

# Remediation Case Studies: In Situ Soil Treatment Technologies (Soil Vapor Extraction, Thermal Processes)

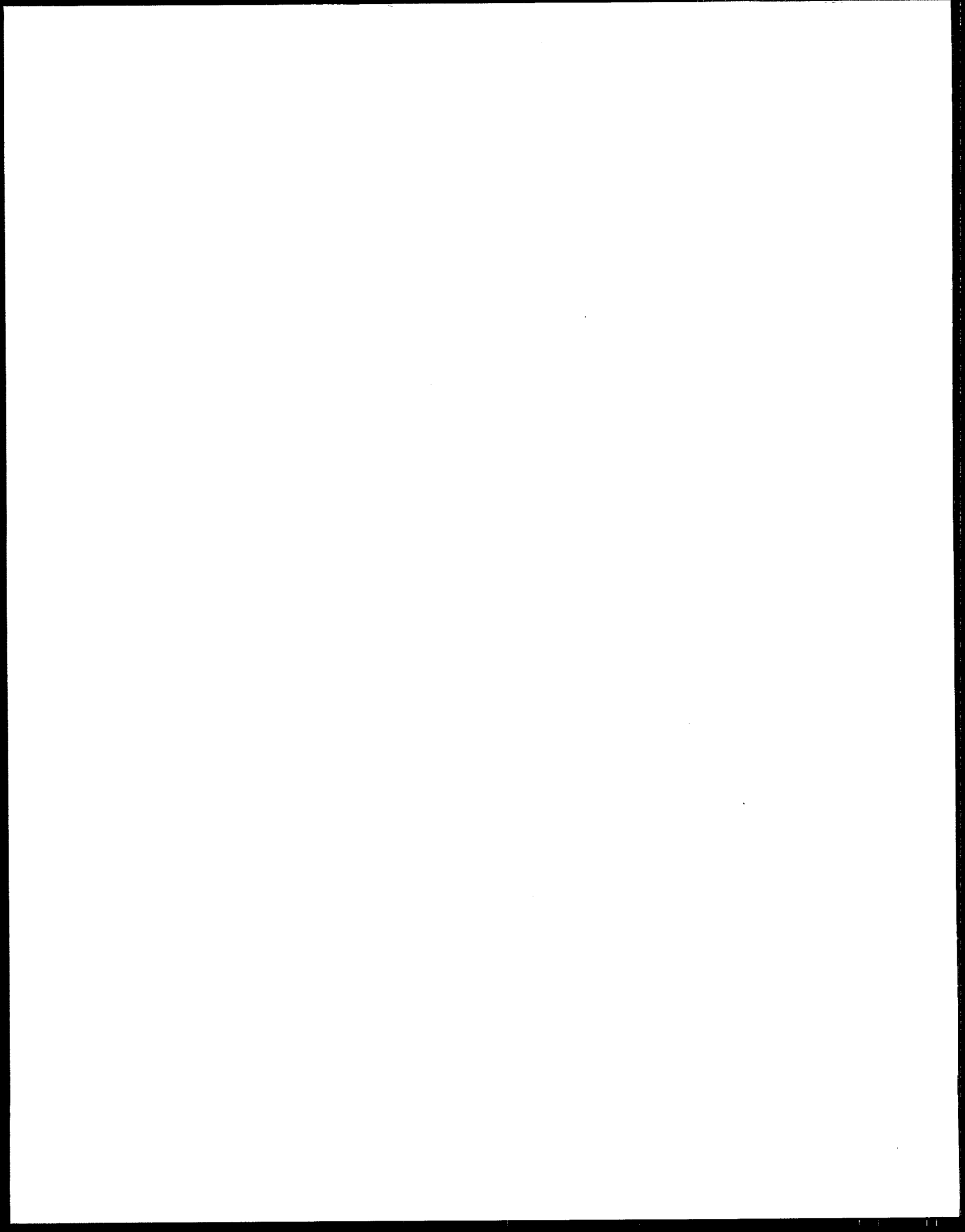
Volume 8



*Federal  
Remediation  
Technologies  
Roundtable*  
<[www.frtr.gov](http://www.frtr.gov)>



*Prepared by the*  
**Member Agencies of the  
Federal Remediation Technologies Roundtable**



# **Remediation Case Studies: In Situ Soil Treatment Technologies (Soil Vapor Extraction, Thermal Processes)**

**Volume 8**

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Federal Remediation Technologies Roundtable**

Environmental Protection Agency  
Department of Defense  
    U.S. Air Force  
    U.S. Army  
    U.S. Navy  
Department of Energy  
Department of Interior  
National Aeronautics and Space Administration  
Tennessee Valley Authority  
Coast Guard

**September 1998**

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## NOTICE

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## FOREWORD

This report is a collection of 14 case studies of in situ soil treatment technology projects prepared by federal agencies. The case studies, collected under the auspices of the Federal Remediation Technologies Roundtable, were undertaken to document the results and lessons learned from technology applications. They will help establish benchmark data on cost and performance which should lead to greater confidence in the selection and use of cleanup technologies.

The Roundtable was created to exchange information on site remediation technologies, and to consider cooperative efforts that could lead to a greater application of innovative technologies. Roundtable member agencies, including the U.S. Environmental Protection Agency, U.S. Department of Defense, and U.S. Department of Energy, expect to complete many site remediation projects in the near future. These agencies recognize the importance of documenting the results of these efforts, and the benefits to be realized from greater coordination.

The case study reports and abstracts are organized by technology in a multi-volume set listed below. Remediation Case Studies, Volumes 1-6, and Abstracts, Volumes 1 and 2, were published previously, and contain 54 case studies. Remediation Case Studies, Volumes 7-13, and Abstracts, Volume 3, were published in September 1998. Volumes 7-13 cover a wide variety of technologies, including in situ soil treatment technologies such as soil vapor extraction and thermal processes (Volume 8). The 14 soil vapor extraction case studies in this report include completed full-scale remediations and large-scale field demonstrations. In the future, the set will grow as agencies prepare additional case studies.

### 1995 Series

- Volume 1: Bioremediation, EPA-542-R-95-002; March 1995; PB95-182911
- Volume 2: Groundwater Treatment, EPA-542-R-95-003; March 1995; PB95-182929
- Volume 3: Soil Vapor Extraction, EPA-542-R-95-004; March 1995; PB95-182937
- Volume 4: Thermal Desorption, Soil Washing, and In Situ Vittrification, EPA-542-R-95-005; March 1995; PB95-182945

### 1997 Series

- Volume 5: Bioremediation and Vittrification, EPA-542-R-97-008; July 1997; PB97-177554
- Volume 6: Soil Vapor Extraction and Other In Situ Technologies, EPA-542-R-97-009; July 1997; PB97-177562

### 1998 Series

- Volume 7: Ex Situ Soil Treatment Technologies (Bioremediation, Solvent Extraction, Thermal Desorption), EPA-542-R-98-011; September 1998
- Volume 8: In Situ Soil Treatment Technologies (Soil Vapor Extraction, Thermal Processes), EPA-542-R-98-012; September 1998

### 1998 Series (continued)

- Volume 9: Groundwater Pump and Treat (Chlorinated Solvents), EPA-542-R-98-013; September 1998
- Volume 10: Groundwater Pump and Treat (Nonchlorinated Contaminants), EPA-542-R-98-014; September 1998
- Volume 11: Innovative Groundwater Treatment Technologies, EPA-542-R-98-015; September 1998
- Volume 12: On-Site Incineration, EPA-542-R-98-016; September 1998
- Volume 13: Debris and Surface Cleaning Technologies, and Other Miscellaneous Technologies, EPA-542-R-98-017; September 1998

### Abstracts

- Volume 1: EPA-542-R-95-001; March 1995; PB95-201711
- Volume 2: EPA-542-R-97-010; July 1997; PB97-177570
- Volume 3: EPA-542-R-98-010; September 1998

### *Accessing Case Studies*

The case studies and case study abstracts are available on the Internet through the Federal Remediation Technologies Roundtable web site at: <http://www.frtt.gov>. The Roundtable web site provides links to individual agency web sites, and includes a search function. The search function allows users to complete a key word (pick list) search of all the case studies on the web site, and includes pick lists for media treated, contaminant types, and primary and supplemental technology types. The search function provides users with basic information about the case studies, and allows them to view or download abstracts and case studies that meet their requirements.

Users are encouraged to download abstracts and case studies from the Roundtable web site. Some of the case studies are also available on individual agency web sites, such as for the Department of Energy.

In addition, a limited number of hard copies are available free of charge by mail from NCEPI (allow 4-6 weeks for delivery), at the following address:

U.S. EPA/National Center for Environmental Publications and Information (NCEPI)  
P.O. Box 42419  
Cincinnati, OH 45242  
Phone: (513) 489-8190 or  
(800) 490-9198  
Fax: (513) 489-8695

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## INTRODUCTION

Increasing the cost effectiveness of site remediation is a national priority. The selection and use of more cost-effective remedies requires better access to data on the performance and cost of technologies used in the field. To make data more widely available, member agencies of the Federal Remediation Technologies Roundtable (Roundtable) are working jointly to publish case studies of full-scale remediation and demonstration projects. Previously, the Roundtable published a six-volume series of case study reports. At this time, the Roundtable is publishing seven additional volumes of case study reports, primarily focused on soil and groundwater cleanup.

The case studies were developed by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Defense (DoD), and the U.S. Department of Energy (DOE). The case studies were prepared based on recommended terminology and procedures agreed to by the agencies. These procedures are summarized in the Guide to Documenting and Managing Cost and Performance Information for Remediation Projects (EPA 542-B-98-007; October 1998). (The October 1998 guide supersedes the original Guide to Documenting Cost and Performance for Remediation Projects, published in March 1995.)

The case studies present available cost and performance information for full-scale remediation efforts. They are meant to serve as primary reference sources, and contain information on site background and setting, contaminants and media treated, technology, cost and performance, and points of contact for the technology application. The studies contain varying levels of detail, reflecting the differences in the availability of data and information. Because full-scale cleanup efforts are not conducted primarily for the purpose of technology evaluation, data on technology cost and performance may be limited.

The case studies in this volume describe 14 applications of soil vapor extraction (SVE) and in situ thermal processes. These include 10 full-scale and one pilot-scale SVE applications used to treat soil contaminated with chlorinated solvents and petroleum hydrocarbons. Three of these applications involved treatment or containment of both contaminated soil and groundwater through a combination of SVE, air sparging, groundwater extraction, and/or in situ bioremediation technologies. One case study describes a photolytic technology demonstrated for treatment of contaminated vapors from an SVE system. In addition, this volume describes two in situ thermal treatment applications, one used to recover free and residual coal tar, and one that was a demonstration of an in situ process to desorb PCBs from soil.

Table 1 provides a summary including information on technology used, contaminants and media treated, and project duration for the 14 applications in this volume. This table also provides highlights about each application. Table 2 summarizes cost data, including information on quantity of media treated and quantity of contaminant removed. In addition, Table 2 shows a calculated unit cost for some projects, and identifies key factors potentially affecting technology cost. (The column showing the calculated unit costs for treatment provides a dollar value per quantity of soil treated and/or contaminant removed, as appropriate.) Cost data are shown as reported in the case studies and have not been adjusted for inflation to a common year basis. The costs should be assumed to be dollars for the time period that the project was in progress (shown on Table 1 as project duration).

While a summary of project costs is useful, it may be difficult to compare costs for different projects because of unique site-specific factors. However, by including a recommended reporting format, the Roundtable is working to standardize the reporting of costs to make data comparable across projects. In addition, the Roundtable is working to capture information in case study reports that identify and describe the primary factors that affect cost and performance of a given technology. Key factors that potentially affect project costs for soil vapor extraction and in situ thermal projects include economies of scale, concentration levels in contaminated media, required cleanup levels, completion schedules, matrix characteristics such as soil classification, clay content and/or particle size distribution, moisture content, air permeability, porosity, depth and thickness of zone of interest, total organic carbon, presence of NAPLs, and other site conditions.

**Table 1. Summary of Remediation Case Studies: In Situ Soil Treatment Technologies  
(Soil Vapor Extraction, Thermal Processes)**

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	PAHs	Pesticides/Herbicides	Explosives	Metals			
Soil Vapor Extraction									
Camp LeJeune Military Reservation, Site 82, Area A, NC (Soil Vapor Extraction)	●						Soil (17,500 yd <sup>3</sup> )	4/7/95 - 12/21/95	SVE application using a combination of vertical and horizontal wells
Davis-Monthan AFB, Site ST-35, AZ (Soil Vapor Extraction)		●					Soil (63,000 yd <sup>3</sup> )	9/95 - 7/97	SVE application to remove TPH from soil; extracted vapors used as fuel for internal combustion engines
Defense Supply Center Richmond, OU 5, VA (Soil Vapor Extraction)	●						Soil (1,000 yd <sup>3</sup> )	12/1/92 - 12/11/92	Pilot study of SVE for VOC contaminated soil
Fort Greely, Texas Tower Site, AK (Air Sparging, In Situ Bioremediation, and Soil Vapor Extraction)		●					Soil (6,300 yd <sup>3</sup> ) Groundwater	2/94 - 2/96	Combination of three technologies used to treat DRO-contaminated soil and groundwater in situ
Fort Lewis, Landfill 4, WA (Soil Vapor Extraction and Air Sparging)	●					●	Soil - saturated and unsaturated (volume not determined)	Status: Ongoing Report Covers: 12/5/94 - 10/31/97	Application of a combination of innovative technologies to treat halogenated organic contamination in soil and groundwater
Fort Richardson, Building 908 South, AK (Soil Vapor Extraction)		●					Soil (4,600 yd <sup>3</sup> )	Status: Ongoing Report Covers: 2/95 - 3/96	Application of SVE to treat gravelly-soil contaminated with diesel fuel
Holloman AFB, Sites 2 and 5, NM (Soil Vapor Extraction)		●					Soil (9,500 yd <sup>3</sup> )	4/94 - Ongoing	Treatment system has operated successfully with minimal downtime or maintenance requirements

**Table 1. Summary of Remediation Case Studies: In Situ Soil Treatment Technologies  
(Soil Vapor Extraction, Thermal Processes) (continued)**

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	PAHs	Pesticides/Herbicides	Explosives	Metals			
Intersil/Siemens Superfund Site, CA (Soil Vapor Extraction)	●						Soil (280,000 yd <sup>3</sup> )	5/88 - 8/23/93	SVE application using paired wells - one shallow and one deep - to improve contaminant extraction
NAS North Island, Site 9, CA (Photolytic Destruction)	●						Soil Vapor (estimated 1,151 lbs of VOCs)	10/12/97 - 2/6/98	Demonstrate the effectiveness of PTT's photolytic destruction units in treating VOC-contaminated vapor from an SVE system
Seymour Recycling Corporation Superfund Site, IN (Soil Vapor Extraction)	●						Soil (200,000 yd <sup>3</sup> )	Status: Ongoing Report Covers: 6/92 - 1996	SVE system using horizontal wells under a multimedia cap
Shaw AFB, OU 1, SC (Soil Vapor Extraction and Groundwater Containment)		●					Soil (30,000 ft <sup>2</sup> , confining clay layer at 70 to 80 ft bgs) Groundwater	SVE system - 12/95 - ongoing Groundwater - 2/92 - 9/97	SVE system to remediate soil and two interim response action systems to contain groundwater
Tyson's Dump Superfund Site, PA (Soil Vapor Extraction)	●						Soil (30,000 yd <sup>3</sup> )	11/88 - 9/96	SVE application involving more than 14 enhancements



**Table 1. Summary of Remediation Case Studies: In Situ Soil Treatment Technologies  
(Soil Vapor Extraction, Thermal Processes) (continued)**

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	PAHs	Pesticides/Herbicides	Explosives	Metals			
Thermal Processes									
Brodhead Creek Superfund Site, PA (Contained Recovery of Oily Waste)			●			●	Free Product - coal tar (1,500 gallons)	7/95 - 6/96	Recover free and residual coal tar using the CROW™ process
Missouri Electric Works Superfund Site, MO (In Situ Thermal Desorption)							Soil (52 yd³)	4/21/97 - 6/1/97	Demonstrate the performance of in situ thermal desorption to treat PCB-contaminated soil

\* Principal contaminants are one or more specific constituents within the groups shown that were identified during site investigations.

**Table 2. Remediation Case Studies: Summary of Cost Data**

Site Name, State (Technology)	Technology Cost (\$) <sup>a</sup>	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment <sup>**</sup>	Key Factors Potentially Affecting Technology Costs <sup>***</sup>
<b>Soil Vapor Extraction</b>					
Camp LeJeune Military Reservation, Site 82, Area A, NC (Soil Vapor Extraction)	Total: \$469,949 C: \$222,455 O: \$247,485	17,500 yd <sup>3</sup>	Not provided	\$27/yd <sup>3</sup>	Costs were reduced for this application because some overhead and operation costs were shared with other activities ongoing at the site, such as operation of a pump and treat system use of an on-site laboratory
Davis-Monthan AFB, Site ST-35, AZ (Soil Vapor Extraction)	Total: \$207,000 C: \$162,000 O: \$45,000 (total) \$1,818-2,602 (monthly)	63,000 yd <sup>3</sup>	585,700 lbs (14,700-67,800 lbs/month)	\$3.30/yd <sup>3</sup> \$0.35/lb O: \$0.06/lb	Costs were reduced because extracted vapors were used as fuel for operating internal combustion engines that ran extraction system
Defense Supply Center Richmond, OU 5, VA (Soil Vapor Extraction)	Total: \$76,099 C: \$18,225 O: \$57,874	1,000 yd <sup>3</sup>	Not provided	\$76/yd <sup>3</sup>	Costs were low because the cleanup goals for this site were achieved during a 10-day pilot test involving one extraction well
Fort Greely, Texas Tower Site, AK (Air Sparging, In Situ Bioremediation, and Soil Vapor Extraction)	Total: \$295,760 C: \$178,530 O: \$117,230	6,300 yd <sup>3</sup>	Not provided	\$47/yd <sup>3</sup>	Because the site is isolated, the USACE reported that the cost of transportation of equipment to the site and setup at the site was a significant portion of the total cost; operating costs were kept low by monitoring the system remotely
Fort Lewis, Landfill 4, WA (Soil Vapor Extraction and Air Sparging)	Total: \$1,710,303 (negotiated cost to date)	Not provided	60 lbs	Not calculated	Unit costs could not be calculated; only preliminary results available at this time; technology used to treat soil and groundwater contaminated with relatively low concentrations of contaminants; system operation included extensive variations in operating conditions

**Table 2. Remediation Case Studies: Summary of Cost Data (continued)**

Site Name, State (Technology)	Technology Cost (\$)*	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment**	Key Factors Potentially Affecting Technology Costs***
Fort Richardson, Building 908 South, AK (Soil Vapor Extraction)	Total (for entire RA): \$305,053 Total (for technology): \$252,200	4,600 yd <sup>3</sup>	Not provided	\$55/yd <sup>3</sup>	No supplemental technology was needed for air emissions
Holloman AFB, Sites 2 and 5, NM (Soil Vapor Extraction)	Total: \$610,000	9,500 yd <sup>3</sup>	44,000 lbs	\$64/yd <sup>3</sup> \$14/lb	Use of fiberglass piping caused increase in technology cost
Intersil/Siemens Superfund Site, CA (Soil Vapor Extraction)	Total: \$770,000 C: \$550,000 O: \$220,000	280,000 yd <sup>3</sup>	3,000 lbs	\$3/yd <sup>3</sup> \$260/lb	Unit cost per volume of soil treated was kept low because economies-of-scale in treating a relatively large site; also cleanup was achieved within the time frame predicted for treatment
NAS North Island, Site 9, CA (Photolytic Destruction)	Total: \$93,726 (for demonstration)	1,151 lbs of VOCs	Not provided	Full-scale projected as \$3.77/lb (only for treatment of extracted vapors)	Projected costs reflect the first demonstration of this technology
Seymour Recycling Corporation Superfund Site, IN (Soil Vapor Extraction)	Total: Not provided C: \$1,200,000	200,000 yd <sup>3</sup>	30,000 lbs	Not calculated	Unit costs could not be calculated; separate costs not provided for the complex activities at this site (a combination of soil, groundwater, and other remedial activities)
Shaw AFB, OU 1, SC (Soil Vapor Extraction and Groundwater Containment)	O: \$568,500 (total) \$18,000-57,500 (monthly)	30,000 ft <sup>2</sup>	518,000 lbs (2,560-94,800 lbs/month)	O: \$1.09/lb	Use of pulsed system reduced operating costs; report provides data only for operating costs
Tyson's Dump Superfund Site, PA (Soil Vapor Extraction)	Total: \$43,400,000	30,000 yd <sup>3</sup>	200,000 lbs	\$1,400/yd <sup>3</sup> \$220/lb	Several conditions at the site limited the diffusion rate for VOCs (e.g., geology), and the technology vendor implemented 14 enhancements to improve system performance

**Table 2. Remediation Case Studies: Summary of Cost Data (continued)**

Site Name, State (Technology)	Technology Cost (\$)*	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment**	Key Factors Potentially Affecting Technology Costs***
<b>Thermal Processes</b>					
Brodhead Creek Superfund Site, PA (Contained Recovery of Oily Waste)	Total: \$1,200,000	Not provided	1,500 gals	\$800/gal	Elevated costs due to complexity of contaminants (coal tar); problems with methodology used to estimate amount of coal tar removed resulted in system being required to operate longer
Missouri Electric Works Superfund Site, MO (In Situ Thermal Desorption)	Not provided	52 yd <sup>3</sup>	Not provided	Full-scale projected as \$120-200/yd <sup>3</sup> for "most standard sites"	Factors affecting full-scale costs include the moisture content of the soil, and the extent and depth of contamination, which affects the number and depth of wells required for treatment

**Technology Cost\***

C = Capital costs

O = Operation and maintenance (O&M) costs

**Calculated Cost for Treatment\*\***

Calculated based on sum of capital and O&M costs, divided by quantity treated or removed. Calculated costs shown as "Not Calculated" if an estimate of costs or quantity treated or removed was not available. Unit costs calculated based on both quantity of media treated and quantity of contaminant removed, as appropriate.

\*\*\* For full-scale remediation projects, this identifies factors affecting actual technology costs. For demonstration-scale projects, this identifies generic factors which would affect costs for a future application using this technology.

**In Situ Soil Treatment Technologies  
(Soil Vapor Extraction, Thermal Processes)**

**Case Studies**

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**SOIL VAPOR EXTRACTION  
CASE STUDIES**

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**Soil Vapor Extraction at Camp LeJeune Military Reservation,  
Site 82, Area A, Onslow County, North Carolina**

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**Soil Vapor Extraction at Camp LeJeune Military Reservation,  
Site 82, Area A, Onslow County, North Carolina**

<b>Site Name:</b> Camp LeJeune Military Reservation, Site 82, Area A	<b>Contaminants:</b> Volatile Organic Compounds: - Trichloroethene (TCE) - Tetrachloroethene (PCE) - Benzene	<b>Period of Operation:</b> April 7 - December 21, 1995 (March 29 - April 7, 1995 - system startup and optimization performed)
<b>Location:</b> Onslow County, North Carolina		<b>Cleanup Type:</b> Full-scale
<b>Vendor:</b> Jim Dunn Project Manager, MCB Camp LeJeune OHM Remediation Services, Inc. 5445 Triangle Parkway, Suite 400 Norcross, GA 30092 (770) 734-8072	<b>Technology:</b> Soil Vapor Extraction: - Eight vertical vapor extraction wells and one horizontal air injection well - 32 soil probe clusters - Vapor-liquid separator; vapor-phase carbon vessel - One positive displacement vacuum blower for extraction wells - Range of total system flow rates - 268 to 499 cfm, with an average of 409 cfm; range of flow rates at the well heads - 22 to 132 cfm. - Well head vacuums ranged from 3.9 inches to 7.0 inches Hg, with an average of 5.8 inches Hg.	<b>Cleanup Authority:</b> CERCLA - ROD signed: September 24, 1993
<b>Naval Facilities Engineering Command Remedial Project Manager:</b> Katherine H. Landman MCB Camp LeJeune Atlantic Division, Code 1823 LANTDIV 1510 Gilbert Street Norfolk, VA 23511-2699 (757) 322-4818		<b>EPA Remedial Project Manager:</b> Gena Townsend U.S. EPA Region 4 61 Forsyth Street Atlanta, GA 30303-3415 Phone: (404) 562-8538
<b>Waste Source:</b> Disposal of waste drums and debris	<b>Type/Quantity of Media Treated:</b> Soil - 17,500 cubic yards	
<b>Purpose/Significance of Application:</b> SVE application using a combination of vertical extraction and horizontal injection wells		
<b>Regulatory Requirements/Cleanup Goals:</b> - The ROD identified the following cleanup goals for soil: TCE - 32.2 µg/kg, PCE - 10.5 µg/kg, benzene - 5.4 µg/kg. - No air emission standards were specified for this application, however the State of North Carolina required the facility to provide documentation about potential air emissions for this application and to include carbon treatment for air emissions.		

## Soil Vapor Extraction at Camp LeJeune Military Reservation, Site 82, Area A, Onslow County, North Carolina (continued)

### Results:

- Results of confirmation soil boring samples showed TCE and benzene at nondetectable levels in all soil boring samples. PCE was reported at levels below the cleanup goal of  $10.5 \mu\text{g/kg}$  in all but one sample.
- According to LANTDIV, EPA approved shutdown of the system because the single exception was slightly above the soil remedial goals and the contaminated groundwater under the area of concern was being addressed by a pump-and-treat system.
- For the discharge stack, concentrations ranged as follows: TCE - ND to  $2.2 \mu\text{g/L}$ ; PCE - ND to  $147.4 \mu\text{g/L}$ ; benzene - ND to  $10.2 \mu\text{g/L}$ ; and ethylbenzene - ND to  $7.4 \mu\text{g/L}$ .

### Cost:

- Total cost of \$469,949 was expended for remedial activities at Area A including \$222,455 for capital costs and \$247,485 for operation and maintenance (O&M) costs.
- The total cost of \$469,940 corresponds to a unit cost of \$27 per cubic yard ( $\text{yd}^3$ ) for  $17,500 \text{ yd}^3$  of soil treated.

### Description:

Camp LeJeune Military Reservation (also known as Marine Corps Base Camp LeJeune), established in 1941, is a 170-square-mile installation near Jacksonville, North Carolina, that provides housing, training, logistical, and administrative support for Fleet Marine Force Units. Site 82 is was used for waste disposal and, in 1994, drums and debris were removed from the site. Area A was a portion of Site 82 at which residual soil and groundwater contamination remained after removal of drums and debris. Soil at Area A was contaminated with volatile organic compounds (VOC), primarily TCE, PCE, and benzene. The ROD specified SVE for remediation of contaminated soil.

The SVE system used at Area A included eight vertical vapor extraction wells (installed to a depth of 15 to 16 feet bgs), one horizontal air injection well (horizontal displacement of 330 feet; total depth of 15 feet bgs), 32 soil probe clusters (for measurement of subsurface vapors; each cluster consisted of one shallow and one deep probe at approximately 6 feet and 12 feet bgs, respectively), a vapor phase separator, a vapor-phase carbon vessel (granular activated carbon), and a vacuum extraction unit (VEU) that included a positive displacement blower that was used to apply vacuum to the extraction wells. The results of confirmation sampling showed that TCE and benzene met the cleanup goals in all soil boring samples. For 23 of 24 soil boring samples, PCE was reported at levels below the cleanup goal of  $10.5 \mu\text{g/kg}$ . For one soil boring sample, PCE was reported at  $29 \mu\text{g/kg}$  compared to the cleanup goal of  $10.5 \mu\text{g/kg}$ . According to LANTDIV, EPA approved shutdown of the system because the single exception was slightly above the soil remedial goals and the contaminated groundwater under the area of concern was being addressed by a pump-and-treat system.

According to the Naval Facilities Engineering Command Remedial Project Manager, the SVE system at Area A was cost-effective. Significant other work was being performed at the site, including the construction and operation of a 500-gallon-per-minute (gpm) pump-and-treat plant to treat groundwater contaminated with VOCs, and helped to keep costs down because overhead and operations costs were shared. In addition, an on-site laboratory was being used for other analytical work on the base, and the shared cost of the use of that facility also helped to keep the cost of the SVE application low.

# Cost and Performance Summary Report

## Soil Vapor Extraction at Camp LeJeune Military Reservation, Site 82, Area A

### Onslow County, North Carolina

#### Summary Information [1, 2, 6]

Camp LeJeune Military Reservation (also known as Marine Corps Base Camp LeJeune), established in 1941, is a 170-square-mile installation near Jacksonville, North Carolina, that provides housing, training, logistical, and administrative support for Fleet Marine Force Units. Site 82 is located adjacent to Storage Lot 203. Lot 203 was operated from the 1940s to the 1980s for the Defense Reutilization Marketing Organization (DRMO) as a military scrap dealing and disposal area. Site 82 was a wooded area that also was used for disposal.

Drums and debris, both on the surface and buried, were removed from Site 82 in 1994. Area A was a portion of Site 82 at which residual soil and groundwater contamination remained after removal of drums and debris. Area A also is referred to as Operable Unit 2 (OU 2), Site 82, Area of Concern 1, Area A. No additional information is provided about OU 2 or Area of Concern 1.

Soil at Area A was found to be contaminated with volatile organic compounds (VOCs), primarily trichloroethene (TCE), tetrachloroethene (PCE), and benzene. Results of analysis of soil borings taken in July 1994 showed concentrations of TCE as high as 6.5 micrograms per kilogram ( $\mu\text{g}/\text{kg}$ ) and PCE as high as 1,800  $\mu\text{g}/\text{kg}$ . Benzene was not detected at levels above analytical quantification limits.

In the record of decision (ROD) for OU 2, signed September 24, 1993, soil vapor extraction (SVE) was selected for remediation of contaminated soil. From April 7 through December 21, 1995, approximately 17,500 cubic yards ( $\text{yd}^3$ ) of contaminated soil were treated by a full-scale soil vapor extraction (SVE) system application at Area A.

CERCLIS ID Number: NC6170022580

Lead: DoD - Atlantic Division, Naval  
Facilities Engineering  
Command (LANTDIV),  
representing the Navy and  
Marine Corps and DoD

#### Timeline [1, 2]

September 24, 1993	Final ROD signed for OU 2, including Area A
December 1994	System construction awarded
February 1995	Final work plan approved; construction commenced
March 29 - April 7, 1995	System startup and optimization performed
April 7 - December 21, 1995	SVE system operation conducted
October 12 - 30, 1995	System temporarily shut down while awaiting results of analysis of confirmation samples
February 2, 1996	Final soil confirmation sampling performed

#### Factors That Affected Cost or Performance of Treatment [1, 8]

The Camp LeJeune site is underlain by five distinct sand horizons of variable thicknesses. The sand units typically are fine- to medium-grained and moderately sorted, contain traces of clay and silt, and extend to the water table at approximately 18 feet below ground surface (bgs).

Listed below are the key matrix characteristics at Area A that affected the cost or performance of this technology and the values measured for each during site characterization.

#### Matrix Characteristics

Parameter	Value
Soil Classification:	Not reported
Clay Content and/or Particle Size Distribution:	Sand with trace of clay and silt
Moisture Content:	Not measured
Air Permeability:	$1.2 \text{ to } 2.8 \times 10^{-7} \text{ cm}^2$
Porosity:	Not measured
Total Organic Carbon:	Not measured
Nonaqueous Phase Liquids:	Not identified

**Treatment Technology Description [1, 2]**

The SVE system used at Area A included eight vertical vapor extraction wells (installed to a depth of 15 to 16 feet bgs), one horizontal air injection well (horizontal displacement of 330 feet; total depth of 15 feet bgs), 32 soil probe clusters (for measurement of subsurface vapors; each cluster consisted of one shallow and one deep probe at approximately 6 feet and 12 feet bgs, respectively), a vacuum extraction unit (VEU), one vapor-phase carbon vessel (initially loaded with 4,000 pounds (lbs) of vapor-phase granular activated carbon), a piping and manifold system, a diesel-powered generator, and a water storage tank (20,000 gallon). The VEU included a positive displacement vacuum blower rated at 1500 cubic feet per minute (cfm) at 15 inches Hg, a vapor-liquid separator, a liquid transfer pump, particulate filters, a silencer, a discharge stack, and a control panel. The positive displacement blower was used to apply a vacuum to the eight vertical vapor extraction wells.

Extracted soil vapors were routed through the piping and manifold system to a vapor-liquid separator to remove liquids entrained in the vapor stream. They then were treated with activated carbon before they were reinjected through the horizontal well or released to the atmosphere. Extracted liquids were pumped to a water storage tank and subsequently to the nearby groundwater treatment plant at Site 82.

Flow rates at the well heads ranged from 22 to 132 cfm. Total system flow rates ranged from 268 to 499 cfm, with an average of 409 cfm. Well head vacuums ranged from 3.9 inches to 7.0 inches Hg, with an average of 5.8 inches Hg.

Startup and optimization was conducted from March 29 through April 7, 1995. From April 4 through December 21, 1995, the system logged a total of 5,889 hours and an on-line time of 85 percent. The system was shut down from October 12 to October 30, 1995, while awaiting results of laboratory analysis of confirmation samples that were collected on October 4, 1995. No modifications of the system were reported by the vendor.

Listed below are the key operating parameters that affected the cost or performance of this technology and the values measured for each.

**Operating Parameters**

Parameter	Value
Air Flow Rate:	266-499 cfm (average 409 cfm)
Operating Vacuum:	3.9-7.0 inches Hg (average 5.8 inches Hg)

**Performance Information [1, 2, 7]**

The ROD identified the following cleanup goals for soil:

- TCE - 32.2  $\mu\text{g/kg}$
- PCE - 10.5  $\mu\text{g/kg}$
- Benzene - 5.4  $\mu\text{g/kg}$

Data were provided for TCE, PCE, and benzene for soil borings taken from 24 sampling locations, 8 locations and 3 depths per location, ranging in depth from 2 to 16 feet bgs. Soil boring samples were collected six times during this application (July 1994, July 1995, August 1995, October 1995, December 1995, and February 1996).

The results of analyses of soil borings collected before operation of the SVE system (July 1994) for contaminants exceeding the cleanup goals showed concentrations of PCE as high as 1,800  $\mu\text{g/kg}$ . Benzene was nondetected (ND) and TCE levels were detected at levels less than the cleanup goal. Results of analyses of soil borings taken after startup (July 1995) showed maximum concentrations of TCE (101  $\mu\text{g/kg}$ ), PCE (16.3  $\mu\text{g/kg}$ ), and benzene (132  $\mu\text{g/kg}$ ) higher than the cleanup goals.

After treatment was complete, confirmation samples showed TCE and benzene at nondetectable levels in all soil boring samples. For 23 of 24 soil boring samples, PCE was reported at levels below the cleanup goal of 10.5  $\mu\text{g/kg}$ . For one soil boring sample, PCE was reported at 29  $\mu\text{g/kg}$ , compared to the cleanup goal of 10.5  $\mu\text{g/kg}$ . According to LANTDIV, EPA approved shutdown of the system because the single exception was slightly above the soil remedial goals and the contaminated groundwater under the area of concern was being addressed by a pump-and-treat system.

Sampling data for extracted vapor were provided for PCE, TCE, benzene, and ethylbenzene for the total system and the discharge stack for sampling events conducted from April through August 1995. For the total system, concentrations ranged as follows: TCE - 44 to 583 micrograms per liter ( $\mu\text{g/l}$ ); PCE - ND to 10.5  $\mu\text{g/l}$ ; benzene - ND to 18  $\mu\text{g/l}$ ; and ethylbenzene - ND to 17.5  $\mu\text{g/l}$ . For the discharge stack, concentrations ranged as follows: TCE - ND to 2.2  $\mu\text{g/l}$ ; PCE - ND to 147.4  $\mu\text{g/l}$ ; benzene - ND to 10.2  $\mu\text{g/l}$ ; and ethylbenzene - ND to 7.4  $\mu\text{g/l}$ . No air emission standards were specified for this application, however the State of North Carolina required the facility to provide documentation about potential air emissions for this application and to include carbon treatment for air emissions.

**Performance Data Quality [1, 2]**

For this application, quality assurance activities included use of trip blanks, field blanks, and duplicate samples. Data reported on July 18, 1995, and August 23, 1995, for field gas chromatography (GC) analysis of soil samples showed elevated levels of benzene in the soil that had not been seen previously at the site. According to LANTDIV, additional investigations and subsequent sampling events indicated that the anomalous levels were caused by inaccuracy in laboratory data, rather than elevated concentrations of benzene in the soils at the site.

**Cost Information [2, 3, 8]**

Actual cost information provided by Atlantic Division, Naval Facilities Engineering Command indicated that a total of \$469,949 was expended for remedial activities at Area A. The total consists of \$222,455 for capital costs and \$247,485 for operation and maintenance (O&M) costs. The total cost of \$469,940 corresponds to a unit cost of \$27 per cubic yard (yd<sup>3</sup>) for 17,500 yd<sup>3</sup> of soil treated. No information was provided about the mass of contaminant removed, and therefore no unit cost per pound of contaminant was calculated for this application.

**Actual Project Costs**

Cost Element	Cost (\$ in 1995)
<b>Capital</b>	
Equipment and Appurtenances	
- Injection well	77,682
- System installation	26,741
- Equipment and installation (includes extraction wells)	66,768
Site Work/Preparation	
- Magnetic survey	2,587
- Clear and grub work	21,335
- Construction of access road	7,485
Startup and Testing	
- System start-up	1,344
Management Support	
- Proposal estimate	18,513
<b>Capital Subtotal</b>	<b>222,455</b>

Cost Element	Cost (in 1995 \$)
<b>Operation &amp; Maintenance</b>	
O&M (direct labor, equipment rental, fuel/oil/lube, final report preparation)	229,226
Analytical (related to technology performance, not compliance monitoring)	
- SVE area sampling	18,259
<b>O&amp;M Subtotal</b>	<b>247,485</b>
<b>Disposal of Residuals</b>	<b>Included in total</b>
Analytical (related to compliance monitoring, not technology performance)	0
<b>Total Project Cost</b>	<b>469,940</b>

**Observations and Lessons Learned [1]**

The fact that significant other work was being performed at the site, including the construction and operation of a 500-gallon-per-minute (gpm) pump-and-treat plant to treat groundwater contaminated with VOCs, helped to keep costs down because overhead and operations costs were shared. In addition, an on-site laboratory was being used for other analytical work on the base, and the shared cost of the use of that facility also helped to keep the cost of the SVE application low.

The SVE system at Area A combined a horizontal air injection well with vertical extraction wells to remediate soil contaminated with chlorinated solvents, benzene, and ethylbenzene. The system met soil cleanup goals in less than 10 months of operation. According to the Naval Facilities Engineering Command Remedial Project Manager, the SVE system at Area A was cost-effective.

**Contact Information**

For more information about this application, please contact:

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\* Primary contact for this application

**References**

The following references were used in the preparation of this report.

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7. Record of Telephone Conversation. 1998. Richard J. Weisman, Tetra Tech EM Inc. and Katherine Landman, MCB Camp LeJeune. Review and Comment on Draft C&P Summary Report. August 25.
8. Record of Telephone Conversation. 1998. Richard J. Weisman, Tetra Tech EM Inc. and Jim Dunn, OHM. Review and Comment on Draft C&P Summary Report. September 8.

**Acknowledgments**

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**Soil Vapor Extraction at  
the Site ST-35, Davis-Monthan AFB, Arizona**

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**Soil Vapor Extraction at  
the Site ST-35, Davis-Monthan AFB, Arizona**

<b>Site Name:</b> Site ST-35, Davis-Monthan AFB	<b>Contaminants:</b> Petroleum Hydrocarbons - Total petroleum hydrocarbon (TPH) was detected in soil at levels up to 320,000 ppm - Benzene was detected in soil at levels up to 110 ppm	<b>Period of Operation:</b> September 1995 - July 1997
<b>Location:</b> Arizona		<b>Cleanup Type:</b> Full-scale cleanup
<b>Vendor/Consultant:</b> Montgomery Watson JMM, Consulting Engineers	<b>Technology:</b> Soil Vapor Extraction (SVE) - Six vapor extraction wells, a blower system, moisture separator, thermal oxidizer, and air treatment system - Two 460 cubic inch internal combustion engines (ICE) were used to create the vacuum. The extracted vapors were burned as fuel in the ICEs, with supplemental fuel added as contaminant concentrations were reduced. - System operated at an average flow rate of 123 scfm - System removed about 1,200 lb/day of contaminant	<b>Cleanup Authority:</b> Installation Restoration Program
<b>Additional Contacts:</b> U.S. Air Force Air Combat Command		<b>Regulatory Point of Contact:</b> Information not provided
<b>Waste Source:</b> Fuel Spill	<b>Type/Quantity of Media Treated:</b> Soil - 63,000 cubic yards - Contamination extended to a depth of about 260 feet (ft) below ground surface (bgs) - Sandy clay with interbedded gravels and sands in upper 260 ft - Caliche (cemented silts and clays) layer at about 240 ft bgs impeded vertical migration of contamination	
<b>Purpose/Significance of Application:</b> SVE application to remove TPH from soil; extracted vapors used as fuel for ICEs.		
<b>Regulatory Requirements/Cleanup Goals:</b> The objective of the SVE system was to remove contamination in the soil as cost-effectively as possible to prevent contamination of surrounding soil and groundwater.		
<b>Results:</b> - Performance results for the system were reported for the first 16 months of operation (through December 1996) - After 16 months of operations, the system had removed 585,700 pounds (lbs) of total volatile hydrocarbons (TVH); monthly contaminant removal rates ranged from 14,700 to 67,800 lbs. - No concentration data for contaminants was reported.		

## Soil Vapor Extraction at the Site ST-35, Davis-Monthan AFB, Arizona (continued)

### **Cost:**

- Total capital cost (estimated) - \$162,000
- Total O&M cost after 22 months of operation - September 1995 through July 1997 - \$45,000
- Report also includes monthly O&M costs for the first 16 months of operation - ranged from \$1,818 to \$2,602/month for a total of \$32,700 through December 1996
- Data on cumulative O&M costs versus cumulative total volatile hydrocarbons removed showed that the cost per unit of contaminant began to increase in October 1996. The ICE engine was reconfigured with a smaller engine to reduce the need for supplemental fuel and thereby reduced the overall operating costs.
- The average O&M cost per unit of contaminant removed after 16 months of operation was \$0.06/lb.

### **Description:**

Site ST-35 at the Davis-Monthan Air Force Base (AFB), located in Arizona, was the site of a spill of JP-4 fuel. An estimated 63,000 cubic yards of soil were contaminated to a depth of about 260 ft bgs. TPH and benzene were detected in the soils at levels as high as 320,000 ppm and 110 ppm, respectively. In addition, benzene was detected in groundwater at levels as high as 510 ppb, and there was a 1 to 3 inch layer of free product floating on the groundwater. An SVE system was used to remediate the soil contamination at the site. The SVE operational objectives were to remove contamination at the site as cost-effectively as possible to prevent contamination of the surrounding soil and groundwater. No specific contaminant goals were identified in the report.

The SVE system consisted of six vapor extraction wells, a blower system, moisture separator, thermal oxidizer, and air treatment system. Vacuum was created using two 460 cubic inch ICEs. Extracted soil gas was burned as fuel in the ICEs; when contaminant concentrations in the soil gas were reduced, supplemental fuel was used to operate the ICEs. The SVE system was operated from September 1995 through July 1997. Performance data on amount of contaminant removed were available through December 1996. After 16 months of operation, a total of 585,700 lbs of TVH were removed. Monthly TVH removal rates ranged from 14,700 lbs to 67,800 lbs. In October 1996, the contaminant removal rate began to level off. The ICE was then reconfigured to reduce the need for supplemental fuel. System performance was reported to have improved following the reconfiguration, and the system was reported to be meeting its operational objectives.

The total capital cost for the system was \$162,000. O&M costs through July 1997 were \$45,000. Monthly O&M data were provided for the first 16 months of operation (through December 1996) and ranged from \$1,818 to \$2,602/month for a total of \$32,700. Monthly O&M costs per unit of contaminant removed ranged from about \$0.03/lb to \$0.16/lb. From July to October 1996, there was a steady decrease in the O&M cost per lb of contaminant removed. However, the O&M cost began to increase in October 1996 at which time the ICE engine was reconfigured to reduce the need for supplemental fuel. The average O&M cost per unit of contaminant removed after 16 months of operation was \$0.06/lb.

# SVE at Site ST-35

## Davis-Monthan AFB

### Site Background

This section focuses on the SVE system located at Site ST-35, Davis-Monthan AFB.

Performance of the groundwater system is not evaluated. A site map for ST-35 is included as Figure 4.

#### Contaminants in Soil

- Approximately 63,000 cubic yards of soil were contaminated with JP-4 fuel. Soil contamination extended from near the ground surface to a depth of about 260 feet below ground surface (bgs).
- Total petroleum hydrocarbons (TPH) was detected in soil at levels up to 320,000 parts per million (ppm), and benzene was detected at levels up to 110 ppm.

#### Contaminants in Groundwater

- The groundwater at the site was contaminated with JP-4 from the fuel spill.
- Groundwater sampling and analysis at two monitoring wells identified dissolved hydrocarbons (including benzene with a concentration of 510 parts per billion [ppb]) and 1 to 3 inches of floating JP-4.

#### Lithology

- Groundwater at the site is encountered approximately 320 feet bgs.
- The lithology at Site ST-35 is comprised mainly of sandy clay with interbedded gravels and sands in the upper 260 feet.
- A caliche (cemented silts and clays) layer located at approximately 240 feet bgs impeded much of the vertical migration of the fuel toward groundwater.

#### SVE System Details

- A full-scale SVE System with two 460 cubic inch internal combustion engines (ICEs).
- The SVE/ICE system consisted of 6 vapor extraction wells, a blower system, moisture separator, thermal oxidizer, and air treatment system.
- The SVE system operated at an average flow rate of 123 standard cubic feet per minute (scfm).
- The SVE system treated approximately 1,200 lbs/day.
- Soil gas is extracted from the vadose zone by the vacuum created by the ICEs and subsequently burned as fuel in the ICEs. As contaminant concentrations were reduced, supplemental fuel is added to operate the ICEs.

#### Operation Period

- The SVE/ICE system was operated from September 1995 through July 1997.

#### Total Capital Costs

- \$162,000 (estimated).

#### Total O&M Costs

- The total O&M cost for the SVE/ICE system from September 1995 through July 1997, after 22 months of operation, was approximately \$45,000 (Radian, 1997).
- O&M costs for the SVE/ICE system from September 1995 through December 1996 were \$32,700.

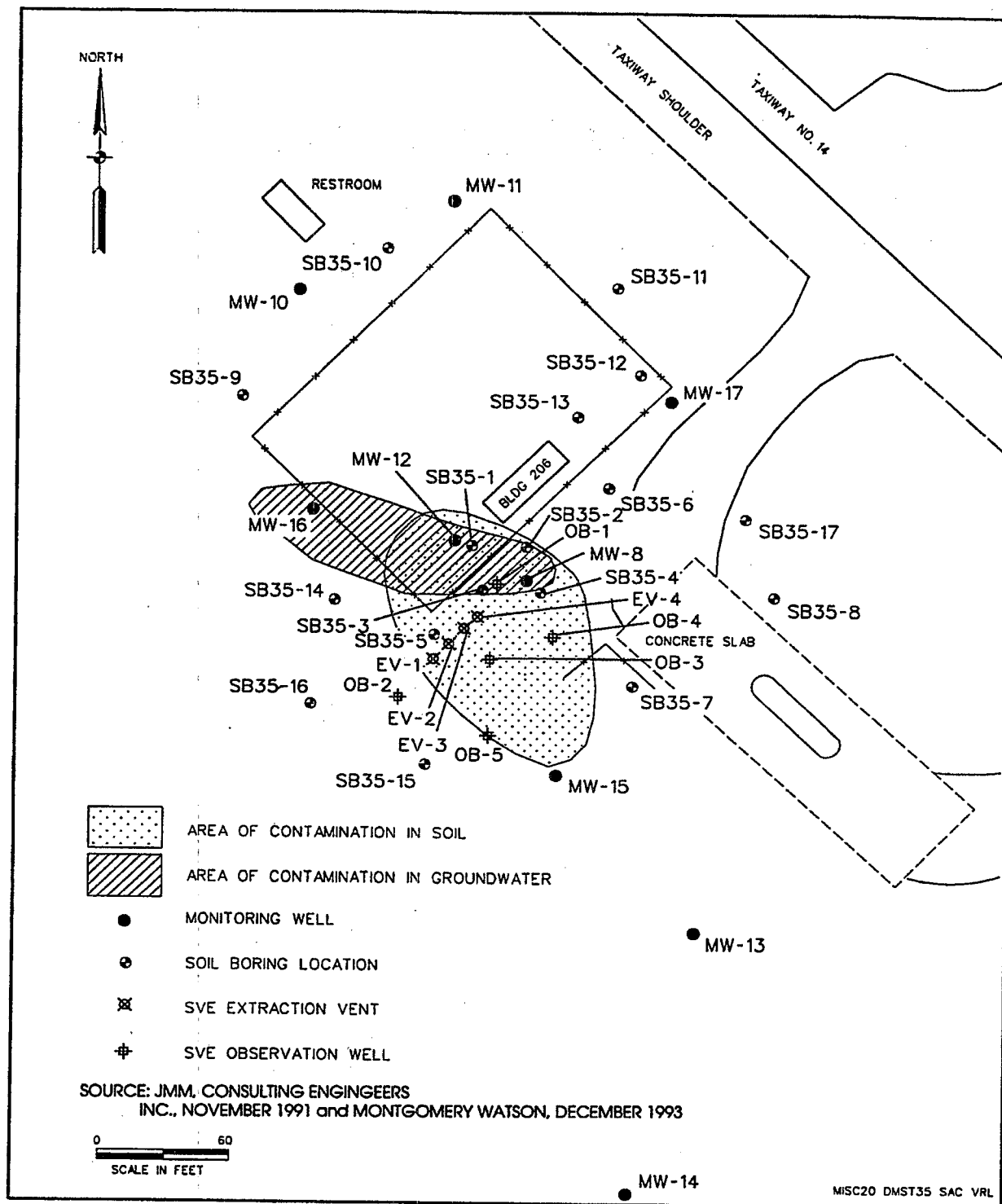


Figure 4. Extent of Known Groundwater and Soil Contamination at ST-35, Davis-Monthan AFB

## **Cost and Performance of SVE at Site ST-35**

### **SVE Operational Objectives**

The objective of SVE is typically to remove contamination in the soil as cost-effectively as possible to prevent contamination of surrounding soil and groundwater.

### **Cost for Operation**

Figure 5 illustrates the O&M costs for the SVE at Site ST-35. The monthly O&M costs range from \$1,818 to \$2,602. Total O&M costs after 16 months of operation were \$32,700.

### **Contaminant Removal**

Figure 6 illustrates the contaminant removal rates of total volatile hydrocarbons (TVH) for the SVE system at Site ST-35. Monthly contaminant removal rates ranged from 14,700 to 67,800 lbs. Total contaminant removal after 16 months of operation was 585,700 lbs. of TVH. In October 1996, the curve representing the cumulative removal rate had begun to flatten. The ICE engine was reconfigured with a smaller engine to reduce the need for supplemental fuel. Following the reconfiguration, the system performance improved and was meeting its operational objectives.

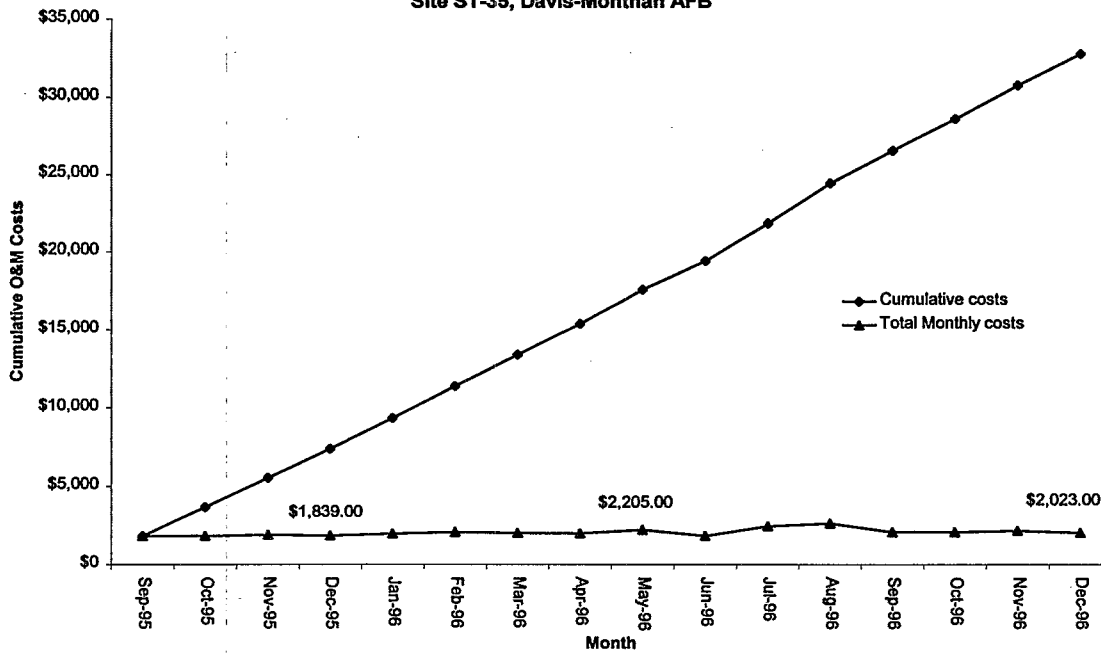
### **Correlation of Costs and Contaminant Removal**

Figures 7 and 8 illustrate the relationship between the O&M costs and the removal rates for the SVE system at Site ST-35.

Figure 7 illustrates the cumulative O&M cost over the cumulative contaminant removal. As of October 1996, this curve had begun to steepen as the cost per unit of contaminant removal rose. The ICE engine was reconfigured with a smaller engine to reduce the need for supplemental fuel. Following the reconfiguration, the system performance improved and was meeting its operational objectives.

Figure 8 illustrates the monthly as well as the cumulative cost per unit of contaminant removal over the operation time of the technology. The first curve illustrates the cost per unit of contaminant removal in each month. The cumulative curve illustrates that the average cost per unit of contaminant removal for after 16 months of operation time (December 1996) was \$0.06/pound of JP-4.

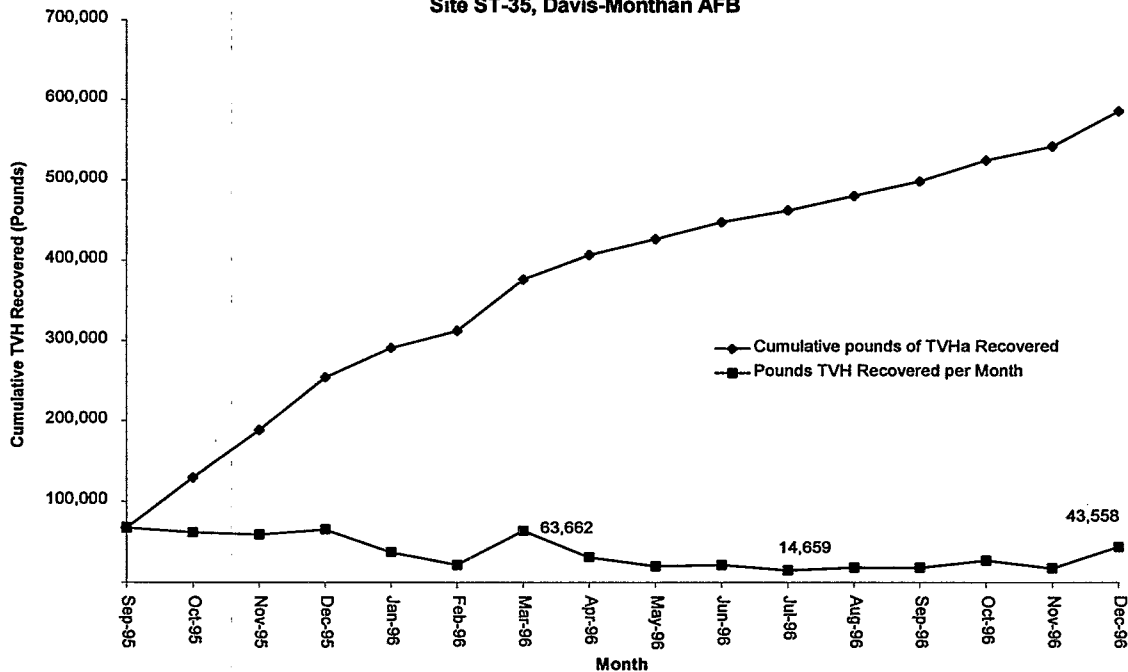
**Figure 5**  
**Monthly and Cumulative O&M Costs vs. Time**  
**Site ST-35, Davis-Monthan AFB**



Capital cost of SVE/ICE system = \$162,000

Davis\_m1.xls; Cumm Cost\_Pound

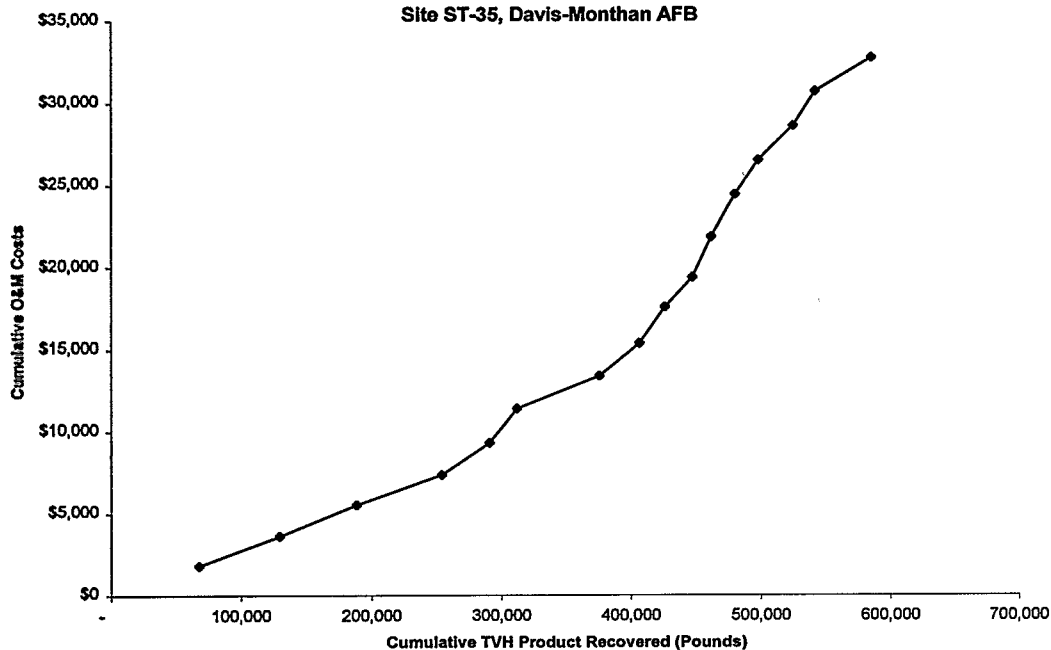
**Figure 6**  
**Monthly and Cumulative TVH<sup>a</sup> Recovered vs Time**  
**Site ST-35, Davis-Monthan AFB**



<sup>a</sup> TVH = total volatile hydrocarbons  
 Hydrocarbons were removed via an SVE system with modified ICEs

Davis\_m1.xls; Cumm Removal

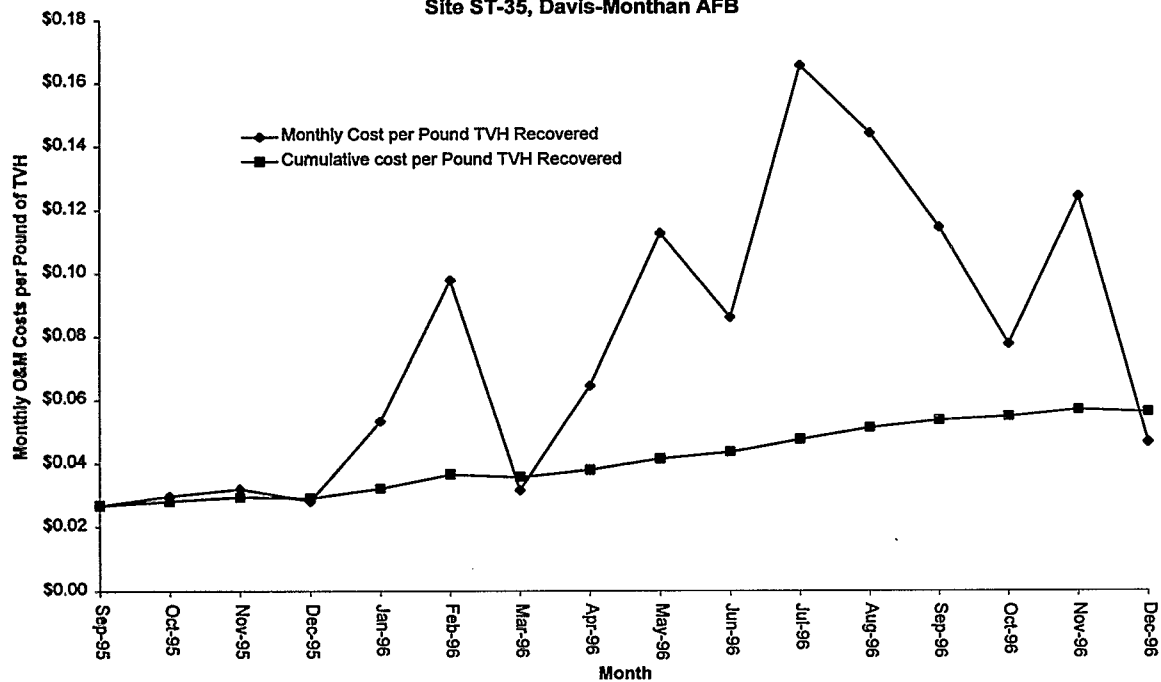
**Figure 7**  
**Cumulative O&M Costs vs. Cumulative TVH<sup>a</sup> Recovered**  
**Site ST-35, Davis-Monthan AFB**



<sup>a</sup> TVH = total volatile hydrocarbons  
 Capital Cost = \$162,000

Davis\_m1.xls; OM vs Mass

**Figure 8**  
**Cumulative and Monthly O&M Cost per Pound of TVH<sup>a</sup> vs. Time**  
**Site ST-35, Davis-Monthan AFB**



<sup>a</sup> TVH = total volatile hydrocarbons

Davis\_m1.xls; Monthly Cost



**APPENDIX A**  
**Detailed Cost and Performance Data Table**

**FULL SCALE OPERATION  
SITE ST-35 DAVIS-MONTHAN AFB  
TUSCON, AZ**

Month	Days of Operation	Average Influent TVH Concentration	Average Flow Rate (scfm)	Pounds of TVH Recovered per Month	Cumulative pounds of TVH Recovered	Monthly Cost per Pound TVH Recovered	Cumulative cost per Pound of TVH Recovered	Monthly Costs	Cumulative Costs
Sep-95	30	43,000	141	67,791	67,791	\$0.03	\$0.03	\$1,818	\$1,818
Oct-95	31	39,000	137	61,732	129,523	\$0.03	\$0.03	\$1,831	\$3,649
Nov-95	22	50,000	144	59,037	188,560	\$0.03	\$0.03	\$1,890	\$5,539
Dec-95	27	42,000	155	65,511	254,071	\$0.03	\$0.03	\$1,839	\$7,378
Jan-96	30	22,000	150	36,898	290,969	\$0.05	\$0.03	\$1,962	\$9,340
Feb-96	23	19,000	130	21,173	312,142	\$0.10	\$0.04	\$2,070	\$11,410
Mar-96	31	38,000	145	63,662	375,804	\$0.03	\$0.04	\$2,007	\$13,417
Apr-96	30	25,000	110	30,748	406,552	\$0.06	\$0.04	\$1,980	\$15,397
May-96	31	16,000	106	19,595	426,147	\$0.11	\$0.04	\$2,205	\$17,602
Jun-96	30	19,000	100	21,244	447,391	\$0.09	\$0.04	\$1,827	\$19,429
Jul-96	23	19,000	90	14,659	462,050	\$0.17	\$0.05	\$2,421	\$21,850
Aug-96	28	22,500	77	18,080	480,130	\$0.14	\$0.05	\$2,602	\$24,452
Sep-96	30	15,000	108	18,048	498,178	\$0.11	\$0.05	\$2,062	\$26,514
Oct-96	31	21,000	111	26,712	524,890	\$0.08	\$0.05	\$2,068	\$28,582
Nov-96	27.5	13,000	129	17,228	542,118	\$0.12	\$0.06	\$2,136	\$30,718
Dec-96	31	29,000	130	43,558	585,676	\$0.05	\$0.06	\$2,023	\$32,741

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**Soil Vapor Extraction at Defense Supply Center Richmond, OU 5  
Chesterfield County, Virginia**

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**Soil Vapor Extraction at Defense Supply Center Richmond, OU 5  
Chesterfield County, Virginia**

<b>Site Name:</b> Defense Supply Center Richmond, OU 5	<b>Contaminants:</b> Tetrachloroethene (PCE) and Trichloroethene (TCE) Maximum concentrations measured for soil during the RI were PCE - 1.5 mg/kg and TCE - 0.036 mg/kg	<b>Period of Operation:</b> December 1 - 11, 1992
<b>Location:</b> Chesterfield County, Virginia		<b>Cleanup Type:</b> Pilot-scale
<b>USACE Point of Contact:</b> Suzanne Murdock Engineering and Support Center Directorate of Engineering Civil-Structures Division PO Box 1600 Huntsville, AL 35816-1822 (205) 895-1635	<b>Technology:</b> Soil Vapor Extraction: - One extraction well (12 ft deep) - Vacuum - 35 inches of water - Air flow rate - 40 standard cubic feet per minute (scfm).	<b>Cleanup Authority:</b> CERCLA - ROD dated March 25, 1992 - ESD dated March 8, 1996
<b>DSCR Remedial Project Manager:</b> Bill Saddington Defense Supply Center Richmond 8000 Jefferson Davis Highway Richmond, VA 23297-5000 (804) 279-3781		<b>EPA Remedial Project Manager:</b> Todd Richardson U.S. EPA Region 3 1650 Arch Street (MC 3HS50) Philadelphia, PA 19103-2029 (215) 814-5264
<b>Waste Source:</b> Disposal of wastes in open pits	<b>Type/Quantity of Media Treated:</b> Soil - 1,000 cubic yards	
<b>Purpose/Significance of Application:</b> Pilot study of SVE for VOC contaminated soil		
<b>Regulatory Requirements/Cleanup Goals:</b> - Soil action levels of PCE - 0.58 mg/kg and TCE - 0.20 mg/kg		
<b>Results:</b> - Results of soil samples collected following completion of the pilot study showed that the soil action levels had been achieved during the 10-day pilot test. - Maximum concentrations reported for PCE - 0.18 mg/kg and for TCE - 0.11 mg/kg		
<b>Cost:</b> - Total actual cost of the pilot study was \$76,099, consisting of \$18,225 for capital equipment and \$57,874 for operation and maintenance. - Unit cost of the pilot study treatment activities was \$76/yd <sup>3</sup> (1,000 yd <sup>3</sup> treated).		

## Soil Vapor Extraction at Defense Supply Center Richmond, OU 5 Chesterfield County, Virginia (continued)

### Description:

The Defense Supply Center Richmond (DSCR) is a 565-acre installation located in Chesterfield County, Virginia, on property owned by the Department of the Army. The mission of DSCR, built in the early 1940s, is to manage and furnish general military supplies to the Armed Forces and several civilian federal agencies. In August 1987, the site was placed on the National Priorities List (NPL). A remedial investigation (RI), conducted in November 1988, identified volatile organic compounds (VOC) in the soil and groundwater in the vicinity of a pit area. While solvents or other organics were not used in these metal cleaning operations, the pits were open and may have been used for undocumented disposal of organics from other operations at DSCR. In September 1990, DSCR entered into a federal facilities agreement (FFA) with EPA and the Commonwealth of Virginia to address contamination at operable units (OU) at the site. OU 5, the Acid Neutralization Pits source area, is the focus of this report. The record of decision (ROD), signed on March 25, 1992, specified soil vapor extraction (SVE) as the remedy for OU 5 and identified cleanup goals for PCE of 0.58 mg/kg and TCE of 0.20 mg/kg.

A pilot study of SVE was conducted from December 1 to December 11, 1992, to identify additional design parameters for a full-scale system. The study consisted of two tests, a hydraulic influence test conducted over a 24-hour period, followed by a 10-day hydrocarbon removal test. For the hydrocarbon removal test, one extraction well was used along with a carbon adsorption unit for the treatment of the off-gas. The results of soil samples collected following completion of the pilot study showed that the soil action levels had been achieved during the study. The maximum concentration reported for PCE was 0.18 mg/kg and 0.11 mg/kg for TCE. An ESD was signed in March 1996 indicating that a full-scale system was not required. Covers were installed on the pits, as required in the ROD. According to the ESD, several factors contributed to the success of the pilot test, including: the actual area of contamination was smaller than originally estimated; natural attenuation may have contributed to decreased contaminant levels; and PCE concentrations in the untreated soil were only slightly higher than the cleanup goals.

# Cost and Performance Summary Report

## Soil Vapor Extraction at Defense Supply Center Richmond, OU 5

### Chesterfield County, Virginia

#### Summary Information [1, 2, 5]

The Defense Supply Center Richmond (DSCR) is a 565-acre installation located in Chesterfield County, Virginia, on property owned by the Department of the Army. The installation, built in 1941 and 1942, originally included two separate facilities: the Richmond General Depot and Richmond Holding and Reconsignment Point. In the early 1990's, the installation became known as DSCR. The mission of DSCR was to organize, direct, and manage supplies, and to operate a storage facility of the Defense Supply Agency. Today, DSCR's main function is to manage and furnish general military supplies to the Armed Forces and several civilian federal agencies.

In August 1987, the site was placed on the National Priorities List (NPL). A remedial investigation (RI), conducted in November 1988, identified volatile organic compounds (VOCs) in the soil and groundwater in the vicinity of a pit area. While solvents or other organics were not used in these metal cleaning operations, the pits were open and may have been used for undocumented disposal of organics from other operations at DSCR.

In September 1990, DSCR entered into a federal facilities agreement (FFA) with EPA and the Commonwealth of Virginia. Under that agreement, DSCR was divided into eight operable units (OU). OU 5, the Acid Neutralization Pits source area, is the focus of this report.

OU 5 is the site of two former concrete settling pits that received wastewater from the metal cleaning operations conducted in Warehouse 65. The metal cleaning operations, which included a boiling bath of sodium hydroxide followed by a hot water dip rinse, were conducted from 1958 until the early 1980s. The pits were closed in 1985 and filled with soil. During closure, cracks and holes were observed in the concrete, indicating the potential for leaks to the subsurface.

The primary contaminants of concern were tetrachloroethene (PCE) and trichloroethene (TCE) in the groundwater, and VOCs in the soil. The maximum concentrations measured for soil during the RI were PCE - 1.5 mg/kg and TCE - 0.036 mg/kg.

Because the contaminated soil in the vicinity of the pit area was determined to be the source of groundwater contamination, the record of decision (ROD), signed on March 25, 1992, specified soil vapor extraction (SVE) as the remedy for OU 5. The ROD specified operation of the SVE system until concentrations for the contaminants of concern in the soil were reduced to below specified action levels. The ROD also indicated an estimated time of four years for the system to reduce concentrations to the action levels.

The estimated quantity of soil treated during this application was 1,000 cubic yards (yd<sup>3</sup>). The SVE system reduced the concentrations for the contaminants of concern sooner than anticipated, and EPA issued an Explanation of Significant Differences (ESD) in March 1996 to describe how the remedial action completed at this site differed from that identified in the ROD.

CERCLIS ID Number: VA 3971520751

Lead: Defense Logistics Agency and  
U.S. Army Corps of Engineers

#### Timeline [1, 2, 5]

March 25, 1992	ROD signed
December 1 - 11, 1992	Pilot study of SVE conducted
March 8, 1996	ESD signed

#### Factors That Affected Cost or Performance of Treatment [6, 8]

Listed below are the key matrix characteristics for this technology and the values measured for each during site characterization. According to the draft RI, soils underlying this area consist of 72% Tetotum, 18% Bourne, and 10% other soils (Aquults, Atlee, Dunbar, Faceville, Gitney, Norfolk and Vacluse soils). Additional data showed that soils at this site consist of approximately 50% clay.

## Matrix Characteristics

Parameter	Value
Soil Classification:	Clean to silty sand and silty clay
Clay Content and/or Particle Size Distribution:	Approximately 50% clay
Moisture Content:	Soil characterized as ranging from slightly damp to moist
Air Permeability:	$3.49 \times 10^{-8} \text{ cm}^2$ to $7.5 \times 10^{-7} \text{ cm}^2$ (calculated range using three methods)
Porosity:	30% (assumed by EPA based on general knowledge of site area)
Total Organic Carbon:	Not available
Nonaqueous Phase Liquids:	Not identified

## Treatment Technology Description [1, 2, 4, 5, 6, 7]

A pilot study of SVE was conducted from December 1 to December 11, 1992, to identify additional design parameters for a full-scale system. The study consisted of two tests, a hydraulic influence test conducted over a 24-hour period, followed by a 10-day hydrocarbon removal test. For the hydrocarbon removal test, one extraction well was used along with a carbon adsorption unit for the treatment of the off-gas. The well was installed at a depth of 12 feet (ft) below ground surface (bgs), and was screened from 6.5 ft bgs to 11.5 ft bgs. It was operated at a vacuum of 35 inches of water and at an air flow rate of 40 standard cubic feet per minute (scfm). The maximum removal rate for total volatile hydrocarbons was 0.00021 lb/hr.

Listed below are the key operating parameters for this technology and the values measured for each.

### Operating Parameters

Parameter	Value
Air Flow Rate:	40 scfm
Operating Vacuum:	35 inches of water

## Performance Information [1, 2, 5]

The ROD identified the following risk-based soil action levels for OU 5 developed based on the protection of groundwater at the site:

- PCE - 0.58 mg/kg
- TCE - 0.20 mg/kg

Following completion of the pilot study, 19 soil samples from the area beneath six pits were collected and analyzed for PCE and TCE. The results showed that the soil action levels had been achieved during the pilot study. Samples from three of the six pits were below detection levels for PCE and TCE. The maximum concentrations reported for PCE (0.18 mg/kg) and for TCE (0.11 mg/kg) were below the soil action levels. In addition, the areal extent of the contaminated soil was determined to be limited to a small area under one pit. An ESD was signed in March 1996 indicating that a full-scale system was not required. Covers were installed on the pits, as required in the ROD.

During the first day of the hydrocarbon removal test, high levels of toluene were detected. It was determined that the source of the toluene was a sealant used to make air-tight connections with the wellhead. All components of the flow system that had come into contact with the sealant were replaced, and rubber couplings were used to create an air-tight seal. The toluene levels dropped below detection limits by the fourth day of testing.

## Performance Data Quality

No information was provided on the quality assurance/quality control activities performed for this application.

## Cost Information [2, 3, 7]

Cost data obtained from the U.S. Army Corps of Engineers (USACE) indicated that the total actual cost of the pilot study was \$76,099, consisting of \$18,225 for capital equipment and \$57,874 for operation and maintenance. The unit cost of the pilot study treatment activities was \$76/yd<sup>3</sup> (1,000 yd<sup>3</sup> treated). Information was not provided on the mass of contaminant removed, and therefore a unit cost per pound of contaminant removed was not calculated for this application.

Actual Project Costs

Cost Element	Cost (\$ in 1992)
<b>Capital</b>	
Site Work and Preparation	
- Electrician	1,300
- Driller	8,500
Equipment and Appurtenances	
- Vacuum extraction pilot unit rental (\$1,250/wk x 3 wks)	3,750
- Vapor extraction well (\$575/well x 2 wells)	1,150
- Vapor probes (\$60/probe x 8 probes)	480
- Flexible hose, SS hose, clamps, vacuum pressure gauges	800
- Data logger, transducer (\$610/wk x 2 wks)	1,220
- Additional transducers (\$125/wk x 8 wks)	1,000
- Camera (\$25/wk x 1 wk)	25
<b>Capital Subtotal</b>	<b>18,225</b>
<b>Operation and Maintenance</b>	
Direct Labor	20,904
Travel	
- Airfare	550
- Subsistence	2,075
- Auto Rental	1,500
Direct Materials	
- Carbon canisters and disposal (\$2,300/can x 2 cans)	4,600
- Field sampling materials	300
- Field notebook	14
Equipment Overhead	
- Telephone	100

Cost Element	Cost (\$ in 1992)
- PC Rental	231
- Facsimile	106
- Overnight express	684
- Photocopier	25
Health and Safety	
- Draeger bellow/tube (\$90/wk x 3 wks)	270
- Microtip (\$300/wk x 3 wks)	900
- Eye Wash (\$35/wk x 2 wks)	70
Analytical (related to technology performance, not compliance monitoring)	
- On-site GC services	18,625
- Soil VOC (method 8240) (\$280/analysis x 20 analyses)	5,600
<b>O&amp;M Subtotal</b>	<b>57,874</b>
<b>Disposal of Residuals</b>	<b>Included in total</b>
Analytical (related to compliance monitoring, not technology performance)	
Soil TCLP (\$1,300/analysis x 1 analysis)	1,300
<b>Total Project Cost</b>	<b>76,099</b>

**Observations and Lessons Learned [2, 5]**

Since implementation of a full-scale system was not required, the cost for remediation of OU 5 was lower than the \$116,000 ROD estimate.



The cleanup goals were achieved during a 10-day pilot test involving one extraction well. According to the ESD, several factors contributed to the success of the pilot test, including:

- The actual area of contamination was smaller than originally estimated
- Natural attenuation may have contributed to decreased contaminant levels
- PCE concentrations in the untreated soil were only slightly higher than the action levels.

According to the EPA RPM, rubber couplings were determined to be better sealants than solvent-based materials because the solvent-based materials were found to cause toluene contamination in the off-gas stream.

#### Contact information

For more information about this application, please contact:

##### **EPA Remedial Project Manager:**

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##### **DSCR Remedial Project Manager:**

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DSCR-WEP  
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##### **USACE Point of Contact:**

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Engineering and Support Center  
Directorate of Engineering  
Civil-Structures Division  
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Telephone: (205) 895-1635

\* Primary contact for this application

#### References

The following references were used in preparation of this report.

1. U.S. Environmental Protection Agency (EPA) Region 10. 1992. *Record of Decision for OU 5 - Acid Neutralization Pits Source Area, Defense General Supply Center*. March.
2. U.S. Army Corps of Engineers (USACE), Huntsville Division. 1995. *Explanation of Significant Differences for Acid Neutralization Pit Soils (Operable Unit 5), Defense General Supply Center, Chesterfield County, Virginia*. September.
3. USACE-Huntsville Division. 1992. *Defense General Supply Center, Operable Unit 5, Remedial Design, Task 3, Pilot Plant Construction and Operation with Onsite GC*. December 21.
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8. Bill Saddington, DSCR. 1998. *Comments on Review Draft of the Superfund Cost Report for Soil Vapor Extraction at Defense General Supply Center, OU5*. August 14.

#### Acknowledgments

This report was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Tetra Tech EM Inc. under EPA Contract No. 68-W5-0055.

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**Air Sparging, In Situ Bioremediation, and Soil Vapor Extraction at  
the Texas Tower Site,  
Ft. Greely, Alaska**

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**Air Sparging, In Situ Bioremediation, and Soil Vapor Extraction at  
the Texas Tower Site,  
Ft. Greely, Alaska**

<b>Site Name:</b> Texas Tower Site	<b>Contaminants:</b> Petroleum hydrocarbons - diesel range organics (DRO). Average concentrations of DRO in soil were 500 mg/kg, and diesel range petroleum hydrocarbons in groundwater ranged from 0.085 to 18.6 mg/L.	<b>Period of Operation:</b> Status: Complete Report covers: February 1994 to February 1996
<b>Location:</b> Ft. Greely, Alaska		<b>Cleanup Type:</b> Corrective Action
<b>Vendor:</b> James J. Landry Senior Project Geologist AGRA Earth and Environmental, Inc. 711 H Street, Suite 450 Anchorage, Alaska 99501-3442 (907) 276-6480	<b>Technology:</b> Air Sparging, In Situ Bioremediation, and Soil Vapor Extraction <ul style="list-style-type: none"><li>- System consisted of two air sparging wells drilled to 55 ft bgs, three SVE wells drilled to 52 ft bgs, and associated equipment.</li><li>- No air pollution control devices were included in this system.</li><li>- Air sparging provided 23-60 cfm of air to the saturated zone; SVE removed 400 cfm (average) from the vadose zone, at 50 inches water across the blower.</li><li>- After 18 months of operation, nutrient solution was injected into the SVE wells.</li></ul>	<b>Cleanup Authority:</b> State of Alaska Underground Storage Tank Regulations [18AAC78]
<b>Additional Contacts:</b> Cristal Fosbrook, Chief, Environmental Restoration/ Compliance Branch U.S. Army - Alaska, Directorate of Public Works 730 Quartermaster Road Ft. Richardson, Alaska 99505 (907) 384-3044		<b>USACE Point of Contact:</b> Bernard T. Gagnon Environmental Engineering and Innovative Technology Advocate U.S. Army Corps of Engineers - Alaska District P.O. Box 898 Anchorage, Alaska 99506-0898 Telephone: (907) 753-5718
<b>Waste Source:</b> Leak from fuel line	<b>Type/Quantity of Media Treated:</b> Soil (in situ) and Groundwater <ul style="list-style-type: none"><li>- Approximately 6,300 cubic yards of contaminated soil (a portion of the soil was in the saturated zone; this portion was not quantified).</li><li>- Soils consisted mainly of sand, gravel, cobble, and silt.</li><li>- Groundwater was encountered between 23 and 50 ft bgs, with a saturated zone approximately 27 ft thick and a hydraulic gradient of approximately 0.008 ft per ft.</li><li>- Subsurface materials encountered in all soil borings were generally uniform throughout the site, from ground surface to 65 ft bgs.</li></ul>	
<b>Purpose/Significance of Application:</b> Combination of three technologies used to treat DRO-contaminated soil and groundwater in situ.		
<b>Regulatory Requirements/Cleanup Goals:</b> <ul style="list-style-type: none"><li>- The following remedial goals were specified for soil and groundwater at the Texas Tower site: soil (total BTEX - 10 mg/kg, benzene - 0.1 mg/kg, and DRO - 100 mg/kg); groundwater (benzene - 0.005 mg/L, toluene - 1 mg/L, ethylbenzene - 0.7 mg/L, xylenes - 10 mg/L, and diesel range petroleum hydrocarbons - 0.1 mg/L) as set forth in the Alaska Department of Environmental Conservation UST regulations.</li></ul>		

**Air Sparging, In Situ Bioremediation, and Soil Vapor Extraction at  
the Texas Tower Site,  
Ft. Greely, Alaska (continued)**

**Results:**

- Over two years of system operation, approximately 1,300 lbs of contaminants were extracted through the SVE wells. Those contaminants consisted of 829 lbs of DRO, 418 lbs of GRO, and 55 lbs of total BTEX compounds. The estimate above does not include contaminants removed through biodegradation, which was not measured.
- Concentrations of contaminants in treated soil and groundwater met the remedial goals in all samples with the exception of three soil sample locations and three groundwater sample locations. Because the soil samples were from locations that had not been sampled prior to the design of the treatment system, the USACE concluded that the results suggested an additional "hot spot" outside of the original treatment area. Based on the results of a "mini-risk assessment" performed by the USACE, no additional remedial activities were identified. The State of Alaska accepted the closure report for this application.
- The operations contractor cited the following reasons for why no additional remedial activities were necessary: the leaking fuel lines that had been the source of the release had been removed; highly contaminated soil had been excavated and treated off site; no compounds for which maximum contaminant levels (MCLs) have been established had been detected at concentrations above MCLs during more than two years of monitoring; and the potential for exposure from residual hydrocarbons was negligible.

**Cost:**

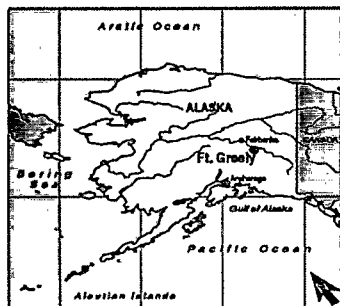
- The total proposed cost for the air sparging, in situ bioremediation, and SVE system at the Texas Tower site was \$295,760, including \$145,420 for construction, \$117,230 for operation, and \$33,110 for work plan preparation.
- A unit cost of treatment of \$47 per cubic yard was calculated from the total cost of \$295,760 to remediate 6,300 cubic yards of soil (in situ); a portion of this soil was in the saturated zone.
- Because the site is isolated, the USACE reported that the cost of transportation of the equipment to the site and setup at the site was a significant portion of the total cost of the project.
- Costs of operation were kept low by monitoring the operation of the remediation system remotely. The system was not staffed, except for monthly sampling events. This savings in operating cost was not quantified for this application.

**Description:**

The Texas Tower site consists of four buildings surrounded by a chain-link fence at the U.S. Army's Ft. Greely military facility, located approximately five miles south of Delta Junction, Alaska, near Fairbanks. During demolition of one of the buildings in 1990, a release of petroleum hydrocarbons was discovered, reportedly originating from an underground heating oil supply line. Site investigations determined that the release had impacted both subsurface soil and groundwater. In 1990, approximately 2,000 cubic yards of contaminated soil were excavated and transported off site for thermal treatment, and in 1993 the excavation was backfilled with clean soil.

In August 1993, the USACE contractor conducted a pilot test of an SVE and air sparging system, and a biotreatability test. On the basis of the results from these tests, the contractor concluded that the site was amenable to remediation by a combination of the three technologies. The full-scale system was installed between November 1993 and January 1994 and was operated from February 1994 to February 1996. Closure samples were collected in April 1996 and, based on the data from these samples and a "mini risk assessment", the State of Alaska accepted the closure report for this application.

## SITE INFORMATION



### IDENTIFYING INFORMATION

**Site Name:** Texas Tower Site  
**Location:** Fort Greely, Alaska  
**Technology:** Air Sparging, In Situ Bioremediation, Soil Vapor Extraction  
**Type of Action:** Corrective Action (under State of Alaska Underground Storage Tank Regulations [18AAC78])

### TECHNOLOGY APPLICATION (2.5)

**Period of Operation:** Full-scale operation - February 1994 to February 1996

**Quantity of Material Treated During Application:** Approximately 6,300 cubic yards (yd<sup>3</sup>) of contaminated soil (a portion of which contained groundwater) was treated in situ.

### BACKGROUND (1.4)

#### **Site Background:**

- The Texas Tower Site is located at the U.S. Army's Fort Greely military facility. Ft. Greely is located approximately five miles south of Delta Junction, Alaska, near Fairbanks.
- The Texas Tower Site consists of four buildings surrounded by a six-foot high chain-link fence.
- During demolition of one of the buildings in 1990, a release of petroleum hydrocarbons was discovered.
- The release was reported to have originated from an underground fuel line that had supplied heating oil to the demolished building from an aboveground storage tank (AST).

**Waste Management Practices that Contributed to Contamination:** Leak from fuel line

**Site Investigation:** Phase I site investigation activities included an electromagnetic survey, active and passive soil gas monitoring and analysis, and test pit excavations. Phase II site investigation activities included the soil and groundwater sampling described below.



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## **Soil**

- Nine soil borings were collected during the site investigation and analyzed for:
  - Volatile organic compounds (VOC)
  - Total petroleum hydrocarbons (TPH)
  - Diesel range organics (DRO)
- Data indicated that contamination extended vertically from the ground surface to 50 feet below ground surface (bgs) and horizontally over an area of approximately 5,655 square feet (ft<sup>2</sup>).
- Levels of DRO contamination ranged from Not Detected (ND) to 740 milligrams per kilogram (mg/kg) and levels of TPH ranged from ND to 9,200 mg/kg. Average concentrations of DRO were 500 mg/kg. It was estimated that approximately 2,500 pounds of DRO were present in the contaminated soil.
- No VOC contamination at levels above cleanup standards was detected in any of the nine soil borings.
- In four of the nine soil borings, levels of DRO contamination exceeded the standard of 100 mg/kg established by the Alaska Department of Environmental Conservation (ADEC) under the state's underground storage tank (UST) regulations (18 AAC 78.315).

## **Groundwater**

- In 1991 and 1992, three monitoring wells were sampled for TPH and diesel-range petroleum hydrocarbons (DRPH).
- TPH was detected in two of the three monitoring wells; concentrations ranged from ND to 14.3 milligrams per liter (mg/L).
- DRPH concentrations ranged from 0.085 to 18.6 mg/L.

## **Historical Activities Prior to Technology Application (1):**

- In 1990, contaminated soil at the site was excavated to a depth of approximately 15 ft (approximately 2,000 yd<sup>3</sup>). The excavated soil was treated thermally off site.
- In 1993, the excavated area was backfilled with clean fill.



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**SITE LOGISTICS/CONTACTS**

**USACE Point of Contact:**

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**U.S. Army - Alaska District**

**Cristal Fosbrook, Chief, Environmental Restoration/Compliance Branch**

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**Telephone: (907) 276-6480**

**\*Primary point of contact for this application**

**MATRIX AND CONTAMINANT DESCRIPTION**

**MATRIX IDENTIFICATION**

**Soil (in situ)**

**Groundwater (in situ)**

**SITE STRATIGRAPHY (1)**

- Subsurface materials encountered in all soil borings were generally uniform throughout the project site, from ground surface to 65 ft bgs.
- Soils consisted mainly of sand, gravel, cobble, and silt.
- Groundwater was encountered between 23 and 50 ft bgs, with a saturated zone approximately 27 ft thick.



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- The inferred groundwater gradient at the site was to the north-northwest, with a hydraulic gradient of approximately 0.008 ft per ft.
- Four distinct zones were observed through the total depth of the borings; the units were identified as A, B, C, and D and are described as follows:

Unit A: Sand, fine to very coarse, and gravel (surface to 30 feet bgs)

Unit B: Sand, fine to very coarse, with some gravel and silt (30 to 40 feet bgs)

Unit C: Silt, sand, gravel, and cobble (35 to 50 feet bgs)

Unit D: Sand, fine to coarse, with silt and some gravel, very dense (50 to 65 feet bgs)

### **CONTAMINANT CHARACTERIZATION**

Semivolatile and volatile nonhalogenated hydrocarbons - diesel fuel

### **CONTAMINANT PROPERTIES (1.6)**

- Diesel fuel (No. 2 fuel oil) consists primarily of unbranched paraffins (straight chained alkanes) with a flash point between 110 ° and 190°F (43-88°C)
- Approximately one-half of the diesel fuel appeared to be within the range of volatile hydrocarbons
- Little preexisting natural weathering of the contaminant was evident
- Toxicity: High
- Flammability: High
- Solubility: 13 - 1,780 ppm at 20 °C

### **MATRIX CHARACTERISTICS AFFECTING TREATMENT COST OR PERFORMANCE (1)**

<b>Parameter</b>	<b>Value</b>
Soil classification	Primarily sand with some silt, gravel, and cobble at various depths
Clay content and/or particle size distribution	Clay content: low Particle size: fine to coarse
Hydraulic conductivity/water permeability	Moderate to high
Moisture content	2.8 to 4.0% from 10 to 25 feet bgs 19.8 to 23.0% at 30 feet bgs 7.3 to 9.9% at 49 to 54 feet bgs
Air permeability	Information not available
pH	6.0 to 7.0
Porosity	25 to 50%
Total organic carbon	Information not available
Nonaqueous phase liquids	None identified
Contaminant sorption	Information not available
Lower explosive limit	Information not available
Presence of inclusions	Information not available
Nitrogen concentration	Soil - 6 ppm Groundwater - <1 ppm
Biological oxygen demand	Information not available
Humic content	Low



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## TREATMENT SYSTEM DESCRIPTION

### PRIMARY TREATMENT TYPES

Air Sparging, In Situ Bioremediation, Soil Vapor Extraction

### SUPPLEMENTARY TREATMENT TECHNOLOGY TYPES

None

### TIMELINE (1,2)

Date	Activity
1990	Petroleum contamination identified at Texas Tower Site
1990	2,000 yd <sup>3</sup> of contaminated soil excavated and thermally treated offsite
1991 to 1993	Phase I and II site investigation and feasibility study conducted
July 1993	Excavated area backfilled
August 1993	Delivery order awarded to Beck Environmental
August to September 1993	Treatability studies conducted
November 1993 to January 1994	Treatment system constructed and installed by Beck Environmental
February 1994 to February 1996	Treatment system operated and monitored by AGRA Earth & Environmental, Inc.
April 1996	Soil and groundwater closure samples collected and analyzed
April 1997	Treatment system operated and monitored by AGRA Earth & Environmental, Inc.



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## TREATMENT SYSTEM (1.5.7)

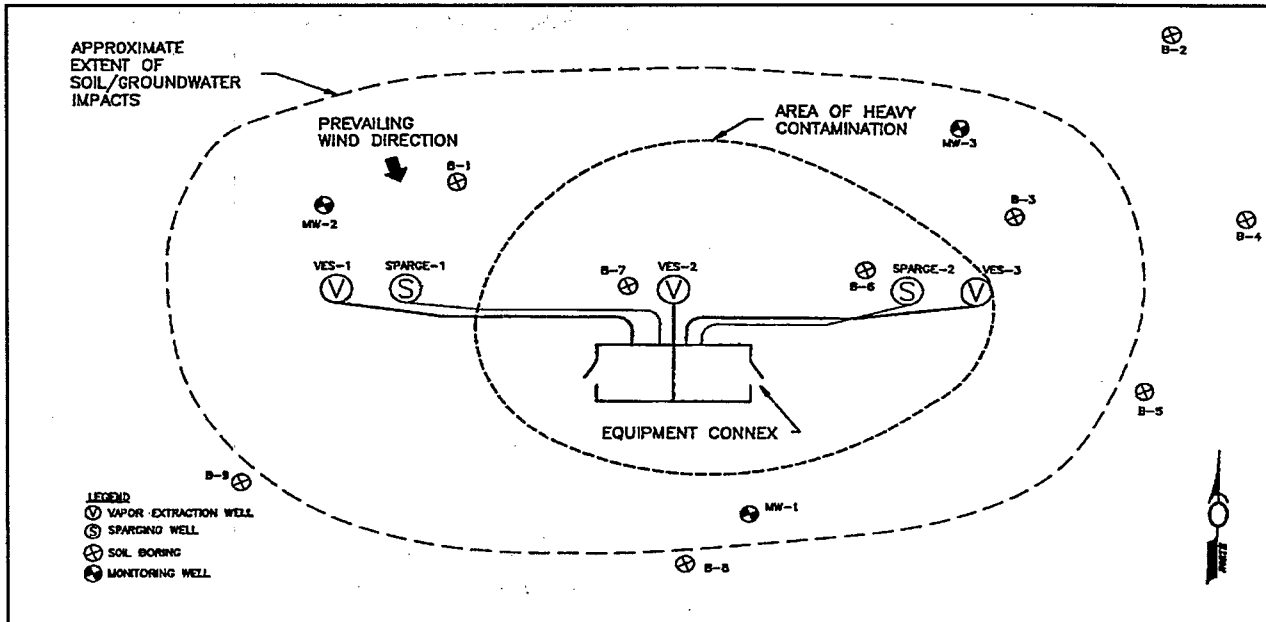


Figure 1. Treatment System Layout (No scale) (2)

### Construction

- As shown in Figure 1, the treatment system included two air sparging wells, three soil vapor extraction (SVE) wells, and associated equipment for adding nutrients. In addition, a number of wells were installed for monitoring of groundwater.
- The contractor mobilized equipment for the treatment system by barge from Sumner, Washington.
- An equipment enclosure building, including remote monitoring equipment, also was installed at the site.

### Pilot Test

- In August 1993, USACE contracted with Beck Environmental to design and install an in situ bioremediation system to reduce levels of residual diesel in the soil and groundwater; the system consisted of SVE and air sparging.
- Beck Environmental and AGRA Earth & Environmental conducted a pilot test on September 4, 1993 at the Texas Tower Site. The pilot test consisted of a test of the SVE and air sparging system and a biotreatability study.
- For the SVE and air sparging test, a Rotron DR-404 blower was used to pull air from a monitoring well at a rate of 80 cubic foot per minute (cfm) while a compressor was used to inject air into a sparge well.



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- The effective radius of influence for the SVE well, defined as the distance at which the vacuum influence was equal to 1 percent of the operating vacuum, was approximately 70 ft.
- Measurements of the SVE air stream by organic vapor meter ranged from 285 ppm after 5 minutes to 265 ppm after 20 minutes.
- A composite grab soil sample and a groundwater sample were taken from the Texas Tower Site and shipped to the contractor's laboratory in Kirkland, Washington for a two-week biotreatability test.
- Groundwater and soil samples were analyzed to determine growth of heterotrophic bacteria and corresponding concentrations of petroleum.
- Application of heat to the groundwater did not appear to increase the effectiveness of the treatment; results of the study of culture growth indicated similar trends at high concentrations of nutrients in both low and high temperature environments.
- Analysis of aerated groundwater samples, both with and without added nutrients demonstrated a reduction in petroleum concentrations that was greater than the reduction obtained without aeration.
- On the basis of the results of the pilot test, the contractor concluded that the site was amenable to remediation by a combination of air sparging, in situ bioremediation, and SVE.

#### Air Sparging System

- Two air sparging wells were drilled to a depth of 55 feet bgs and constructed of 2-inch-diameter galvanized steel pipe.
- The wells were installed through the long axis of the contamination zone (12 to 32 ft bgs).
- Each well had 5 feet of 0.020-inch slot "V" wire screen at the base of the saturated zone.
- The first 45 feet and the last 5 feet of each well were solid pipe; the last 5 ft served as a collection sump for siltation that might occur during a sparge cycle.
- A Cyclo Blower Model 3LDL5 was used to inject air in the wells; flow control valves allowed manual control of the air flow rate and pressure to each of the sparging wells.

#### SVE System

- Three SVE wells were drilled to 52 feet bgs, constructed of 4-inch-diameter polyvinyl chloride (PVC) pipe, and screened with 0.050-inch slot "V" wire screen from 12 to 32 feet bgs. The wells were used as extraction and monitoring wells.
- Soil vapor was removed from the wells by an EN-12 Rotron Blower capable of a maximum flow rate of 600 cfm at 0 pounds per square inch (psi) vacuum and 200 cfm at 3.6 psi. Vacuum lines from the SVE wells were equipped with a flow control valve, an air velocity monitoring port, and a sampling port.



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- Vapors extracted from the subsurface were directed through a 55-gallon condensate tank that preceded the blower. No air pollution control devices were incorporated into the SVE system.
- The exhaust from the SVE system was vented to the atmosphere through a 4-inch-diameter exhaust stack extending to 6 feet above the top of the blower.
- The exhaust stack was equipped with an air velocity monitoring port, an air sampling port, and a combustible gas indicator (CGI). The CGI continuously monitored the lower explosive limit (% LEL) of the air stream and would shut the system down if the LEL exceeded 20%.
- According to the USACE, no offgas treatment was incorporated into the design because the emissions were below regulatory levels.

#### Operation

- The air sparging system provided from 23 to 60 cfm of air to the saturated zone during operation of the system.
- The air sparging system was shut down temporarily in January 1995, June 1995, and October and November 1995 for maintenance and repair; the system also was shut down from February to April 1995 because the groundwater levels were below the screen intervals of the sparge wells.
- The SVE system removed an average of 400 cfm of vapor from the vadose zone.
- Measurements by photoionization detector (PID) taken from the exhaust stack ranged from 165 ppm at startup to ND in February 1996, when the system was shut down.
- On August 15, 1995, the contractor injected 4,000 gallons of nutrient solution (using a mixture of 50 lbs of fertilizer to 1,000 gallons of water) into the SVE wells. The fertilizer contained 17 lbs of ammonium nitrate per 50 lb bag of fertilizer (32% ammonium nitrate by weight).
- The remediation equipment enclosure was separated into potentially hazardous and nonhazardous areas by a wall. The air sparging equipment was installed on the nonhazardous side. The SVE system, made up of explosion-proof (Class 1, Division 2D) equipment, was installed on the hazardous side. All electrical equipment was equipped with low voltage protection. In addition, the LEL in the exhaust from the SVE system was monitored continuously, and the monitoring equipment was set to shut the system down automatically if the LEL exceeded 20 percent.
- The entire treatment system was monitored remotely. The system monitored the LEL of the SVE exhaust and the operational status of the equipment and ventilation systems in the enclosure. The equipment could be shut down automatically (or remote manually) if operating parameters were exceeded.
- The enclosure for the remediation equipment was not staffed during normal operation. Site workers wore level D personal protective equipment during the monthly monitoring events.
- For demobilization, the equipment enclosure was removed from the site, and all SVE and air sparging wells were removed and abandoned in accordance with the project specifications.



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## System Monitoring Requirements (5)

Media Monitored	Frequency	Parameters Monitored
<b>Air Sparging System</b>		
Air in sparging system	At startup, four days after startup, weekly for the first month, and once a month until the system was shut down	Sparge line pressure and air flow rate
Groundwater	Monthly	Water level in monitoring wells
Groundwater	Monthly	Benzene, toluene, ethylbenzene, and xylene (BTEX), DRO, dissolved oxygen (DO), pH, temperature, and conductivity
<b>In Situ Bioremediation</b>		
Groundwater	August 15 and September 28, 1995	Carbon dioxide (CO <sub>2</sub> ) and oxygen (O <sub>2</sub> ) levels
Groundwater	August 1994	Bacteria
<b>SVE System</b>		
Ambient air	February and August 1994	BTEX, gasoline-range organics (GRO)
Extracted vapors	At startup, four days after startup, weekly for the first month, and once a month until the system was shut down	Concentrations of organic vapor in air stream, air flow rates, vacuum at condensate tank, percent LEL

OPERATING PARAMETERS AFFECTING TREATMENT COST OR PERFORMANCE (2, 5)

<b>Air Sparging</b>	
Air flow rate	23 to 60 cfm
Pressure at monitoring point	2 to 5 psi
<b>In Situ Bioremediation</b>	
pH	6.0 to 7.0
Temperature	30 to 60°F
Microbial activity	106 colony forming units per milliliter
Oxygen uptake rate (average)	30 mg O <sub>2</sub> /L soil gas/day
Carbon dioxide evolution (average)	20 mg CO <sub>2</sub> /L soil gas/day
Hydrocarbon degradation (average)	Information not available
Nutrient and other amendments	Fertilizer (32% ammonium nitrate by weight)
<b>SVE System</b>	
Air flow rate	400 cfm (total system)
Vacuum	50" WC (measured across blower)



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**Closure (2.3)**

- A closure report for the application was submitted to the State of Alaska in April 1997.
- According to USACE, the state of Alaska accepted the closure report for the application. For the application, USACE was required to apply the "best available technology" for a duration that would perform to the maximum extent practicable (a point of diminished returns as evidenced by a lack of contaminants in the off gas).

## TREATMENT SYSTEM PERFORMANCE

- **PERFORMANCE OBJECTIVES (2)**

- The following remedial goals were specified for soil and groundwater at the Texas Tower site:

Matrix	Contaminant	Remedial Goal
Soil	Total BTEX	10 mg/kg
	Benzene	0.10 mg/kg
	DRO	100 mg/kg
Groundwater	Benzene	0.005 mg/L
	Toluene	1.0 mg/L
	Ethylbenzene	0.70 mg/L
	Xylenes	10.0 mg/L
	Hydrocarbons	0.10 mg/L

**TREATMENT PERFORMANCE DATA (2)**

- During closure, a total of 10 soil samples was collected from five soil borings at depths of 20 and 35 ft bgs; a split spoon sampler was used. The samples were analyzed by Superior Analytical Laboratory for the following groups of contaminants:
  - GRO by EPA Method 8015
  - BTEX by EPA Method 8020
  - DRO by EPA Method 8100-M
  - VOCs by EPA Method 8260
  - Semi volatile organic compounds (SVOCS) by EPA Method 8270
- AGRA Earth & Environmental collected groundwater samples from vapor extraction, air sparging, and groundwater monitoring wells. The samples were analyzed by Superior Analytical Laboratory for the contaminant groups listed above.
- AGRA Earth & Environmental reported that most measured values were lower than the remedial goals. Results of analysis showed that concentrations of contaminants exceeded specific remedial goals in three soil sample locations and three groundwater sample locations. In addition, two soil sample locations and one groundwater sample locations contained detectable concentrations of specific contaminants or groups of contaminants for which there were no corresponding remedial goals, referred to below as "other". The reported concentrations that



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were greater than their respective remedial goals, and other closure sampling results, are provided below:

Matrix	Contaminant	Remedial Goal	Closure Sampling Results Exceeding Remedial Goals	Other Closure Sampling Results	Sample Location
Soil	Total BTEX	10 mg/kg	18.9 mg/kg	-	CB-1 (35')
	GRO	None	-	990 mg/kg	CB-1 (35')
	DRO	100 mg/kg	2,000 mg/kg	-	CB-4 (35')
	DRO	100 mg/kg	3,000 mg/kg	-	CB-4 (20')
	DRO	100 mg/kg	2,700 mg/kg	-	CB-5 (20')
	VOCs	None	-	ND	CB-5 (20')
	SVOCs	None	-	1.8 mg/kg <sup>1</sup>	CB-1 (35')
Groundwater	BTEX	11.705		0.0037 mg/L	VES-2
	GRO	0.10 mg/L (as hydrocarbons)	0.21 mg/L		VES-2
	VOC	None	-	0.0181 mg/L <sup>2</sup>	VES-2
	SVOC	None	-	0.2 mg/L <sup>3</sup>	VES-2
	DRO	0.10 mg/L (as hydrocarbons)	5 mg/L		VES-2
	DRO	0.10 mg/L (as hydrocarbons)	0.77 mg/L		AS-2
	DRO	0.10 mg/L (as hydrocarbons)	0.13 mg/L		MW-5

**Notes:**

ND Not detected

<sup>1</sup> 2-methyl-naphthalene detected at 1.8 mg/kg

<sup>2</sup> 1,3,5-trimethylbenzene detected at 0.0068 mg/L and p-isophopyltoluene detected at 0.0043 mg/L

<sup>3</sup> bis(2-ethylhexyl)phthalate detected at 0.20 mg/L

- No additional information about the concentrations of specific contaminants or contaminant groups in soil or groundwater at the site was provided in the references available.
- As discussed above, the State of Alaska accepted the closure report for this application. USACE performed a "mini-risk assessment" to show that the concentration of contaminants did not pose a sufficient risk to warrant additional remedial activities.
- On the basis of the quantitative results and the air flow rates for the SVE system, AGRA Earth & Environmental estimated that approximately 1,300 lbs of contaminants had been removed from the vadose zone by the SVE system. That total consisted of 829 lbs of DRO, 418 lbs of GRO,



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and 55 lbs of total BTEX compounds. The estimate does not include contaminants removed from the saturated or vadose zones through biodegradation.

- The highest removal rates for DRO and GRO were 5.9 lbs per day and 1.6 lbs per day, respectively.
- Although results of monitoring suggested that biological activity is present at the site, no estimate was made of the mass of hydrocarbons degraded through biological activity.
- The areal extent of the contamination was estimated to be 5,655 ft<sup>2</sup> before treatment and 730 ft<sup>2</sup> after treatment; a reduction of approximately 87 percent.
- AGRA Earth & Environmental reported that the results of analyses of soil borings indicated that, when treatment had been completed, contamination was limited to two isolated areas at the site. The first area was a zone near CB-1 approximately 15 to 20 feet thick, containing elevated concentrations of BTEX and GRO. The second area was a zone from CB-4 (approximately 15-20 feet thick) to CB-5 (approximately 20-25 feet thick). In the second zone, concentrations of DRO ranged from 2,000 to 3,000 mg/kg.

**Material Balance:** No information is currently available to correlate the mass of contaminants at the site before treatment with the mass after treatment. For example, no information is available to match the concentrations measured in the nine original soil borings and the five soil borings collected at closure. In addition, no information is available to correlate data from groundwater monitoring wells with data from extraction wells.

#### **PERFORMANCE DATA QUALITY (2)**

- The contractor performed monitoring activities in accordance with the ADEC UST regulations (18 AAC 78) and the requirements of the Quality Assurance Project Plan (QAPP), which had been approved by ADEC.
- USACE North Pacific Division Laboratory (NPDL) prepared a chemical quality assurance report (QAR) for the analytical data produced during the investigation.
- During the cleanup process, quality control (QC) samples were submitted to Superior Analytical Laboratory, and quality assurance (QA) samples were submitted to NPDL.
- NPDL submitted split samples to Applied Research & Development in Mt. Vernon, Illinois for analysis.
- The NPDL QA/QC report verified that all results were accurate, except the results of VOC analysis for 1,3,5-trimethylbenzene and p-isopropyltoluene in three water samples.



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## TREATMENT SYSTEM COST

### PROCUREMENT PROCESS (5)

- The procurement process was a firm, fixed-price contract competitively solicited by request for proposals. Contractors' proposals were evaluated against technical evaluation criteria that included the contractor's qualifications, experience, and training. The contractor was selected based on consideration of a combination of technical qualifications and proposed costs.
- The contract was separated into one base item, preparation of the work plan, and two optional items, construction of the system and operation of the system. This approach was used to allow the government to cease the contract after the work plan had been prepared if the contractor submitted a poor work plan or if it was determined that the treatment process would not work.

### TREATMENT SYSTEM COST (3)

- USACE identified the following proposed costs for the application:

Preparation of work plan	\$33,110
Construction	\$145,420
Operation	\$117,230

<b>TOTAL</b>	<b><u>\$295,760</u></b>
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- No information is available comparing actual costs with proposed costs.

## REGULATORY/INSTITUTIONAL ISSUES

- Cleanup criteria for the Texas Tower Site were included in the original USACE solicitation; the criteria were based on the ADEC regulations that govern remediation of USTs (18 AAC 78).

## OBSERVATIONS AND LESSONS LEARNED

### COST OBSERVATIONS AND LESSONS LEARNED (5)

- The total proposed cost for the air sparging, in situ bioremediation, and SVE system at the Texas Tower Site was \$295,760, including \$145,420 for construction, \$117,230 for operation, and \$33,110 for work plan preparation.
- A unit cost of treatment of \$47 per yd<sup>3</sup> was calculated from the total cost of \$295,760 to remediate 6,300 yd<sup>3</sup> of in situ soil and groundwater.



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- Because the site is isolated, the USACE reported that the cost of transportation of the equipment to the site and setup at the site was a significant portion of the total cost of the project.
- Costs of operation were kept low by monitoring the operation of the remediation system remotely. The system therefore could be unstaffed, except for monthly sampling events. This savings in operating costs was not quantified for this application.

### **PERFORMANCE OBSERVATIONS AND LESSONS LEARNED**

- Over the two years during which the system operated, approximately 1,300 lbs of contaminants were removed from the vadose zone. Those contaminants consisted of 829 lbs of DRO, 418 lbs of GRO, and 55 lbs of total BTEX compounds. The estimate above does not include contaminants removed through biodegradation.
- Concentrations of contaminants in treated soil and groundwater met the remedial goals in all samples with the exception of three soil sample locations and three groundwater sample locations. Because the soil samples were from locations that had not been sampled prior to the design of the treatment system, the USACE concluded that the results suggested an additional "hotspot" outside of the original treatment area. Based on the results of a "mini-risk assessment" performed by USACE, no additional remedial activities were warranted. The State of Alaska accepted the closure report for this application.
- The operation contractor cited the following reasons, why no additional remedial activities were necessary: The leaking fuel lines that had been the source of the release had been removed; highly contaminated soil had been excavated and treated off site; no compounds for which maximum contaminant levels (MCLs) have been established had been detected at concentrations above MCLs during more than two years of monitoring; and the potential for exposure from residual hydrocarbons was negligible.

### **OTHER OBSERVATIONS**

- USACE Alaska District operated the system remotely by a state-of-the-art monitoring and telemetry system. The USACE estimates that in situ treatment of soils was considerably less expensive than the conventional method of excavation and thermal treatment off site.

### **REFERENCES**

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## **ACKNOWLEDGMENTS**

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**Air Sparging and Soil Vapor Extraction  
at Landfill 4, Fort Lewis, Washington**

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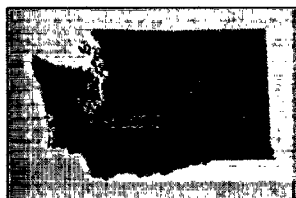
# Air Sparging and Soil Vapor Extraction at Landfill 4, Fort Lewis, Washington

<b>Site Name:</b> Fort Lewis Landfill 4	<b>Contaminants:</b> Volatiles (halogenated), and metals (manganese). Maximum concentrations of halogenated constituents in soil gas were: 4.1 mg/m <sup>3</sup> dichloroethene, 1.6 mg/m <sup>3</sup> trichloroethene, and 0.2 mg/m <sup>3</sup> vinyl chloride. Maximum concentrations of halogenated constituents in groundwater were 7 µg/L dichloroethene, 79 µg/L trichloroethene, and 7.8 µg/L vinyl chloride. Manganese was detected in groundwater at concentrations up to 13 mg/L.	<b>Period of Operation:</b> Status: Ongoing Report covers: 12/5/94 through 10/31/97
<b>Location:</b> Tacoma, Washington		<b>Cleanup Type:</b> Remedial Action
<b>Vendor:</b> Fred Luck, P.E. Garry Struthers Associates, Inc. 3150 Richards Road, Suite 100 Bellevue, WA 98005-4446 (206) 519-0300	<b>Technology:</b> Soil vapor extraction (SVE) and air sparging (AS): <ul style="list-style-type: none"> <li>- A pilot test of three SVE wells and one AS well was operated from December 5 through 15, 1994.</li> <li>- The full system consisted of six SVE, five AS wells, ten vadose zone piezometers, three dissolved oxygen sensor wells, and four passive air injection wells.</li> <li>- The SVE wells were piped through a set of parallel treatment systems each consisting of a vapor/water separator, a blower, and two GAC canisters connected in series.</li> <li>- Operations included various combinations of extraction and sparge flow rates, and use of injection wells.</li> </ul>	<b>Cleanup Authority:</b> The cleanup at Landfill 4 is being performed in accordance with a Federal Facilities Agreement between the Department of the Army, EPA, and the Washington Department of Ecology, and a ROD signed October 15, 1993.
<b>USACE Contacts:</b> Kira Lynch and Bill Goss U.S. Army Corps of Engineers, Seattle District CENWS-TB-ET (Lynch) CENWS-PM-HW (Goss) P.O. Box 3755 Seattle, Washington 98124 (206) 764-6918 (Lynch) (206) 764-6682 (Goss)		<b>Regulatory Point of Contact:</b> Bob Kievit EPA Remedial Project Manager, Region 10 300 Desmnd Drive Suite 102 Lacey, Washington 98503 (360) 753-9014

## Air Sparging and Soil Vapor Extraction at Landfill 4, Fort Lewis, Washington (continued)

<b>Waste Source:</b> Leaks and spills of solvent waste to soil surfaces on and near Landfill 4; unlined liquid waste disposal pits	<b>Type/Quantity of Media Treated:</b> In situ soil (both saturated and unsaturated) - volume not determined - Sandy gravel to sandy silty gravel - Moisture content (unsaturated soil) - 9 - 12 %
<b>Purpose/Significance of Application:</b> Application of a combination of innovative technologies to treat halogenated organic contamination in situ in both soil and groundwater.	
<b>Regulatory Requirements/Cleanup Goals:</b> - The ROD specified four objectives for the remedy: to prevent exposure to contaminated groundwater, to restore the contaminated groundwater to its beneficial use, to minimize movement of contaminants from soil to groundwater, and to prevent exposure to the contents of the landfill. - No soil cleanup levels were identified in the available reference material. - The cleanup levels established for groundwater in the upper aquifer beneath the site were: TCE - 5 µg/L and vinyl chloride - 1 µg/L. - Monitoring for manganese in groundwater also was required for areas of the site.	
<b>Results:</b> - Pilot test and startup phases of the remediation were used to determine the optimum system parameters for the treatment system. - It was estimated that approximately 60 pounds of TCE were removed from as of October 30, 1997. - Although the impact of the AS system on the degradation of TCE was not conclusively determined, it was recommended that the AS system be operated until an impact/benefit analysis for the system is completed. - It was concluded that an additional hot spot of TCE contamination may be located upgradient and out of the area of influence of the remediation system.	
<b>Cost:</b> - The total cost of the pilot study for this application was \$241,000. - The negotiated cost for the full-scale remediation system was \$1,710,303.	
<b>Description:</b> Ft. Lewis began operation in 1917. The Landfill 4 area consists of approximately 52 acres, which is divided into three cells located adjacent to a former gravel pit. These cells were used from the early 1950s to the late 1960s, reportedly, for the disposal of refuse, including domestic and light industrial solid waste and construction debris. After disposal activities was ceased, the landfill was covered with native material and has since been overgrown with vegetation.  Site investigations beginning in 1988 identified chlorinated hydrocarbon and metal contamination in the groundwater beneath the landfill. An RI/FS, conducted in 1993, led to the ROD for the site signed on October 15, 1993, which prescribed a remedy consisting of SVE and AS and monitoring of groundwater for manganese.  An SVE/AS pilot test was conducted at the site in December 1994 and the full-scale SVE/AS system was put on line in October 1996. The system had removed approximately 60 pounds of TCE (in soil gas) from the subsurface as of October 31, 1997, and currently continues to operate.	

## SITE INFORMATION



### IDENTIFYING INFORMATION

**Site Name:** Ft. Lewis Landfill 4  
**Location:** Tacoma, Washington (Figure 1)  
**Technology:** Air Sparging and Soil Vapor Extraction  
**Type of Action:** Remedial

### TECHNOLOGY APPLICATION

**Period of Operation:** Pilot Study - December 5 - 15, 1994; Full-scale Operation October 1, 1996 - ongoing (report covers period from October 1, 1996 through October 31, 1997)

**Quantity of Material Treated During Application (13):** Since this application is ongoing, the quantity of material treated has not been estimated. Approximately 60 pounds of trichloroethene (TCE) have been removed from the subsurface as of October 31, 1997 (based on concentrations in extracted soil gas).

### BACKGROUND

**SIC Code:** 9711 (National Security)

**Waste Management Practice that Contributed to Contamination:** Leaks and spills of solvent waste to soil surfaces on and near Landfill 4; unlined liquid waste disposal pits

#### **Site Background (1, 6, 8):**

- Ft. Lewis occupies about 86,000 acres at the southern end of Puget Sound, and is located approximately 12 miles from Tacoma Washington. Ft. Lewis began operating in 1917 and currently serves as a military reservation. Ft. Lewis is divided by I-5 into North Ft. Lewis and the Main Post.
- Landfill 4 (LF4) is located on North Ft. Lewis near Sequelitchew Lake and Sequelitchew Springs, which is the primary drinking water supply for the fort. The 52 acre landfill is divided into three cells - South, Northeast, and Northwest and is located adjacent to a gravel pit (Figure 2).



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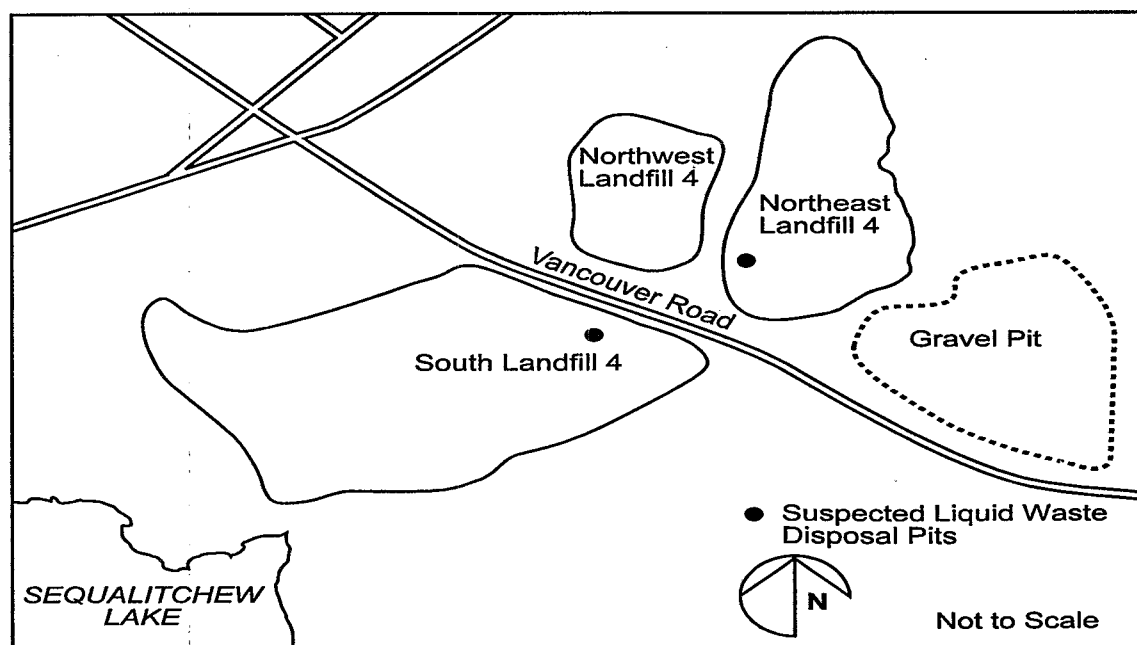


Figure 2: Landfill 4 - Location of Three Cells [6]

- From the early 1950's to the late 1960's, LF4 was reportedly used for the disposal of refuse, including domestic and light industrial solid waste and construction debris, and for the disposal of liquid waste in unlined cells. In addition, LF4 was reportedly used as a gravel quarry in the 1940's and for equipment storage and maintenance. After disposal activities ceased, the landfill was covered with native materials such as sand, gravel and soil; the landfill is currently covered with trees and grass.
- According to the 1993 Remedial Investigation (RI), there were no reports of disposal of hazardous waste in LF4. However, historical aerial photographs show two suspected liquid waste disposal pits located in Northeast and South LF4 and evidence of equipment maintenance activities near Northeast LF4. Tetrachloroethene (PCE) and TCE are suspected of having been used in degreasing and equipment maintenance operations at Ft. Lewis; leaks and spills of solvents from maintenance operations on or near LF4 and disposal of solvents in unlined pits are the suspected sources of contamination.
- In 1988, a limited site investigation of LF4 was conducted by Batelle's Pacific Northwest Laboratory. The investigation indicated that the shallow groundwater beneath the landfill was contaminated with chlorinated hydrocarbons, aromatic hydrocarbons, and manganese (Mn). While the data were not provided in the available references, TCE was reported to have been found at concentrations ranging from 1 to 32 micrograms per liter (ug/L).
- In 1991, Applied Geotechnology Incorporated (AGI) conducted several pre-RI activities including a test pit investigation, a passive soil gas survey, and a preliminary ecological assessment. According to AGI, the results of these activities indicated that TCE and PCE were widely distributed in the area around LF4.



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- The RI/FS, completed in 1993 by AGI, included a more extensive landfill and soil gas survey and a groundwater investigation. The RI confirmed the presence of chlorinated hydrocarbons and aromatic hydrocarbons contamination at LF4. Elevated levels of TCE, PCE, and dichloroethene (DCE) were detected in the soil. TCE, VC and benzene, toluene, ethylbenzene, and xylene (BTEX) contamination was detected in the groundwater. Elevated levels of Mn were also detected in the groundwater along the western borders of South and Northwest LF4. However, the RI attributes these elevated levels to the dissolution of Mn from geologic materials in the area of LF4.

#### **Remedy Selection (6, 9):**

- In a Record of Decision (ROD) signed in October 1993, the remedy selected for LF4 included treatment of contaminated soils in areas that were suspected sources of groundwater contamination (soil hot spots) using soil vapor extraction (SVE), treatment of contaminated groundwater using air sparging (AS), monitoring of the upper aquifer to determine the effectiveness of the selected remedy, and maintenance of institutional controls, including access restrictions. The groundwater AS system was to work in conjunction with the SVE system.
- The ROD also required that Mn be monitored in the groundwater in the localized areas where elevated levels were detected during the RI. The ROD specified that if the results of the monitoring indicated that levels were not declining, then the need for remediation was to be reevaluated.
- Including limited groundwater extraction and treatment in addition to AS/SVE was considered as an alternative remedy. However, AS/SVE was determined to be more cost effective than AS/SVE plus groundwater extraction and treatment while still being protective of human health and the environment.

#### **SITE LOGISTICS/CONTACTS**

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## MATRIX AND CONTAMINANT DESCRIPTION

### MATRIX IDENTIFICATION

Soil (in situ)  
 Groundwater

### CONTAMINANT CHARACTERIZATION

Volatiles (Halogenated):      Dichloroethene (DCE)  
    Tetrachloroethene (PCE)  
    Trichloroethene (TCE)  
    Vinyl chloride (VC)

Metals:                              Manganese (Mn)

### CONTAMINANT PROPERTIES

Chemical Name	CAS No.	Specific Gravity <sup>1</sup>	Toxicity	Flammability	Solubility In Water (mg/L)	Vapor Pressure
Dichloroethene (DCE)	540-59-0	1.250 (15°/4°)	High	Flammable Liquid	2,250	180-265 mm
Tetrachloroethene (PCE)	127-18-4	1.631 (15°/4°)	High	Non-combustible	150	14 mm
Trichloroethene (TCE)	79-01-6	1.466 (20°/20°)	High	Combustible liquid	1,100	58 mm
Vinyl Chloride (VC)	75-01-4	0.908 (25°/25°)	High	Flammable Gas	2,670	3.3 atm

<sup>1</sup> Specific gravity of compound at 20°C referred to water at 4°C (25°/4°) unless otherwise specified

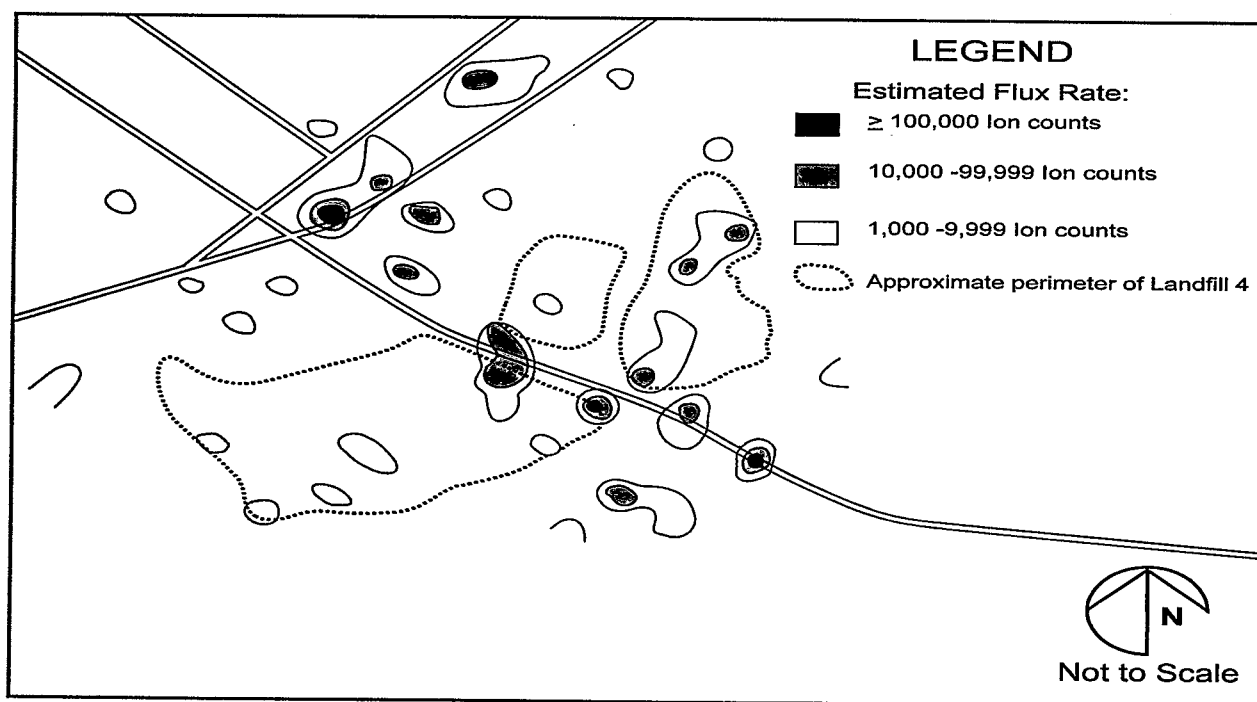


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**CONTAMINANT CONCENTRATIONS (4)****Soil [4, 6]**

- Table 1 presents a summary of the compounds detected during the RI investigations of landfill gas (gas probes within the landfill) and soil gas (gas probes in the area surrounding the landfill). As shown in the table, chlorinated and aromatic hydrocarbons were detected within LF4 and in the surrounding soil gas at levels as high as 7 mg/m<sup>3</sup>. The maximum TCE concentration was detected in soil gas at 1.6 mg/m<sup>3</sup>. The maximum VC and DCE concentrations of 4.1 mg/m<sup>3</sup> and 0.2 mg/m<sup>3</sup>, respectively, were detected in the landfill gas.
- TCE flux rates were measured during the RI in soil gas within LF4 and in the area surrounding LF4. As shown in Figure 3 high TCE flux rates were measured throughout the area. Within LF4, areas of high TCE flux rates (>10,000 ion counts) were found in Northeast and South LF4 with the highest TCE flux rates (≥100,000 ion counts) measured at the northeast corner of South LF4.
- The RI also reported that the landfill and soil gas investigations showed elevated concentrations of PCE, DCE, and VC in various areas at LF4. The RI also stated that the highest flux rates for PCE were measured in two areas of Northeast LF4, and in two areas of South LF4.

**Figure 3: Landfill 4: TCE in Soil Gas [6]**

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Table 1: Summary of Compounds Detected in LF4 Landfill Gas and Soil Gas [6]

Detected Analyte	Gas Probes Within Landfill	Gas Probes Outside Landfill
	Concentration Range (mg/m <sup>3</sup> )	Concentration Range (mg/m <sup>3</sup> )
Benzene	<0.06-0.17	<0.06-1.6
Chlorobenzene	<0.06-0.09	<0.06
Chloroethane	<0.06-0.79	<0.06
1,4-Dichlorobenzene	<0.06-5.9	<0.06
cis-1,2-Dichloroethene	<0.06-0.20	<0.06
Dichlorotetrafluoroethane	<0.06-7.0	<0.06-3.9
Ethylbenzene	<0.06-3.7	<0.06
Methylene chloride	<0.06-0.07	<0.06-0.10
1-Methyl-4-ethylbenzene	<0.06-3.2	<0.06
Toluene	<0.06-4.3	<0.06-0.21
1,2,4-Trichlorobenzene	<0.06-0.09	<0.06
1,1,1-Trichloroethane	<0.06	<0.06-0.11
Trichloroethene	<0.06	<0.06-1.6
1,1,2-Trichlorotrifluoroethane	<0.06	<0.06-0.26
1,2,4-Trimethylbenzene	<0.06-3.2	<0.06-0.06
1,3,5-Trimethylbenzene	<0.06-3.0	<0.06
Vinyl chloride	<0.06-4.1	<0.06
m,p-Xylene	<0.06-7.1	<0.06-0.10
o-Xylene	<0.06-2.8	<0.06



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**Groundwater [6]**

- Table 2 presents a summary of compounds detected during the RI in the upper and lower aquifers at LF4. In the upper aquifer TCE was detected at concentrations as high as 79 ug/L, cis-1,2-DCE at concentrations as high as 7ug/L, and VC at concentrations as high as 7.8 ug/L.
- Figure 4 shows the area where TCE concentrations greater than 5 ug/L were detected in the upper aquifers during the RI. The figure shows elevated TCE concentrations throughout the groundwater beneath LF4 as well as in an area to the west of the landfill.
- PCE was not detected in the RI groundwater investigation. AGI attributed the lack of PCE in the groundwater to the degradation of this compound.

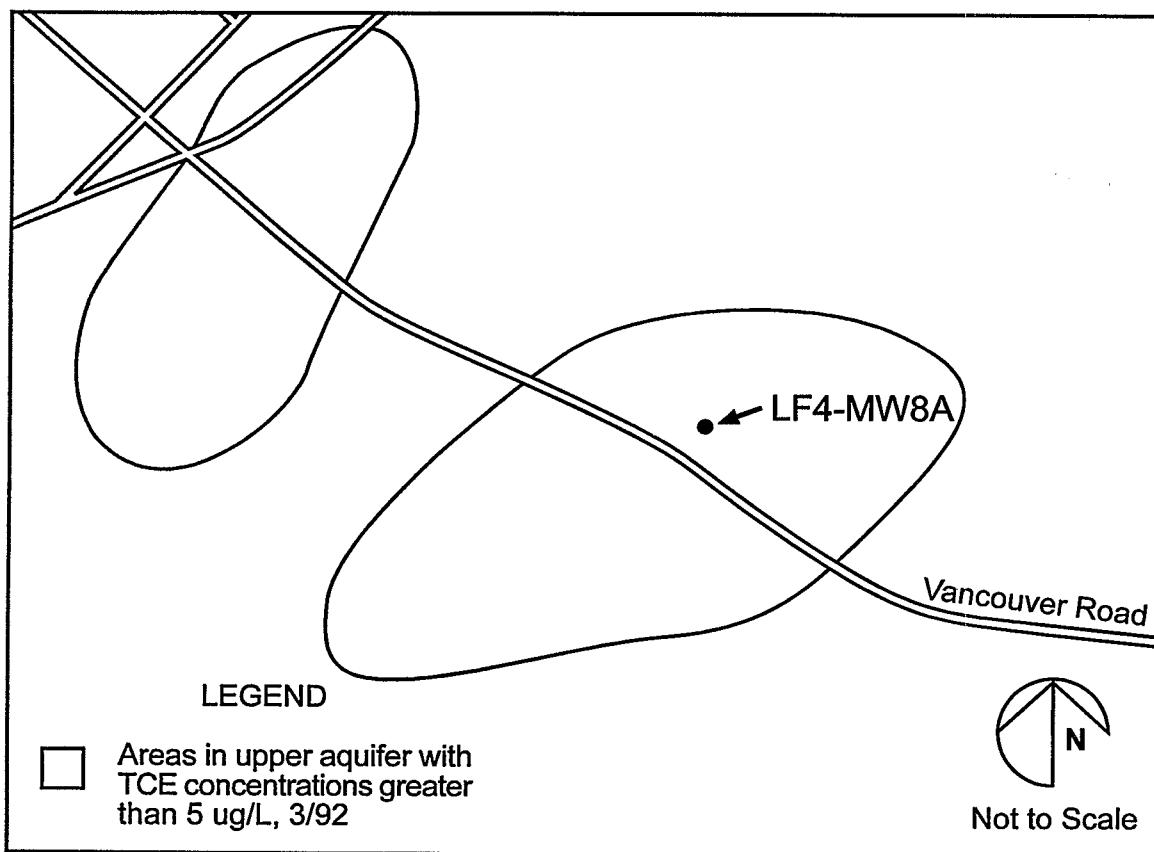


Figure 4: TCE concentrations greater than 5 ug/L in the upper aquifer of Landfill 4 [6]



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Table 2: Summary of Selected Contaminants Detected in LF4 Groundwater During the RI [6]

Contaminant	Concentration Ranges
<b>Upper Aquifer</b>	
<b>VOCs</b>	
cis-1,2-DCE	<0.3-5 µg/L
trans-1,2-DCE	<0.2-7 µg/L
TCE	<0.2-79 µg/L
VC	<1.0-7.8 µg/L
<b>Total Metals</b>	
Mn	<0.01-12 mg/L
Iron	<0.088-510 mg/L
<b>Dissolved Metals</b>	
Mn	1.0-49 mg/L
Iron	<0.025-7.7 mg/L
<b>Lower Aquifer</b>	
<b>VOCs</b>	
Benzene	<0.5-2 µg/L
Ethylbenzene	<0.5-0.6 µg/L
Toluene	<0.5-5.8 µg/L
Xylenes	<0.5-4 µg/L
<b>Total Metals</b>	
Mn	3.8-13 mg/L
Iron	0.16-9.3 mg/L
<b>Dissolved Metals</b>	
Mn	<0.01-0.30 mg/L
Iron	<0.025-0.24 mg/L



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- As shown in Table 2, low levels of BTEX were detected in the lower aquifer (<0.5 ug/L to 5.8 ug/L). However, TCE, DCE, VC, and PCE, while detected in the upper aquifer, were not detected in the lower aquifer.
- Mn and iron were detected in both the upper and lower aquifers (Table 2). The RI determined that the elevated levels of Mn were caused by dissolution of manganese from geologic material.
- Results of groundwater quality indicator parameters measured during the RI, including increased specific conductance, dissolved metals and biochemical oxygen demand, indicated that low levels of metals and inorganic compounds were leaching from the landfill into the upper aquifer. However, the parameters were reported to rarely exceed five times their background levels. There was no evidence of leaching to the lower aquifer.

#### **MATRIX CHARACTERISTICS AFFECTING TREATMENT COST OR PERFORMANCE [4, 6, 7]**

Soil Classification	Sandy gravel to sandy silty gravel (see Table 3)
Particle Size Distribution	Stratigraphic units range from well sorted to unsorted (see Table 3)
Moisture Content	9 - 12 %
Permeability	Information not provided
Hydraulic conductivity	232 darcies (sieve analysis) 370 darcies (computer modeling)
Effective Porosity	30%
Total Organic Carbon	580 -17,000 ppb (as measured during the pilot study)
Contaminant Sorption/Soil Organic Content	Information not provided
Lower Explosive Limit	Information not provided
Presence of Inclusions	Information not provided
Humic Content	Information not provided

### **GEOLOGY AND HYDROGEOLOGY**

#### **GEOLOGY (4):**

- LF4 is situated on a glacial drift plain with an elevation of 200 to 250 ft above mean sea level (MSL). During the RI, six stratigraphically distinct geologic formations were encountered in the LF4 area. These are summarized in Table 3.



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Table 3: Geologic Units at LF4 [4, 6, 9]

Geologic Unit	Description	Thickness (ft)
Vashon Drift	sandy gravel with cobbles	75
Discovery Nonglacial Unit	well sorted stratified sand with occasional gravel bed	30-70 (absent beneath portions of northeast and northwest LF4)
Narrows Glacial Unit	oxidized lodgement till - unsorted dense mixture of silt, sand, gravel and cobbles	5-80
Kitsap Formation	well sorted sand overlying silt with interbedded sand and peat	10-45
Flett Creek Glacial Unit	oxidized lodgement till overlying sandy gravel and silty gravel outwash	70-85
Clover Park Nonglacial Unit	stratified sand with silt, gravel, peat and wood fragments	100

### Hydrogeology [4,6]

- The RI identified four hydrostratigraphic units - two aquifers and two aquitards, described below.
- Upper Aquifer - this aquifer occurs in unconfined conditions (water table) at depths ranging from ground surface around Sequelitchew Springs and the surrounding lakes to a depth of 43 ft below ground surface (bgs), with a saturated thickness of 105 to 135 ft. The depth near LF4 generally ranges from 15 to 25 ft. The upper aquifer is divided into the "upper part" at or near the water table (Vashon Drift) and the "lower part" for the deeper portions of the aquifer (Discovery Nonglacial unit, Narrows Glacial unit, or Kitsap Formation).
- The upper aquifer is recharged by infiltration of precipitation and by lateral groundwater flow from the east and south. Water elevations are directly affected by precipitation, peaking during the wet winter and spring months. Groundwater flows from the east and south towards LF4, then continues in a north/northwest direction. The groundwater also flows west beneath LF4.
- Sequelitchew Springs is the primary drinking water source for the fort. Pumping at Sequelitchew Springs can cause a reverse in the groundwater flow direction southeast of LF4. This reversal in flow creates a northeast/southwest-trending groundwater divide in the southern portion of Northeast LF4.
- Upper Aquitard - this aquitard consists of the Narrows Glacial Till unit located in the upper aquifer. This aquitard is most clearly defined at the northern edge of South LF4 and around Northwest LF4. The upper aquitard beneath the northeast portion of LF4 acts as a hydraulic dam, creating a large area of flat hydraulic gradients between LF4 and Sequelitchew Lake.



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- Middle Aquitard - this aquitard consists of low permeability deposits of silt and peat (Kitsap Formation) and lodgment till (Flett Creek Glacial unit) which separates the upper and lower aquifers. This aquitard is laterally extensive and is present beneath the entire landfill area.
- Lower Aquifer - groundwater is confined in the lower aquifer and generally flows from east to west, discharging to Puget Sound.

## TREATMENT SYSTEM DESCRIPTION

### PRIMARY TREATMENT TECHNOLOGY TYPE (7)

Soil - Soil Vapor Extraction  
Groundwater - Air Sparging

### SUPPLEMENTARY TREATMENT TECHNOLOGY TYPE

Post Treatment - Carbon Treatment System (Granular Activated Carbon units for SVE system air emissions)

### TIMELINE [1. 6]

Date	Activity
1940s	LF4 used as a gravel quarry and as an equipment storage and maintenance area
1951-1967	LF4 used for refuse disposal
1988	Battelle's Pacific Northwest Laboratory conducted a limited site investigation
1991	Pre-Remedial Investigation (RI) activities conducted
1993	RI/FS completed
October 15, 1993	Record of Decision signed
December 5-15, 1994	AS/SVE Pilot test conducted at LF4
August 16, 1996	Remedial Action Management Plan completed
October 1, 1996 and ongoing	AS/SVE full-scale operation, including AS/SVE startup activities at LF4 (October 1, 1996 to January 29, 1997)



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## **TREATMENT SYSTEM SCHEMATIC AND TECHNOLOGY DESCRIPTION AND OPERATION**

### **Technology Description**

- The technology description for this application is discussed separately below for the pilot system and full-scale system. The pilot system design and testing was performed by USACE. The full-scale system design and testing was performed by Garry Struthers Associates (GSA). The locations of the wells for LF4 are shown in Figure 5.

### **PILOT SYSTEM [8]**

#### **Construction**

- The pilot system used in this application consisted of 1 air sparging (AS) well, 3 soil vapor extraction (SVE) wells, 10 vadose zone piezometer (VZP) wells, 2 groundwater monitoring wells, and 3 dissolved oxygen sensor (DOS) wells, as well as an impermeable plastic cover for the ground surface and well monitoring equipment. The AS and SVE wells were located near LF4-MW8A, which had the highest recorded TCE concentrations for ground water in the project area.
- The AS well was used to inject clean air into the aquifer, using an above-ground blower, to strip volatile contaminants from the aquifer into the soil in the subsurface at the site. Dissolved oxygen (DO) concentrations in the aquifer were measured during air sparging using DOS wells. The DO results were used to estimate the radius of influence of the AS well during the pilot test. The SVE wells were used to extract volatile contaminants from the subsurface soil, and the VSP wells were used to measure the radius of influence of the SVE wells.
- The impermeable plastic cover was used to enhance the radius of influence for the SVE wells by moving the air recharge boundary a greater distance from the SVE wells. The cover was constructed of a 20 millimeter (mil) thick layer of very low density polyethylene (VLDPE) laid down over a cleared area. The cover had a radius of approximately 200 feet, and was covered with 4 to 6-inches of gravel to assure tight contact with the ground surface, and to allow for the use of light vehicular traffic (pickup trucks) over the cover.
- Table 4 summarizes well construction details such as number of wells, depth of wells, and depth of well screen, for each of the 5 types of wells used in the pilot system. All wells were drilled using a 4-inch inner diameter (ID) hollow stem auger.



Table 4. Summary of Construction Details for Wells Used in Pilot System [8]

Type of Well	No. of Wells	Depth of Well	Location of Well Screen	Screen Length (ft)	Screen Slot Openings (in)
AS	1	20 ft below static water level (SWL); 50 ft below ground surface (BGS)	15 to 20 ft below SWL	5	0.01
SVE	3	30 ft BGS	2 ft above seasonal high water level (SHWL) to 12 ft above SHWL	10	0.01
VZP	10	30 ft BGS	2 ft above SHWL to 12 ft above SHWL	10	0.01
Groundwater monitoring	2	40 ft BGS	1 ft above SHWL to 7-8 ft below SWL	10	0.01
DOS	3	40 ft BGS	1 ft above SHWL to 7-8 ft below SWL	10	0.01

### Operation

- Operation of the pilot system consisted of a SVE pilot test and a combined AS/SVE pilot test. Details of the operations of the pilot system are discussed under the Treatment Performance Data section of this report.

### FULL-SCALE SYSTEM [2]

#### Construction

- The full-scale system used in this application consisted of 5 AS wells, 6 SVE wells, 10 VZP wells, 3 groundwater monitoring wells, 3 DOS wells, 4 passive injection wells, and associated well-monitoring equipment. Figure 5 shows the relative locations of these wells. Passive injection wells were placed at locations where modeling results showed significant stagnation zones when 2 adjacent SVE wells were operated at the same time. The full-scale system used



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the same impermeable plastic cover for the ground surface that was used in the pilot system. Two parallel systems of vapor-phase granular activated carbon (GAC) were used in the full-scale system.

- Figure 6 is a process flow diagram showing the equipment used in the full-scale SVE system. As shown on Figure 6, extracted vapors were first treated using a moisture (water/vapor) separator to remove entrained water, followed by treatment using activated carbon filter canisters (GAC), prior to discharge to the atmosphere.
- Figure 7 is a process flow diagram showing the equipment used in air sparging at the site. As shown in Figure 7, air sparging consisted of an inlet particulate filter, compressor, moisture separator, and flow control valve.
- The six SVE wells were piped to two parallel treatment trains, each consisting of a water/vapor separator, a blower, and two vapor-phase GAC canisters. These two sets of parallel equipment were operated to provide additional insurance that the system performance would not be affected by a system breakdown.

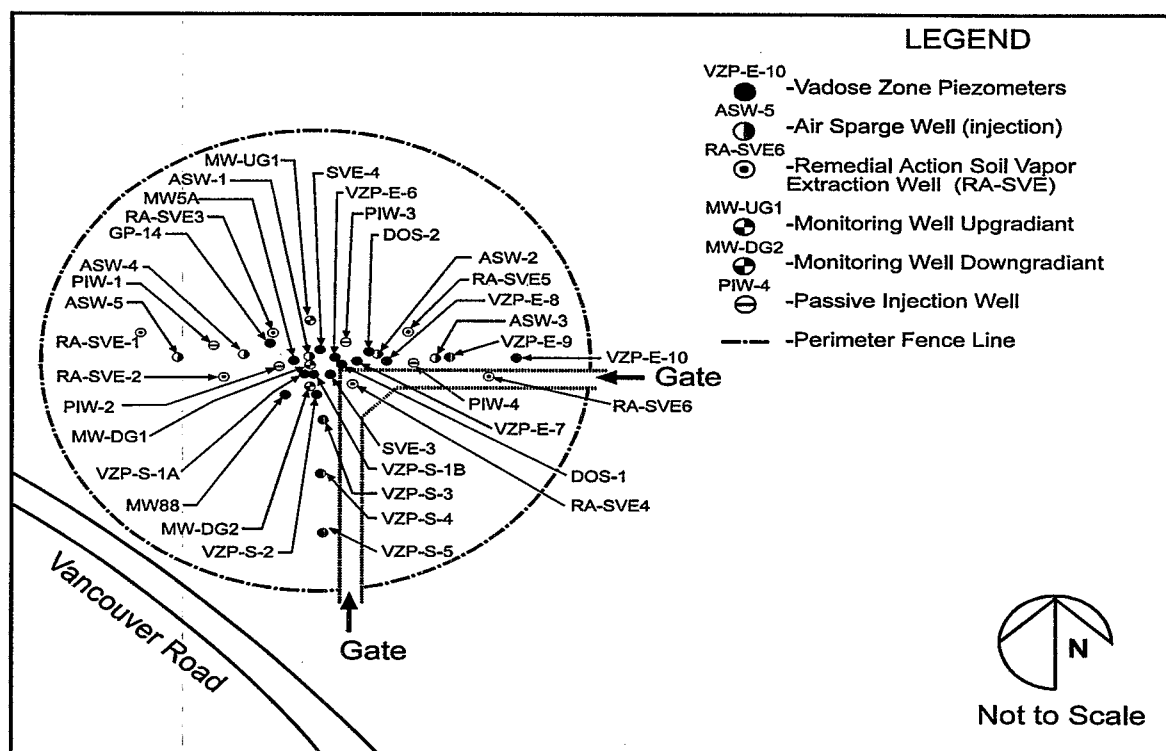


Figure 5: Well Location Map for Landfill 4 [2]



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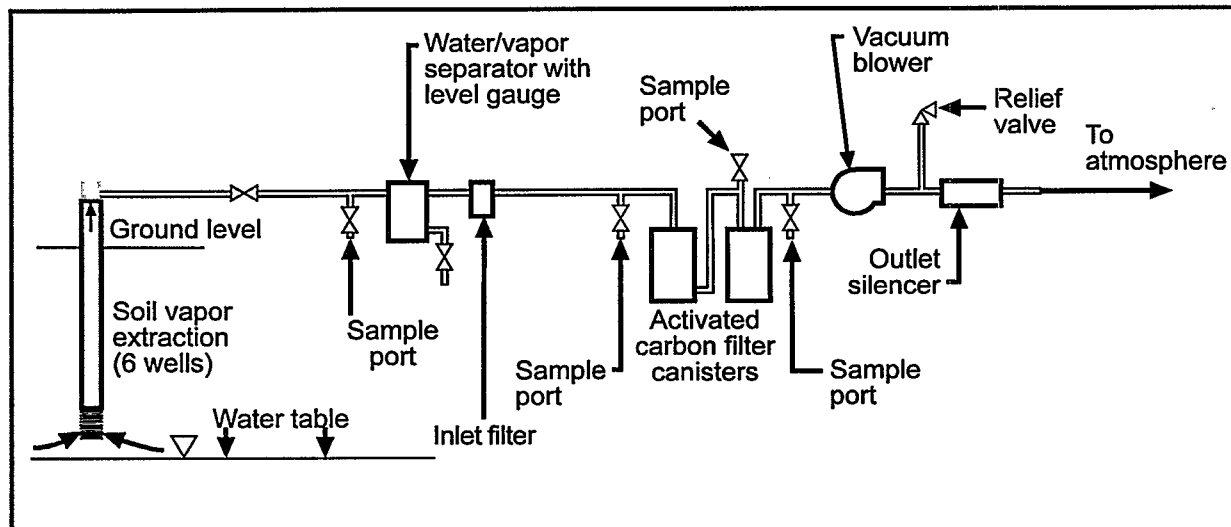


Figure 6: SVE Schematic for Landfill 4 [2]

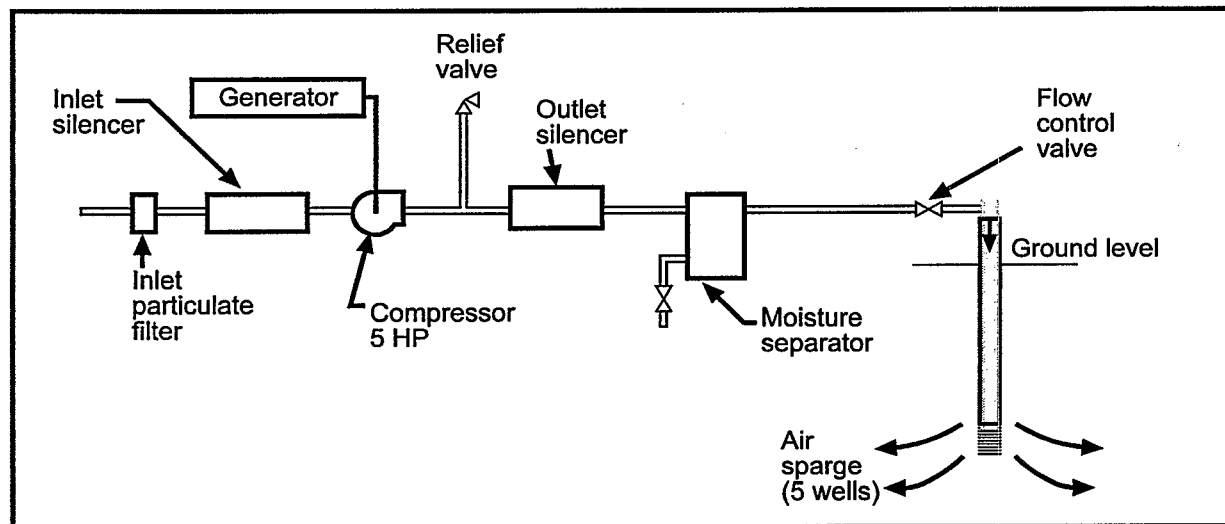


Figure 7: AS Schematic for Landfill 4 [2]



**Operation**

- Initial startup of the full-scale system was conducted in three phases. A detailed discussion of the startup activities is included in the Treatment Performance Data section of this report. The operating parameters affecting treatment cost or performance are presented below.

**OPERATING PARAMETERS AFFECTING TREATMENT COST OR PERFORMANCE [2]**

Operating Parameter	Value and Units
<b>Soil Vapor Extraction System</b>	
Air flow rate	440 - 1290 cfm
Operating vacuum	5-inches mercury vacuum at blower inlet
Operating time	Continuous
Temperature	85 - 155°F
<b>Air Sparging System</b>	
Air flow rate	60 - 210 cfm
Operating pressure	7 pounds per square inch (psi) (design value)
Operating time	Cyclical

**TREATMENT SYSTEM PERFORMANCE****PERFORMANCE OBJECTIVES [4, 5, 9, 14, 15]**

- The ROD specified four objectives for the remedy: to prevent exposure to contaminated groundwater, to restore the contaminated groundwater to its beneficial use (drinking water), to minimize movement of contaminants from soil to groundwater, and to prevent exposure to the contents of the landfill.
- No soil cleanup levels were identified in the available reference material.
- The cleanup levels established for groundwater in the upper aquifer beneath the site were:  
TCE - 5 ug/L - MCL from the Federal Safe Drinking Water Act  
VC - 1 ug/L - the Washington State Model Toxics Control Act Method B
- Monitoring of Mn was required along the western border of South and Northwest LF4 to determine any changes in concentration.



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- A site-specific air emission threshold limit of 2.5 parts per million volume (ppmv) TCE was calculated by USACE using Screen Model 3 and the PSAPCA acceptable source impact levels. The air stream between the first and second carbon canisters are monitored every other week using a photoionization detector (PID). The PID breakthrough action level is 1.5 ppmv total VOCs. The breakthrough action level is used to determine when the first carbon bed needs to be removed from service.
- To assess the overall performance of the system, performance monitoring is required throughout the operation of the system. The specific requirements are detailed in the Compliance Monitoring Plan [5] and include contaminant reduction monitoring to evaluate progress towards achieving the cleanup goals, contaminant migration monitoring to confirm that the plume is being contained, and contaminant treatment monitoring for air emissions.

#### **TREATMENT PERFORMANCE DATA AND PERFORMANCE DATA ASSESSMENT**

Treatment performance data were available for the pilot study, the initial startup activities (Phases 1, 2, and 3) for the full-scale system, and the ongoing full-scale system (through October 31, 1997).

##### **Treatment Plan**

- The treatment plan for this project include several stages: 1) installation and operation of a pilot-scale study of the AS/SVE system to assess the potential of the system to meet the required cleanup goals within a time frame of 2-5 years; 2) detailed design and installation of the full-scale AS/SVE system followed by a three-phase startup of the system; and 3) full-scale system operation and maintenance activities.
- The pilot test was conducted from December 5 - 15, 1994. Startup activities were conducted in three phases from October 1, 1996 - January 29, 1997. Full-scale operations are ongoing and performance data is available for operations through October 31, 1997.

##### **Performance Data Assessment - Pilot Study [7, 8]**

- The pilot study included pilot test design, well installation, cover installation, and running the pilot system. The pilot test was located in the area near well MW8A, where the highest level of TCE in groundwater had been reported. The wells were installed and developed from June to August 1994; the cover was installed from October 3 to December 4, 1994. The actual pilot test was run from December 5 to December 9, 1994 as a series of five 8-hour tests and from December 11 to December 15, 1994 as one 72-hour continuous test.
- The first two 8-hour tests used the SVE system only. For the remaining three 8-hour tests, the SVE system was operated for the first two hours, then the AS system was turned on and operated with the SVE system for the remaining 6 hours. For the 72-hour continuous test, the SVE system was run alone for the first 24 hours; the AS and SVE systems were then operated together for the remaining 48 hours. During the AS process, air was injected through the air sparging well into the aquifer using an above ground blower to create an "in-situ" air stripping effect. Air extracted from the SVE wells was sent through granular activated carbon units prior to discharge to the atmosphere.



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## Soil Gas

- Soil gas samples were collected on an hourly basis from well SVE-4 and analyzed for TCE, VC, DCE, and PCE by an on-site mobile laboratory. TCE was the only target analyte detected in the soil gas samples in the field.
- The results for TCE are presented in Table 5 for each of the 8-hour tests and in Table 6 for the 72-hour test.
- As shown in Table 5, during the first two 8-hour runs (SVE only), TCE concentrations decreased from 185 ppb to 145 ppb during the first run and from 160 ppb to 125 ppb during the second run. During the three remaining runs, the system was operated as SVE only for the first two hours of operation followed by 6 hours of operation with AS. The results of samples collected during the SVE only period (hours 0-2) showed TCE concentrations decreased from initial concentrations in the 150 ppb to 170 ppb range to concentrations in the 120 ppb to 150 ppb range after two hours of operation. TCE concentrations following AS startup (hours 2-6) showed decreases for all three days - about 16% (day 3), 8% (day 4) and 40% (day 5). The final TCE concentration achieved on day 5 was 90 ppb.
- As shown in Table 6, the results of the first 24-hours of the 72-hour test (SVE only) TCE concentrations decreased from 235 ppb to 120 ppb after the first hour of operation, then to 110 ppb after 24 hours of operation. At the startup of the AS system (hour 25), TCE concentrations initially decreased to 25 ppb, then increased to 94 ppb. (In Chemical Data Report #1, this initial decrease in TCE concentration was attributed to dilution of soil gas in the vadose zone from the addition of atmospheric air by the AS well.) After 72 hours of operation, TCE concentrations had decreased to 56 ppb.

**Table 5. TCE Concentrations (ppbv) in Soil Gas, LF4, 8 Hour Tests (Pilot Study) [7]  
December 5 & 6 SVE only, December 7 - 9 combined AS/SVE with SVE-Only First 2 Hours**

HR	5-Dec	6-Dec	7-Dec	8-Dec	9-Dec
0	--	95	150	170	170
1	--	160	140	135	150
1.5	185	--	--	--	--
2	--	160	120	120	150
3	180	150	150	120	110
3.5	190	--	--	--	--
4	--	140	140	120	110
4.5	190	--	--	--	--
5	--	140	125	110	110
5.5	140	--	--	--	--
6	--	125	110	100	95
6.5	150	--	--	--	--
7	--	--	100	95	100
7.8	145	--	--	--	--
8	--	--	--	110	90

-- - No sample analyzed



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**Table 6. TCE Concentrations (ppbv) Soil Gas, LF4, 72 Hour Test (Pilot Study) [7]**  
**0-24 hours SVE only, 24-72 hours combined AS/SVE**

HR	TCE
0	235
1	120
2	160
3	150
4	150
5	--
6	150
7	--
8	150
9	150
10	150
11	150
12	160
13	150
14	120
15	115
16	--
17	120
18	--
19	115
20	120
21	120
22	110
23	--
24	110

HR	TCE
25	25
26	94
27	--
28	3.5
29	--
30	22
31	--
32	39
33	9
34	29
35	57
36	52
37	12
38	--
39	18
40	64
41	--
42	51
43	44
44	--
45	--
46	--
47	--
48	--
49	--

HR	TCE
50	--
51	52
52	--
53	51
54	--
55	39
56	--
57	51
58	48
59	50
60	52
61	--
62	53
63	59
64	59
65	59
66	59
67	--
68	59
69	58
70	59
71	56
72	--
--	--
--	--

-- No sample analyzed



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## Groundwater

- Groundwater samples were collected from wells before and after each sparging event and analyzed for volatile organic compounds by method 8010. As discussed above, the sparging events took place on December 7, 8, and 9 (about 6 hours each in duration) and during the final 48 hours of the 72-hour continuous test (December 11-15). Other parameters measured included vacuum pressure for SVE, dissolved oxygen in the aquifer before, during and after air sparging and during SVE operation.
- TCE was the only volatile organic compound detected in the groundwater samples. Elevated TCE concentrations were found in wells DOS-1, DOS-2, and MW8, which were located closest to the sparge well. Table 7 presents the TCE concentrations detected in the three wells.
- As shown in Table 7, data from DOS-1, DOS-2 and MW8A show an overall decrease in TCE concentrations. For DOS-1, there was an overall decrease in TCE concentrations from about 330 ppb to 170 ppb and for DOS-2, from 220 ppb to 170 ppb. For MW8A, TCE concentrations decreased from 140 ppb to 23 ppb.
- The effect of sparging on TCE concentrations varied by well. For DOS-1 and DOS-2, TCE concentrations decreased after sparge events 2, 3, and 4 but remained unchanged after sparge event 1. For MW8A, TCE concentrations decreased after sparge events 2 and 4 but increased after sparge events 1 and 3. Possible reasons given in Chemical Data Report #1 for the observed increases in TCE concentrations in MW8A after sparging were fluctuations in the water level, which may have created a smear zone, or introduction of new source material caused when precipitation onto the contaminated soil infiltrated into the groundwater.

**Table 7: TCE Concentrations Detected in Wells DOS-1, DOS-2, and MW8A [7]**

Sample Date	DOS-1		DOS-2		MW8A	
	Time	TCE (ppb)	Time	TCE (ppb)	Time	TCE (ppb)
12/6	2030	30	1900	220	1830	140, 86
Sparge 1						
12/7	1700	330, 310	1830	220	1800	150
12/8	630	300	600	200	700	190
Sparge 2						
12/8	1700	280	1630	170	1800	140, 130
12/9	630	300	630	190, 190	700	120
Sparge 3						
12/9	170	280	1700	170	1800	140
12/11	830	300	830	190	930	110
Sparge 4						
12/15	830	240, 170	800	170	930	27, 23

- Two rounds of groundwater sampling were performed for Mn - before sparging and after sparging. The results are presented in Table 8. As shown in this table, Mn concentrations decreased after sparging in seven of 11 wells and increased in five of the 11 wells. The greatest increases in Mn



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concentrations were observed in wells MW10 (69 ppb to 440 ppb) and DOS-2 (290 ppb to 360 ppb).

- During the RI, elevated Mn levels were attributed to dissolution of geologic materials by landfill leachate in the area of LF4.

**Table 8: Mn Concentrations in Groundwater [7]**

Well	Pre-Sparge Mn (ppb)	Post-Sparge Mn (ppb)
ASW-1	17	12
MW8A	6.1	3.9
MW8B	11	ND
DOS-1	680	660
DOS-2	290	360
PNL-3	7.7	ND
MW3B	5.1	4.6
MW5	58	60
MW10	69	440
SW-MW-1	23	30
NW-MW-2	2700	2500

ND - Not detected

#### **Performance Data Assessment - Full-Scale System Startup Activities [1]**

- The startup activities for this system were conducted from October 1, 1996 to January 29, 1997 and included an initial SVE startup (Phase 1), initial sparging startup (Phase 2), and total system startup (Phase 3). In addition, two rounds of groundwater sampling were conducted during the startup activities.

#### **Phase 1 - Initial SVE Startup Activities:**

- Phase 1 was conducted from October 17 to November 17, 1996, and included six individual well tests and a combined system test to determine mass removal rates, site heterogeneity, proximity to contaminant sources, and optimal extraction rates. Vapor samples collected during this phase were analyzed by an on-site lab.



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- The original test plan as defined in the LF4 RAMP, called for each well to be operated at 100 scfm until stabilization had occurred. Stabilization was defined as "after 24 hours of SVE operation at the specified extraction flow rate have elapsed, and the percent difference between the current extracted gas TCE concentration and each of the prior three samples is less than 20 percent." After stabilization had occurred, the extraction rate was to be increased by 25 scfm. If after one hour the mass removal rate was higher, then the extraction rate was to again be increased by 25 scfm, with this "step-up" process continuing as long as the extraction rate increased (to a maximum of 150 scfm). A minimum shutdown period of 24-hours was scheduled between each well test to allow the system to return to equilibrium and contaminant concentrations to stabilize.
- Figures 8-19 summarize the analytical data collected during the initial startup activities. Figures 8-13 show the mass removal rate in mg/min for each of the 6 wells, while Figures 14-19 show the concentration in mg/ft<sup>3</sup> for each of these wells. In addition, these figures show the extraction rate used in each well at each point of the test.
- Mass removal and concentration data were measured at a sample point in the above ground equipment after moisture separation and prior to the activated carbon filter canister. Mass removal was calculated as the product of the concentration and extraction air flow rate.
- Well SVE-1 was operated according to the original plan, starting at 100 scfm. As shown in Figure 8, stabilization was achieved after 28 hours, and the extraction flow rate was increased to 125 scfm for 8 hours, during which time the mass removal rate increased from 22 to 41 mg/min. The extraction flow rate was then increased to 150 scfm for 36 hours, during which time the mass removal rate increased to 110 mg/min, and was reported to still be increasing at the end of the test. TCE concentration data for SVE-1 (Figure 14) shows a corresponding increase in concentration levels in the soil gas (from about 0.13 mg/ft<sup>3</sup> to over 0.70 mg/ft<sup>3</sup>) as the extraction flow rate increased.
- Based on the results of well SVE-1, the testing procedure was modified to allow for testing at higher extraction rates for the remaining wells. Wells SVE-2 to SVE-6 were tested at rates of up to 600 scfm.
- Wells SVE-2 to SVE-5, were operated at two extraction rates (starting at 100 scfm and increased to 600 scfm after about 1.5 hours of operation). As shown in Figures 9 through 12, the increase in extraction rate resulted in a sharp increase in the TCE mass removal rate, with all five wells achieving their maximum removal rates at 600 scfm. The maximum TCE mass removal rates achieved by each well were about 250 mg/min (SVE-2), 275 mg/min (SVE-3), 170 mg/min (SVE-4), and 380 mg/min (SVE-5). TCE concentrations (Figures 14 through 19) in the vapor samples from each well showed corresponding increases in concentrations as the extraction rate increased.
- Well SVE-6 was operated at 100, 150, 200, 300, 400, 500 and 600 scfm. As with wells SVE-2 to SVE-5, the maximum TCE mass removal rate and concentration were achieved at 600 scfm. As shown in Figures 13 and 19, the greatest increases were observed when the extraction rate was increased from 200 to 300 scfm, from 300 to 400 scfm and from 500 to 600 scfm.
- While the data for the SVE wells showed that operation at 600 scfm resulted in higher TCE mass removal rates and concentrations in the vapor flow operation than at lower extraction rates, Chemical Data Report #1 concluded that the data did not provide a further indication of the optimal extraction rate for an individual well. Therefore, the "optimal" extraction rate" for the SVE wells at LF4 was determined to be in the range of 150 to 600 scfm.



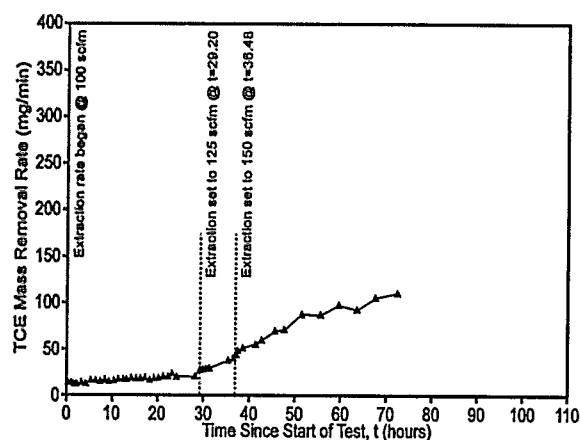


Figure 8: Well SVE-1 TCE Mass Removal Rate vs. Time [1]

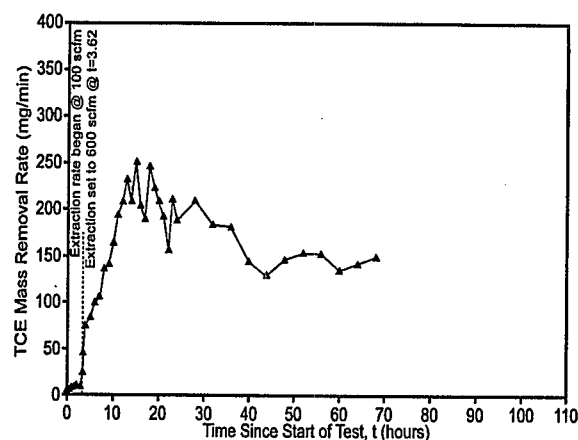


Figure 9: Well SVE-2 TCE Mass Removal Rate vs. Time [1]

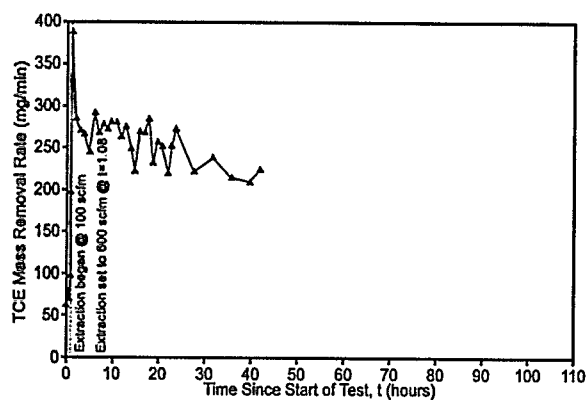


Figure 10: Well SVE-3 TCE Mass Removal Rate vs. Time

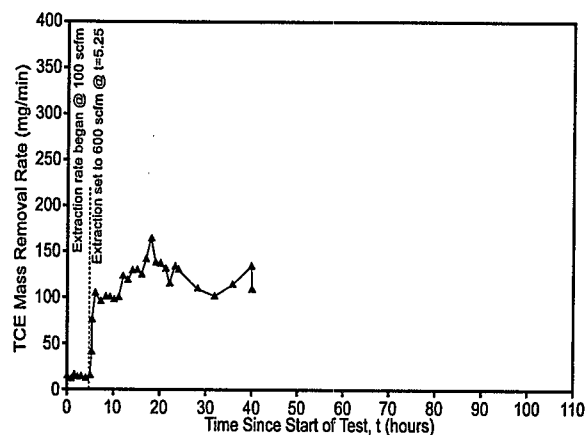


Figure 11: Well SVE-4 TCE Mass Removal Rate vs. Time [1]

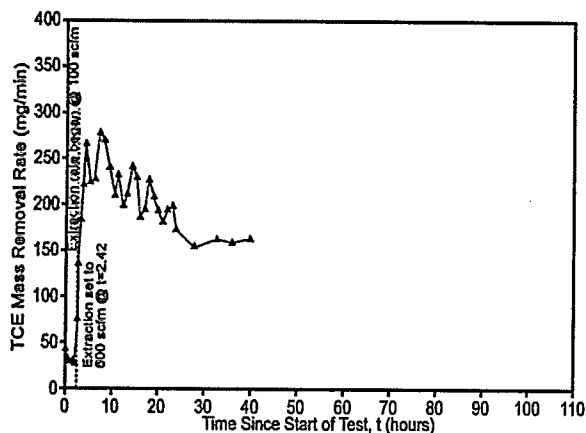


Figure 12: Well SVE-5 TCE Mass Removal Rate vs. Time [1]

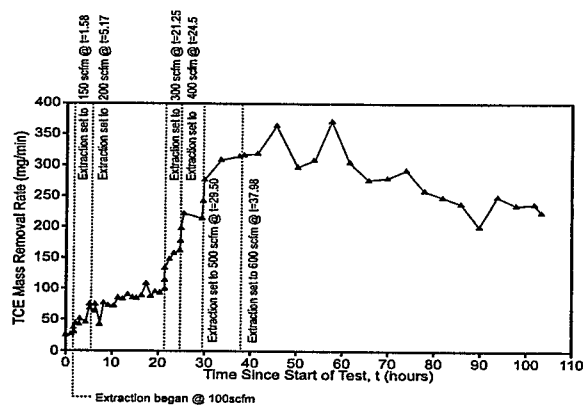


Figure 13: Well SVE-6 TCE Mass Removal Rate vs. Time [1]



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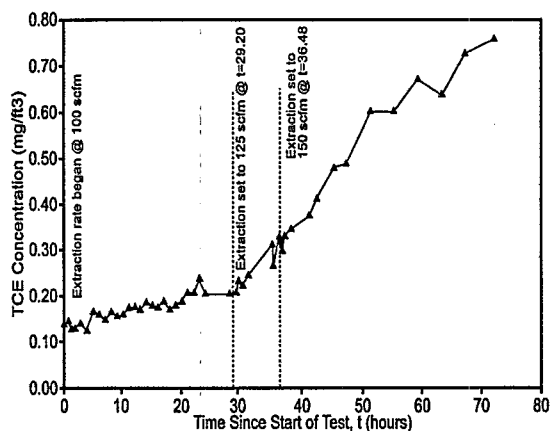


Figure 14: Well SVE-1 TCE Concentration vs. Time [1]

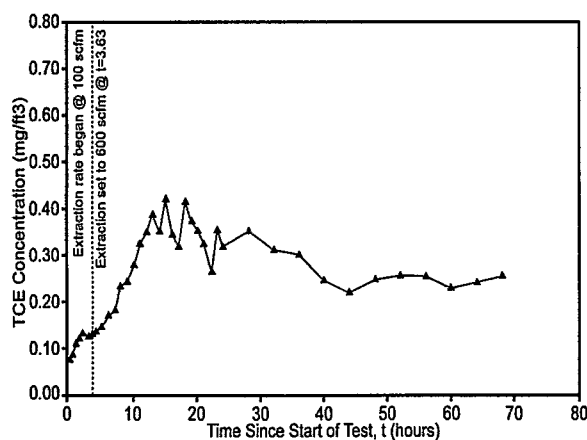


Figure 15: Well SVE-2 TCE Concentration vs. Time [1]

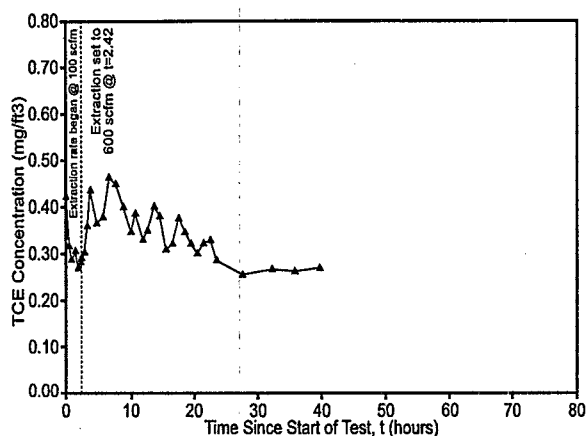


Figure 16: Well SVE-3 TCE Concentration vs. Time [1]

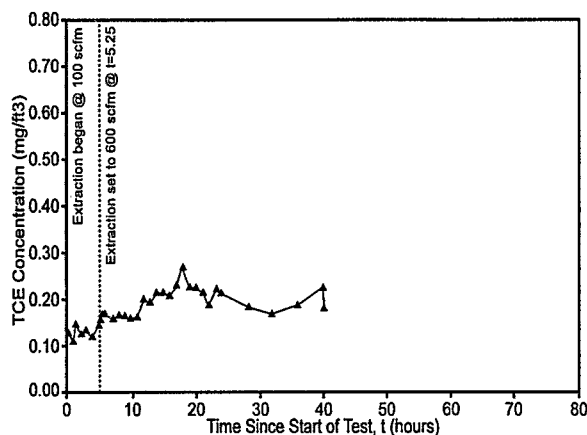


Figure 17: Well SVE-4 TCE Concentration vs. Time [1]

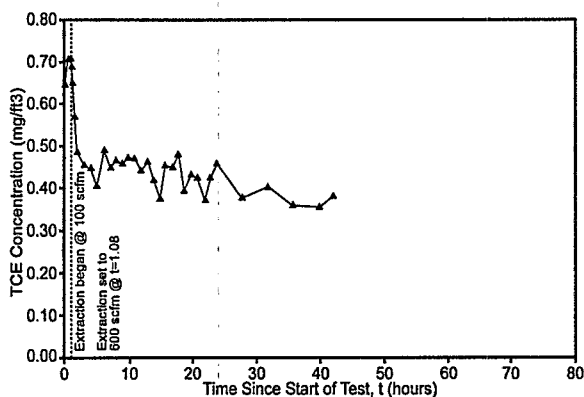


Figure 18: Well SVE-5 TCE Concentration vs. Time [1]

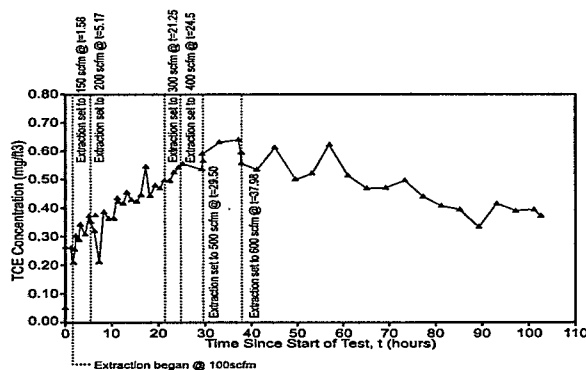


Figure 19: Well SVE-6 TCE Concentration vs. Time [1]



- The full system was tested during an initial 48-hour period with SVE only, to allow stabilization of TCE removal, followed by 48 hours where the air sparge wells were operated individually at varying flow rates of 50, 75, and 100 scfm. Data on the full system test conducted during Phase 1 are presented in Figures 20 and 21. During the SVE-only period of operation, the TCE mass removal rate and TCE concentration remained relatively stable. The TCE mass removal rate remained approximately the same (225 mg/min) when AS-3 and AS-4 were operated at 50 scfm and 100 scfm, but decreased (to 160 mg/min) when these wells were operated at 75 scfm each. For wells AS-2 and AS-5 increasing the air flow rate resulted in a decrease in the TCE mass removal rate and concentration. Operation of the full-system with all wells adjusted to 90 scfm, then decreased to 75 scfm, resulted in a decrease in TCE mass removal rates from approximately 100 mg/min to 50 mg/min.
- For the Phase 1 full-scale system, there was an overall decrease in TCE mass removal rates and concentration. As discussed under Phase 2 and 3, this overall TCE concentration decrease may have masked the changes from the operation of the AS wells.

### Phases 2 and 3 - Initial Sparging and Full System Startup:

- As described above, initial testing of the AS wells at varying air flow rates was performed as part of the full system test under Phase 1. During Phase 2 and 3, additional testing of the AS wells and the full system was performed under varying operating conditions in order to determine the optimal system settings for full scale operation. Phase 2 activities were conducted from November 18 to November 21, 1996 and Phase 3 activities were conducted from November 21, 1996 to January 29, 1997. Because Phases 2 and 3 activities are interrelated, the performance of the system during these startup activities is discussed together.
- Phase 2 startup activities included operating the individual sparge wells to collect data on injection pressure and flow rate. Each sparge well was tested at 50, 75, and 100 scfm to determine breakthrough, defined as when the system air pressure was sufficient to overcome the combination of the static water head in the sparge well and the resistance of the soil formation in the immediate area of the sparge well). During the initial sparging activities, all SVE wells were operated at an extraction rate of 200 scfm (1200 scfm for the system). The results of the breakthrough pressure testing are presented in Table 9. These data were used in calculating air flow rates for the AS wells that would be used in system optimization.



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Table 9: Initial Sparge Testing Data [1]

Sparge well	Breakthrough Pressure (psi)	50 scfm [0.70 in of H <sub>2</sub> O] psi	75 scfm [1.45 in of H <sub>2</sub> O] psi	100 scfm [2.60 in of H <sub>2</sub> O] psi
ASW-1	7.0	7.75	9.5	9.5
ASW-2	7.75	8.5	9.0	10.0
ASW-3	6.4	6.5	6.6	6.6
ASW-4	7.0	7.5	8.25	8.25
ASW-5	8.25	8.25	8.5	8.5

- During the total system test, the system was operated under a number of settings, with adjustments made to determine the optimum system settings for maximum contaminant removal. The full system was operated using a combination of cycling of the sparge wells on and off and varying the extraction rates and extraction wells used. According to Chemical Data Report #1, when the line of sparge wells is perpendicular to the direction of the groundwater flow, as in the case of LF4, air injection can create air entrainment in the aquifer which can significantly lower the hydraulic conductivity, causing the groundwater to flow around, rather than through, the wells. By cycling the sparge wells on and off, this problem can be alleviated. When the sparge wells are off, water flows normally into the sparge area and is then treated when the wells are turned on.

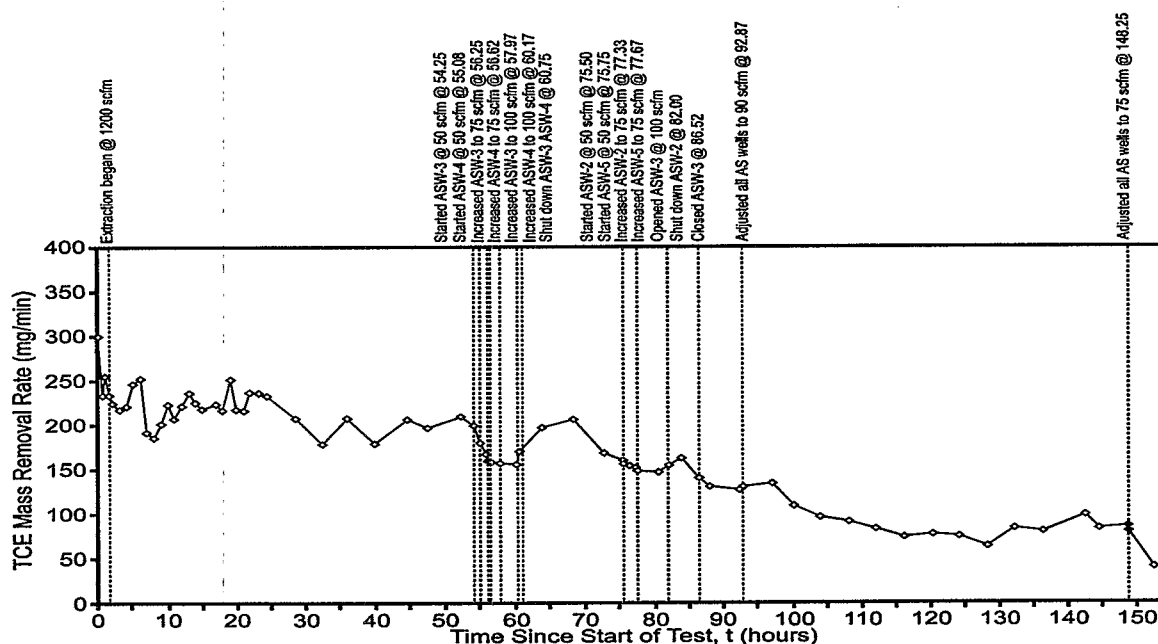
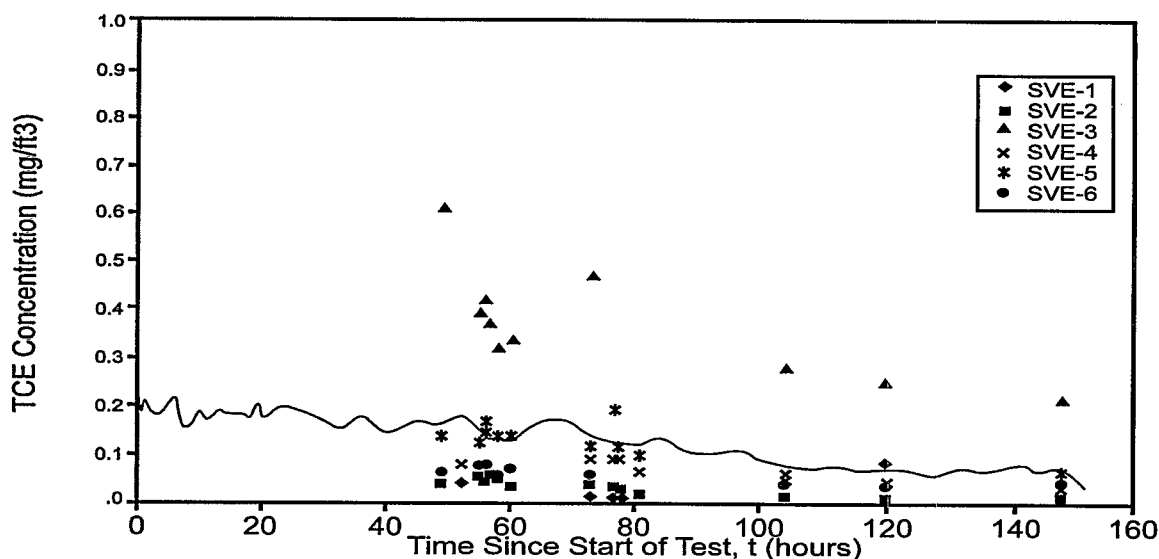


Figure 20: Full system (Phase 1) TCE Mass Removal Rate vs. Time [1]





**Figure 21: Full System (Phase 1) TCE Concentration vs. Time [1]**

- The system settings used during the full system test are presented in Table 10. Specific adjustments made to the system include:
  1. Equal usage of extraction wells (each well set at about 200 scfm) with injection flow rates and well usage varied to determine ideal injection well usage method. (21Nov96-1Dec96 & 25Jan97-29Jan97)
  2. Extraction concentrated on SVE-3 (hot spot identified in Phase 1) with injection flow rates and well usage varied to determine ideal injection well usage method for "hot spots." (2Dec96-21Dec96)
  3. Extraction concentrated primarily on individual well pairs to determine if an extraction rate of 450 to 600 scfm at a pair of wells would be more efficient than equal extraction of all six wells at 200scfm. Injection flow rates and well usage were varied to determine ideal injection well usage method. (21Dec96-22Jan97)
  4. Operation of passive injection wells to determine if usage of this type of well would accelerate contaminant removal in "dead zones" (areas where modeling performed by USACE indicated areas of stagnant or "dead" air). (23Nov96-17Dec96).
- Table 11 presents data on TCE mass removal rates and concentrations over time, and include data on the changes to the extraction flow rates and air flow rates of the full system. During the full system operation, TCE mass removal rates decreased from 110 mg/min to 42 mg/min and TCE concentrations decreased from 660 ppb to 217 ppb.
- Table 12 shows the airflow and TCE removal data from system startup activities, including volume of air injected and soil gas extracted, mass of TCE removed, and mass of TCE removed per volume of air extracted. This table shows those results individually by well for Phase 1, during the Phase 1 full-system test, during the test of Phase 2 and 3, and for the total of all startup activities. As shown in Table 12, the mass of TCE removed varied from 0.53 to 3.21 lbs for a well during Phase 1, with the Phase 1 full system test removing 2.73 lbs of TCE and the test of Phases 2 and 3 removing 14.92 lbs of TCE. A total of 25.87 lbs of TCE were removed during startup activities.



Table 10: System Settings Used During Phase 2 and 3 Startup [1]

	Nov. 21, 1996	Nov. 23, 1996	Nov. 27, 1996	Dec. 1, 1996	Dec. 9, 1996	Dec. 13, 1996	Dec. 17, 1996	Dec. 21, 1996	Jan. 6, 1997	Jan. 10, 1997	Jan. 14, 1997	Jan. 18, 1997	Jan. 24, 1997	Jan. 29, 1997
<b>Passive Injection Wells</b>														
PIW-1	Closed	Closed	Open	Open	Open	Open	Open	Closed	Closed	Closed	Closed	Closed	Closed	Closed
PIW-2	Closed	Closed	Open	Open	Open	Open	Open	Closed	Closed	Closed	Closed	Closed	Closed	Closed
PIW-3	Closed	Closed	Open	Open	Open	Open	Open	Closed	Closed	Closed	Closed	Closed	Closed	Closed
PIW-4	Closed	Closed	Open	Open	Closed	Closed	Open	Closed	Closed	Closed	Closed	Closed	Closed	Closed
<b>Extraction Wells</b>														
RA-SVE-1 Flow Rate (scfm)	200	210	200	200	400	400	Closed	Closed	Closed	Closed	Closed	Closed	Closed	210
RA-SVE-2 Flow Rate (scfm)	210	210	200	200	400	390	410	390	570	480	Closed	Closed	490	220
RA-SVE-3 Flow Rate (scfm)	190	210	200	190	400	390	410	420	Closed	150	600	580	120	210
RA-SVE-4 Flow Rate (scfm)	210	220	210	200	Closed	Closed	420	450	Closed	130	600	650	110	200
RA-SVE-5 Flow Rate (scfm)	230	220	210	220	Closed	Closed	Closed	Closed	630	510	Closed	Closed	510	230
RA-SVE-6 Flow Rate (scfm)	200	220	210	210	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	220
<b>Sparge Wells</b>														
ASW-1 Flow Rate (scfm)	80	80	80	Closed	Closed	Closed	100	Closed	Closed	50	110	Closed	Closed	Closed
ASW-2 Flow Rate (scfm)	60	30	70	Closed	Closed	Closed	Closed	Closed	Closed	60	Closed	Closed	Closed	Closed
ASW-3 Flow Rate (scfm)	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
ASW-4 Flow Rate (scfm)	70	30	50	Closed	Closed	90	90	Closed	Closed	50	Closed	Closed	Closed	Closed
ASW-5 Flow Rate (scfm)	Closed	Closed	Closed	Closed	Closed	90	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Mode	Equal extraction rates				Concentrated extraction				Well pairs					Equal extraction rates



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Table 11: Phase 2-3 Startup Results [1]

Activity Date	Leg A Extraction Flow Rate (cfm)	Leg B Extraction Flow Rate (cfm)	Total Sparge Flow Rate	TCE Concentration (ppbv)	TCE Mass Removal Rate Total (mg/min)	Total Cumulative Mass Extracted (mg)
18-Nov-96	560	540	225		110	90051
21-Nov-96	540	540	210	660	108	547755
23-Nov-96	560	590	240	546	95	813912
27-Nov-96	575	575	240	532	93	1371490
01-Dec-96	580	590	0	675	119	2014791
09-Dec-96	550	540	0	480	79	2955393
13-Dec-96	600	600	180	450	82	3406284
17-Dec-96	620	620	190	390	73	3827419
21-Dec-96	600	570	0	450	80	4311638
26-Dec-96	675	675	290	450	2	4947817
03-Jan-97	0	0	0	0.0	0	4947817
06-Jan-97	590	580	200	460	81	5274519
10-Jan-97	600	630	160	281	52	5585439
14-Jan-97	610	610	110	266	49	5874816
18-Jan-97	630	600	0	270	50	6153621
24-Jan-97	620	580	0	235	43	6524735
26-Jan-97	600	600	0	226	41	6607192
27-Jan-97	690	0	0	226	24	6658732
29-Jan-97	645	645	0	217	42	6779623



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Table 12: Airflow and TCE Removal Summary for System Startup Activities [7]

Test Period	Total Air Injected (millions of ft3)	Total Soil Gas Extracted (millions of ft3)	Total Mass of TCE Removed (lbs)	Mass of TCE removed per million cubic feet of air extracted (lbs)
Phase 1 - Individual Wells				
SVE-1	0	0.56	0.53	0.95
SVE-6	0	3.03	3.21	1.06
SVE-2	0	2.38	1.43	0.60
SVE-5	0	1.54	1.40	0.91
SVE-3	0	1.51	1.06	0.71
SVE-4	0	1.3	0.58	0.43
Phase 1 - Full System Test	1.22	10.30	2.73	0.26
Phases 2&3 Test	9.69	109.18	14.92	0.14
Startup Total	10.91	129.86	25.87	0.20

- While VC was not measured during startup activities, Chemical Data Report #1 estimated that a maximum of 0.093 lbs of VC were removed from the subsurface during startup activities. This estimate was based on one sample collected from the location where VC levels had been detected. Because this estimate did not account for areas where VC was not detected, it was concluded that the actual quantity of VC removed is likely to be significantly less than the estimate.
- The effect of sparging on the system was reported in Chemical Data Report #1 to be difficult to quantify because of the overall TCE concentration decrease. While TCE concentrations decreased during sparging events, they also continued to decrease when the sparging wells were not operational. For example, from November 21 to 27 when air sparging was conducted, TCE concentrations decreased from 660 ppb to 532 ppb. When the air sparging wells were turned off (December 1), TCE concentrations initially increased to 675 ppb. However, for the next sampling event (December 9), TCE concentrations had decreased to 480 ppb even though the air sparging wells remained closed.
- Sampling data from the period when the passive injection wells were operated (November 27 to December 17) showed TCE concentrations initially increasing from 532 ppb to 675 ppb, then decreasing to 390 ppb. However, the specific effect of the operation of these wells is not evident as the extraction flow rates and use of the AS wells were varied during this time period.



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- Because of the significant decreases in TCE concentrations during Phases 2 and 3, the optimal system settings were not determined. The results of the startup activities were used to establish the tentative system settings that were used for the second and third quarters of operation, during which time the operation of the system was continuously adjusted. These settings include operating SVE wells 1-6 between 210 and 150 scfm; cycling the sparging wells, and leaving the passive injection wells closed.

#### **Performance Data Assessment - Full-Scale System Operation [13]**

- The full-scale system operation began when the startup activities were completed on January 29, 1997, and is currently ongoing. Performance data through October 31, 1997 were included in Chemical Data Report #2, which was the most recent document used in preparation of this report.
- The system settings used during the full-scale system operation between February 6, 1997 and October 31, 1997, including SVE and air sparging system flow rates, TCE concentrations in the extracted soil gas, and TCE mass removal rates are summarized in Appendix A, Table A-1.
- In general, the SVE system was operated at between 0 and 1,290 cfm extracted, and the air sparging system was operated at between 0 and 210 cfm injected. The passive air injection wells remained closed between February 6, 1997 and July 9, 1997, after which they were opened. It was determined that the passive injection wells should remain open unless a detrimental effect could be demonstrated.
- The concentration of TCE in the soil gas extracted by the SVE system generally decreased from 210 parts per billion by volume (ppbv) to 140 ppbv during the period of February 6, 1997 through July 18, 1997. The extracted soil gas concentration then increased to a maximum of 640 ppbv during the period of July 31, 1997 through October 31, 1997. This increase generally corresponds to the opening of the passive injection wells after July 9, 1997, suggesting that the use of the passive injection wells enhanced the system's performance.

#### **Groundwater Sampling:**

- Seven rounds of groundwater sampling were conducted (two before the remediation system was installed and five after). The first round of sampling was performed during March 1992 and the last round for which data is available was performed in October 1997.
- TCE was the only contaminant in groundwater consistently identified above the cleanup levels established for the site. In addition, monitoring for Mn was required. The average concentrations of TCE and Mn measured in Contaminant Reduction monitoring wells and Migration Monitoring wells during the seven groundwater monitoring rounds are summarized in Table 13.



**Table 13: TCE and Mn Groundwater Results [13]**

Date	Average TCE Concentration ( $\mu\text{g/L}$ )		Average Total Mn Concentration ( $\mu\text{g/L}$ )	
	CRM <sup>1</sup>	MM <sup>2</sup>	CRM <sup>1</sup>	MM <sup>2</sup>
March 92	79.0	4.3	11,000	488.0
June 92	37.0	6.6	1,400	361.2
October 96 (after remediation system was installed)	69.7	12.0	4.2	89.0
January 97	13.9	7.0	4.0	172.0
April 97	10.7	4.5	3.5	95.5
July 97	14.5	3.8	2.0	51.0
October 97	6.4	4.2	8.0	40.0

**Notes:**<sup>1</sup> Average concentration from Contaminant Reduction Monitoring wells<sup>2</sup> Average concentration from Migration Monitoring wells

- The average TCE concentration in the Contaminant Reduction Monitoring wells has decreased from 79 to 6.4  $\mu\text{g/L}$  from March 1992 to October 1997, while the average TCE concentration in the Migration Monitoring wells has showed no consistent trend (average concentrations have ranged from 3.78 to 12.03  $\mu\text{g/L}$ ). TCE concentrations in both areas were still above the site cleanup level of 5  $\mu\text{g/L}$  in October 1997.
- The average total Mn concentration in the Contaminant Reduction Monitoring wells has decreased from a high of 11,000  $\mu\text{g/L}$  in March 1992 to 8.0  $\mu\text{g/L}$  in October 1997, while the average Mn concentration in the Migration Monitoring wells has generally decreased from 488.0 to 40.0  $\mu\text{g/L}$ .
- Vinyl chloride, the other contaminant with a cleanup level for the site, was only detected above method detection limits on one occasion and was never detected above site cleanup levels.

**Air Emissions Sampling:**

- Based upon the effluent sampling by the emissions monitoring system, the PSAPCA emission action levels were not exceeded during the SVE system operation.

**PERFORMANCE DATA QUALITY (6, 13)**

- According to the technical memorandum on the results of the pilot study [7], the required QA/QC samples were collected. Field duplicates, field blanks, rinseate blanks, and travel blanks were required in the final management plan for the LF4 pilot study [8] for QA/QC of the field study sampling program. Method blanks, reagent blanks, matrix spike samples, matrix spike duplicates, duplicates, and laboratory control samples were required for laboratory QA/QC. No exceptions to the QA/QC procedures were noted in the available reference materials.



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- The data quality for the startup activities is summarized in Table 14. With the exception of dissolved oxygen, no significant data quality problems were identified. The dissolved oxygen data were determined to be unacceptable as a result of significant fluctuations measured from the sensors.

Table 14: Summary of Data Quality for Startup Activities [1]

Analyte/Parameter	Technology	EPA Method	Comments
TCE, VC, DCE and PCE (Air emissions)	Mobile Laboratory and Photoionization Detector (PID)	8021	Method used to calculate mass removal rates. No significant data quality problems identified.
Volatile Organic Compounds (Air emissions)	Laboratory and Summa™ Canisters	TO-14	Method used to quantify concentrations of organic constituents in air samples; these concentrations were used to calculate mass removal rates. For air emissions, method TO-14 was used for confirmation of the primary measurement system (portable PID). Data are acceptable for computing mass removal rates.
Volatile Organic Compounds (Water)	Laboratory GC/MS	8260	Data used to provide water quality results as per the ROD. No significant data quality problems identified.
Dissolved and Total Manganese (Water)	Laboratory GC/MS	6010	Data used to provide water quality results as per the ROD. No significant data quality problems identified.
Dissolved Oxygen	Dissolved Oxygen Sensors	N/A	All data was rejected as a result of significant fluctuations measured from both sensors.

- According to the contractor, there were no significant data quality problems identified during the Full-Scale System Operation.



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## TREATMENT SYSTEM COST

### PROCUREMENT PROCESS

- Limited information on the procurement process for the pilot study is provided in the available references. The USACE prepared a government cost estimate [10] and requested bids in August 1994.
- For the full-scale system, the USACE issued a Basic Ordering Agreement to GSA for remediation of LF4 at Ft. Lewis, under contract number DACA67-95-G0001, Task Order No. 28. The USACE negotiated the contract in May 1996.

### TREATMENT SYSTEM COST

#### **Pilot Study [10]**

- The government estimate for the cost for the AS/SVE pilot system was \$241,193. A cost breakdown is shown below.

Mobilization and Preparatory Work	5,547
Site Work	222,528
Access Road	13,118
Total	\$241,193

#### **Full-scale System [11]**

- The original negotiated costs for the LF4 remediation included \$206,954 for carbon replacement and \$189,652 for air emissions sampling to determine compliance with PSAPCA requirements. According to the USACE [12], the concentrations of contaminants in air emissions from the system were subsequently determined to be below the allowable air emissions standards. USACE negotiated with PSAPCA to allow USACE to eliminate the requirement to change out the carbon units during the life of the remediation system and to use the T014 GC/MS air analysis method unless screening with the PID showed elevated VOC levels. According to USACE, the costs for carbon replacement should be deleted from the contract costs. However, the money associated with a decrease in air compliance monitoring will be used to increase the amount of system performance testing performed under the contract. The total revised negotiated cost is \$1,710,303.



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- The revised negotiated costs for the LF4 remediation are broken into cost elements as follows.

Activity	Negotiated Price (\$)
Before Treatment Activities (includes site preparation, mobilization, obtaining permits, project meetings and sampling to determine compliance with air emissions).	766,136
Treatment Activities	
Carbon replacement	0*
Monitoring	130,024
Operate and maintain system for 33 months	814,143
Subtotal to date	1,710,303
Options **	
Operate system for 1 additional year	370,451
Operate system for 6 months	195,451

## Notes:

\*Only a portion of the negotiated cost for carbon replacement of \$206,954 will be spent to cover the analysis and disposal of the spent carbon at the end of the site remediation.

\*\*Options were included in negotiations on project costs. At the time of this report, USACE had not exercised these options; therefore, they are not included in the total treatment cost to date.

- Because this application is ongoing and no estimate of the amount of material treated has been made, no unit cost has been calculated.

## REGULATORY/INSTITUTIONAL ISSUES

- The cleanup of LF4 is being performed in accordance with a Federal Facilities Agreement (FFA) between the Department of the Army, EPA, and the Washington Department of Ecology (Ecology) and the ROD signed October 15, 1993. Under the FFA, Ft. Lewis, assisted by the USACE, is responsible for the LF4 cleanup; EPA and Ecology are the responsible regulatory agencies and provide oversight as needed. The Remedial Action Contractor was selected by USACE.

## OBSERVATIONS AND LESSONS LEARNED

### COST OBSERVATIONS AND LESSONS LEARNED

- The total cost for the pilot study of the AS/SVE system at LF4 was \$241,000.



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- Subsequent to original negotiations, the contaminant concentrations in system air emissions were determined to be below the allowable air emission standards, and PSAPCA agreed to allow USACE to eliminate the need to change the carbon units from the system and to reduce air compliance monitoring requirements. USACE is planning to reallocate money from any savings on air compliance monitoring to increase the system performance air testing. However, several modifications reduced the project costs. The revised costs for this application are \$1,710,303. Because this application is ongoing, the amount of material treated by the system is not known at this time. Therefore, unit costs were not calculated at this time.

## **OTHER OBSERVATIONS AND LESSONS LEARNED**

### **Pilot Study**

- The results of the pilot-scale AS/SVE test reduced TCE concentrations in the soil gas at LF4. During the tests of the pilot system in SVE-only mode, TCE concentrations were reduced from initial concentrations of 160 ppb to 190 ppb to final concentrations of 125 ppb to 145 ppb during the 8-hour tests and from 235 ppb to 110 ppb during the 72-hour test. The addition of AS to the system reduced TCE concentrations in the soil gas from initial concentrations of 120 ppb to 160 ppb to final concentrations of 90 to 110 ppb during the 8-hour tests and from 110 ppb to 56 ppb during the 72-hour test.
- During the pilot-scale tests, AS/SVE reduced TCE concentrations in groundwater. At the three wells located near suspected hot spots of contamination, TCE concentrations were reduced from 310 ppb to 170 ppb (DOS-1), from 220 ppb to 170 ppb (DOS-2), and from 140 ppb to 23 ppb (MW8A). However, the levels were above the cleanup goal of 5 ppb for TCE.
- VC was not detected in the groundwater samples during the pilot test.
- The results of Mn sampling before and after sparging indicated that Mn levels decreased in six of the 11 wells samples, but increased in five of the wells.

The following observations were made in the technical memorandum [7] summarizing the results of the pilot study.

- With respect to optimal air extraction rate, an extraction rate of 110 cfm is likely to capture all volatilized contaminants within about 200 feet of each extraction well.
- The radius of influence of an air injector well is about 20-30 feet.
- A pressure of approximately 8 psi was required to overcome resistance in the injection well. However, at injection pressures above 8 psi, air bubbles would be more likely to occur. At 8 psi, the air injection rate into the aquifer was about 45 cfm. The 45 cfm (8 psi pressure) was determined to be the optimal flow rate, reflecting site and conditions of injections 12 feet below static water level. The vendor noted that changes in depth of the injection well will affect the injection pressure and radius of influence.
- The major problem encountered during the pilot test was that the SVE vacuum pump did not produce a vacuum sufficient to be detected by the automated sensors. Because of schedule



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constraints, a larger blower could not be obtained. However, according to the vendor, adequate data was obtained from the pilot test to design the full-scale system.

- While overall TCE concentrations decreased in the groundwater, there were several instances when TCE concentrations increased during operation. These increases may be attributed to the new source material (from contaminated soil) infiltrating into the groundwater.

### Startup Activities for Full-Scale System

- The startup activities for the full-scale system were conducted in three phases to provide data for use in optimizing full-scale operations. Phase 1 was designed to collect data on the optimal extraction flow rates for the SVE wells; Phase 2 focused on optimizing the air flow rates for the AS system; and Phase 3 included a number of adjustments to the entire system to determine the optimum system settings for maximum contaminant removal.
- During Phase 1, the first well was tested according to the testing procedures in the LF4 RAMP, which specified a maximum extraction flow rate of 150 scfm. During testing, a five-fold increase in TCE mass removal rate was observed in well SVE-1 when the extraction flow rate was increased from 125 to 150 scfm. Based on these results, the testing procedure was modified to allow wells to be operated at extraction flow rates up to 600 scfm.
- Wells SVE-2 to SVE-6 were operated at the increased extraction flow rates. All five well achieved their highest TCE mass removal rates and highest TCE concentrations in the vapor stream at 600 scfm. However, only well SVE-6 was tested at more than two extraction rates. These data did not provide any additional indication of the optimal extraction flow rates for the individual SVE wells. Therefore, the optimal extraction flow rate was established as a range of between 150 and 600 scfm.
- The total system test performed during Phase 1 included operating all six SVE wells at 200 scfm (1200 scfm for the system) and testing of individual AS wells at varying air flow rates. The addition of the AS wells to the system had little impact on TCE mass removal rates and concentrations. Increasing the air flow rates of an AS well from 50 to 75 scfm resulted in decreased TCE mass removal rates and concentrations for several wells; increasing the air flow rate to 100 scfm generally did not produce mass removal rates higher than that achieved at 50 scfm. However, during the total system test, there was an overall decrease in TCE mass removal rates and concentrations from the start of the test to the end point of the test.
- While TCE concentrations in the groundwater or soil gas were not measured during Phase 1, the results of Phase 2/3 operations (see below) suggest that TCE concentrations at LF4 were trending downward, and therefore, the effects of the operational changes to the system were masked.
- During Phases 2 and 3, a number of adjustments were made to the system including varying injection air flow rates, concentrating extraction in hot spot areas, and concentrating extraction on pairs of wells. Data collected during the system adjustments did not show distinct differences on system operation as a results of the adjustments. During this testing, TCE concentrations in the soil gas were measured and were shown to be decreasing during the period of the testing. In Chemical Data Report #1, the apparent downward trend in TCE concentrations at LF4 were



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reported to have masked the effects of operational changes made to the system. As a result, the optimal system settings could not be determined during the Phase 2/3 startup activities.

- The results of Phase 2 and 3 activities were used to establish tentative system settings which included operating SVE wells between 150 and 210 scfm; cycling air sparging wells, and leaving the passive injection wells closed.
- The results of the two rounds of groundwater sampling showed a decrease in TCE concentrations in most wells between October 1996 and January 1997; however, TCE concentrations remain above the cleanup goal of 5 ppb.

### **Full-Scale System Operation**

The following observations about the system operation were made in the Chemical Data Report #2.

- The emphasis of vapor data collection in the future should shift to the individual extraction wells rather than the combined extracted flow. In the fifth quarter of the full-scale operation, quarterly vapor sampling from the individual wells was initiated.
- Based on the testing of the untreated and the treated condensate removed by the remediation system, the potential life of the aqueous-phase carbon units was estimated to be in excess of ten million gallons.
- An SVE system flow rate of less than the design maximum flow rate may be more efficient at TCE removal than continuous operation at the maximum flow rate. The vendor recommended that the system be evaluated at moderate SVE system flow rates during the ongoing optimization of the system.
- The data supports the remedial investigation findings that numerous TCE hot spots exist at the site, and that the presence of TCE (and/or its degradation products) at one location may or may not be related to its presence at other locations at the site.
- Studying the natural degradation of the leachate at the site may provide a more widespread picture of the fate of contamination at the site than focusing on the natural attenuation of chlorinated hydrocarbons alone.
- Although the impact of the air sparging system on the degradation of TCE at the site had not been conclusively determined, it was recommended that the air sparging system continued to be operated until an impact/ benefit analysis for the system is completed.
- Because one of the Contaminant Reduction Monitoring wells upgradient of the remediation system had maintained an elevated concentration of TCE, a TCE hot spot may be located upgradient of this location beyond the influence of the remediation system. An additional SVE/air sparge well pair could be added to this area to increase the reach of the remediation system.
- The concentrations of contaminants downgradient from the treatment system may remain above the cleanup levels for the site, even if contaminant concentrations are reduced to below cleanup levels in the treatment system area.



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## ACKNOWLEDGMENTS

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Table A-1: System Settings and Results During Full-Scale Operation [13]

	Feb. 6, 1997	Feb. 13, 1997	Feb. 20, 1997	Feb. 27, 1997	Mar. 6, 1997	Mar. 14, 1997	Mar. 20, 1997	Mar. 27, 1997	Apr. 3, 1997	Apr. 11, 1997	Apr. 17, 1997	Apr. 24, 1997	Apr. 30, 1997	May 8, 1997
<b>Passive Injection Wells</b>														
	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
<b>Extraction Wells</b>														
RA-SVE-1 Flow Rate (scfm)	200	200	160	160	160	160	160	160	160	160	160	160	160	Closed
RA-SVE-2 Flow Rate (scfm)	220	230	230	160	160	160	160	160	160	160	160	160	160	Closed
RA-SVE-3 Flow Rate (scfm)	210	200	200	160	160	160	160	160	160	160	160	160	160	Closed
RA-SVE-4 Flow Rate (scfm)	200	210	210	160	160	160	160	160	160	160	160	160	160	Closed
RA-SVE-5 Flow Rate (scfm)	230	220	220	160	160	160	160	160	160	160	160	160	160	Closed
RA-SVE-6 Flow Rate (scfm)	220	210	210	160	160	160	160	180	180	180	180	180	180	Closed
<b>Injection Wells</b>														
ASW-1 Flow Rate (scfm)	Closed	Closed	Closed	30	30	Closed	Closed	30	30	30	30	30	30	Closed
ASW-2 Flow Rate (scfm)	Closed	Closed	Closed	30	Closed	30	30	Closed	Closed	Closed	Closed	Closed	Closed	Closed
ASW-3 Flow Rate (scfm)	Closed	Closed	Closed	Closed	30	Closed	Closed	30	30	30	30	30	30	Closed
ASW-4 Flow Rate (scfm)	Closed	Closed	Closed	Closed	Closed	30	30	Closed	Closed	Closed	Closed	Closed	Closed	Closed
ASW-5 Flow Rate (scfm)	Closed	Closed	Closed	Closed	30	30	30	30	30	30	30	30	30	Closed
<b>TCE Concentration</b>														
ppbv in System influent	210		180		200		200		200		190		200	0
mg/min TCE Removed	41		31		28		29		28		26		30	0.0



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Table A-1: System Settings and Results During Full-Scale Operation [13]

	May. 16, 1997	May. 23, 1997	May. 29, 1997	Jun. 5, 1997	Jun. 12, 1997	Jun. 20, 1997	Jun. 26, 1997	Jul. 3, 1997	Jul. 9, 1997	Jul. 18, 1997	Jul. 24, 1997	Jul. 31, 1997	Aug. 5, 1997	Aug. 15, 1997
<b>Passive Injection Wells</b>														
	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Open	Open	Open	Open	Open
<b>Extraction Wells</b>														
RA-SVE-1 Flow Rate (scfm)	160	170	170	160	160	180	170	Closed	Closed	80	120	130	130	160
RA-SVE-2 Flow Rate (scfm)	160	150	150	160	150	150	160	Closed	Closed	90	130	120	130	150
RA-SVE-3 Flow Rate (scfm)	170	160	160	160	160	170	160	Closed	Closed	70	110	110	130	250
RA-SVE-4 Flow Rate (scfm)	160	160	160	150	140	150	150	Closed	Closed	70	90	90	120	270
RA-SVE-5 Flow Rate (scfm)	160	160	160	180	160	170	180	Closed	Closed	70	90	90	120	180
RA-SVE-6 Flow Rate (scfm)	160	160	160	170	160	160	160	Closed	Closed	70	120	120	140	140
<b>Injection Wells</b>														
ASW-1 Flow Rate (scfm)	Closed	40	25	Closed	Closed	20	25	Closed	Closed	Closed	Closed	Closed	35	Closed
ASW-2 Flow Rate (scfm)	Closed	Closed	Closed	30	35	Closed	Closed	Closed	Closed	Closed	Closed	Closed	35	Closed
ASW-3 Flow Rate (scfm)	Closed	35	30	35	35	30	25	Closed	Closed	Closed	Closed	Closed	35	Closed
ASW-4 Flow Rate (scfm)	Closed	Closed	Closed	40	35	Closed	Closed	Closed	Closed	Closed	Closed	Closed	35	Closed
ASW-5 Flow Rate (scfm)	Closed	35	45	Closed	Closed	25	35	Closed	Closed	Closed	Closed	Closed	30	Closed
<b>TCE Concentration</b>														
ppbv in System influent	200		190		200		230	0	0	140		350		
mg/min TCE Removed	26.9		26.7		26.9	31.0	32.0	0.0	0.0	9.5	30.7	25.4	39.2	59.2



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Table A-1: System Settings and Results During Full-Scale Operation [13]

	Aug. 20, 1997	Aug. 29, 1997	Sep. 5, 1997	Sep. 10, 1997	Sep. 19, 1997	Sep. 28, 1997	Oct. 5, 1997	Oct. 10, 1997	Oct. 15, 1997	Oct. 20, 1997	Oct. 31, 1997
<b>Passive Injection Wells</b>											
	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open
<b>Extraction Wells</b>											
RA-SVE-1 Flow Rate (scfm)	160	140	140	150	250	160	250	240	160	150	150
RA-SVE-2 Flow Rate (scfm)	140	150	150	150	270	160	240	230	160	150	150
RA-SVE-3 Flow Rate (scfm)	260	150	160	160	270	150	250	240	270	270	270
RA-SVE-4 Flow Rate (scfm)	250	150	160	160	250	150	220	230	270	270	270
RA-SVE-5 Flow Rate (scfm)	160	150	160	150	Closed	Closed	Closed	Closed	170	160	160
RA-SVE-6 Flow Rate (scfm)	140	140	150	150	Closed	Closed	Closed	Closed	160	160	150
<b>Injection Wells</b>											
ASW-1 Flow Rate (scfm)	Closed	Closed	30	35	Closed	Closed	25	35	35	35	35
ASW-2 Flow Rate (scfm)	Closed	Closed	30	30	Closed	Closed	Closed	Closed	Closed	Closed	Closed
ASW-3 Flow Rate (scfm)	Closed	Closed	30	30	Closed	Closed	Closed	Closed	Closed	Closed	Closed
ASW-4 Flow Rate (scfm)	Closed	Closed	35	35	Closed	Closed	30	30	30	30	30
ASW-5 Flow Rate (scfm)	Closed	Closed	30	30	Closed	Closed	35	35	35	35	35
<b>TCE Concentration</b>											
ppbv in System influent	380	530		480		640		560		360	
mg/min TCE Removed	59.2	68.9	60.3	61.7	97.8	58.1	76.2	72.0	61.0	61.0	61.5



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**Soil Vapor Extraction at  
Fort Richardson Building 908 South,  
Anchorage, Alaska**

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**Soil Vapor Extraction at  
Fort Richardson Building 908 South,  
Anchorage, Alaska**

<b>Site Name:</b> Fort Richardson Building 908 South	<b>Contaminants:</b> Volatile - nonhalogenated: BTEX; volatile - halogenated: chlorobenzenes; and Petroleum Hydrocarbons: GRO and DRO. Maximum contaminant concentrations were DRO (17,000 mg/kg), total BTEX (2.28 mg/kg), and total chlorobenzenes (11.93 mg/kg).	<b>Period of Operation:</b> Status: Ongoing Report covers: 2/95 through 3/96 (closure planned for Spring of 1999)
<b>Location:</b> Anchorage, Alaska		<b>Cleanup Type:</b> Indefinite Delivery Type Remedial Action; voluntary cleanup
<b>Vendors:</b> Linder Construction 8220 Petersburg Street Anchorage, AK 99507 (907) 349-6222  AGRA Earth & Environmental 711 H Street, Suite 450 Anchorage, AK 99501 (907) 276-6480	<b>Technology:</b> Soil vapor extraction - Two SVE wells screened from 7 to 50 ft bgs were installed to a total depth of 55 ft bgs. - Soil gas extracted by a rotary blower was discharged to the ambient air after passing through a knockout drum and a particulate filter. - The system was operated at an air flow rate of 205-220 scfm, with a vacuum at the wells of 2-7.5 inches water.	<b>Cleanup Authority:</b> Alaska Department of Environmental Conservation UST Regulations (18 AAC 78)
<b>USACE Contact:</b> Deirdre M. Ginter USACE - Alaska District P.O. Box 898 Anchorage, AK 99506-0898 (907) 753-2805		<b>Regulatory Point of Contact:</b> Information not provided
<b>Waste Source:</b> Leaking underground storage tank	<b>Type/Quantity of Media Treated:</b> Soil - Estimated as 4,600 yd <sup>3</sup> . - Primarily consisted of gravel with either sand or clay. - Geology consists of surface deposits of glacial till, outwash, and silt.	
<b>Purpose/Significance of Application:</b> Application of SVE to treat gravelly-soil contaminated with diesel fuel.		
<b>Regulatory Requirements/Cleanup Goals:</b> - ADEC Matrix Level B cleanup levels were identified for this application. These levels are as follows: DRO (200 mg/kg), GRO (100 mg/kg), Benzene (0.5 mg/kg), Total BTEX (15 mg/kg). - No performance objectives were established for air emissions from the blower for the application.		

**Soil Vapor Extraction at  
Fort Richardson Building 908 South,  
Anchorage, Alaska (continued)**

**Results:**

- In a soil boring collected in March 1996 (after approximately one year of operation), the concentrations of DRO, GRO, benzene, and total BTEX were lower than their respective cleanup goals at all depths sampled.
- Analytical data from March 1995 to February 1996 indicate that DRO emissions from the blower were reduced by approximately 90 percent, and that GRO emissions were reduced by approximately 95 percent, over that time period.
- The system is planned for shutdown in the Spring of 1999, after evaluation of analytical results from confirmation samples.

**Cost:**

- The award cost for this application was \$305,053, with \$252,200 being directly attributed to construction and operation of the treatment system. This corresponds to \$55 per yd<sup>3</sup> of soil treated.
- Since the application has not yet been completed, information about actual costs were not available, and it was not known how the actual costs will compare with the award costs.

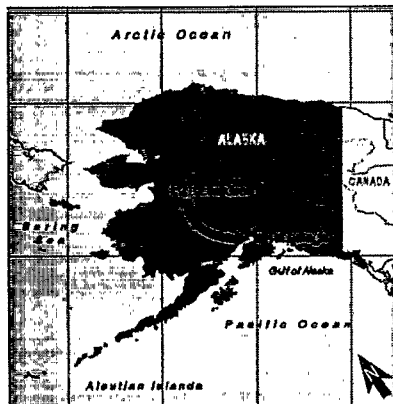
**Description:**

Ft. Richardson, constructed in 1950, is located adjacent to Elmendorf Air Force Base and is eight miles from Anchorage, Alaska. Four USTs were removed in 1989 and 1990. One of these tanks, a 1,000-gallon fuel oil tank removed in September 1989 from an area adjacent to Building 908 South, was found to be leaking. Contaminated soil was excavated to 26 ft bgs, but remained at the bottom of the excavation. ADEC allowed the backfilling of the excavation with the understanding that the contamination would be remediated at a later date.

In the initial remedy selection process, low-impact bioventing was selected over aggressive bioventing and natural attenuation with or without the installation of a protective cap. However, SVE was eventually selected for implementation at Ft. Richardson because it did not require the nutrient addition or monitoring of biological activity parameters that would have been needed for bioventing. The SVE system was installed in February 1995.

An interim soil boring was drilled between the two SVE wells in March 1996, and samples from the boring showed that cleanup goals were being met in that area. The system was operating as of July 1998 and is currently slated for shutdown in the Spring of 1999 if additional sampling confirms that cleanup goals have been met throughout the area.

## SITE INFORMATION



### IDENTIFYING INFORMATION

**Site Name:** Fort Richardson, Building 908 South  
(Ft. Richardson)  
**Location:** Anchorage, Alaska  
**Technology:** Soil Vapor Extraction (SVE)  
**Type of Action:** Indefinite Delivery Type Remedial Action (IDTRA)

### TECHNOLOGY APPLICATION (7, 8)

**Period of Operation:** February 1995 - ongoing (closure planned for Spring of 1999)  
**Quantity of Material Treated During Application:** Estimated as 4,600 cubic yards of soil

### BACKGROUND

**SIC Code:** 9711 (National Security)

**Waste Management Practice that Contributed to Contamination:** Leaking underground storage tank

#### **Site Background (4,5):**

- Ft. Richardson, constructed in 1950, is located adjacent to Elmendorf Air Force Base (AFB) and is eight miles from Anchorage, Alaska.
- At Ft. Richardson, four underground storage tanks (UST) were removed in 1989 and 1990. Those tanks included a 1,000-gallon unregulated heating oil tank (Tank No. 82) that was removed in September 1989 from an area adjacent to Building 908 South. Building 908 is referred to as the 1117th Signal Battalion Stockroom and is in an industrial area at Ft. Richardson. A railroad spur runs next to the building.
- Excavation of soil was to proceed until the site was free of contamination; however, no clean reading was obtained after the affected soil had been removed. The Alaska Department of Environmental Conservation (ADEC) allowed backfilling of the site, with the understanding that the Ft. Richardson Directorate of Public Works (DPW) would remediate the site at a later time.
- The excavation at Building 908 South was completed to a depth of 26 feet and was backfilled with clean soil.



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- At the time the excavation was performed, soil contaminated with petroleum products, primarily diesel range organics (DRO), were identified under the excavation; those soils were identified for remediation at a later date.
- At a meeting on June 13, 1990 attended by ADEC, DPW, and the U.S. Army Corps of Engineers (USACE) Alaska District, the representatives of ADEC recommended that further site characterization be conducted before proceeding with remediation activities. In August and September 1990, USACE performed the additional characterization activities, including collection of soil borings.
- This report is limited to a discussion of activities at Building 908 South at Ft. Richardson.

#### **Remedy Selection (4, 7):**

- Several remedies were considered for treating the petroleum-contaminated soil at Ft. Richardson, including low-impact bioventing, aggressive bioventing, natural attenuation with installation of a protective cap, and natural attenuation (natural attenuation was identified as the "baseline" alternative). Low-impact bioventing was selected for this application. The factors that supported the decision to use low-impact bioventing included project cost, duration of treatment, anticipated capability to meet cleanup goals, monitoring requirements, and management factors (such as the use of interagency agreements and considerations related to public acceptability).
- In the selection process, low-impact bioventing scored the highest of the four options, with a final score of 1.2. Natural attenuation scored 0, natural attenuation with a protective cap scored 0.78, and aggressive bioventing scored 0.88. The relatively high score for low-impact bioventing was in part a result of the relatively high score for management assigned to that option.
- Although low-impact bioventing was initially selected for this application, SVE was the remedy used. The SVE system did not require the nutrient injection or monitoring of biological activity parameters that would have been needed for bioventing.

#### **SITE LOGISTICS/CONTACTS**

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**Remediation Contractors (5, 6):**

Linder Construction served as prime contractor to USACE for this application and was responsible for installation of the treatment system and for mechanical operations of the monitoring system. AGRA Earth & Environmental (AEE), a subcontractor to Linder, was responsible for the monitoring of system effectiveness and for preparation of a conceptual design report and an interim remedial action report.

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**MATRIX AND CONTAMINANT DESCRIPTION**

**MATRIX IDENTIFICATION**

Soil (in situ)

**CONTAMINANT CHARACTERIZATION**

Semivolatiles (Nonhalogenated): DROs

Volatiles (Nonhalogenated): Gasoline range organics (GRO), benzene, toluene, ethylbenzene, and xylenes (BTEX)

Volatiles (Halogenated): Chlorobenzenes

**CONTAMINANT PROPERTIES**

- The terms DRO and GRO are indicator parameters that refer to a range of hydrocarbons and are defined by ADEC as follows:
  - DRO - hydrocarbons in the range of C<sub>10</sub> - C<sub>28</sub>
  - GRO - hydrocarbons in the range of C<sub>6</sub> - C<sub>10</sub>



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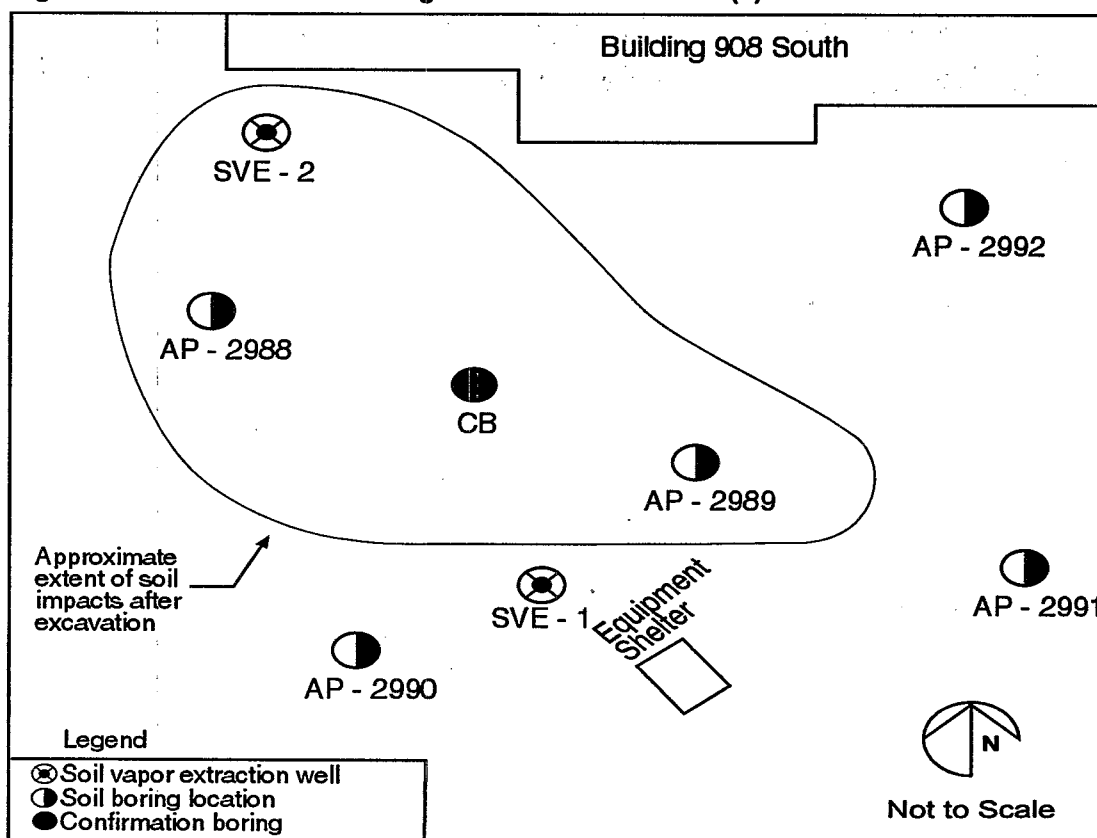
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- Provided below are the properties of BTEX and chlorobenzene.

Property	Benzene	Toluene	Ethyl-benzene	Xylenes	Chloro-benzene
Chemical Formula	$C_6H_6$	$C_6H_5CH_3$	$C_6H_5C_2H_5$	$C_6H_4(CH_3)_2$	$C_6H_5Cl$
Molecular Weight	78.11	92.14	106.17	106.17	112.5
Specific Gravity (at 20° C)	0.88	0.87	0.87	0.86 - 0.88	1.105
Vapor Pressure (mm Hg at 70° F)	79.4	23.2	10.4	5.2 - 9	10.1
Boiling Point (°C at 760 mmHg)	80.1	110.6	136.2	138.3 - 144.4	131.6
Octanol-Water Partition Coefficient ( $K_{ow}$ )	132	537	1,100	1,830	692

Figure 1. Location of Soil Borings and Extraction Wells (6)



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**CONTAMINANT CONCENTRATIONS (4)**

- In September 1989, at the time of the excavation, five soil borings were completed in the vicinity of Building 908 South. Figure 1 shows the locations of these borings. Soil samples were collected from the borings at depths ranging from 5 to more than 50 feet below ground surface (bgs) and analyzed for kerosene K-1, diesel fuel #2, jet fuel A, bunker fuel #6D, BTEX, and chlorobenzenes. Table SB-1 shows results of analysis of the soil samples. (Kerosene, diesel fuel, jet fuel, and bunker fuel include constituents identified as DROs.)
- As Table SB-1 shows, concentrations of diesel fuel #2 as high as 17,000 milligrams per kilogram (mg/kg) were detected (Bore Hole AP-2989; sample depth 5 to 6.5 feet). Five soil samples contained diesel fuel #2 concentrations higher than 200 mg/kg. In addition, Table SB-1 shows concentrations of kerosene as high as 18 mg/kg, concentrations of jet fuel as high as 1,200 mg/kg, and concentrations of bunker fuel as high as 94 mg/kg.
- Table SB-1 also shows concentrations of benzene detected as high as 0.11 mg/kg, toluene as high as 7.1 mg/kg, chlorobenzene as high as 6.7 mg/kg, m-dichlorobenzene as high as 11.0 mg/kg, and o-, p-dichlorobenzene as high as 91.0 mg/kg.

**MATRIX CHARACTERISTICS AFFECTING TREATMENT COST OR PERFORMANCE. [4]**

Listed below are the major matrix characteristics affecting cost or performance for this technology and the values measured for each parameter.

Parameter	Value
Soil Classification	See Table ST-1
Clay Content and/or Particle Size Distribution	Information not available
Moisture Content	Information not available
Air Permeability	Information not available
Porosity	Information not available
Total Organic Carbon	Information not available
Nonaqueous Phase Liquids	Not identified
Contaminant Sorption	Information not available
Lower Explosive Limit	Information not available
Presence of Inclusions	Information not available
Humic Content	Information not available



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Table SB-1. Results of Analysis of Soil Borings Collected in September 1989\* (4)

Bore Hole Number	AP-2988	AP-2988	AP-2988	AP-2988	AP-2988	AP-2989	AP-2989	AP-2989	AP-2989	AP-2989	AP-2989	AP-2990	AP-2990	AP-2990
Sample ID (90FRUST-)	123	126	127	130	131	132	133SL QC	133SL QA	137	138	139	143	144SL QC	145SL QA
Sample Depth (ft)	20-21.5	35-36.5	40-41.5	45-46.5	>50	5-6.5	5-6.5	5-6.5	25-26.5	30-30.5	35-36.5	5-6.5	5-6.5	5-6.5
<b>Petroleum Hydrocarbons (EPA Method 8015M) (mg/kg)</b>														
Kerosene K-1	<2.4	<180	<19	18	<1.9	<89	NR	NR	<190	<18	<18	<1.8	NR	NR
Diesel fuel #2	17	<180	<19	1900**	160**	5300**	8300	17000	1800**	370**	43**	<1.8	NR	310
Jet Fuel A	<2.4	1200	460	<18	<1.9	<89	NR	NR	<190	<18	<18	74**	56	NR
Bunker Fuel #6D	<12	<920	94	<92	<97	<450	NR	NR	<930	<91	<91	<8.9	NR	NR
<b>Volatile Organics (EPA Method 8020) (mg/kg)</b>														
Benzene	<0.14	<0.54	<0.56	<0.05	<0.47	<0.63	NR	NR	0.11	<0.05	<0.01	<0.01	NR	NR
Toluene	<0.14	<0.54	4.1	<0.05	2.1	2.1	7.1	0.016	0.39	<0.05	<0.01	<0.01	NR	0.012
Chlorobenzene	<0.14	1.4	6.7	0.22	1.1	2.7	6.5	NR	0.529	0.045	<0.01	<0.01	NR	NR
Ethylbenzene	<0.14	<0.54	<0.56	<0.05	<0.57	0.75	2.4	0.23	0.12	<0.05	<0.01	<0.01	NR	0.008
m-Xylene	0.38	4.3	10.0	0.72	1.8	11.0	70.0	0.215	1.4	0.1	0.046	<0.01	NR	0.06
o-, p-Xylene	<0.14	<0.54	<2.5	<0.05	1.3	18.0	NR	NR	0.26	0.054	0.013	<0.01	NR	0.015
m-Dichlorobenzene	0.85	8.4	5.9	0.49	1.3	11.0	2.4	NR	2.1	0.21	0.12	<0.02	NR	NR
o-, p-Dichlorobenzene	<0.28	11.0	8.8	3.0	6.7	51.0	91.0	NR	9.3	1.2	0.48	<0.02	NR	NR

\* Results are summarized here only for those samples in which at least one contaminant was detected at a concentration of 1 mg/kg or higher. Additional analytical data on soil borings are provided in reference 4.

\*\* Laboratory estimate

NR = Not Reported



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- During installation of soil borings in 1989, soil types were identified according to the Unified Soil Classification System. The soil types were identified for depths ranging from 5 to 50 feet bgs and are shown in Table ST-1. (4)

**Table ST-1. Soil Types Identified for 1989 Soil Borings, According to the Unified Soil Classification System (4)**

Depth (ft bgs)	Soil Boring No.				
	AP-2988	AP-2989	AP-2990	AP-2991	AP-2992
5	SP	-	GW	-	GW-GM
10	SP	GW	GW-GC	-	GW-GC
15	GP	-	GW	-	GW-GC
20	SP	GP-GC	GP-GC	GP-GC	GP-GC
25	-	GW-GC	GW	GP-GC	-
30	GW-GC	GW	GW	GP-GC	GW-GC
35	GW-GC	GP	GP-GC	-	GW-GC
40	GW	GP-GC	GW-GC	-	GP
45	GW-GC	GW	-	-	-
50	GP-GC	GW-GC	-	-	-

SP = Poorly graded sand with gravel and cobbles  
 GP = Poorly graded gravel with sand  
 GW = Well-graded gravel with sand  
 GP-GC = Poorly graded gravel with clay and sand  
 GW-GC = Well-graded gravel with clay and sand  
 GW-GM = Well-graded gravel with silt, sand, and cobbles

#### **GEOLOGY (4):**

- Ft. Richardson occupies lowlands to the west of the Chugach Mountains. The lowlands consist of surface deposits of glacial till, outwash, and silt. The Elmendorf Moraine transects the installation in a northeast-southwest direction and consists of glacial deposits of unconsolidated till composed of poorly sorted boulders, gravel, sand, and silt.
- A thin mantle of fine-grained soil, generally about two to five feet in thickness, blankets the area. Relatively clean, coarse-grained soils derived from outwash and glacial debris underlie the surface fines and extend to depths ranging approximately from 10 to 50 feet.
- Groundwater under Ft. Richardson occurs primarily as a result of percolation from surface water. At Building 908, the groundwater is present at depths greater than 50 ft bgs.



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**TREATMENT SYSTEM DESCRIPTION****PRIMARY TREATMENT TECHNOLOGY TYPE (7)**

SVE

**SUPPLEMENTARY TREATMENT TECHNOLOGY TYPE**

None

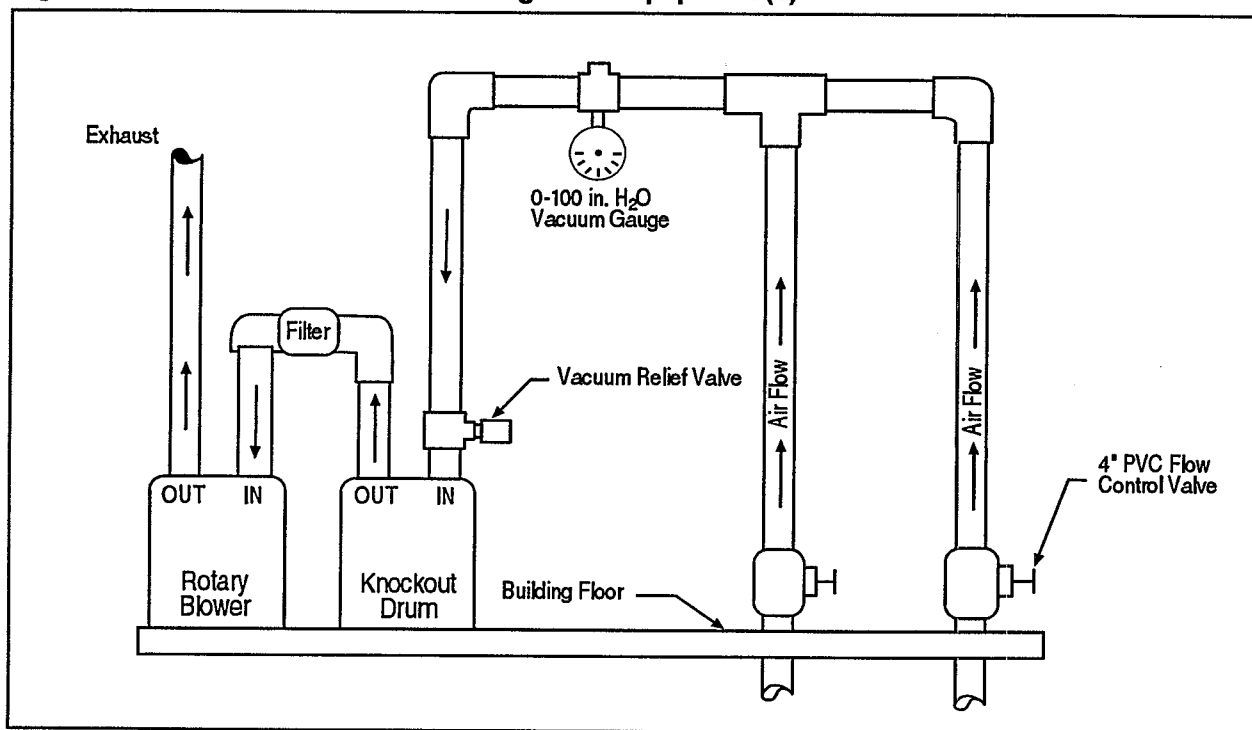
**TIMELINE (4, 5, 6, 8)**

Date	Activity
September 1989	1,000-gallon unregulated heating oil (Tank No. 82) was removed from an area adjacent to Building 908 South; with five soil borings collected during excavation
August - September 1990	Additional site characterization activities were conducted at Building 908 South
November 17, 1994	Construction began for SVE system
February 20, 1995	SVE treatment system began operation
March 1996	Interim soil boring collected
May 1996	Interim remedial action report was prepared
Spring 1999	Closure activities planned



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**TREATMENT SYSTEM SCHEMATIC AND TECHNOLOGY DESCRIPTION AND OPERATION****Figure 2. Process Schematic for Aboveground Equipment (6)****System Design and Construction (5, 6)**

- The SVE system designed for Ft. Richardson consisted of two SVE wells (SVE-1 and SVE-2) and aboveground equipment that included a knockout drum, a particulate filter, and a rotary blower. Figure 1 shows the locations of the two extraction wells and shelter for the aboveground equipment. Figure 2 presents a process schematic for the aboveground equipment.
- The SVE wells were installed to a depth of 55 ft bgs, and were screened in the interval from 7 to 50 ft bgs. To accommodate the low temperatures expected for the application, heat trace (5 watts per ft) was installed in each well to a depth of 8 ft bgs. The references available provide no information about temperatures expected for the application.
- The wells were piped individually to the equipment shelter through horizontal trenches installed 30 inches bgs. Heat-traced, insulated arctic pipe was used in the trenches.
- The rotary blower used in the application was a EG&G Rotron EN-707 regenerative blower, a three-phase, five-horsepower blower with a maximum suction of 85 standard cubic feet per minute (scfm) at 87 inches of water.



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### **Operation (5, 6, 8)**

- The SVE system began operation on February 20, 1995 and is expected to operate through Spring 1999, when closure sampling will be conducted.
- The following system parameters were monitored during the application: extraction air flow rate, vacuum at wells SVE-1 and SVE-2, vacuum from each extraction line in the equipment shelter, change in pressure from inlet to outlet side of the filter (filter differential), change in pressure from inlet to outlet side of the blower (blower differential), total organic vapor concentration (measured with a photoionization detector (PID) from each extraction line in the equipment shelter, and total organic vapor concentration in the exhaust stack from the rotary blower. Table TSO-1 shows the results of monitoring of system parameters as of February 15, 1996.
- As Table TSO-1 shows, vacuums from wells SVE-1 and -2 measured at the shelter were as high as 37 inches water (Well SVE-1, January 16, 1996), and were generally higher than vacuums measured at the wells. Air flow rates and filter and blower differentials were relatively constant over the course of the monitoring period, while concentrations of volatile organic compounds decreased both at the shelter and in the blower exhaust.
- The references available provide no information about the percentage of time that the system was on line during the period from February 1995 to March 1996.

### **Initial Activities (5)**

The remediation contractor performed the following activities for the application:

- Soil collected during installation of the extraction wells was used as source material for a nutrient and bacteriological evaluation and in a laboratory-scale test to determine optimal nutrient and thermal parameters for operation of the system.
- The need for passive or active air injection and the need for thermal enhancement (direct steam injection, steam recirculation, hot water recirculation, and buried electrical element (heat trace) heating systems) were evaluated.
- An assessment was made of the initial soil respiration rate and the soil permeability. For the respiration test, a very-low-volume air extraction blower was used to obtain representative samples of soil gas for analysis of oxygen, carbon dioxide, and extracted contaminants. For the permeability test, a higher-volume blower was used.

The references available provide no information about the results of the initial nutrient, bacteriological, air injection, thermal enhancement, soil respirometry, and soil permeability evaluations.



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Table TSO-1. System Monitoring Results (6)

Date	Extraction Air Flow Rate (scfm)	Vacuum at Well SVE-1 (inches water)	Vacuum at Well SVE-2 (inches water)	Vacuum at Shelter from Well SVE-1 (inches water)	Vacuum at Shelter from Well SVE-2 (inches water)	Filter Differential (inches water)	Blower Differential (inches water)	Total Organic Vapor Conc. at Shelter from SVE-1 (ppm)	Total Organic Vapor Conc. at Shelter from SVE-2 (ppm)	Total Organic Vapor Conc. at Exhaust Stack/Blower (ppm)
2/20/95	210	6.6	3.2	NR	NR	22	33	10	100	29
3/1/95	205	6.4	3.6	8.7	8.7	22	34	2	39	20
4/18/95	205	NT	NT	9.0	9.0	23	34	NT	NT	1
5/16/95	205	6.0	3.2	34.0	34.0	24	34	3	NT	4
7/27/95	210	NT	NT	7.5	7.5	23	33	3	9	4
8/21/95	210	NT	NT	10.0	33.0	23	33	2	12	10
10/19/95	215	6.0	4.5	7.5	7.5	23	33	1	2	1
11/14/95	220	NT	NT	7.6	7.6	23	32	NT	NT	1
12/14/95	210	5.0	3.3	8.0	6.4	23	33	2	1	4
1/16/96	205	NT	NT	37	*	*	34	0.7	*	1.8
2/15/96	205	7.5	2	12	12	22	34	0.5	*	0

NR = Not reported  
 NT = Not taken  
 \* = Water present in line



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**Closure and Site Restoration (1, 8)**

- Closure and site restoration activities will be conducted after operation of the system has been completed (projected Spring 1999) and will include additional soil sampling.

**OPERATING PARAMETERS AFFECTING TREATMENT COST OR PERFORMANCE**

Listed below are the major operating parameters affecting cost or performance for this technology and the values measured for each parameter.

Parameter	Value
Air Flow Rate	205 - 220 scfm
Operating Pressure/Vacuum	2 - 7.5 inches water vacuum (at wells)
Operating Time	Information not available
Temperature	Information not available

**TREATMENT SYSTEM PERFORMANCE****PERFORMANCE OBJECTIVES (4)**

- ADEC Matrix Level B cleanup levels were identified for the application. Table CL-1 shows those levels.

**Table CL-1. Cleanup Levels for Soil at Ft. Richardson Building 908 South (4)**

Contaminant	Cleanup Level (mg/kg)
DRO	200
GRO	100
Benzene	0.5
Total BTEX	15

- Confirmation that cleanup levels have been met will be performed during close-out sampling.
- No performance objectives were established for air emissions from the blower for the application.



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**TREATMENT PERFORMANCE DATA (6)**

- In March 1996, a soil boring, located within the area of contamination (Figure 1), was collected and analyzed for DRO by method AK 102, GRO by method AK 101, and benzene and total BTEX by method 8020. From March 1995 through February 1996, six samples from the exhaust stack from the blower were collected and analyzed for DRO by EPA Method 5030/8100 and GRO by EPA method 5030/8015. The results of analysis of the exhaust stack samples and soil boring are shown in Tables TPD-1 and TPD-2, respectively.
- In addition, samples were collected from the soil excavated during installation of wells SVE-1 and SVE-2. The samples were collected at depths of 25, 45, and 55 ft bgs and analyzed for DRO, GRO, benzene, and total BTEX. According to the remediation contractor, analysis of all samples showed that concentrations of those parameters were lower than their respective cleanup levels, with the exception of a soil sample taken from SVE-2 at 40 ft bgs, which showed DRO at 250 mg/kg. However, the results of those analyses were not included in the available references.
- According to USACE, the concentrations in the soil boring collected in March 1996 were assumed to represent the average concentrations of contaminants in the treated soil.

**Table TPD-1. Results of Analysis of Sample from Blower Exhaust Stack (6)**

Date	DRO (lbs/day)	GRO (lbs/day)
3/1/95	1.10	0.52
4/18/95	0.16	0.00
5/16/95	0.50	0.21
7/27/95	0.34	0.10
10/19/95	0.34	0.09
2/15/96	0.10	0.02

**Table TPD-2. Results of Analysis of Soil Boring Collected March 1996 (6)**

Depth (ft bgs)	DRO (mg/kg)	GRO (mg/kg)	Benzene (mg/kg)	Total BTEX (mg/kg)
Cleanup Level	200	100	0.5	15
25	53	20	ND	0.199
30	10	ND	ND	ND
30 (duplicate sample)	7	ND	ND	ND
35	ND	ND	ND	ND
40	ND	ND	ND	ND
45	15	ND	ND	ND
50	10	ND	ND	ND



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### **PERFORMANCE DATA ASSESSMENT**

- The analytical data presented in Table TPD-2 show that, as of March 1996, the concentrations of DRO, GRO, benzene, and total BTEX in the soil boring were lower than their respective cleanup goals at all soil depths sampled (25 to 50 ft bgs). The highest concentrations were found at 25 ft bgs, where DRO was measured at 53 mg/kg, GRO at 20 mg/kg, and total BTEX at 0.199 mg/kg.
- The analytical data shown in Table TPD-1 indicate that emissions of DRO from the blower were reduced by approximately 90 percent over a one-year operating period (from March 1995 to February 1996) and that emissions of GRO were reduced by approximately 95 percent over the same period.

**Material Balance:** Only a limited amount of analytical data were available for the application (for example, no data were available on quantity of contaminants in the soil before treatment or on the cumulative mass of contaminant removed); therefore no material balance was performed for this application.

### **PERFORMANCE DATA QUALITY (6)**

- Available information related to the quality of treatment performance data includes names of analytical laboratories, analytical methods used, and results of quality control analyses.
- Samples of blower exhaust air were analyzed by Commercial Testing & Engineering Co. (CT&E). CT&E analyzed DRO by EPA Method 5030/8100 and GRO by EPA Method 5030/8015. National Institute for Occupational Safety and Health (NIOSH) Method 1501 was used to extract the samples.
- The soil boring samples were collected by a split-spoon sampler and analyzed by Superior Analytical Laboratory (Superior). Superior analyzed DRO by Method AK101, GRO by Method AK102, and BTEX by Method 8020.
- The remediation contractor noted no exceptions to quality assurance and quality control (QA/QC) procedures or protocols for the application. QA/QC procedures included use of duplicate soil samples, method blanks, equipment blanks, and trip blanks.

## **TREATMENT SYSTEM COST**

### **PROCUREMENT PROCESS (2, 7)**

- The references available provide only limited information about the procurement process.
- In September 1994, USACE prepared a detailed government estimate of costs for the application, using the MCASES Gold Edition software, release 5.30. The estimate was based on use of the hazardous, toxic, and radioactive waste (HTRW) work breakdown structure (WBS)



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for in situ biodegradation and bioreclamation. The government estimated that performance of the application would cost \$354,608, a total consisting of \$61,376 for preparation and submittal of the work plan, \$220,943 for site work and the bioventing system, and \$72,289 for site work and installation and operation of the nutrient addition system.

- The project was conducted as a delivery order under an IDTRA contract. USACE solicited proposals for the contract, and a prime contractor was selected on the basis of technical qualifications to perform a variety of remedial actions that might be necessary for the application. Prime contractors were required to prepare cost estimates when they were issued a delivery order; for work that was to be performed by a subcontractor, the prime contractor was required to obtain at least three bids from prospective subcontractors.

#### **TREATMENT SYSTEM COST (1)**

- Cost information was provided for award cost only:
  - The award cost for this application was \$305,053, approximately 86 percent of the cost estimated by the government. The \$305,053 consisted of approximately \$52,800 for before-treatment activities (such as preparation and submittal of a work plan; completion of a biotreatability test; performance of in situ respirometry, air permeability, and groundwater sparging tests; system design; and site investigation); \$190,000 for construction and operation of a bioventing system, and \$62,200 for construction and operation of a nutrient addition system. (The costs of the bioventing and nutrient addition systems are assumed to be equal to the costs of an SVE system). The latter two costs (a total of \$252,200) are the costs of activities directly attributed to treatment.
  - The \$252,200 total for SVE was divided into costs for construction and operation. Construction costs were estimated at \$116,900, with operation costs estimated at \$135,300.
- The application at Ft. Richardson has not yet been completed; information about actual costs therefore was not available. It is not yet known how the actual costs will compare with award costs.

#### **REGULATORY/INSTITUTIONAL ISSUES**

- This application was a voluntary cleanup action that involved treatment of petroleum-contaminated soil near an unregulated heating oil tank. According to the contractor, the cleanup was conducted under the guidelines set forth in the ADEC Underground Storage Tank Regulations (18 AAC 78). The treated soil was required to meet ADEC Matrix Level B cleanup levels. (6, 7)



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## OBSERVATIONS AND LESSONS LEARNED

### COST OBSERVATIONS AND LESSONS LEARNED

- The award cost for SVE at Ft. Richardson Building 908 South was \$252,200 for activities directly attributed to treatment, representing a unit cost of \$55 per cubic yard of soil treated (4,600 cubic yards treated). The available references contain insufficient information to calculate a unit cost per pound of contaminant extracted.

### PERFORMANCE OBSERVATIONS AND LESSONS LEARNED

- The soil boring collected in March 1996 showed that after one year of operation all contaminants were measured at concentrations less than their respective cleanup levels (DRO - 200 mg/kg, GRO - 100 mg/kg, benzene 0.5 mg/kg, and total BTEX - 15 mg/kg).
- Data on the concentrations of the target contaminants in soil before cleanup operation began is limited; therefore, the percent reduction of these contaminants during treatment cannot be calculated. However, data collected during the 1989 site investigations showed concentrations of petroleum hydrocarbons in the soil as high as 17,000 mg/kg for diesel fuel #2 and 1,200 mg/kg for kerosene. In addition, VOCs were detected as high as 91 mg/kg for o-, p-dichlorobenzene and 70 mg/kg for m-xylene.
- According to a representative of USACE, the reductions in concentrations of contaminants at the site were greater than expected for a site contaminated with diesel fuel in gravelly soil mixed with clay. (7)
- The mass of DRO and GRO in the exhaust stack of the extraction system was reduced by greater than 90 percent during the period from March 1995 to February 1996.
- The system will be shut down if closure sampling planned for Spring 1999 confirms that contaminants in the entire area have been reduced to below cleanup levels. (8)

### OTHER OBSERVATIONS AND LESSONS LEARNED

The remediation contractor provided the following additional observations and lessons learned:

- By February 1996, the bioventing system was approaching an asymptotic level of performance.
- The lateral extent of contamination could not be estimated accurately from the data available. The contractor recommended that three additional soil borings be installed and that each of the borings be sampled at five-foot intervals from 25 to 50 ft bgs and the samples analyzed for DRO, GRO, and BTEX. The references available do not indicate whether the borings were installed.



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## ACKNOWLEDGMENTS

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**Soil Vapor Extraction at Sites 2 and 5**  
**Holloman AFB, New Mexico**

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## Soil Vapor Extraction at Sites 2 and 5 Holloman AFB, New Mexico

<b>Site Name:</b> Sites 2 and 5 - Petroleum Oils and Lubricants Area	<b>Contaminants:</b> Volatiles (nonhalogenated) <ul style="list-style-type: none"> <li>• BTEX and TPH</li> <li>• Maximum concentrations – Benzene (48,000 ug/kg), Toluene (210,000 ug/kg), Xylene (500,000 ug/kg), Ethylbenzene (180,000 ug/kg) and TPH (17,500 mg/kg)</li> </ul>	
<b>Location:</b> Holloman AFB, New Mexico	<b>Technology:</b> In-Situ Soil Vapor Extraction <ul style="list-style-type: none"> <li>• Network of 22 extraction wells (varying combinations are used)</li> <li>• 2 Horsepower SVE blower motor</li> <li>• Knockout tank to separate vapor and liquid phases.</li> </ul>	<b>Cleanup Type:</b> Remedial Action
<b>Project Management:</b> U.S. Air Force Drew Lessard Restoration Program Manager 49 CES/CEVR 550 Tabosa Avenue Holloman AFB, New Mexico 88330 (505) 475-5395		<b>Vendor:</b> IT Corporation (Construction) Foster Wheeler (Current O&M) Ronald Versaw, P.E. Delivery Order Manager 143 Union Boulevard Suite 1010 Lakewood, Colorado 80228-1824
<b>SIC Code:</b> 9711 (National Security)	<b>Period of Operation:</b> <ul style="list-style-type: none"> <li>• April 1995 to present</li> <li>• Treatment system currently in operation</li> </ul>	<b>Cleanup Authority:</b> State and EPA
<b>Waste Sources:</b> Chronic and acute surface releases of JP-4 jet fuel, AVGAS and diesel fuel from aboveground storage tanks	<b>Type/Quantity of Media Treated:</b> Soil <ul style="list-style-type: none"> <li>• Estimated 9,500 cubic yards of soil (in-situ)</li> <li>• Estimated 44,000 pounds of TPH removed from the soil</li> </ul>	<b>Regulatory Point of Contact:</b> Cornelius Amindyas NMED 2044 Galisteo Santa Fe, New Mexico 87502 (505) 827-1561
<b>Purpose/Significance of Application:</b> Treatment system has operated successfully with minimal downtime or maintenance requirements	<b>Regulatory Requirements/Cleanup Goals:</b> NMED has set the following soil cleanup criteria for POL sites at Holloman AFB: <ul style="list-style-type: none"> <li>• 1000 mg/kg TPH</li> <li>• 25 mg/kg Benzene</li> <li>• Removal of all floating free-phase hydrocarbons</li> </ul>	



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## Soil Vapor Extraction at Sites 2 and 5 Holloman AFB, New Mexico (continued)

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**Costs:**

The total cost for this project (through August 1997) was \$610,000. This translates to a cost of \$64 per cubic yard of soil treated.

**Results:**

Confirmatory soil samples collected in 1997 indicate that soil TPH concentrations have been reduced below the regulatory guideline of 1,000 mg/kg. Previous sampling has indicated that benzene concentrations are below 25 mg/kg. Floating free-phase hydrocarbons have never been observed in the subsurface at the site.

**Description:**

During the 1960s and 1970s, several releases of JP-4 jet fuel, AVGAS and diesel fuel occurred in a POL storage area at Holloman AFB. Releases included chronic leaks and a 30,000-gallon spill that occurred in 1978. The site previously contained 14 aboveground POL storage tanks. All 14 tanks were removed from the site in 1987.

The site of the releases was investigated as part of the IRP program and two sites (Sites 2 and 5) were identified in the vicinity of the POL storage area. Because the two sites were similar in nature and in close proximity to each other, they were ultimately combined into one site (Site 2/5). Subsequent investigations at Site 2/5 identified an area requiring soil remediation. This area was selected based on soil cleanup criteria developed for POL sites at Holloman AFB. This area is 80 feet wide by 200 feet long. Soil borings indicated that soil contamination extended 16 below the ground surface at the site. It was determined that groundwater remediation was not required based on the quality of the groundwater and the lack of floating free-phase hydrocarbons at the site.

In 1994 and 1995, an SVE system was constructed at the site. The system includes 22 extraction wells, a 2-horsepower blower and a knockout tank to separate vapor and liquid phases in the extraction stream. The system was started in April 1995 and is currently still in operation (as of October 1998). It is estimated that 44,000 pounds of TPH have been removed from the soil at the site. Since 1995, several different extraction well configurations have been used. For a period in 1997, all 22 wells were in use simultaneously.

On several occasions since system start up, soil borings have performed at the site to determine if cleanup goals have been met at the site. The most recent sampling event (October 1997) indicated that the goals had been met. In March 1998, a Final Characterization Study was submitted to NMED for review. This study recommended that no further remedial action be conducted at Site 2/5. Approval of this recommendation was pending at the time of this report.

In addition to meeting soil cleanup criteria at Site 2/5, the SVE system has consistently operated below limits set by NMED for allowable air emissions of organic compounds.

**SITE INFORMATION****IDENTIFYING INFORMATION**

**Site Name:** Sites 2 and 5 (Site 2/5)  
**Location:** Holloman AFB, New Mexico  
**Technology:** Soil Vapor Extraction (SVE)  
**Type of Action:** Remedial

Figure 1 shows the location of Holloman AFB in New Mexico.

**TECHNOLOGY APPLICATION (1,2)**

**Period of Operation:** Full-scale operation - April 1995 through October 1998 (currently in operation)

**Quantity of Material Treated During Application:** 9,500 cubic yards of soil (contaminated zone is estimated to be 80 feet wide by 200 feet long by 16 feet deep). Soil treatment at Site 2/5 is ongoing.

**BACKGROUND****Site Background (1,3,13):**

- Holloman AFB is located on 50,700 acres of land in Otero County in south-central New Mexico. The nearest population center is Alamogordo, which is located approximately 7 miles east of the base boundary. Holloman AFB was operated prior to World War II as a transitional flight training facility. The base was reactivated after WWII as a guided missile research and testing facility. In 1968, the base became host to the 49<sup>th</sup> Tactical Fighter Wing.
- An area surrounded by soil berms was previously used for storage of petroleum, oils and lubricants (POLs). This area included fourteen 25,000-gallon aboveground storage tanks (ASTs). The ASTs were used to store JP-4 jet fuel and diesel fuel and were removed in 1987.
- The former POL storage area was located on one-third of an acre in the northeastern portion of the main base area at Holloman AFB. Figure 2 shows the location of Site 2/5 at Holloman.

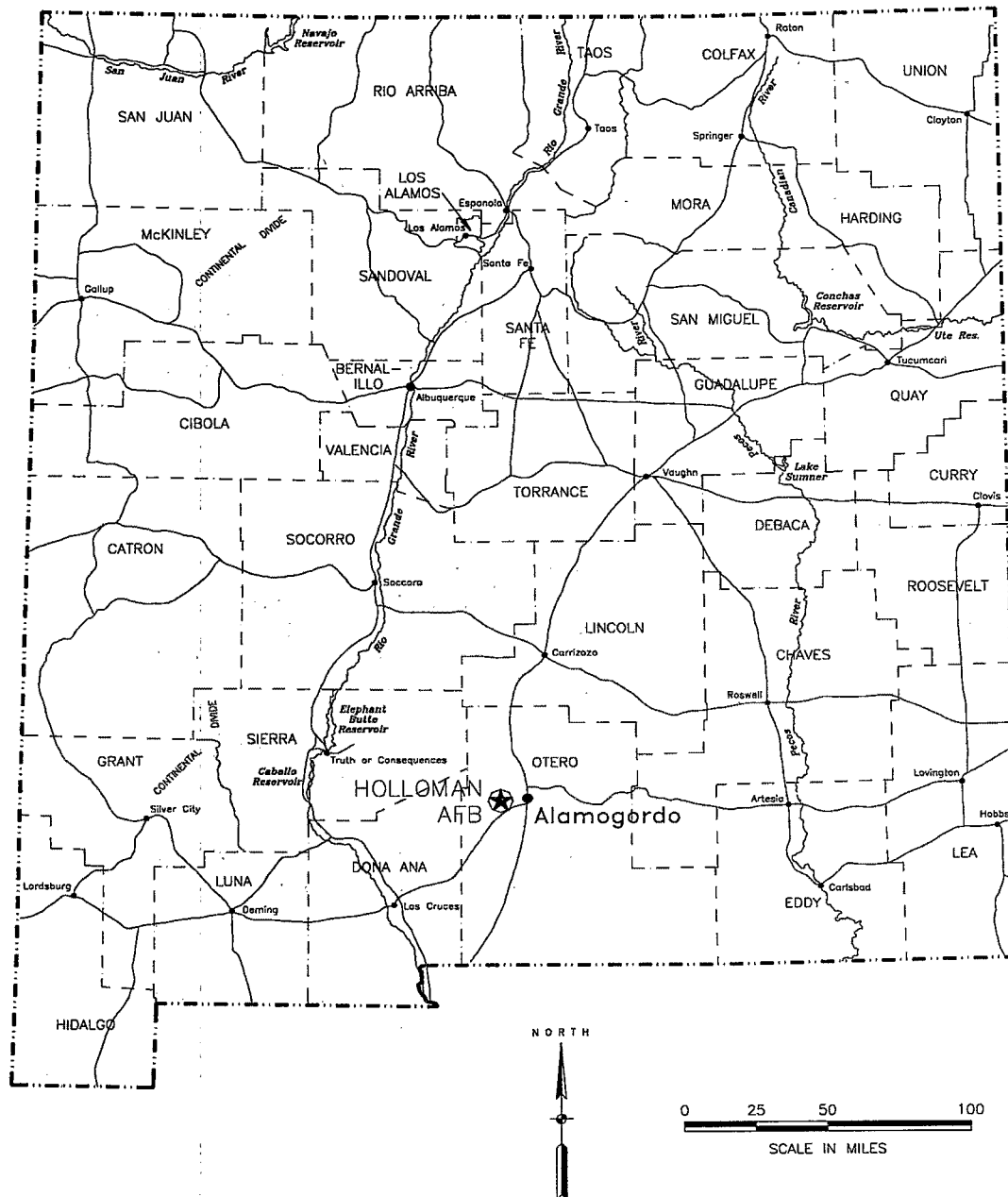
**SIC Code:** 9711 (National Security)

**Waste Management Practice that Contributed to Contamination:** Chronic and acute surface releases of JP-4 jet fuel, AVGAS, and diesel fuel from aboveground storage tanks.



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**Figure 1. Location of Holloman AFB**



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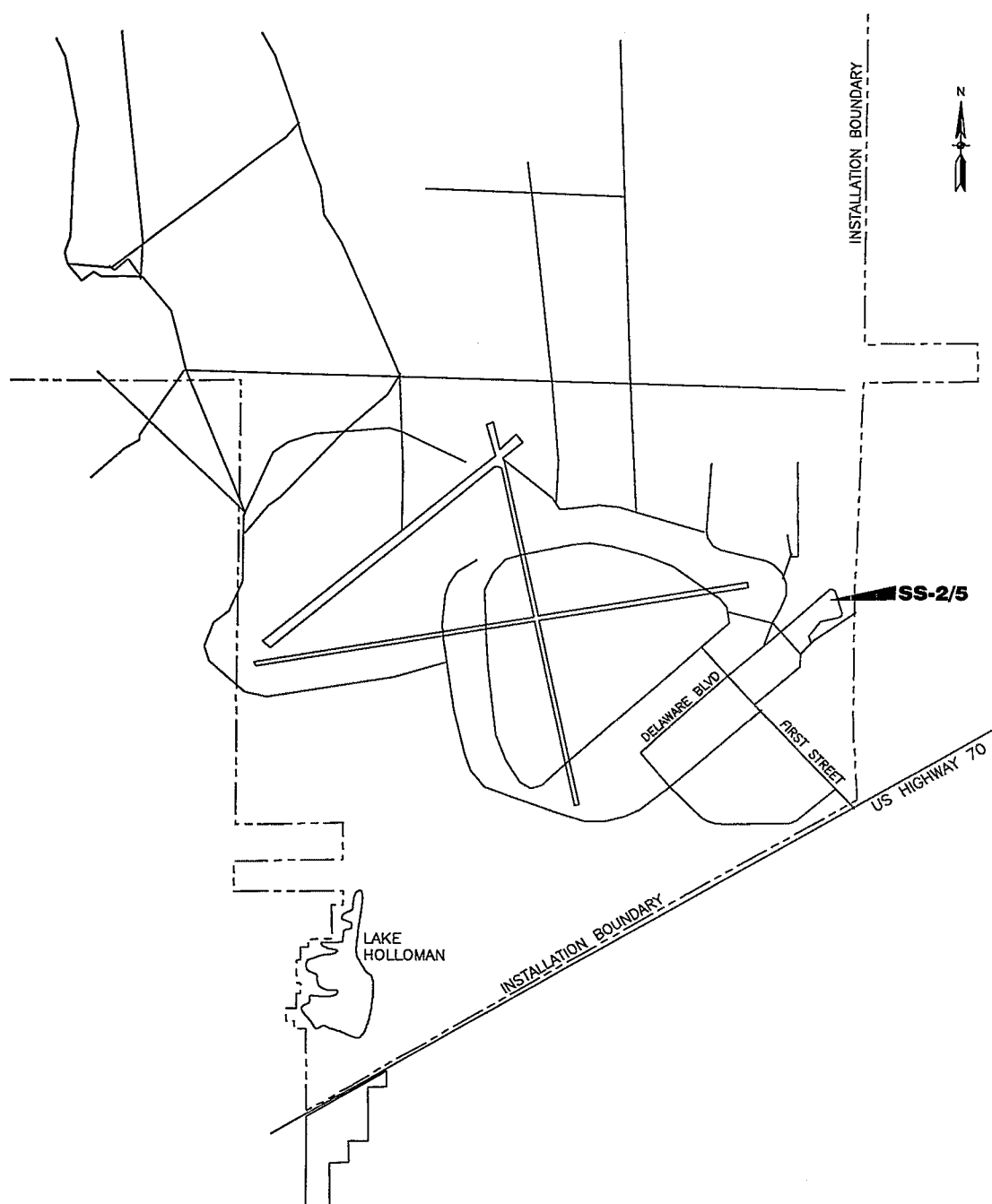


Figure 2. Location of Site 2/5 at Holloman AFB



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**Historical Activities Prior to Technology Application (3):**

- Periodic overtopping of the ASTs in the POL storage area caused several spills of JP-4 jet fuel and AVGAS in the 1960s and 1970s. The total volume of fuel spilled was not recorded. The areas around these spills were identified as POL Spill Site 1.
- In 1978, 30,000 gallons of JP-4 jet fuel was released into the bermed area around the ASTs. According to facility personnel, all but 1500 gallons of released fuel was recovered. The area around this spill was identified as POL Spill Site 2.
- In 1987, the 14 ASTs at IRP Site 2 (POL Spill Site 1) and Site 5 (POL Spill Site 2) were removed.

**Site Investigation (3,4,13):**

- An IRP Phase I Records Search was conducted for Holloman AFB in 1982 and 1983 (CH2M Hill, 1983). Sites 2 and 5 were identified separately in the Phase I report.
- In 1991 and 1992, a Remedial Investigation (RI) was performed and risk assessments were conducted for 29 sites at Holloman AFB, including Sites 2 and 5 (Radian, 1992). Sites 2 and 5 were combined into one site based on their close proximity to each other and similar nature. Risk assessments determined that three sites, including Site 2/5, would require remedial action. Investigation at Site 2/5 included completion of 16 soil borings and installation of 5 groundwater monitoring wells. Contaminants of concern at the site included petroleum hydrocarbons, especially benzene, toluene, ethylbenzene and xylenes (BTEX).
- In 1992, a Corrective Measures Study was performed for the 29 sites at Holloman AFB. Remedial Action Objectives (RAOs) were established for Holloman AFB in this plan. The New Mexico Environmental Department (NMED) recommended that all petroleum-contaminated sites at Holloman have soil clean up goals of 1000 mg/kg for Total Petroleum Hydrocarbons (TPH) and 25 mg/kg for benzene.
- In 1993, a Predesign Investigation (PDI) was performed at Site 2/5, including completion of 9 soil borings.
- In 1993, a feasibility study was performed for the three sites recommended for remediation (Radian, 1993). Alternatives considered for Site 2/5 included: No action; Containment (clay capping); In situ treatment (SVE/bioventing), In situ treatment (SVE/biosparging), Excavation/on-site treatment (low-temperature thermal treatment) and backfill with treated soil; and, Excavation and off-site disposal.
- In 1995, a Phase II RCRA Facility Investigation Report was issued for Table 1 SWMUs at Holloman AFB.
- In 1995, A Decision Document for Site 2/5 was issued. This document described the selected remedy (SVE), and long-term monitoring requirements for Site 2/5.
- A Final Characterization Study for Site 2/5 was submitted to NMED in March 1998. The site had not been officially closed as of October 1998.



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**MATRIX AND CONTAMINANT DESCRIPTION****MATRIX IDENTIFICATION**

Soil (in situ)

**SITE GEOLOGY/STRATIGRAPHY (1,3)**

- Holloman AFB is located within the Tularosa Basin in New Mexico. This basin is a bolson, which means that there is no surface drainage outlet from the basin. The bolson fill in the Tularosa Basin is derived from the erosion of limestone, dolomite and gypsum in the surrounding mountains. Coarser material is deposited at the base of the surrounding mountains; finer material is carried to the basin's interior. The near-surface bolson deposits consist of sediments that are of alluvial, eolian, and lacustrine or playa origin.
- Soil at Site 2/5 in the contaminated zone (down to 16 feet below ground surface (bgs)) is exclusively characterized as "sm" (USCS designation) according to soil borings completed at the site. The sm designation is described as: sand with fines; silty sands and sand-silt mixtures, which may be poorly graded; nonplastic. Site stratigraphy consists primarily of clean to silty sand deposits interbedded with silt and clay lenses.



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- Groundwater at Site 2/5 occurs in a shallow unconfined aquifer approximately 10 feet bgs. Despite this reported depth in the Holloman RI Report, the boring logs from the 22 wells installed for the SVE system indicated that the depth to groundwater was approximately 15 feet bgs in two wells, and deeper (groundwater not encountered) in the remaining wells. The primary groundwater flow direction at the site is to the northeast.
- The groundwater beneath Holloman AFB is designated as unfit for human consumption based on New Mexico Water Quality Control Commission regulations because it exceeds New Mexico Human Health Standards for total dissolved solids (TDS) and sulfates. Based on guidance provided under the EPA Groundwater Protection Strategy, the groundwater at Holloman was classified as III B. This classification indicates that the groundwater, by virtue of having a TDS concentration above 10,000 mg/L, is not considered a source or potential source of drinking water. In addition, Class III B groundwater is characterized by a low degree of interconnection with adjacent surface waters or groundwaters of a higher class.

### **CONTAMINANT CHARACTERIZATION**

Volatiles (nonhalogenated) – BTEX

### **CONTAMINANT PROPERTIES**

Contaminant properties are provided below for benzene, toluene, ethylbenzene, and xylene (BTEX).

Property	Units	Benzene	Toluene	Ethylbenzene	Xylenes
Chemical Formula	-	C <sub>6</sub> H <sub>6</sub>	C <sub>6</sub> H <sub>5</sub> CH <sub>3</sub>	C <sub>6</sub> H <sub>5</sub> C <sub>2</sub> H <sub>5</sub>	C <sub>6</sub> H <sub>4</sub> ((CH <sub>3</sub> ) <sub>2</sub> )
Molecular Weight	g/mole	78.11	92.14	106.17	106.17
Specific Gravity	-	0.88	0.87	0.87	0.86 - 0.88
Vapor Pressure	Mm Hg	95.2	28.1	7	10
Boiling Point	°C	80.1	110.6	136.2	138.3 - 144.4
Octanol-Water Partition Coefficient (K <sub>ow</sub> )	-	132	537	1,100	1,830
Soil-Water Partition Coefficient (K)	-	83	300	1,410	240

### **NATURE AND EXTENT OF THE CONTAMINANTS**

It is estimated that the extent of soil contamination at Site 2/5 is limited to a 80 foot wide by 200 foot long rectangular area, and that the contamination extends to a depth of 16 feet bgs at the site. Figure 3 shows the estimated area of contamination at Site 2/5. Soil samples collected during the RI were analyzed for metals using EPA SW-846 Methods 6010, 7060 and 7421, and were analyzed for organic compounds using EPA SW-846 Methods 418.1 and 8240. Metals were either not detected or were detected below applicable guidance levels in all samples, except for lead in one surface sample. Organic compounds and TPH were detected in most of the borings, and indicated the presence of petroleum-related contaminants in soil at the site. Results from organic compound analyses are discussed below.



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HOLLO1.DWG DC-RTG 8/27/98

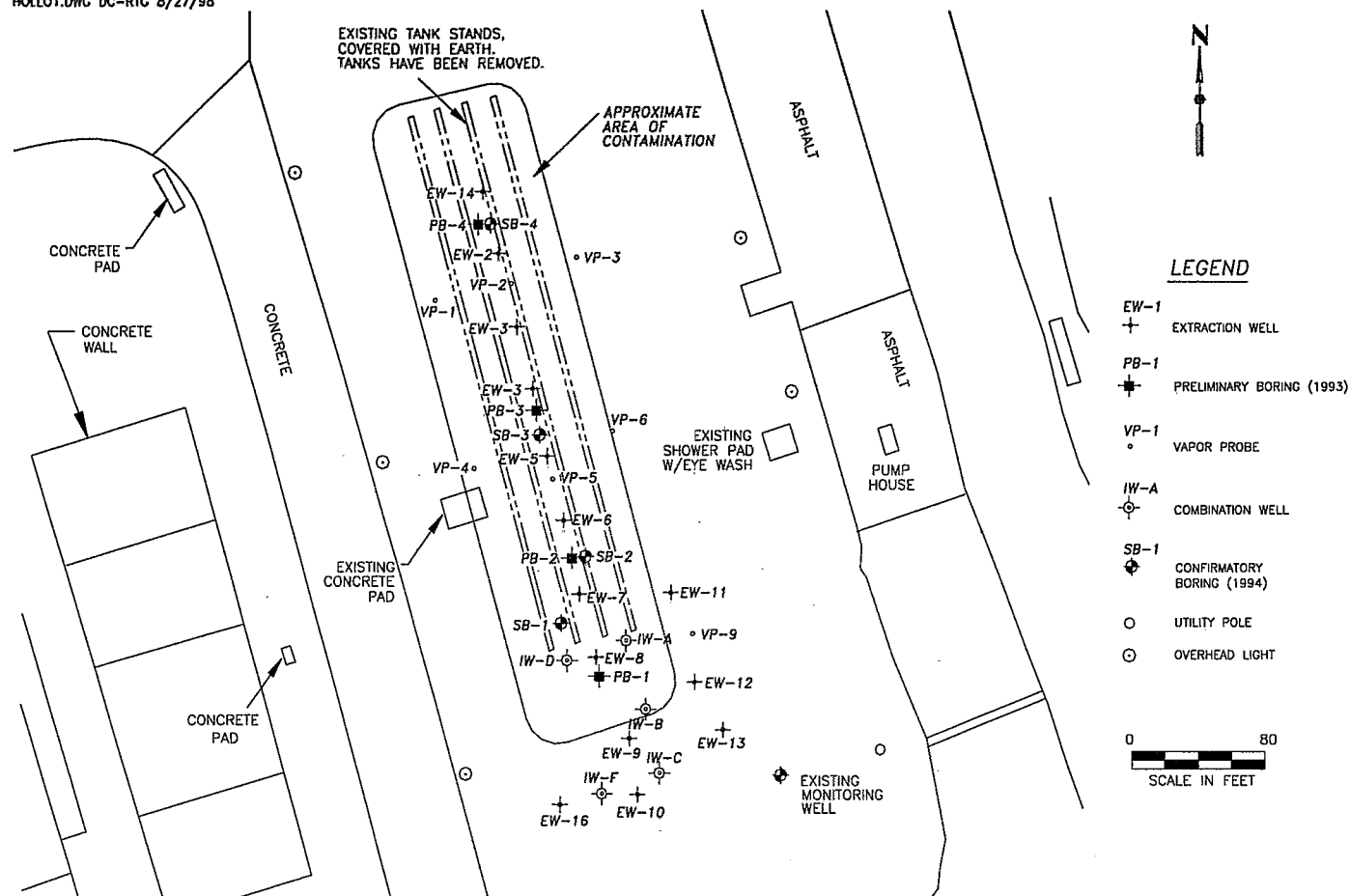


Figure 3. Layout of Site 2/5



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**CHARACTERISTICS OF UNTREATED SOIL (1,3)**

- Soil samples were collected at Site 2/5 from 16 borings completed during the RI in 1991 and from 9 additional borings completed during a PDI performed in May 1993. Selected results (highest concentrations) from these borings are shown in Table C-1.
- The following table contains average pre-remediation concentrations for selected contaminants at Site 2/5. These concentrations were calculated using all soil sampling results generated for site 2/5 during the RI and PDI, including samples collected outside of the estimated area of contamination.

Average Soil Concentrations from Borings Performed During the RI and PDI at Site 2/5	
Parameter	Average Concentration*
Benzene	1,887 µg/kg
Toluene	11,824 µg/kg
Ethylbenzene	33,710 µg/kg
Xylene	62,362 µg/kg
TRPH	1,565 mg/kg

\*During calculation of average concentrations, it was assumed that all non-detect results were equal to zero.

- Soil samples were collected from four borings immediately prior to construction of the SVE system. Borings were located along the approximate lengthwise centerline of the 200-foot by 80-foot contaminated area. Each boring was sampled at 5 to 7 feet bgs, 10 to 12 feet bgs and 15 to 17 feet bgs. It has been speculated that the TRPH concentrations from this sampling event were anomalous. TRPH concentrations observed during this preliminary sampling event were significantly lower than concentrations detected after 17 months of SVE system operation. For the purposes of evaluating the performance of the SVE system, it was assumed that the initial average TRPH concentration in contaminated area at Site 2/5 was 3,000 mg/kg. This assumption is documented in Reference 10 to this report (The Operation and Maintenance Phase Final Engineering Report). Table C-2 shows the maximum concentrations and Unified Soil Classification System (USCS) description for each pre-construction boring.

**Table C-1. Characteristics of Untreated Soil (3,7)\***

Boring ID (Depth)	Maximum Benzene Concentration Found (µg/kg)	Maximum Toluene Concentration Found (µg/kg)	Maximum Xylene (total) Concentration Found (µg/kg)	Maximum Ethylbenzene Concentration Found (µg/kg)	Maximum TRPH Contamination Found (mg/kg)
SB-02&5-09 (15-17 ft bgs)	12,000	16,000	150,000	62,000	17,500
SB-02&5-12 (15-17 ft bgs)	48,000	210,000	450,000	180,000	5,220
SB-02&5-18 (16-18 ft bgs)	15,700	43,500	244,000	101,000	5,050
SB-02&5-19 (8-10 ft bgs)	1,060	41,900	332,000	87,000	5,600
SB-02&5-21 (6-8 ft bgs)	3,950	78,800	500,000	135,000	5,600

\*Results from selected samples collected during the RI and PDI.



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Table C-2. Characteristics of Untreated Soil (1)\*

Boring ID (Location)	Maximum Benzene Concentration Found (µg/kg)	Maximum Toluene Concentration Found (µg/kg)	Maximum Xylene (total) Concentration Found (µg/kg)	Maximum Ethylbenzene Concentration Found (µg/kg)	Maximum TRPH Contamination Found (mg/kg)	USCS Soil Type
PB-1 (south)	2,900	35,000	130,000	49,000	1,100	sm
PB-2 (south- central)	ND	21,000	79,000	48,000	970	sm
PB-3 (north- central)	24,000	45,000	130,000	59,000	890	sm
PB-4 (north)	1,000	35,000	35,000	65,000	1,400	sm

\*Results from samples collected immediately prior to startup of the SVE system.

ND – not detected

sm – sand with fines; silty sands and sand-silt mixtures, which may be poorly graded; nonplastic

#### MATRIX CHARACTERISTICS AFFECTING TREATMENT COST OR PERFORMANCE

Soil Classification	USCS classification sm
Clay Content and/or Particle Size Distribution	Information not available
Moisture Content	Information not available
Air Permeability	Information not available
Porosity	Information not available
Total Organic Carbon	Information not available
Contaminant Sorption	Information not available
Presence of Inclusions	Information not available
Humic Content	Information not available

### TREATMENT SYSTEM DESCRIPTION

#### PRIMARY TREATMENT TECHNOLOGY

##### Soil Vapor Extraction

#### SUPPLEMENTARY TREATMENT TECHNOLOGIES

##### Post-treatment (Water)

A knockout tank is used to collect condensate from the extraction system prior to contacting the vacuum blower. Collected condensate is stored in 55-gallon drums and is disposed properly as necessary.

##### Post-treatment (Air)

In August 1997, a bioreactor was installed to treat a fraction of the vapor stream from the knockout tank. Prior to August 1997, treatment of the vapor stream from the SVE system was not performed at Site 2/5. It should be noted that treatment of the vapor stream from this system is not required by NMED. The bioreactor was installed as part of a research project conducted by New Mexico State University.



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Unfortunately, the unit did not function properly, and no meaningful vapor treatment performance data are available for the bioreactor.

### TIMELINE (3,10)

Date	Activity
1982-1983	CH2M Hill performed a Phase I Records Search for Holloman AFB.
1992	Radian Corporation performed a Remedial Investigation for Holloman and risk assessments for 29 sites at Holloman.
1993	Radian Corporation performed a Feasibility Study for three sites (including Site 2/5) at Holloman.
December 1994	IT Corporation began construction of the SVE system at Site 2/5 at Holloman. Construction included installation of 22 SVE/passive air vent wells.
March 1995	IT Corporation completed construction of the SVE system.
April 1995	IT Corporation began operation of the SVE system.
November 1996	IT Corporation completed 18 months of operation and maintenance (O&M) of the SVE system. Foster Wheeler took over the O&M on 1 November 1996.
August 1997	A bioreactor was installed to treat the vapor discharge stream from the SVE system (no vapor stream treatment had been used previously with the system).
March 1998	A Final Characterization Summary was submitted to NMED recommending that no further remedial action be taken at Site 2/5.

### TREATMENT SYSTEM SCHEMATIC AND TECHNOLOGY DESCRIPTION AND OPERATION

Figure 4 shows a simplified process flow diagram for the SVE system installed at Site 2/5.

#### Mobilization (1)

The contractor (IT Corporation) mobilized to the site on December 12, 1994. Mobilization included establishment of the project field office, surveying of proposed boring, vapor probe and well locations and inspection of all well installation equipment.

#### Construction (1)

- Sixteen (16) extraction wells, and six (6) combination extraction/passive vent wells were installed.
- Nine (9) soil vapor monitoring probe groups were installed to monitor the performance of the SVE system.
- Four (4) preliminary soil borings were installed to determine initial contaminant concentrations in site soil.

SVE system process piping, the 2-horsepower SVE blower, the knockout tank and a system control panel were installed. All of this equipment (other than the piping) was placed on an outdoor concrete slab surrounded by a fence.



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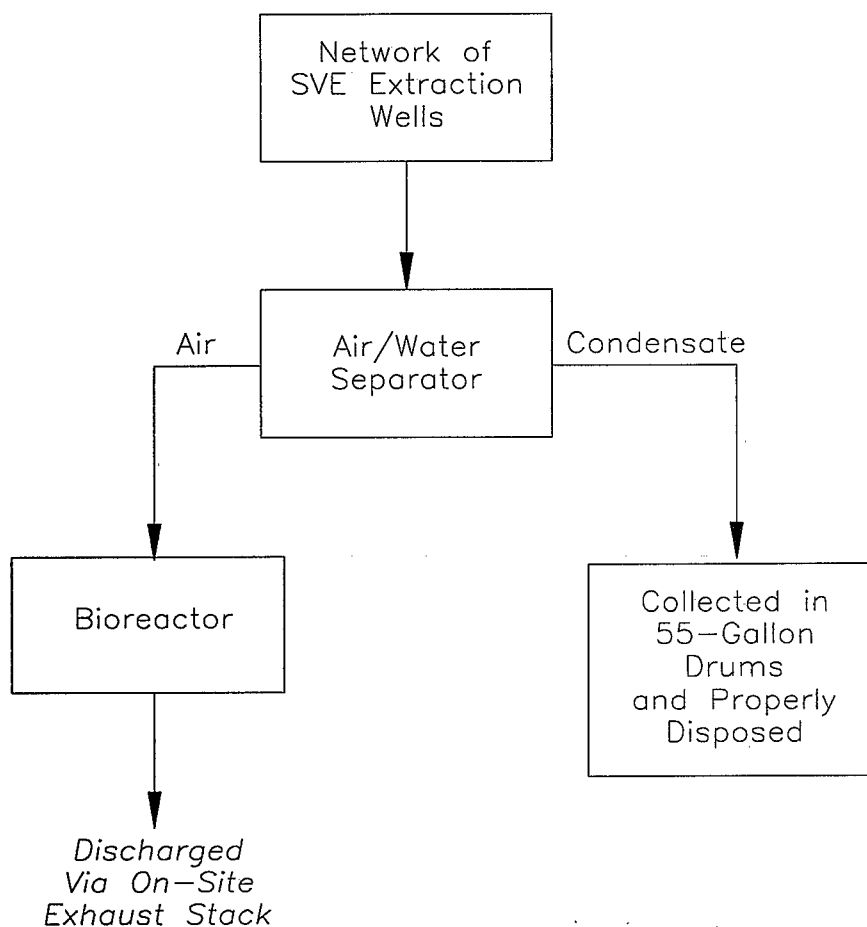


Figure 4. Treatment Process Flow Diagram for the SVE System at Site 2/5



- The system was tested prior to full-scale operation. Testing included:
  - Confirmation of system vacuum pressure, and methods of adjusting pressure (system inlet valve and fresh air bleed-in valve).
  - The volume of system exhaust was calculated and air samples were collected to determine system emissions;
  - Piping was visually and audibly inspected for leaks;
  - All system valves were checked for proper operation and for any leakage or obstructions; and
  - System alarms were set and tested.

#### Operation (10)

- The system was put into full-scale operation in April 1995 and is currently operating.
- The system experienced approximately 1.5 months of down time during the first three months of operation due to odor problems. These problems were addressed by raising the exhaust stack.
- The system experienced approximately 1.5 months of down time from October to December 1995 due to repeated rapid filling of the water collection tank. This problem was addressed by increasing the inspection schedule and emptying the collection tank more frequently.
- In July 1997, all 22 wells were converted to full extraction mode, and the system vacuum pressure was increased. These modifications were made to increase the contaminant removal rate of the system. The rate increase was possible because the system was operating well below New Mexico air emission guidelines (10 tons of VOCs allowed per year). It was determined that the system would be operated at a higher removal rate until site soil concentrations were below the guidance value of 1,000 mg/kg TPH, or until maximum allowable air emissions were achieved. Since July 1997, the well configuration has been modified several times. As of June 1998, 12 extraction wells were in use.
- In August and September 1997, a bioreactor (water-filled column) was installed to treat a fraction of the air stream from the SVE system. The bioreactor was installed by New Mexico State University. Prior to this time the air stream was not treated, as NMED did not require treatment. This unit did not function properly and is no longer in use.
- Throughout system operation, various extraction well configurations have been used. Prior to July 1997, the maximum number of extraction wells employed was 16. As many as 22 wells (all wells at the site) have been used for extraction since July 1997.



**OPERATING PARAMETERS AFFECTING TREATMENT COST OR PERFORMANCE (2,10)**

Air Flow Rate (typical)	70 standard cubic feet per minute (SCFM)
Operating Pressure/Vacuum (typical)	25.0 inches of water (since 11/96)
Operating Time	23,492 hours of operation through June 1998
Air Discharge Temperature (typical)	65-75 degrees Fahrenheit

**TREATMENT SYSTEM PERFORMANCE****PERFORMANCE OBJECTIVES**

- The soil cleanup goals for this application were developed based on the results of negotiations with the New Mexico Environmental Department (NMED).
- The negotiated cleanup goals for this application consist of the following:
  - TPH - 1000 mg/kg
  - Benzene - 25 mg/kg
  - Removal of floating free-phase hydrocarbons from groundwater

These are basewide goals for remedial activities at all POL sites.
- Groundwater at Holloman AFB was classified according the EPA Groundwater Protection Strategy. The groundwater was given a classification of III B (groundwater not a source of drinking water). Based on this classification, and because no floating free-phase hydrocarbons have been observed at the site, no groundwater cleanup goals were established for this site.

**TREATMENT PLAN**

No treatability studies or pilot tests were conducted prior to remediation at Site 2/5. SVE treatment was selected based on the recommendation of the December 1993 Feasibility Study.

**TREATMENT PERFORMANCE DATA (6,10)**

- Using data gathered prior to system startup, it was estimated that average soil TPH concentrations were 3,000 mg/kg prior to implementation of the SVE system. As mentioned previously, this assumption is documented in Reference 10 to this report. In September 1996, sampling indicated that the average soil TPH concentrations were approximately 1,600 mg/kg. As with the preliminary soil sampling event, samples were collected along the approximate centerline of the contaminated area. Data from the September 1996 sampling event are presented below in Table TPD-1.
- In September and October 1997, soil sampling was performed at Site 2/5 to determine if clean up criteria had been met. Sample locations were similar to those chosen for the 1994 and 1996 sampling events. In addition two borings (LT05 and LT06) were completed south of the main area of contamination. Results indicated that TPH concentrations at Site 2/5 had been reduced below 1,000 mg/kg (average TPH concentration was 150 mg/kg) and that benzene concentrations in soil remained below 25 mg/kg, as they have throughout the project. Table TPD-2 shows results from the 1997 sampling event. Figure 5 shows the sampling point locations for the 1996 and 1997 sampling events.



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Table TPD-1. Preliminary and Interim Confirmatory Soil Sampling Data at Site 2/5 [10]

Boring ID (Location)	Depth Interval (feet bgs)		Benzene Concentration (ug/kg)		Toluene Concentration (ug/kg)		Xylene (total) Concentration (ug/kg)		Ethylbenzene Concentration (ug/kg)		TPH Concentration (ug/kg)	
	12/94	09/96	12/94	09/96	12/94	09/96	12/94	09/96	12/94	09/96	12/94*	09/96
SB-01 (south end)	5-7	4-8	ND	ND	9,100	ND	90,000	ND	27,000	120	1,100	244
	10-12	9.5-10.5	ND	ND	35,000	ND	44,000	38,000	13,000	6,500	490	945
	15-17	13-15	2,900	ND	27,000	ND	130,000	32,000	49,000	4,800	760	787
	NS	13-5 (dup)	NS	ND	NS	ND	NS	35,000	NS	5,300	NS	1,530
SB-02	5-7	5-6	ND	ND	21,000	ND	79,000	410	48,000	99	970	619
	10-12	9.5-10.5	ND	ND	6,900	ND	71,000	260,000	22,000	19,000	820	4,030
	15-17	14-15	ND	ND	5,900	ND	70,000	200,000	28,000	58,000	520	2,670
SB-03	5-7	4.5-5.5	ND	ND	14,000	ND	130,000	ND	26,000	ND	140	2,080
	10-12	10-11	ND	ND	6,300	ND	70,000	14,000	19,000	1,700	560	895
	15-17	13-15	24,000	ND	45,000	ND	130,000	110,000	59,000	33,000	890	1,640
SB-04 (north end)	5-7	4.5-5.5	ND	ND	4,100	ND	60,000	170	27,000	ND	390	440
	10-12	10-11	1,000	ND	18,000	ND	180,000	220,000	65,000	82,000	1,400	3,930
	15-17	14-15	810	2,300	6,400	5,800	50,000	75,000	19,000	26,000	480	962
	5-7(dup)	NS	ND	NS	1,700	NS	11,000	NS	4,600	NS	1,100	962

ND - Not Detected

NS - Not Sampled

\* - 12/94 results were determined to be anomalous for TPH. 3000 mg/kg TPH was assumed to be the initial soil concentration.



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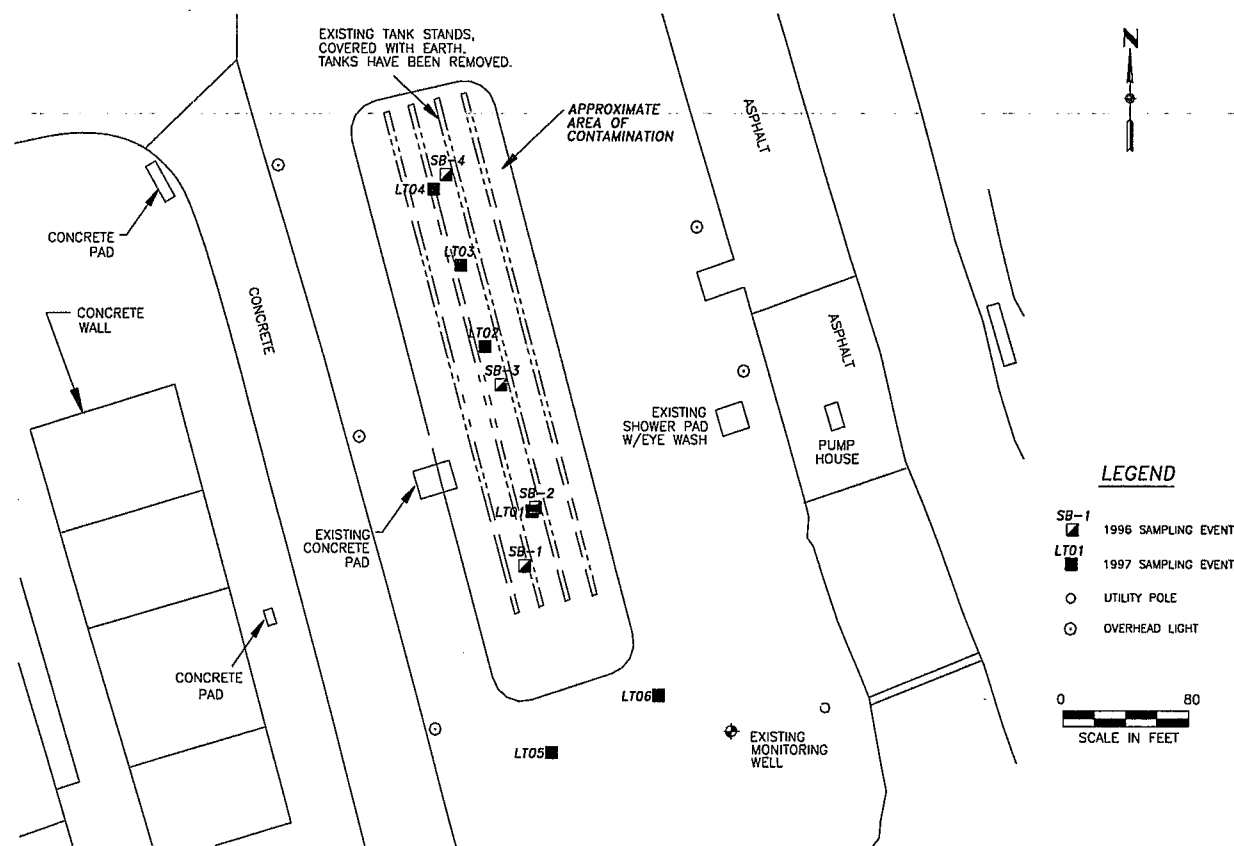
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Table TPD-2. Final Confirmatory Soil Sampling Results (13)

Boring ID	Depth (feet bgs)	Benzene Concentration (mg/kg)	Toluene Concentration (mg/kg)	Ethylbenzene Concentration (mg/kg)	Xylene Concentration (mg/kg)	TPH Concentration (mg/kg)
LT01	10-11	ND	ND	ND	ND	390
	17-18	ND	ND	8.6	100.0	300
LT02	13-14	ND	ND	28.0	4.0	170
	16-17	ND	ND	ND	0.9	ND
LT03	12-13	1.1	9.9	72.0	254.0	220
	17-18	ND	0.7	6.5	16.9	67
LT04	11-12	ND	3.6	41.0	103.0	80
	16-17	9.1	65.0	190.0	379.0	130
LT05	11-12	ND	ND	ND	ND	ND
LT06	12.5-13.5	ND	0.4	5.7	60.0	150







NOTE: PREVIOUS BORINGS (PRIOR TO 1997) WITH SOIL TPH CONCENTRATIONS BELOW 1000 mg/kg ARE NOT SHOWN ON THIS FIGURE.

Figure 5 - Confirmatory Sampling Locations



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Based on Monthly Project Metrics and Quarterly Project Status Reports generated throughout the course of the project, the following additional treatment performance data have been generated:

- The total estimated mass of TPH removed from the site (through December 1997) is 44,000 pounds (22 tons). This mass was calculated using results from air sampling of the exhaust stream from the SVE system.
- The monthly unit cost for TPH removal has varied from less than \$3 per pound removed to nearly \$21 per pound. The majority of the monthly unit costs have fallen between \$3 and \$6 per pound removed.
- As discussed earlier, average soil TPH concentrations at Site 2/5 have dropped from an estimated 3000 mg/kg to 150 mg/kg (October 1997). The clean up goal for the site is 1000 mg/kg. Sampling data indicate that benzene concentrations in site soil do not exceed the base-wide clean up goal of 25 mg/kg.
- The average monthly VOC concentrations in air emissions from the system were consistently near 1000 ppm from April 1995 through September 1996. In 1997, discharge concentrations varied from 1000 ppm to 4000 ppm due to various modifications to system operating parameters.
- The monthly O&M cost has typically varied between \$3000 and \$6000, with two sharply higher months in 1995 and 1996.
- The average TPH removal rate has typically varied between 2 and 3 pounds per hour.

**Material Balance:** A material balance cannot be performed for this application because initial contaminant volumes were not known. Removals can be estimated by using air emission concentrations, but there are no initial volumes for comparison and mass balance calculation.

**Removal Efficiencies (10,13):** At the time of the September 1996 interim sampling event, removal efficiencies were estimated by comparing VOC average concentrations with data gathered in December of 1994 (prior to system start up). Because TPH results from the December 1994 sampling event were considered anomalous, an initial TPH concentration of 3000 mg/kg was assumed. As mentioned previously, this assumption is documented in Reference 10 to this report. Based on these comparisons the following interim percent removals were achieved:

TPH	47%
Benzene	53%
Toluene	91%
Ethylbenzene	42%
Xylenes (total)	12%

Percent removals based on data gathered during the October 1997 sampling event are shown below. These percentages were also calculated using 3000 mg/kg as an initial concentration for TPH.

TPH	95%
Benzene	99%
Toluene	99%
Ethylbenzene	99%
Xylenes (total)	99%



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**PERFORMANCE DATA QUALITY**

It appears that a plan for sampling and analysis QA/QC was used for the confirmatory and initial sampling events at Site 2/5, including the collection of field duplicates, and the performance of typical laboratory QA/QC procedures. This plan was not available when this report was written.

**TREATMENT SYSTEM COST****PROCUREMENT PROCESS**

Details regarding the procurement process were not available for this project. IT Corporation was selected as the prime contractor for construction of the SVE system. The scope of work for IT also included performance of one year of treatment system O&M. The contract price for this project was \$548,046. In November 1996, after 18 months of system O&M, Foster Wheeler took over operation of the system. Foster Wheeler has performed system O&M from November 1996 through October 1998 (treatment ongoing). The mass of contaminants present at Site 2/5 has never been estimated, however, it has been estimated that 9500 cubic yards of soil were contaminated prior to commencement of remedial activities. Therefore, the bid cost can be converted to \$58 per cubic yard of contaminated soil.

**TREATMENT SYSTEM COST (2,7)**

- Bid specifications and a scope of services were developed in August 1993 for the Holloman AFB Site 2/5 remediation project. The government estimate for the project was \$550,780. The project tasks included installation of the SVE treatment system and 12 months of system operation and maintenance (O&M).
- In 1993, IT Corporation was awarded a contract for \$548,046 to perform the Site 2/5 remediation project. It was estimated that \$343,000 of the cost was for construction of the system, and that 12 months of system O&M would cost \$205,000.
- Following 18 months of system operation (completed in September 1996), O&M was turned over to Foster Wheeler. From October 1996 through August 1997 the cost for system O&M has been approximately \$60,000, bringing the total project cost to approximately \$610,000. This has increased the unit cost for treatment to \$64 per cubic yard of contaminated soil.
- The costs for Site 2/5 remediation (soil vapor extraction) were categorized according to the HTRW Remedial Action Work Breakdown Structure (WBS), which includes specific cost elements for before-treatment activities, cost elements for activities directly attributed to treatment, and cost elements for after-treatment activities. Using the WBS, the costs for remediation at Site 2/5 were categorized as shown below in Table Cost 1.

**Table Cost 1. Summary of Costs for SVE Activities at Site 2/5  
Categorized According to the WBS (12)**

WBS No.	Activity	Cost (\$)	Comment
33-01 and 33-21	Mobilization and demobilization	34,884	Before treatment activities
33-02	Sampling and Analysis	21,941	Sampling ongoing
33-113-23	SVE installation costs	286,822	
33-113-23-02-08	SVE system O&M	267,000	Treatment ongoing



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## REGULATORY/INSTITUTIONAL ISSUES

According to facility personnel at Holloman AFB, no permits were required for installation and operation of the SVE treatment system. It was necessary for the system to meet applicable state requirements pertaining to operation, including allowable air emissions.

For the duration of this project, the state of New Mexico (NMED) has taken the lead in implementing closure of Site 2/5. The USEPA has been involved with the project, but mostly to provide concurrent review of plans and reports.

Site 2/5 clean up criteria are base-wide criteria previously developed for Holloman AFB. These criteria are:

- 1000 mg/kg TPH in soil;
- 25 mg/kg benzene in soil; and
- Removal of free-phase hydrocarbons from the groundwater surface.

Because benzene has never been detected above 25 mg/kg and free-phase hydrocarbons have not been observed in the groundwater at Site 2/5, only TPH removal was required at Site 2/5.

## OBSERVATIONS AND LESSONS LEARNED

### COST OBSERVATIONS AND LESSONS LEARNED

The awarded contract amount of \$548,046 can be converted to an estimated cost for treatment of \$58 per cubic yard of contaminated soil (9500 cubic yards to be treated). Based on the current cumulative project cost of approximately \$610,000, the treatment cost has increased to \$64 per cubic yard.

According to project personnel, equipment costs for the treatment system could have been reduced by substituting less expensive, painted PVC piping for fiberglass piping. It is unknown why fiberglass piping was used for this project.

### PERFORMANCE OBSERVATIONS AND LESSONS LEARNED

According to project personnel, the treatment system performance could have been improved by minimizing groundwater fluctuations at the site. Contaminant removal rates could have been increased by keeping the groundwater levels from rising significantly during periods of wet weather. A system of extraction wells could have been used to perform dewatering at the site.

In addition, field personnel have reported that the plastic sampling ports on the treatment system become degraded easily when exposed to direct sunlight, and require replacement.

## REFERENCES

- 1) Construction Phase Final Report, Site 2/5, POL Site Remediation, Holloman AFB, New Mexico, Prepared by IT Corporation, Denver, Colorado, August 1995.
- 2) Quarterly Project Status Report, April – September 1997, Sites 2 and 5/BX Service Station/Former Fire Training Area/POL Washrack/Officer's Club/T-38 Test Cell/Building 828/SWMU 136 Treatment System, Prepared by Foster Wheeler Environmental Corporation, Lakewood, Colorado, November 1997.



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- 3) Remedial Investigation Report, Investigation, Study and Recommendation for 29 Waste Sites, Prepared by Radian Corporation, October 1992.
- 4) Draft Final Feasibility Study, Investigation, Study and Recommendation for 29 Waste Sites, Prepared by Radian Corporation, December 1993.
- 5) RCRA Facility Investigation, Holloman Air Force Base, New Mexico, October 1994.
- 6) Project Metrix Update for Holloman Air Force Base, Prepared by Foster Wheeler Environmental Corporation, Lakewood, Colorado, September 1997.
- 7) Scope of Services for Contract No. DACW45-89-D-0504, Soil Vapor Extraction System, Site 2/5 & Infiltration well System, Site 57, Holloman AFB, New Mexico, August 1993.
- 8) Quarterly Project Status Report, January – March 1997, BX Service Station/ T-38 Test Cell /POL Washrack/Building 828/FT-31 Former Fire Training Area /Sites 2 and 5/Officer's Club Treatment Systems, Prepared by Foster Wheeler Environmental Corporation, Lakewood, Colorado, November 1997.
- 9) Cost Data for Innovative Treatment Technologies, Project Name: Sites 2 and 5, Soil Vapor Extraction System (SVE), Holloman AFB, Otero County, New Mexico, Prepared by the USACE, no date provided.
- 10) Operation and Maintenance Phase, Final Engineering Report, Site 2/5 POL Site Remediation, Holloman AFB, New Mexico, Prepared by IT Corporation, Denver, Colorado, March 1997.
- 11) Specifications (For Construction Contract), Attachment E, Site 2/5 POL Site Remediation, Prepared by the USACE, Omaha District, August 1993.
- 12) Facsimile communication from Rick Macfarlane (CESWA-CO-SA-H) to Jim Peterson (CEMRO-HX-T), Description of to date costs for Holloman AFB Site 2/5 project, November 1996.
- 13) Final Characterization Summary and No Further Action Documentation for IRP Sites SS-2/5 POL Yard (SWMU AOC-T), SD-47 POL Washrack Area (SWMU 133), and SS-60 Building 828 (SWMU 230), Prepared by Foster Wheeler Environmental Corporation, Lakewood, Colorado, March 1998.

## **ACKNOWLEDGEMENTS**

This report was prepared for the U.S. Army Corps of Engineers under USACE Contract No. DACA45-96-D-0016, Delivery Order No. 12.



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**Soil Vapor Extraction at Intersil/Siemens Superfund Site  
Cupertino, California**

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## Soil Vapor Extraction at Intersil/Siemens Superfund Site Cupertino, California

<b>Site Name:</b> Intersil/Siemens Superfund Site	<b>Contaminants:</b> Trichloroethene (TCE)	<b>Period of Operation:</b> May 1988 to August 23, 1993
<b>Location:</b> Cupertino, California		<b>Cleanup Type:</b> Full-scale
<b>Vendor/Consultant:</b> Susan Colman Geomatrix Consultants, Inc. 100 Pine Street, 10th Floor San Francisco, CA 94111 (415) 743-7031	<b>Technology:</b> Soil Vapor Extraction: - Seven extraction wells (six installed in pairs - one in the shallow vadose zone the other in the deep vadose zone - Three carbon bins to adsorb contaminants from the extracted soil vapor - Air flow rates in individual wells ranged from 3 to 38 scfm (data on total system flow was not available)	<b>Cleanup Authority:</b> CERCLA - ROD date: September 1990
<b>Additional Contacts:</b> Information not provided		<b>EPA Remedial Project Manager:</b> Richard Procnier U.S. EPA Region 9 75 Hawthorne Street San Francisco, CA 94105 (415) 744-2219  <b>State Contact:</b> Habte Kifle* California Regional Water Quality Control Board 1515 Clay Street, Suite 1400 Oakland, CA 94612 (510) 622-2371
<b>Waste Source:</b> Waste from the manufacture of semiconductors and related wafer fabrication	<b>Type/Quantity of Media Treated:</b> Soil - 280,000 cubic yards	
<b>Purpose/Significance of Application:</b> SVE application using paired wells		
<b>Regulatory Requirements/Cleanup Goals:</b> <ul style="list-style-type: none"> <li>- The ROD identified the following remedial goals for soil: total VOCs - 1 mg/kg and total SVOCs - 10 mg/kg.</li> <li>- Air emissions standards for the SVE system, identified as the Bay Area Air Quality Management District, allowed an annual average of 2 pounds per day (lbs/day) of organics to be emitted.</li> </ul>		
<b>Results:</b> <ul style="list-style-type: none"> <li>- Total VOCs were below the remedial goal of 1 mg/kg for 79 of 80 soil boring confirmatory samples. For one sample, total VOCs was reported as 1.1 mg/kg. However, the results of an assessment of the significance of the single exceedance indicated that, with a confidence level of greater than 95 percent, the soil remedial goal was met.</li> <li>- According to Geomatrix, SVOCs were not detected in any samples.</li> <li>- From May 1988 to December 1992, the removal rate for TCE decreased from approximately 15.5 lbs/day to less than 0.5 lbs/day and approximately 3,000 lbs of TCE were extracted.</li> </ul>		



## **Soil Vapor Extraction at Intersil/Siemens Superfund Site Cupertino, California (continued)**

**Cost:**

- Total cost of \$770,000, including \$550,000 in capital and \$220,000 in O&M costs.
- Corresponds to a unit cost of \$3 per cubic yard for 280,000 cubic yards of soil treated, and \$260 per pound of contaminant removed (3,000 lbs removed).

**Description:**

The 12-acre Intersil/Siemens Superfund site, located in suburban Cupertino, California, includes two industrial properties used for the manufacture of semiconductors and related wafer fabrication - the Intersil facility, which operated from 1967 to 1988, and the Siemens facility, which has manufactured semiconductors at the site since 1978 and is an operating facility. The facilities used a variety of chemicals and chemical solutions in their manufacturing operations, including etching solutions, organic solvents and chemical mixtures. Soils and groundwater contaminated with volatile organic compounds (VOCs) and semivolatile organic compounds (SVOCs) were discovered on each of the sites, and several interim actions, including SVE, were implemented at the site. The site was listed on the NPL in August 1990. A Record of Decision (ROD) was signed in September 1990 that incorporated the interim remedies including SVE. This report focuses on the completed SVE application at the Intersil property. The ROD identified the following remedial goals for soil: total VOCs - 1 mg/kg and total SVOCs - 10 mg/kg. Air emissions standards for the SVE system, identified as the Bay Area Air Quality Management District, allowed an annual average of 2 pounds per day (lbs/day) of organics to be emitted.

The interim SVE system, which began operating in May 1988, included four vertical vapor extraction wells. As part of the final remedy, the SVE system was expanded in May 1991 to include three additional extraction wells. Six of the wells were installed in pairs along the eastern portion of the Intersil building - one well in the shallow vadose zone (about 10 to 50 feet deep) and the other in the deep vadose zone (about 60 to 100 feet deep). The sixth well was located along the western portion of the building. Three carbon bins were used to adsorb contaminants from the extracted soil vapor. Air flow rates in individual wells ranged from 3 to 38 scfm. According to the vendor (Geomatrix), total system flow and TCE concentrations for the total system were not available and the SVE system generally operated continuously until it was shut down (August 23, 1993). Based on the results of confirmatory soil samples, total VOCs were below the remedial goal of 1 mg/kg for 79 of 80 of the samples. For one sample, total VOCs was reported as 1.1 mg/kg. However, the results of an assessment of the significance of the single exceedance indicated that, with a confidence level of greater than 95 percent, the soil remedial goal was met. According to Geomatrix, SVOCs were not detected in any samples. From May 1988 to December 1992, the removal rate for TCE decreased from approximately 15.5 lbs/day to less than 0.5 lbs/day and approximately 3,000 lbs of TCE were extracted.

The total cost of \$770,000 for this application included \$550,000 in capital costs and \$220,000 in O&M costs. This corresponds to a unit cost of \$3 per cubic yard for 280,000 cubic yards of soil treated, and \$260 per pound of contaminant removed (3,000 lbs removed).

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# Cost and Performance Summary Report

## Soil Vapor Extraction at the Intersil/Siemens Superfund Site

### Cupertino, California

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#### Summary Information [1, 2, 4, 5, 6, 7]

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The 12-acre Intersil/Siemens Superfund site is located in suburban Cupertino, California. The site includes two industrial properties used for the manufacture of semiconductors and related wafer fabrication - the Intersil facility, which operated from 1967 to 1988, and the Siemens facility, which has manufactured semiconductors at the site since 1978 and is an operating facility. The facilities used a variety of chemicals and chemical solutions in their manufacturing operations, including etching solutions, organic solvents (for example, trichloroethene (TCE), 1,1,1 - trichloroethane (TCA), methanol, isopropanol, n-butyl acetate, acetone, xylene, freon, and ethylbenzene) and chemical mixtures that reportedly contained phenols and toluene. The facilities had a number of underground waste handling facilities - five waste solvent tanks and an acid dilution basin at Siemens; three acid neutralization systems, two scrubber sumps, and a waste storage tank at Intersil.

During a 1982 underground storage tank investigation conducted by the state, soils contaminated with volatile organic compounds (VOCs) were discovered on each of the sites, as well as outside the property boundaries. The suspected sources of the contamination included spills, leaks from the underground waste handling facilities, and leaks from underground piping. A remedial investigation (RI) was initiated in 1982. Initial subsurface investigations found TCE, TCA, and trichlorobenzene contamination at the Siemens property in the vicinity of former waste solvent tanks 1 and 3. TCA concentrations were reported in the soil as high as 11,000 milligrams per kilogram (mg/kg). Additional site investigations found TCA and TCE contamination at the Intersil property at concentrations as high as 10 mg/kg.

The results of the groundwater investigation of both properties showed on-site and off-site contamination of the groundwater. Groundwater TCE concentrations were found as high as 26,000 micrograms per liter ( $\mu\text{g/L}$ ) at the Siemens property and as high as 33,000  $\mu\text{g/L}$  at the Intersil property. The groundwater contamination plumes from both properties in the upper hydrogeologic unit, or A-zone, had commingled, migrated to the lower unit, or B-zone, and migrated off-site.

The RI continued over a period of eight years. During this time, several interim remedial actions occurred. At the Siemens property, a soil vapor extraction (SVE) system and a groundwater pump-and-treat system were installed in 1983. At the Intersil property, the east underground acid neutralization system and a waste solvent tank were removed in 1986 and an SVE system and a groundwater pump-and-treat system were installed in 1987. In the fall of 1988, additional potential source areas of contamination were removed from the Intersil property. These included the north neutralization system, the scrubber sumps, and an above-ground waste storage area. A groundwater pump-and-treat system was installed by both companies to treat the off-site groundwater contamination.

The site was proposed for the NPL in June 1988 and was listed in August 1990. A Record of Decision (ROD) was signed in September 1990. The selected remedy in the ROD incorporated the interim response actions described above. The ROD specified continued operation of the SVE and groundwater pump-and-treat systems at both properties, continued operation of the off-site groundwater pump-and-treat system, excavation and off-site disposal of soil contaminated with greater than 10 mg/kg semivolatile organic compounds (SVOCs) at the Siemens property, continued monitoring of the soil at both properties, and continued on- and off-site groundwater monitoring.

This report focuses on the completed SVE application at the Intersil property. The SVE application at the Siemens property was on-going at the time of this report and, therefore, is not addressed in this report.

From May 1988 to August 1993, approximately 280,000 cubic yards ( $\text{yd}^3$ ) of contaminated soil were treated by the SVE system application at Intersil. The volume of soil requiring treatment was based on an estimate of the quantity of soil which contained TCE in excess of the remedial goal (1 mg/kg of total VOCs).

CERCLIS ID Number: CAD041472341

Lead: California Regional Water  
Quality Control Board  
(CA RWQCB)

**Timeline [2, 3, 4, 7]**

1987	Interim SVE system designed and installed at Intersil
May 1988	Interim SVE system full-scale operation began
January 1990	RI at Intersil site completed
August 15, 1990	Site Cleanup Requirements (SCR) Order No. 90-119 issued by RWQCB
September 27, 1990	ROD for Intersil issued
May 31, 1991	SVE system expanded from four to seven vapor extraction wells as part of the final remedy described in SCR Order No. 90-119
November 2 - December 31, 1992	Confirmation sampling conducted to evaluate cleanup progress
December 28, 1993	SCR Order No. 90-119 amended, reducing groundwater monitoring frequency from quarterly to semi-annually
May 14, 1993	Complete curtailment of soil remediation approved by RWQCB
August 23, 1993	SVE system shut down
August - December 1993	SVE system decommissioned; site backfilling and compaction of excavations conducted

**Factors That Affected Cost or Performance of Treatment [4, 7]**

Geology at the Intersil site consists of interbedded coarse- and fine-grained sediments which are characteristic of alluvial stream channel and associated floodplain deposits. These deposits extend to between 105 and 120 feet below ground surface (bgs), the approximate depth of the water table.

Listed below are the key matrix characteristics that affected the cost or performance of this technology and the values measured for each.

**Matrix Characteristics**

Parameter	Value
Soil Classification/ Particle Size Distribution:	Interbedded coarse-grained sand and gravel, and fine-grained silt and clay
Moisture Content:	4.4-21.9%
Air Permeability:	Not available
Porosity:	33-47%
Total Organic Carbon:	6-12%
Nonaqueous Phase Liquids:	Not identified

**Treatment Technology Description [2, 3, 4]**

The interim SVE system, which began operating in May 1988, included four vertical vapor extraction wells (VE-1 through VE-4). As part of the final remedy, the SVE system was expanded in May 1991 to include three additional extraction wells (VE-5, VE-7, VE-8). As shown in Figure 1, six of the wells were installed in pairs along the eastern portion of the Intersil building. For these pairs, one well was installed in the shallow vadose zone (about 10 to 50 feet deep) and the other in the deep vadose zone (about 60 to 100 feet deep). Well VE-5 was located along the western portion of the building. Three carbon bins were used to adsorb contaminants from the extracted soil vapor.

Data on flow rates, TCE concentrations, and TCE removal rates were collected on a monthly basis at each well head. Table 1 presents available data through March 1993. According to the vendor (Geomatrix), total system flow and TCE concentrations for the total system were not available.

According to the vendor, the SVE system generally operated continuously until it was shut down (August 23, 1993).

Figure 1. Site Plan Showing Vadose Zone Wells [3]

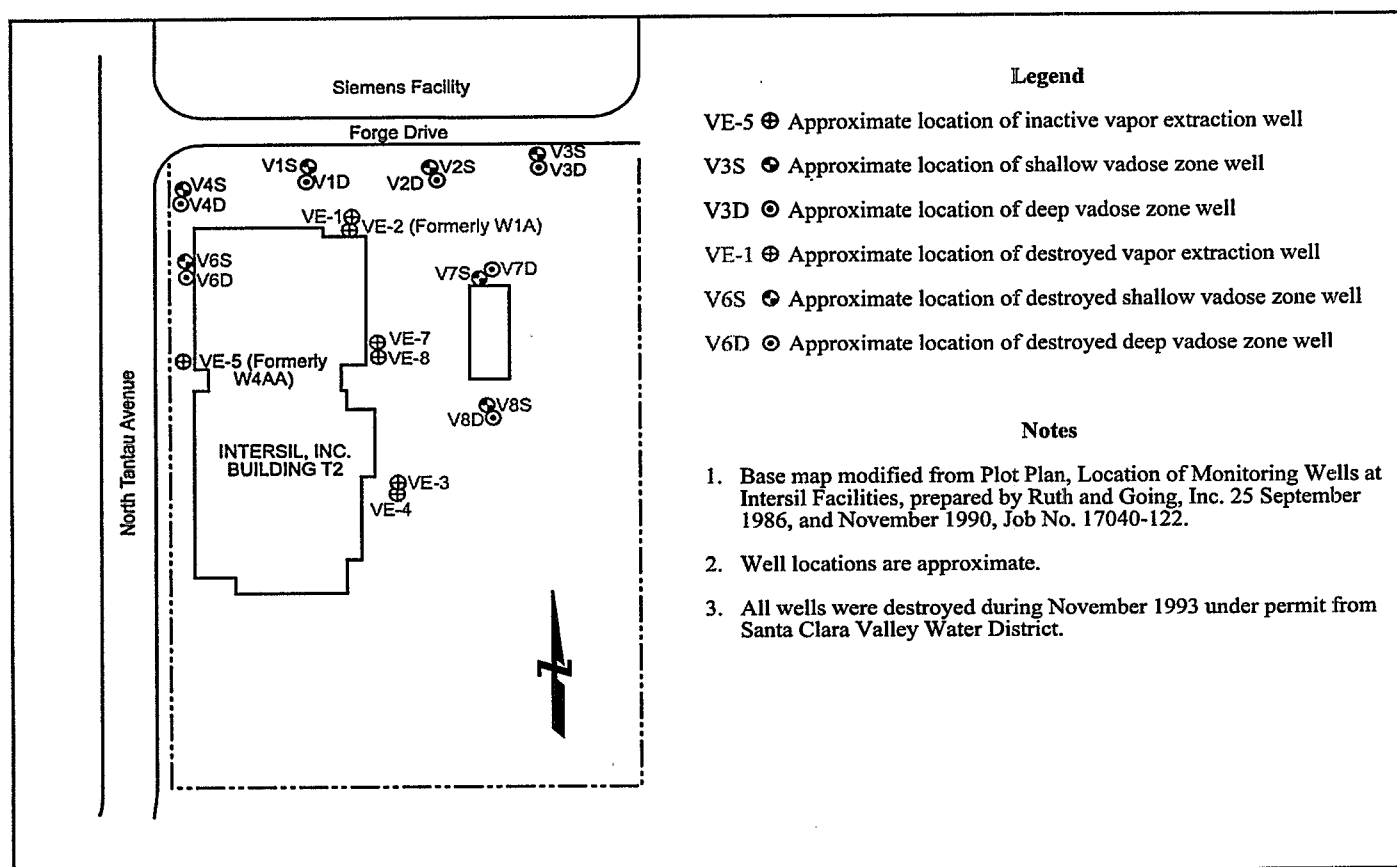


Table 1. Extraction Well Data (Through March 1993) [2, 7]

Well No.	Flow Rate Range (scfm)	TCE Concentration Range (ppmv)	TCE Removal Rate Range (lb/day)
VE-1	11 - 37.9	<0.02 - 590	0.03 - 7.61
VE-2	9 - 21	<0.09 - 548	0 - 5.5
VE-3	6.5 - 30	<0.02 - 161	0.01 - 2.3
VE-4*	NA	NA	NA
VE-5	13 - 26	<0.73 - 24.2	<0.01 - 0.21
VE-7	3 - 7	1.0 - 22.4	<0.01 - 0.06
VE-8	1.6 - 5.4	<0.3 - 33.5	<0.01 - 0.04
Total System	NA	NA	0.27 - 15.41

\* Flow rates from VE-4 were lower than could be measured with available instrumentation.  
 NA = Not available

Listed below are the key operating parameters that affected the cost or performance of this technology and the values measured for each.

#### Operating Parameters

Parameter	Value
Air Flow Rate:	See Table 1
Operating Vacuum:	Approximately 4.5 inches Hg at blower; approximately 1 inch Hg at SVE well heads

#### Performance Information [1, 2, 4, 7]

The ROD identified the following remedial goals for soil:

- Total VOCs - 1 mg/kg
- Total SVOCs - 10 mg/kg

Total VOCs was defined as the sum of the detected volatile organic compounds. Total SVOCs was defined as the sum of the detected semivolatile organic compounds.

Air emissions standards for the SVE system were identified as the Bay Area Air Quality Management District, Regulation 8, Rule 47 requirements. The operating permit allowed an annual average of 2 pounds per day (lbs/day) of organics to be emitted.

An estimated 429 soil samples were collected from 50 soil borings during the RI. Table 2 summarizes the range of concentrations measured in selected soil borings during the RI. According to Geomatrix, only 33 of the 429 samples (less than 10 percent) contained total VOC concentrations above 1 mg/kg. The maximum concentration of VOCs detected during RI sampling was 7.0 mg/kg.

A total of 80 soil samples were collected from 16 soil borings during confirmation sampling (November 2 - December 31, 1992). Results from these samples, summarized in Table 2, show total VOCs below the remedial goal of 1 mg/kg for 79 of 80 soil boring samples. For one sample, total VOCs was reported as 1.1 mg/kg. According to Geomatrix, SVOCs were not detected in any samples. Figure 3 shows the locations of RI and confirmation sample borings.

To assess the significance of the single exceedance, Geomatrix analyzed the data using the methodology presented in EPA's *Methods for Evaluating the Attainment of Cleanup Standards, Volume I: Soil and Solid Media*. Results of the analysis indicated that, with a confidence level of greater than 95 percent, the soil remedial goal was met. RWQCB approved curtailment on May 14, 1993.

The concentrations of TCE in the confirmation samples were identical to the concentrations of total VOCs in 15 of the 16 soil boring locations, indicating that TCE was the primary contributor to the total VOC concentration.

According to Geomatrix, the SVE system at the Intersil site met the air emissions standards for this application.

Figure 2 shows the removal rate and cumulative mass removal for TCE from May 1988 to December 1992. During this time, the removal rate for TCE decreased from approximately 15.5 lbs/day to less than 0.5 lbs/day and approximately 3,000 lbs of TCE were extracted.

Removal rate data for TCE were also provided for each well as monthly averages from the start date of well operation through March 1993 (Table 1). TCE removal rates ranged as follows for each well: (VE-1) - 0 to 7.61 lbs/day; (VE-2) - 0 to 5.5 lbs/day; (VE-3) - 0 to 2.3 lbs/day; (VE-5) - 0 to .21 lbs/day; (VE-7) - <.01 to .06 lbs/day; (VE-8) - 0 to .04 lbs/day.

As shown in Table 1, TCE concentrations ranged as follows for each well: (VE-1) - <0.02 to 590 parts per million dry volume (ppmv); (VE-2) - <0.09 to 548 ppmv; (VE-3) - <0.02 to 161; (VE-5) - <0.03 to 24.2 ppmv; (VE-7) - 1 to 22.4 ppmv; (VE-8) - <0.3 to 33.5 ppmv. Extracted vapor sampling data for the total system were not available.

#### Performance Data Quality [2]

Confirmation soil samples were analyzed by Anamatrix, Inc. for Geomatrix in accordance with EPA-approved methods. Samples from borings VB-1 through VB-6 were analyzed in accordance with EPA Methods 8010 and 8020. Samples from borings VB-7 through VB-16 were analyzed in accordance with EPA Method 8010. No exceptions to quality assurance/quality control (QA/QC) protocols were noted in the available references.

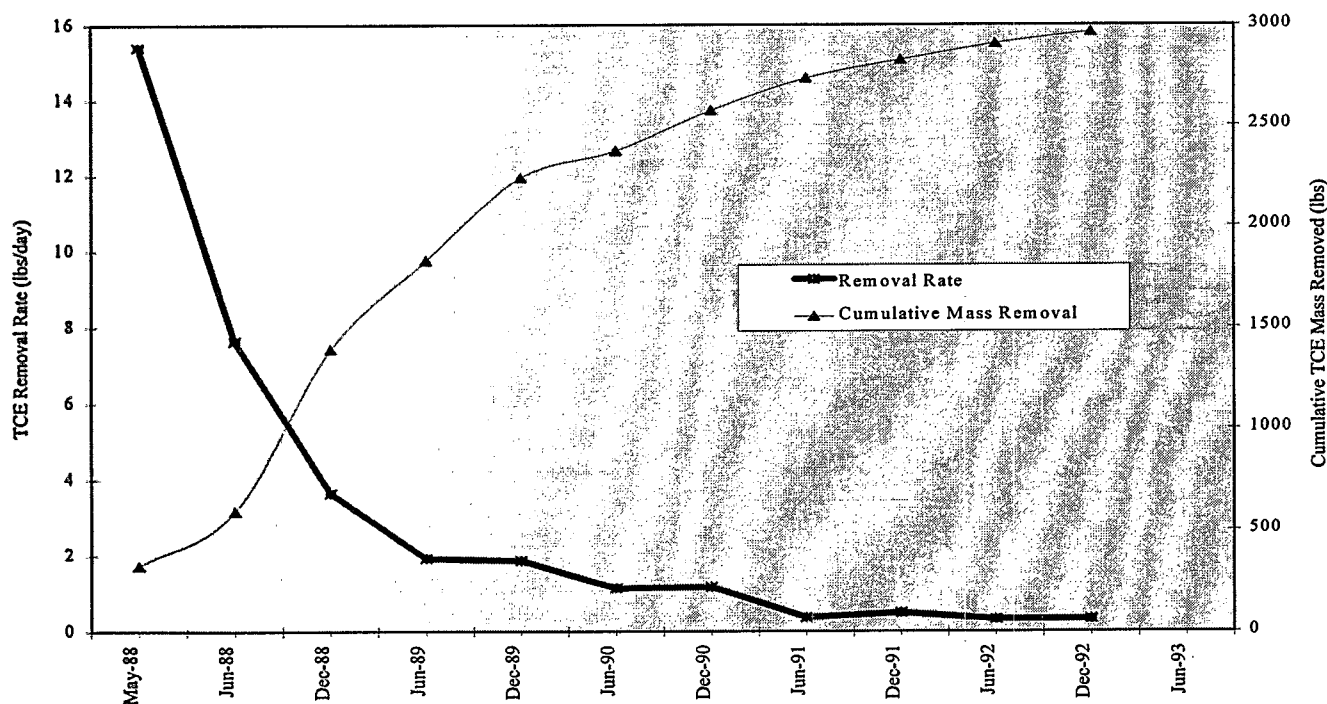
Table 2. Treatment Performance Data [2]

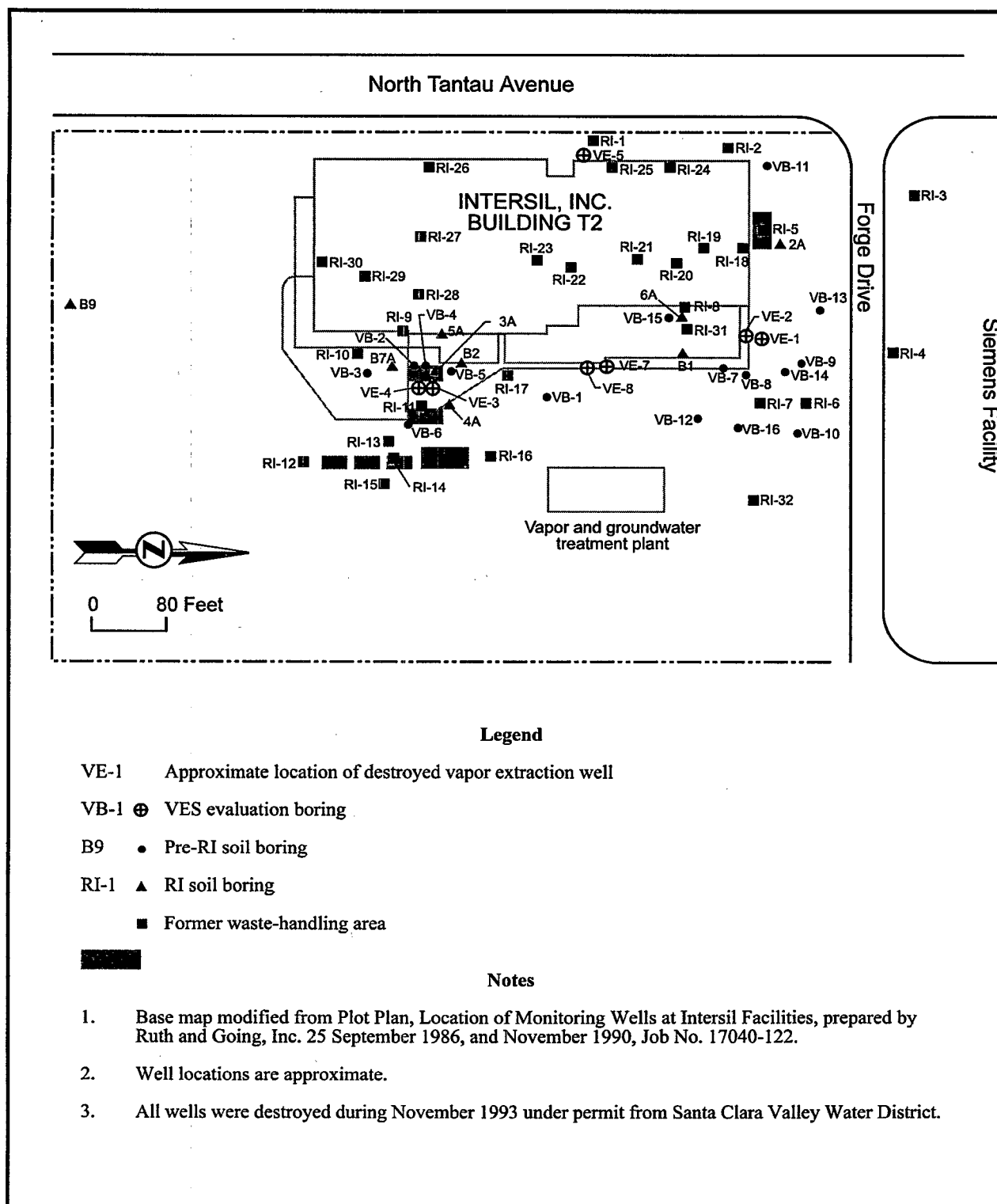
Soil Boring I.D.	Range of Depths Sampled (ft bgs)	Range of Concentrations from RI Sampling (mg/kg)*	Range of Concentrations from Confirmation Sampling (mg/kg)	
		Total VOCs	TCE	Total VOCs
VB-1	6.5 - 40.5	0.015 - 0.172	ND - 0.004	ND - 0.004
VB-2	4.5 - 52.5	<0.5 - 3.3	ND - 0.0081	0.0008 - 0.0081
VB-3	6.5 - 56.5	0.017 - 3.3	ND	ND
VB-4	4.5 - 54.5	0.39 - 1.44	ND - 0.012	ND - 0.012
VB-5	4.5 - 50.5	0.333 - 1.44	ND - 0.011	ND - 0.011
VB-6	8.5 - 52.5	0.009 - 0.063	ND - 0.0034	ND - 0.0034
VB-7	4.5 - 70.5	0.009 - 0.073	ND - 0.015	ND - 0.015
VB-8	4.5 - 66.5	0.095 - 0.750	ND - 0.069	ND - 0.069
VB-9	8.5 - 86.5	0.394 - 1.32	ND - 0.25	ND - 0.25
VB-10	8.5 - 78.5	0.038 - 1.5	0.00056 - 1.1	0.00056 - 1.1
VB-11	4.5 - 82.5	0.056 - 7.0	ND - 0.16	ND - 0.16
VB-12	4.5 - 90.5	0.009 - 0.073	ND - 0.017	ND - 0.017
VB-13	4.5 - 92.5	0.394 - 1.32	ND - 0.019	ND - 0.02
VB-14	10.5 - 86.5	0.394 - 1.32	ND - 0.016	ND - 0.016
VB-15	12.5 - 90.5	0.006 - 0.227	0.0035 - 0.022	0.0035 - 0.022
VB-16	12.5 - 96.5	0.022 - 0.75	0.002 - 0.043	0.002 - 0.043

ND = not detected at 0.0005 mg/kg detection limit.

\* A total of 429 soil borings were taken during the RI. The RI data included in this table are from 90 of the soil borings that were closest to the location of the soil borings taken during confirmation sampling.

Figure 2. SVE Total System Removal Rate and Cumulative Removal Mass of TCE (May 1998 - Dec 1992) [2]





**Figure 3. Site Plan Showing VES Wells and Sampling Locations [2]**

### Cost Information [3]

Cost information provided by Geomatrix indicated that a total of \$770,000 was expended for SVE activities at Intersil. Prior to remediation, a total of \$439,000 was expended on the remedial investigation and feasibility study. All costs were rounded to the nearest \$1,000 by Geomatrix. No additional detail on the elements included within capital and O&M costs was provided.

The total cost of \$770,000 (capital and O&M) corresponds to a unit cost of \$3 per cubic yard for 280,000 cubic yards of soil treated, and \$260 per pound of contaminant removed (3,000 lbs removed).

### Actual Project Costs

Cost Element	Cost (\$ in 1994)
Capital	550,000
Operation & Maintenance	220,000
Disposal of Residuals	0
Analytical (related to compliance monitoring, not technology performance)	0
Total Project Cost	770,000
Other - RI/FS	439,000

### Observations and Lessons Learned [1, 2, 4]

The SVE system application at Intersil achieved the remedial goal for this application of 1 mg/kg for total VOCs. TCE, the primary contributor to total VOCs at this site, was reduced from a maximum of 7.0 mg/kg to less than 1 mg/kg, with one exception.

Geomatrix performed a statistical analysis using EPA methodology to assess whether the soil remedial goal of 1 mg/kg for total VOCs was met for this application. For one soil boring analysis, the TCE concentration was slightly higher than the remedial goal; however, it was shown that the goal was met with a confidence level of greater than 95%.

The ROD estimated the time to achieve soil cleanup using SVE to be five years. Based on confirmatory sampling in December 1992, the SVE system at Intersil had met the remedial goal of 1 mg/kg for total VOCs within five years of operation; the system was shut down after 63 months of operation.

The TCE removal rate (lbs/day) for the three wells added in May 1991 as part of the final remedy (VE-5, VE-7, VE-8) was lower than the rate for the original extraction wells. By May 1991, the system had already removed about 2,700 lbs of TCE or 90 percent of the total amount of TCE removed by the system.

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\* Primary contact for this application

### References

The following references were used in the preparation of this report.

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2. Geomatrix Consultants, Inc. 1993. *Proposal to Curtail Soil Vapor Extraction, Former Intersil Facility, Cupertino, California*. Prepared for Intersil, Inc. May.



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6. EPA. 1996. Innovative Treatment Technologies Annual Status Report (96 Annual Status Report). Detailed Site Information. Intersil. September.
7. Susan Colman, Geomatrix Consultants. 1998. Comments on Draft Cost and Performance Report. September 25.

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#### **Acknowledgments**

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**Photolytic Destruction Technology Demonstration at  
NAS North Island, Site 9**

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## Photolytic Destruction Technology Demonstration at NAS North Island, Site 9

<b>Site Name:</b> NAS North Island, Site 9	<b>Contaminants:</b> Volatile Organic Compounds (VOCs) - Halogenated and non-halogenated VOCs, including 1,2-dichloroethene, trichloroethene, tetrachloroethene, toluene	<b>Period of Operation:</b> 10/12/97 - 10/18/97 - startup 10/24/97 - 1/8/98 - parametric tests 1/17/98 - 2/6/98 - steady-state tests
<b>Location:</b> San Diego, CA		<b>Cleanup Type:</b> Demonstration
<b>Vendor:</b> Process Technologies Inc (PTI)	<b>Technology:</b> Photolytic Destruction - Fluidized bed concentration unit, including an absorber, desorber, and chilled-water condenser - Photolytic destruction unit (PDU), consisting of photolytic reactors and a wet scrubber	<b>Cleanup Authority:</b> CERCLA
<b>Additional Contacts:</b> Naval Facilities Engineering Service 1100 23rd Avenue Port Hueneme, CA 93043-4301		<b>Regulatory Point of Contact:</b> Information not provided
<b>Waste Source:</b> Disposal of liquid chemical waste	<b>Type/Quantity of Media Treated:</b> Soil vapor - estimated 1,151 lbs of VOCs	
<b>Purpose/Significance of Application:</b> Demonstrate the effectiveness of PTI's photolytic destruction units in treating VOC-contaminated vapor from an SVE system		
<b>Regulatory Requirements/Cleanup Goals:</b> The goal of the demonstration was to obtain cost and performance data on PTI's system and to make comparisons to other treatment technologies demonstrated at the site. The objectives included determining the total average destruction and removal efficiencies of the system, developing cost data for a 3000 scfm PTI system, and characterizing and quantifying secondary waste streams and residuals.		
<b>Results:</b> - The PTI system removed VOCs in the SVE off-gas to levels below the maximum allowable emissions of 25 ppmv. The average total DRE for VOCs was 95%. - The report provides more detailed information comparing PTI's technology performance to other treatment technologies.		
<b>Cost:</b> - The total demonstration cost was \$93,726, including work plan, mobilization/demobilization, site work, liquids collection and containment, treatment, monitoring, sampling and analysis, and residuals disposal. The report included a detailed cost breakout. - The estimated unit cost to treat the SVE off-gas at NAS North Island's Site 9, using a 3000 scfm system, is \$3.77 per lb of VOC.		

## Photolytic Destruction Technology Demonstration at NAS North Island, Site 9 (continued)

### Description:

NAS North Island Site 9, the Chemical Disposal Area, was used for the disposal of liquid chemical wastes from the 1940s to the 1970s. A wide range of contaminants were detected in soils at the site including VOCs, semi-volatile organic compounds (SVOCs), petroleum hydrocarbons, PCBs, and metals. As part of a non-time-critical removal action, an SVE system has been installed at the site in Areas 1 and 3 to remove and treat VOCs. As part of the Navy Environmental Leadership Program, PTI was selected to demonstrate their Photolytic Destruction Technology for NAS North Island, Site 9 and to make comparisons with other commercially-available treatment technologies. The PTI system was demonstrated with the existing SVE system at the site, specifically treating soil vapor from Area 3 wells. The demonstration was conducted in two phases. Phase 1 involved parametric testing to establish the optimal process configuration, and Phase 2 which involved Steady-State Testing using the system configuration from Phase 1.

The PTI system consisted of a fluidized bed concentration unit and a PDU. The three main components of the concentration unit were: an adsorber to develop a fluidized bed of adsorbent beads to extract organic vapors from the SVE vapor stream; a desorber containing a steam-heated heat exchanger that warms the adsorbent to 300 °F to evaporate the VOCs from the loaded adsorbent beads; and a chilled-water condenser to remove the water vapor and non-halogenated organics from the concentrated vapor. The PDU consisted of two main components: two photolytic reactors capable of treating up to 5 acfm each of concentrated VOC vapor and a wet scrubber to remove any trace amounts of acidic by-products from the photolytic reactor stream. The PTI system used for the demonstration was designed to treat 500 scfm of vapor from the SVE system (which was rated at 3000 scfm) and to remove a minimum of 3.6 lbs/hr of VOCs. The maximum flow rate during the demonstration was 440 scfm and the average amount of VOCs removed was 1.22 lbs/hr. The results of the Steady-State operations showed an average DRE for the PTI system of 95.44%, with the PDU alone achieving an overall DRE of 97%. In addition, the PTI system was found to be relatively quick to install and was operational 89% of the time. As a result of the demonstration, PTI recommended several design modifications to enhance system performance including redesigning the weather seals in the concentration unit to prevent rainwater and humidity from entering the adsorber, which was the primary operational problem encountered with this component during the demonstration. In addition, PTI recommended evaluating the performance of different adsorbent materials to determine which offers the most cost effective removal efficiencies. The report also presents detailed information on secondary wastes and residuals generated during the demonstration as well as a detailed discussion of operational problems encountered during the demonstration.

The total demonstration cost was \$93,726, including work plan, mobilization/demobilization, site work, liquids collection and containment, treatment, monitoring, sampling and analysis, and residuals disposal. The report included a detailed cost breakout. The data from the demonstration were used to estimate the cost of implementing a 3000 scfm PTI system at NAS North Island Site 9. The estimated unit cost for such a system was \$3.77 per lb of VOC treated. According to PTI, the commercialization of the technology over the next few years will lower the treatment costs further.

## **Section 1.0 Introduction**

### **1.1 Demonstration Program Background**

In July 1996, the Navy Environmental Leadership Program (NELP) issued a Broad Agency Announcement (BAA), Solicitation N47408-96-R-6342, for demonstrating a remediation technology for environmental cleanup. The Navy's goal in issuing this BAA was to demonstrate innovative technologies that are at the advanced development stage and are ready for field implementation. Process Technologies' Incorporated (PTI) responded to the BAA, which resulted in the selection of their Photolytic Destruction Technology for demonstration at Naval Air Station (NAS) North Island Installation Restoration (IR) Site 9. The goal of the demonstration was to obtain the necessary cost and performance data on the PTI system demonstration at NAS North Island, Site 9, and make a comparison with other commercially-available treatment technologies. This data will be compiled by the Naval Facilities Engineering Service Center (NFESC) and provided in a summary report to be distributed within all of the Department of Defense (DoD). The two potential benefits to PTI are potential immediate full-scale implementation at NAS North Island and potential future use within the federal government at other sites with similar volatile organic compound (VOC) air streams requiring treatment.

### **1.2 Site Description**

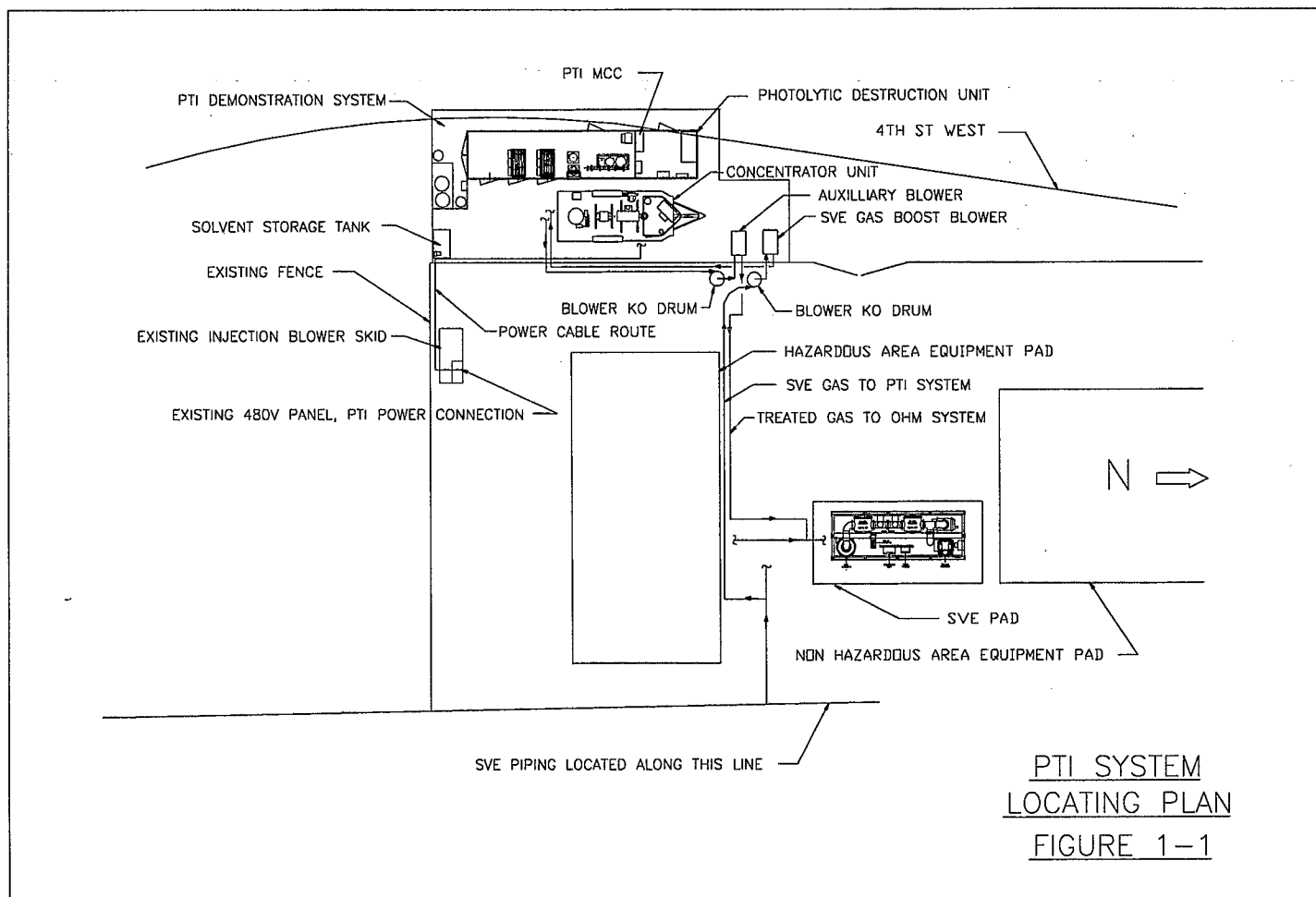
#### **Location**

NAS North Island is located in southern San Diego County, across San Diego Bay from the downtown area, on the northern end of Coronado. Twelve sites on NAS North Island were identified as IR sites owing to their historical use as hazardous materials generating and/or disposal sites. Site 9 is one of these IR sites.

For this demonstration, the PTI System was installed to interface with an existing Soil Vapor Extraction and Treatment System (SVE&T). The SVE&T was installed at Site 9 in 1997, to remove and treat the contaminated soil vapor from Site 9's Area 1 and 3 SVE wells. PTI treated soil vapor from the Area 3 wells only. Figure 1-1 presents the PTI System Locating Plan indicating the location of the PTI System as it relates to SVE&T the facility.

#### **Geology**

The uppermost layer at Site 9 consists of approximately 100 feet of poorly graded fine sand and silty sand with shell beds. Several layers of clay, clayey sand and silt exist from approximately 35 feet below grade surface (bgs) to 150 feet bgs. The character of the vadose zone, which is 8 to 10 feet thick, is suitable for soil vapor extraction (SVE). The shallow nature of the vadose zone at Site 9 required installation of horizontal SVE wells to effectively capture VOCs in the vadose zone (OHM Remediation Services Corp. (OHM)1996).



### Chemicals of Concern

Five VOCs were found in vadose zone soil at Site 9 in concentrations that exceed the United States Environmental Protection Agency (EPA) Region IX Industrial Preliminary Remediation Goals (PRGs). These are cis-1,2-dichloroethylene (DCE), 1,1-DCE, tetrachloroethene (PCE), trichloroethene (TCE), and vinyl chloride (OHM 1996). For the demonstration, compounds known to exist at concentrations >2ppmv were also added to this list.

**Table 1-1: Chemicals of Concern**

Chemical Name	Concentration in SVE Vapor <sup>1</sup>
Octane <sup>2</sup>	96.44
Tetrachloroethene	31.40
Trichloroethene	27.60
cis-1,2-Dichloroethene	22.20
Toluene	14.20
1,1-Dichloroethene	N.D.
Vinyl Chloride	N.D.

**Notes:**

1. Average SVE vapor concentration, as measured during Steady-State Operations, by EPA Method TO-14.
2. The concentration of Octane was calculated using the equation:  
$$\text{Concentration}_{\text{Octane}} = [(\text{Total Vapor Concentration by FID}) - (\text{Total Vapor Concentration by TO-14}) - (\text{Methane Concentration})] \div 8.$$

### Site History

Site 9, the Chemical Waste Disposal Area, includes a low-lying depressed area in the northeastern corner that was used for liquid chemical waste disposal beginning in the 1940s (OHM 1996). Disposal in this area was halted when it became apparent that mixing of wastes was generating chemical reactions that caused fires. Part of the depression was excavated and back-filled with clean, compacted fill for construction of the aircraft run-up pad and taxi-way in 1974. The remainder was filled in with soil and concrete rubble in 1978 (OHM 1996).

Beginning in 1968, wastes were segregated into four parallel trenches near the eastern edge of Site 9. The trenches received solvents, caustics, acids, and Sermetel W (a semi-synthetic high-temperature coating of ceramic and metallic compounds consisting of metallic carbides). Disposal of wastes in the trenches ended in the mid-1970s when installation of an Industrial Waste Treatment Plant (IWTP) was completed. The southeast corner of Site 9, extending to the fence line which houses the Naval Weapons Center (NWC), was used intermittently for liquid waste disposal from the 1950s to 1978 (OHM 1996).

In general, VOCs, semi-volatile organic compounds (SVOCs), petroleum hydrocarbons, metals, and polychlorinated biphenyls (PCBs) have been detected in soils at the Site 9 disposal areas (OHM 1996).



### **Non-Time-Critical Removal Action (NTCRA)**

Presently, a Non-Time-Critical Removal Action is in place at Site 9 to remove VOCs from vadose zone soil. The NTCRA work at Site 9 consists of the following, and is described in more detail in Section 2.3:

- Extraction of VOCs from soil by SVE. A series of horizontal SVE wells and air injection wells have been installed in Areas 1 and 3.
- Treatment of extracted soil vapor by vapor phase activated carbon adsorption.

### **1.3 Demonstration Objectives**

This demonstration was performed to obtain the relevant data needed for Navy project managers, and other decision makers, to evaluate the PTI system's applicability for a project while reducing cost on the project. The PTI technology will be compared with all other emerging and commercially available technologies so remedial project managers (RPMs) can make the optimum business decisions for the Navy and other DoD.

The objectives of this demonstration were as follows:

1. Determine the total average DRE achieved by the PTI system for all VOCs measured in the SVE off-gas, as well as individual DREs for critical VOCs.
2. Develop treatment cost data for a 3,000 standard cubic feet per minute (scfm) PTI system, designed to achieve the DREs measured above, for VOC-contaminated soil vapor similar to those at Site 9.
3. Characterize and quantify secondary waste streams generated by the PTI system at Site 9 and determine the appropriate disposal option(s) for each. Estimate the costs of disposal of all secondary waste streams generated.
4. Characterize and quantify all residuals, including hydrochloric acid, chlorine, phosgene, carbon monoxide and dioxins, exiting the PTI system.
5. Document observed operating problems and their solutions.
6. Disseminate the results of the demonstration throughout the DoD, DOE, private industry, state regulatory agencies and the NAS North Island RAB.

## **Section 2.0 Technology Description**

PTI's VOC treatment system consists of a fluidized bed concentration unit and a photolytic destruction unit (PDU). The concentration unit produces a low flow, high concentration VOC vapor that is then processed through the PDU. For most treatment or recovery technologies, it is desirable for the unit to receive a low cubic feet per minute (cfm) flow with high levels of VOCs, rather than the high flow and dilute VOCs typically found. The concentration unit can pre-concentrate organics up to 1,000 times while correspondingly decreasing the cfm flow.

The concentration unit includes a chilled-water condenser to preferentially remove non-chlorinated hydrocarbons from the vent gas prior to treatment in the photolytic destruction unit. The PDU is most cost-effective when treating high concentration vapors containing chlorinated hydrocarbons. PTI has combined the two technologies to provide a system that can treat a variety of contaminated VOC vapor streams. Figure 2-1 is a simplified schematic diagram of the PTI System. A detailed description of the technology as it was demonstrated at Site 9 is presented below.

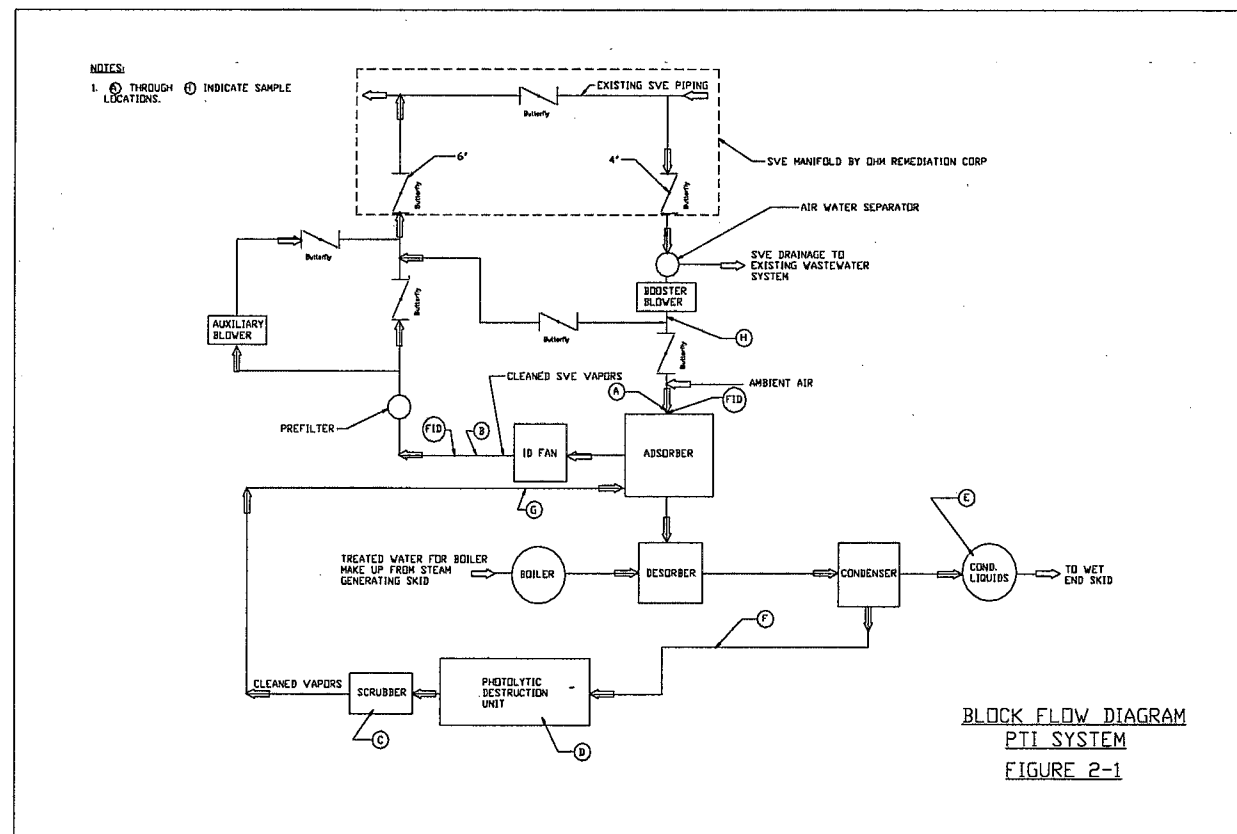
### **2.1 Concentration Unit**

The Concentration Unit consists of three major components: an adsorber, desorber and condenser. The following is a description of each component and its basic unit operations:

#### **Adsorber**

The adsorber develops a fluidized bed of adsorbent beads to extract organic vapors from the SVE vapor. The adsorbent beads are specifically designed to extract VOCs from high humidity gas streams. The adsorber has multiple stages of adsorption trays to control the flow of adsorbent beads. As the beads flow from one tray to the next, they adsorb the VOCs from the gas stream, in a process referred to as "loading". Fluidization of the adsorbent media bed enhances the kinetics and improves the capture rate. On a static bed, a small break between carbon pieces will allow the gas flow to select the path of least resistance and much of the flow will pass without adsorption. The constant movement of the media allows for all portions of the adsorbent to be utilized.

The adsorber is operated under a slight negative pressure so that SVE vapors can be drawn into the adsorber. A manually operated flow control system is used to bring 250 scfm of SVE vapors into the unit. As noted earlier, the SVE flow rate is adjusted based on the actual VOC concentrations that are experienced during operation. Additional ambient air (trim air) is mixed with the SVE vapor before entering the adsorber. A manually operated flow control system is used to draw a minimum of 400 scfm of combined gas flow into the unit.



The combined gas flow moves upward through multiple stages of trays to contact the adsorbent media used to adsorb VOCs from the gas stream. The adsorbent beads flow downward through the unit (tray-to-tray) while the gas flows upward at sufficient velocity to fluidize each stage of adsorbent media. This allows intimate and thorough contact of the gas with the adsorbent. The treated gas passes through an internal screen prior to its return to the existing SVE piping at a point down-stream from the tie-in. The internal screen ensures that the adsorbent beads are retained within the adsorber.

### **Desorber**

The Desorber evaporates the VOCs from the loaded adsorbent beads. High-pressure steam (60 psig) provides energy through a heat exchanger to desorb the organics from the adsorbent beads. A low pressure steam (atmospheric pressure) is used as the carrier vapor to sweep the desorbed organic vapors from the desorber. The desorbed "lean" adsorbent beads are then immediately recycled to the adsorber, to begin another cycle.

The "loaded" adsorbent beads are pneumatically transferred from the bottom of the adsorber to the top of the desorber. The adsorbent beads flow downward in a plug-flow manner. The desorber contains a steam-heated heat exchanger that warms the adsorbent to 300o F. This heat vaporizes the adsorbed VOCs. Low pressure, superheated steam is used to sweep the desorbed VOCs out of the desorber and into the condenser. The "lean" adsorbent is pneumatically recycled to the top of the adsorber for reuse. This provides for the continuous, closed-loop operation of the adsorbent beads through the concentrator system.

A small electrically-heated boiler was used to generate steam for the desorber and provide the low pressure sweep steam. Make-up water for the steam generator was provided from the existing SVE&T Steam Generating Skid, and boiler blowdown was drained to an existing wastewater sump located adjacent to the SVE&T Steam Generating Skid.

### **Condenser**

The condenser is cooled with chilled water to preferentially remove the water vapor and non-halogenated organics in the concentrated sweep vapor. A portion of the halogenated chemicals is also removed in the condenser. The condenser temperature can be controlled with a thermostat to achieve the desired condensing conditions. During the first few weeks of operation, evaluations were made to determine the preferred operating temperature for the condenser. A chilled water system is used for the condenser. Heat is rejected from the refrigeration unit using an air-cooled heat exchanger. Condensate was collected in a "day" tank and then transferred to the existing gravity separator located on the SVE&T wet-end skid. The day tank was sampled prior to transfer of the SVE&T gravity separator.

## **2.2 Photolytic Destruction Unit (PDU)**

The PDU, located between the condenser and the recycle line to the adsorber, processes the non-condensable vapors from the condenser. The PDU consists of tow major components: the photolytic reactors and a wet scrubber. A description of each component and its basic unit operations is discussed below:

### **Photolytic Reactors**

Two photolytic reactors, each capable of treating up to 5 scfm of concentrated, contaminated vapor were included with the system. Non-condensable vapors from the condenser flow into the PDU. The non-condensable vapors are mixed with ambient air prior to entering the PDU to control the vapors to less than 20% of the lower explosive limit (LEL) for the gas mixture. This adjustment is made manually, based on analytical test results.

The mixture of VOC-laden vapor and ambient air passes through the photolytic reactors, where the vapors are exposed to high levels of photons produced by ultraviolet (UV) lamps. The VOCs break into free radicals which react with the alkaline compounds contained in the reagent panels. This reaction works to prevent the formation of undesirable by-products in the process exhaust stream. The reagent panels are located adjacent to the UV lamps.

When the reagent panels are exhausted (fully utilized), acid gases from the reactors will be predominantly reacted in the Wet Scrubber system. The pH of the scrubber solution is reduced as high loadings of acid gas are processed. A rapid drop in the scrubber solution pH is an indicator that the reagent panels need to be replaced. During the demonstration, two sets of reagent panels were used. At the completion of the technology demonstration, the reagent panels were tested using the EPA Toxicity Characteristic Leaching Procedure (TCLP) to verify that the panels could be disposed as sanitary rather than hazardous waste.

To control the temperature inside the reactors, a closed-loop cooling water system provides cooling water to plate-type heat exchangers that are located between the reagent panels. Heat energy from the lamps, and heat of reaction from the neutralization reactions, are removed via the internal heat exchangers. The closed-loop cooling system circulates the water from the heat exchangers through a radiator system where air rejects the heat to atmosphere. The cooling system has two pumps, one operating and one backup.

### **Wet Scrubber**

The VOC-free gas from the photolytic reactors flows through a caustic scrubber system to remove any trace amounts of hydrogen chloride, or other acidic by-products that are not reacted with the reagent panels. The scrubbing system operates with a 5% caustic soda solution as the reagent. Two pumps are provided with the system, one operating and one backup.

The clean, scrubbed gas flows back to the inlet of the Concentration Unit. An emergency by-pass system is included so the cleaned and scrubbed gas can be processed through a canister of activated carbon prior to recycle to the adsorber outlet in the event that the Concentration Unit trips off-line.

Prior to disposal, the spent scrubber solution is pumped out of the scrubber recycle tank, through an activated carbon canister, and into a 55 gallon drum. Samples of the solution

in the drum were analyzed for comparison with the site discharge permit requirements. This analysis proved the water could be drained into the site sanitary sewer system.

The PTI System is capable of being operated in three different process configurations. They are:

Configuration-1: Concentration-Condensation-Photolytic Destruction

Configuration-2: Concentration- Condensation

Configuration-3: Concentration- Photolytic Destruction

Each of these process flow configurations was evaluated during this technology demonstration. Refer to "*Process Technologies Incorporated Technology Demonstration Final Work Plan*" (Work Plan) for additional information regarding the process flow configurations that were evaluated.

### **2.3 PTI and SVE System Interface**

For this demonstration, the PTI System was installed to interface with an existing SVE&T. The SVE&T was installed at Site 9 in 1997, to remove and treat the contaminated soil vapor. Figure 1-1 presents the PTI System Locating Plan indicating the location of the PTI System as it relates to the SVE&T facility.

The SVE vapor is drawn from the wells by SVE blowers located at the treatment facility. The SVE&T System is rated at 3,000 scfm of vapor flow. VOCs are removed from the SVE vapor using a regenerative vapor phase activated carbon (VPAC) system. The SVE&T System consists of six equipment skids: the SVE System Skid, VPAC System Skid, Wet-End Skid, Steam Generating Skid, Injection Blower Skid, and Cooling Water Skid. The PTI System pulled SVE vapors from, and re-injected treated gas to, the SVE System Skid.

The PTI System used for this demonstration was designed to treat 500 scfm of SVE vapor, and to remove a minimum of 3.6 pounds per hour (lbs/hr) of VOCs. During the operation of the system it was determined that the maximum flow rate that could be treated was actually 440 scfm. The average composition of the SVE vapor from the Area 3 wells was calculated to be 191.84 ppmv of VOCs. This is equivalent to approximately 1.22 lbs/hr of VOCs at the 500 scfm design rate, which is approximately one-third the projected VOC removal capability of the PTI System used for this demonstration.

The SVE vapor was drawn from the Area 3 SVE piping from a nozzle located on the SVE well manifold piping. OHM installed the manifold system, complete with a diversion valve and isolation block valves. Figure 2-1 identifies the approximate tie-in point, and schematically shows the major process operations associated with the PTI System. PTI installed a booster blower to draw the SVE vapors into the PTI System. The booster blower was equipped with an air/water separator to remove any free

moisture from the SVE vapor. Water collected in the separator was drained to the existing OHM Wet End system.

After treatment through the PTI System, the treated gas was returned to the manifold piping for subsequent processing through the existing VPAC System. In addition to the booster blower, PTI also provided an auxiliary blower for the treated gas leaving the PTI system. This blower was used when the SVE&T blower systems were inoperative to allow the PTI technology to continue to operate.

## **2.4 Technology Applicability**

Photolytic destruction has been demonstrated to destroy VOCs in SVE and chemical storage tank vents off-gas. Off-gas streams from air strippers, air spargers and process vent streams are other likely applications for the technology. Pilot and commercial-scale work has shown that photolytic destruction is best suited for destroying low-flow, high concentration gas streams containing halogenated VOCs. For the treatment of high flow, dilute gas streams, a concentrator is used as a pretreatment method, prior to destruction by photolytic destruction. The Concentration Unit has been installed and in use in Europe for the control of VOC emissions from paint spray booth and fiberglass reinforced plastics operations. This demonstration was the first commercial demonstration of the PDU and Concentration Unit in the United States.

## **2.5 Commercialization and Intellectual Property**

The photolytic destruction technology is manufactured and sold as PDUs by PTI. The PDUs are protected by 5 U.S. and 2 international patents. The concentrator technology is manufactured and sold by PTI under license to MIAB, an air pollution control equipment manufacturer located in Mölnbacka, Sweden.

## **2.6 Competing Technologies**

The PTI system competes with conventional VOC treatment technologies such as activated carbon and flameless thermal oxidation.

## **2.7 Technology Maturity**

Photolytic destruction is an innovative air treatment technology, although variations have been applied for the treatment of contaminated water. The technology, together with the concentrator, is being implemented on a commercial scale for the treatment of air stripper off-gas and other SVE sites. The Concentration Unit has been in use in Europe since 1990.

## Section 3.0 Experience And Findings Of The Demonstration

Below is a summary table listing the order and dates of major events completed during the demonstration.

**Table 3-1. Schedule of Project Activities**

Activity	Date(s)
Contract Award	July 31, 1997
Kick-Off Meeting	August 15, 1997
Work Plan Development	August 16 - October 3, 1997
Mobilization	October 7-11, 1997
Installation	October 11, 1997
Startup	October 12 - October 18, 1997
Parametric Tests	October 24, 1997 - January 8, 1998
Steady-State Tests	January 17 - February 6, 1998
Demobilization	February 7 - February 12, 1998

### 3.1 PTI System Mobilization and Installation

Prior to initiating the on-site work, the PTI system was pre-assembled and tested to verify mechanical, electrical and instrumentation integrity. This testing was performed at PTI's facility in Boise, Idaho. The U.S. Navy's Project Manager and Contracting Officer's Technical Representative (COTR) were on hand to witness a portion of the pre-mobilization testing.

Prior to mobilizing the PTI system to Site 9, PTI personnel together with assistance from OHM site personnel, performed various on-site mobilization activities. These activities were performed several days in advance of shipping the PTI System. They included:

- Preparation of an area of approximately 20' wide by 50' long to receive the PTI System, the Booster Blower and Auxiliary Blower Modules.
- Installation of tie-in connections for the field-run piping for the boiler feed water, SVE vapor inlet piping, treated vapor outlet piping, potable water, and condensate transfer piping. Since this was a temporary facility, piping runs were all above ground and were anchored onto cribbing supports. Walk-over stiles were placed where appropriate to prevent tripping hazards.
- Installation of conduit and wiring from an existing 480 volt, 200 amp electrical service, adjacent to the Injection Blower Skid, to the PTI System (see Figure 1-1).



The PTI equipment was delivered to the site, on October 11, 1997, in the form of modules that were interconnected with field-run piping, and electrical and instrumentation wiring. The equipment modules consisted of:

- Concentrator Unit Trailer Module (adsorber, desorber, fan, pneumatic transfer system, condenser, refrigeration unit, boiler unit, and all associated electrical equipment and controls - see Figure 3-1).
- Solvent Storage Tank Module (skid-mounted condensate storage tank and pump).
- The PDU Container Module (all of the PDU process equipment pre-piped, pre-wired and pre-instrumented. This module also contained the motor control center and the programmable logic control (PLC) system common to all of the modules. A small work office was also included in the PDU Module - see Figure 3-2).
- SVE Booster Blower Module (booster blower, water knockout, motor starter, and instrumentation/controls).
- Auxiliary Blower Module (auxiliary blower, pre-filter, motor starter, and instrumentation/controls).

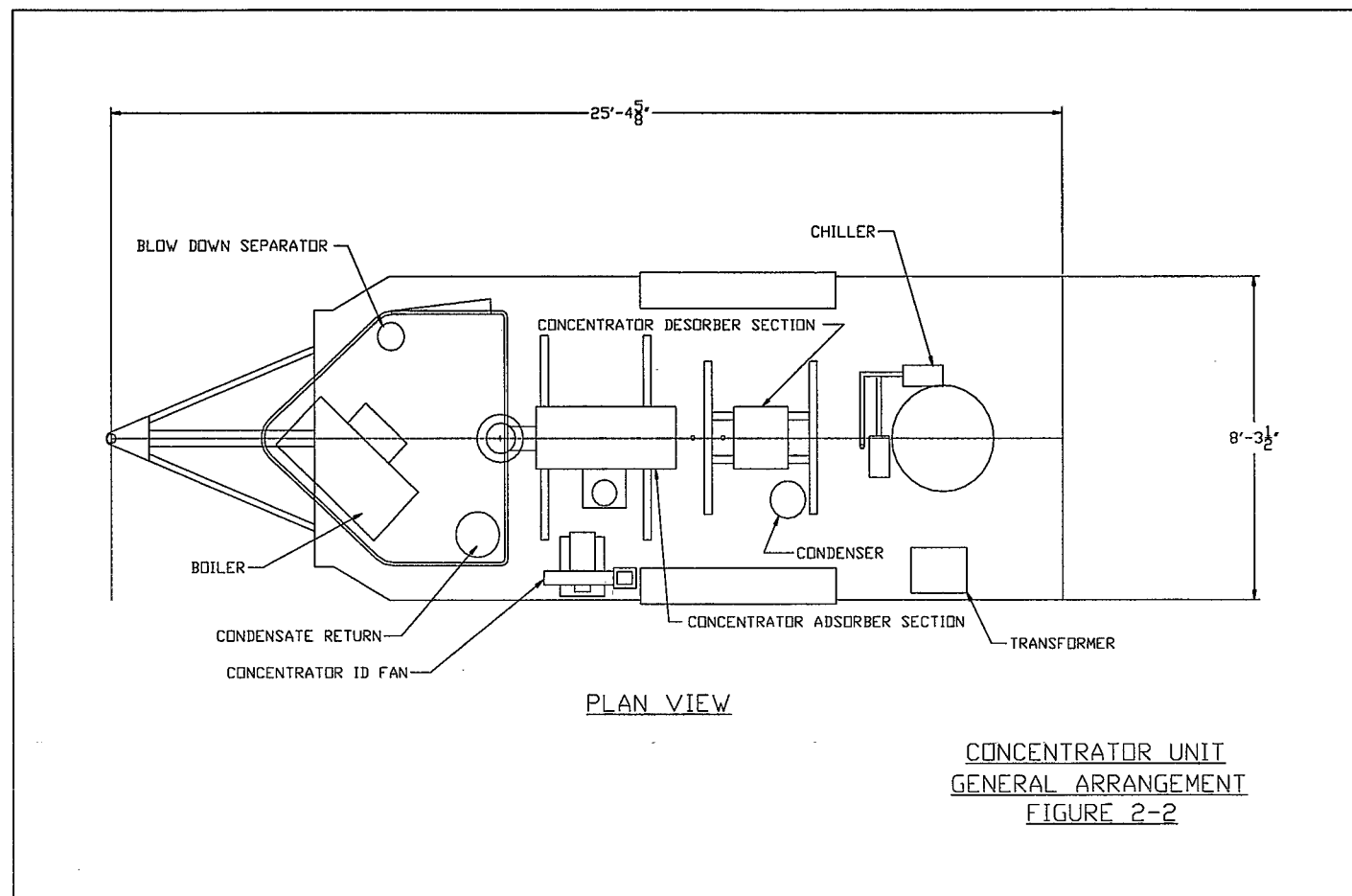
The PTI System was installed adjacent to the southwest section of the security fencing surrounding the SVE&T system. Figure 1-1 identifies the location of the PTI System installation at the SVE&T facility. A crane was used for positioning of the equipment at the proper location. All of the PTI System modules were placed on cribbing as the primary support for the units. Grounding rods were placed at appropriate locations and grounding wires were provided to ensure the safe operation of the System. Installation of the equipment was completed in one day.

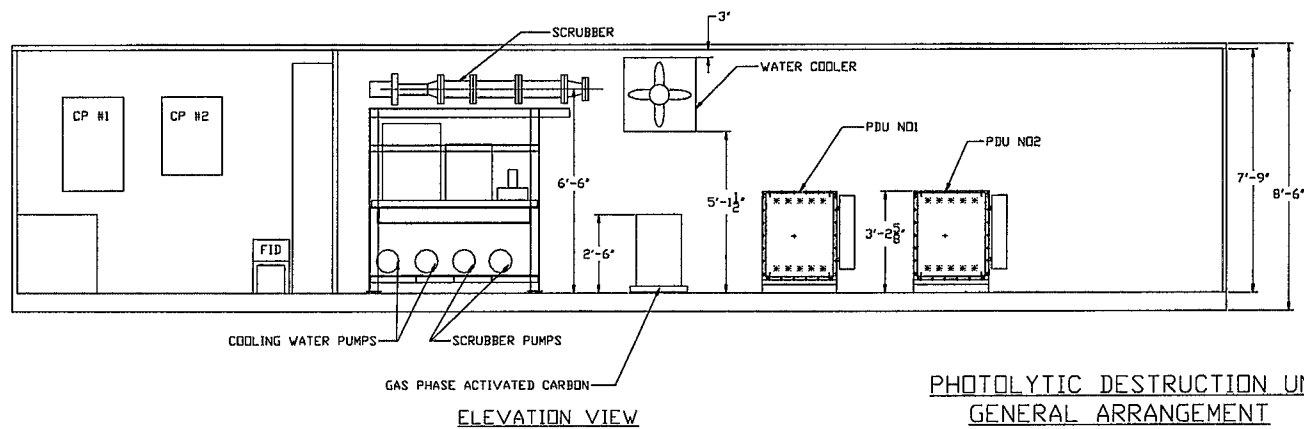
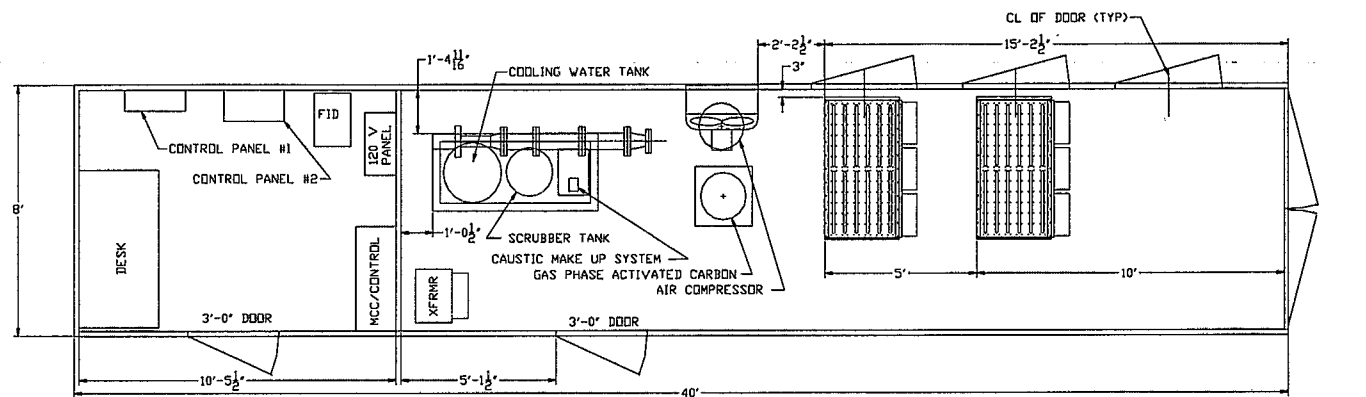
### **3.2 PTI System Start-Up**

A mechanical check-out of the PTI system commenced on October 12<sup>th</sup>, after completion of installation activities. During this phase of the demonstration, the following start-up activities were completed:

- Field-run piping and electrical inter-ties to connect the existing SVE&T modules and SVE manifold piping to the PTI System modules.
- Performed system integrity checks (mechanical, piping, electrical, and instrumentation).
- Verified operation of SVE booster and auxiliary blowers.
- Loaded adsorbent beads into adsorber and desorber.
- Loaded reagent panels in PDU reactors.
- Performed mechanical start-up of the Concentrator Unit.
- Modified PDU inlet gas piping to accept dilution air.

PTI began processing SVE vapors from the Area 3 well piping beginning October 18<sup>th</sup>.





PHOTOLYTIC DESTRUCTION UNIT  
GENERAL ARRANGEMENT  
FIGURE 2-3

### 3.3 PTI System Operation

The PTI technology demonstration was performed in two phases. Phase 1 involved Parametric Testing to establish the optimal process configuration for Site 9 conditions. Once established, this configuration was implemented for Phase 2 of the demonstration, Steady-State Testing.

#### Parametric Tests (October 24, 1997 through January 8, 1998)

Phase 1 consisted of Parametric Testing, which involved varying the feed gas flow from the SVE system and the condenser temperature. Three process configurations, discussed in detail below, were evaluated during the Parametric Testing. During this period the PTI System processed SVE off-gas for a total of 378 hours. Between tests, the system was shutdown to make the necessary process changes to perform the next series of tests. Because of this intermittent operation of the system, an on-line availability rating was not calculated for the Parametric Tests. The results of the Parametric Tests are discussed below:

#### Configuration 1: Concentration-Condensation-Photolytic Destruction

Process Configuration-1 involved the use of all of the PTI System components. In this mode of operation, low boiling, non-condensable organics that do not condense in the condenser unit, are processed through the PDU.

Table 3-2 presents the operational parameters and performance results achieved during Configuration-1 tests. The VOC concentration data was collected and recorded using an on-line FID. The use of an on-line, continuous monitoring system allowed PTI to readily observe the effect of making system changes on performance. Note that Test 1-1, involving an SVE flow rate of 100 cfm, was not performed per the Work Plan, as it was not possible to operate the SVE Booster Blower at a flow-rate less than 150 cfm.

**Table 3-2. Configuration 1 Parametric Test Results**

Process Parameters	Test 1-2	Test 1-3	Test 1-4	Test 1-5	Test 1-6
SVE Flow (scfm)	151	209	245	290	259
Make-up Air (scfm)	306	290	223	160	111
Condenser Temperature (°F)	69	67	59	52	60
Inlet Concentration (ppmc) <sup>1</sup>	279	309	366	1,367	1,453
Outlet Concentration (ppmc)	188	86	127	513	463
Average DRE (%)	32.62	72.17	65.30	62.47	68.13

Note: 1. VOC concentration as measured by an on-line FID.

The system was shutdown after completion of Test 1-6 to make the following modifications to the concentrator with the intention of improving system removal efficiencies:

- Replaced the flapper/check valve that controls the flow of adsorbent beads into the top of the desorber. Because the original valve was not sealing well, it was believed that concentrated VOCs could be discharged to the top adsorber tray, and vented to the VPAC System.
- Installed taller weir plates in the adsorber to allow for a thicker layer of beads to form on each adsorption tray.
- Replaced the desorber downcomer tubes with smaller diameter tubes to increase the Adsorbent beads residence time in the desorber.
- Increased desorption temperature by 20 °F, to approximately 285 °F, to increase the removal of solvent from the adsorbent beads.
- Increased vacuum pressure in desorber from -0.3 mm to -0.5mm to increase the solvent desorption rate, and ensure that no solvent vapors could be allowed to vent back to the adsorber.
- Added additional adsorbent beads to the Concentrator Unit.

After making the above modifications, the system was restarted and tests 1-4 through 1-6 were repeated. The results of these tests are presented in Table 3-3.

**Table 3-3. Configuration 1A Parametric Test Results**

Process Parameters	Test 1-4a	Test 1-5a	Test 1-6a
SVE Flow (scfm)	265	267	266
Make-up Air (scfm)	149	130	133
Condenser Temperature (°F)	62	52	69
Inlet Concentration (ppmc) <sup>1</sup>	928	1,009	1,022
Outlet Concentration (ppmc)	55	112	265
Average DRE (%)	94.07	88.90	74.07

Note: 1. VOC concentration as measured by an on-line FID.

It was evident, based on the higher DREs achieved during Configuration 1A Tests, that the System mechanical and operational changes were very effective. The lower "Average DRE %" achieved during Test 1-6A is related to the condenser temperature. At high condenser temperatures, less VOCs are condensed, thereby causing a greater recycle load of VOCs to return to the adsorber. A high recycle load of VOCs can "overload" the adsorber, thereby reducing process removal efficiencies.

**Configuration 2 Test: Concentration-Condensation (No PDU)**

Process Configuration-2 eliminates the use of the PDU to destroy the low boiling organic compounds. Rather, the VOCs are condensed into a liquid for off-site disposal. Any non-condensable vapors are recycled to the inlet of the adsorber. The results achieved during this series of tests, illustrated in Table 3-4, as evidenced by the lower "Average DRE %", show an increase in the recycle load of VOCs into the adsorber, leading to break-through of the chemicals into the adsorber outlet. PTI believes that higher "Average DRE %" might have been achieved if tests were run at lower condenser temperatures. Operating the condenser at lower temperatures would have decreased the re-circulation load of low boiling point compounds to the adsorber.

**Table 3-4. Configuration 2 Parametric Test Results**

Process Parameters	Test 2-2	Test 2-3	Test 2-4	Test 2-5	Test 2-6
SVE Flow (scfm)	148	211	258	262	215
Make-up Air (scfm)	169	210	68	141	124
Condenser Temperature (°F)	80	66	78	50	67
Inlet Concentration (ppmc) <sup>1</sup>	966	337	1,427	1,860	1,110
Outlet Concentration (ppmc)	582	115	414	551	433
Average DRE (%)	39.75	65.88	70.99	70.38	60.99

Note: 1. VOC concentration as measured by an on-line FID.

**Configuration 3 Test: Concentration- PDU (No Condensation)**

Process Configuration-3 eliminates the use of the condenser and instead, all of the concentrated organic vapors are processed through the PDU. In this mode of operation, air rather than steam was used to sweep the concentrated vapors from the desorber. In order to operate the unit safely, the concentration of organic vapors was limited to levels that do not exceed 20% of the LEL.

Table 3-5 presents the operational parameters and performance results achieved during Configuration-3 tests. The lower than expected level of VOCs in the SVE off-gas enabled PTI to run Test 3-1 at a much higher SVE flow rate than originally designed. No further Configuration-3 tests were conducted because it was felt that no improvement over Configuration-1 test results would be achieved in this operational mode. Therefore, the System was shut-down to prepare for Steady-State Operation.

**Table 3-5. Configuration 3 Parametric Test Results**

Process Parameters	Test 3-1
SVE Flow (scfm)	215
Make-up Air (scfm)	200
Condenser Temperature (°F)	NA
Inlet Concentration (ppmc) <sup>1</sup>	1,443
Outlet Concentration (ppmc)	480
Average DRE (%)	66.74

Note: 1. VOC concentration as measured by an on-line FID.

Upon review of the Parametric Test data, it was determined that the optimal operation parameters for long-term operation at Site 9 would be those which mimicked Test 1-4a. During this test, the System achieved the highest DRE (91.79%), using a higher condenser temperature (62° F), than other tests run at or near an average SVE flow rate of 265 scfm.

**Steady-State Operation (January 17, 1998, through February 6, 1998)**

After completion of the Parametric Tests, the System was shutdown to prepare for Steady-State operation. During this shutdown the following work was performed:

- Installed software in the PLC to record the inlet and outlet FID measurements 24-hours per day.
- Installed a kilowatt meter to monitor system power consumption.
- Installed a water meter to monitor water consumption by the steam boiler (the PDU cooling water and condenser chiller water systems are self-contained and require little make-up water).
- Added adsorbent media to the Concentration Unit to replace any adsorbent beads lost to attrition during the Parametric Tests.
- Replaced the reagent panels with new panels. A sample was taken and sent to an independent laboratory for analysis.
- Repaired a number of small leaks observed in the condenser.
- Installed an eductor system to transport the adsorbent beads from the adsorber to the desorber. A positive pressure transport system, rather than the original negative pressure system, was used to prevent the plugging of adsorbent beads at the desorber inlet flapper valve.

Steady-State Operation began on January 17, 1998, and was completed on February 6, 1998. During this phase of testing, the System was operated 24-hours per day, 7-days per week, except during process shutdowns and holidays. The unit operated unattended during normal off-hours, weekends, and during weapons loading activities. The PTI System operated for a total of 440 hours during this period, and achieved an 89% on-line availability.

During the second week of Steady-State Operation, the decision was made to switch from using hot-air desorption to steam desorption. It was determined from the analytical test results that using steam desorption resulted in a higher removal efficiency. PTI chose to continue the use of steam as a desorption gas for the remainder of the demonstration. A summary of system performance during this period is provided in Tables 3-6 and 3-7.

**Table 3-6. Steady-State Test Results - Hot Air Desorption**

Process Parameters	Low	High	Average
SVE Flow (scfm)	239	267	245
Make-up Air (scfm)	57	157	100
Condenser Temperature (°F)	80	90	83
Inlet Concentration (ppmc) <sup>1</sup>	890	1,175	995
Outlet Concentration (ppmc)	83	170	125
DRE	80.90	92.94	87.37

Note: 1. VOC concentration as measured by an on-line FID.

**Table 3-7. Steady-State Test Results - Steam Desorption**

Process Parameters	Low	High	Average
SVE Flow (scfm)	243	307	267
Make-up Air (scfm)	51	102	76
Condenser Temperature (°F)	88	110	96
Inlet Concentration (ppmc) <sup>1</sup>	1,010	1,141	1,056
Outlet Concentration (ppmc)	14	93	44
DRE	91.85	96.76	95.93

Note: 1. VOC concentration as measured by an on-line FID.

### 3.4 Demobilization

After completion of the Phase 2 Steady-State Tests, the System was decontaminated and decommissioned. The decontamination work was performed in two steps. First, the Concentrator Unit was operated, using ambient air only, in a recycle mode to remove organics retained in the adsorbent beads. The organics were treated with the PDUs.

After the adsorbent was regenerated, the system was taken off-line and disassembled. Mechanical equipment that had been exposed to contamination was cleaned in conformance with the procedures defined in the Health and Safety Plan (Work Plan). Decontamination materials were also disposed in conformance with the Health and Safety Plan.



The reagent panels were composite sampled during removal from each of the PDUs. The sample was subjected to TCLP testing. The results of the tests, proved the panels to be safe for landfill disposal. Originally, PTI had planned to dispose of the panels in the Miramar Landfill, however this landfill's disposal application requirements were such that demobilization would have been delayed. As PTI had committed the use of the equipment for another project, it chose to have the panels shipped to its facility in Boise, Idaho, where the panels were disposed.

The liquid condensate collected during the demonstration was pumped into 55-gallon liquid storage containers and stored on the OHM Hazardous Waste Pad. Each of the containers were labeled as follows: "*Solvent Condensate, Analysis Pending, Generated on February 12<sup>th</sup>, 1998*". The condensate was sampled by PTI and analyzed for VOCs as per the Quality Assurance Project Plan (QAPP). The results of the analysis showed the composition of the condensate to be similar to that collected by the OHM treatment system. The condensate was then combined with the OHM solvent for disposal.

The scrubber liquid was treated with liquid-phase granular activated carbon and analyzed as per the QAPP. The results of the testing showed the liquid to be safe for disposal in the OHM sump, for discharge to the base sanitary sewer system.

Similarly, the chiller water, cooling water and boiler blowdown were all discharged to the OHM sump, for discharge to the base sanitary sewer system.

### 3.5 System Performance

This section discusses the test results with respect to the objectives of the demonstration.

**Objective 1. Determine the total average DRE achieved by the PTI System for all VOCs measured in the SVE off-gas, as well as individual DREs for critical VOCs.**

The determination of the total VOC removal efficiency for the PTI System was to be calculated by inputting the process inlet and outlet VOC concentrations, as measured with EPA Method TO-12, into the following equation:  $(TO-12_{inlet} - TO-12_{outlet}) / TO-12_{inlet}$ . However, a review of the analytical results show that the TO-12 analysis does not account for all VOCs in the SVE gas stream. This is manifested by comparing the VOC concentration as measured by the on-line FID, with that measured by EPA Method TO-12. The FID method has the advantage of pulling the gas sample through a heated line directly to the internal GC. The use of a heated line prevents the condensation, or "drop out", of any compounds with high boiling points. EPA Method TO-12, on the other hand, requires the capture of the sample gas in a summa canister. When the summa canister has been received by the analytical lab, it is pressurized to 10 psig to remove the volatile constituents. Unfortunately, the heavier weight compounds remain in the canister. For this reason, PTI chose to use the on-line FID reading to measure total VOC removal efficiency. The results of the total VOC removal calculations, presented in Table 3-8, shows an average System DRE of 95.44%, during Steady-State Operations, and using steam as the desorption gas in the Concentration Unit.

**Table 3-8. PTI System Average Total VOC Removal Efficiency**

Date	Desorption Method	Inlet Conc. <sup>1</sup> (ppmc)	Outlet Conc. <sup>1</sup> (ppmc)	DRE (%)
1/19/98	hot air	890	170	80.90
1/22/98	hot air	920	124	86.52
1/26/98	steam	1,175	83	92.94
1/30/98	steam	1,141	93	91.85
2/4/98	steam	1,090	49	95.50
2/5/98	steam	1,020	33	96.76
2/5/98	steam	1,020	14	98.63
2/6/98	steam	1,010	31	96.93
<i>Average</i>		1,033	75	92.50 <sup>2</sup>

**Notes:**

1. VOC concentration as measured by an on-line FID.
2. Average system DRE using steam desorption was 95.93%.

Individual DREs for the critical VOCs were determined by TO-14 analysis. The critical VOCs were selected from a composite list of chemicals from recent sampling events at Site 9, Area 3. Critical VOCs are defined as those which were present in the composite data at levels  $\geq 2$  ppmv. Table 3-9 presents the individual DREs for each of the critical VOCs.

**Table 3-9. Individual VOC Removal Efficiencies for Critical Compounds**

Compound Name	Inlet		Outlet		Average DRE (%)
	Conc. <sup>1</sup> (ppmv)	Mass Rate (lbs/hr)	Conc. (ppmv)	Mass Rate (lbs/hr)	
As Octane <sup>2</sup>	96.44	0.5831	0.06	0.0004	99.92
Tetrachloroethene	31.40	0.2703	2.44	0.0278	89.72
Trichloroethene	27.60	0.1895	4.02	0.0363	80.83
cis-1,2-Dichloroethene	22.20	0.1129	4.40	0.0294	73.98
Toluene	14.20	0.0679	0.74	0.0047	93.13
1,1-Dichloroethene	ND <sup>3</sup>	0.0000	ND	0.0000	NA <sup>4</sup>
Vinyl Chloride	ND	0.0000	ND	0.0000	NA
<i>Totals</i>	191.84	1.2238	11.65	0.0986	91.94

**Notes:**

1. Compound concentrations as measured by EPA Method TO-14.
2. The concentration of Octane was calculated as: [(Total VOC concentration by FID) - (Total VOC concentration by TO-14) - (Methane concentration)]  $\div$  8.
3. "ND" denotes the concentration was below the detection limit of the analytical equipment.
4. "NA" denotes not applicable as the compound was not detected in the SVE vapor.

The destruction and removal efficiency of the PDUs was calculated separately by measuring the VOC concentrations at the inlet and outlet to the PDU System. The results of these calculations, presented in Table 3-10, show an average PDU DRE of 97.29%.

**Table 3-10. PDU Average Total and Individual VOC Removal Efficiencies**

Compound Name <sup>1</sup>	Inlet		Outlet		Average DRE (%)
	Conc. (ppmv)	Mass Rate (lbs/hr)	Conc. (ppmv)	Mass Rate (lbs/hr)	
cis-1,2-Dichloroethene	742.86	0.0623	8.11	0.0007	98.85
1,1,1-Trichloroethane	12.00	0.0013	0.08	0.0000	99.27
Trichloroethene	688.57	0.0799	17.70	0.0022	97.29
Toluene	205.86	0.0172	11.62	0.0010	94.18
Tetrachloroethene	334.29	0.0501	11.79	0.0018	96.36
Ethylbenzene	2.80	0.0003	0.10	0.0000	96.21
Xylenes (total)	11.60	0.0012	0.44	0.0000	95.89
1,2,4-Trimethylbenzene	4.50	0.0005	ND	0.0000	>92.22
<b>Totals</b>	<b>2,002.47</b>	<b>0.2128</b>	<b>49.82</b>	<b>0.0058</b>	<b>&gt;97.27</b>

**Note:** 1. Only those compounds measured at the PDU inlet are included. Several additional compounds were measured at the PDU outlet, but because of the large difference in reporting limits were not measured at the PDU inlet.

**Objective 3. Characterize and quantify secondary waste streams generated by the PTI system at Site 9 and determine the appropriate disposal option(s) for each. Estimate the costs of disposal of all secondary waste streams generated.**

The secondary waste streams produced from the PTI system included: spent reagent panels from the PDUs, scrubber blowdown, and liquid condensate from the condenser. Each of these waste sources was monitored throughout the demonstration. A brief discussion of the evaluation methods used for secondary waste streams from each sub-system is given below:

#### **Reagent Panels**

The reagent panels are used to capture and transform acidic radicals, formed by photo-dissociation of halogenated compounds, into stable, inert organic salts. One set each of fresh panels were installed in the PDU reactors for Phase 1 and Phase 2 tests. At the completion of the demonstration, samples taken from the spent reagent panels were analyzed according to the TCLP test method. The results of these analyses demonstrate that the panels were non-hazardous waste. The total weight of reagent used in the demonstration was approximately 960 lbs, over a period of 1,229 hours. The approximate cost of the panels consumed during the demonstration was \$700.00. Due to strict time limitations, PTI chose to landfill the waste in Boise, Idaho, rather than in the Miramar landfill.

### **Scrubber Blowdown**

The PTI system includes a small (25 scfm) acid gas scrubber which operates in a batch mode. The aqueous scrubber discharge was tested to determine whether the waste meets the NAS North Island sanitary sewer acceptance criteria. The scrubber blowdown was analyzed for VOCs by EPA Method 8260A. Total dissolved solids (TDS) and total suspended solids (TSS) were determined by methods 160.1 and 160.2, respectively; and pH was determined with the pH probe in the scrubber unit. The results of these analyses show that the liquid met the discharge requirements. The total volume of liquid discharged at the completion of the demonstration was 18.5 gallons. The approximate cost of the caustic chemicals used in the scrubber during the demonstration was \$62.00.

### **Liquid Condensate**

The PTI system utilizes a water-cooled condenser to preferentially remove non-chlorinated hydrocarbons from the concentrated gas stream, prior to treatment in the PDUs. This condensate was sampled and analyzed for disposal purposes using EPA Method 8260A. As the sample analysis confirmed, the composition of the condensate was found to be typical of the current SVE&T operation. Therefore, the condensate was pumped to the SVE&T wet-end skid. Approximately 255 gallons of condensate were collected during the demonstration. The estimated cost to dispose of the liquid condensate, at \$0.17/lb., was \$347.00.

### **Objective 4. Characterize and quantify all residuals, including hydrochloric acid (HCl), ozone, chlorine, phosgene, carbon monoxide and dioxins, exiting the PTI system.**

The concentrations of HCl, chlorine, phosgene and carbon monoxide were measured at the PDU outlet and the PTI system outlet. Ozone analysis was not performed due to an oversight by PTI. Dioxin analysis was not performed as no PCB-indicating compounds were measured in the SVE off-gas.

### **HCl and Chlorine**

Sampling and analysis for HCl and chlorine was performed using EPA Method 26A. Gas samples were taken at the outlet of the PDU scrubber and at the outlet of the adsorber, the total system outlet. HCl was measured at a concentration of 22.1 ppbv (PDU scrubber outlet) and 0.18 ppbv (System outlet), while chlorine was measured at a concentration of 7.4 ppbv and 0.04 ppbv, respectively.

### **Phosgene**

Phosgene was determined by EPA Method TO-6. Gas samples were taken at the outlet of the PDU scrubber and at the outlet of the adsorber. At these sample locations, phosgene was measured at concentrations of 1,472.7 ppbv and 23.8 ppbv, respectively.

### **CO**

Carbon monoxide was determined by ASTM D-1946. CO was measured in the SVE off-gas and at the PTI System outlet, to determine the amount of CO produced in the System. The concentration of CO was below the detection limit of 0.0025% (v/v) in the

SVE off-gas, and an average of 0.0056% (v/v) at the system outlet. Therefore, the amount of CO produced in the PTI System was between 0.0031 and 0.0056%.

### **Dioxins**

Dioxin testing was to be performed, using EPA Method 23.0, only if PCB-indicating compounds were found to be in the SVE off-gas stream. Past demonstrations of the PTI system have shown no dioxin formation when PCBs are not present. Because the potential for PCBs exists in the contaminated soil at Site 9, Area 3, PCBs, pesticides and SVOCs were sampled for during week 1 using California Air Resources Board (CARB) Method 429. This analysis showed no presence of PCB-indicating compounds present in the SVE off-gas, therefore no dioxin tests were performed.

A tabular comparison of the System residuals to allowable levels within the San Diego Air pollution Control District is presented in Table 3-11. This comparison shows that the residual levels were in fact below known maximum allowable levels for CO and HCl. In a conversation with a San Diego Air Pollution Control District manager, PTI learned that emission standards for chlorine and phosgene are not established but reviewed and determined on a case-by-case basis. For the purposes of this report a formal emissions review application was not submitted.

**Table 3-11. Residuals Data**

<b>Contaminant</b>	<b>Measured Concentration</b>	<b>Maximum Allowable Emission<sup>1</sup></b>	<b>Analytical Method</b>
Carbon Monoxide	5.9 ppmv	none	ASTM-D1946
Chlorine	0.04 ppbv	NA <sup>2</sup>	EPA Method 26A
Hydrochloric Acid	0.18 ppbv	<10 ppmv	EPA Method 26A
Phosgene	23.8 ppbv	NA <sup>2</sup>	EPA Method TO-6

**Notes:**

1. "Maximum Allowable Emissions" as determined by the San Diego Air Pollution Control District.
2. "NA" denotes no standard available. According to the San Diego County Air Pollution District, the maximum allowable emission for this compound is determined on a case-by-case basis. A formal review of the process residues by the governing regulatory agencies was not part of the scope of this project.

### **3.6 Parameters Affecting Treatment Cost or Performance**

This section discusses the observations and lessons learned with respect to the objectives of the demonstration. Table 3-12 shows the Parameters Affecting Treatment Cost or Performance.

**Table 3-12. Parameters Affecting Treatment Cost or Performance**

System Parameters	Value	Measurement Procedure
SVE Flow Rate	239 to 307 cfm	Flow meter, pitot tube.
Operating Vacuum	0 to -35" w.c.	Pressure gauge.
Residence Time	9 seconds - Concentrator 3 minutes - PDU	Calculated.
System Throughput	0.83 to 1.45 lbs/hr	On-line FID reading at system inlet and outlet.
Gas Inlet Temperature	89 to 113° F	Thermocouple.

**Objective 5. Document observed operating problems and their solutions.**

This demonstration of an integrated Concentrator Unit and PDU was the first of its kind for the treatment and destruction of gas-phase VOCs. In fact, this project was the first field implementation of a concentrator system by PTI. This demonstration provided an invaluable learning experience for PTI, and will hopefully provide valuable cost and performance data for the U.S. Navy and other DoD agencies.

Process operating parameters were monitored by PTI personnel throughout the test period on a regular basis. A discussion of problems encountered with each of the PTI System modules follows. PTI is confident that all of the operational problems encountered were resolved satisfactorily, and further plans to incorporate design modifications into the system to prevent these problems on future installations. A discussion of these problems and their solutions for each component of the system is given below.

**Concentrator Unit**

- The most significant operational problems were encountered during the Parametric Tests as a direct result of very heavy rains. All of these problems were due to rain water or condensate getting sucked into the adsorber or desorber (both units operate under vacuum), and subsequently plugging the flow of adsorbent beads. This plugged flow would result in a system shutdown due to a high pressure alarm. Several measures were taken to prevent this plugging from occurring: insulating the desorber and adsorbent transfer lines to prevent condensate from forming in these areas; extending the PDU return line into the adsorber approximately 12 inches (") to prevent condensate from collecting in the adsorber downcomer sections; sealing all seams in the adsorber and adsorbent transfer containers with silicon; piping the adsorber pressure vents to a manifold header to prevent the transfer of rain water into the adsorber; and placing c-clamps to tighten the seals between adsorber stages.
- A fine mesh screen, installed at the outlet of the adsorber to prevent adsorbent beads from exiting the system, became plugged with a very fine black powder. PTI believes this powder was created from the conditioning of the adsorbent beads. If not monitored, PTI found that this plugging would eventually shutdown the system on a high pressure alarm. To solve this problem, the screen was replaced with a perforated plate having 60% free area and 0.05" diameter holes.

- A high-temperature excursion (650 °F) was noted in the desorber, forcing the shutdown of the system. PTI determined that the temperature excursion was caused by the plugging of adsorbent beads at the bottom of the desorber. Once plugged, the beads were subjected to high temperatures (285 °F) for a prolonged period of time, in excess of 12 hours. PTI believes these high temperature conditions, coupled with high concentrations of solvent, led to an exothermic reaction. The system was allowed to cool and later inspected. No visible signs of damage were present, and samples of the adsorbent beads were taken for analysis. This problem was not experienced again.
- A couple of leaks were noted at a weld point in the condenser. These were repaired on-line with J-B Weld®.
- Higher than expected attrition of the adsorbent beads was experienced throughout the demonstration. PTI is not sure if this is a characteristic of the adsorbent material itself or, a result of high shear forces breaking the adsorbent beads down. PTI will be making equipment modifications to reduce gas flow velocities in the adsorber and the transfer tubes to reduce high shear forces.
- Initially, PTI was unable to operate the desorber using strip steam unattended due to a PLC programming error. This was corrected by making a minor modification in the control program.

#### **PDU**

- During continuous operation, the outlet manifold of each PDU reactor would become choked with a very dry, friable, material believed to be caused by the condensation of heavy-chained hydrocarbons leaving the relatively hot reactor internal area and entering the cooler transfer line to the scrubber. A similar material was noted during operations at McClellan Air Force Base (AFB). During the McClellan AFB demonstration this material was tested using EPA Method 8015-M and shown to contain "unidentified extractable hydrocarbons in the C9 to C22 range" (CH<sub>2</sub>M Hill). To overcome this problem, PTI would routinely "rod-out" this material, thereby clearing the outlet manifold and capturing the material in the scrubber. PTI plans to incorporate an automatic purge system to keep the outlet manifold clear in future designs.
- PTI discovered that a transformer ballast used to power the UV lamps in the PDU reactors had been damaged during shipping. The damaged ballast was replaced.

### **3.7 System Costs**

This section discusses the costs with respect to the objectives of the demonstration.

**Objective 2. Develop treatment cost data for a 3,000 standard cubic feet per minute (scfm) PTI system, designed to achieve the DREs measured above, for VOC-contaminated soil vapor similar to those at Site 9. PTI will operate their system in several configurations and parameters to fully demonstrate the performance of the system under differing conditions while obtaining the supporting cost data. Cost data will be reduced to a \$/lb. of VOC treated at various removal efficiencies. These costs will be compared to the costs to achieve an overall removal efficiency of 99% of VOCs at NAS North Island Site 9 using regenerative carbon adsorption and thermal oxidation.**

The cost estimate shown in Table 3-13 was developed using data collected from the demonstration. Standard engineering principles were used to scale-up costs for a 3,000 scfm system. This is the size system presently required to treat 100% of the soil vapor gas being extracted at Site 9. The \$/LB. of VOC treated is estimated to be \$3.77. The assumptions made to derive the 3,000 scfm treatment system cost are in Table 3-14. Table 3-15 displays costs by the standardized work-breakdown (WBS) structure.

**Table 3-13. 3,000 scfm PTI System Cost Summary**

<b><u>Capital Costs</u><sup>1,2</sup></b>		
<b>Concentrator Unit</b>	Size (cfm)	3,000
	Cost	\$310,000
<b>PDU</b>	Size (cfm)	6
	Cost	\$87,343
<b>Mobilization &amp; Installation</b> <sup>3</sup>		\$17,146
	<b>Total Capital Costs</b>	<b>\$414,489</b>
<b><u>Annual Operations and Maintenance Costs</u></b>		
<b>Power</b>	On-Line Availability <sup>4</sup>	89%
	Removal Efficiency <sup>5</sup>	95%
	Power Costs/kwh <sup>6</sup>	\$0.07
	Total Load <sup>7</sup> (kw)	218
	<b>Total Electricity Cost</b>	<b>\$118,973 per year</b>
<b>Consumables</b>	Reagent Panels <sup>8</sup>	\$4,061
	UV Lamps <sup>9</sup>	\$3,817
	Caustic Solution <sup>10</sup>	\$783
	Boiler Chemicals <sup>11</sup>	\$6,184
	<b>Total Consumables Cost</b>	<b>\$14,844 per year</b>
<b>Solvent Condensate</b>	Condensate Disposal <sup>12</sup>	<b>\$18,339 per year</b>
<b>Labor</b>	Maintenance Labor <sup>13</sup>	\$5,436
	Operating Labor <sup>14</sup>	\$67,364
	<b>Total Labor Cost</b>	<b>\$72,800 per year</b>
	<b>Total Operating Cost</b>	<b>\$224,957 per year</b>
<b><u>Cost per Pound of VOC Treated</u><sup>15</sup></b>		
<b>VOCs Treated (pounds)</b>		95,479 per year
	Over Cleanup	<b>286,437 in 3 years</b>
<b>Equipment &amp; Operating Costs</b>	Over Cleanup	\$1,081,254 in 3 years
	<b>Cost per Pound</b>	<b>\$3.77</b>



**Table 3-14. Assumptions and Basis for Costs**

1. Costs are based on those incurred during the demonstration.
2. Equipment Capital Costs are vendor-supplied prices.
3. Mobilization and Installation costs are based on actual costs incurred for the demonstration, plus 20% to account for the additional weight of a 3,000 scfm Concentration Unit.
4. On-line availability is 89%, or 7,796 operational hours per year.
5. Average VOC loading at 3,000 scfm is 196 ppmv, or 12.24 lbs/hr.
6. The process controls VOC emissions to <25 ppmv.
7. Total Power Load of 218 kwh, calculated as follows:  

$$\text{Concentrator power load} = (3,000 \text{ cfm} \div 300 \text{ cfm}) \times 31 = 310 \text{ kw}$$

$$\text{PDU power load (2 reactors)} = 15.1 \text{ kw}$$

$$\text{Other utilities power load} = 5.2 \text{ kw}$$

$$\text{Total design power load} = 310 + 15.1 + 5.2 = 330.30 \text{ kw}$$

$$\text{Design power load for 440 cfm system} = 57 \text{ kw} = 66\%$$

$$\text{Actual measured power load} = 38.5 \text{ kw}$$

$$\text{Actual normal power load} = 330.30 \text{ kw} \times 66\% = \underline{218 \text{ kw}}$$
8. Reagent panel cost = 24 panels, replaced every 4 weeks x \$14.63/panel
9. UV lamps replacement cost = 144 lamps with a 10,000 hour lifetime x \$34.00/lamp.
10. Scrubber caustic solution = 231.55 gallons/year x \$186.00 per 55-gallon barrel.
11. Boiler water chemicals = (584.73 gallons of chemical x \$10.00/gallon) + (\$12.00/month water softener rental) + (1.07 filter changes/month \* \$15.00/filter)
12. Condensate disposal assumes 70% of VOCs condensed, yielding (76,192 lbs/year x \$0.17/lb.) + (4 pickups/year x (\$1,275.00 transportation + \$65.00 labor)) + (solvent profile at \$550.00)
13. Maintenance labor for the PDU = labor cost of \$35.00/hr x 74 hours per year ( to replace reagent panels, UV lamps and caustic solution); maintenance labor for the concentrator = \$35.00/hr x 81 hours per year (for boiler water treatment).
14. Operating labor = (1) technical service person, making \$35.00/hr (including overhead factor of 1.4) x (2,080 hours per year - maintenance hours listed above in 13.)
15. Cost per lb. of VOC Treated = (Equipment & Operating Costs for a 3-year cleanup)  $\div$  (VOCs treated in a 3-year period)

**Table 3-15. Standardized Cost Breakdown**

	<b>WBS No.</b>	<b>Cost Element</b>	<b>Unit Cost</b>	<b>No. of Units</b>	<b>Cost</b>
Before Treatment Cost Elements	331.01.03	<b>Demonstration Work Plan</b>	\$7,628.80	fixed price	\$7,628.80
	331.01	<b>Mobilization and Preparatory Work:</b> mobilization of equipment and personnel	\$3,124.00	fixed price	\$3,124.00
	331.03	<b>Site Work:</b> installation of electrical utilities, field run gas piping equipment installation	\$12,011.00	fixed price	\$12,011.00
	331.09	<b>Liquids Collection and Containment:</b> establish liquids containment area field run piping to discharge waste water to site sewer	\$2,000.00	fixed price	\$2,000.00
Treatment Cost Elements	331.12	<b>Chemical Treatment:</b> Photolytic Oxidation of VOCs equipment rental equipment O&M	\$1.51/lb of VOC treated	1,151	\$1,738.01
	331.13	<b>Physical Treatment:</b> VOC Concentration equipment rental equipment O&M	\$1.74/lb of VOC treated	1,151	\$2,002.74
	331.02	<b>Monitoring, Sampling, Testing, and Analysis:</b> of SVE gas stream, process outlet, process residues	\$57,762.50	fixed price	\$57,762.50
After Treatment Cost Elements	331.21	<b>Demobilization:</b> of equipment and personnel	\$3,124.00	fixed price	\$3,124.00
	331.19	<b>Disposal:</b> of liquid condensate, PDU reagent panels, PDU cooling water, condenser chiller water scrubber solution	included in price above	fixed price	included in price above
	331.21.06	<b>Prepare and submit Final Report</b>	\$4,334.64	fixed price	\$4,334.64
		<b>Total Demonstration Costs:</b>			\$93,725.69

## Section 4.0 Conclusions and Recommendations

The following conclusions were developed by PTI from the technology demonstration:

- The PTI System is relatively quick to install and ready for operation as demonstrated by the experience at Site 9, where it was installed and commissioned within one week. The equipment operated continuously, 24-hours per day, seven days per week, achieving an on-line availability of 89%.
- For treatment of the SVE off-gas at Site 9, Configuration-1: "Concentration-Condensation-Photolytic Destruction" was the most efficient setup.
- The PTI system was successful in removing VOCs in the SVE off-gas to below the maximum allowable emissions at Site 9 of 25 ppmv. The average total DRE for VOCs was 95%. The PDU alone achieved an overall DRE of 97%. These results were computed from FID data.
- The estimated unit cost of implementing a 3,000 scfm PTI System at Site 9 is \$3.77 per lb. of VOC treated. The commercialization of the technology over the next few years will lower the treatment costs further.

Based upon this demonstration, PTI recommends implementing the following design modifications to enhance system performance and/or reduce treatment costs:

- Redesign the weather seals in the Concentration Unit to prevent ambient rainwater and humidity from entering the adsorber.
- Evaluate the performance of different adsorbent materials to determine which adsorbent would offer the highest removal efficiencies, cost effectively.

**Objective 6. Disseminate the results of the demonstration throughout the DoD, DOE, private industry, state regulatory agencies and the NAS RAB.**

The results of this technology demonstration will be presented to other Naval Remedial Project Managers, compiled into a database for distribution to interested public and private sector parties, and shown on the NFESC web page. The RAB is a partnership between NAS North Island, local regulatory agencies and the local community. The purpose of the RAB is to review and comment on remedial action methods prior to implementation. Therefore, any innovative technology that is considered for implementation at NAS North Island will be reviewed by the RAB. This Final Report will be submitted to the RAB for their information and review.

## Section 5. References

*"Process Technologies Incorporated, Technology Demonstration Final Work Plan"*, NAS North Island, Site 9, Contract No. N47408-97-C0125, October 1997.

*"Photolytic Destruction Technology Memorandum"*, McClellan Air Force Base, Site S, Operable Unit D, CH<sub>2</sub>M Hill, June 1996.

*"Final Project Plan for Non-Time Critical Removal Action for Sites 9 and 11, Naval Air Station North Island, San Diego County, CA"*, OHM Remediation Services Corporation, April 1996.

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**Soil Vapor Extraction at Seymour Recycling Corporation Superfund Site  
Seymour, Indiana**

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# Soil Vapor Extraction at Seymour Recycling Corporation Superfund Site Seymour, Indiana

<b>Site Name:</b> Seymour Recycling Corporation Superfund Site	<b>Contaminants:</b> Volatile and Semivolatile Organic Compounds (VOCs) and (SVOCs) - More than 35 compounds identified including trichloroethane (TCA), tetrachloroethane (PCA), trichloroethene (TCE), tetrachloroethene (PCE), carbon tetrachloride, and benzene	<b>Period of Operation:</b> June 1992 to Present (Report covers period of June 1992 through 1996)
<b>Location:</b> Seymour, Indiana		<b>Cleanup Type:</b> Full-scale
<b>Vendor:</b> Information not provided	<b>Technology:</b> Soil Vapor Extraction - 19 horizontal vapor extraction wells, 11 horizontal air inlet wells (passive), a vacuum blower, a moisture separator, and an activated carbon adsorption system - Air flow rate - 52.9 to 122.6 cfm (average per quarter); 80 cfm (average over 2.8 years of operation) - Operating vacuum 27 - 40 inches of water	<b>Cleanup Authority:</b> CERCLA - ROD date: September 30, 1987
<b>State Contact:</b> Prabhakar Kasarabada IDEM 100 N. Senate Avenue, 12 <sup>th</sup> Fl. North Indianapolis, IN 46206-6015 (317) 308-3117  <b>PRP Lead Contractor:</b> Victoria Kramer Geraghty & Miller, Inc. 88 Duryea Road Melville, NY 11747 (516) 391-5268	<b>Multimedia Cap</b> - Constructed over the horizontal SVE wells (24-inch vegetative cover, geotextile fabric, 12-inch thick drainage layer, 60 mil thick synthetic liner, 2-ft thick clay/till layer)  <b>In Situ Bioremediation</b> - Nutrient addition - 8/86-10/86; 1/97-2/97; and 8/90 - Mechanical injection of nutrient solution (nitrogen, phosphorus, potassium, and sulfur)	<b>Remedial Project Manager:</b> Jeff Gore EPA Region 5 77 West Jackson Boulevard Chicago, IL 60604-3590 (312) 886-6552
<b>Waste Source:</b> Improper waste management practices	<b>Type/Quantity of Media Treated:</b> Soil - 200,000 cubic yards of soil, based on an area of 12 acres and a depth of 10 ft.	
<b>Purpose/Significance of Application:</b> SVE system using horizontal wells, in combination with in situ bioremediation, under a multimedia cap.		

## Soil Vapor Extraction at Seymour Recycling Corporation Superfund Site Seymour, Indiana (continued)

**Regulatory Requirements/Cleanup Goals:**

- Chemical-specific soil cleanup levels were not specified for this application. Instead, requirements were specified in terms of a system design goal.
- The design goal for the SVE system was to extract a total volume of soil vapor equal to 500 pore volumes from beneath the site within 30 years. The system was to be operated to extract between 2 and 35 pore volumes per year. After 500 pore volumes of soil vapor had been extracted, the system was to be operated as a passive system.

**Results:**

- As of 1997, 430 pore volumes and about 30,000 pounds of VOCs had been extracted by the SVE system.

**Cost:**

- Capital cost for the SVE system - \$1.2 million
- O&M data were provided only as a aggregate for all remediation activities at the site; therefore, O&M costs specific to the SVE system were not available.

**Description:**

From 1970 to early 1980, the Seymour Recycling Corporation (SRC) and its corporate predecessor, Seymour Manufacturing Company, processed, stored, and incinerated chemical wastes at the Seymour site. The site, which occupies about 14 acres, was closed when SRC failed to meet a 1978 agreement with the State of Indiana to cease receiving wastes and to institute better waste management practices. In 1980, the site was placed under receivership by a state court. In 1982, EPA signed a Consent Decree with a small group of Potentially Responsible Parties (PRPs) to complete "surface cleanup" at the site. On September 9, 1983, the site was listed on the NPL. A ROD signed in September 1986 specified an interim groundwater pump-and-treat system remedy. A second ROD, signed in September 1987, specified more comprehensive remediation of the site, including the use of SVE.

The SVE system included 19 horizontal vapor extraction wells, 11 horizontal air inlet wells (passive), a vacuum blower, a moisture separator, and an activated carbon adsorption system. Approximately 12,700 linear feet of horizontal vapor extraction piping (laterals) were installed about 30 inches below grade. Wells were spaced approximately 50 ft apart and a multimedia cap was constructed above the wells. During installation of the SVE system, five lateral extraction wells were damaged. Repair of these wells was not feasible because of possible cap damage; therefore, the damaged wells were converted to fresh-air inlet wells. Air inlet wells were maintained at atmospheric pressure and extraction wells maintained at less than atmospheric pressure. This configuration resulted in ambient air entering the inlet wells at atmospheric pressure, being drawn through the unsaturated zone, and then being exhausted through the sub-atmospheric-pressure extraction wells. With the exception of the five damaged wells described above, all wells were designed to be able to operate as either extraction or inlet wells. In situ bioremediation was included in the remedy because it was believed that not all of the compounds detected at the site would be amenable to SVE treatment. As of 1997, 430 pore volumes and about 30,000 pounds of VOCs had been extracted by the SVE system. Remedial activities at the site were ongoing at the time of this report.

## SITE INFORMATION

### Identifying Information

**Site Name:** Seymour Recycling Corporation Superfund Site

**Location:** Seymour, Indiana

**CERCLIS ID No.:** IND040313017

**Record of Decision (ROD) Date:**  
September 30, 1987

### Treatment Application [17]

**Type of Action:** Remedial

**Technology:** Soil Vapor Extraction

**EPA SITE Program Test Associated With Application?** No

**Period of Operation:** June 1992 to Present  
(Report covers period of June 1992 through 1996)

**Quantity of Material Treated During Application:** 200,000 cubic yards of soil, based on an area of 12 acres and a depth of 10 ft.

### Background Information [1, 2, 9]

**Waste Management Practice that Contributed to Contamination:** Improper waste management practices

**Site History:** From 1970 to early 1980, the Seymour Recycling Corporation (SRC) and its corporate predecessor, Seymour Manufacturing Company, processed, stored, and incinerated chemical wastes at the Seymour site. The site, which occupies about 14 acres, was closed when SRC failed to meet a 1978 agreement with the State of Indiana to cease receiving wastes and to institute better waste management practices.

In 1980, the site was placed under receivership by a state court. In 1981, the U.S. Environmental Protection Agency (EPA) fenced the site to restrict access, constructed dikes to control site runoff, installed an on-site carbon adsorption unit to treat surface water, and sampled on-site soil and the contents of on-site drums and tanks.

In 1982, EPA signed a Consent Decree with a small group of Potentially Responsible Parties (PRPs) to complete "surface cleanup" at the site. Surface cleanup activities, conducted by Chemical Waste Management (CWM) between December 1982 and January 1984, involved the removal and disposal off-site of all wastes stored at the ground surface, including about 50,000 drums and 100 storage tanks. Contaminated soil was excavated from about 75 percent of the site to a depth of 1 foot. In addition, contaminated soil was excavated to a depth of 2 feet from a drum crushing pad area that had been constructed during cleanup activities. The excavated soil was disposed off-site. The site was backfilled with clean fill and covered with a protective clay cap.

Shallow groundwater from the site flows towards a nearby farm and the Snyder Acres subdivision, which has about 100 residences. EPA entered into agreements in 1982 and 1983 with additional PRPs to establish funds for extending Seymour's municipal water system to the farm and Snyder Acres subdivision. This extension of the water system was performed in 1985.

### Regulatory Information [3, 11]

On September 9, 1983, the site was listed on the Superfund National Priority List (NPL).

In September 1986, EPA and the Indiana Department of Environmental Management (IDEM) prepared a ROD for the Seymour site that specified an interim groundwater pump-and-treat system to treat groundwater at the site. On September 30, 1987, a second ROD was signed that outlined a comprehensive site cleanup. In December 1988, a Consent Decree outlining the Seymour site remedial



EPA

U.S. Environmental Protection Agency  
Office of Solid Waste and Emergency Response  
Technology Innovation Office



## SITE INFORMATION (CONTINUED)

design/remedial action (RD/RA) cleanup was signed by EPA, IDEM, the City of Seymour, and approximately 150 PRPs. The PRPs are represented by the Seymour Site Trust.

### Remedy Selection:

The second ROD (September 1987) for Seymour identified the following remedial actions:

- Implementation of a full-scale soil vapor extraction (SVE) system
- In situ bioremediation of soils
- Groundwater extraction and treatment by air stripping (an expansion of the interim system specified in the 1986 ROD)
- Mixed-media capping
- Excavation of 800 yds<sup>3</sup> of contaminated creek sediment and consolidation of the sediment beneath the cap
- Deed and access restrictions and other institutional controls

According to the ROD, the use of a cap and operation of SVE would be useful in preventing leaching of contaminants from the soil to the groundwater, preventing direct contact with contaminated soil, and preventing run-off of contaminated water or sediment. The ROD also indicated that SVE was expected to reduce substantially the concentrations of volatile organic compounds (VOCs) in the unsaturated soils, and that, by including SVE, the selected remedy would be more protective of human health and the environment than a similar remedy without SVE.

The remedial action at Seymour consists of two response actions, one for groundwater and one for the source area. The response action for

contaminated groundwater is identified as Operable Unit 1 (OU 1) and for the source area as OU 2. This report is focused on the SVE application at the site. Limited information about the design, operation, performance, and cost of the groundwater cleanup system is provided in this report to present a context for the SVE application.

### Site Contacts

**Site Lead:** PRP

**Oversight:** EPA

### **Site Management:**

EPA Lead  
Jeff Gore, Remedial Project Manager (RPM)  
EPA Region 5  
77 West Jackson Boulevard  
Chicago, IL 60604-3590  
Telephone: (312) 886-6552

### **State Contact:**

Prabhakar Kasarabada  
Indiana Department of Environmental  
Management  
100 N. Senate Avenue, 12<sup>th</sup> Floor North  
P.O. Box 6015  
Indianapolis, IN 46206-6015  
Telephone: (317) 308-3117

### **PRP Lead Contractor:**

Victoria Kramer  
Geraghty & Miller, Inc.  
88 Duryea Road  
Melville, NY 11747  
Telephone: (516) 391-5268

## MATRIX DESCRIPTION

### Matrix Identification

**Type of Matrix:** Soil

### Contaminant Characterization [1, 2, 3, 9]

**Primary Contaminant Groups:** From August 1983 to May 1986, EPA performed a remedial

## MATRIX DESCRIPTION (CONTINUED)

investigation (RI) at the site. Major RI results are summarized below.

- On-site soils at various depths were contaminated with hazardous organic and inorganic compounds. More than 35 organic compounds were identified, including relatively high concentrations of 1,1,2-trichloroethane (TCA); benzene; vinyl chloride; carbon tetrachloride; 1,1,2,2-tetrachloroethane (PCA); and trichloroethene (TCE). Concentrations of VOCs detected in on-site soils ranged from 10 milligrams per kilogram (mg/kg) to greater than 1,000 mg/kg.
- During the RI, shallow groundwater located at 6 to 8 feet below ground surface (bgs) was found to be contaminated with several organic compounds including chloroethane; tetrahydrofuran; 1,4-dioxane; 1,2-dichloroethane; benzene; vinyl chloride; and 1,1,1-TCA. Subsequent sampling determined that tetrahydrofuran and 1,4-dioxane had migrated about 3,900 feet north-northwest of the site boundary.
- The deep aquifer located at 55 to 70 feet bgs is separated from the shallow aquifer by a silty clay aquitard. As of 1994, continued monitoring of the deep aquifer showed trace levels of site-specific compounds; however, these compounds do not appear to have migrated off site.
- Sediment in the nearby northwest drainage ditch area was contaminated with VOCs but at concentrations of less than 10 mg/kg.

Table 1 summarizes the highest average VOC concentrations in on-site soils above the water table (1.5 to 6.0 feet bgs), as measured during the 1986 RI. The ROD indicated that there were an estimated 200,000 lbs of VOCs present in the soil at the site.

**Table 1: On-Site Soil Contaminants and Concentrations [1]**

Contaminant	Maximum Concentration (mg/kg)
Benzene	1.4
Carbon tetrachloride	280
Chloroform	15.5
1,2-Dichloroethane	0.0064
Hexachlorobenzene	0.43
Hexachloroethane	5.5
PCE	37
1,1,2,2-PCA	120
TCE	420
1,1,2-TCA	95

### Matrix Characteristics Affecting Treatment Cost or Performance [1]

The key matrix characteristics that affect cost or performance for this technology, and the values measured for each, are provided below in Table 2. Hydrogeologic conditions at the Seymour site included the following: a shallow water table (1.5 to 6.0 feet bgs) that flows primarily north and northwest, a complex distribution of soil types, and low air permeabilities in the soil. As discussed later, use of a clay cover allowed for extraction of a relatively large amount of VOCs.



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## MATRIX DESCRIPTION (CONTINUED)

Table 2: Matrix Characteristics [1, 18]

Matrix Characteristic	Value
Soil Classification	Information not provided
Clay Content and/or Particle Size Distribution	Sands, silts
Moisture Content	Information not provided
Air Permeability	Medium to high
Porosity	Information not provided
Total Organic Carbon	Information not provided
Nonaqueous Phase Liquids	Not observed

## DESCRIPTION OF THE TREATMENT SYSTEM

### Primary Treatment Technology

SVE

### Supplemental Treatment Technology

Activated carbon adsorption  
In situ bioremediation  
Multimedia cap

### System Description and Operation

#### System Description [1, 2, 17, 18]

The remediation system for contaminated soil at Seymour consisted of the following:

- Construction and operation of a SVE system using horizontal wells
- In situ bioremediation of soils
- Construction of a multi-media cap over the SVE system

The SVE system was constructed at Seymour between July and October 1990. The system

consisted of 19 horizontal vapor extraction wells, 11 horizontal air inlet wells (passive), a vacuum blower, a moisture separator, and an activated carbon adsorption system. Approximately 12,700 linear feet of horizontal vapor extraction piping (laterals) were installed about 30 inches below grade. The piping was installed on a bed of compacted sand and buried with a minimum of 8 inches of sand compacted using a mechanical hand tamper. The laterals were constructed using 4-inch diameter slotted, corrugated, polyethylene pipe wrapped in a filter sock. Extraction wells were connected to a common, 4-inch diameter, 765-ft long, high-density polyethylene (HDPE) header pipe.

The air inlet wells each had a 30 ft long coil of black plastic pipe attached to the well. Ambient air first passed through the coiled pipe to warm the air by solar radiation before it entered the well.

Figure 1 shows a plan view of the design of the vapor extraction and air inlet wells at Seymour. Figure 2 shows a cross-section view of the design for the wells. Wells were spaced approximately 50 ft apart and a multimedia cap was constructed above the wells.

During installation of the SVE system, five lateral extraction wells were damaged. Repair of these wells was not feasible because of

## DESCRIPTION OF THE TREATMENT SYSTEM (CONT.)

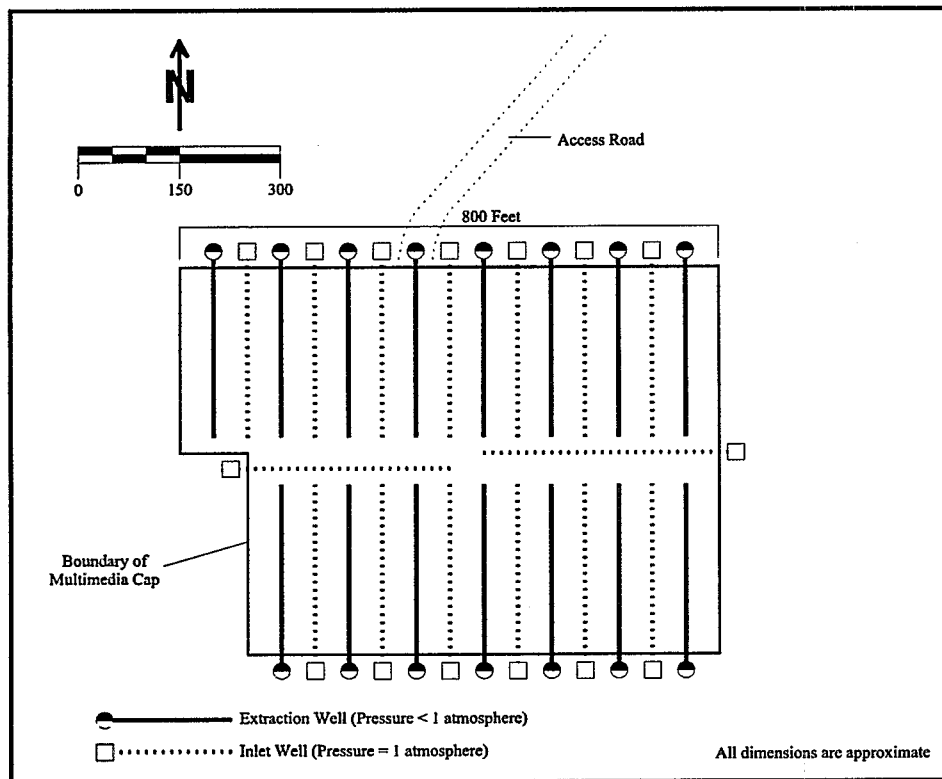


Figure 1. Plan View of the Design for the SVE Wells [1]

possible cap damage; therefore, the damaged wells were converted to fresh-air inlet wells.

Air inlet wells were maintained at atmospheric pressure and extraction wells maintained at less than atmospheric pressure. This configuration resulted in ambient air entering the inlet wells at atmospheric pressure, being drawn through the unsaturated zone, and then being exhausted through the subatmospheric-pressure extraction wells. With the exception of the five damaged wells described above, all wells were designed to be able to operate as either extraction or inlet wells. Each extraction well was retrofitted to accept a wind-driven turbine ventilator.

The vacuum blower used in this system is a 3-horsepower (HP) belt-driven model originally designed to deliver 40 standard cubic feet per minute (scfm) at 27 inches of water. However,

the blower actually operated at an average of 6 to 100 scfm, with higher flow rates in the summer (100 scfm) and lower flow rates in the winter (30 scfm). The blower is housed in a fiberglass building on the north-central portion of the site.

A multimedia cap was constructed over the horizontal SVE wells at Seymour. The design of the cap included (from top to bottom) a 24-inch vegetative cover, geotextile fabric, a 12-inch thick drainage layer, a 0.060-inch (60 mil) thick synthetic liner, a 2-ft thick clay/till layer,



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# DESCRIPTION OF THE TREATMENT SYSTEM (CONT.)

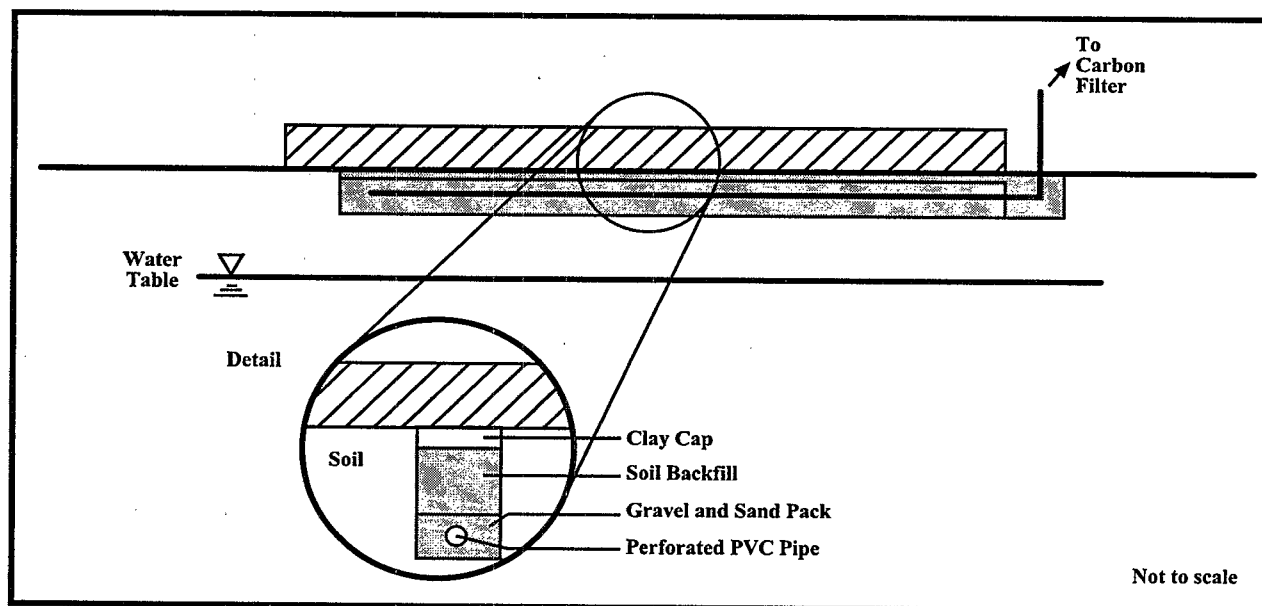
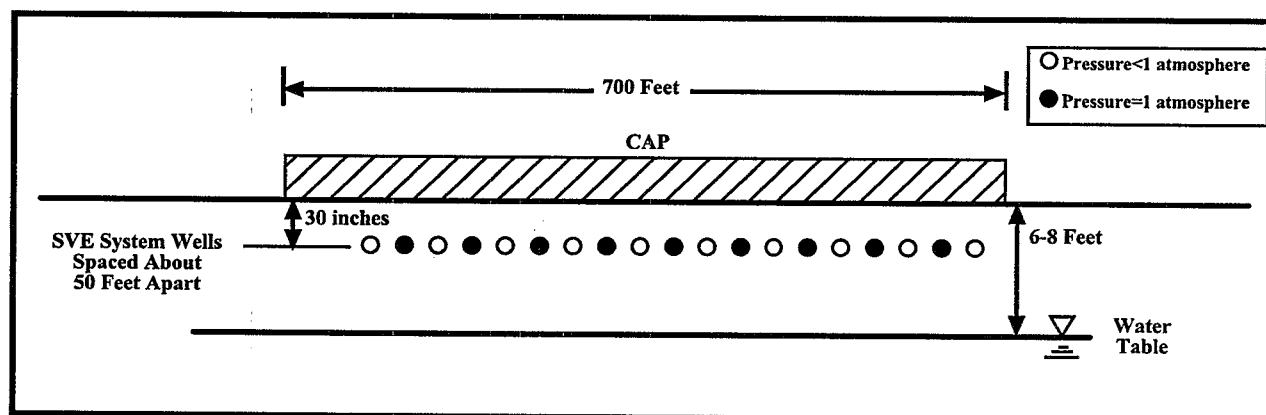


Figure 2. Cross Section of the Design for the SVE System Wells and Multimedia Cap [1]

## DESCRIPTION OF THE TREATMENT SYSTEM (CONT.)

and another geotextile fabric. The cap was constructed in December 1990.

In situ bioremediation of contaminated soils was included as part of the remedy for this site because it was believed that not all of the compounds detected in soil at the site would be amenable to treatment using vapor extraction. Bioremediation was intended to be stimulated by the addition of nutrients to the soil prior to installation of the SVE system and cap. Nutrient addition was performed August to October 1986, January to February 1987, and July to August 1990 by mechanical injection and tilling of nutrients 18-24-inches below grade. One tanker-truck load of nutrient solution was added to the soil (5 - 10,000 gallons), consisting of nitrogen, phosphorus, potassium, and sulfur fertilizer.

### System Operation [2, 4]

The design goal for the SVE system was to extract a total volume of soil vapor equal to 500 pore volumes from beneath the site within 30 years. The system was to be operated to extract between 2 and 35 pore volumes per year. After 500 pore volumes of soil vapor had been extracted, the system was to be operated as a passive system.

The design goal of extracting 500 pore volumes could be achieved after one or more temporary shutdowns. The system shut down active SVE operation 12/31/97 and is in the process of 1 year of passive activity (1/1/98 - 12/31/98). Passive operation is intended to allow build up of vapors under the clay cap and anaerobic bioremediation of chlorinated solvents in soil.

The system began operating in June 1992 at an average flow rate of 104 scfm. Samples were collected and analyzed for VOCs, semivolatile organic compounds (SVOC), and permanent

gases that include oxygen, carbon dioxide, methane, carbon monoxide, and nitrogen. Permanent gas samples were collected to evaluate aeration and biological activity at the site.

### Operating Parameters Affecting Treatment Cost or Performance

The key operating parameters that affect cost or performance for this technology, and the values measured for each, are provided below.

**Table 3: Operating Parameters [5-8, 19]**

Operating Parameter	Value
Air Flow Rate	52.9 to 122.6 cfm (average per quarter); 80 cfm (average over 2.8 years of operation)
Operating Vacuum	27 - 40 inches of water

### Groundwater Pump-and-Treat System [11]

In addition to the remediation system for contaminated soil, an interim pump-and-treat system for contaminated groundwater was installed at the site in 1987. A permanent pump-and-treat system was completed in February 1991.

The pump-and-treat system at Seymour consists of two extraction wells located about 300 and 1,000 ft from the northern site boundary, with a combined pumping rate of approximately 140 gallons per minute (gpm). An additional well is located approximately 3/4 mile from the source area (at the far edge of the groundwater contamination plume), and is used only as a monitoring well. Extracted groundwater is treated on site with an iron reaction and settling system, air stripping, and additional filtering including activated carbon. The treated groundwater is discharged to the City of Seymour's Publicly-Owned Treatment Works (POTW).



## DESCRIPTION OF THE TREATMENT SYSTEM (CONT.)

### Timeline

**Table 4: Timeline [4]**

Start Date	End Date	Activity
1970	1980	Seymour Recycling Corporation and its predecessor, Seymour Manufacturing Company, processed, stored, and incinerated chemical wastes at the Seymour site.
1980	-	The site was placed under receivership by state court.
1982	-	A consent decree was signed by EPA and the PRPs requiring "surface cleanup."
December 1982	January 1984	Surface cleanup was performed.
August 1983	May 1986	EPA conducted an RI at the site.
September 9, 1983	-	The site was listed on the NPL.
September 1986	-	The first ROD was signed for this site.
September 30, 1987	-	The second ROD was signed for this site.
December 1988	-	A Consent Decree outlining the Seymour site RD/RA cleanup was signed by EPA, IDEM, the City of Seymour, and approximately 150 PRPs.
July 1990	October 1990	The SVE system was constructed.
December 1990	-	The multi-media cap was constructed at the site.
June 1992	1997	The SVE system was operated.
1/1/98	12/31/98	The SVE system was shut down to allow the soils to return to an anaerobic state.

## TREATMENT SYSTEM PERFORMANCE

### Cleanup Goals/Standards [3]

No performance goals or standards for contaminated soil were identified in the ROD for this site. However, a design goal for the SVE system was to extract a total volume of soil vapor equal to 500 pore volumes within 30 years.

While no specific soil cleanup goals were included in the ROD, the ROD specified that groundwater be restored to attain a cumulative excess cancer risk of  $1 \times 10^{-5}$  at the site boundaries and a risk of  $1 \times 10^{-6}$  at the nearest current receptor, and to meet the MCLs at the site boundary for specific carcinogenic

constituents including benzene, chloroform, 1,2-dichloroethane, 1,1-dichloroethene, trichloroethene, and vinyl chloride. In addition, the ROD specified that the total health index (HI) not exceed 1, to account for the non-carcinogenic effects of contaminants in the groundwater using procedures specified in the Superfund Public Health Manual.

### Treatment Performance Data [5-8]

Treatment performance data for this application, presented below, include the following: the concentration and mass of contaminants extracted from the soil and groundwater, the number of soil pore volumes extracted, the

## TREATMENT SYSTEM PERFORMANCE (CONT.)

concentrations of "permanent" gases (oxygen, carbon monoxide, carbon dioxide, methane, and nitrogen) in the extraction system effluent, and the results from ambient air monitoring for VOCs and SVOCs.

### SVE Performance Data [4, 5, 6, 7, 8, 11]

The vendor's plan for collection and analysis of samples of extracted vapors was different for VOCs than for SVOCs. For VOCs, the vendor was to collect samples on a monthly basis from startup through June 1993 (1 year), on a quarterly basis through December 1993 (6 months), on a semiannual basis through September 1995 (2 years), and annually after that time for the duration of system operation. For SVOCs, the vendor was to collect samples on a quarterly basis from January 1993 to December 1993 (1 year), on a semiannual basis through December 1994 (1 year), and annually after that time for the duration of system operation.

The mass of VOCs extracted by the SVE and pump-and-treat systems are summarized on Table 5 for the period 1989 through 1996. The mass of VOCs was calculated as the sum of the masses of 48 specific constituents, as provided in References 5 through 8.

As shown on Table 5, the SVE system extracted a total of 29,166 pounds of VOCs (of an estimated 200,000 pounds) over a four and one-half year period from June 1992 to December 1996. The mass of VOCs extracted per year by the SVE system decreased by more than 90% over the four year period. Figure 3 summarizes the total mass of VOCs removed by the SVE system as a function of time. As shown on Figure 3, the total mass of VOCs removed is approaching an asymptotic value. The following VOCs accounted for approximately 85 percent of the total mass of VOCs extracted by the SVE system over the four year period: cis-DCE (8.7%), PCE (9.7%), toluene (4.8%), 1,1,1-TCA (31.8%),

TCE (23.2%), and 1,1,2-Trichlorotrifluoroethane (freon) (7.0%).

Constituent-specific concentration data were available for nine VOCs in the vapors extracted from the vadose zone; concentrations ranged as follows during a four year period from 1993-1996:

Benzene - ND to 2 parts per million by volume (ppmv)  
Carbon tetrachloride - ND to 1.5 ppmv  
Chloroform - ND to 2 ppmv  
1,2-Dichloroethane - ND to 6 ppmv  
DCE - ND to 1.5 ppmv  
Methylene chloride - ND to 2 ppmv  
PCE - ND to 130 ppmv  
TCE - ND to 600 ppmv  
Vinyl chloride - ND to 8 ppmv

According to the EPA RPM, SVOCs have never been measured at concentrations above a level that was considered a risk to human health and the environment. EPA stopped sampling for SVOCs in 1995. SVOCs were analyzed for in 8 sampling events during 1992 and 1993 by collecting samples of extracted vapors in a Tedlar bag near the blower. SVOCs were measured as below detection limits (DL) in 4 of the 8 events. In the events where they were detected, concentrations included the following:

SVOCs	Concentrations Measured Above DL (mg/kg)
Naphthalene	0.6
Naphthalene	0.02
Nitrobenzene	0.07
2-Methyl Naphthalene	0.014
Butyl Benzyl Phthalate	0.065
Butyl Benzyl Phthalate	0.045
Bis (2-ethylhexyl) Phthalate	0.014



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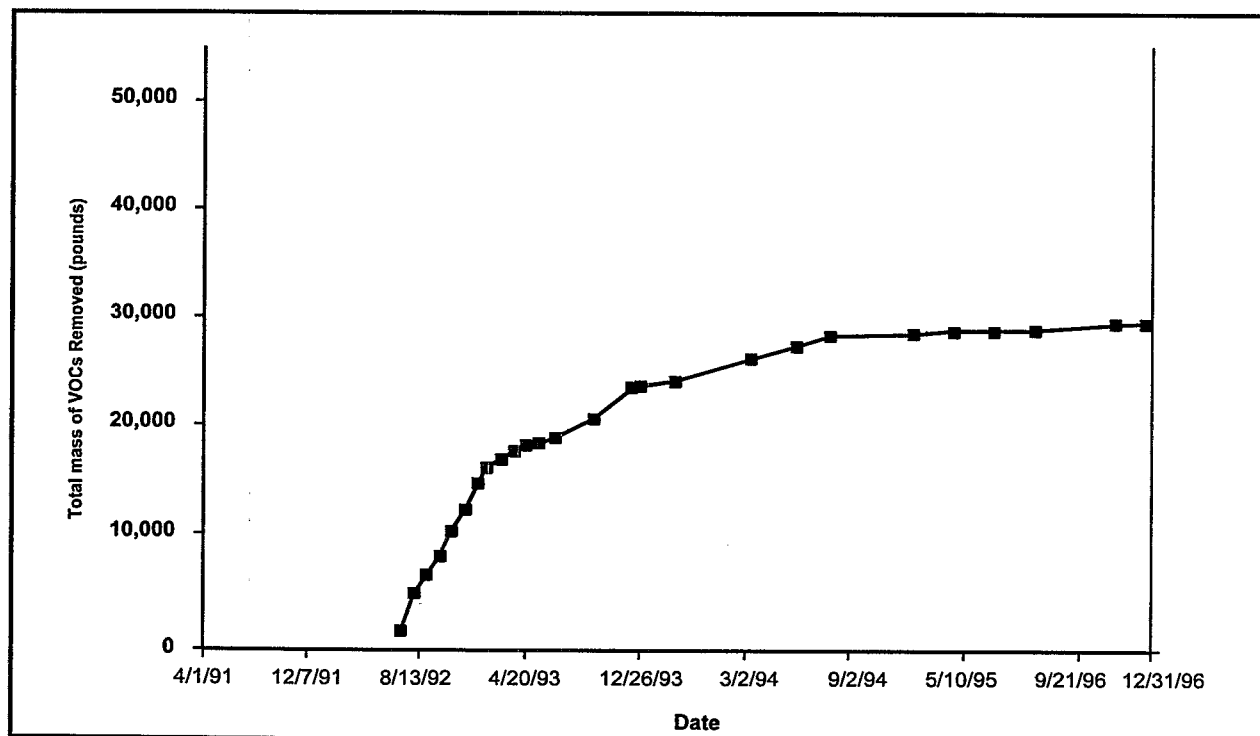
## TREATMENT SYSTEM PERFORMANCE (CONT.)

**Table 5: Mass of VOCs (lbs) Extracted By SVE and  
Groundwater Pump-and-Treat Systems [5, 6, 7, 8, 11]**

Time Period	SVE System		Pump-and-Treat System	
	Mass per Time Period	Cumulative Mass	Mass per Time Period	Cumulative Mass
1989 - December 31, 1992*	15,019	15,019	1,081	1,081
January 1 - December 31, 1993	8,543	23,562	684	1,765
January 1 - December 31, 1994	3,741	27,303	491	2,256
January 1 - December 31, 1995	1,302	28,606	167	2,423
January 1 - July 31, 1996	162	28,768	342	2,765
August 1 - December 31, 1996**	398	29,166	Not Provided	Not Provided

\* SVE system operation began on June 9, 1992

\*\* Derived from Ref. 11, p. 5



**Figure 3. Total Mass of VOCs Removed by SVE System Over Time [5-8]**

## TREATMENT SYSTEM PERFORMANCE (CONT.)

Table 6 summarizes information about the number of pore volumes extracted by the SVE system from startup through December 31, 1997 (2.8 years of operation). Almost 430 pore volumes were extracted during this period (a pore volume at this site is equal to 460,000 cubic feet). The number of pore volumes extracted per quarter ranged from as high as 35 (3rd quarter 1992) to 15 (1st quarter 1994). Also as shown on Table 6, the average flow rate for the SVE system at this site ranged from 122.6 cfm to 52.9 cfm over this time period.

Permanent gases were analyzed using samples collected in Tedlar bags. Methane was detected

at concentrations as high as 7.8 percent at startup, at concentrations of less than 0.1 percent after completing two months of system operation (August 1992), and has remained at that lower concentration since that time. Carbon dioxide was detected at concentrations as high as 9.5 percent at startup, at concentrations of less than 0.1 percent after 9 months of operation (March 1993), and has remained at that lower concentration since that time. The concentration of oxygen was measured as low as 3.6 percent at startup, increased to atmospheric levels (21 percent) after 4 months of operation (October 1992), and has remained at this elevated concentration since that time.

**Table 6: Number of Pore Volumes Extracted by SVE System [6, 11, 18]**

Integrating Period	Starting Date	Ending Date	Flow Average (cfm) <sup>1</sup>	Number of Pore Volumes Removed <sup>2</sup>
Startup	06/09/92	06/30/92	121.8	8.0
3 <sup>rd</sup> Quarter 1992	07/01/92	09/30/92	122.6	34.9
4 <sup>th</sup> Quarter 1992	10/01/92	12/31/92	101.2	28.8
1 <sup>st</sup> Quarter 1993	01/01/93	03/31/93	85.7	24.1
2 <sup>nd</sup> Quarter 1993	04/01/93	06/30/93	103.5	29.5
3 <sup>rd</sup> Quarter 1993	07/01/93	09/30/93	78.3	22.5
4 <sup>th</sup> Quarter 1993	10/01/93	12/31/93	64.8	18.7
1 <sup>st</sup> Quarter 1994	01/01/94	03/31/94	52.9	14.9
2 <sup>nd</sup> Quarter 1994	04/01/94	06/30/94	61.5	17.5
3 <sup>rd</sup> Quarter 1994	07/01/94	09/30/94	88.7	25.6
4 <sup>th</sup> Quarter 1994	10/01/94	12/31/94	62.5	18.0
1 <sup>st</sup> Quarter 1995	01/01/95	03/31/95	60.0	16.9
2 <sup>nd</sup> and 3 <sup>rd</sup> Quarters 1995	4/1/95	9/30/95	85	30
4 <sup>th</sup> Quarter 1995	10/1/95	12/31/95	75	10
1 <sup>st</sup> and 2 <sup>nd</sup> Quarters 1996	1/1/96	6/30/96	37.5	40
3 <sup>rd</sup> and 4 <sup>th</sup> Quarters 1996	7/1/96	12/31/96	53	40
1 <sup>st</sup> and 2 <sup>nd</sup> Quarters 1997	1/1/97	6/30/97	27	13
3 <sup>rd</sup> and 4 <sup>th</sup> Quarters 1997	7/1/97	12/31/97	76.5	36
Total (through 12/31/97)				427

<sup>1</sup> SVE flowrate recorded by flow sensor and data logging system flow totalizer.

<sup>2</sup> One pore volume is equal to approximately 460,000 cubic feet.



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## TREATMENT SYSTEM PERFORMANCE (CONT.)

These concentrations of permanent gases indicate that, at startup, the vadose zone was in an anaerobic state, with low concentrations of oxygen but high concentrations of methane and carbon dioxide. However, after several months of system operation, these data show that the vadose zone became aerobic, with atmospheric concentrations of oxygen. Aerobic conditions were identified by the vendor as important for minimizing decomposition of DCE, TCE and PCE and for promoting aerobic biodegradation.

Ambient air samples were collected during initial system startup and during long-term operations (the first annual sampling took place in July 1994.) These samples were collected during the summer from a sampling station located downwind from the site. According to the vendor, samples were collected during the summer because that is when the greatest chance for volatilization and low wind conditions are likely to occur. The vendor indicated that quarterly samples of ambient air showed concentrations of VOCs in the 1 - 2 ppb range, that no SVOCs were detected, and that most compounds that were detected were not related to operations at the site. According to the vendor, these results support their conclusion from a risk assessment that no adverse impacts to the ambient air have resulted from the site operations.

### Pump-and-Treat Performance Data [5, 6, 7, 8, 11, 14, 18]

Table 5 also shows the mass of VOCs extracted from the groundwater using the pump-and-treat system, and compares the mass of VOCs extracted by SVE with the mass extracted from the saturated zone using a pump-and-treat system. As Table 5 shows, the pump-and-treat

system extracted a total of 2,765 pounds of VOCs over a seven year period from 1989 to 1996. The SVE system extracted approximately ten times more mass of VOCs from the vadose zone than the pump-and-treat system extracted from the saturated zone.

According to the EPA RPM, as of December 1997, approximately 30,000 pounds of organics have been extracted from the vadose zone with the SVE system, while only approximately 5,000 pounds have been extracted from the groundwater using the pump-and-treat system.

According to EPA's Five-Year Review Report, monitoring of the groundwater extraction and treatment system indicates that containment and reduction of contaminant concentrations in the groundwater has been achieved at this site. However, this report states that the size of the plume has not been reduced and has "expanded through dilution and groundwater flow at some locations." The PRPs at this site are required to operate the pump-and-treat system for a minimum of 12 years and to meet drinking water standards.

### Performance Data Quality

A written quality assurance (QA) plan and construction QA plan (CQAP) were prepared by Canonie Environmental Services, Inc. (CES), and approved by EPA prior to the start of SVE system construction. In addition, a construction quality control (QC) plan was prepared and followed by CES. QA procedures were developed for each phase of preconstruction, construction, and postconstruction activities. No exceptions to QA/QC procedures were noted in the available references.

## TREATMENT SYSTEM COSTS

### Procurement Process

The PRP's contracted with G&M of Plainview, New York, to design and implement the remedy.

### Treatment System Cost [16]

Table 7 summarizes the construction and operation and maintenance (O&M) costs for the overall remedial activity at Seymour. Actual costs are provided for project inception through

1991, and projected expenditures from 1992 through 1997; this table shows costs for all remedial activities at Seymour, including soil and groundwater cleanups. As shown in Table 7, approximately \$23 million were expended at Seymour from inception through 1991, and approximately \$7 million were projected as expenditures from 1992 through 1997, for a total of approximately \$30 million from inception through 1997.

**Table 7: Remedial Costs for Seymour [16]**

Item	Actual Expenditure - Inception Through 1991 (\$ million)	Projected Expenditures 1992 Through 1997 (\$ million)	Total Projected Expenditures Inception Through 1997 (\$ million)*
Construction Subcontracts (cap, site development, well installation, vapor extraction system, bioremediation, pretreatment plants, sediment removal, building demolition, Elk's Club alternate water supply)	8.71	0.43	9.14
Engineering/Technical Support (cap, site development, well installation, vapor extraction system, air monitoring/risk assessment, bioremediation, pretreatment plants, sediment removal, building demolition, Elk's Club alternate water supply)	4.91	0.19	5.10
Operation and Maintenance (consultant charges, wages/salaries, lab costs, maintenance, utilities, chemical/supplies)	2.20	3.57	5.77
Trust Administration	0.50	0.58	1.08
Agency Oversight	0.46	0.89	1.35
Contingency **	0.00	1.00	1.00
Past Response Actions ***	6.50	0.00	6.50
<b>TOTAL</b>	<b>23.28</b>	<b>6.66</b>	<b>29.94</b>

\* Total Projected Cost Through 1997 includes actual expenditures through 1991 plus projected expenditures 1992 through 1997

\*\* Contingency costs as projected by PRPs

\*\*\* Past response actions are for payments made after formation of the PRP Trust for response costs incurred by EPA and the Coast Guard before trust cleanup activities were begun



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## TREATMENT SYSTEM COSTS (CONT.)

Actual costs for operation and maintenance of the overall remedial action at Seymour are further detailed in Table 8. Table 8 shows actual costs for the elements that are included for each year from 1992 through 1997. As shown in Table 8, the total for actual costs for operation and maintenance was \$3,474,610.

As shown in Table 8, annual O&M costs for the first four years of system operation averaged approximately \$750,000 per year, while annual

O&M costs for the latter two years of system operation averaged approximately \$220,000, less than one-third as much as for the first four years. The O&M costs decreased substantially in the latter two years of system operation because of the relatively lesser amount of time required for document preparation, sampling, data evaluation, and other activities. In addition, since 1995 EPA has had no ARCS/RAC contractors at this site.

**Table 8: Actual Operation and Maintenance Costs - Overall Remedial Action at Seymour [12]**

Sub Item	1992	1993	1994	1995	1996	1997 Through September	Total
Consultant Charges (operations support, SVE and P&T well maintenance, air modeling, SVE exhaust monitoring, air quality monitoring, risk assessment, sampling, modeling/pumping restrictions, extraction optimization, project administration) Consultant Charges	\$293,322	\$272,874	\$199,211	\$112,178	\$72,159	\$29,918	
Wages/Salaries (wages, secretarial services, engineering/purchasing, travel)	124,555	148,058	133,187	65,943	47,175	23,399	
Laboratory Costs (laboratory, sample analysis, SVE monitoring, air quality monitoring, laboratory/freight)	148,852	105,115	83,165	52,907	26,520	44,925	
Maintenance (new equipment, maintenance, replacement parts, drillers, monitoring well replacement, painting/security)	74,574	58,139	99,283	37,831	42,569	21,133	
Utilities (electrical, gas, potable water, telephone)	36,634	34,856	28,432	18,308	15,889	11,632	
Chemical/Supplies	8,201	3,931	7,948	16,039	9,202	7,228	
Trust Administration (local water payments, legal expenses, bank fees, outside auditors, trustee's fees)	65,495	62,070	74,940	110,429	45,179	29,549	
Agency Oversight (EPA, Illinois DEM)	123,203	277,184	33,560	121,246	12,357	4,106	
<b>TOTAL</b>	<b>\$874,836</b>	<b>\$962,227</b>	<b>\$659,726</b>	<b>\$534,881</b>	<b>\$271,050</b>	<b>\$171,890</b>	<b>\$3,474,610</b>

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## TREATMENT SYSTEM COSTS (CONT.)

Table 9 shows only that portion of the total remedial costs that are due to the soil remediation at Seymour. As shown in Table 9, the expenditures for a vapor extraction system were \$1,200,000, consisting of \$320,000 for construction and \$900,000 for engineering/technical support.

According to the EPA RPM, unit costs for SVE would be difficult to identify for this application,

because of the complex series of activities that have taken place at this site in the past, and the relatively large amount of money expended on groundwater pump-and-treat compared with SVE. The RPM indicated that SVE is fairly inexpensive to operate and that blowers used in SVE require very little in O&M (e.g., electricity) as compared with pumps used in groundwater pump-and-treat.

**Table 9: Estimated Costs for Soil Remediation at Seymour [16]**

Cost Element	Cost (\$ in 1991)
<b>Capital</b>	
Equipment and Construction	
- Vapor extraction system	\$320,000
- Bioremediation	\$520,000
- Cap (including all site development)	\$4,840,000
Engineering/Technical Support	
- Vapor extraction system	\$900,000
- Bioremediation	\$200,000
- Cap (including all site development)	\$1,580,000
<b>Capital Subtotal</b>	<b>\$8,360,000</b>
<b>Operation and Maintenance</b>	<b>Information not available</b>
<b>TOTAL</b>	<b>Information not available</b>



## OBSERVATIONS AND LESSONS LEARNED

### Cost Observations and Lessons Learned

Approximately \$8.4 million was expended for capital equipment, construction, and engineering/technical support for soil remediation, including \$1,200,000 for construction of the SVE system. However, information was not provided to identify how much was expended for O&M of the SVE system, separate from the O&M for the total remedial activity at Seymour. Therefore, a unit cost for construction and O&M of the SVE system was not calculated for this application.

The total cost for remedial activities at Seymour was approximately \$30,000,000, from inception through 1997. This amount includes costs for construction and operation of the SVE system, bioremediation, sediment removal, and groundwater pump-and-treat system.

### Performance Observations and Lessons Learned

No performance goals were established for soil at this site, however design goals were established for the total number of pore volumes to be extracted and the number of pore volumes to be extracted on a yearly basis. As of 1997, approximately 430 pore volumes had been extracted, as well as nearly 30,000 pounds of VOCs. For 1993 and 1994 (the two years for which a full year's worth of data are available), the SVE system extracted 76 and 91 pore volumes per year, respectively.

Analytical data from the vadose zone showed that at start-up the vadose zone was in an anaerobic state, with low concentrations of oxygen and high concentrations of methane and carbon dioxide. However, after several months of system operation, the vadose zone became aerobic, thus minimizing the decomposition of DCE, TCE, and PCE.

### Other Observations and Lessons Learned

This application was unusual because the SVE system was installed using horizontal wells in a very shallow vadose zone (less than 10 ft) and was covered with a multimedia cap to prevent short circuiting of air flow in the subsurface.

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### Preparation of Analysis

This case study was prepared for the U.S. Environmental Protection Agency's (EPA) Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.



**EPA**

U.S. Environmental Protection Agency  
Office of Solid Waste and Emergency Response  
Technology Innovation Office



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**Soil Vapor Extraction and Groundwater Containment at  
OU1, Shaw AFB, South Carolina**

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**Soil Vapor Extraction and Groundwater Containment at  
OU1, Shaw AFB, South Carolina**

<b>Site Name:</b> OU1, Shaw AFB - POL yard - Interim Response Area A - Interim Response Area C	<b>Contaminants:</b> BTEX, Petroleum Hydrocarbons, Free Product (JP-4 fuel) - 400,000 gallons of JP-4 in the groundwater; the size of the dissolved phase plume was approximately 47 acres.	<b>Period of Operation:</b> <b>POL SVE system</b> - December 1995 - ongoing (as of April 1998) <b>Interim Response Area A</b> - February 1992 - November 1996 <b>Interim Response Area C</b> - April 1995 - September 1997
<b>Location:</b> South Carolina		<b>Cleanup Type:</b> Full-scale cleanup
<b>Vendor:</b> IT Corporation	<b>Technology:</b> <b>POL Yard - Soil Vapor  Extraction (SVE)</b> - vacuum extraction wells, blowers, an oil/water separator, and thermal/catalytic oxidation units. <b>Interim Groundwater  Containment System - Area A</b> - Fuel recovery and a groundwater treatment system. Recovery wells, iron pretreatment, entrained oil removal, solids removal, packed air stripper. System upgraded in May 1997 with dual-phase recovery pumps, oil/water separator, equalization tank, and shallow-tray air stripper units. <b>Interim Groundwater  Containment System - Area C</b> - Passive free product recovery using one recovery well	<b>Cleanup Authority:</b> Installation Restoration Program
<b>Additional Contacts:</b> U.S. Air Force Air Combat Command		<b>Regulatory Point of Contact:</b> Information not provided
<b>Waste Source:</b> Fuel Spill	<b>Type/Quantity of Media Treated:</b> Soil - 30,000 square feet (areal extent); sands and silts; confining clay layer at 70 to 80 feet below ground surface (bgs) Groundwater - 47 acre plume (dissolved JP-4 fuel)	
<b>Purpose/Significance of  Application:</b> SVE system to remediate soil and two interim response action systems to contain groundwater		

## **Soil Vapor Extraction and Groundwater Containment at OU1, Shaw AFB, South Carolina (continued)**

### **Regulatory Requirements/Cleanup Goals:**

- The operational objective of the SVE system was to remove contamination from the soil as cost-effectively as possible to prevent contamination of surrounding soil and groundwater.
- The operational objectives of the Interim Response for Area A was to contain the plume by removing free product as quickly and cost-effectively as possible to prevent continued contamination of surrounding soil and groundwater; the objective of dissolved phase containment was to operate efficiently over a relatively long period of time.
- The operational objective of the Interim Response for Area C, free product source removal, was to remove liquid-phase contamination as quickly and cost-effectively as possible to prevent continued contamination of surrounding soil and groundwater.

### **Results:**

- SVE at POL Yard - Total contaminant removed through 19 months of operation (July 1997) was 518,000 lbs of JP-4 fuel, with removal rates ranging from 2,560 to 94,800 lbs/month. The system is still operating.
- Groundwater Containment Area A - Data on whether containment was achieved is not available. Total contaminant removed after 4 years of operation (through January 1996) was 114,340 gallons of JP-4 free product (monthly removal rates ranged from 0 to 9,980 gallons) and 171 gallons of dissolved phase JP-4 (monthly removal rates ranged from 0 to 10.7 gallons).
- Groundwater Containment Area C - Total contaminant removal after 1.4 years (through August 1996) was 12,766 gallons of JP-4 free product (monthly removal rates ranged from 266 to 2,145 gallons).

### **Cost:**

The report includes detailed data on O&M costs versus amount of contaminant removed and the effects of system modifications on these costs.

- SVE system at POL Yard - Total O&M costs after 19 months of operation was \$568,500 (monthly ranged from \$18,000 to \$57,500). The average O&M cost per unit of contaminant removed was \$1.09/lb
- Groundwater Containment Area A - Total O&M costs after 4 years of operation was \$995,500 (monthly ranged from \$674 to \$90,100). The average O&M cost per unit of contaminant removed was \$8.69/gallon of JP-4.
- Groundwater Containment Area C - Total O&M cost was \$33,000 (monthly ranged from \$437 to \$6,187). The average O&M cost per unit of contaminant removed was \$2.59/gallon of JP-4.

### **Description:**

OU1 at Shaw AFB, located in South Carolina, includes four IRP sites. This report focuses on the OU1 POL yard SVE system, the OU1 Area A Interim Response groundwater containment/treatment system, and the Interim Response Area C groundwater containment system (free product recovery). Contamination at OU1 included JP-4 fuel and BTEX, with an estimated 400,000 gallons of free product present in the groundwater.

The SVE system at the POL yard included 30 vacuum extraction wells, four vacuum monitoring wells, three SVE vacuum blowers, an oil/water separator, and two thermal/catalytic oxidation (CatOx) units. (Thermal oxidation was used until December 1997; replaced by CatOx). In December 1996, five VEP wells from OU1 Area B were connected to the system. The system was operated under 18 in of Hg and data are provided through July 1997. The Interim Groundwater Containment System at Area A included nine recovery wells, iron pretreatment, entrained oil removal, solids removal, packed air stripper. Treated effluent was discharged to a sewer and data are provided through November 1996. The Interim Groundwater Containment System at Area C included one recovery well for free product recovery and data are provided through August 1996. In September 1997, the Area C system was modified to a full-scale system.

# SVE and Groundwater Containment at OU1, Shaw AFB

## Site Background

Operable Unit 1 (OU1) is comprised of four IRP sites (SS-04, OT-05, ST-14, and Area C). This section focuses on the SVE system located at the OU1 POL yard, the OU1 Area A Interim Response groundwater containment/treatment system, and the Interim Response Area C groundwater containment system (product recovery system) all operating within OU1. The Area B VEP and Area C biosparging systems at OU1 are not addressed in this report. Soil and groundwater contamination within OU1 is presented in Figures 9, 10, and 11.

### Contaminants in Soil

- The contaminant of concern at the POL yard is JP-4 jet fuel with an estimated area of 30,000 sq. feet of contaminated soil.

### Contaminants in Groundwater

- An estimated 400,000 gallons of JP-4 free product and other petroleum hydrocarbons are present in the groundwater at OU1.
- A dissolved phase plume extends over an area of approximately 47 acres.

### Lithology

- Soils are typically sand and silts, followed by confining clay layer at approximately 70 to 80 feet bgs.
- Groundwater depths range from 20-40 feet bgs at OU1.

### Technologies at OU1

- Soil – The contaminated soil at the POL yard (Area A) is being removed by an SVE system.
- Groundwater – Groundwater containment within OU1 (Area A) was performed by the Interim Response OU1 Area A fuel recovery and a groundwater treatment system.
- Groundwater – Area C interim response passive free product recovery remedial action system operated from 1995 to 1997.

### SVE System Details

- The SVE system at the POL yard operates at 18 inches of Hg.
- The SVE system consists of 30 vacuum extraction wells; four vacuum monitoring wells; three SVE vacuum blowers; an oil and water separator; and two thermal Catalytic Oxidation units.
- In December 1996, five VEP wells (used to remediate free-phase product and dissolved-phase groundwater) located in Area B were connected to the SVE system.
- Extracted vapor was treated with Thermal Oxidation (ThermOx) from December 1995 until December 1997. Catalytic Oxidation (CatOx) is now used for vapor treatment.
- The system was shut down in August 1997 to evaluate the cause of the toxicity test failure for the treated effluent.

### Groundwater Containment System Details

- The Interim Response Area A groundwater containment system consisted of nine recovery wells and was designed to treat approximately 75 gallons per minute (gpm) of contaminated groundwater.
- The Interim Response Area A system consisted of a product recovery system, a groundwater recovery system, iron pretreatment, entrained oil removal, solids removal, a packed air stripper, and discharged the treated effluent into the sanitary sewer treatment system.
- The groundwater treatment system and free product recovery system upgrade was completed in May 1997.
- Free product recovery system was upgraded with dual-phase recovery pumps, an oil/water separator, an equalization tank, and two skid-mounted shallow tray air stripper units.

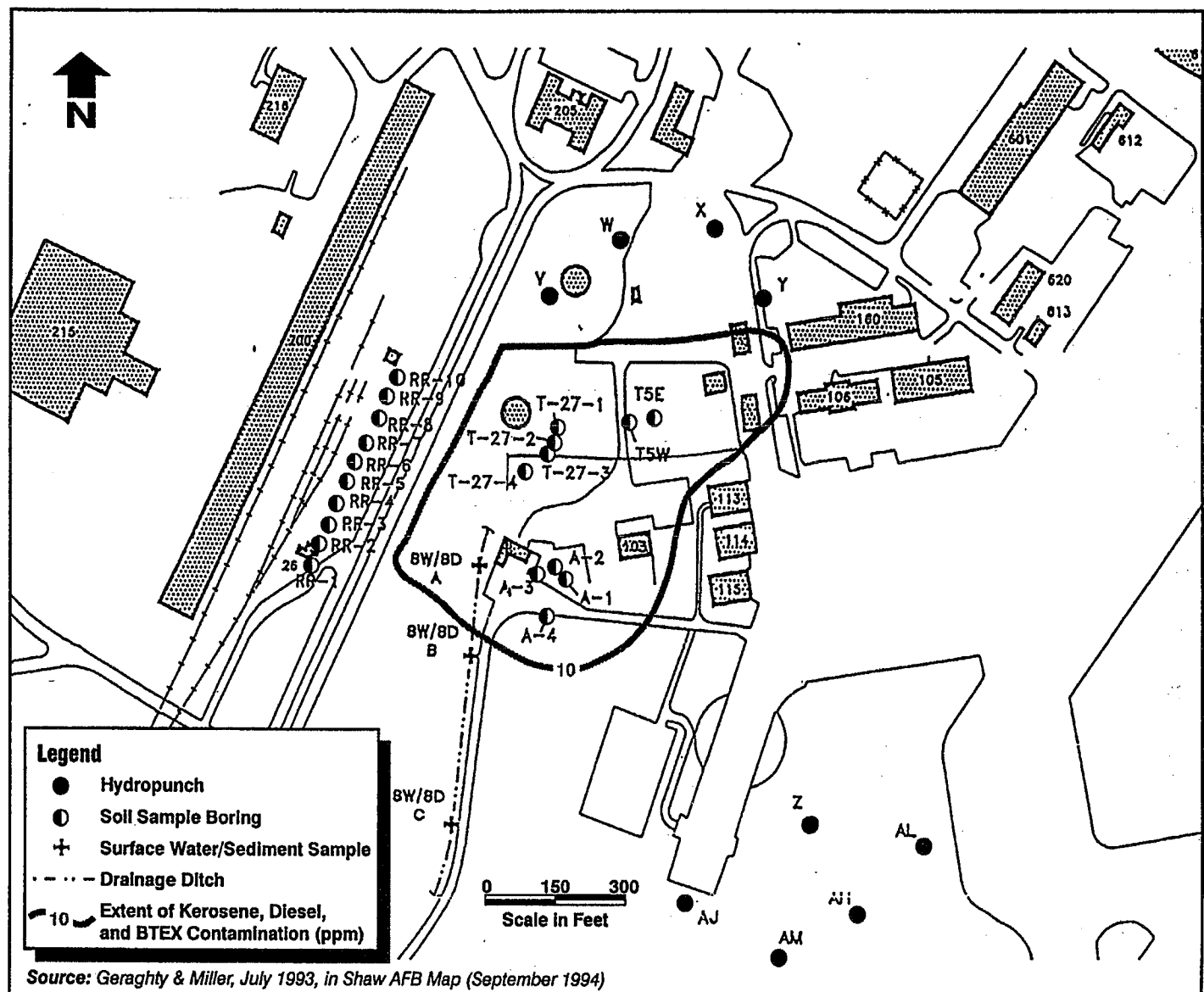


Figure 9. Soil Contamination OU1 POL Yard, Shaw AFB

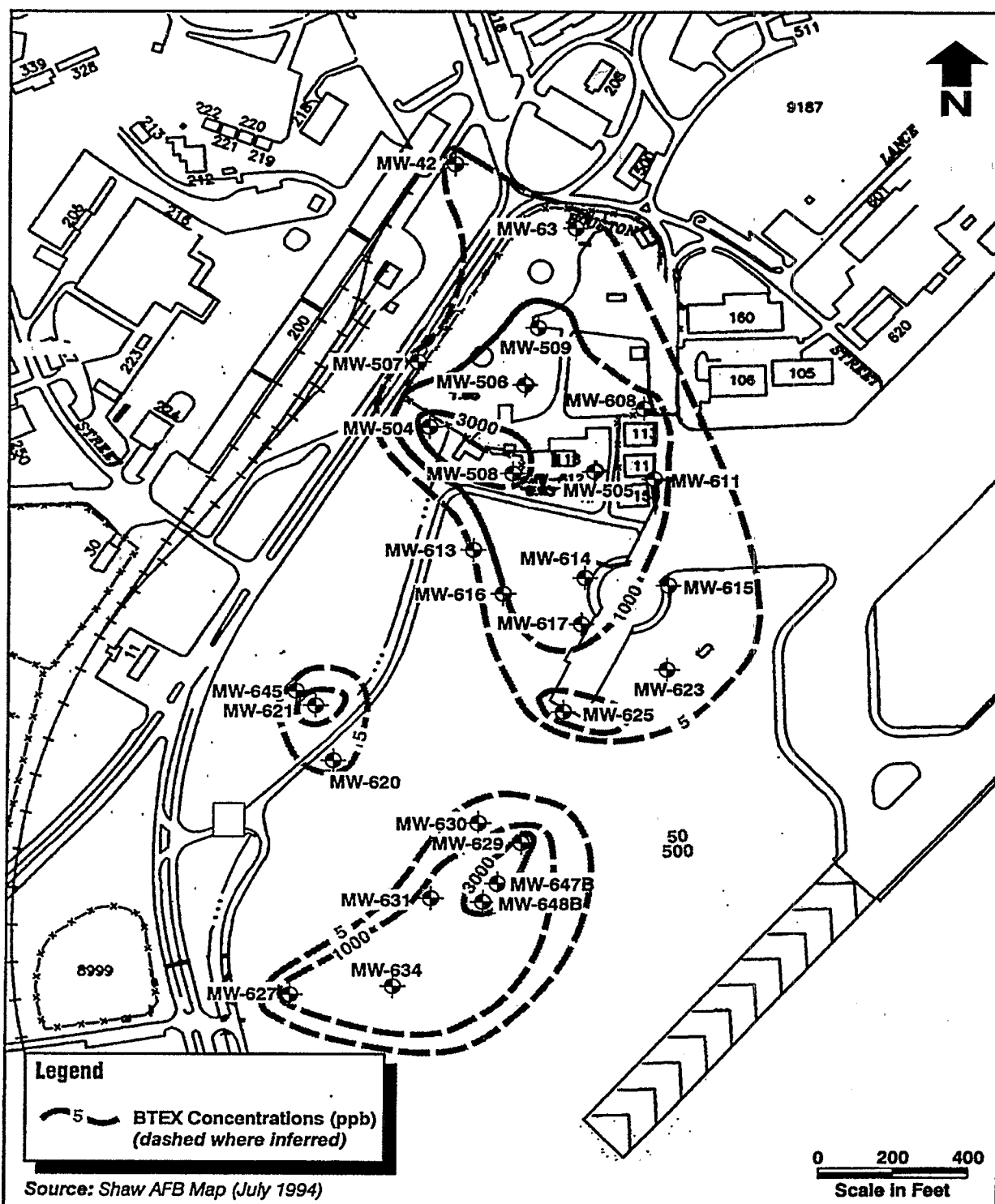


Figure 10. Distribution of Total Dissolved BTEX Concentrations in the Shallow Aquifer at OU1, Shaw AFB

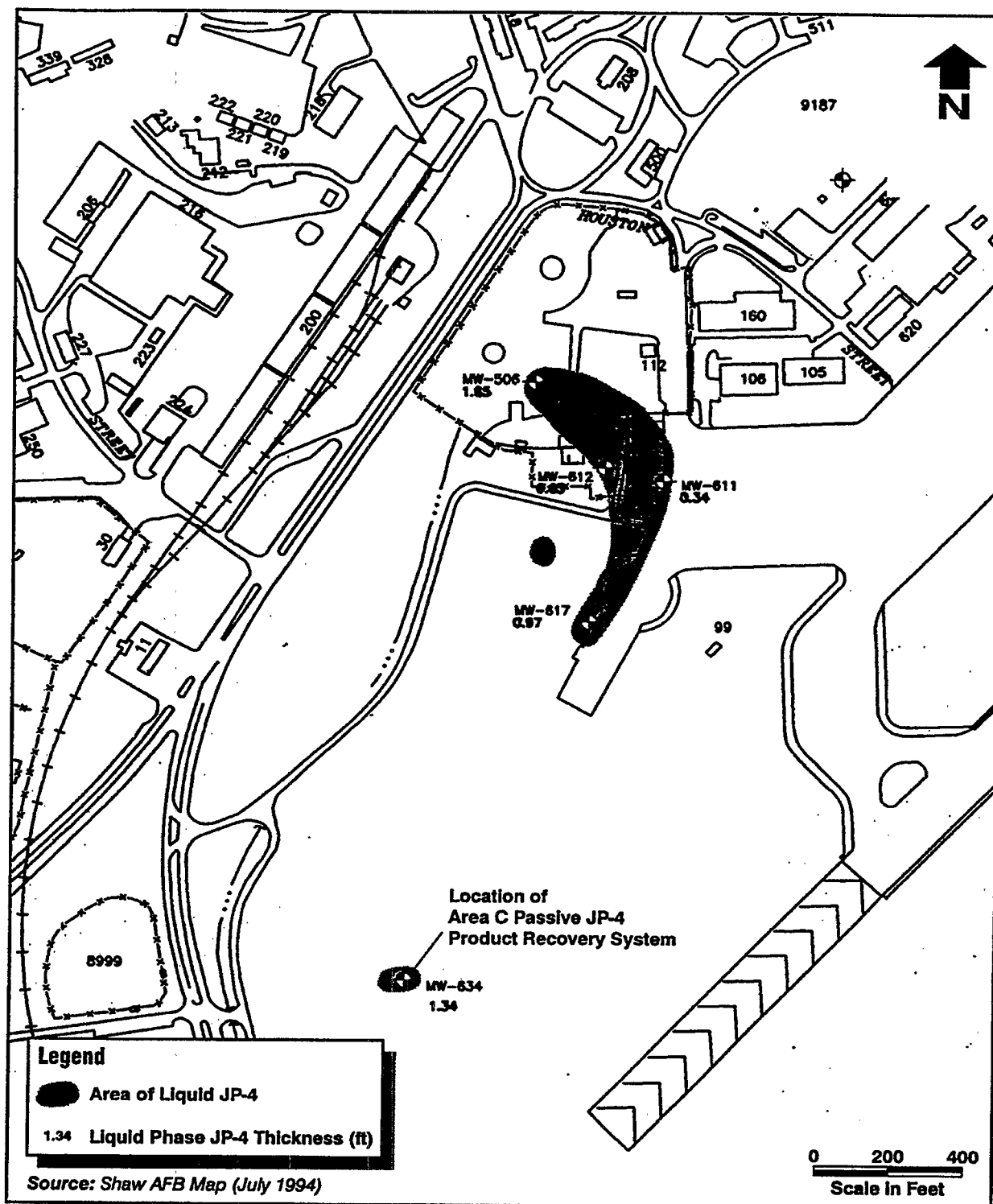


Figure 11. Free Phase JP-4 Distribution in Groundwater at OU1, Shaw AFB

- The interim response Area C passive groundwater containment system consisted of one recovery well (MW-634).
- The Area C system was modified to a full-scale system with five extraction wells in September 1997.

#### **Operation Period**

- The SVE system at the POL Yard began operation in December 1995 and is still operating.
- The Interim Response Area A system began operation in 1989 and was shut down in November 1996.
- The Interim Response Area C system begun operation in April 1995 and was operated until it was upgraded in September 1997.

#### **Total Capital Costs**

- The estimated capital costs for the SVE system at the POL yard (Area A) was \$1,800,000.

- The estimated capital costs for the Interim Response Area A groundwater treatment system was \$980,000.
- The estimated capital costs for the Interim Response Area C system was \$650,000.

#### **Total O&M Costs**

- The cumulative O&M costs for the SVE system at the POL yard were \$568,500 (January 1996 through July 1997).
- The cumulative O&M costs for the Interim Response Area A JP-4 product recovery system were \$995,500 (February 1992 through April 1996).
- Total cumulative O&M costs for the Area C system from June 1995 through August 1996 were \$33,000.

## **Cost and Performance of SVE at OU1 POL Yard**

### **SVE Operational Objectives**

The objective of SVE is typically to remove contamination in the soil as cost-effectively as possible to prevent contamination of surrounding soil and groundwater.

### **Cost for Operation**

Figure 12 illustrates the curves of O&M costs for the SVE at the OU1 POL yard. The monthly O&M costs range from \$18,000 to \$57,500. Total O&M costs after nineteen months of operation were \$568,500.

### **Contaminant Removal**

Figure 13 illustrates curves of the contaminant removal rates of JP-4 jet fuel for the SVE system at the OU1 POL yard. Contaminant removal rates ranged from 2,560 to 94,800 lbs per month. Total contaminant removal after nineteen months of operation was 518,250 lbs. of JP-4. By August 1996, the curve representing the cumulative removal rate began to flatten, indicating that the removal rate was decreasing and a system evaluation for reducing operating cost was warranted.

In 1997, pulsing of the SVE system was performed to reduce operating cost and

enhancing system performance (Shaw AFB, 1997). The cumulative removal rates began to increase in January of 1997, indicating that the pulsing of the SVE system increased system performance.

After the system upgrade in May 1997, the curve indicates an increase in cumulative and monthly removal rates. This may be attributed to the combined vapor flow from the addition of extraction wells after the system upgrade.

### **Correlation of Costs and Contaminant Removal**

Figures 14 and 15 illustrate the relationship between the O&M costs and the removal rates for the SVE system at the OU1 POL yard.

Figure 14 illustrates the curve of the cumulative O&M cost and the cumulative contaminant removal. In the month of August 1996 the curve started to steepen as the cost per unit of contaminant removal rises. However, after modification of the operations of the SVE system in 1997 and the addition of Area B extraction wells in December 1996 the curve flattened as the cost per unit of contaminant removal decreased.



In December 1997, a CatOx unit was installed to reduce vapor treatment cost. It is recommended that the data be re-evaluated following operation of CatOx unit to determine if the system objectives are being met.

Figure 15 illustrates the curves of the monthly and cumulative cost per unit of contaminant

removal over the operation time of the technology. The monthly curve illustrates the cost per unit of contaminant removal in each month. The cumulative curve illustrates that the average cost per unit of contaminant removal after nineteen months of operation time (September 1997) was \$1.09/pound of JP-4.

## **Cost and Performance of OU1 Area A Groundwater Containment**

### **Groundwater Containment Operational Objectives**

Groundwater containment systems are most often used to protect downgradient areas threatened by a contaminant plume. The objective of the free product source removal is typically to remove liquid-phase contamination as quickly and cost-effectively as possible to prevent continued contamination of surrounding soil and groundwater, while the objective of groundwater containment for dissolved phase contaminants is to operate efficiently over a relatively long period of time. The emphasis for free product removal is that the mass of contaminants are cost effectively removed, whereas the emphasis for dissolved phase groundwater containment is whether containment was cost effectively achieved.

Data on whether groundwater containment is being achieved at each site is not available.

Therefore, this report will only present the efficiency of contaminant removal for groundwater containment sites. However, each dissolved phase site should be evaluated to determine if the plume is cost effectively being contained.

### **Cost for Operation**

Figure 16 illustrates the curves of the O&M costs for the Area A groundwater containment system at OU1. The monthly O&M costs range from \$674 to \$90,100. Total O&M costs after four years of operation were \$995,500.

### **Contaminant Removal**

Figures 17 and 18 illustrates curves of the removal rates of dissolved JP-4 jet fuel and JP-4 free product at the Interim Response Area A groundwater containment system at OU1. Monthly removal rates of dissolved JP-4 fuel ranged from 0 to 10.7 gallons. Monthly removal rates of JP-4 free product ranged from 0 to

9,980 gallons. Total contaminant removal after 4 years of operation was 171 gallons of dissolved JP-4 jet fuel and 114,340 gallons of JP-4 free product. By January 1996, both curves representing the cumulative removal rates had flattened, indicating that the removal rates were negligible. The Interim Response Area A system was shut down in November 1996 because the operating objectives were no longer being met.

In May 1997 the OU1 groundwater treatment plant began treating extracted groundwater from both Area A and Area C wells. The combined Area A free product recovery system recovered 960 lbs and 1,920 lbs of free product during July and August 1997, respectively. A total of 5.6 lbs of dissolved contaminants were removed during these two months. The cumulative cost per pound recovered for these two months was \$0.22/pound.

### **Correlation of Costs and Contaminant Removal**

Figures 19 and 20 illustrate curves of the relationship between the O&M costs and the removal rates for the Interim Response Area A groundwater containment system at OU1.

Figure 19 illustrates curves of the cumulative O&M cost relative to contaminant removal. By late 1995, the curve had steepened as the cost per unit of contaminant removal rose exponentially. The Interim Response Area A system was shut down in November 1996 because the operating objectives were no longer being met.

Figure 20 illustrates the monthly and cumulative cost per unit of contaminant removal over the operation time of the technology. The monthly curve represents the cost per gallon of JP-4 removal in each month. The cumulative curve illustrates that the average cost per unit of contaminant removal was \$8.69/gallon of JP-4 after 4 years of operation time.

## **Cost and Performance of Groundwater Containment at OU1 Area C**

### **Groundwater Containment with Free Product Source Removal Operational Objectives**

The objective of free product source removal is typically to remove liquid-phase contamination as quickly and cost-effectively as possible to prevent continued contamination of surrounding soil and groundwater. The emphasis for free product removal is that the mass of contaminants is cost effectively removed.

### **Cost for Operation**

Figure 21 illustrates curves of the O&M costs for the interim response groundwater containment system at Site Area C. The monthly O&M costs range from \$437 to \$6,187. Total O&M costs after 1.4 years of operation were \$33,000.

### **Contaminant Removal**

Figure 22 illustrates the removal rate of JP-4 free product at the interim response groundwater containment system at Area C. Monthly removal rates of JP-4 free product ranged from 266 to 2,145 gallons. Total contaminant removal after 1.4 years (April 1995 through August 1996) of operation was 12,766 gallons of JP-4 free product. By August 1996, the curve representing the cumulative removal rate had not yet begun to flatten, indicating that the removal rate was still adequate for this system's performance and it's operational objectives were being met.

In September 1997, the Area C system was modified to a full scale system.

### **Correlation of Costs and Contaminant Removal**

Figures 23 and 24 illustrate the relationship between the O&M costs and the removal rates for the groundwater containment system at Area C.

Figure 23 illustrates the cumulative O&M cost relative to the cumulative contaminant removal. As of August 1996, this curve had not steepened. In August 1996, the passive groundwater containment system was operating efficiently for this system's performance and the operational objectives were being met.

Figure 24 illustrates the monthly as well as the cumulative cost per unit of contaminant removal over the operation time of the technology. The first curve illustrates the cost per gallon of JP-4 removal in each month. The cumulative curve illustrates that the average cost per unit of contaminant removal was \$2.59/gallon of JP-4 after 1.4 years of operation time.

Figure 12  
Monthly and Cumulative O&M Costs vs. Time  
OU1 POL Yard, Shaw AFB

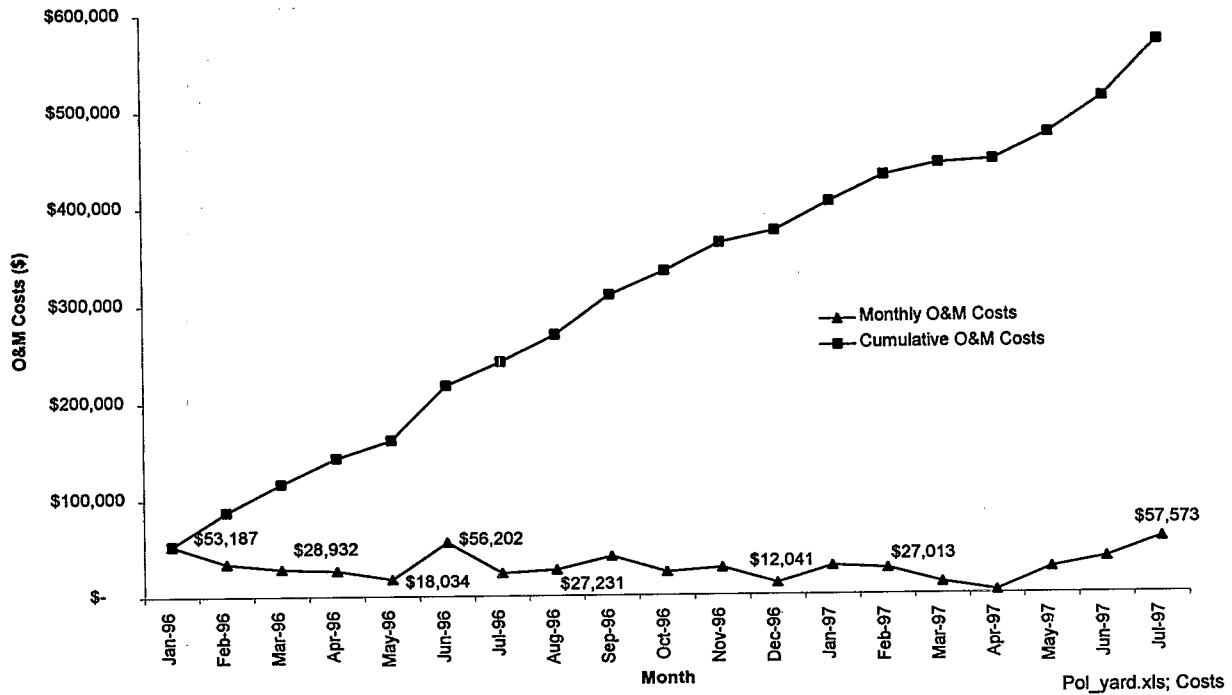


Figure 13  
Cumulative and Monthly JP-4 Product Recovered vs. Time  
OU1 POL Yard, Shaw AFB

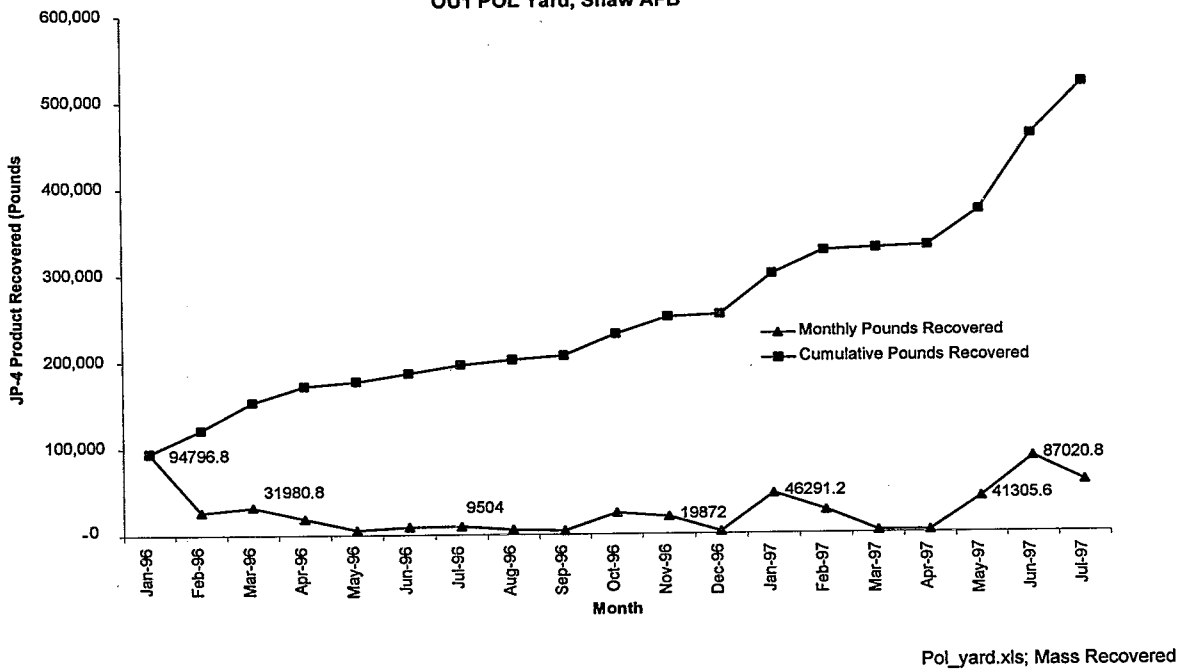
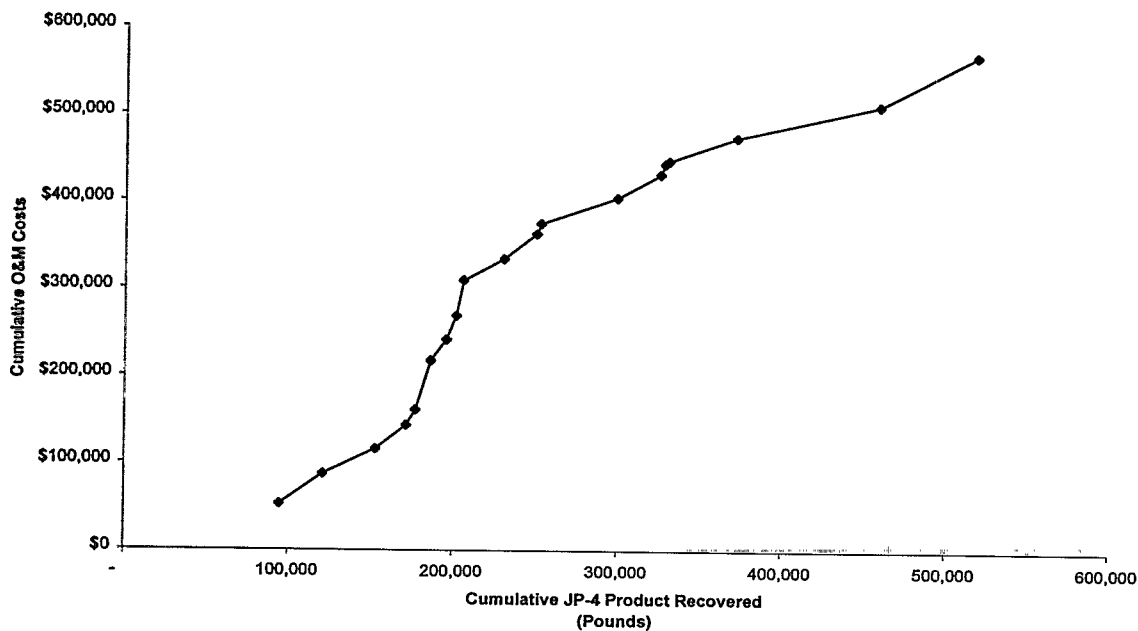
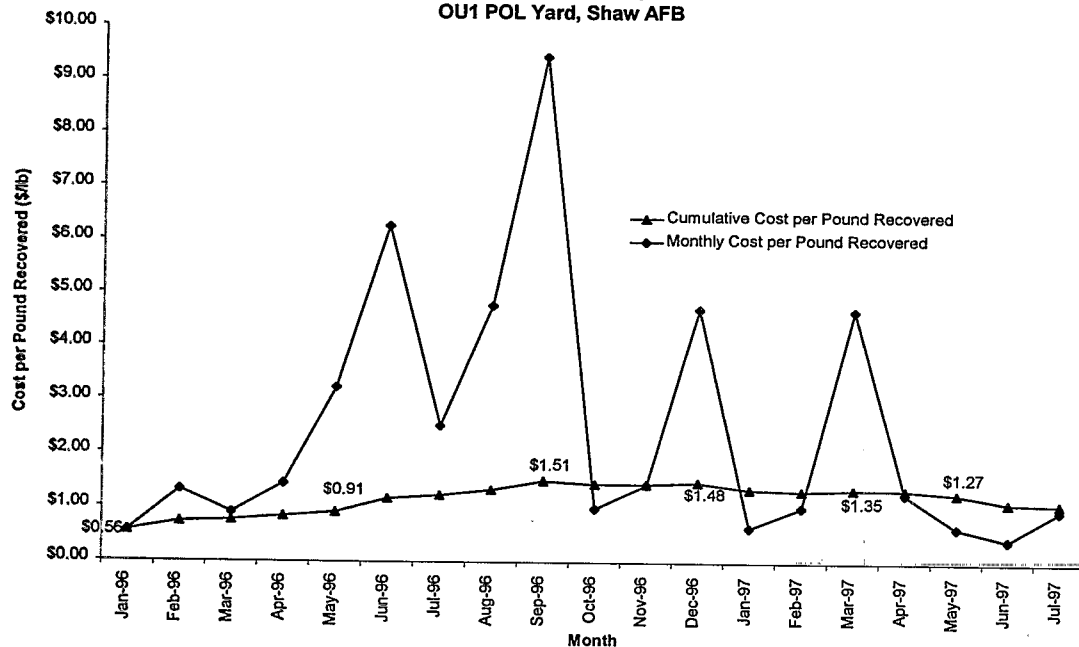


Figure 14  
Cumulative O&M Costs vs. Cumulative JP-4 Product Recovered  
OU1 POL Yard, Shaw AFB



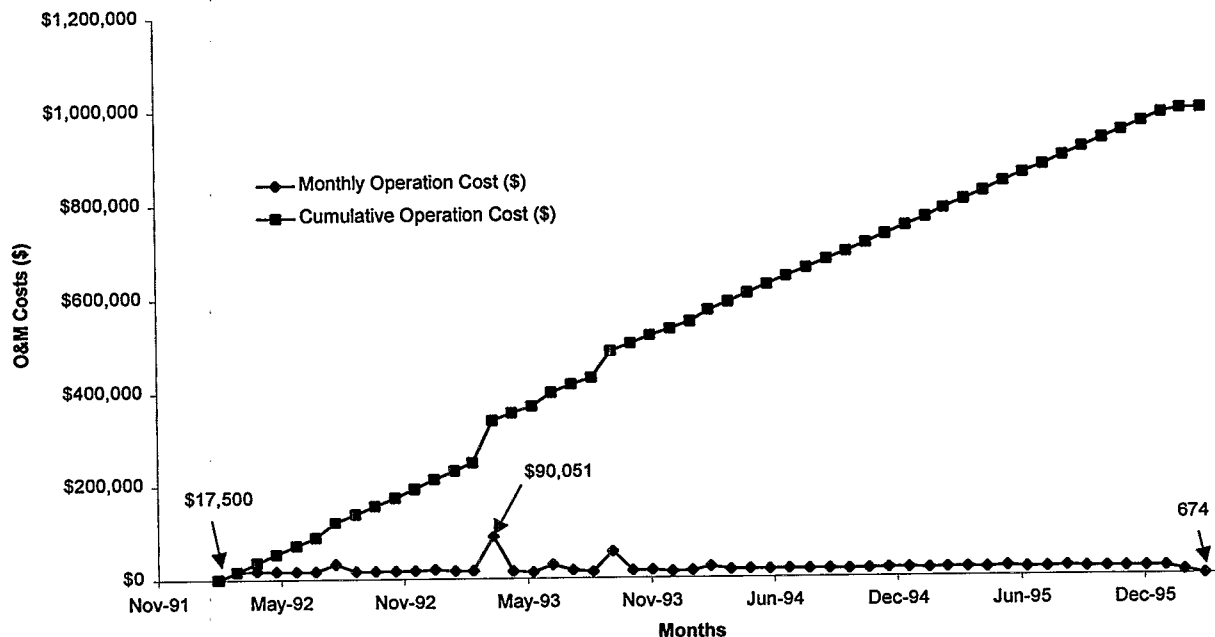
Pol\_yard.xls; Costs vs Mass

Figure 15  
Monthly and Cumulative O&M Cost per Pound vs. Time  
OU1 POL Yard, Shaw AFB



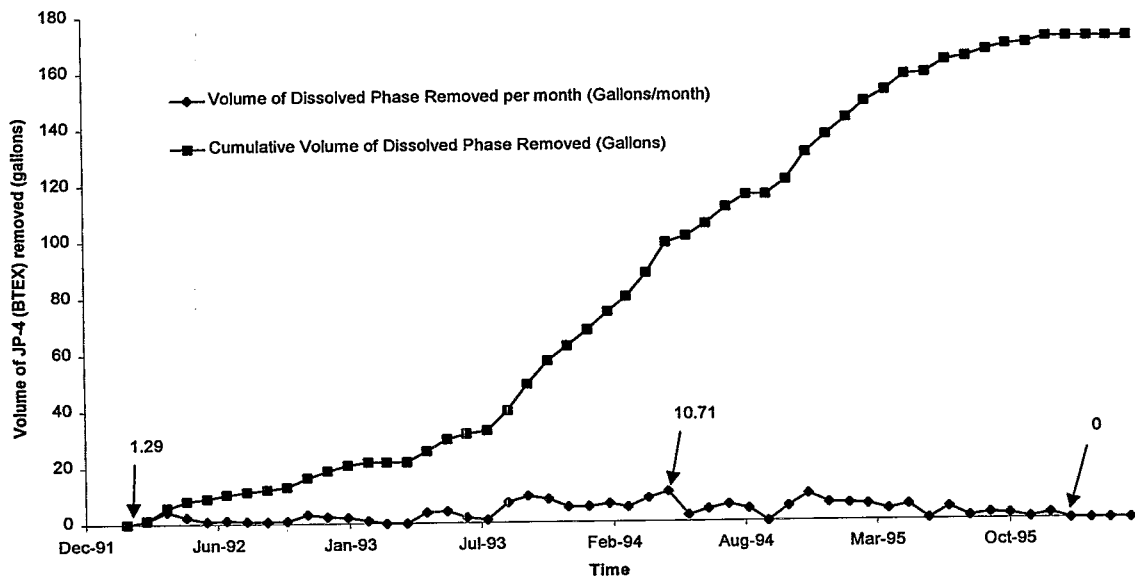
Pol\_yard.xls; Cost per Pound vs Time

**Figure 16**  
**Monthly and Cumulative O&M Costs vs. Time**  
**Dissolved JP-4 and JP-4 Free Product Combined**  
**OU1 Area A, OU1, Shaw AFB**



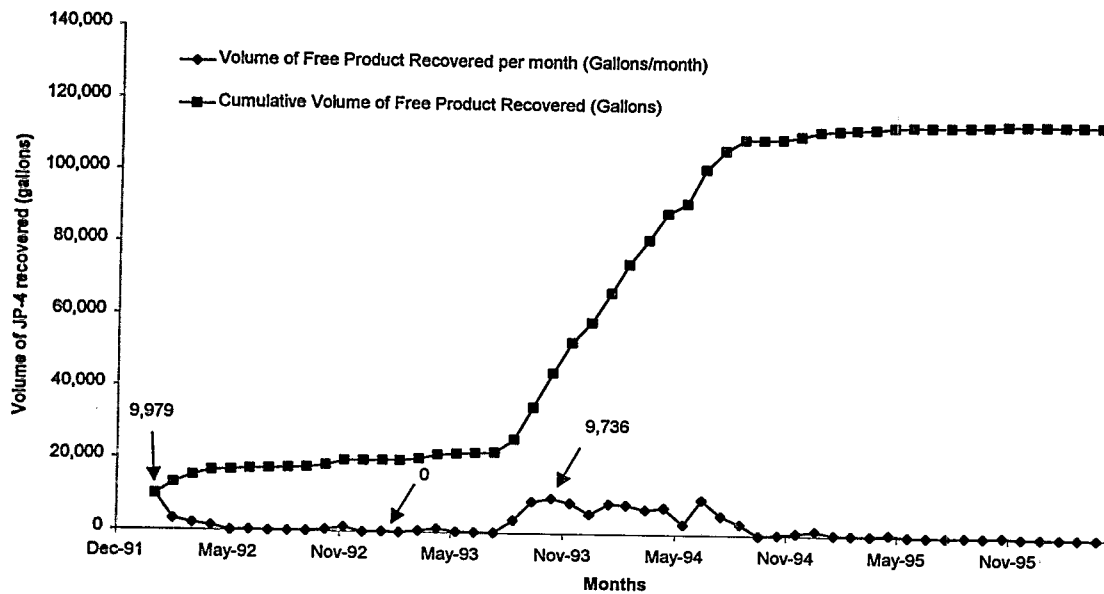
Rawou1.xls; O&M

**Figure 17**  
**Monthly & Cumulative JP-4 Removal vs. Time**  
**Dissolved Product (BTEX)**  
**OU1 Area A, Shaw AFB**



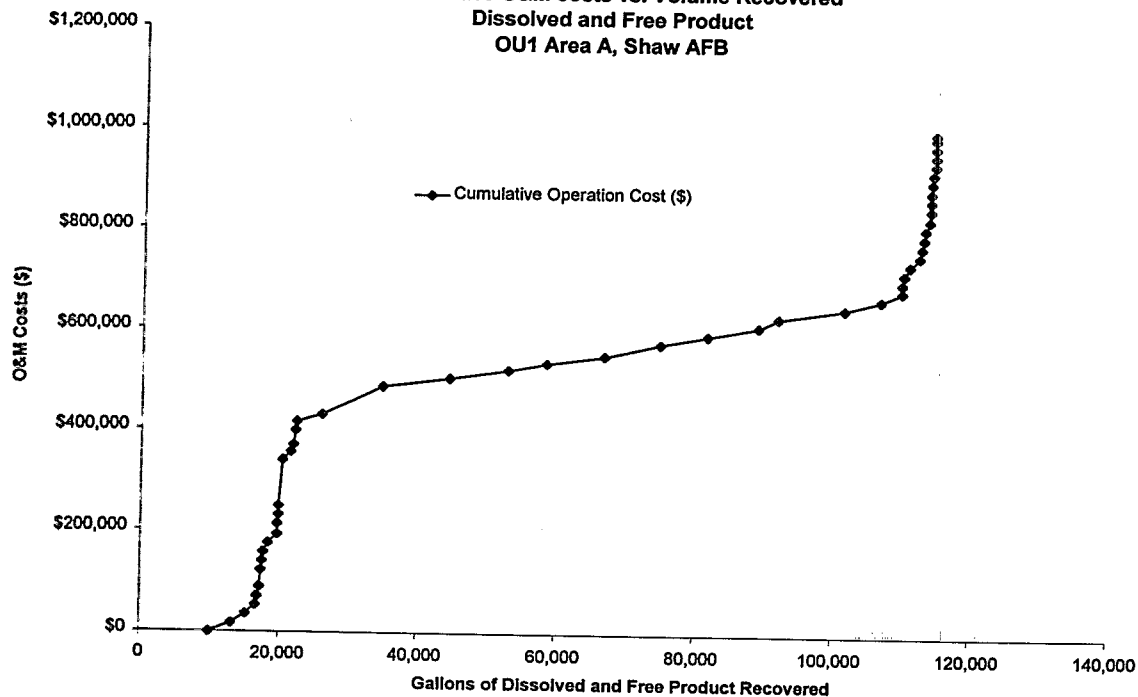
Rawou1; diss vol vs. time

**Figure 18**  
**Monthly & Cumulative Volume of JP-4 Recovered vs. Time**  
**OU1 Area A, Shaw AFB**  
**Free Product**



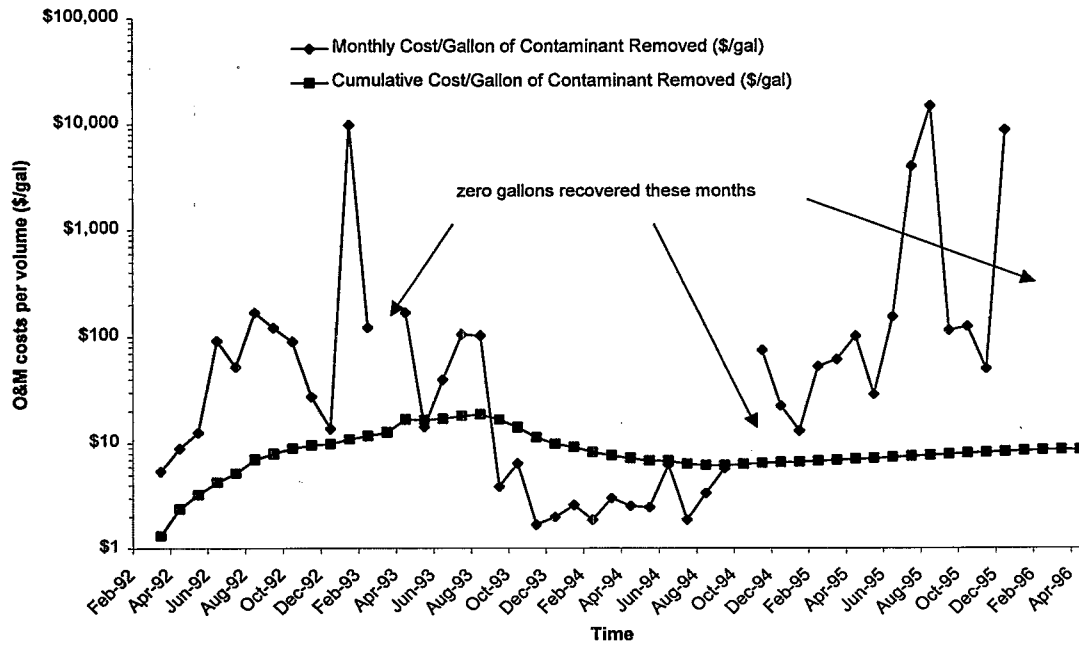
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**Figure 19**  
**Cumulative O&M costs vs. Volume Recovered**  
**Dissolved and Free Product**  
**OU1 Area A, Shaw AFB**



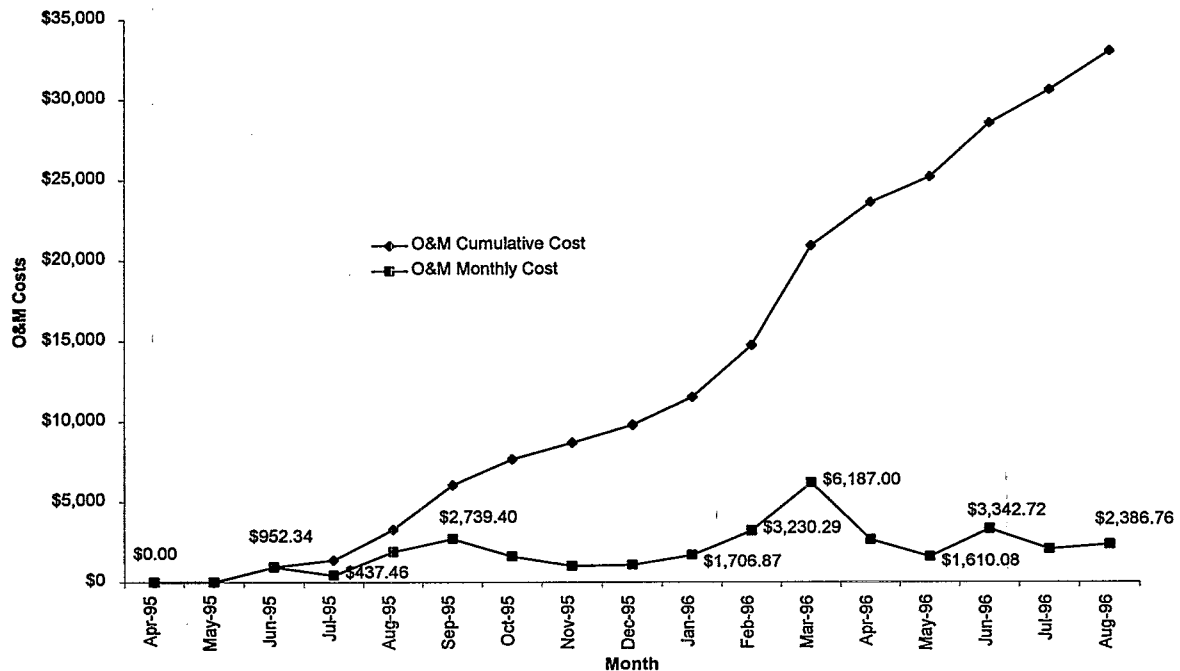
Rawou1.xls; cum & vs vol

**Figure 20**  
**Monthly & Cumulative O&M costs per Volume vs. Time**  
**Dissolved and Free Product Combined (JP-4)**  
**OU1 Area A, Shaw AFB**



Rawou1.xls; \$ per gal vs time

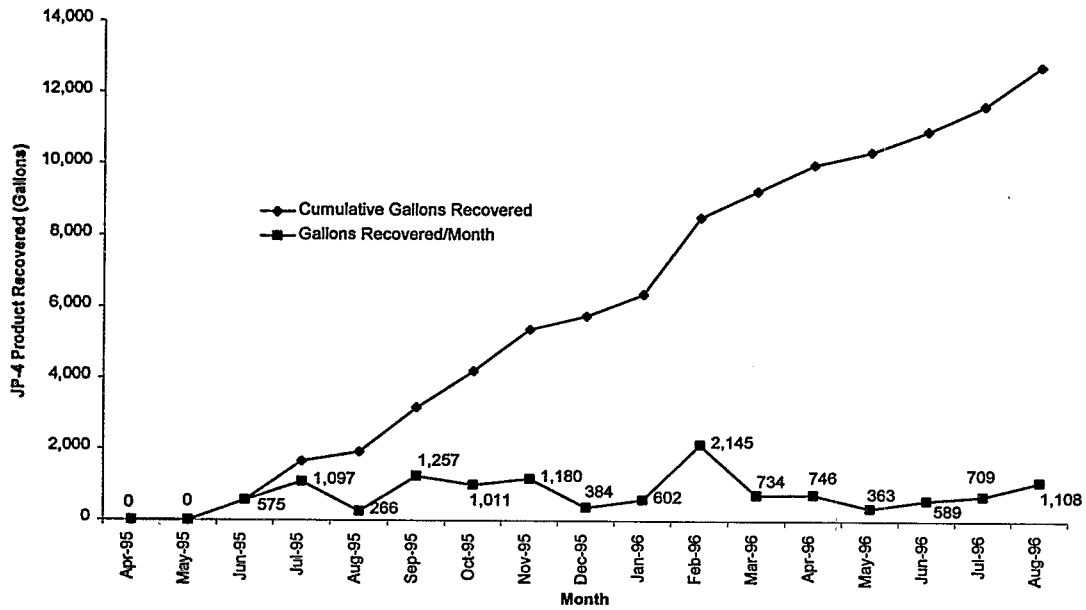
**Figure 21**  
**Monthly and Cumulative O&M Costs vs. Time**  
**OU1 Area C, Shaw AFB**



Note: Initial O/M costs of \$1,359.27 were allocated to the months of June and July 1995.

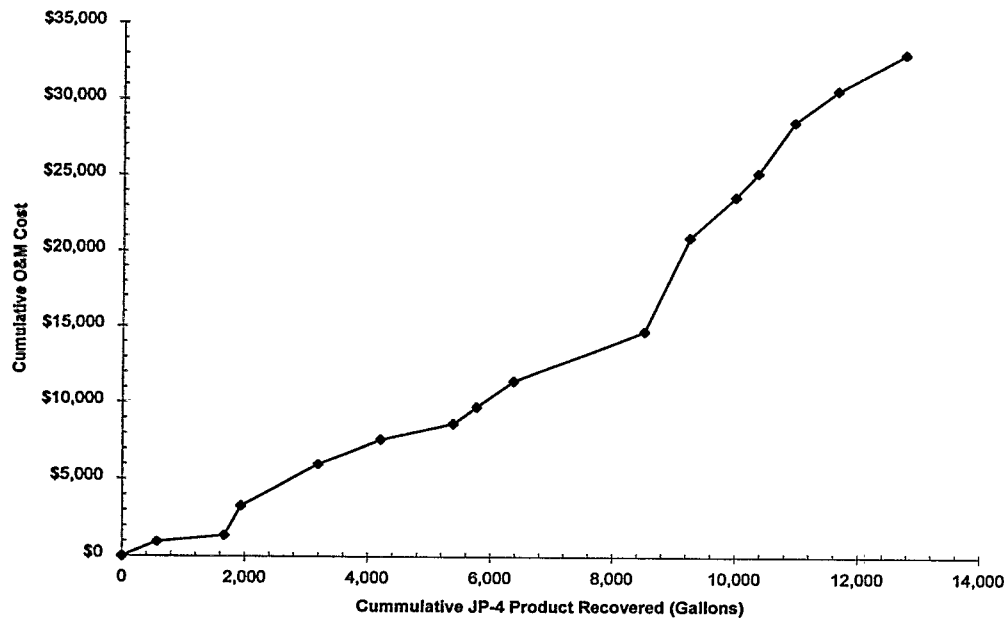
Revss15.xls; Cumulative Cost Per Month

**Figure 22**  
**Cumulative and Monthly JP-4 Product Recovered vs. Time**  
**OU1 Area C, Shaw AFB**



Revss15.xls; Cumulative Gallons Recovered

**Figure 23**  
**Cummulative O&M Cost vs. Cummulative JP-4 Recovered**  
**OU1 Area C, Shaw AFB**

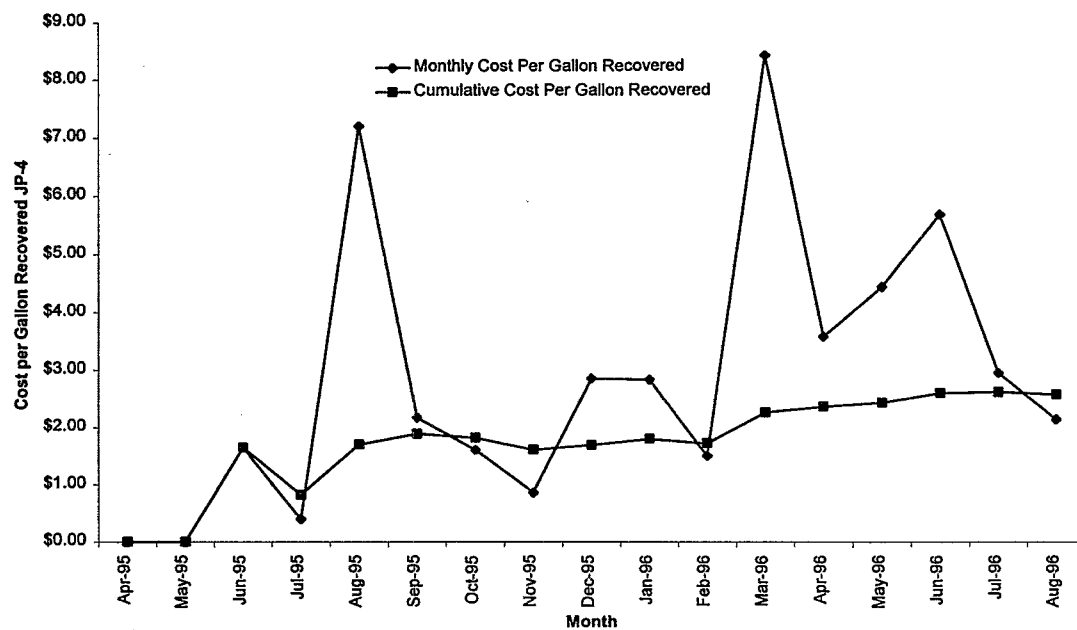


Note: Initial O/M costs of \$1,359.27 were allocated to the months of June and July 1995.

Revss15.xls; Cumm OM vs Recovered



**Figure 24**  
**Monthly and Cumulative O&M Cost Per Gallon of JP-4 Recovered vs. Time**  
**OU1 Area C, Shaw AFB**



Note: Initial O/M costs of \$1,359.27 were allocated to the months of June and July 1995.

Revss15.xls; Cost per Gallo

**APPENDIX A**  
**Detailed Cost and Performance Data Tables**

**BTEX/JP4 REMOVAL RATES VIA AN SVE SYSTEM  
OU1 POL YARD  
SHAW AFB**

DATE	# OF DAYS	MONTHLY BTEX/JP4 REMOVED (Gallons)	Monthly Pounds Recovered	CUMM. REMOVED (Gallons)	Cumulative Pounds Recovered	ACTUAL BTEX/JP4 REMAINING	Monthly O&M Costs	ACT. MONTHLY COST/GALLON	Cumulative O&M Costs	ACTUAL CUMULATIVE COST/GALLON	Monthly Cost per Pound Recovered	Cumulative Cost per Pound Recovered
Dec-95	0	0		0		91780						
Jan-96	31	14812	94796.8	14812	94796.8	76968	\$53,187	\$3.59	\$53,187	\$3.59	\$0.56	\$0.56
Feb-96	59	4114	26329.6	18926	121126.4	72854	\$34,862	\$8.47	\$88,049	\$4.65	\$1.32	\$0.73
Mar-96	90	4997	31980.8	23923	153107.2	67857	\$28,932	\$5.79	\$116,982	\$4.89	\$0.90	\$0.76
Apr-96	120	2900	18560	26823	171667.2	64957	\$26,825	\$9.25	\$143,806	\$5.36	\$1.45	\$0.84
May-96	151	872	5580.8	27695	177248	64085	\$18,034	\$20.68	\$161,840	\$5.84	\$3.23	\$0.91
Jun-96	181	1405	8992	29100	186240	62680	\$56,202	\$40.00	\$218,042	\$7.49	\$6.25	\$1.17
Jul-96	212	1485	9504	30585	195744	61195	\$23,904	\$16.10	\$241,946	\$7.91	\$2.52	\$1.24
Aug-96	243	893	5715.2	31478	201459.2	60302	\$27,231	\$30.49	\$269,176	\$8.55	\$4.76	\$1.34
Sep-96	273	677	4332.8	32155	205792	59625	\$40,873	\$60.37	\$310,049	\$9.64	\$9.43	\$1.51
Oct-96	304	3819	24441.6	35974	230233.6	55806	\$24,124	\$6.32	\$334,173	\$9.29	\$0.99	\$1.45
Nov-96	334	3105	19872	39079	250105.6	52701	\$28,528	\$9.19	\$362,701	\$9.28	\$1.44	\$1.45
Dec-96	365	400	2560	39479	252665.6	84460	\$12,041	\$30.10	\$374,742	\$9.49	\$4.70	\$1.48
Jan-97	396	7233	46291.2	46712	298956.8	77227	\$29,903	\$4.13	\$404,645	\$8.66	\$0.65	\$1.35
Feb-97	424	4145	26528	50857	325484.8	73082	\$27,013	\$6.52	\$431,658	\$8.49	\$1.02	\$1.33
Mar-97	455	400	2560	51257	328044.8	72682	\$11,953	\$29.88	\$443,611	\$8.65	\$4.67	\$1.35
Apr-97	485	400	2560	51657	330604.8	72282	\$3,246	\$8.12	\$446,857	\$8.65	\$1.27	\$1.35
May-97	516	6454	41305.6	58111	371910.4	65828	\$26,772	\$4.15	\$473,629	\$8.15	\$0.65	\$1.27
Jun-97	546	13597	87020.8	71708	458931.2	52231	\$37,271	\$2.74	\$510,900	\$7.12	\$0.43	\$1.11
Jul-97	577	9269	59321.6	80977	518252.8	42962	\$57,573	\$6.21	\$568,473	\$7.02	\$0.97	\$1.10

**JP-4 Product Recovery, Free-Product/Dissolved Phase Pumping with Air Stripping**  
**OU1 Area A**  
**Shaw Air Force Base**

Date of Product Recovery	Total Volume of contaminants Recovered per month (Gallons/month)	Cumulative Total Volume of contaminants recovered (Gallons)	Monthly Operation Cost (\$)	Cumulative Operation Cost (\$)	Monthly Cost/Gallon of Contaminant Removed (\$/gal)	Cumulative Cost/Gallon of Contaminant Removed (\$/gal)	Influent Concentration of BTEX (ug/L)
Feb-92	9,979.00	9,979.00		\$0.00			
Mar-92	3,221.29	13,200.29	\$17,500.00	\$17,500.00	\$5.43	\$1.33	651
Apr-92	2,091.40	15,291.69	\$18,797.00	\$36,297.00	\$8.99	\$2.37	3224
May-92	1,422.33	16,714.02	\$17,924.00	\$54,221.00	\$12.60	\$3.24	1943
Jun-92	189.96	16,903.98	\$17,500.00	\$71,721.00	\$92.12	\$4.24	4598
Jul-92	336.31	17,240.29	\$17,718.00	\$89,439.00	\$52.68	\$5.19	3158
Aug-92	193.94	17,434.23	\$32,797.00	\$122,236.00	\$169.11	\$7.01	3873
Sep-92	145.79	17,580.02	\$17,726.00	\$139,962.00	\$121.59	\$7.96	3194
Oct-92	196.00	17,776.02	\$17,719.00	\$157,681.00	\$90.40	\$8.87	4304
Nov-92	646.27	18,422.29	\$17,719.00	\$175,400.00	\$27.42	\$9.52	5080
Dec-92	1,312.42	19,734.71	\$17,910.00	\$193,310.00	\$13.65	\$9.80	4190
Jan-93	2.10	19,736.81	\$20,477.00	\$213,787.00	\$9,750.95	\$10.83	6351
Feb-93	145.99	19,882.80	\$17,828.00	\$231,615.00	\$122.12	\$11.65	5084
Mar-93	0.00	19,882.80	\$17,719.00	\$249,334.00		\$12.54	
Apr-93	536.00	20,418.80	\$90,051.00	\$339,385.00	\$168.01	\$16.62	
May-93	1,152.75	21,571.55	\$16,300.00	\$355,685.00	\$14.14	\$16.49	4904
Jun-93	354.17	21,925.72	\$14,016.00	\$369,701.00	\$39.57	\$16.86	3012
Jul-93	276.91	22,202.63	\$29,199.00	\$398,900.00	\$105.45	\$17.97	1883
Aug-93	166.07	22,368.70	\$17,061.00	\$415,961.00	\$102.73	\$18.60	1637
Sep-93	3,614.04	25,982.74	\$13,958.00	\$429,919.00	\$3.86	\$16.55	4968
Oct-93	8,781.30	34,764.04	\$56,606.00	\$486,525.00	\$6.45	\$14.00	4459
Nov-93	9,744.16	44,508.20	\$16,369.00	\$502,894.00	\$1.68	\$11.30	4802
Dec-93	8,495.31	53,003.51	\$16,793.00	\$519,687.00	\$1.98	\$9.80	3436
Jan-94	5,503.46	58,506.97	\$14,162.00	\$533,849.00	\$2.57	\$9.12	4735
Feb-94	8,292.47	66,799.44	\$15,451.00	\$549,300.00	\$1.86	\$8.22	3731
Mar-94	8,029.27	74,828.71	\$23,975.00	\$573,275.00	\$2.99	\$7.66	3701
Apr-94	6,813.40	81,642.11	\$17,142.00	\$590,417.00	\$2.52	\$7.23	3996
May-94	7,350.71	88,992.82	\$17,959.00	\$608,376.00	\$2.44	\$6.84	4730
Jun-94	2,866.25	91,859.07	\$17,850.00	\$626,226.00	\$6.23	\$6.82	1837
Jul-94	9,616.33	101,475.40	\$17,949.00	\$644,175.00	\$1.87	\$6.35	2717
Aug-94	5,287.97	106,763.37	\$17,696.00	\$661,871.00	\$3.35	\$6.20	4101
Sep-94	3,059.43	109,822.80	\$17,691.00	\$679,562.00	\$5.78	\$6.19	2472
Oct-94	0.00	109,822.80	\$16,600.00	\$696,162.00		\$6.34	
Nov-94	235.23	110,058.03	\$17,682.00	\$713,844.00	\$75.17	\$6.49	3796
Dec-94	819.57	110,877.60	\$18,488.00	\$732,332.00	\$22.56	\$6.60	4141
Jan-95	1,407.37	112,284.97	\$18,381.00	\$750,713.00	\$13.06	\$6.69	3048
Feb-95	331.02	112,615.99	\$17,609.00	\$768,322.00	\$53.20	\$6.82	4127
Mar-95	299.74	112,915.73	\$18,528.00	\$786,850.00	\$61.81	\$6.97	4316
Apr-95	180.94	113,096.67	\$18,407.00	\$805,257.00	\$101.73	\$7.12	3477
May-95	615.51	113,712.18	\$17,850.00	\$823,107.00	\$29.00	\$7.24	3127
Jun-95	130.51	113,842.69	\$20,128.00	\$843,235.00	\$154.23	\$7.41	4143
Jul-95	4.42	113,847.11	\$17,625.00	\$860,860.00	\$3,987.56	\$7.56	3560
Aug-95	1.19	113,848.30	\$17,591.00	\$878,451.00	\$14,782.35	\$7.72	725
Sep-95	168.29	114,016.59	\$19,387.00	\$897,838.00	\$115.20	\$7.87	1017
Oct-95	141.92	114,158.51	\$17,722.00	\$915,560.00	\$124.87	\$8.02	622
Nov-95	350.56	114,509.07	\$17,722.00	\$933,282.00	\$50.55	\$8.15	365
Dec-95	2.00	114,511.07	\$17,438.00	\$950,720.00	\$8,719.00	\$8.30	3254
Jan-96	0.00	114,511.07	\$17,722.00	\$968,442.00		\$8.46	
Feb-96	0.00	114,511.07	\$17,722.00	\$986,164.00		\$8.61	
Mar-96	0.00	114,511.07	\$8,682.00	\$994,846.00		\$8.69	
Apr-96	0.00	114,511.07	\$674.00	\$995,520.00		\$8.69	

**JP-4 Product Recovery, Free-Product  
OU1 Area A  
Shaw Air Force Base**

<b>Date of Product Recovery</b>	<b>Volume of Free Product Recovered per month (Gallons/month)</b>	<b>Cumulative Volume of Free Product Recovered (Gallons)</b>
Feb-92	9,979	9,979
Mar-92	3,220	13,199
Apr-92	2,087	15,286
May-92	1,420	16,706
Jun-92	189	16,895
Jul-92	335	17,230
Aug-92	193	17,423
Sep-92	145	17,568
Oct-92	195	17,763
Nov-92	643	18,406
Dec-92	1,310	19,716
Jan-93	0	19,716
Feb-93	145	19,861
Mar-93	0	19,861
Apr-93	536	20,397
May-93	1,149	21,546
Jun-93	350	21,896
Jul-93	275	22,171
Aug-93	165	22,336
Sep-93	3,607	25,943
Oct-93	8,772	34,715
Nov-93	9,736	44,451
Dec-93	8,490	52,941
Jan-94	5,498	58,439
Feb-94	8,286	66,725
Mar-94	8,024	74,749
Apr-94	6,805	81,554
May-94	7,340	88,894
Jun-94	2,864	91,758
Jul-94	9,612	101,370
Aug-94	5,282	106,652
Sep-94	3,055	109,707
Oct-94	0	109,707
Nov-94	230	109,937
Dec-94	810	110,747
Jan-95	1,401	112,148
Feb-95	325	112,473
Mar-95	294	112,767
Apr-95	177	112,944
May-95	610	113,554
Jun-95	130	113,684
Jul-95	0	113,684
Aug-95	0	113,684
Sep-95	166	113,850
Oct-95	140	113,990
Nov-95	350	114,340
Dec-95	0	114,340
Jan-96	0	114,340
Feb-96	0	114,340
Mar-96	0	114,340
Apr-96	0	114,340

JP-4 Product Recovery, Dissolved Phase  
OU1 Area A  
Shaw Air Force Base

Date of Product Recovery	Volume of Dissolved Phase Removed per month (Gallons/month)	Mass of Dissolved Phase (JP-4) Removed per month (lbs/month)*	Cumulative Volume of Dissolved Phase Removed (Gallons)	Cumulative Mass of Dissolved Phase (JP-4) Removed (lbs)*
Feb-92			0.00	
Mar-92	1.29	8.26	1.29	8.26
Apr-92	4.40	28.16	5.69	36.42
May-92	2.33	14.91	8.02	51.33
Jun-92	0.96	6.14	8.98	57.47
Jul-92	1.31	8.38	10.29	65.86
Aug-92	0.94	6.02	11.23	71.87
Sep-92	0.79	5.06	12.02	76.93
Oct-92	1.00	6.40	13.02	83.33
Nov-92	3.27	20.93	16.29	104.26
Dec-92	2.42	15.49	18.71	119.74
Jan-93	2.10	13.44	20.81	133.18
Feb-93	0.99	6.34	21.80	139.52
Mar-93	0.00	0.00	21.80	139.52
Apr-93	0.00	0.00	21.80	139.52
May-93	3.75	24.00	25.55	163.52
Jun-93	4.17	26.69	29.72	190.21
Jul-93	1.91	12.22	31.63	202.43
Aug-93	1.07	6.85	32.70	209.28
Sep-93	7.04	45.06	39.74	254.34
Oct-93	9.30	59.52	49.04	313.86
Nov-93	8.16	52.22	57.20	366.08
Dec-93	5.31	33.98	62.51	400.06
Jan-94	5.46	34.94	67.97	435.01
Feb-94	6.47	41.41	74.44	476.42
Mar-94	5.27	33.73	79.71	510.14
Apr-94	8.40	53.76	88.11	563.90
May-94	10.71	68.54	98.82	632.45
Jun-94	2.25	14.40	101.07	646.85
Jul-94	4.33	27.71	105.40	674.56
Aug-94	5.97	38.21	111.37	712.77
Sep-94	4.43	28.35	115.80	741.12
Oct-94	0.00	0.00	115.80	741.12
Nov-94	5.23	33.47	121.03	774.59
Dec-94	9.57	61.25	130.60	835.84
Jan-95	6.37	40.77	136.97	876.61
Feb-95	6.02	38.53	142.99	915.14
Mar-95	5.74	36.74	148.73	951.87
Apr-95	3.94	25.22	152.67	977.09
May-95	5.51	35.26	158.18	1,012.35
Jun-95	0.51	3.26	158.69	1,015.62
Jul-95	4.42	28.29	163.11	1,043.90
Aug-95	1.19	7.62	164.30	1,051.52
Sep-95	2.29	14.66	166.59	1,066.18
Oct-95	1.92	12.29	168.51	1,078.46
Nov-95	0.56	3.58	169.07	1,082.05
Dec-95	2.00	12.80	171.07	1,094.85
Jan-96	0.00	0.00	171.07	1,094.85
Feb-96	0.00	0.00	171.07	1,094.85
Mar-96	0.00	0.00	171.07	1,094.85
Apr-96	0.00	0.00	171.07	1,094.85

\*The density of JP-4 used is 6.4 lb/gal at 60F density of JP-4 6.40  
(U.S. EPA, 1996, Compilation of Air Pollution Emission Factors (AP-42) - Volume 1: Stationary Point and Area Sources, 5th Ed.)

**JP-4 Free Product Recovery  
at OU1 Area C  
Shaw Air Force Base**

**Cost Per Gallon For Free Product Recovery Interim Remedial Action System At MW-634 O&M Cost**

<b>Month</b>	<b>Gallons Recovered/Month</b>	<b>Cumulative Gallons Recovered</b>	<b>O&amp;M Monthly Cost</b>	<b>O&amp;M Cumulative Cost</b>	<b>Monthly Cost Per Gallon Recovered</b>	<b>Cumulative Cost Per Gallon Recovered</b>
Apr-95	0	0	\$0.00	\$0.00	\$0.00	\$0.00
May-95	0	0	\$0.00	\$0.00	\$0.00	\$0.00
Jun-95	575	575	\$952.34	\$952.34	\$1.66	\$1.66
Jul-95	1,097	1,672	\$437.46	\$1,389.80	\$0.40	\$0.83
Aug-95	266	1,938	\$1,916.60	\$3,306.40	\$7.21	\$1.71
Sep-95	1,257	3,195	\$2,739.40	\$6,045.80	\$2.18	\$1.89
Oct-95	1,011	4,206	\$1,628.10	\$7,673.90	\$1.61	\$1.82
Nov-95	1,180	5,386	\$1,025.80	\$8,699.70	\$0.87	\$1.62
Dec-95	384	5,770	\$1,096.60	\$9,796.30	\$2.86	\$1.70
Jan-96	602	6,372	\$1,706.87	\$11,503.17	\$2.84	\$1.81
Feb-96	2,145	8,517	\$3,230.29	\$14,733.46	\$1.51	\$1.73
Mar-96	734	9,251	\$6,187.00	\$20,920.46	\$8.43	\$2.26
Apr-96	746	9,997	\$2,671.30	\$23,591.76	\$3.58	\$2.36
May-96	363	10,360	\$1,610.08	\$25,201.84	\$4.44	\$2.43
Jun-96	589	10,949	\$3,342.72	\$28,544.56	\$5.68	\$2.61
Jul-96	709	11,658	\$2,096.85	\$30,641.41	\$2.96	\$2.63
Aug-96	1,108	12,766	\$2,386.76	\$33,028.17	\$2.15	\$2.59

Note: Initial O/M costs of \$1359.27 were allocated to the months of June and July 1995.

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**Soil Vapor Extraction at Tyson's Dump Superfund Site  
Upper Merion Township, Pennsylvania**

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**Soil Vapor Extraction at Tyson's Dump Superfund Site  
Upper Merion Township, Pennsylvania**

<b>Site Name:</b> Tyson's Dump Superfund Site	<b>Contaminants:</b> Volatile Organic Compounds: - 1,2,3-trichloropropane - Benzene - Trichloroethene - Tetrachloroethene	<b>Period of Operation:</b> November 1988 - September 1996
<b>Location:</b> Upper Merion Township, Pennsylvania		<b>Cleanup Type:</b> Full-scale
<b>Vendor:</b> John S. Miller On-Site Coordinator Terra Vac P.O. Box 2199 Princeton, NJ 08543-2199 (215) 354-8611	<b>Technology:</b> Soil Vapor Extraction - 80 vapor extraction (VE) wells, 9 dual extraction (RD) wells, and 7 bedrock extraction wells connected to a central processing plant - Depth of VE wells- <10 feet (approximate depth to bedrock) - Vapors treated using activated carbon adsorption - Water extracted using the RD wells was treated by air stripping and carbon polishing - Design air flow rate- 15,000 scfm at 13 inches of mercury (Hg) vacuum - More than 14 enhancements were made to the system including varying the number and types of wells, heating the soil using several techniques, destroying contaminants in situ, and physically creating new flow paths	<b>Cleanup Authority:</b> CERCLA - ROD date: 12/21/84 - Revised ROD: 3/31/88 - Revised ROD: 7/20/96
<b>PRP Contact:</b> Kenneth Dupuis Ciba Specialty Chemicals Corp. P.O. Box 71 Toms River, NJ 08754 (732) 914-2810		<b>Remedial Project Manager:</b> Eugene Dennis SARA Special Site Section U.S. EPA Region 3 841 Chestnut Building Philadelphia, PA 19107 (215) 566-3202
<b>Waste Source:</b> Spills and waste disposal in lagoons	<b>Type/Quantity of Media Treated:</b> Soil - 30,000 cubic yards	
<b>Purpose/Significance of Application:</b> SVE application involving more than 14 enhancements		
<b>Regulatory Requirements/Cleanup Goals:</b> - The ROD specified cleanup goals of 0.05 mg/kg each for 1,2,3-trichloropropane, benzene, trichloroethene, and tetrachloroethene. - In addition, the cleanup goals were to be achieved within 26 months after startup of the SVE system. If cleanup goals had not been met within the first year of operation of the SVE system, supplemental measures were to implemented to improve the vacuum extraction process.		

## Soil Vapor Extraction at Tyson's Dump Superfund Site Upper Merion Township, Pennsylvania (continued)

### Results:

- The system initially removed about 10,000 lbs/month of VOC. However, between September and December 1989, extraction rates decreased to 2,000 lb/month. In response, Terra Vac implemented 14 enhancements in an attempt to improve system performance.
- While many of the SVE system enhancements (varying the number and types of wells in the system, heating the soil, destroying contaminants in situ, and physically creating new flow paths as a means to improve the diffusion rate) produced short-term improvements in the extraction rate, in all cases, the results were only temporary. (The report includes a detailed summary of all enhancements and the results of each).
- Results of soil borings taken after 32 months of operation showed that concentrations of 1,2,3-trichloropropane, benzene, trichloroethene, and tetrachloroethene remained above the cleanup goals. In a number of cases, the constituent concentrations reported were higher than pre-remediation concentrations.
- EPA subsequently determined that the SVE system was incapable of meeting the cleanup goals in a timely and cost effective manner, and amended the ROD to change the remedy to a wet soil cover.

### Cost:

- The total actual cost for the SVE system was \$43.4 million, including approximately \$3.5 million for design and pilot studies, and \$39.9 million in treatment costs, including construction and operation and maintenance costs.

### Description:

Tyson's Dump Superfund site is a four-acre, abandoned septic waste and chemical waste disposal site reported to have operated from 1960 to 1970 in a sandstone quarry. Franklin P. Tyson and Fast Pollution Treatment, Inc. used lagoons on the eastern and western portions of the site to dispose of industrial, municipal, and chemical wastes. Results of soil samples from the lagoons taken during the Remedial Investigation indicated the presence of VOCs at concentrations that exceeded 500 mg/kg. A ROD was issued in 1984, specifying excavation and off-site disposal of contaminated soils. In response to the results of a study submitted by the RPs, EPA negotiated a partial consent decree to implement SVE and issued a revised ROD in 1988.

The initial design of the SVE system at Tyson's Dump included 80 vapor extraction wells, nine dual extraction wells, and seven bedrock extraction wells connected to a manifold that led to a central processing plant. Most of the VE wells were drilled to a depth of less than 10 feet (approximate depth to bedrock). Extracted vapors were treated by activated carbon adsorption, with regeneration and solvent recovery on site. Water extracted using the dual extraction wells was treated by air stripping and carbon polishing. VOC extraction rates for the system initially were about 10,000 lb/month. However, by December of 1989 the extraction rate decreased to about 2,000 lbs/month. The results of additional investigations performed by Terra Vac identified several conditions at the site that were limiting the diffusion rate of VOCs and adversely impacting the performance of the SVE system, including greater variation in the permeability, porosity, particle size, and moisture content of the soils than identified during previous investigations. In addition, DNAPL was found to be present over a larger area of the site than had previously been identified. In response, Terra Vac implemented 14 enhancements in an attempt to improve system performance. Many of the SVE system enhancements produced short-term improvements in the extraction rate. However, in all cases, the results were only temporary. After 32 months of operation, sample results showed that concentrations of 1,2,3-trichloropropane, benzene, trichloroethene, and tetrachloroethene remained above the cleanup goals. EPA subsequently determined that the SVE system was incapable of meeting the cleanup goals in a timely and cost effective manner, and amended the ROD to change the remedy to a wet soil cover.

## SITE INFORMATION

### Identifying Information

Tyson's Dump Superfund Site, Upper Merion Township, Pennsylvania

**CERCLIS ID No:** PAD980692024

**Record of Decision (ROD) Date:**

December 21, 1984

March 31, 1988 (revised ROD)

July 20, 1996 (revised ROD)

### Treatment Application

**Type of Action:** Remedial

**Technology:** Soil Vapor Extraction

**EPA SITE Program Test Associated With Application?** No

**Period of Operation:** November 1988 to September 1996

**Quantity of Material Treated During**

**Application:** The 1984 ROD indicated that the estimated amount of contaminated soil was 30,000 cubic yards (yd<sup>3</sup>). [13]

### Background Information [1]

**Waste Management Practice That**

**Contributed to Contamination:** Spill; surface disposal area; surface impoundment/lagoon.

**Site History:** Tyson's Dump (Tyson's) Superfund site is a four-acre, abandoned septic waste and chemical waste disposal site reported to have operated from 1960 to 1970 in a sandstone quarry. Franklin P. Tyson and Fast Pollution Treatment, Inc. (FPTI) used lagoons on the eastern and western portions of the site (east lagoon and west lagoon) to store industrial, municipal, and chemical wastes. Various locations throughout the site were also used for the disposal of septic tank wastes and chemical sludges.

In 1973, the Pennsylvania Department of Environmental Resources (PADER) ordered the owners of the site to close the facility. At that time, although some ponded water was removed, the owners did not arrange for removal of contaminated soils.

In January 1983, EPA investigated an anonymous citizen complaint about conditions at the Tyson's site and subsequently determined that immediate removal measures were required. In March 1983, EPA initiated a removal action which included the construction of a leachate collection and air stripping system, installation of drainage controls and a cover on the site, and erection of a fence around the lagoon area.

Between January 1983 and August 1984, EPA conducted a remedial investigation/feasibility study (RI/FS) in the area of the lagoons. Samples of soil from the lagoons indicated the presence of several volatile organic compounds (VOCs) at concentrations that exceeded 50 milligrams per kilogram (mg/kg).

A ROD was issued in 1984, specifying excavation and off-site disposal of contaminated soils. In June 1987, the responsible parties (RPs) submitted the results of a comprehensive feasibility study (CFS) recommending SVE as an alternative remedy. The RPs had performed an SVE pilot study in November 1986 and submitted the results as part of the CFS. According to the RPs, the CFS also indicated that the contaminants in the bedrock underlying the lagoons would be a source of continuing contamination of the backfilled soils after excavation. In addition, the CFS stated that the remedy selected in the 1984 ROD would be of limited effectiveness without the installation of a barrier to limit upward movement of contamination from the underlying bedrock.

In July 1987, the RPs submitted a proposal to EPA for cleanup of the on-site lagoon areas, upgrading of the leachate collection system, and cleanup of the tributary sediments.

EPA negotiated a partial consent decree to implement SVE and issued a revised ROD as discussed below.



U.S. Environmental Protection Agency  
Office of Solid Waste and Emergency Response  
Technology Innovation Office

## SITE INFORMATION (CONT.)

### Regulatory Context [1, 2, 7, 13]

In December 1984, EPA issued an initial ROD for the site that specified the following remedial actions:

- Excavation of contaminated soils and disposal at a landfill permitted under the Resource Conservation and Recovery Act (RCRA)
- Upgrading of the existing air-stripping facility, which had been constructed as part of the removal measures, to treat leachate, shallow groundwater, and surface runoff encountered during excavation
- Excavation and off-site disposal of contaminated sediments in the tributary that receives effluent from the existing air stripper

In March 1988, EPA revised the ROD to change the remedy for the lagoons from excavation to SVE. The revised ROD, signed in March 1988, did not alter the remedy with respect to air stripping, leachate treatment, or remediation of contaminated sediments.

EPA subsequently determined that the SVE system was incapable of meeting the cleanup levels that had been specified in the revised ROD in a "timely and cost effective manner." According to EPA, the ability of the SVE system to efficiently remove the remaining contamination had decreased significantly beginning in 1993.

In July 1996, EPA issued a ROD Amendment changing the remedy from SVE to placement of a wet soil cover over the lagoons. According to the amendment, the wet soil cover met the remedial action objectives. In addition, the wet soil cover provided effective long-term control of VOC emissions.

### Site Logistics/Contacts

**Site Management:** RP Lead

**Oversight:** Federal

#### **PRP Contact:**

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#### **Treatment System Vendor:**

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\* Primary contact for this application.

## MATRIX DESCRIPTION

### Matrix Identification [3, 13]

**Type of Matrix:** Soil

**Geology:** The natural soils at the site consisted primarily of a less-than-one-foot layer of topsoil, underlain to a depth of six to eight feet by clayey sand to sandy silt. That layer generally was underlain by fine to medium, slightly silty

## MATRIX DESCRIPTION (CONT.)

sand with some gravel, extending to 12 feet in depth. Shallow bedrock in the vicinity of the site was highly fractured with outcroppings of bedrock throughout the site.

In 1991, during installation of horizontal wells in the western portion of the east lagoon, a layer of rock was discovered. The layer varied in depth from 7 to 12 feet below the ground surface (bgs). The layer was estimated to be 200 feet wide and approximately one to two feet thick.

### Matrix Characteristics That Affected Cost or Performance of Treatment [3, 13]

Limited information on matrix characteristics that affected cost or performance was available for this application. The soil at the site was classified as clayey sand to silt (6 to 8 ft. bgs) and slightly silty sand (8 to 12 ft. bgs). Nonaqueous phase liquid (NAPL) was present at the site.

## Contaminant Characterization [1, 7]

### Primary Contaminant Groups: VOCs

The 1988 revised ROD identified the following four contaminants of concern (these contaminants were selected to represent the presence of all VOCs at the site): 1,2,3-trichloropropane, benzene, trichloroethene, and tetrachloroethene. Soil sampling was conducted in 1988 to determine the initial mass and distribution of contaminants in the former lagoon areas. Soil samples were collected from 65 well borings, at 5 to 10 feet intervals, for a total of 82 samples from the east lagoon and 63 samples from the west lagoon.

Concentrations in the soil for the four contaminants of concern ranged from non-detect to maximum concentrations exceeding 250,000 mg/kg. Table 2 presents a summary of the range of average concentrations of those contaminants.

**Table 2: Summary of the Average Concentration of Contaminants of Concern in the 65 Well Borings - 1988 Sampling [7]**

Contaminant of Concern	No. of Well Borings by Concentration			
	Non-Detect	< 50 mg/kg	50 to 500 mg/kg	> 500 mg/kg
1,2,3-Trichloropropane	21	15	9	20
Benzene	55	10	0	0
Trichloroethene	56	8	1	0
Tetrachloroethene	33	19	7	6



## MATRIX DESCRIPTION (CONT.)

Figures 1 and 2 show the estimated percentage of organic mass located in each "soil block" in the east and west lagoons. The mass of VOCs in the soil blocks was estimated using the average concentration in a block (based on the average contaminant concentration of the soil borings within that block) (mg/kg), the surface area of the block (ft<sup>2</sup>), depth of the block (ft, determined from each boring), and density of the soil (lb/ft<sup>3</sup>, assumed to be 110 lb/ft<sup>3</sup>). The mass of each organic compound in the soil was determined using a similar formula.

As shown in Figure 1, the VOC contaminant mass was concentrated in the western portion of the east lagoon. Figure 2 shows that the VOC contaminant mass in the west lagoon was concentrated in the eastern portion. An estimate of mass of the individual compounds indicated that 1,2,3-trichloro-propane accounted for 84 percent of the total mass of VOCs.

## DESCRIPTION OF TREATMENT SYSTEM

### Primary Treatment Technology

Soil vapor extraction

### Supplemental Treatment Technology

Carbon adsorption of off-gas

### System Description and Operation

#### Pilot Study [1, 2]

In November 1986, Ciba-Geigy Corporation, the primary RP for the site, performed a pilot study of an on-site soil vapor extraction (SVE)

process. The pilot study initially operated for fewer than 10 days. The pilot study resumed operation in May, 1987 and operated for three weeks.

#### Description and Operation of System [2, 8, 12, 14]

The initial design of the SVE system at Tyson's included approximately 80 vapor extraction wells, 9 dual extraction (RD) wells, and 7 bedrock extraction wells connected to a manifold that led to a central processing plant. Figures 3 and 4 show the locations of the wells at the east and west lagoons at Tyson's. Most of the VE wells were drilled to a depth of less than 10 feet (approximate depth to bedrock).

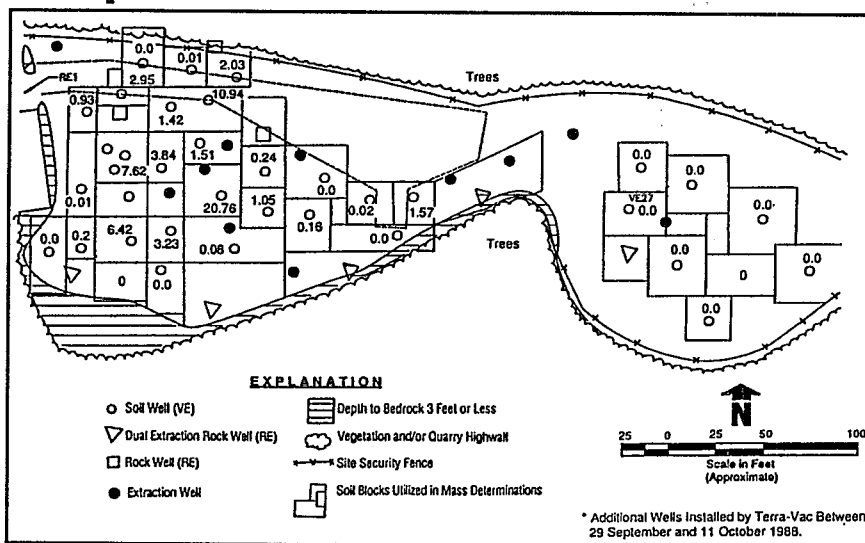
The processing plant contained two 700-horsepower (hp) vacuum units and two 250-hp vacuum units. Extracted vapors were treated by activated carbon adsorption, with regeneration and solvent recovery on site. Recovered solvent was sent off site for destruction.

Support equipment for the system included two air coolers, boilers, a chemical feed system, a fuel oil system, on-line automatic gas chromatograph (GC) analyzers, and an electrical distribution system. The system also was equipped with automated ambient air monitoring, explosive vapor monitoring, and fire suppression systems.

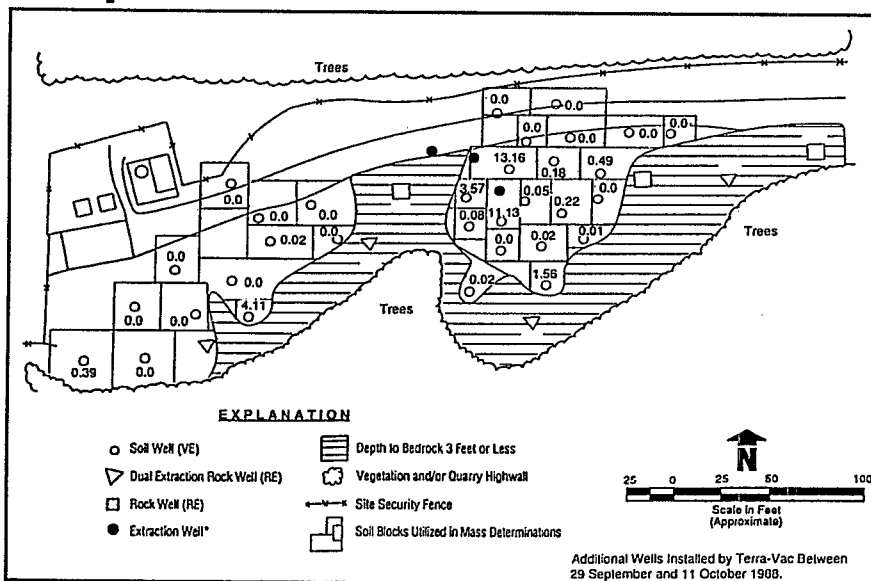
The design air flow rate was approximately 15,000 standard cubic feet per minute (scfm) at 13 inches of mercury (Hg) vacuum. At the blowers, the vapors were pressurized to two pounds per square inch (psi), cooled to 100 degrees Fahrenheit (°F), and passed through a series of 7,000-pound carbon vessels prior to release to the atmosphere. Water extracted using the RD wells was treated by air stripping and carbon polishing.

## DESCRIPTION OF TREATMENT SYSTEM (CONT.)

**Figure 1. Percentage of Organic Mass by Soil Block Area for Tyson's Dump Superfund Site - East Lagoon, 1988 Data [Modified from 17]**



**Figure 2. Percentage of Organic Mass by Soil Block Area for Tyson's Dump Superfund Site - West Lagoon, 1988 Data [Modified from 17]**



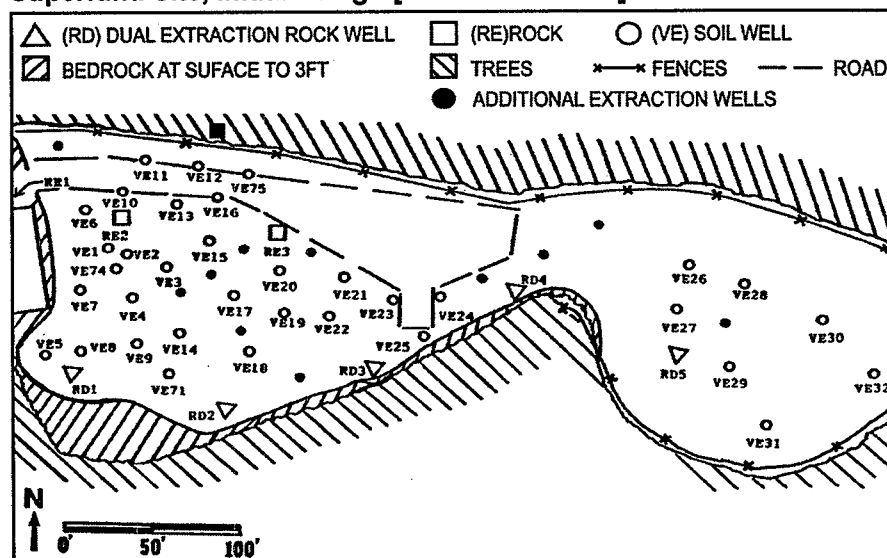
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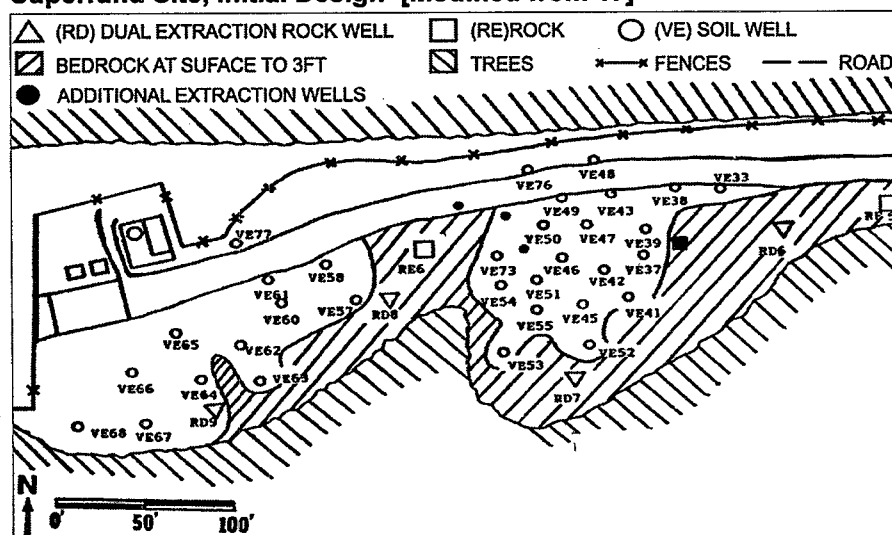


## DESCRIPTION OF TREATMENT SYSTEM (CONT.)

**Figure 3. Location of Wells in East Lagoon at the Tyson's Dump Superfund Site, Initial Design [Modified from 17]**



**Figure 4. Location of Wells in West Lagoon at the Tyson's Dump Superfund Site, Initial Design [Modified from 17]**



## DESCRIPTION OF TREATMENT SYSTEM (CONT.)

The system began full-scale operation on November 14, 1988. For the first ten months of operation, the extraction rate for VOCs ranged from 2,000 lbs/month to over 10,000 lbs/month (September 1989). However, between September and December 1989, the extraction rate decreased to about 2,000 lbs/month. The results of additional investigations performed by Terra Vac identified several conditions at the site that were limiting the diffusion rate of VOCs and adversely impacting the performance of the SVE systems. These conditions included greater variation in the permeability, porosity, particle size, and moisture content of the soils than identified during previous investigations; the presence of DNAPL over a larger area of the site; the presence of tar in 22 wells at the site and perched water at various locations at the site.

As described below, Terra Vac performed a number of modifications to the SVE system in an effort to enhance system performance. These included varying the number and types of wells in the system, heating the soil, destroying contaminants in situ, and physically creating new flow paths as a means to improve the diffusion rate.

### Enhancements to Mitigate the Effects of Newly-Discovered Site Conditions [8]

The following enhancements were made to the SVE system:

- Installation of additional wells
- Steam injection
- Installation of slurp wells
- Decane treatment
- Cover over east lagoon
- Hot air injection
- Increased vacuum pressure
- Use of selectively screened wells
- Pressurized air injection
- Installation of horizontal wells

- Electrical soil heating-Electrovac™
- Removal of ineffective wells
- Geomixing
- In situ contaminant destruction-OxyVac™

Table 3 summarizes the enhancements made in the SVE system, the time frame over which each enhancement was made, and the purpose and results of each enhancement. Additional detail on the Electrovac™ and pressurized air injection enhancements is presented below.

### Electrical Soil Heating - Electrovac™

During May 1991, a pilot test of electrical soil heating was conducted at the site. This test resulted in a small increase in soil temperature and had no significant effect on VOC extraction rates. According to Terra Vac, the limited effectiveness was attributed to the low electrical conductivity of soils and the presence of DNAPL.

### Pressurized Air Injection

During October 1990, tests involving the injection of pressurized air into the soils at the Tyson's site were conducted in the west and east lagoons. Hollow steel rods, ½ inch in diameter, were driven down to about one foot above the bottom of known DNAPL layers. The rods then were connected to an air compressor. Air was injected at a pressure of approximately 15 pounds per square inch in gauge (psig) and at a flow rate of approximately 75 scfm.

After testing, air was injected through pressure injection probes (PIP) for two to four hours. The compressor was then shut down for the same period of time. VOC extraction rates for wells in the east and west lagoons increased in some areas in response to air injection. Therefore, the use of air injection was expanded to more than 100 PIPs that were installed in the east and west lagoons. VOC extraction rates from both lagoons increased during the second quarter of 1991; however, the VOC extraction rate diminished with time.



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## DESCRIPTION OF TREATMENT SYSTEM (CONT.)

**Table 3: Summary of SVE Enhancements at the Tyson's Dump Superfund Site [4, 6, 8, 10]**

Enhancement	Dates Implemented	Purpose	Results
Installation of 40 additional wells	11/15/88 to 12/15/88	To ensure the zone of influence for each well would overlap sufficiently to eliminate preferential flow pathways created by subsurface heterogeneities and remedy the incomplete coverage of the site by the existing wells	Terra Vac indicated that new preferential pathways were formed and the VOC extraction rate increased temporarily. However, within one to two weeks the extraction rate returned to the initial level.
Steam injection	4/89	To remove the tar that had accumulated on the well screens and increase the VOC extraction rates	Increased the VOC extraction rate because of the increase in subsurface temperature. However, tar was not removed and steam quickly condensed in the well inhibiting subsurface air flow.
Conversion of 41 extraction wells to slurp wells - To convert the wells to slurp wells, Terra Vac inserted a flexible hose into the well to a depth just above the total depth. Water was then extracted from the well by applying a vacuum to the hose.	6/89	Wells were converted to slurp wells to remove perched groundwater	Slurp wells were effective in removing excess water but required constant monitoring because wells tended to fill up with water.
Decane treatment - Two to five gallons of decane were added to several wells, agitated with a plunger and allowed to sit for 45 minutes or until the decane seeped into the well packing. The remaining decane was then removed from the well.	6/89	The decane was supposed to dissolve the tar that had plugged the well screens of 22 wells	In July 1990, 6 of 22 wells showed evidence of tar still remaining.
Installation of a nylon-reinforced plastic cover over east lagoon	7/89	Prevent infiltration of precipitation and short circuiting of air through the surface	No data are available on the results of this enhancement.



# DESCRIPTION OF TREATMENT SYSTEM (CONT.)

**Table 3 (continued): Summary of SVE Enhancements at the Tyson's Dump Superfund Site [4, 6, 8, 10]**

Enhancement	Dates Implemented	Purpose	Results
Hot air injection. Hot air (200°F) was injected through injection wells	8/89	To increase the VOC extraction rate by increasing subsurface temperature and eliminating accumulation of water that resulted from condensation of steam from the steam injection enhancement	Terra Vac noted that this enhancement did improve the extraction rate but not as much as anticipated. Terra Vac indicated that the shallow depth of the injection wells limited injection pressures and significant heat losses were experienced.
Increased vacuum pressure [29 inches Hg]	11/20/89 - 2/20/90	Increase VOC extraction rate	Terra Vac indicated the high vacuum increased the extraction rate for extraction wells which had exhibited low flow rates coupled with high VOC concentrations. However, the increase was temporary and the extraction rate became diffusion-limited.
Installation of 166 selectively screened wells in areas where permeability was low and the concentration of contaminants was higher than at other areas	5/90 to 6/91	The selectively screened wells were intended to focus air flow through areas of low permeability and high contaminant concentration, thus increasing the VOC extraction rate	Terra Vac indicated that the VOC extraction rate increased temporarily. Extraction rates became diffusion-limited after the area immediately around the well was treated.
Pressurized Air Injection - Air was injected at 15 psig and a flow rate of 75 scfm	10/90	Develop additional air flow pathways to increase the VOC extraction rate	VOC extraction rates increased temporarily; however, the extraction rate became diffusion-limited.
Installation of 135 horizontal wells	3/91 to 6/92	To provide removal of perched groundwater and enhance extraction rate of VOCs	Some of the highest VOC extraction rates resulted from this enhancement. However, extraction rates eventually became diffusion-limited. No data are available on how effective the horizontal wells were in removing perched groundwater.



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## DESCRIPTION OF TREATMENT SYSTEM (CONT.)

**Table 3 (continued): Summary of SVE Enhancements at the Tyson's Dump  
Superfund Site [4, 6, 8, 10]**

Enhancement	Dates Implemented	Purpose	Results
Electrical Soil Heating - Terra Vac's ElectroVac™ process was used to raise the temperature of the subsurface soil	5/91	Raise the soil temperature to increase the VOC extraction rate.	Terra Vac indicated that the ElectroVac™ process resulted in a very limited increase in the soil temperature and had no significant effect on the VOC extraction rates.
Removal of 94 ineffective wells	12/15/91 to 12/20/91	To remove ineffective wells and reduce the number of wells so that the capacity of the SVE system was not exceeded.	A total of 94 wells were taken off-line. As the number of extraction wells in a given area increased, the competition for subsurface air flow increased among individual wells as their zones of influence began to overlap. Consequently, several wells were taken off-line because their performance was less than that of other wells and because the vapor extraction system did not have the capacity to support all the wells.
Geomixing - Soils were physically mixed with augers and backhoes	1/92 - 10/92	Break up soil heterogeneities and increase the VOC extraction rate.	Geomixing appeared to break up the soil heterogeneities because VOC extraction rates generally increased immediately after mixing but decreased within a week after. In one case the VOC extraction rate increased from 5 to 70 pounds per day. However, it decreased to 10 pounds per day within a week.
OxyVac™ - Adding hydrogen peroxide (H <sub>2</sub> O <sub>2</sub> ) to oxidize contaminated soils and recover the vapor phase oxidation products	10/92	H <sub>2</sub> O <sub>2</sub> would oxidize contaminants and the resulting oxidized product could be recovered by the vapor extraction system.	Pilot results indicated that concentrations of 1,2,3-trichloropropane were reduced by 45 percent. However, the effectiveness of the H <sub>2</sub> O <sub>2</sub> was limited only to those soils that had direct contact with the H <sub>2</sub> O <sub>2</sub> .



## DESCRIPTION OF TREATMENT SYSTEM (CONT.)

### Operating Parameters That Affected Cost or Performance of Treatment

Table 4 shows the operating parameters that affected cost or performance of this technology and the values measured for each.

**Table 4: Operating Parameters That Affected Cost or Performance [14]**

Parameter	Value
Air flow rate	15,000 scfm
Operating pressure/vacuum	13 inches of mercury vacuum

### Timeline

**Table 5: Timeline [1, 4, 6, 8, 12, 13]**

Start Date	End Date	Activity
January 1983	August 1984	EPA and its contractors conducted a series of investigations of the site.
December 1984	-	EPA issued ROD for the on-site area (east and west lagoons).
November 1986	-	Ciba-Geigy Corporation initiated a pilot study of an innovative vacuum extraction technology.
June 1987	July 1987	The four responsible parties submitted a proposal to EPA for cleanup of the lagoon areas, upgrading of the leachate collection systems, and cleanup of the tributary systems.
March 31, 1988	-	EPA issued a revised ROD changing the remedy to soil vapor extraction
November 1988	September 1996	SVE system operation performed
July 1989	-	Terra Vac covered the surface of the east lagoon with a nylon-reinforced plastic cover. Terra Vac initiated a plan to remedy clogged wells through the use of a combination of steam injection and decane treatment. Terra Vac also converted 41 wells to slurp wells.
August 1989	October 1992	Terra Vac added enhancements described in Table 3.
October 1, 1995	April 30, 1996	The SVE system was off line for a seasonal shutdown approved by EPA.
July 20, 1996	-	EPA issued a ROD amendment changing the remedy for the soils in the lagoons to placement of a wet soil cover over the lagoon area soils.

### Cleanup Goals and Standards [1]

Table 6 shows the cleanup standards specified in the 1988 revised ROD for the four contaminants of concern (indicator parameters)

in the lagoon soils at the Tyson's site. EPA also specified cleanup goals for 41 other organic compounds in the lagoon soils, as shown in Appendix A.



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## DESCRIPTION OF TREATMENT SYSTEM (CONT.)

**Table 6: Cleanup Standards for Four Constituents of Concern in the Lagoon Soils [1]**

Compound	Concentration (mg/kg)
Benzene	0.05
Trichloroethene	0.05
Tetrachloroethene	0.05
1,2,3-Trichloropropane	0.05

### Additional Information on Goals [1]

The 1988 revised ROD required the cleanup goals to be achieved within 26 months after startup of the SVE system. It also specified that, if cleanup goals had not been met within the first year of operation of the SVE system, supplemental measures would be implemented to improve the vacuum extraction process. The revised ROD did not provide specific information indicating which supplemental measures were to be implemented or what action would be taken if the cleanup goals were not attained within the 26-month time frame.

### Treatment Performance Data

Terra Vac conducted a limited soil sampling program during August 1991, approximately 32 months after the SVE system began operation. Soil samples were taken from areas adjacent to eight wells. The areas were defined by three soil borings which were drilled in a triangular array about three to five feet from each well (24 borings total). Samples were taken using a continuous split spoon from the surface to auger refusal, with samples taken from the split spoon at intervals of every 4 inches whenever possible and composited into the soil sample per boring.

Table 7 presents the results from the August 1991 sampling event and the August 1988

sampling event (two months before the system began operating). As shown in the table and described below, the concentrations of the four constituents of concern remained above the cleanup goals after 32 months of operation. In a number of cases, the constituent concentrations reported in 1991 were higher than reported in 1988.

The results for 1, 2, 3-trichloropropane showed that concentrations had been reduced to below detection limits in seven of the 24 soil borings. However, the concentrations in the remaining soil borings were above the cleanup goal, and ranged from 16 mg/kg to 32,752 mg/kg. Between 1988 and 1991, concentrations of this constituent decreased in three of the eight soil borings sampled, but increased in the remaining soil borings.

The results for benzene showed that concentrations had been reduced to below detection limits in 18 of the 24 soil borings. The concentrations in the remaining soil borings were above the cleanup goal and ranged from 11 mg/kg to 158 mg/kg. Between 1988 and 1991, benzene concentrations decreased in three of the eight soil borings, but increased in the remaining five. Likewise, concentrations for trichloroethene were reported below detected limits in 17 of 24 soil borings, with concentrations above the cleanup goal (21 mg/kg to 116 mg/kg) reported in the remaining soil borings. Between 1988 and 1991, trichloroethene concentrations decreased in five of the soil borings, but increased in the remaining three.

For tetrachloroethene, 17 of the 24 soil borings showed concentrations below the detection limit. The remaining soil borings showed concentrations above the cleanup goal (21 mg/kg to 3,951 mg/kg). Between 1988 and 1991, concentrations decreased in six soil borings, but increased in the remaining two.

Figure 5 shows the cumulative mass of VOCs removed, the monthly mass extraction rate, and the average extracted air flow per month from 1988 through 1993. Between November 1988 and November 1993, approximately 200,000 pounds of VOCs had been recovered from the



## DESCRIPTION OF TREATMENT SYSTEM (CONT.)

**Table 7: Comparison of Maximum Concentrations Detected in Soil Boring Samples Collected Near Eight Wells at Tyson's Dump Superfund Site from 1988 to 1991 [11]**

Well Number	1,2,3-Trichloropropane (mg/kg)		Benzene (mg/kg)		Trichloroethene (mg/kg)		Tetrachloroethene (mg/kg)	
	1988	1991*	1988	1991*	1988	1991*	1988	1991*
Cleanup Goal	0.05		0.05		0.05		0.05	
VE-06	166	43 63 63	5.10	14 ND ND	0.12	ND ND ND	135	33 ND ND
VE-18	5,660	16 221 435	120	ND ND ND	24.4	ND ND ND	366	ND ND 50
VE-23	0	185 ND ND	0.04	38 29 ND	0.13	46 72 ND	0.43	25 ND 55
VE-26	14	29 ND ND	0	ND ND 71	0	35 22 40	0	ND ND ND
VE-41	249	3,872 ND 86	0.14	ND ND ND	0.80	ND ND ND	6.64	ND ND ND
VE-42	250	102 69 ND	3.03	ND 158 ND	10.60	ND ND 21	12.9	ND ND ND
VE-52	17,200	13,946 286 32,752	34.2	ND ND ND	141	ND ND 116	4,730	898 21 3,951
VE-66	403	22 2,079 ND	0.04	ND 11 ND	0.39	ND ND ND	0.21	ND ND ND

\* Results are provided for three soil borings which were drilled in a triangular array about 3 - 5 feet from each well.

site by the SVE system. There were no data available to indicate which specific contaminants were included as VOCs. Based on the estimate of the mass of VOCs present (434,000 pounds), the vapor extraction system had removed less than 50 percent of the mass of contamination at the site by November 1993. As shown in Figure 5, the VOC extraction rate was lowest during the winter months.

According to EPA, in 1993, concentrations of VOCs ranged from 10 mg/kg in the upper two feet of soil to 10,000 mg/kg in the deeper soils.

The VOC extraction rate reached a maximum of about 10,000 lbs/month in September 1989. The VOC extraction rate then decreased to below 2,000 lbs/month between September and December 1989. As described above, Terra Vac attributed the decrease to site conditions, including soil heterogeneity, soil moisture, and the presence of DNAPLs. Terra Vac installed a number of enhancements to the system (see Table 3) in an attempt to improve performance.

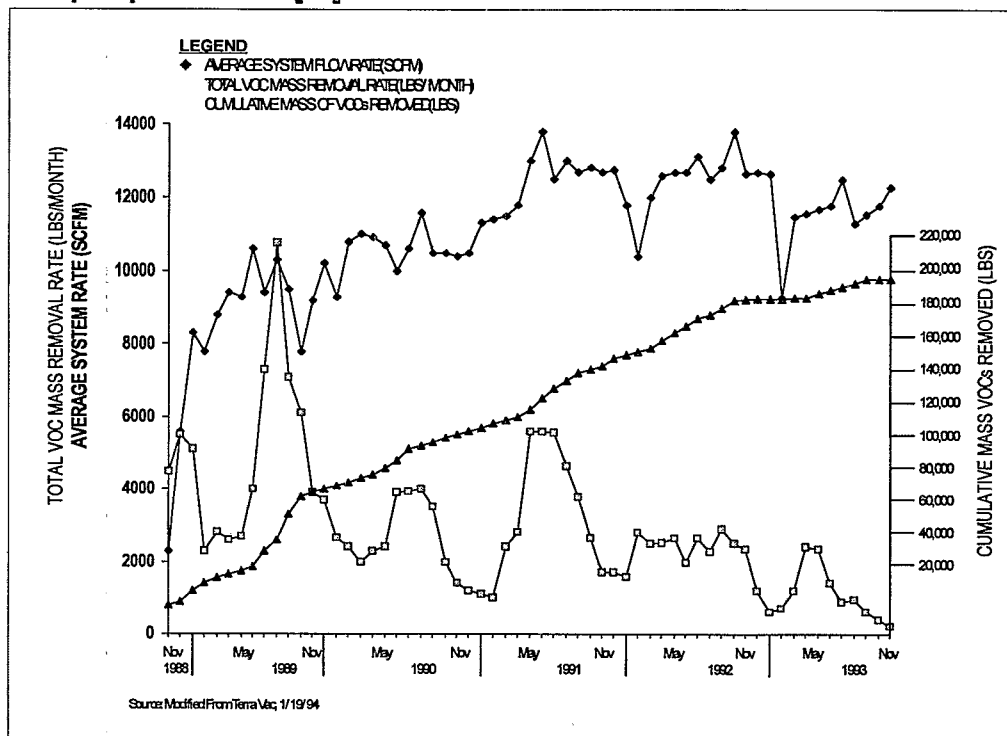


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## DESCRIPTION OF TREATMENT SYSTEM (CONT.)

**Figure 5. VOC Mass Removal and Air Flow for the SVE System at Tyson's Dump Superfund Site [15]**



Many of the enhancements resulted in short-term improvements in the extraction rates. However, as described by Terra Vac, once the new flow paths created by the enhancements had been stripped of VOCs, the extraction rate for the system became limited by the diffusion rate.

In October 1995, EPA approved a seasonal shut-down of the SVE system based on the low VOC extraction rates obtained during the winter months.

EPA subsequently determined that, beginning in 1993, the ability of the SVE system to efficiently remove the remaining contaminants had decreased significantly. EPA concluded that the SVE system was incapable of meeting the cleanup levels specified in the 1988 revised

ROD. As a result, in a 1996 ROD amendment, the remedy was changed from SVE to installation of a wet cover over the site.

### Performance Data Completeness [7, 11, 15]

Performance data for the SVE application at the Tyson's site included initial soil sample data from 1988, and soil sample data from 1991 for the four constituents of concern. No data were provided on any of the 41 constituents listed in Appendix A. Mass extraction data was available from 1988 through 1993. No data were provided after 1993. Data on concentrations of contaminants in the soil after startup (November 1988) of the SVE system were available for only 8 VE wells at the site. Data on concentrations of contaminants in the soil at over 80 other wells at the site was not provided.

## DESCRIPTION OF TREATMENT SYSTEM (CONT.)

### Quality of Performance Data [11]

Terra Vac indicated that split-spoon samples were collected to obtain soil samples. The methanol extraction method was used to prepare samples. Duplicate samples were collected at a frequency of at least 10 percent. Field and trip blanks were analyzed for each boring. No discrepancies from established QA/QC procedures were noted by Terra Vac.

## COST OF THE TREATMENT SYSTEM

### Procurement Process

In February 1988, Terra Vac was contracted by the RPs to provide the technology and operate a vacuum extraction system of sufficient size to remediate the Tyson's site within two years. The construction phase of the project was procured through a fixed price contract. The operation and maintenance phase of the project was procured through a time and materials contract.

### Cost Analysis [9, 16]

The total actual cost for the SVE system was reported by the RPs as \$43.4 million. Approximately \$3.5 million was incurred for design and pilot studies. Treatment costs were \$39.9 million and consisted of construction and operation and maintenance costs. Construction costs were \$18.5 million. Operation and maintenance costs, which included all enhancements, were \$21.4 million. No other cost data were available.

## OBSERVATION AND LESSONS LEARNED

### Performance Observations and Lessons Learned

After 32 months of system operation, a total of about 200,000 lbs of VOCs had been removed from the soil. However, the cleanup goals had not been achieved. EPA subsequently determined that the SVE system was incapable of meeting the cleanup goals in a timely and cost effective manner, and amended the ROD by changing the remedy to a wet soil cover.

Tetra Vac attributed the SVE system's performance problems to the presence of a number of conditions at the site that had not been identified or fully characterized during previous investigations. These conditions included greater variation in soil conditions (porosity, permeability, moisture), greater occurrence of DNAPLs, and the presence of perched water at the site.

Enhancements that were made to the system in an effort to improve performance included varying the number and types of wells, heating the soil using several techniques, destroying contaminants in situ, and physically creating new flow paths. In a number of cases, an enhancement was operated for a short period of time only to evaluate its performance and effect on extraction rate. According to Terra Vac, there was no significant difference in performance between the different types of enhancements. In all cases, only temporary increases in extraction rate were observed.



## OBSERVATION AND LESSONS LEARNED (CONT.)

### Cost Observations and Lessons Learned

The total cost for treatment was \$39.9 million or \$1,330 per cubic yard of soil treated (based on 30,000 cubic yards). This cost includes costs for construction, operation, and maintenance of the SVE system including modifications and enhancements. Because these costs include the 14 enhancements, the costs may be high when compared to other SVE applications.

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12. Hazardous Waste Management Division, EPA Region 3. 1994. Five Year Review (Type 1) Tyson's Dump, Upper Merion, Pennsylvania. September 30.
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### Preparation of Analysis

This case study was prepared for EPA's Office of Solid Waste and Emergency Response Technology Innovation Office. Assistance was provided by Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.



## APPENDIX A

Table A-1: Cleanup Levels for Lagoon Soils (in addition to those shown in Table 6) [1]

Compound	Concentration (mg/kg)
Aniline	1.4
Anthracene	12,400
Benzoic Acid	6.95
Bis (2-ethylhexyl) phthalate	83,100
2-Butanone	36.8
Chlorobenzene	11.5
2-Chloronaphthalene	170
2-Chlorophenol	3.80
Chrysene	0.06
Cycloheptatriene	0.21
Cyclohexanone	262
Di-n-Butyl Phthalate	894
Di-Octyl Phthalate	16,400
Dichlorobenzenes	60
2,4-Dimethylphenol	10.8
Dodecane	490,000
Ethylbenzene	599
1-Ethyl-2-Methylbenzene	107
Fluoranthene	408
Hexadecane	2,900,000
Hexadecanoic Acid	0.197
2-Methyl Phenol/4-Methyl Phenol	33.5
2-Methyl-2-Pentanone	18.7
2-Methylnaphthalene	478
Methylene Chloride	5.84
N-Nitrosodiphenylamine	4.80
Naphthalene	3.03
Nitrobenzene	0.300
N,N-Dimethyl-1,3-Propanediamine	6.50
1,1-Oxybis-(2-ethoxyethane)	9.22
Phenanthrene	7.09
Phenol	4.19
Pyrene	3,890
Tetramethylurea	7.50
Toluene	588
1,2,4-Trichlorobenzene	479
1,2,4-Trimethylbenzene	1,230
1,3,5-Trichlorobenzene	479
Tridecane	54,000
Undecane	23,000
o-xylene	6.28



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**OTHER THERMAL PROCESSES  
CASE STUDIES**

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**Contained Recovery of Oily Waste (CROW)<sup>TM</sup> Process at Brodhead Creek  
Superfund Site, Stroudsburg, Pennsylvania**

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**Contained Recovery of Oily Waste (CROW)<sup>TM</sup> Process at Brodhead Creek  
Superfund Site, Stroudsburg, Pennsylvania**

<b>Site Name:</b> Brodhead Creek Superfund Site	<b>Contaminants:</b> Coal tar and coal tar residual containing: - PAHs - benzo(a)pyrene and naphthalene - Nonhalogenated semivolatile organic compounds (SVOCs) - Volatile organic compounds (VOCs) - benzene - Metals - arsenic	<b>Period of Operation:</b> July 1995 - June 1996
<b>Location:</b> Stroudsburg, Pennsylvania		<b>Cleanup Type:</b> Full-scale
<b>Vendor:</b> Mark Moeller RETEC 9 Pond Lane, Suite 3A Concord, MA 07142 (508) 371-1422  Lyle Johnson Western Research Institute 365 North 9 <sup>th</sup> Street Laramie, WY 82070 (307) 721-2281	<b>Technology:</b> CROW™ process - Hot water injected into subsurface; water and coal tar extracted and treated using a tar-water separator - Six injection wells and two production wells (used for extraction) - Water from separator treated using carbon adsorption; recovered tar sent off site for treatment - Injection pressure - 20 psig - Extraction rate - design of 100 gpm; actual of 40 gpm	<b>Cleanup Authority:</b> CERCLA - ROD date: 3/29/91 - ESD date: 7/19/94
<b>PRP Lead:</b> Jim Villaume Senior Project Manager Pennsylvania Power and Light (PP&L) Two North Ninth Street Allentown, PA 18101 (610) 774-5094		<b>EPA Remedial Project Manager:</b> John Banks U.S. EPA Region 3 841 Chestnut Street Philadelphia, PA 19107 (215) 566-3214
<b>Waste Source:</b> Disposal of waste in open pit	<b>Type/Quantity of Media Treated:</b> Free product (coal tar) - 1,500 gallons of coal tar	
<b>Purpose/Significance of Application:</b> Recover free and residual coal tar using the CROW™ process		
<b>Regulatory Requirements/Cleanup Goals:</b> - The ROD specified removal of 60 percent of the total free-phase coal tar from the subsurface soils. However, the results of the preremedial design investigation found that an accurate measurement of the amount of free-phase coal tar was not possible. - An ESD was issued to change the standard. The system was required to operate until the amount of free-phase coal tar recovered was minimal.		



## **Contained Recovery of Oily Waste (CROW)<sup>TM</sup> Process at Brodhead Creek Superfund Site, Stroudsburg, Pennsylvania (continued)**

### **Results:**

- Initial estimate of total volume of coal tar removed - 1,500 gallons (based on estimate of amount removed for each pore volume of water flushed through the recovery zone). In addition, no measurable material had been recovered during the last three months of operation.
- However, EPA determined that the method used for this estimate was inaccurate and therefore could not be used to determine whether the performance standard had been met. In response, the PRPs were required to collect three additional pore volumes and perform quantitative analyses per EPA requirements.
- The results showed that the recovered process water did not contain free or separable coal tar; EPA agreed that the performance standard had been met and allowed the system to be shut down.

### **Cost:**

- Total cost - \$1.9 million, including \$1.2 million for treatment costs.
- Costs for this application were shared among DOE, the Gas Research Institute, and PP&L.

### **Description:**

Citizen Gas and Electric operated a coal gasification plant at this site from 1888 until 1944. Coal tar from these operations was disposed of in open pits at the site. In October 1980, coal tar was observed to be seeping into Brodhead Creek. In December 1982, the site was placed on the National Priorities List. The results of the Remedial Investigation identified free-phase coal tar at the site. In addition, the soil and groundwater at the site were contaminated with PAHs, other SVOCs, VOCs, and metals. The ROD signed in 1991 specified the use of an enhanced recovery technology to remove free-phase coal tar from subsurface soils. The Contained Recovery of Oily Waste (CROW)<sup>TM</sup> process was selected for use at the site.

The CROW<sup>TM</sup> process involved injecting hot water into the subsurface through six wells to decrease the viscosity of the coal tar and facilitate recovery, then extracting the water and coal tar using two production wells. The extracted water and coal tar were treated using a tar-water separator. Water from the separator was treated using carbon adsorption; recovered tar was sent off site for treatment. While the design called for the system to be operated at a rate of 100 gpm, the actual rate was 40 gpm. A reason for the reduced rate included iron fouling problems in the well screens. Initial results indicated that the CROW<sup>TM</sup> process had removed 1,500 gallons of coal tar and that no measurable coal tar had been recovered during the last three months of operation. In March 1996, samples of the recovered material were taken from the storage tank. The results indicated that the contents were primarily water, and raised concerns about the method that was being used to calculate the volume of tar recovered. EPA determined that the method was not accurate, and therefore could not be used to determine whether the performance standard had been met. Additional pore volumes were collected and the results of quantitative analyses performed per EPA requirements showed that the cleanup goals had been met.

## SITE INFORMATION

### Identifying Information:

Brodhead Creek Site  
Stroudsburg, Pennsylvania

**CERCLIS #:** PAD980691760

**ROD Date:** 29 March 1991

**ESD Date:** 19 July 1994

### Treatment Application:

**Type of Action:** Remedial

**EPA SITE Program test associated with application?** Yes

**Period of operation:** July 1995 - June 1996

**Quantity of material recovered during application:** 1,500 gallons of coal tar

### Background [1, 7, 8]

**Historical Activity That Generated Contamination at the Site:** Coal gasification plant

**Corresponding SIC:** 4925 (Mixed, Manufactured, or Liquefied Petroleum Gas Production and/or Distribution)

**Waste Management Practice That Contributed to Contamination:** Waste product disposed of in an open pit.

**Location:** Stroudsburg, Pennsylvania

**Operations:** Coal gasification plant

Citizen Gas and Electric operated a coal gasification plant from about 1888 until 1944.

A waste product from those operations was a black tar-like liquid (coal tar) with a density greater than water (specific gravity equal to 1.014) and principally composed of polyaromatic hydrocarbons (PAH). Coal tar was disposed of in an open waste pit on site.

In October 1980, during repairs of a flood control levee near the site, material identified as coal tar was observed seeping into Brodhead Creek.

As a result of the contamination, several investigations and removal response actions were initiated, between 1981 and 1984. The actions included:

- Installation of filter fences and underflow dams to intercept coal tar seepage
- Installation of a coal tar recovery pit on the bank of Brodhead Creek
- Construction of a slurry wall to mitigate coal tar migration from the site into Brodhead Creek
- Excavation of a backwater channel area where seepage of coal tar appeared to be significant
- Installation of recovery wells in the main coal tar pool that recovered approximately 8,000 gallons of coal tar

In December 1982, the site was placed on the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) National Priorities List. The remedial investigation (RI) was completed in April, 1989, and a feasibility study (FS) was completed in January 1991.

An interim record of decision (ROD) signed on March 29, 1991 called for the use of an enhanced recovery technology to recover free phase coal tar from subsurface soils. On July 19, 1994, an explanation of significant differences (ESD) was approved. The ESD modified the performance standard of the coal tar recovery operations and addressed requirements under the Resource Conservation and Recovery Act (RCRA) for management of coal tar.



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## SITE INFORMATION (CONT.)

### Regulatory Context:

On August 20, 1987, the potentially responsible parties (PRP) for the site entered into an agreement with the Pennsylvania Department of Environmental Protection (DEP) to conduct the RI/FS.

On March 29, 1991, EPA issued a ROD for the site. The ROD called for the use of an enhanced recovery technology to recover free phase coal tar from subsurface soils.

**Remedy Selection:** The remedy called for enhanced recovery of coal tar in the subsurface soils; separation of the coal tar from the process waters; discharge of the process waters after treatment to Brodhead Creek; incineration of recovered coal tar at a permitted off-site facility; fencing, deed restrictions and monitoring of groundwater; and testing of biota in Brodhead Creek.

### Site Logistics/Contacts

**Site Management:** (PRP Lead)  
Jim Villaume, Senior Project Scientist  
Pennsylvania Power and Light Company  
Two North Ninth Street  
Allentown, PA 18101  
(610) 774-5094

**Oversight:**  
U.S. EPA (John Banks);  
PA DEP Northeast Regional Office (Len Zelinka);  
EPA Consultants CH<sub>2</sub>M HILL (Murray Rosenberg)

**Remedial Project Manager:**  
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Philadelphia, PA 19107  
(215) 566-3214

**State Contact:**  
Len Zelinka  
Pennsylvania DEP  
Northeast Regional Office  
2 Public Square  
Wilkes Barre, PA 18711-0790  
(717) 826-2511

### Contained Recovery of Oily Waste (CROW™) System Vendor:

Mark Moeller  
RETEC (Licence holder)  
9 Pond Lane, Suite 3-A  
Concord, MA 07142-2851  
(508) 371-1422

Lyle Johnson  
Western Research Institute (Technology Developer)  
365 N. 9<sup>th</sup> Street  
Laramie, WY 82070  
(307) 721-2281

## MATRIX DESCRIPTION

### Matrix Identification

**Type of Matrix Processed Through the Recovery System:** Waste product and process water.

### Contaminant Characterization [1, 7]

**Primary Contaminant Groups:** PAHs, nonhalogenated semivolatiles, volatiles, and metals

Coal tar from coal gasification operations has migrated vertically through the unsaturated and saturated portions of the stream gravel units to the interface with the silty sand. The silty sand prevents further downward movement of the coal tar because of the higher capillary pressures within that unit. Further movement of the coal tar has been lateral toward the natural depressions in the silty sand unit where it has accumulated.

As shown in Figure 1, potentially recoverable coal tar is trapped in a portion of the natural stratigraphic depression east of the slurry wall near monitoring well 2 (MW-2) and in the lower portion of the stratigraphic depression west of the slurry wall, as measured in the central recovery well cluster (RCC) which was part of the initial product recovery system. Both of these tar accumulations were considered to be confined from further downward migration as a bulk nonaqueous phase by the top of the silty



## MATRIX DESCRIPTION (CONTINUED)

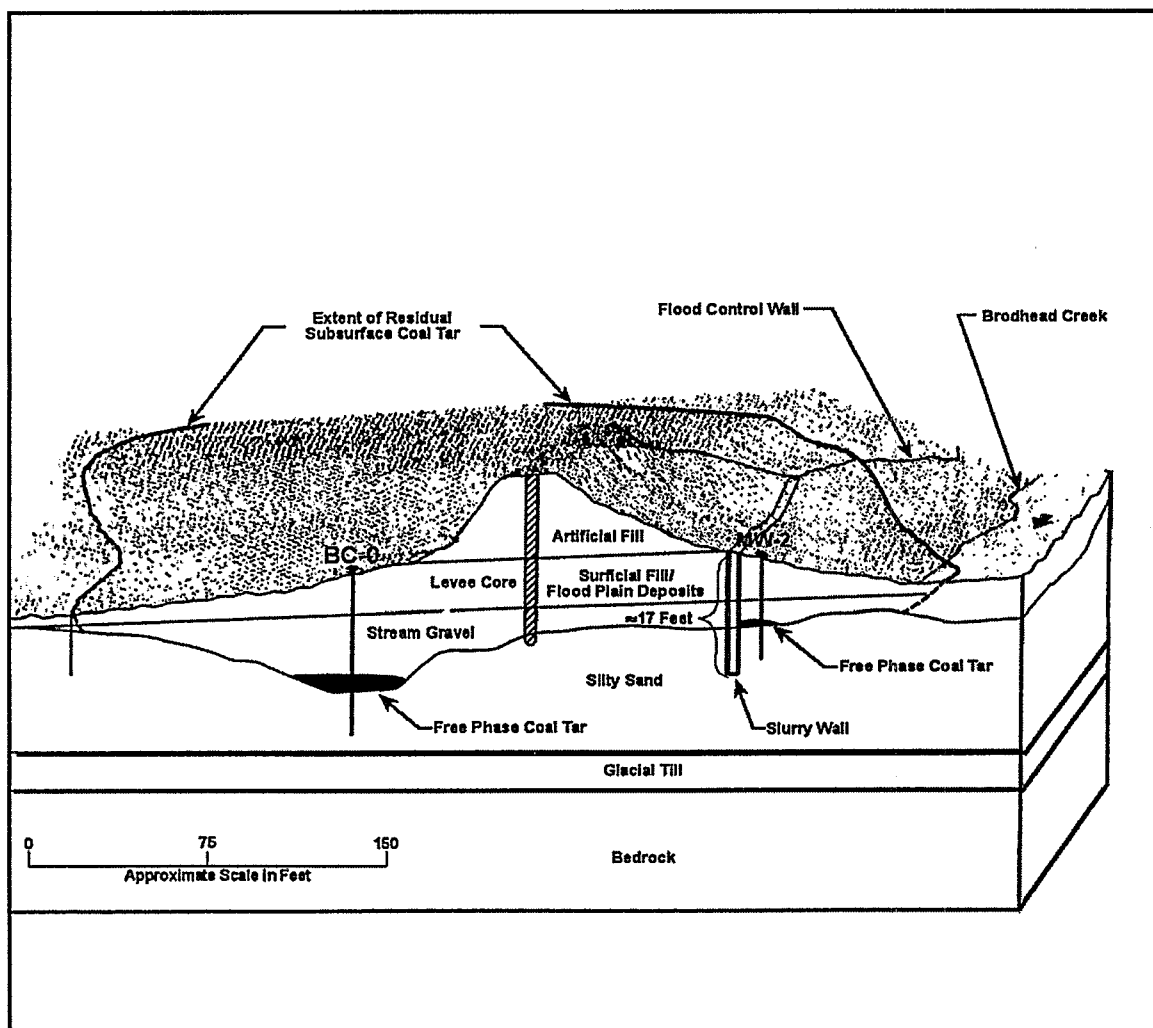


Figure 1. Schematic of Extent of Free and Residual Coal Tar [3]

sand unit. The 1991 ROD estimated the total volume of free phase coal tar associated with these areas to be 9,000 gallons, with 8,715 gallons and 338 gallons of free phase coal tar associated with the RCC and MW-2 areas, respectively.

The primary contaminants at the site were benzo(a)pyrene (representative of carcinogenic PAHs), naphthalene (representative of noncarcinogenic PAHs), benzene, and arsenic.

Soil samples from the silty sand unit (monitoring wells 9 and 10) indicated the presence of chloroform at a concentration of  $2 \mu\text{g/kg}$ . Soil samples from the gravel unit (monitoring wells 11 and 12) showed evidence of low VOC concentrations in only MW-11 where traces of coal tar were noted in sampled materials. Semivolatile organic results for the four soil sample locations ranged from non detect in the silty sand to high concentrations in the gravel unit at MW-11. The concentration of SVOCs in



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## MATRIX DESCRIPTION (CONTINUED)

MW-11 were very high suggesting the presence of residual saturation of coal tar in that area. In MW-11, reported concentrations ranged from 590  $\mu\text{g/kg}$  for indeno(1,2,3-cd)pyrene and up to 54,000  $\mu\text{g/kg}$  for 2-methyl naphthalene. Total PAHs were identified tentatively at concentrations of 450,000  $\mu\text{g/kg}$ .

Contaminants in the groundwater that were detected at concentrations above EPA's maximum contaminant levels (MCL) for groundwater include: benzene (maximum concentration, 1,100  $\mu\text{g/L}$ ), arsenic (maximum concentration, 108  $\mu\text{g/L}$ ). Several PAHs including benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, and chrysene were detected in groundwater at concentrations ranging from 250  $\mu\text{g/L}$  to 300  $\mu\text{g/L}$ .

### Matrix Characteristics Affecting Treatment Costs or Performance [1, 3, 7]

**Type of Matrix:** Free Phase Coal Tar in soil)

**Geology:** The site is located within the Valley and Ridge physiographic province of the Appalachian Mountains. As shown in Figure 1, the Brodhead Creek site is underlain by at least 60 feet of unconsolidated sediments of glacial, recent fluvial, and human origin. Four distinct strata make up this unconsolidated interval: surficial fill, flood-plain deposits, stream gravels, and silty sands. The thickness of the stream gravel averages about 10 to 15 feet, but ranges to a maximum of 25 feet in a stratigraphic depression in the center of the site. Bedrock at the site is the Devonian Age Marcellus Shale. Directly underlying the Marcellus Shale is the Devonian Age Buttermilk Falls Formation, which is composed of limestone and is a viable water supply.

## DESCRIPTION OF TREATMENT SYSTEM

### Primary Treatment Technology

Contained Recovery of Oily Waste (CROW)

### Supplemental Treatment Technology

Oil/water separation; carbon adsorption

### System Description and Operation [6, 8]

This enhanced recovery process used hot water (approximately 200° F) injected into subsurface areas where free-phase tar had been identified. The heat of the injected water decreased the viscosity of the tar, facilitating recovery. Heating the tar also reversed the difference in density between the oily waste and water. The density of heavy organics is almost equivalent to the density of water at a temperature of about 100°F. At higher temperatures, the oil phase has a lower density than water because water is more polar and resists thermal expansion.

Figure 2 shows a cross section of the subsurface activity associated with the CROW system. Figure 3 presents a plan view of the entire operation at the site and shows the system's well fields.

Downward migration of oily wastes was reduced by thermal expansion and lower density of the oils and floating of coal tar. Balancing the hot-water injection and production rates controlled the upper boundary of the contaminated area, preventing fluid displacement through density induced flotation into the overlying material. Six injection wells were installed in such a manner as to encircle the estimated areal extent of the deposit of tar. The design injection flow rate of approximately 100 gallons per minute (gpm) never was achieved. That failure was the result of iron fouling problems in the well screens and possibly the formation itself. Two production wells were installed near the center of the deposit. Water and tar were extracted from the production wells at approximately 40 gpm, producing a drawdown in the wells that induced a gradient from the injection points to the production points. The induced gradient also



## DESCRIPTION OF TREATMENT SYSTEM (CONTINUED)

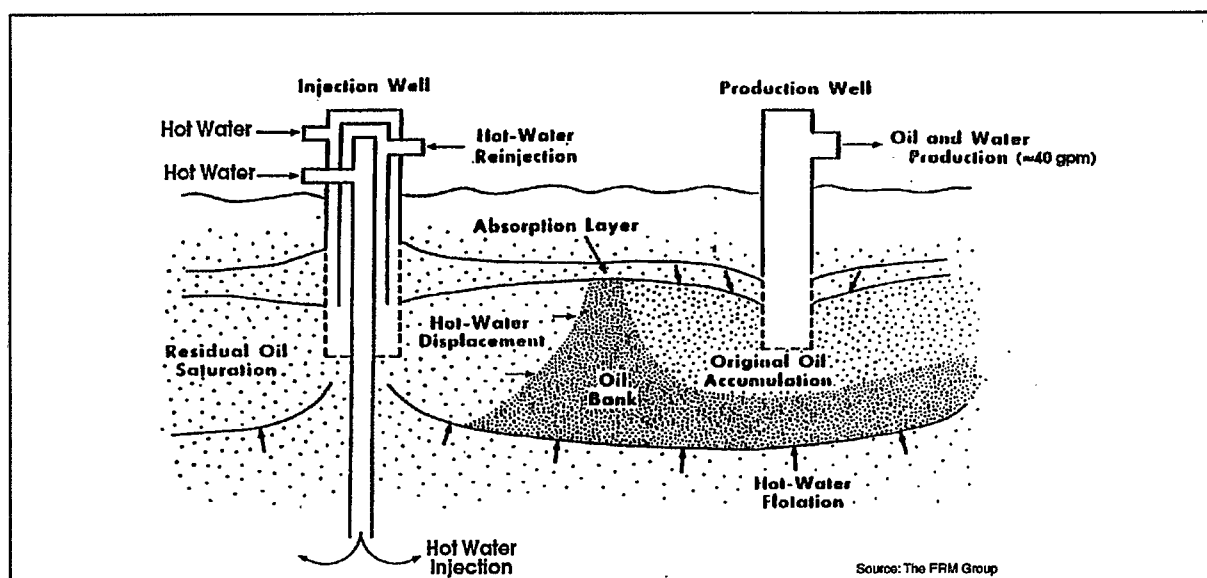


Figure 2. Cross section of subsurface setup of CROW process [6]

limited the heat to levels within the target zone and prevented the release of the mobilized constituents into the surrounding aquifer. After the mixture of tar and water was pumped to the surface, it underwent treatment through a tar-water separator. Approximately 33 gpm of the separated water was recycled through the water heater and discharged into the six injection wells. The remaining 7 gpm was pumped to the FBR unit where the organic constituents were degraded biologically. The treated water then was pumped through two carbon adsorption units to meet limits set by the state under the National Pollutant Discharge Elimination System (NPDES) before it was discharged to Brodhead Creek.

It originally was anticipated that, when the level of recovered coal tar in Oil Storage Tank 4 had reached 50 percent of the tank's capacity (approximately 5,000 gallons), transfer procedures for the coal tar would begin.

However, the level in the oil storage tank never reached 50 percent. Therefore, all recovered tar was transferred off site for treatment at the end of the project. The contracted disposal company provided the necessary equipment to transfer the coal tar properly from the settling tanks and the oil storage tank to the truck. The coal tar was dewatered at a facility in Ohio, then transported to a permitted boiler or industrial furnace (BIF) facility in Pennsylvania.

Process water was run through a series of three 20,000 gallon tanks that served as an oil-water separation system, then treated further by the GAC-FBR units, before it was discharged to Brodhead Creek.

Recovered coal tar (deemed a RCRA characteristic waste for toxicity) was dewatered at an off-site facility, then shipped to and burned at another offsite facility permitted as a BIF, in compliance with the off-site rule.



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## DESCRIPTION OF TREATMENT SYSTEM (CONTINUED)

### System Operation

The proposed operating conditions for the CROW system were:

Nominal Pattern Distribution	40 ft x 80 ft
Number of Patterns	2
Number of Wells	
Injection	6
Extraction	2
Interior Monitoring	4
Exterior Monitoring	4
Average Injection/Extraction Well Spacing	28 ft
Average Gross Thickness of Saturated Zone	20 ft
Injection Pressure (at bottom of well)	20 pounds per square inch gauge (psig)
Injection Wellhead Temp.	~170°F
Pattern Injection Rate	
(design)	100 gpm
(actual)	40 gpm
Total Water Injected	13-17 x 10 <sup>6</sup> gallons
Water Production (Extraction) Rate/Per Well	35-45 gpm
Total Water Production (Extraction) Rate	70-90 gpm
Total Water Extracted	21 x 10 <sup>6</sup> gal
Injection/Production Time	11 months

Nominal pattern distribution refers to how the injection wells and production wells are placed relative to each other to enhance the recovery of the coal tar. There were six injection wells and two production wells in the pattern. The pattern was designed so that four wells were aligned with one production well, with a crossover of injection wells 3 and 4 to the production well. Figure 3 shows the position of the wells at Brodhead Creek.

The CROW process enhances recovery of oily waste by reducing its viscosity and reversing the difference in density between the oil and the water.

Laboratory and pilot work performed indicated that the optimal temperature for flushing of the Brodhead Creek site was 156°F. The average temperature of the targeted area was less than 156°F. The average temperature of the targeted area varied from 150 to 180°F near the injection wells to 110 to 130°F near the production wells. This was the result of the system operating at a lower flow rate than originally designed due to iron fouling of the wells and the formation itself. The lower-than-optimum temperature (156°F) may have resulted in recovery of less tar because the viscosity of the tar had not been reduced as much as had been anticipated.

Suspended solids also caused operational difficulties throughout the system. They interfered with tar settling calculations; fouled the granular activated carbon-fluidized bed reactor (GAC-FBR), carbon drums, and injection wells; and increased the concentrations of dissolved PAHs in the discharge water. Suspended solids occur in the form of silt, iron floc (or other precipitated metals), or biomass. Filters were installed in line at various points in the system to remove the suspended solids.

Modifications to the system included:

- rewiring of heater elements for optimal performance and increased temperature;
- reconfiguring the heater control unit for greater temperature regulation;
- replacing inflatable packers into injection wells (W1, W2, W6);
- utilizing supplementary interior monitoring wells as injection wells.
- repairing and replacing damaged flow meters for increased injection flow control;
- repairing production pumps to increase the capacity and permit increased injection; and
- replacing all four carbon adsorption units with new units.
- modifying the water treatment system to enhance iron flue removal.



## DESCRIPTION OF TREATMENT SYSTEM (CONTINUED)

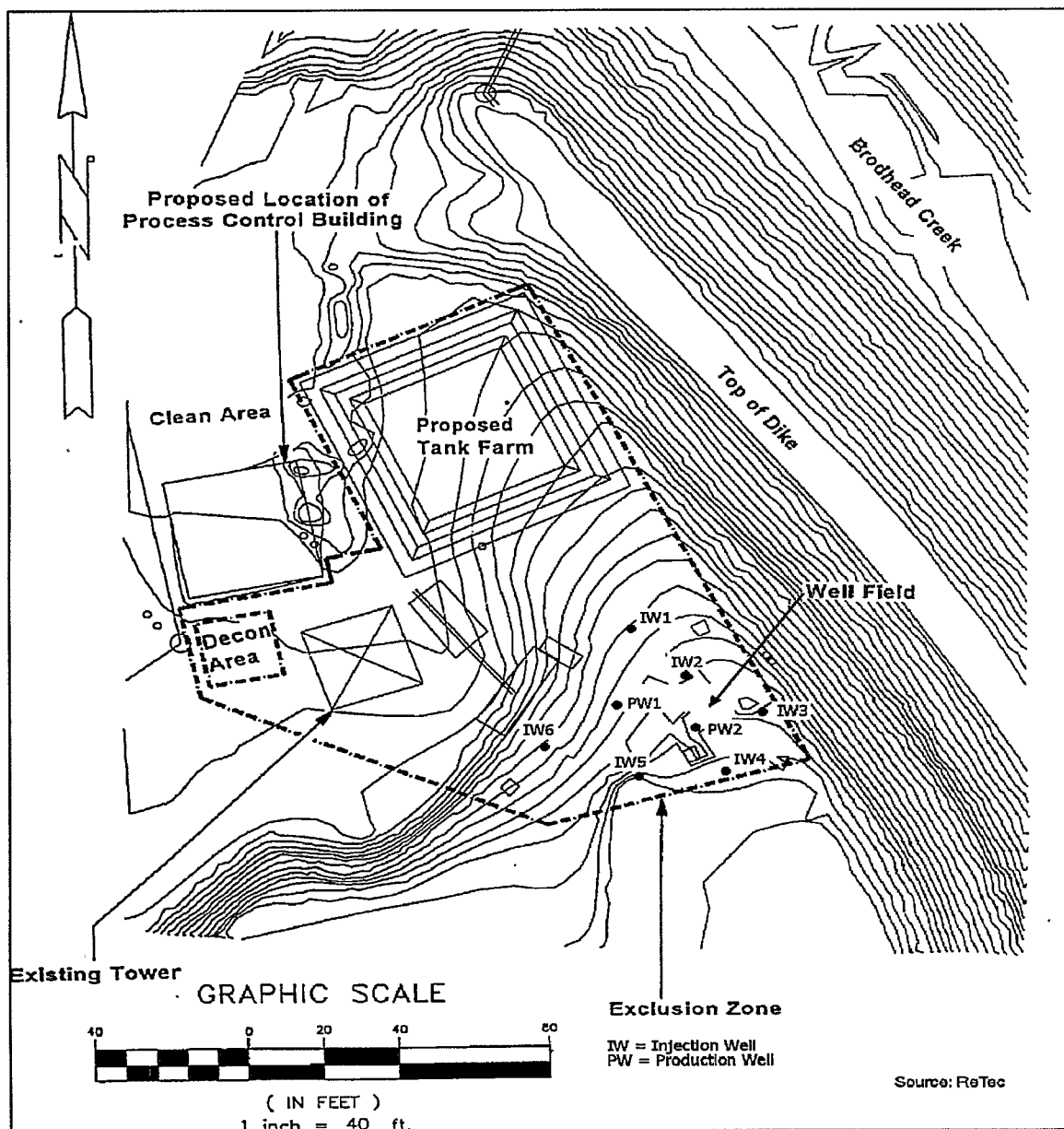


Figure 3. Plan View of CROW System Operations and Positions of Injection and Recovery Wells at Brodhead Creek [6]



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## TREATMENT SYSTEM PERFORMANCE

### Cleanup Goals/Standards [2, 7]

The ROD called for removal of 60 percent of the total free phase coal tar from the subsurface soils. However, the preremedial design investigation revealed that an accurate measurement of the amount of free phase coal tar initially present was not possible, mainly because of the heterogeneity of the subsurface and difficulty experienced with collecting representative samples. During the remedial design, it was learned that, although free phase coal tar was present at both the RCC and MW-2 areas, it was discontinuous, and therefore a direct estimate of the initial volume present could not be made. Consequently, it was not possible to determine when 60 percent of the total free phase coal tar had been removed. The July 1994 ESD revised the standard, requiring the system to be operated until "the incremental change in the amount removed is 0.5% or less of the cumulative coal tar removed per pore volume."

### Timeline [5, 6, 8]

Start Date	End Date	Activity
1888	1944	Coal gasification plant operates along the west bank of Brodhead Creek near Stroudsburg, PA.
---	October 1980	Coal tar seepage to Brodhead Creek is discovered during repair of the toe of the flood control levees.
1981	1984	Various investigations and Superfund removal response actions are initiated to mitigate the flow of coal tar into Brodhead Creek.
---	December 1982	The site is placed on the CERCLA National Priorities List.
---	August 1987	Pennsylvania Power and Light (PP&L) Co. and Union Gas enter into a consent agreement with the state of Pennsylvania to conduct an RI/FS for the site.
August 1988	April 1989	Field work for the RI is conducted.
---	January 1991	The FS for the site is completed.
---	March 1991	An interim ROD is approved.
---	September 1992	The consent decree to implement the remedy set forth in the ROD was entered into U.S. District Court for the Eastern District of Pennsylvania.
January 1993	March 1994	The remedial design was completed.
May 1994	October 1994	The remedial construction was completed.
December 1994	June 1996	The remedial action was completed; the performance standard had been met.

Previous laboratory and field data indicate that it is at this point that 98.5 percent of the total recoverable coal tar will have been recovered.

### Additional Information on Goals

RCRA hazardous waste regulations were determined to be applicable for the management, storage, treatment, and disposal of the coal tar recovered at the site. The coal tar was RCRA characteristic (toxic) for benzene and arsenic. EPA also determined that the recovered coal tar could be disposed of in an offsite BIF that was in compliance with interim status requirements pursuant to 40 CFR Part 266 Subpart H.

Process water was treated to levels meeting NPDES requirements for Brodhead Creek prior to discharge.



## TREATMENT SYSTEM PERFORMANCE (CONTINUED)

### Treatment Performance Data [6, 8]

Approximately 20 pore volumes of water flushed through the recovery zone resulted in an estimated total volume of coal tar removed from the subsurface of approximately 1,500 gallons. This measure was estimated during each pore volume flushed, but was not verified until the end of the project, when the storage tanks were pumped (see discussion below). Figure 4 shows the estimated cumulative amount of tar recovered over life of the project.

Figure 5 shows the estimate of the percentage increase in cumulative amount recovered, compared with pore volume at the site. For the last three pore volumes (18, 19, and 20) the figure shows an incremental change in the amount removed of less than 0.5 percent of the cumulative amount of coal tar recovered per

pore volume of water flushed through the subsurface soils. However, because of problems with the measuring methodology, the accuracy of this estimate cannot be verified directly. The measurement of the amount of tar recovered in the production well during the final pore volume flushes indirectly verified that the performance standard had been achieved. (see discussion below).

Figures 4 and 5 show that the majority of the coal tar recovered occurred in the first three pore volumes. On the measurements made during the process, approximately half the recovered tar was recovered in the first 3 pore volumes, and the other half in the latter 17 pore volumes flushed through the subsurface soils. However, as discussed below, confidence in the measurements was suspect, and the initial recovery cannot be verified.

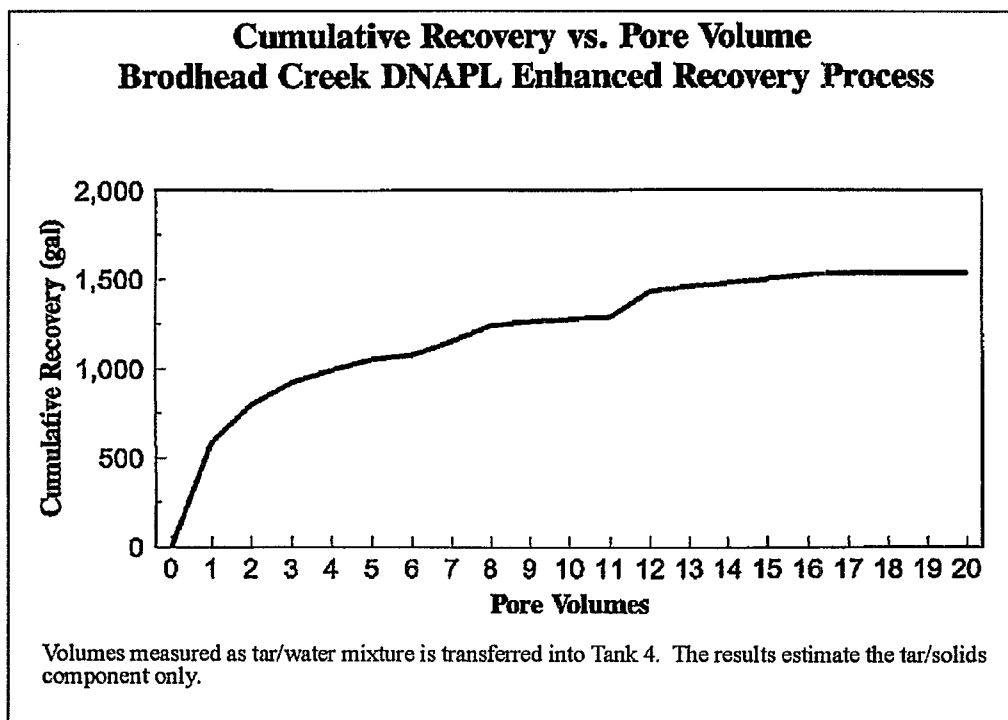


Figure 4. Estimated Cumulative Recovery of Tar Over Life of Project [6, 8]



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## TREATMENT SYSTEM PERFORMANCE (CONTINUED)

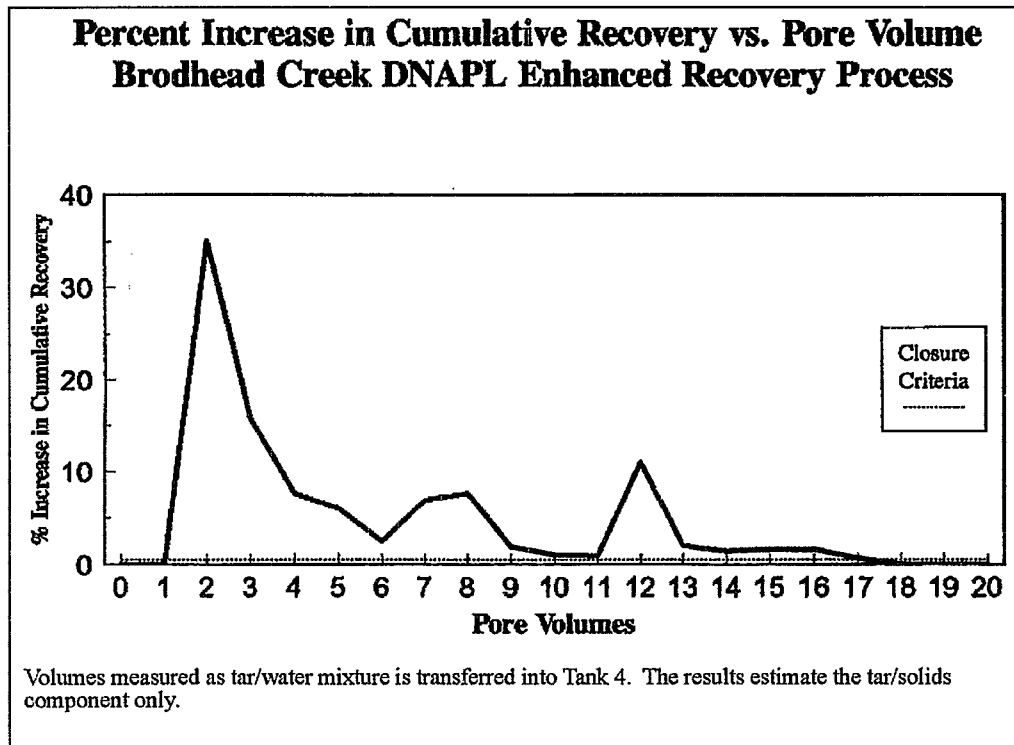


Figure 5. Estimate of the Percent Increase in cumulative Amount Recovered Per Pore Volume [6, 8]

The original design included an automatic tar separation and measuring system that consisted of conductivity meters and a flow meter with a totalizer. In theory, a conductivity meter would sense any dense accumulation of tar at the bottom of the settling tank. The conductivity meter was wired to a tar transfer pump. As long as the meter sensed the presence of tar, the valve would stay open, and the liquid would be pumped from the tank bottom to the oil storage tank. The flow meter and totalizer would measure the transfer of oil. Ideally, at the end of the project, the totalizer would indicate how much tar had been transferred to the oil storage tank. However, viscous tars or oils fouled the conductivity and the flow meters, making accurate readings impossible. This condition caused a problem in determining whether the performance of the system met established standards.

To measure the increase in the cumulative amount of tar recovered, two items of information were needed: the total cumulative amount recovered and the amount recovered in the last pore volume. The initial methods for measuring those quantities were unreliable because of the technical difficulties described above. To estimate the quantities, the site operator checked the bottoms of tanks 1, 2, and 3 each day by collecting a small sample of liquid near the bottom of each tank. If the sample appeared murky, it was allowed to settle overnight.

Generally, the sample would separate by morning into two phases. A light, clear, water phase would rise to the surface, and a dark oily phase would sink to the bottom. This bottom phase, referred to as the "solid mixture," was a mixture of silt, iron floc, and tar. If the solid



## TREATMENT SYSTEM PERFORMANCE (CONTINUED)

mixture made up more than 50 percent (by visual inspection) of the sample, a transfer of tar was conducted. A small amount of material at the bottom of that particular tank would be pumped into the oil storage tank. Because the flow meter was not working, it was not possible to measure accurately the flow rate or quantity of tar transferred. Therefore, the operator estimated the quantity. To do so, the operator timed the pump while monitoring the rise in the level of liquid in the oil storage tank. By converting the rise in the level of liquid to a volume, the operator was able to determine the flow rate produced by the oil transfer pump. The flow rate was estimated at 50 gpm. By timing the transfer of tar, the operator could record the total quantity of liquid transferred. To determine the percentage of tar in that liquid, the operator collected a second sample from the same sample port in the tank. That sample also was allowed to settle overnight. The next day, the percentage of solid mixture was observed and recorded. The quantity of tar then was estimated by averaging the before and after percentages of the solid mixture and multiplying by the total volume of liquid transferred.

The results represented the total volume of tar, iron floc, and silt transferred because those materials could not be separated in the solid mixture. As the system was operated, those volumes were recorded. By tracking the pore volumes flushed over the same period of time, an estimate was made that allocated a specific volume of tar transferred to a specific pore volume.

In March 1996, near the end of the project, a sample of recovered solid mixture was collected from the oil storage tank. The sample had an oily aroma and had a murky brownish-orange appearance. The sample was analyzed for its primary components. The results were:

Moisture Content	99.60%
Organic Content	0.27%
<u>Inorganic Content</u>	<u>0.13%</u>
Total	100.00%

The results which indicated that the contents of the oil storage tank were primarily water, prompted concern about the representativeness of the sample. Subsequent sampling showed that a darker phase was present in the bottom few feet of the tank, and that most of the tank was filled with water. However, samples of the darker, denser phase at the bottom of the tank revealed similar results. On the basis of those results, EPA concluded that the modified method of calculating the volume of tar recovered was inaccurate and therefore the results could not be used to certify achievement of the performance standard.

Upon analysis of the contents of the other tank bottoms, it was discovered that much of the dense organic material had accumulated in the primary settling tanks. The material that was transferred into the oil storage tank throughout the operation of the system consisted of a dilute mixture that floated on top of the dense organic material. In addition, pumping from a low point on the tank likely caused a high energy point so that less viscous fluids immediately filled the pipe space. This condition resulted in the transfer of a large amount of water and a small amount of organic material. EPA concluded that it would be necessary to change the performance standard or devise an alternative measure of the performance of the system.

Because no measurable material had been recovered from the production water for three months, the PRPs believed that the performance standard had been met and that it should not be changed. However, EPA required a quantitative measure before it would allow the PRPs to shut down the system. EPA agreed that, if the quantity of tar recovered in the latest pore volume flushing was zero, the total amount of tar recovered could be quantified after the system was shut down. Therefore, EPA required evidence that no measurable separable tar was being recovered from the subsurface as a demonstration of compliance with the performance standard.



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## TREATMENT SYSTEM PERFORMANCE (CONTINUED)

EPA also required that the PRPs monitor the quality of the production water for three additional pore volume flushings at the highest heat possible. To comply with that request, the heater was rewired, additional injection points were installed, using the existing interior monitoring wells and the production pumps were serviced to increase the capacity and permit increased injection of hot water. That maintenance resulted in the hottest three pore volume flushings of the project; injection temperatures averaged about 180°F and production temperatures averaged about 145 °F.

During the final flushing, EPA required that samples of production well water be collected three times per week and analyzed for total PAHs and BTEX. The results were evaluated to determine whether the concentrations of specific constituents were associated with free phase coal tar. Water that is in contact with free phase coal tar tends to have concentrations of constituents near their solubility levels. The analysis showed that most of the constituents analyzed for were present at levels significantly below their individual solubility limits, even before the samples were filtered. This finding indicated that the process water being recovered did not contain free or separable coal tar.

On June 7, 1996, EPA agreed that the performance standard had been met and that injection and production could be halted.

### Performance Data Quality

A field sampling plan and groundwater monitoring plan was submitted as part of the final design. The field sampling and groundwater monitoring plan for the Brodhead Creek site covered the sampling objectives, data gathering activities, and groundwater monitoring activities. The sampling objectives covered process monitoring, process water sampling, waste characterization sampling, post-treatment for monitoring, and health and

safety concerns. Data gathering activities covered all activities associated with operating and monitoring the CROW process. The groundwater monitoring plan addressed the activities to be conducted for monitoring groundwater responses, such as temperature and water levels, to the CROW process.

## TREATMENT SYSTEM COSTS

### Procurement Process

To design and implement the remedy, the PRPs contracted with Remediations Technology, Inc. (RETEC) of Concord, Massachusetts, which holds a licence for the CROW process developed by Western Research Institute.

### Cost Analysis [5, 8]

Costs for the Brodhead Creek site began to accumulate in 1980, when EPA responded to the leaking of coal tar into the creek. However, it was not until the consent decree was lodged in 1992 that the remedial action for coal tar recovery began.

As shown in Table 1, the total cost of the project was \$1.9 million. Costs were shared by DOE, GRI, and PP&L. The decommissioning work was funded entirely by PP&L. Data on before, during, and after-treatment costs were estimated by the vendor, and are presented in Tables 2, 3, and 4, respectively. The estimated total cost for treatment directly associated with treatment is \$1,283,000. The vendor indicated that costs for disposal of residuals and wastes were minimal and that demobilization accounted for most of the cost.

Modifications of the recovery system to meet verification standards increased the cost of the project. Information on the exact increase in cost was not available.



## TREATMENT SYSTEM COSTS (CONTINUED)

### Quality Of Cost Data

The cost data shown in Tables 2, 3, and 4 represent the vendor's best estimate of the actual costs for each cost element and total about \$1.4 million. Table 1 shows a total cost of \$1.9 million; the additional elements contributing to the total cost were not provided.

**Table 1: Total Costs and Costs Sharing for Implementation of CROW Process at Brodhead Creek Site [8]**

Source of Funds	Contractor	Construction and Operation (\$)	Decommissioning (\$)	Total (1995 \$)
DOE	WRI	314,200		314,200
GRI		20,000		20,000
PP&L	WRI	332,400		332,400
	RETEC	1,116,493	92,400	1,208,893
	Direct Payments	41,674		41,093
Total		1,824,767	92,400	1,917,167

**Table 2: Treatment Costs<sup>1</sup> [5]**

Cost Elements	Cost(\$)
Solids Preparation and Handling	
Residuals and waste handling and transporting	3,000
Startup Testing and Permits	
Permitting and regulatory	25,000
Startup	40,000
Operation	
Labor	150,000
Supplies and consumables	200,000
Utilities	40,000
Equipment repair and replacement	50,000
Engineering support	30,000
Operation (continued)	

<sup>1</sup> Costs were estimated by the vendor. Costs reflect 1995 dollar values.



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## TREATMENT SYSTEM COSTS (CONTINUED)

**Table 2 (continued): Treatment Costs<sup>1</sup> [5]**

Cost Elements	Cost(\$)
Instrumentation	25,000
Laboratory	50,000
Subcontractors	70,000
Travel and living expenses	70,000
Project management	50,000
Regulatory reporting and coordination	10,000
Miscellaneous/health and safety	10,000
Performance Evaluation	10,000
Treatment Verification	10,000
Remedial Construction	400,000
Cost of Ownership	
Capital equipment	40,000
<b>Total</b>	<b>1,283,000</b>

**Table 3: Before-Treatment Costs<sup>1</sup> [5]**

Cost Elements	Cost(\$)
Site preparation	20,000
Equipment transport to the site	10,000
Initial setup	15,000
Installing utilities	5,000
Installing decontamination facilities	2,000
<b>Total</b>	<b>52,000</b>

**Table 4: Post-Treatment Costs<sup>1</sup> [5]**

Cost Elements	Cost(\$)
Disposal of residuals and wastes	
Demobilization	80,000
<b>Total</b>	<b>80,000</b>

<sup>1</sup> Costs were estimated by the vendor. Costs reflect 1995 dollar values.



## OBSERVATIONS AND LESSONS LEARNED

### Observations and Lessons Learned

The CROW™ process achieved the cleanup goal for the site within a year. Initial results in the Spring of 1996 indicated that the cleanup goal had been met. However, EPA subsequently determined that the method used to estimate the amount of free coal tar recovered was not accurate and could not be used to demonstrate that the cleanup goal had been met. The method was modified and, based on the results of additional samples, EPA determined in June 1996 that the cleanup goal had been met.

The enhanced recovery process was to remove at least 60 percent of the free phase coal tar from the subsurface soils. However, this performance standard required an accurate determination of initial conditions of either the volume or concentration of free phase coal tar present. Several attempts were made during the remedial design to quantify the amount of free phase coal tar present or determine the concentration of free phase coal tar in the RCC and MW-2 areas. A number of piezometers were installed at the site to determine the lateral extent of the free phase coal tar. EPA learned that, although free phase coal tar was present in both the RCC and MW-2 areas, it was discontinuous (it was not present in a uniform layer at a constant elevation). Therefore, direct estimates of its volume could not be made.

Installation of wells was impeded because of the cobble-filled strata in the subsurface soils. The geology underlying the site consists of the following stratigraphic units in ascending order: bedrock; silty sands; stream gravels; flood plain deposits; and surficial fill. In that type of geology, the drilling method selected should be capable of drilling through large stones. In addition, the boreholes for the injection wells should be oversized and installed by a cased drilling method, rather than by hollow stem auger. This reduces the potential for smearing the borehole sidewall and allows for adequate gravel pack to increase the hydraulic connection

to the aquifer, thereby increasing the injection capacity of the wells.

Because of problems with iron fouling of the injection wells, the system operated at a lower injection capacity than expected. To keep the capacity as high as possible, juttering heads were installed on each well. The juttering procedure involved pouring a dilute acid solution into the well, then alternately opening and closing the valves on the juttering head as the air pressure in the well increased. This practice moved water up and down within the well, causing the release of iron particles and biomass from the well screen and gravel pack.

Several attempts were made with split spoon sampling devices to retrieve intact samples from the subsurface soils. However, because of the large size of the gravel present in the subsurface, only partial (disturbed) samples were retrieved. Those samples did not provide reliable information about the concentration of free phase coal tar actually present in the formation. EPA, therefore, determined that accurately measuring the removal of 60 percent of the free phase coal tar would not be possible, EPA then changed the performance standard through an ESD.

The original design called for the CROW process to address the free phase coal tar at the MW-2 area as well. However, because of the expected high cost of treating this area with CROW, EPA decided to allow PP&L to remove the tar by pumping which has been completed.

System failures involving the water heater, fouling of the wells, conductivity and flow within the formation and subsequent changes in the performance standard, as well as in the methods used to measure the performance of the system extended the project by approximately six months. The inability to measure performance as designed required additional time to develop a new measuring system and three additional pore volumes to verify that the performance standard was achieved.



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## REFERENCES

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2. *Explanation of Significant Differences*, EPA Region 3, July 1994.
3. *Field Sampling Plan and Groundwater Monitoring Plan*, Prepared for PP&L by, May 1994.
4. *Guide to Documenting Cost and Performance for Remediation Progress*, EPA-542-B-95-002, EPA March 1995.
5. Letter to James Villaume, PP&L Project Manager, from Mark Moeller, About Discontinuation of Operations at Brodhead Creek, February 29, 1996.
6. *Operations and Maintenance Plan*, Prepared for PP&L by, May 1994.
7. *Record of Decision*, U.S. Environmental Protection Agency (EPA) Region 3, March 1991.
8. *Remedial Action Report*, Prepared for PP&L by, August 1996.

### Preparation of the Analysis

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Tetra Tech EM, Inc. under EPA Contract No. 68-W4-0004.



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**In Situ Thermal Desorption at the  
Missouri Electric Works Superfund Site, Cape Girardeau, Missouri**

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# In Situ Thermal Desorption at the Missouri Electric Works Superfund Site, Cape Girardeau, Missouri

<b>Site Name:</b> Missouri Electric Works Superfund Site	<b>Contaminants:</b> PCBs - Detected in surface and subsurface soils at levels as high as 58,000 mg/kg - Areal extent of PCB contamination at levels greater than 10 mg/kg was estimated to be 6.8 acres	<b>Period of Operation:</b> April 21 - June 1, 1997
<b>Location:</b> Cape Girardeau, Missouri		<b>Cleanup Type:</b> Demonstration
<b>Vendor:</b> John Reed Terra Therm Environmental Services 1077 Grogan's Mill Road The Woodlands, TX 77380 (281) 296-1000	<b>Technology:</b> In situ thermal desorption - 12 heater/vacuum wells installed in a triangular pattern to a depth of 12 feet - Each well equipped with an insulated heating element; capacity to inject 350 to 700 watts/square foot at heater temperatures of 1600 to 1800°F - Small surface heating pads placed at the center of each triangle; vapor seal constructed over entire test area - Particulate cyclone, Thermatrix ES-125 flameless thermal oxidizer, and carbon canisters	<b>Cleanup Authority:</b> CERCLA - ROD date: 9/28/90 - Demonstration Test Plan approved 1/97
<b>Additional Contacts:</b> Information not provided		<b>EPA Point of Contact:</b> Remedial Project Manager Pauletta France-Isetts U.S. EPA Region 7 726 Minnesota Ave Kansas City, KS 66101 (913) 551-7701
<b>Waste Source:</b> Leaks and spills from storage of PCB waste oils	<b>Type/Quantity of Media Treated:</b> Soil - 52 cubic yards	
<b>Purpose/Significance of Application:</b> Demonstrate the performance of in situ thermal desorption to treat PCB-contaminated soil		
<b>Regulatory Requirements/Cleanup Goals:</b> Soil cleanup goal for PCBs - 2 mg/kg DRE - 99.9999%		
<b>Results:</b> - PCB concentrations in all 94 soil samples taken during the demonstration were below the 2 mg/kg cleanup goal; 83 of the samples were reported below the detection limit - Results of stack testing showed that the DRE for PCBs was 99.9999998%, meeting the goal of 99.9999%		
<b>Cost:</b> - No costs were reported for the demonstration. - The vendor used data from the demonstration to estimate that the cost for a full-scale application is between \$120 and \$200 per cubic yard for "most standard sites."		

## **In Situ Thermal Desorption at the Missouri Electric Works Superfund Site, Cape Girardeau, Missouri (continued)**

### **Description:**

From 1953 until 1992, the Missouri Electric Works Inc. (MEW) operated a 6.4 acre site, located in an industrial area in Cape Girardeau, Missouri. MEW sold, serviced, and maintained electric motors, transformers, and transformer controls at this facility. Historical operations included salvaging transformer oil and materials from old equipment; copper wire was sold and the transformer oil was filtered and reused. It was estimated that 28,000 gallons of oil were released at the site. The results of a Remedial Investigation (RI), conducted between September 1989 and March 1990, showed PCBs in the surface and subsurface soils (as high as 58,000 mg/kg in soils found on site and 2,030 mg/kg in off-site soils). The areal extent of PCB concentrations in the soil that were greater than 10 mg/kg was estimated to be 295,000 square feet (ft<sup>2</sup>) or 6.8 acres. A Record of Decision (ROD), signed in 1990, specified excavation of PCB-contaminated soil followed by incineration, and extraction and treatment of groundwater. However, the MEW PRP Steering Committee proposed in situ thermal desorption of the soil, and an Explanation of Significant Differences (ESD) was issued for this site in January 1995 which included thermal desorption as an acceptable process for treating site soils. In January 1997, EPA and MDNR accepted a Demonstration Test Plan for this technology.

TerraTherm's in situ thermal desorption (ISTD) technology was demonstrated at MEW to treat subsurface soil contamination in an area near a former PCB storage pad. The objectives of the demonstration were to clean soils to below cleanup levels and achieve a destruction and removal efficiency (DRE) of greater than 99.9999% for PCBs. Twelve heater/vacuum wells were installed in a triangular pattern, spaced 5 ft apart. A vapor seal was constructed over the entire test area to insulate and reduce heat loss, and to seal the surface of the test area against vapor emissions. The MU-125 mobile process unit used for the demonstration was equipped with a particulate cyclone, a Thermatrix ES-125 flameless thermal oxidizer, and two carbon canisters in series. Three distinct temperature phases were recorded during the heating process. During the third (superheating) phase soil temperatures rose to over 1000°F. The vendor used this data to estimate that about 50% of the total soil volume reached a temperature of over 1100°F. The results of soil samples taken after completion of the 42-day demonstration showed that the concentration of PCBs in all samples was below the 2 mg/kg cleanup goal and that PCB concentrations were below the detection limit in the majority of samples. Results of stack testing showed that the DRE for PCBs was 99.9999998%, meeting the goal of 99.9999%.

The vendor used data from the demonstration to estimate that the cost for a full-scale application is between \$120 and \$200 per cubic yard for "most standard sites." According to the RPM, the Missouri Electric Works Steering Committee has retained another experienced vendor to perform the full-scale work at the Missouri Electric Works site. The vendor submitted a lower cost proposal than TerraTherm.

# Cost and Performance Summary Report

## In Situ Thermal Desorption at the Missouri Electric Works Superfund Site Cape Girardeau, Missouri

### Summary Information [1, 2, 4, 5, 6]

From 1953 until 1992, the Missouri Electric Works Inc. (MEW) operated a 6.4 acre site, located in an industrial area in Cape Girardeau, Missouri. MEW sold, serviced, and maintained electric motors, transformers, and transformer controls at this facility. More than 16,000 transformers have been repaired or scrapped at the facility. Historical operations included salvaging transformer oil and materials from old equipment; copper wire was sold and the transformer oil was filtered and reused. During the oil recovery process, approximately 90% of the oil was recovered while the remainder was spilled or leaked onto the ground. In addition, solvents were used to clean electrical equipment, and spills and disposal of solvents are believed to have occurred at the site.

In October 1984, the Missouri Department of Natural Resources (MDNR) inspected the site and discovered a number of 55-gallon drums of waste transformer oil. It was estimated that 28,000 gallons of oil were released at the site; about 5,000 gallons of drummed waste oil were removed from the site. In November 1984, EPA conducted a Toxic Substances Control Act (TSCA) inspection of the site and noted several violations for the storage of PCB waste oils. Two soil samples taken during the inspection showed PCB concentrations of 310 milligrams per kilogram (mg/kg) and 21,000 mg/kg. Further investigations performed by EPA between October 1985 and June 1987 confirmed PCB contamination in the surface and subsurface soils, and in the drainage pathways. The results of a Remedial Investigation (RI), conducted between September 1989 and March 1990, showed PCBs in the surface and subsurface soils (as high as 58,000 mg/kg in soils found on site and 2,030 mg/kg in off-site soils). Volatile organic compounds (VOCs) were detected in the groundwater (as high as 320 milligrams per liter); no PCBs were detected in the groundwater. The RI also indicated that PCBs had migrated off site through storm water drainage areas onto surrounding properties. The areal extent of PCB concentrations in the soil that were greater than 10 mg/kg was estimated to be 295,000 square feet (ft<sup>2</sup>) or 6.8 acres.

A Record of Decision (ROD), signed in 1990, specified excavation of PCB-contaminated soil followed by incineration, and extraction and treatment of groundwater. In August 1994, a Consent Decree (CD) between EPA and the potentially responsible parties (PRPs) was approved by the federal district court to design the remedy and clean up the soil under EPA supervision. According to the RPM, a group of non-settling parties appealed the CD entry because they had not been allowed to intervene. The eighth circuit court of appeals agreed with the non-settling parties, vacated the CD entry and, after allowing the

non-settling parties to intervene, approved the CD during August 1996. Although the non-settling parties again appealed entry of the CD, the eighth circuit court upheld the district courts decision and the consent decree became effective during March 1998. The MEW PRP Steering Committee proposed in situ thermal desorption of the soil. An Explanation of Significant Differences (ESD) was issued for this site in January 1995 which included thermal desorption as an acceptable process for treating site soils. In January 1997, EPA and MDNR accepted a Demonstration Test Plan for this technology.

The objectives of the demonstration were to clean soils to below cleanup levels and achieve a destruction and removal efficiency (DRE) of greater than 99.9999% for PCBs. The demonstration was conducted at a former PCB storage pad, where PCB concentrations were reported as high as 20,000 mg/kg. Soils in the demonstration area were analyzed to determine pre-test soil PCB concentrations. PCBs were found at depths of up to 10 feet (ft) below ground surface (bgs), with the highest concentrations found at 0 to 4 ft bgs. The results are presented in Table 1.

CERCLIS ID Number: MOD980965982

Lead: EPA Region 7

### Timeline [1, 2]

October 1984 - June 1987	Site investigation performed
September 1989 - March 1990	RI performed
September 28, 1990	ROD signed
August 29, 1994 August 14, 1996 March 3, 1998	Consent Decree approved by Federal District Court
January 1995	ESD issued
January 1997	Demonstration Test Plan approved
April 21 - June 1, 1997	Demonstration performed

**Table 1 - Soil Sample Results Summary, Cape Girardeau, MO [3]**  
(see Figure 1 for locations)

Pre-Demo Soil Sampling Results							Post-Demo Soil Sampling Results											
Boring ID	Sample #	Depth (ft)	ATAS Lab Result PCB Concentration (mg/kg)	Boring ID	Sample #	Depth (ft)	AS Lab Result PCB Concentration (mg/kg)	Boring ID	Sample #	Depth (ft)	ATAS Lab Result PCB Concentration (ppm)	Boring ID	Sample #	Depth (ft)	ATAS Lab Result PCB Concentration (ppm)			
TW-1	S1-A	0.0-2.0	1590	TW-13	S1	0.2-2.2	253	PTW-1	S1	0.0-0.5	<0.033	PTW-8	S1	0.0-0.5	<0.033			
	S1-B	2.0-3.4	367		S2	2.2-4.2	2.23		S2	0.5-1.0	<0.033		S2	0.5-1.0	<0.033			
	S2-A	3.4-5.4	<0.5		S3	4.2-6.2	0.099		S3	1.0-1.5	<0.033		S3	1.0-2.0	<0.033			
	S2-B	5.4-8.1	<0.5		S4	6.2-8.2	NA		S4	1.5-2.0	<0.033		S4	2.0-4.0	<0.033			
	S5	8.2-10.0	NA		S5	8.2-10.2	<0.50		S5	2.0-2.5	<0.033		S5	4.0-6.0	0.036			
	S6	10.0-12.0	13.5*		S6	10.2-12.2	<0.50						S6					
TW-3	S1-A	0.2-2.2	2190	TW-14	S1	0.2-2.2	4100	PTW-2	S1	0.0-0.5	<0.033	PTW-9	S1	0.0-0.5	<0.033			
	S1-B	2.2-4.2	59.5		S2	2.2-4.2	1060		S2	0.5-1.0	<0.033		S2	0.5-1.0	<0.033			
	S2-A	4.2-6.2	ND		S3	4.2-6.2	276		S3	1.0-2.0	<0.033		S3	1.0-2.0	<0.033			
	S2-B	6.2-8.2	ND		S4	6.2-8.2	67.5		S4	2.0-4.0	<0.033		S4	2.0-4.0	<0.033			
	S5	8.2-10.0	6.37*		S5	8.2-10.2	3.98		S5	4.0-6.0	<0.033		S5	4.0-6.0	<0.033			
	S6	10.0-12.0	4.34*		S6	10.2-12.2	<0.50		S6	6.0-8.0	<0.033		S6	6.0-8.0	<0.033			
TW-3T	S1	0.0-0.5	614	TW-14T	S1	0.0-0.5	9210	PTW-3	S1	0.0-0.5	<0.033	PTW-10	S1	0.0-0.5	<0.033			
	S2	0.5-1.0	2970		S2	0.5-1.0	1450		S2	0.5-1.0	<0.033		S2	0.5-1.0	<0.033			
	S3	1.0-2.0	16.5		S3	1.0-2.0	984		S3	1.0-2.0	<0.033		S3	1.0-2.0	<0.033			
	S4	2.0-4.0	0.694		S4	2.0-4.0	1470		S4	2.0-4.0	<0.033		S4	1.0-2.0	<0.033			
	S5	4.0-6.0	4.42		S5	4.0-6.0	134		S5	4.0-6.0	<0.033		S5	2.0-4.0	<0.033			
	S6	6.0-8.0	2.32		S6	6.0-8.0	11.8		S6	6.0-8.0	<0.033		S6	4.0-4.0	<0.033			
	S7	8.0-10.0	0.084		S7	8.0-10.0	<0.033		S7	8.0-9.9	<0.033		S7	6.0-8.0	<0.033			
	S8	10.0-12.0	<0.033		S8	10.0-12.0	<0.033						S8	8.0-9.9	0.302			
	S9	12.0-14.0	<0.033		S9	12.0-14.0	<0.033	PTW-4	S1	0.0-0.5	<0.033	PTW-11	S1	0.0-0.5	<0.033			
	S10	14.0-16.0	<0.033		S10	14.0-16.0	<0.033		S2	0.5-1.0	<0.033		S2	0.5-1.0	<0.033			
TW-4	S1-A	0.2-2.2	3030/8030	TW-15	S1	0.2-2.2	93.8	PTW-6	S1	0.0-0.5	<0.033		TW-12	S1	0.0-0.5	<0.033		
	S1-B	2.2-4.2	NA		S2	2.2-4.2	5.3		S2	0.5-1.0	<0.033			S2	0.5-1.0	<0.033		
	S2-A	4.2-6.2	0.913		S3	4.2-6.2	NA		S3	1.0-2.0	<0.033	S3		1.0-2.0	<0.033			
	S2-B	6.2-8.2	<0.50		S4	6.2-8.2	2.03		S4	2.0-4.0	<0.033	S4		1.0-2.0	<0.033			
	S5	8.2-10.0	0.418		S5	8.2-10.2	NA		S5	4.0-6.0	<0.033	S5		2.0-4.0	<0.033			
	S6	10.0-12.0	3.63*		S6	10.2-12.2	8.35*		S6	6.0-8.0	<0.033	S6		4.0-6.0	<0.033			
TW-6	S1-A	0.2-2.2	299	TW-16	S1	0.2-2.2	61.8	PTW-7	SS DUP	1.0-2.0	<0.033	PTW-14		S1	0.0-0.5	<0.033		
	S1-B	2.2-4.2	393		S2	2.2-4.2	NA		S4	2.0-4.0	<0.033			S2	0.5-1.0	<0.033		
	S2-A	4.2-6.2	342		S3	4.2-6.2	1.14		S5	4.0-6.0	<0.033			S3	1.0-2.0	<0.033		
	S2-B	6.2-8.2	114		S4	6.2-8.2	NA		S6	6.0-8.0	<0.033			S4	2.0-4.0	<0.033		
	S3-A	8.2-10.2	<0.50		S5	8.2-10.2	3.11		S7	8.0-10.0	<0.033			S5	4.0-6.0	<0.033		
	S3-B	10.2-12.2	0.973		S6	10.0-12.0	1.22(10.2)*		S8	10.0-12.0	<0.033			S6	6.0-8.0	<0.033		
TW-6T	S1	0.0-0.5	19600	TW-17	S1	0.0-0.5	93.7		PTW-7	S1	0.0-0.5			<0.033	TW-13	S1	0.0-0.5	0.045
	S2	0.5-1.0	2190		S2	0.5-1.0	2530			S2	0.5-1.0			<0.033		S2	0.5-1.0	0.045
	S3	1.0-2.0	885		S3	1.0-2.0	<0.5			S3	1.0-2.0			<0.033		S3	1.0-2.0	0.042
	S4	2.0-4.0	234		S4	2.0-4.0	1.66			S4	2.0-4.0			<0.033		S4	2.0-4.0	<0.033
	S5	4.0-6.0	46.2		S5	4.0-6.0	<0.50			S5	4.0-6.0		<0.033	S5		4.0-6.0	<0.033	
	S6	6.0-8.0	5.33		S6	6.0-8.0	<0.033			S6	6.0-8.0		<0.033	S6		6.0-8.0	<0.033	
	S7	8.0-10.0	0.061		S7	8.0-10.0	0.146			S7	8.0-9.9		0.168	S7		8.0-9.9	<0.033	
	S8	10.0-12.0	0.158		S8	10.0-12.0	<0.033											
	S9	12.0-14.0	0.22		S9	12.0-14.0	1.27											
	S10	14.0-16.0	0.043		S10	14.0-16.0	0.395											
TW-7	S1-A	0.2-2.2	25.7	TW-18	S1	0.0-0.5	9090		NOTES:				PTW-14	S1	0.0-0.5	<0.033		
	S1-B	2.2-4.2	<0.50		S2	0.5-1.0	1690			1. NA denotes that sample analysis results are not available at this time.	S2	0.5-1.0		<0.033				
	S2-A	4.2-6.2	11.4		S3	1.0-2.0	762			2. NS indicates no sample was collected.	S3	1.0-2.0		<0.033				
	S2-B	6.2-8.2	<0.50		S4	2.0-4.0	450			3. Samples taken at locations of thermal wells, e.g. TW-1 as shown on Figure 1.	S4	1.0-2.0		<0.033				
	S3-A	8.2-10.2	<0.50							4. "T" denotes twinned geoprobe location.	S5	2.0-4.0		<0.033				
	S3-B	10.2-12.2	<0.50							5. * Split spoon sample, possible contamination from shallow cavings	S6	4.0-6.0		<0.033				
TW-10	S1-A	0.2-2.2	2.39		S5	4.0-6.0	293			S5	2.0-4.0	<0.033			S6	4.0-6.0	<0.033	
	S1-B	2.2-4.2	<0.50		S6	6.0-8.0	1.53			S6	4.0-6.0	<0.033			S7	6.0-8.0	<0.033	
	S2-A	4.2-6.2	<0.50		S7	8.0-10.0	0.421			S7	6.0-8.0	<0.033			S8	8.0-9.9	<0.033	
	S2-B	6.2-8.2	<0.50		S8	10.0-12.0	0.136											
	S5	8.2-10.0	0.475		S9	12.0-14.0	0.051											
	S6	10.0-12.0	<0.50		S10	14.0-16.0	<0.033											

This report covers the results of the in situ thermal desorption demonstration for PCB-contaminated soils conducted April 21 - June 1, 1997. A total of 52 cubic yards (yd<sup>3</sup>) of soil was treated during this demonstration.

#### Factors that Affected Cost or Performance of Treatment [1, 6]

Listed below are the key matrix characteristics for this technology and the values measured for each.

#### **Matrix Characteristics**

Parameter	Value
Soil Classification:	Brown clay with traces of silt, overlain by a thin layer of top soil
Clay Content and/or Particle Size Distribution:	2-9% sand, 68-81% silt, 17-23% clay
Moisture Content:	12-28%
pH:	5.3-8.0
Oil and Grease:	Soil soaked with oil in transformer storage areas
Bulk Density:	115-125 pcf
Lower Explosive Limit:	N/A

#### Treatment Technology Description [1]

In situ thermal desorption (ISTD) simultaneously applies heat and vacuum to soils to extract vapors which are collected and sent to a mobile processing unit for further treatment prior to release to the atmosphere. According to the vendor (TerraTherm), a typical ISTD process uses thermal blankets (modular blankets that are 8 ft x 20 ft) placed on the soil surface to treat shallow contamination and thermal wells (heater/vacuum wells) placed in the ground in triangular patterns to treat deeper contamination (>3 ft bgs). The thermal well process was demonstrated at MEW to treat subsurface soil contamination in an area near a former PCB storage pad.

Figure 1 shows the layout of the thermal heater wells used at MEW. As shown in Figure 1, twelve heater/vacuum wells were installed in a triangular pattern, spaced 5 ft apart. Each well included 12-ft long nichrome wire heating element threaded through ceramic insulation. The insulated heating element was placed within a 2.5-inch (in) diameter stainless steel pipe and sealed at both ends to create a "heater can" (to isolate the heating elements from fluids and vapors during operation). The heater can, in turn, was enclosed with a 4-in diameter stainless steel

slotted liner. Each well was completed to a depth of 12 ft in a sand-filled annulus designed to improve the inflow of vapors from the soil to the well. Heat from the thermal wells was transferred to the soil by radiation and thermal conduction. According to the vendor, thermal conduction is estimated to account for 80% of the heat transfer. Vacuum was applied to the wells to remove soil vapors from the subsurface.

To compensate for heat losses to the lower soils and the atmosphere, the thermal wells were designed such that the lower 2 ft of the well and the upper 1 ft of the well delivered more power (57% more) than the middle portion of the well. Each well had the capacity to inject 350 to 700 watts/ft<sup>2</sup> at heater temperatures of 1600 to 1800°F. Surface heating pads (18 in<sup>2</sup>) were placed at the center of each triangle to assist in treating the soils between the wells and operated at 500 watts/ft<sup>2</sup>.

A vapor seal was constructed over the entire test area to insulate and reduce heat loss, and to seal the surface of the test area against vapor emissions. A vacuum frame structure was constructed around the well area. Rectangular pieces of steel shim stock (4 ft x 20 ft) were fitted together to cover the test area and were welded to the wells at the point of penetration. A 16-in thick layer of vermiculite insulation was placed over the steel plate and covered with an impermeable silicone tarpaulin, which extended 5 ft beyond the edges of the treatment area.

To monitor temperatures during operation, fifteen thermocouple tubes were installed at locations roughly in the center of each of the 13 triangular areas between the thermal wells and at two central locations within the treatment area (see Figure 1). Each 1-in steel tube was installed to a depth of 7 ft and was sealed at the bottom.

Two pressure monitoring wells (PW-1 and PW-2), located near the center of the treatment area (see Figure 1), were used to monitor the subsurface vacuum. Each well was perforated pipe completed with 1 ft of sand at a depth of 6 ft and sealed to the surface with bentonite grout.

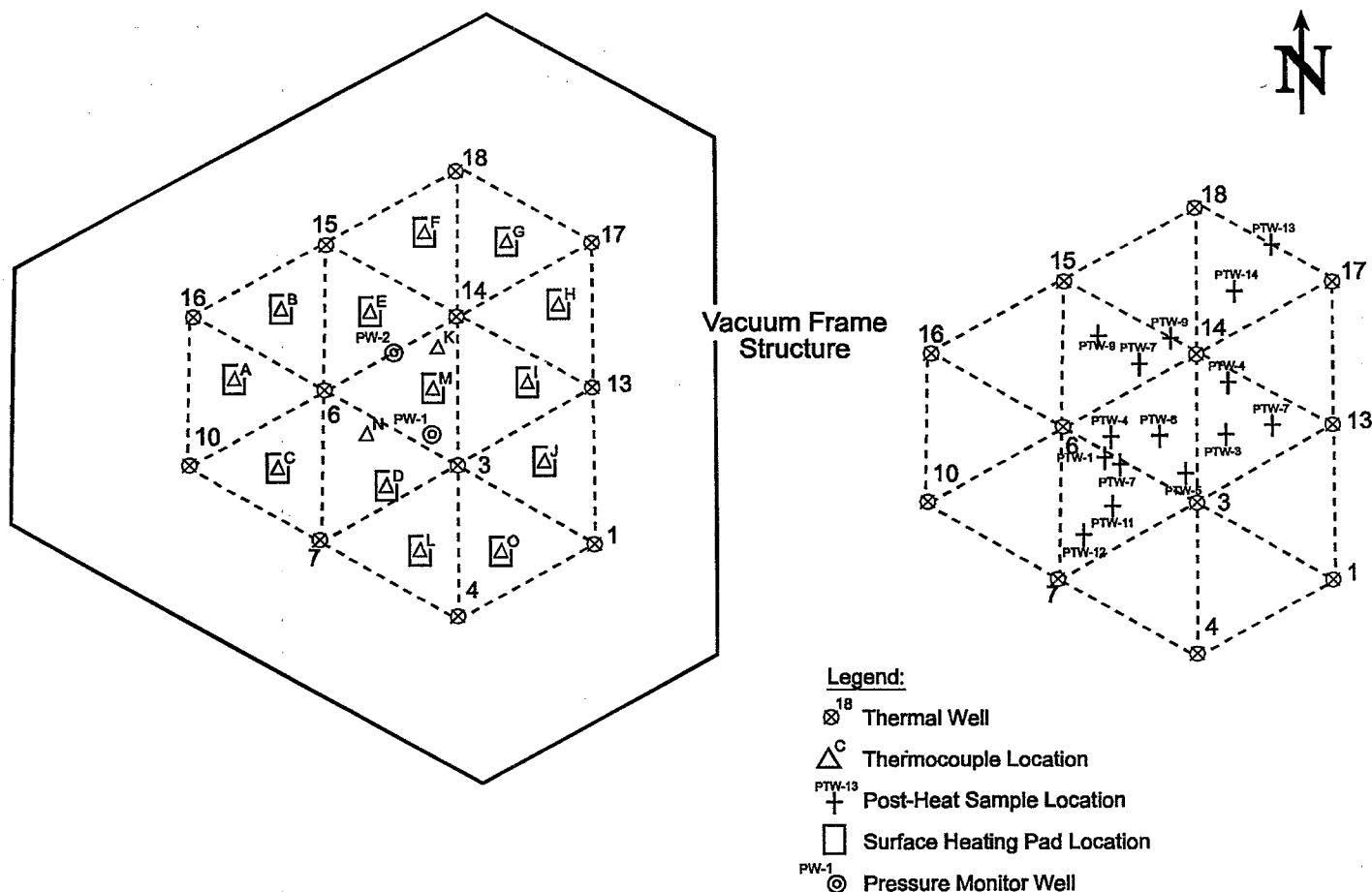
To control surface run-off, a 1-ft deep trench was dug around the perimeter of the test area and equipped with a sump pump.

The MU-125 mobile process unit was equipped with a particulate cyclone, a Thermatrix ES-125 flameless thermal oxidizer, and two carbon canisters in series. Auxiliary equipment included the control room housing, a programmable logic control system, heater controllers, and a PC-based data acquisition system.

#### Operation [1, 3]

On April 21, 1997, the well heaters were energized by increasing power to the 12 injectors over a three-hour period to an initial rate of 500 watts/ft<sup>2</sup>. Power was then increased in all injectors until the maximum operating temperature (as measured by the





**Figure 1: Left, position of thermal heater wells and thermocouples. Right, post-heat sample locations. Well spacing = 5 ft [3]**

thermocouples) reached 1600°F. Within 48 hours of the start of the demonstration, two changes in operating conditions were observed that indicated that the soil permeability had increased as a result of the heating process: 1) the vacuum at the heater wells decreased from 25 to 5 in of water; and 2) the vacuum at the pressure monitoring wells increased from 1 to 4.5 in of water. Following the increase in soil permeability, the surface heating pads were energized at 500 watts/ft<sup>2</sup>. During the 42-day demonstration period, the flow rate was maintained between 50 and 70 standard cubic feet per minute (scfm) with a well vacuum of 3 to 5 in of water.

Temperature was measured every 12 hours during the test. When the upper 1 ft of soil reached 900°F, the power to the surface heating pads was reduced to avoid excessive corrosion of the vapor seal.

Three distinct temperature phases were recorded during the heating process. During the first phase (250 hrs of operation), soil temperatures rose to the boiling point of water (212°F). During the second phase, water boiling occurred and the temperature remained near 212°F. During the third phase, also called the superheating phase (630 hours to end of operation), soil temperatures rose to over 1000°F. A soil temperature of 900°F was measured at the center of all triangles and a temperature of 1100°F was measured at the center of the treatment area (thermocouple K); the vendor used this data to estimate that about 50% of the total soil volume reached a temperature of over 1100°F.

Listed below are the key operating parameters for this technology and the values measured for each.

## Operating Parameters

Parameter	Value
Vacuum:	3-5 in of water
Air Flow:	50-70 scfm
Heating Power:	350-500 watts/ft <sup>2</sup>
Soil Temperature:	212°F to > 1100°F

## Performance Information [1, 2, 6]

The site cleanup level identified in the ROD was 2 mg/kg. Site soils contaminated with PCBs at concentrations greater than or equal to 10 mg/kg at depths from 0 to 4 feet below ground surface, and at concentrations greater than 100 mg/kg at depths greater than 4 feet below ground surface, were to be treated using thermal treatment. The PCB concentrations at which treatment was to occur was variable because the greatest risk to human health is due to direct contact. A DRE of greater than 99.9999% for PCBs was specified for stack emissions. The PCB cleanup goals represent a lifetime cancer risk of  $2 \times 10^{-5}$ .

Following the completion of the 42-day demonstration, 94 samples were collected from 13 core boring locations as shown on Figure 1 (depths of about 10 ft except in the center, PTW-6, which was 16 ft deep). Samples were analyzed for PCBs, porosity, permeability, and soil texture. The results of the PCB analyses are presented in Table 1.

As shown in Table 1, the concentration of PCBs in all samples was below the 2 mg/kg cleanup goal. PCB concentrations were below the detection limit of 0.33 mg/kg in 83 of the 94 samples. For the remaining samples, PCB concentrations ranged from 0.036 mg/kg to 0.302 mg/kg. According to the RPM, a lateral migration demonstration test was conducted adjacent to an area previously treated by thermal blankets. The test areas were overlapped 6 inches. Pre-test sampling typically indicated PCB concentrations less than 33 micrograms per kilogram; two samples indicated PCB concentrations of approximately 2 mg/kg. Post-test sampling indicated no significant increase in PCB concentrations in the area which had been non-detect prior to the test and a reduction in the PCB concentrations in those areas which had detectable concentrations prior to the test.

In addition, four composite samples were collected and analyzed for PCDD and PCDF. The "vertical" composite sample consisted of soil from 0-8 ft at the center of the treatment area. Three "areal" composite samples were collected: 0-2 ft; 2-4 ft; and 4-6 ft (from the locations of PTW-3, 4, 5, 6, 7, 8 and 10). PCDD and PCDF were not detected in analyses for the vertical composite samples. The areal composites were 0.00284 mg/kg toxic equivalent (TEQ) for 0-2 ft; 0.00684 mg/kg TEQ for 2-4 ft; and 0.0033 mg/kg TEQ for 4-6 ft.

Results of stack testing showed that the DRE for PCBs was 99.999998%, exceeding the goal of 99.9999%. According to the vendor, a total of 0.10 mg of PCB was emitted from the stack (from an estimated 40 kg of PCB in the treated area). Details of the DRE calculation are presented in Appendix A.

Porosity in post-heat soil samples was reported to have increased from approximately 30% of pore volume to 40%. The horizontal air permeability increased from  $3 \times 10^{-3}$  millidarcies (md) to 50 md; vertical air permeability increased from  $1 \times 10^{-3}$  md to 30 md. According to the vendor, reasons for increased porosity and permeability included fracturing, clay desiccation, removal of organics from the soil, and evaporation of in situ soil moisture.

Changes in soil textures also were observed. In areas exposed to temperatures of at least 1100° F, the soil solidified (siltstone) and an iron oxide coating was observed. According to the vendor, the solidification may have occurred by sintering silicate materials, particularly clay materials.

## Performance Data Quality [1, 6]

PCB soil samples were analyzed using EPA Method 8080. PCB concentrations in stack emissions were analyzed using EPA Method 680. PCDD and PCDF samples were analyzed using EPA Method 8280. Each analytical procedure was performed in compliance with applicable EPA protocols. Each data package contained chain-of-custody documents, analytical report forms, site-specific quality assurance/quality control, sample preparation chronologies and raw material data. Data validation reports reviewed each sample analysis for compliance with method-specific and project-specific QA/QC requirements in accordance with the "Functional Guidelines for Evaluating Organic Analyses", EPA 1988. Based on the review of the data packages, the analytical data were judged to be representative of site conditions at the time the samples were obtained.

## Cost Information [1, 6]

TerraTherm used the results of the demonstration to project the cost for a full-scale application. TerraTherm estimated that the cost for a full-scale application is between \$120 to \$200 per cubic yard for "most standard sites." According to the RPM, factors that could affect actual costs include the moisture content of the soil, the cost of electricity required to operate the system, and the extent and depth of the contamination which affects the number of wells required and the depth of the wells.

## Observations and Lessons Learned

In situ thermal desorption reduced PCB concentrations in soils at the MEW site from levels as high as 20,000 mg/kg to below the cleanup level of 2 mg/kg. PCB concentrations were reduced to below detection limits (0.33 mg/kg) in 83 of the 94 post-treatment samples.

The in situ thermal desorption technology achieved a PCB DRE of 99.999998%, exceeding the goal of 99.9999%.

The heating process increased both soil porosity and permeability. Soil porosity increased from 30% of pore volume to 40%; permeability increased from  $1 \times 10^{-3}$  to 30 md. According to the vendor, the mechanisms for increases in these parameters included fracturing, clay desiccation, removal of organic content, and evaporation of in situ moisture.

Requests for proposals (RFPs) for the soil remediation activities at the Missouri Electric Works Site were issued during April 1998. Terra Therm submitted a proposal for the work. However, according to the RPM, the cost associated with their proposal was not the lowest and the Missouri Electric Works Steering Committee has retained another experienced vendor whose cost proposal for the remediation effort was less to perform the work at the Missouri Electric Works site.

According to the RPM, demonstration tests should not be conducted during the winter months. In addition, the results of such tests should be viewed as the final arm of research and development. The RPM noted that full-scale applications often identify problems not considered or confronted in a laboratory or pilot-scale test.

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The following references were used in the preparation of this report.

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## APPENDIX A

## DRE CALCULATION FOR THE ISTD DEMONSTRATION AT MEW

The following was excerpted from the TerraTherm Report (Ref 1.)

**DESTRUCTION/REMOVAL EFFICIENCY**

The overall effectiveness of the ISTD remediation process can be evaluated from the destruction and removal efficiency (DRE) of the treatment system. The components used to calculate the PCB destruction and removal efficiency for the thermal well demonstration at Cape Girardeau were as follows:

1. The pre-treatment and post-treatment calculations for the mass of PCBs in soil was calculated based on the arithmetic mean of the pre-treatment soil concentration in the 0-4 ft depth range within the well array area;
2. The mass of PCBs removed was calculated by subtracting the post-treatment PCB mass (essentially zero) from the pre-treatment PCB mass;
3. The mass of PCBs emitted from the treatment process was calculated from the stack test results, including the emission rate and stack-test duration to arrive at a flow-weighted total mass;
4. PCB destruction and removal efficiency (%) for the system operation was calculated as follows:

$$DRE = \frac{PCB_{removed} - PCB_{emitted} * 100}{PCB_{removed}}$$

Where DRE is the destruction and removal efficiency percentage,  $PCB_{removed}$  is the mass of PCBs treated, and  $PCB_{emitted}$  is the mass of PCBs discharged.

**Soil Sampling & Air Monitoring Data for DRE Calculation**

Pre-treatment and post-treatment soil samples were collected to determine the quantity of PCBs extracted from the soil during Thermal Well heating and to demonstrate effective removal of PCBs from soils at a depth up to 10 ft below the original surface grade. Pre- and post-treatment soil analytical results were reported directly by the designated laboratory and are summarized in Table 1 and Figure 1. Soil concentration summaries were produced directly from the laboratory report data to illustrate PCB profiles before and after treatment.

A stack test for PCBs and breakdown products was conducted during 28 hours of system operation on May 11-12, 1997. Stack sampling for PCBs, PCDDs, and PCDFs was conducted in accordance with procedures provided in EPA Method 23. Stack sample analyses were conducted as prescribed by EPA method 23 for PCDDs/PCDFs and modified EPA Method 680 for PCB homologues.

**Thermal Well Demonstration DRE Calculation**

Maximum detected concentration in the upper 4 ft of the central triangle was 19,900 mg/kg, and the arithmetic mean was 4,600 mg/kg. All post-treatment soil samples collected in this interval were determined to contain less than 0.033 mg/kg, which is the low level detection limit reported for EPA Method 8080A by the laboratory. Therefore, the pre-treatment soil mass is the  $PCB_{removed}$ .

Based on a mean PCB concentration in the upper 4 ft of the treated area (4,600 mg/kg), a soil density of 43.2 kg/ft<sup>3</sup> (RI Report, Earth Technologies Corp, July 1990), and a conservative treated soil volume of 200 ft<sup>3</sup> (approximately 4.6 triangular patterns to a depth of 4 ft) the mass of PCBs treated was determined to be at least 40 kg.

The total PCB detected in the stack sample was 400 nanograms. The total volume of effluent passed through the XAD resin during the test was 24.5 cubic meters (m<sup>3</sup>). The flow determined by EPA Method 2C within the stack during sampling was 123 standard cubic feet per minute (SCFM). The total mass of  $PCB_{emitted}$  during the 28-hour stack test was calculated to be 0.0955 mg.

The DRE, as presented above, was calculated by subtracting 0.0000955 grams (g)  $PCB_{emitted}$  from 40,000 g  $PCB_{removed}$  divided by  $PCB_{removed}$ , and multiplied by 100% for a DRE of 99.9999998% for the thermal well demonstration at the Cape Girardeau Site.