer. If DO is present, anaerobic conditions would first have to be induced and sustained in the aquifer, followed by injection of a primary substrate and nutrients. Anaerobic pathways for TCE and PCE are reductive and lead to the formation of intermediates such as 1,2-DCE and VC. Because reductive dehalogenation slows down with each chlorine atom knocked off from the contaminant, 1,2-DCE and VC tend to be somewhat persistent, and therefore anaerobic degradation tends to be slower than aerobic degradation. On the other hand, PCE can be degraded only anaerobically, and continuous introduction of oxygen is not required.

Whether aerobic or anaerobic biostimulation is followed, implementation could be challenging because of the necessity of sweeping large volumes of the aquifer occupied by the plume with liquids containing nutrients and/or oxygen as distinguished from gaseous-phase oxygen in the air such as that used in air sparging (Grubb and Sitar, 1994). Any ZORLPs or other heterogeneities could hamper the distribution of nutrients and/or oxygen. Although in situ biodegradation has the potential for relatively low-cost application, treatability studies would have to be conducted to determine the ability of natural microbial populations to degrade chlorinated compounds, and to determine other nutrient and environmental requirements and byproduct formations. Also, biodegradation is a slow process (sometimes requiring decades or centuries) and may require periodic replenishment of nutrients. The region would have to be monitored for as long as it takes biodegradation to be completed.

4.2.3 Permeable Barriers

In this *innovative* technology, a trench filled with iron filings is placed in the path of the plume. As the plume moves through this permeable barrier, the iron acts as a reducing agent and dechlorinates the TCE/PCE. The attractiveness of this technique lies in the inexpensive nature of the reagent (iron) and the absence of energy-driven components during operation. Depending on the period of operation, the iron filings in the barrier may have to be replenished every few years.

5.0 EVALUATION OF APPLICABLE TECHNOLOGIES

The applicability of the potential remedies identified in previous sections is discussed in this section as it pertains to the chlorinated solvent source zone and plume at the Coors Road Site.

5.1 Source Zone Technologies

5.1.1 Soil Flushing

At the Coors Road site, soil flushing would face several difficulties. Achieving a uniform distribution of flushing agents (surfactant, alcohol) would be challenged by the presence of the ZORLPs and other heterogeneities. Alcohols, especially, have a tendency to override the DNAPL when injected. Soil flushing currently is best suited for sites that are relatively homogeneous and where chlorinated compounds are present mostly as residual DNAPL. If mobile DNAPL has accumulated on the ZORLP, soil flushing could push it further down into the ZORLP, with the potential for increasing the contamination in the lower zones. Alcohol flushing with nonpartitioning alcohols (e.g., methanol, ethanol) is somewhat more benign in the sense that potential for downward mobilization is reduced. However, nonpartitioning alcohol flushing has seen only one pilot demonstration so far, and further development is required to address such issues. Therefore, this technology is not feasible for the Coors Road Site.

5.1.2 Thermal Technologies

Although some of the thermal techniques have been used in the past for tertiary oil recovery by the petroleum industry, their use for chlorinated contaminant source zone remediation is not yet proven. Controlling the distribution of heat in the subsurface is often a challenge. With steam injection, for example, the steam may have a tendency to override the DNAPL because of density differences. Heterogeneities can make distribution difficult. Resistive (electrical) heating is somewhat more independent of site geometry and heterogeneity. The depth of the contamination is an important cost consideration.

Thermal technologies may be very costly for the Coors Road Site because of the greater (65 ft or more) depths involved; for example, steam has to be injected at higher pressures at greater depths. High steam injection pressures may cause sterilization of aquifer media. Electrical heating would be a little more suitable for this site because electrical heating would not be overly hampered by the presence of the ZORLPs. However, the 50 ft or more of aquifer thickness that would have to be heated may make the application costly. Also, the pore fluids recovered (DNAPL, steam condensate, pore water) will have to be treated above ground before discharge. In addition, the issues of contaminants spreading beyond the zone of heat application and complete capture of mobilized DNAPL have not been fully demonstrated. Therefore, this technology is not feasible for the Coors Road Site.

5.1.3 Impermeable Barriers

Although the placement of impermeable barriers is a proven technology for the source zone, the depth of contamination is a challenge, in terms of both technical practicability and cost. Sheet piling generally can be installed at depths of 75 to 100 ft in unconsolidated deposits. Slurry walls generally can be installed at depths of 50 to 80 ft in unconsolidated deposits (Burris and Cherry,

1992). At the Coors Road Site, where the aquifer extends more than 100 ft deep, installing such barriers is likely to be difficult and costly.

Also, the DNAPL stays in the subsurface, although it is now enclosed by the barrier. The source therefore takes longer to dissipate. At some point in time, the barrier may have to be re-established or the DNAPL inside may have to be removed. Therefore, this technology is not feasible for the Coors Road Site.

5.1.4 Air Sparging

Air sparging is now commercially available. Various means are being employed to increase air distribution in the aquifer. One recent development is the use of horizontal wells. According to one vendor, 300 horizontal wells have been drilled in the United States, most of them for air sparging (Doesburg, 1995). Air sparging has some advantages at the Coors Road Site. If contamination is present in both the vadose and saturated zones, air sparging could be a means of addressing both these regions. Air sparging with conventional vertical wells can be relatively cost effective as long as a reasonable radius of influence is achieved by each well. This would have to be determined by a pilot test. Radii of influence of up to 300 ft have been reported in some cases where the site is overlain by paved areas and buildings (Gudemann and Hiller, 1988).

There are some challenges in applying this technology to the Coors Road Site. Heterogeneities would make air distribution difficult. Specifically, if contaminants are present both above and below the ZORLP, air distribution would be very difficult.

There is also some uncertainty as to the nature of the air distribution around the well. Initially, it was believed that air rises in the form of tiny discrete bubbles with a large available area for mass transfer of the contaminants (from dissolved phase to the air). Recently, there has been a growing perception that air actually forms preferential flow paths or channels on its way up to the vadose zone (Baker et al., 1995). This significantly reduces the area available for mass transfer. Also, dissolved contaminants have to diffuse to the air channels before mass transfer can occur.

Another problem in applying air sparging for source remediation is the potential for migration of the DNAPL. The combined effect of sparging in the saturated zone and vacuum in the vadose zone often results in an increase in the water table elevation. This groundwater mounding can be on the order of several feet and has the potential to drive contaminants out laterally. Many view air sparging as more suitable for light, nonaqueous-phase liquid (LNAPL) rather than for DNAPL sites (Cherry et al., 1995). Therefore, this technology is not feasible for the Coors Road Site.

5.1.5 Bioventing

Bioventing has been used at hundreds of sites contaminated with LNAPL. However, its application for cleaning up chlorinated contaminants in the vadose zone is not proven. PCE does not biodegrade aerobically, so supplying oxygen will not help. Lower chlorinated (TCE, TCA, DCE) will require adding a primary substrate (e.g., methanol), which will be difficult to do in the vadose zone. This technology is not feasible for the Coors Road Site.

5.1.6 Soil Vapor Extraction (for the vadose zone)

SVE is a technique that has been used at several sites for the cleanup of petroleum hydrocarbons in the vadose zone. It could be applied similarly at the Coors Road Site for remediating the portion of the chlorinated solvent source that lies in the vadose zone and is contributing to the soil gas contamination. Being volatile, chlorinated solvents such as TCE and TCA are transferred to the vapor phase by SVE and recovered. This technology is offered by several vendors locally in most states. A pilot test typically is performed before full-scale implementation to determine air permeabilities and radii of influence. Depending on the contaminant concentrations, the effluent air may have to be treated before discharge. Generally, effluent air concentrations are higher at the beginning and taper off as implementation proceeds. The SVE system would have to be operated until the vadose zone chlorinated solvent source is depleted. The feasibility of successfully implementing SVE at the Coors Road Site is uncertain, because additional characterization data are needed from deeper levels in the vadose zone.

5.1.7 Pump & Treat

A P&T system can be used at the Coors Road Site to isolate the source. For such a strategy, experts recommend that pumping be conducted at the lowest rate required to capture the contaminant mass flux emanating from the source under natural conditions (Cherry et al., 1995; National Research Council, 1994). This minimizes the volume of water generated that requires treatment above ground. Pumping at low rates may make the difference between whether or not the effluent air from the air stripper exceeds the local discharge limits; accordingly, effluent air treatment may or may not be necessary. Aggressive pumping can be carried out at higher rates to reduce cleanup time, but this will involve treating larger volumes of water.

The existing P&T system at the site has succeeded in isolating the source in the UFZ. This system will have to be expanded to capture the contamination in the lower flow zones.

P&T systems have been used successfully to isolate the source at several chlorinated sites. At the Dayton, New Jersey industrial site, P&T successfully isolated the PCE source from 1978 to 1984, and again from 1990 onwards (Feenstra and Cherry, 1995).

At another site, formerly a metals-anodizing facility, P&T was applied to remediate PCE that was released into the subsurface and has traveled to the aquifer (Nelson and Lakey, 1994). The site is underlain by heterogeneous layers of synthetic fill and native estuarine sediment. In addition, a network of underground utilities have contributed to make this a particularly complex site. After adequate characterization of the hydrostratigraphy of the site and the distribution of the free-phase PCE, a pumping well network was installed at the site to isolate and contain the source. At the time of the report (Nelson and Lakey, 1994), the P&T system had been operational for 1 year. Over that period, the system was improved progressively as understanding of the site response grew. Future improvements include optimizing the pumping well network, evaluating the effectiveness of the system as a flow barrier, evaluating alternative aboveground treatment techniques for the extracted groundwater, and supplementing this source isolation measure by soil vapor extraction in the vadose zone.

Using P&T for source containment at the Coors Road Site is technically practicable, likely to succeed, and cost effective. Estimation of its success is based on the facts that P&T has been used to contain the source at other sites, has been successfully demonstrated to contain the source in the UFZ

at the Coors Road Site since 1989, and makes use of existing capital equipment (air stripper). This technology is considered to be feasible for the Coors Road Site.

5.2 Dissolved Plume Control/Remediation Technologies

5.2.1 Permeable Barriers

Installation of permeable barriers is being considered at several sites as a cost-effective way for long-term control and remediation of the plume. Because a barrier has the potential to last for several years before it needs replacement, this technology is applicable even when the source is not known or has not been isolated from the plume. However, few demonstrations of this technology have been conducted and the long-term performance of this technology is not yet well understood. The uncertainties include the mechanism of reduction by iron, clogging of the barrier with precipitates, microbial fouling, and flow around the barrier. This option may not be technically practical at the Coors Road Site because of the width of the plume and the depth of the contamination. Trenching down to below the water table is infeasible. Also, the iron filings in the barrier will have to be excavated and replaced if the plume lasts over several years. This technology is not feasible for the Coors Road Site.

5.2.2 In Situ Biodegradation

For aerobic biodegradation, a cometabolic substrate, an electron donor, and (possibly) oxygen will have to be introduced into the plume. For anaerobic biodegradation, an electron donor and growth substrate will be required. The difficulty will be to ensure the distribution of these compounds in plume region. Another approach would be to create a biological barrier at the edge of the plume, similar to the iron barrier described above. Periodic replenishment of these compounds may be necessary to sustain the microbial population if the plume lasts for an extended period of time. In situ remediation would be more suitable for application after the source has been isolated or removed. This technology is not feasible for the Coors Road Site.

5.2.3 Air Sparging

Air sparging for plume control/remediation is affected by the same technology limitations as for the source (e.g., air channeling, etc.). The radius of influence of the sparging wells will affect the cost of the application. Unless the source has been isolated or removed, air sparging in the plume, or at the edge of the plume, may have to be continued for several years. Therefore, this technology is not feasible for the Coors Road Site.

5.2.4 Natural Attenuation

As Table 3 indicates, there is considerable 1,1-DCE present in the plume. This indicates that TCA is abiotically degrading to 1,1-DCE. 1,1-DCE is not a commonly used cleaning solvent by itself and its presence is probably the result of TCA breakdown, which occurs irrespective of the aerobic or nonaerobic nature of the plume.

The oxidative state of the Sparton plume is not known, but the fact that periodic recharge occurs through irrigation appears to indicate that the aquifer may be aerobic. If the plume is aerobic, a cometabolic substrate is required for biodegradation. Benzene and toluene (possible cometabolic substrates) are sporadically present in a few of the monitoring well samples; but their levels are too

low to sustain aerobic biodegradation. No other cometabolic substrate is apparent in the available data. Therefore, there is no indication in the available data of aerobic degradation occurring in the plume.

As far as anaerobic degradation is concerned, the possibility of anaerobic conditions within the plume will have to be determined with DO measurements. As the plume progresses away from the recharge areas, it may develop an anaerobic core. Available data on contaminant concentrations do not show any presence of 1,2-DCE or VC, which are necessary indicators of anaerobic degradation. Therefore, there is no indication in the available data of anaerobic degradation occurring in the plume. This technology is not feasible at the Coors Road Site.

5.2.5 Pump & Treat

P&T is an established technology that has been shown to remove chlorinated solvents from groundwater flow systems. Plume containment at the Coors Road Site should be feasible using extraction wells once additional characterization data have been collected in the area of the plume's leading edge. However, available site characterization data on the Coors Road Site are not sufficient to assess the feasibility of P&T in terms of its technical practicability, likelihood of success, and cost effectiveness for achieving drinking water standards.

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