EXECUTIVE SUMMARY

This report presents cost and performance data for a soil vapor extraction system at the Rocky Mountain Arsenal (RMA) Superfund site, Motor Pool Area, in Commerce City, Colorado. Soil vapor extraction (SVE) was conducted from July to December 1991 as an interim response action to treat soil between the ground surface and groundwater (vadose zone). The contaminants of concern at the site were halogenated organics, primarily trichloroethylene (TCE). This action was conducted in response to requirements in a Record of Decision from February 1990 and a Federal Facilities Agreement between the U.S. Environmental Protection Agency (EPA), the Army, and other parties. This action was initially considered to be a pilot study because it was expected to provide performance data on SVE at this site that could be used to expand the system. During this application, the pilot-scale SVE system removed sufficient vapor contaminants from the vadose zone, and expansion of the system beyond pilot-scale was not necessary.

The Motor Pool Area at RMA, referred to as Operable Unit 18, had been used for cleaning and servicing equipment, vehicles, and railroad cars, and for storing diesel, gasoline, and oil products in aboveground and underground storage tanks. VOCs, detected in the Motor Pool Area's soil and groundwater, have been attributed to releases of chlorinated solvents used during cleaning operations; these solvents were discharged through floor drains and pipes into unlined ditches at the site. Soil gas studies, completed within the Motor Pool Area in 1986 and 1989, identified a trichloroethylene (TCE) soil vapor plume extending north, northwest from the Motor Pool Area. A SVE system was installed in this area in the location where the highest soil vapor concentrations of TCE were measured within the vadose zone, as identified in the 1989 study. The SVE system at this site was principally designed to remediate the soil vapors identified by the soil gas studies.

The SVE system used within the Motor Pool Area consisted of one shallow vapor extraction well and one deep vapor extraction well, and an activated carbon system for treatmen of extracted vapors. Four clusters of vapor monitoring wells were installed as part of this remedial action to aid in the assessment of the performance of the SVE system. Within five months of system operation, TCE levels i soil vapors were reduced from levels as high as 65 ppm to levels less than 1 ppm. Approxi mately 70 pounds of TCE were recovered during this cleanup action. The operating parameters collected during the system's 1991 operation indicated that a clay lense located beneath the site affected the SVE system's performance by limiting both the shallow and deep vapor extraction wells' vertical zones of influence.

The total cost for procuring, installing, and operating the SVE pilot system, as well as preparing a pilot study report was $182,800 This cost was approximately 15% less than t preliminary cost estimate provided by the remediation contractor for the project.

Approximately $74,600 of the total costs were for activities directly related to treatment. This value does not include costs for disposal of carbon. The $74,600 for treatme activities corresponds to $2.20 per cubic yar of soil treated (for 34,000 cubic yards of soil) the soil treated contained relatively low level of contaminants.

Rocky Mountain Arsenal
Motor Pool Area (Operable Unit 18)
Commerce City, Colorado
CERCLIS #: C05210020769
ROD Date: 26 February 1990

Type of Action: Remedial
Treatability Study Associated with Applic tion? No
EPA SITE Program Test Associated with Application? No
Period of Operation: 7/16/91 - 12/16/91
Quantity of Material Treated During Appl cation: 34,000 cubic yards of soil. This valu is an estimated amount based on a treatmen area 70 feet in radius (approximate distance of the farthest well cluster at which an appre ciable vacuum was measured during vapor extraction) by 60 feet in depth (approximate total depth of the deep extraction well and depth to the water table).

Background

Historical Activity that Generated Contamination at the Site: Motor vehicle, railcar, and heavy equipment maintenance, repair, and cleaning activities.

Corresponding SIC Code(s):
7699—Repair Shops and Related Services, Not Elsewhere Classified

Waste Management Practice that Contributed to Contamination: Discharge to sewer

Site History: The Rocky Mountain Arsenal is a former U.S. Army chemical warfare and incendiary munitions manufacturing and assembly facility that occupies more than 17,000 acres northeast of Denver, Colorado, as shown on Figure 1. Since 1970, facility activities have primarily involved the destruction of chemical warfare materials. The Motor Pool Area, referred to as Operable Unit 18, is located within the Rocky Mountain Arsenal in the southeastern corner of Section 4, as shown on Figure 2. Since 1942, this area has been primarily used by the Rocky Mountain Arsenal for cleaning and servicing equipment, vehicles, and railroad cars, and for storing diesel, gasoline, and oil products in aboveground and underground storage tanks. [6]

From the early 1940s to at least 1985, chlorinated solvents were used during equipment cleaning activities within the Motor Pool Area's Buildings 624 and 631. [7] Halogenated volatile organic compounds, including trichloroethylene (TCE) and tetrachloroethylene, have been detected in the Motor Pool Area's soil and groundwater and the contami nation has been attributed to the use of

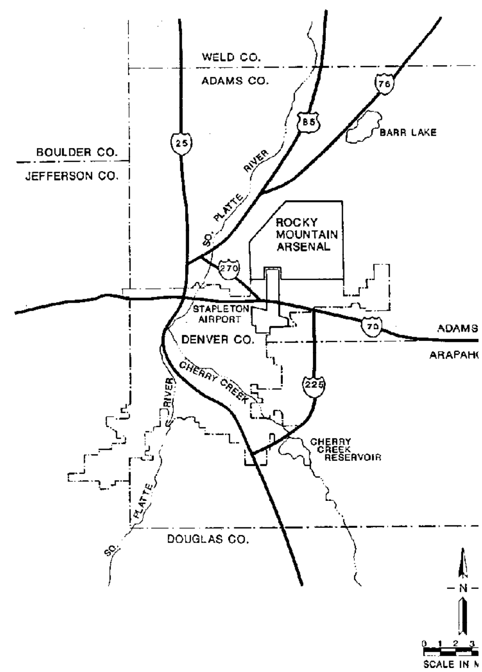

Figure 1. Rocky Mountain Arsenal Location Ma

chlorinated solvents during equipment cleaning activities within these two buildings. Chlorinated solvents, along with oil, grease, fuel, and other liquids and residues generated from maintenance operations, were discharged through floor drains and pipes into unlined ditches located between Buildings 624 and 631, and Buildings 624 and 625. Figure 2 shows the relative locations of Buildings 624, 625, and 631 within the Motor Pool Area. [6]

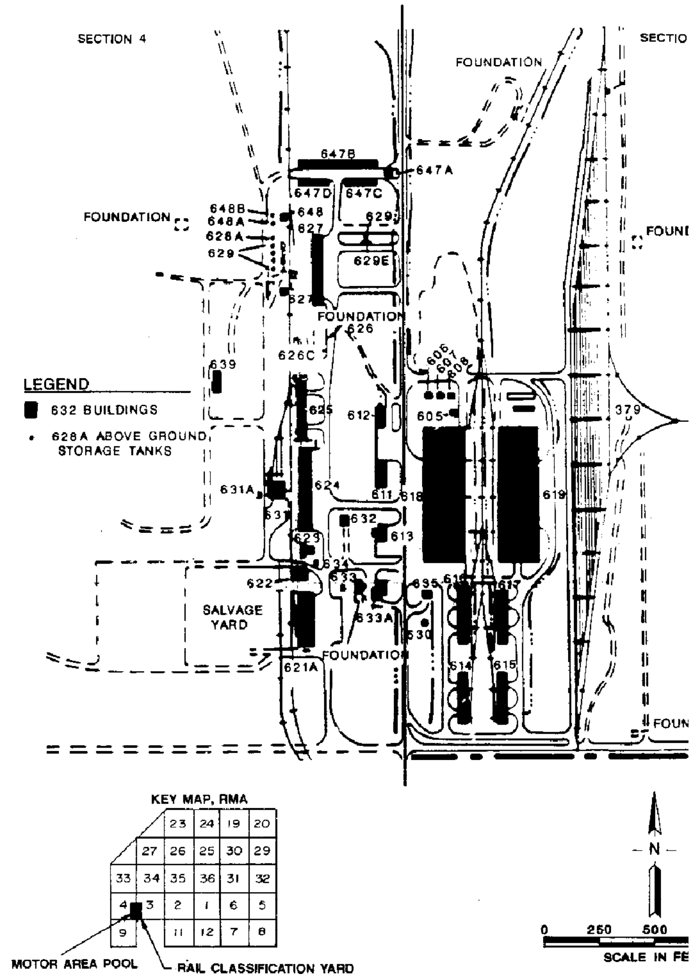

Figure 2. Motor Pool Area Pilot Study Vicinity Map [6]

Regulatory Context: Rocky Mountain Arsenal was added to the National Priorities List in July 1987. In 1988, as a result of a Consent Decree in the case of *United States v. Shell Oil Company*, a Federal Facilities Agreement was entered into between five federal agencies: EPA, the Army, the Department of the Interior, the Department of Health and Human Services, and the Department of Justice. This Federal Facility Agreement established procedures for implementing cleanup of the RMA, as specified in the Technical Program Plan. The Army and Shell Oil Company agreed to share certain costs of the remediation to be developed and performed under the oversight of EPA. The Federal Facilities Agreement specified 13 interim response actions determined to be necessary and appropriate, including the "Remediation of Other Contamination Sources," which covered the Motor Pool Area. [1 and 10]

Remedy Selection: The ROD for the Motor Pool Area was signed on February 26, 1990. Interim response action alternatives considered for the Motor Pool Area were no action, monitoring, institutional controls, capping, on-site and off-site incineration, bioremediation, thermal desorption, and soil vapor extraction.

Soil vapor extraction was selected as the interim response action for the Motor Pool Area because it was a cost effective alternative that was expected to provide an easily implemented and, if necessary, expandable method of reducing the volume of soil contaminated with volatile organic compounds, specifically the halogenated volatile organics detected in the Motor Pool Area's soil vapor. The potential benefits in the utilization of soil vapor extraction were the use of relatively simple equipment in the implementation of the technology, the application of a minimal amount of intrusive procedures such as excavation, and the generation of a small amount of contaminated materials requiring disposal. [1 and 8]

Site Management: U.S. Army - Lead

Oversight: EPA

Remedial Project Manager:
Stacey Eriksen
U.S. EPA, Region 8
One Denver Place
999 18th Street
Denver, CO 80202-2466
(303) 294-1083

Program Manager: *(Primary contact for further information on this application)*
James D. Smith
Program Manager
Rocky Mountain Arsenal
Attn: AMCPM-RME
Commerce City, CO 80022-1749
(303) 289-0249

Construction Manager/Vendor:
Rick Beyak
Woodward-Clyde Federal Services
4582 S. Ulster St., Suite 1200
Denver, CO 80237
(303) 740-2600

State Contact:
Jeff Edson
Colorado Department of Health
4300 Cherry Creek Drive South
Denver, CO 80222-1530
(303) 692-2000

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed by the Treatment System During this Application: Soil (in situ)

Contaminant Characterization

Primary contaminant groups that this technology was designed for in this treatment application: Halogenated Volatile Organic Compounds

Two soil gas studies were completed in the Motor Pool Area near Buildings 624 and 631 in 1986, and a third soil gas study was completed in this area during July of 1989. The grid sampling results from the July 1989 soil gas study are shown in Figure 3, and an iso-concentration map of those results is provided in Figure 4. Figures 3 and 4 show a TCE soil vapor plume extending north, northwest from an area north of Building 631 and west of Buildings 624 and 625. [6]

In addition to the soil gas studies, soil investigations were conducted in the Motor Pool Area, and documented in 1988. The soil investigations indicated that VOCs, including TCE, ethylbenzene, and toluene, were present in near surface soil samples at or below 4 µg/g. [6]

In October 1990, five soil borings were collected to further characterize the lateral and vertical extent of halogenated VOCs in the soil west of Buildings 624 and 625. The soil borings, shown in Figure 5, were collecte to the depth of groundwater. Soil borings were sampled at 5-foot intervals and analyzed for halogenated VOCs by Datachem laboratories using a gas chromatography analytical method with an electrolytic condu tivity detector. [2 and 6]

The results of this sampling indicated that carbon tetrachloride (CCl_4) was the only analyte detected. CCl_4 was detected in a single sample collected from the 18 to 19-foot below ground surface (BGS) interval in boring COEMPA0005, at a concentration of 0.592 µg/g. However, analysis of the duplica

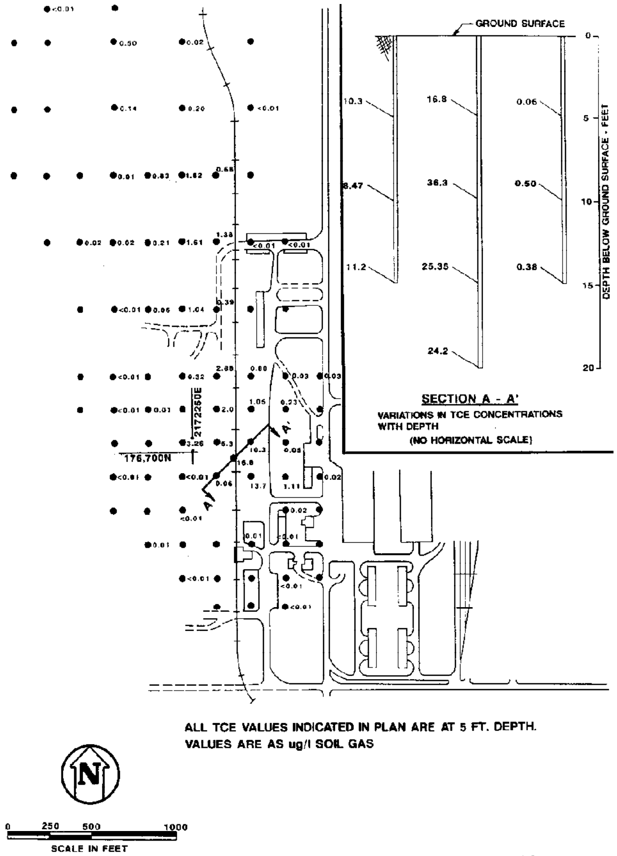

Figure 3. Motor Pool Area Pilot Study 1989 TCE Soil Gas Survey [6]

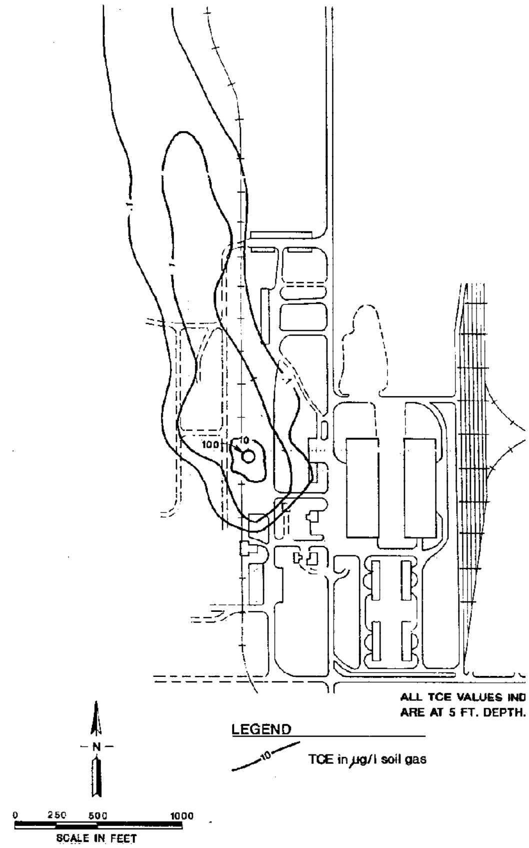

Figure 4. Motor Pool Area Pilot Study 1989 Soil Gas Survey Iso-Concentration Profil

sample collected from the 17 to 18-foot BGS interval within the same boring did not detect any halogenated VOCs. The reason for the disparity between these sampling intervals is not known. [6]

Site Geology/Stratigraphy

The unconsolidated deposits beneath the Motor Pool Area consist of discontinuous sand and gravel lenses, interbedded with silt and clay. In the area of the SVE system, a low permeability clayey sand to clay layer 1 to 3 feet thick exists between 32 and 38 feet BGS. The water table is approximately 65 feet below ground surface in the Motor Pool Area. The topography around the Motor Pool Area is generally flat with a minor slope toward the northwest. Quaternary Alluvium is the upper-most stratigraphic unit encountered in the

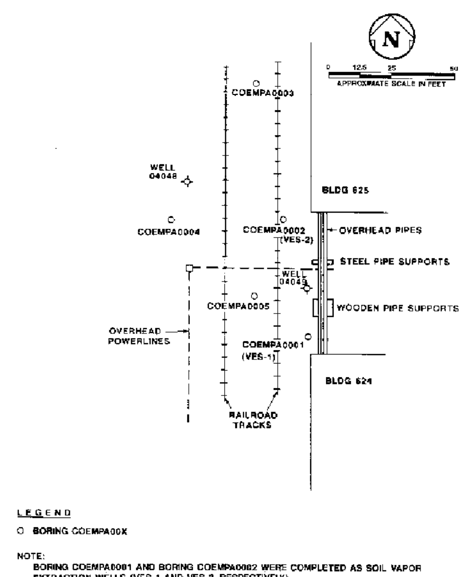

Figure 5. October 1990 Soil Boring Locations [

area. Figure 6 shows the relative locations of 5 borings and the A-A′ and B-B′ cross sections that helped to characterize the geology of the Motor Pool Area and to define the aerial extent of volatile halogenated organics in the soil west of Buildings 624 and 625. The geologic cross sections that were produced, based on the information gathered from these borings, are shown in Figures 7 and 8. Gravel and gravelly sands are present at the base of the alluvium, especially in ancient stream channels called paleochannels. [6]

The Denver Formation is the bedrock below the approximately 70 to 100 feet thick alluvium. It predominantly consists of claystone with interbedded sandstone, siltstone, and lignite beds that vary from approximately 2 to 20 feet in thickness. The bedrock surface generally slopes to the northwest, except near the northern boundary of the Motor Pool Area, where a northwest trending paleochannel with approximately 70 feet of relief exists. [6]

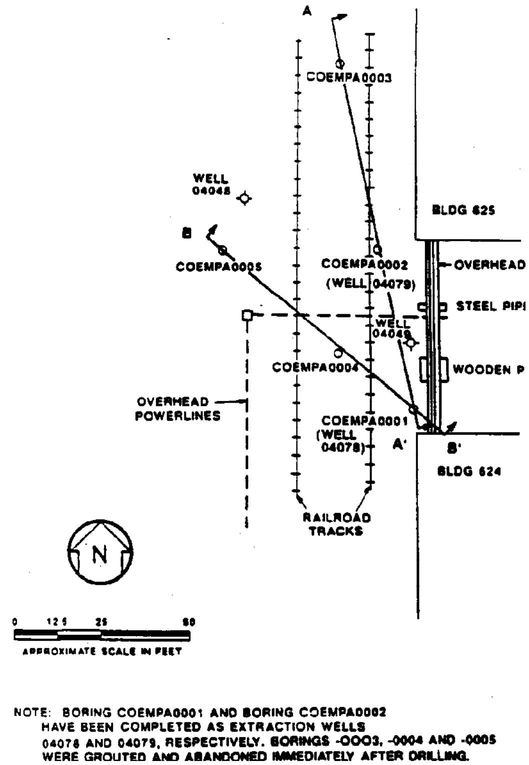

Figure 6. Motor Pool Area Pilot Study Site Pla

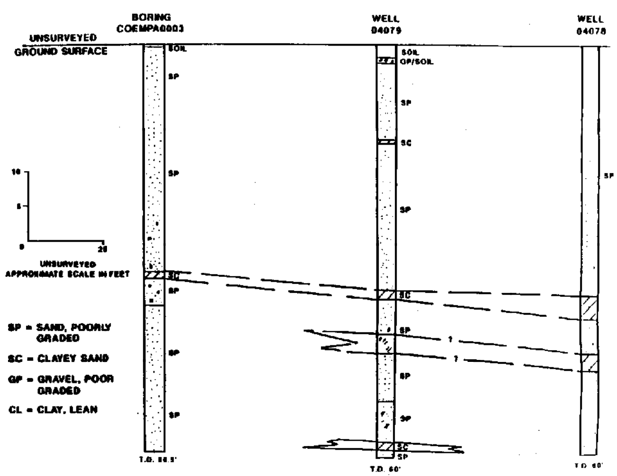

Figure 7. Motor Pool Area Pilot Study Cross Section A-A' [2]

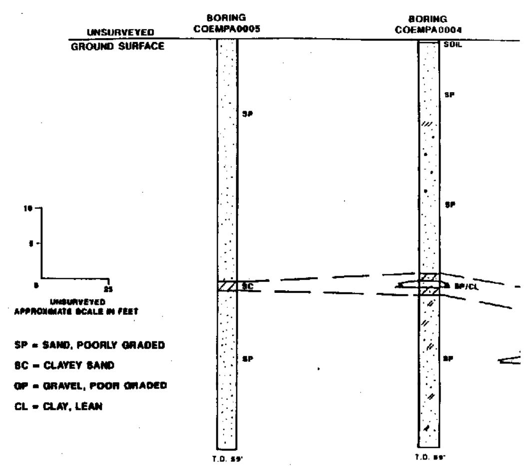

Figure 8. Motor Pool Area Study Area Cross Sectio

The major matrix characteristics affecting cost or performance for this technology are shown below in Table 1.

Table 1. Matrix Characteristics [6, 11, and 16]

Parameter	Value	Measurement Method
Soil Types (Soil classification and particle size distribution)	0 to 35 ft. below ground surface (BGS): poorly graded sand (SP), poorly graded sand with gravel (SP), and poorly graded sand with silt (SP-SM). 35.5 ft BGS: lean clay with sand (CL). 55 ft. BGS: poorly graded sand (SP).	Particle Size Analysis: ASTM Method D422-63
Moisture Content	4.7 to 30.9%	Gravimetric Analysis: ASTM Method D2216-90
Permeability	0 to ~38 ft. BGS: 167 darcys ~55 ft. BGS: 2,860 darcys	Vacuum readings were taken at five-minute intervals P-7B and VES-4 during the system start-up until stea state conditions were observed. Vacuum readings at e location were plotted against the natural log of time. slope and y-intercept of each plot were used in a Johns al., 1990, equation to predict soil permeability to air fl
Porosity	Not measured	—
Total Organic Carbon	Not measured	—
Non-Aqueous Phase Liquids	No evidence of NAPLs was found within Operable Unit 18	Not Reported

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology Type:
Soil Vapor Extraction

Supplemental Treatment Technology Type
Post-Treatment of Vapors using Carbon Adsorption

Soil Vapor Extraction System Description and Operation

As shown in Figure 9, the SVE system used in the Motor Pool Area consisted of a shallow vapor extraction well, VES-3, located above the clay layer and screened between 13 and 28 feet BGS, and a deep vapor extraction well, VES-4, located below the clay layer and screened between 43 and 58 feet BGS. The purpose of installing both shallow and deep vapor extraction wells was to provide a means for assessing the affect of the clay layer on the removal of VOCs. The extraction wells were connected by insulated PVC pipe to a liquid vapor separator tank designed to remove condensed water, a sediment filter, and a 10-horsepower regenerative blower. Exhaust air from the blower was discharged to two sets of vapor-phase granular activated carbon (GAC) canisters consisting of three canisters each. The first series of GAC canisters was designed to remove approximately 90% of the TCE from the extracted gas, while the second series was used as a polishing step to remove remainin TCE. A temporary building housed the blowe and associated equipment. [6]

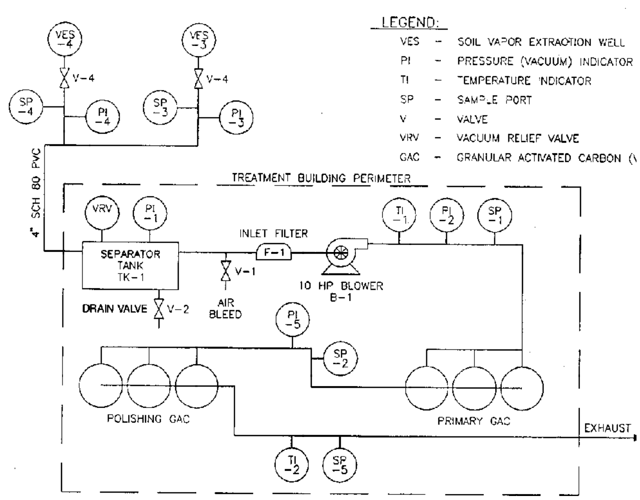

Figure 9. Soil Vapor Extraction System Process Flow Diagra

To better assess the performance of the SVE system, four clusters of soil vapor monitoring wells were installed in the Motor Pool Area. Figure 10 shows the locations of the vapor extraction wells and vapor monitoring well clusters. The vapor monitoring well clusters P-5, P-6, and P-7 were installed at the locations shown on Figure 10 based on an analysis of the results from the 1989 soil gas survey that showed a TCE vapor plume extending in a

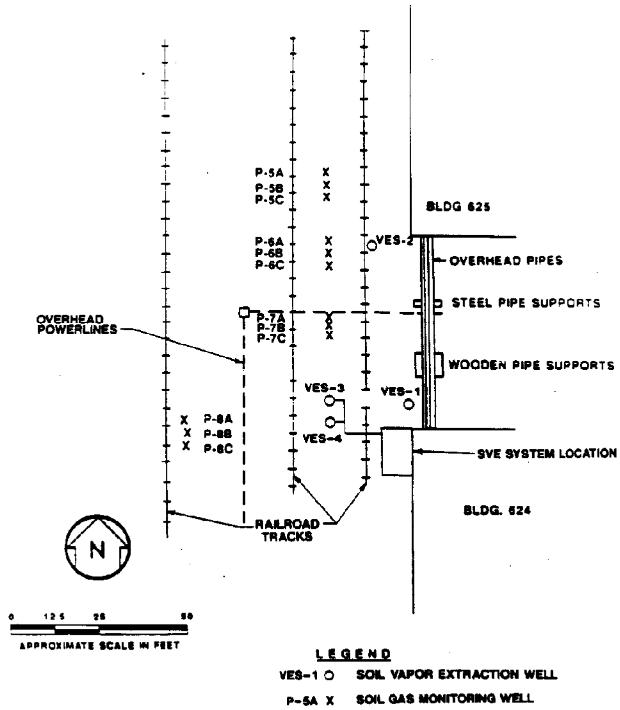

Figure 10. Motor Pool Area Pilot Study SVE Well Locations [6]

generally north to northwesterly direction from the area west of Buildings 624 and 625. Monitoring well cluster P-8 was installed to the west of the vapor extraction wells to evaluate any radial heterogeneities. Each cluster had a shallow vapor monitoring well screened between 12 and 14 feet BGS, an intermediate vapor monitoring well screened within the 30 to 38 feet BGS sandy clay to clay layer, and a deep vapor monitoring well screened between 52 and 56 feet BGS. The shallow, intermediate, and deep vapor monitoring wells shown in Figure 10 are identified by the letters A, B, and C, respectively. [6]

Vapor extraction wells VES-1 and VES-2 sho on Figure 10 were used to perform an initial air permeability test in October 1990 to determine the relationship between the soil gas flow rate and vacuum applied at well locations within the Motor Pool Area; these wells were not connected to the Motor Pool Area's soil vapor extraction system. VES-1 and VES-2 were constructed withi borings COEMPA0001 and COEMPA0002, respectively, and the dat collected from them was used during th design of the SVE system. [6]

The in situ soil vapor extraction system was operated in 1991 and again briefly i 1993. During the first four weeks of operation in 1991, referred to as the short-term operating period, vapor was extracted from VES-3 for weeks one anc two and then from VES-4 for weeks thre and four. The long-term operation begar immediately after the short-term operation period and continued for approximately four additional months. During tl first part of the long-term operation, soil gas was extracted from VES-3 for approx mately two weeks before extraction was suspended for one week, to allow time for the desorption of VOCs from the soil and VOC vapor recovery within the well. This cycle was then repeated three times The second part of the long-term operation consisted of the same extraction and recover cycle, repeated three times, for VES-4. [6]

The system was operated again in 1993 for a 48-hour period to assess the longer-term effectiveness of the treatment provided duri the system's 1991 operation. This 48-hour operating period is referred to as a verificatic program test. [5]

Listed below in Table 2 are the key operating parameters for this technology and the values measured in this application. Additional typical operating parameters and data are shown on Table 3 below.

Table 2. Operating Parameters [6]

Parameter	Value	Measurement Method
Air Flow Rate	145 to 335 cfm at blower exhaust (SP-1)	Orifice type flow meters
Operating Vacuum	0 to 30 inches of water	Magnehelic vacuum gauges

Table 3. SVE Pilot Study Summary of Typical Operating Conditions [6]

Well	Type of Vapor Well	Vacuum (in H_2O)
VES-3	Shallow Extraction	0 - 13.8
VES-4	Deep Extraction	0 - 30
P-5A	Shallow Monitoring	0 - 0.74
P-5B	Intermediate Monitoring	0 - 0.50
P-5C	Deep Monitoring	0 - 0.50
P-6A	Shallow Monitoring	0.10 - 1.2
P-6B	Intermediate Monitoring	0.4 - 1.55
P-6C	Deep Monitoring	0 - 2.05
P-7A	Shallow Monitoring	0.32 - 1.80
P-7B	Intermediate Monitoring	0.30 - 3.0
P-7C	Deep Monitoring	0.30 - 3.05
P-8A	Shallow Monitoring	0 - 1.85
P-8B	Intermediate Monitoring	0 - 2.10
P-8C	Deep Monitoring	0 - 2.30

Separator Tank Vacuum (PI-1):.....18.2 to 36.5
Separator Level Gauge:......................0
Blower Exhaust Temp. (TI-1):............123 to
Blower Exhaust Pressure (PI-2):........ 8 to 12
Blower Exhaust (SP-1):
HNu.................0 to 20 ppm
Sensidyne............0 to 15 ppm
Velocity......2,600 to 6,000 ft/min
Flow Rate.........145 to 335 cfm
GAC Exhaust Temp (TI-2)................85 to
GAC Exhaust Concentration (SP-5) (13.7 lbs/day st
emission limit):
HNu................0 to 3.7 ppm
Sensidyne.................0 ppm

Timeline

A timeline for this application is provided in Table 4.

Table 4. Timeline [5 and 6]

Start Date	End Date	Activity
1942	—	Active use of Motor Pool Area (MPA) by U.S. Army.
1986	1989	Soil gas studies conducted.
February 1990	—	Record of Decision signed.
October 1990	—	Site characterization of area west of Buildings 624 and 625 in the MPA using five soil borings.
16 July 1991	12 August 1991	Short-term SVE system operating period (4 weeks).
12 August 1991	16 December 1991	Long-term SVE system operating period (4 months).
29 September 1993	1 October 1993	Verification program testing and air monitoring of the soil vapor extraction system.

Neither the ROD [7] nor the Implementation Document [2] specified quantifiable cleanup goals for the Motor Pool Area.

Additional Information on Goals

While no cleanup goals were specified for the Motor Pool Area, chemical-specific goals, including 5 µg/L benzene, were established for groundwater treatment for the Rail Classification Yard, located adjacent to the Motor Pool Area. [2, 7]

In addition, although not a quantifiable goal, the results of the SVE pilot study were to be assessed after completion of the 1991 opera period to determine whether the TCE concen tions in the system's exhaust were low and relatively constant. The results of this asses were to be used to determine if a full-scale system would be required for soil cleanup at Motor Pool Area.

Treatment Performance Data

Performance data for the SVE system operated in 1991 include TCE concentrations in the vapor extraction and monitoring wells, and in the blower exhaust, as well as the vacuum measured in the monitoring wells. Table 5 contains a summary of the TCE concentrations determined by laboratory analysis of charcoal tube samples of vapor from the extraction and monitoring wells.

Field sampling and analysis of extraction and monitoring well vapors during the 1991 operating period was performed using TCE-indicating Sensidyne tubes and a HNu photoionization detector. Laboratory analysis of gas samples from these wells was by a modified NIOSH method utilizing a Gillan personal sampling pump and charcoal tube samples. [6]

Figures 11 through 26 show the following information:

- Figure 11—Summary of TCE Concentrations Determined by Laboratory Analysis in the Blower Exhaust.
- Figure 12—Vacuum Measured in Soil Gas Monitoring Wells (SGMW) During VES-3 Extraction.
- Figure 13—Vacuum Measured in Soil Gas Monitoring Wells (SGMW) During VES-4 Extraction.
- Figures 14 through 17—TCE Concent tions Determined by Laboratory Anal in the Shallow Monitoring Wells.
- Figures 18 through 21—TCE Concent tions Determined by Laboratory Anal in the Medium (intermediate depth) Monitoring Wells.
- Figures 22 through 25—TCE Concent tions Determined by Laboratory Anal in the Deep Monitoring Wells.
- Figure 26—Total mass of TCE extrac during the 1991 SVE system operati a function of the number of days of system operation.

Performance data for the SVE system operat 1993 include TCE and tetrachloroethylene c centrations in the vapor extraction and monit wells. Field sampling and analysis of well vap samples associated with the 48-hour test we performed with an on-site Photovac 10S70 Chromatograph. In addition, passivated S canister samples were collected and sent for site laboratory analysis. [5]

The performance data are presented in Table through 9 as follows:

- Table 6—TCE and Tetrachloroethene Concentrations Measured Onsite in Shallow, Medium, and Deep Monitor Wells Prior to the 48-Hour Test.

Table 5. SVE Pilot Study Summary of Analytical Results [6]

Sampling Date	TCE Concentrations (ppm)												
	P-5A	P-5B	P-5C	P-6A	P-6B	P-6C	P-7A	P-7B	P-7C	P-8A	P-8B	P-8C	VES-3
STS													
7/16/91	12.9	30.2	34.2	27.8	36.8	34.1	65.4	44.4	36.3	15.5	19.4	4.3	N/A
7/17/91	23.5	6.3	ND	12.2	6.5	ND	7.6	10.8	ND	2.1	2.2	0.9	51.6
7/19/91	5.3	20.0	23.4	6.5	20.1	26.5	ND	24.6	25.7	ND	11.6	11.9	16.7
7/24/91	1.0	3.1	7.5	3.1	7.3	20.2	ND	14.4	8.3	ND	4.2	ND	10.6
STD													
7/29/91	ND	2.1	ND	1.1	3.1	2.1	ND	3.1	2.1	ND	3.2	ND	N/A
7/31/91	ND	0.7	2.8	ND	1.4	ND	ND	ND	2.2	ND	2.1	2.2	N/A
8/2/91	ND	ND	0.7	ND	1.4	1.4	ND	ND	1.4	ND	2.1	ND	N/A
8/7/91	ND	ND	0.7	ND	1.4	1.5	ND	ND	1.4	ND	2.9	7.8	N/A
LTS													
8/12/91	ND	ND	2.8	ND	ND	ND	ND	ND	ND	ND	ND	2.1	3.6
8/19/91	ND	0.7	ND	ND	0.7	2.8	ND	2.1	2.1	ND	0.7	2.1	3.5
8/26/91	ND	1.1	0.4	ND	0.7	ND	ND	0.7	ND	ND	0.7	ND	2.7
8/30/91	ND	1.1	ND	ND	0.7	0.4	ND	1.1	1.1	ND	0.4	0.7	—
9/3/91	ND	0.4	0.7	ND	ND	0.4	ND	ND	3.9	ND	0.4	ND	4.3
9/9/91	ND	ND	0.4	ND	ND	0.4	ND	ND	ND	ND	ND	1.0	2.8
9/16/91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.5
9/20/91	ND	ND	ND	ND	ND	0.7	ND	ND	1.1	ND	0.4	ND	—
9/23/91	ND	0.7	0.7	ND	ND	2.0	ND	ND	ND	ND	0.3	1.0	3.6
10/1/91	ND	0.5	1.2	ND	0.7	1.4	ND	1.1	1.6	ND	0.5	ND	2.8
10/7/91	ND	0.7	0.4	ND	0.9	2.1	ND	0.7	2.3	ND	0.5	1.6	3.2
LTD													
10/11/01	ND	0.5	1.6	ND	0.7	1.2	ND	0.4	2.0	ND	ND	1.9	N/A
10/15/91	ND	0.3	0.7	ND	0.4	ND	ND	ND	ND	ND	0.4	2.1	N/A
10/21/91	ND	ND	0.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
10/28/91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4	ND	N/A
11/1/91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
11/4/91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
11/11/91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
11/18/91	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
12/2/91	ND	ND	ND	ND	ND	ND	ND	ND	1.1	ND	0.2	1.4	N/A
12/9/91	ND	ND	ND	ND	ND	ND	ND	ND	0.6	ND	0.4	0.4	N/A
12/16/91	ND	ND	ND	ND	ND	ND	ND	ND	0.2	ND	ND	0.4	N/A

— Sample not taken (recovery phase)
N D Not Detected
STS Short-term, shallow well (VES-3) extraction
STD Short-term, deep well (VES-4) extraction
LTS Long-term, shallow well (VES-3) extraction
LTD Long-term, deep well (VES-4) extraction
N/A Not Applicable

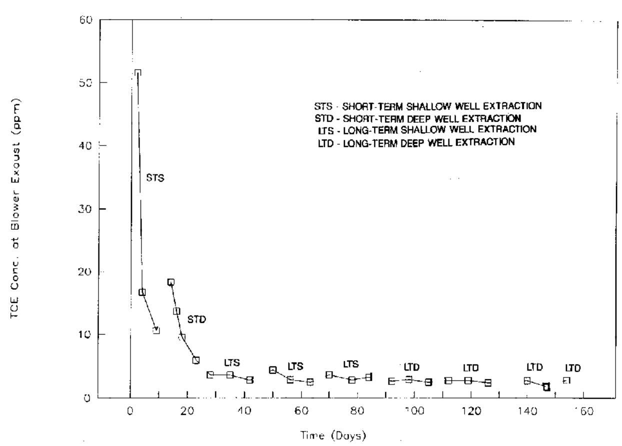

Figure 11. Summary of Long -and Short-Term Operations [6]

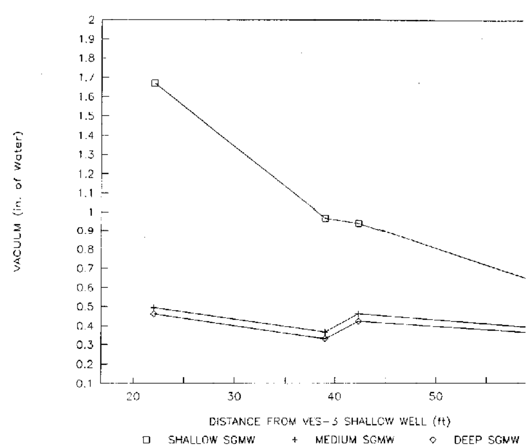

Figure 12. Shallow Extraction Well Vacuum Readi

RPF-042.PM5\0601-01.pm5

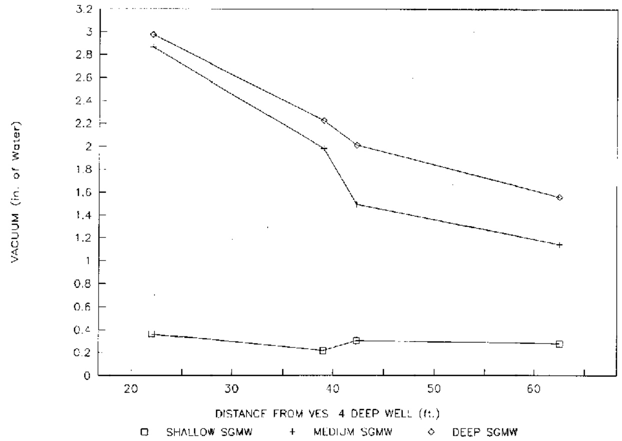

Figure 13. Deep Extraction Well Vacuum Readings [6]

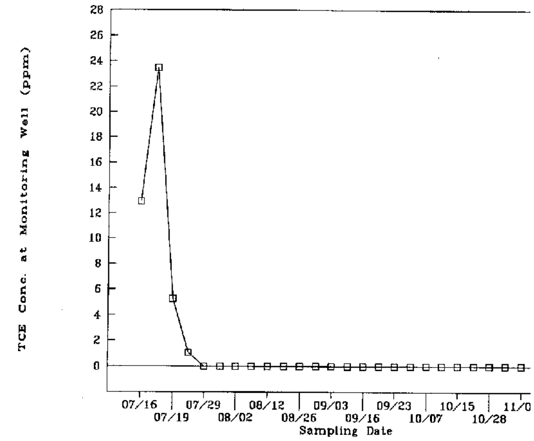

Figure 14. P-5A Shallow Monitoring Well [6]

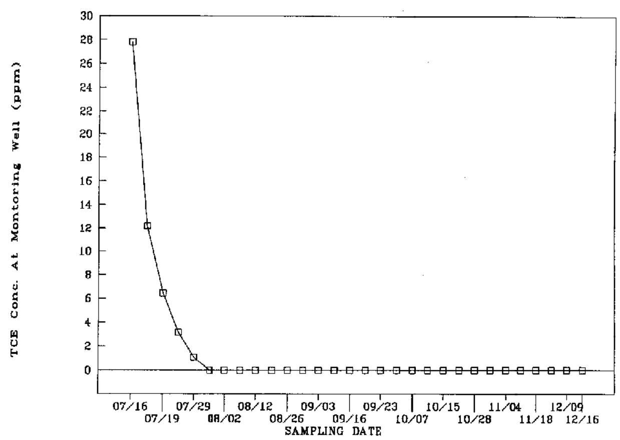

Figure 15. P-6A Shallow Monitoring Well [6]

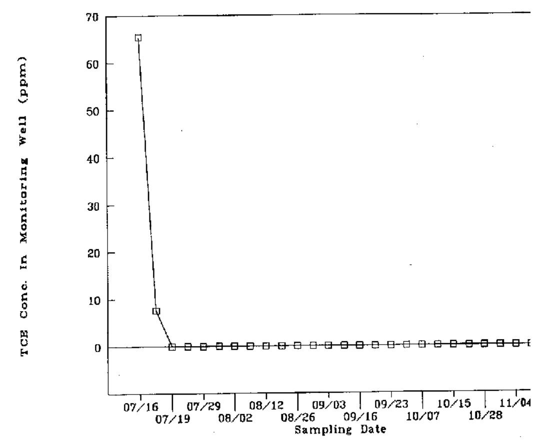

Figure 16. P-7A Shallow Monitoring Well [6]

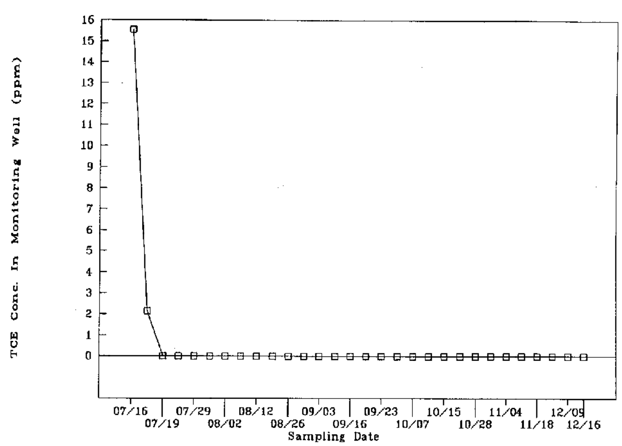

Figure 17. P-8A Shallow Monitoring Well [6]

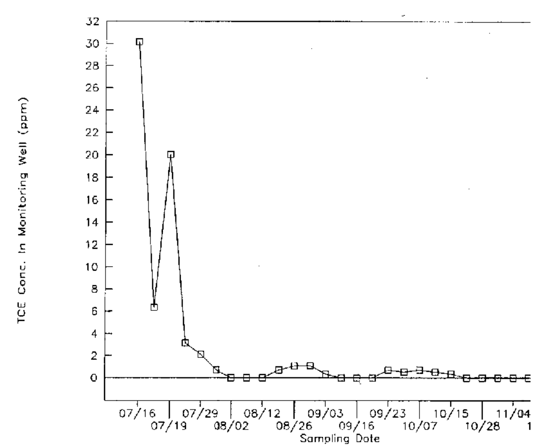

Figure 18. P-5B Medium Monitoring Well [6

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Solid Waste and Emergency Response
Technology Innovation Office

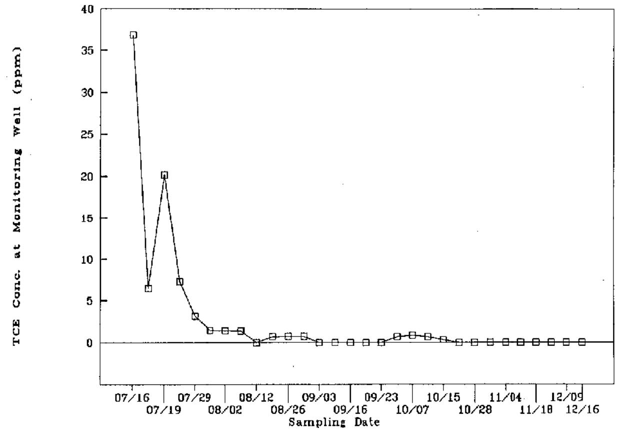

Figure 19. P-6B Medium Monitoring Well [6]

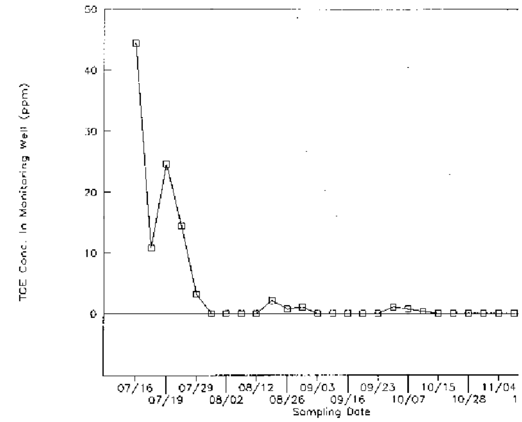

Figure 20. P-7B Medium Monitoring Well [6]

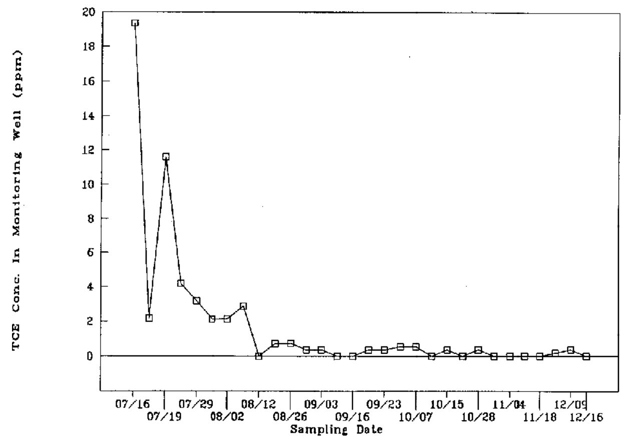

Figure 21. P-8B Medium Monitoring Well [6]

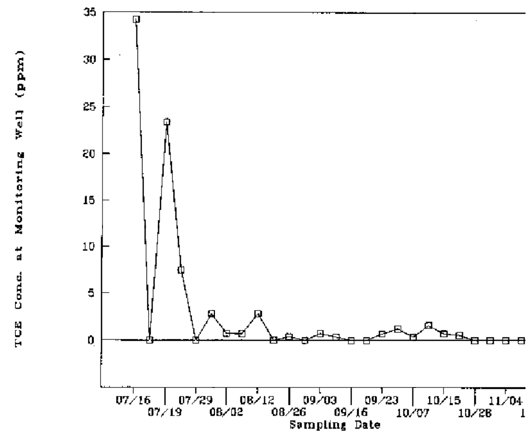

Figure 22. P-5C Deep Monitoring Well [6]

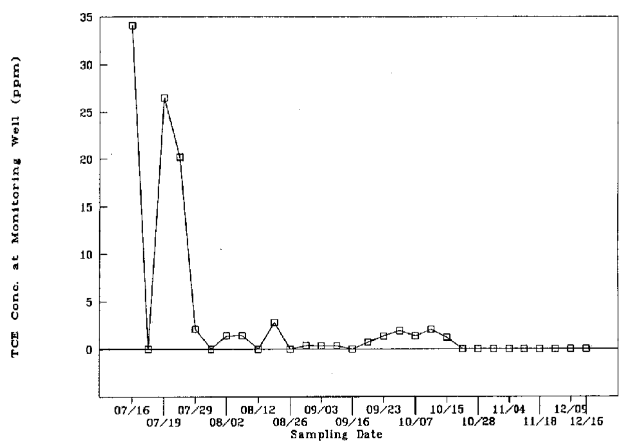

Figure 23. P-6C Deep Monitoring Well [6]

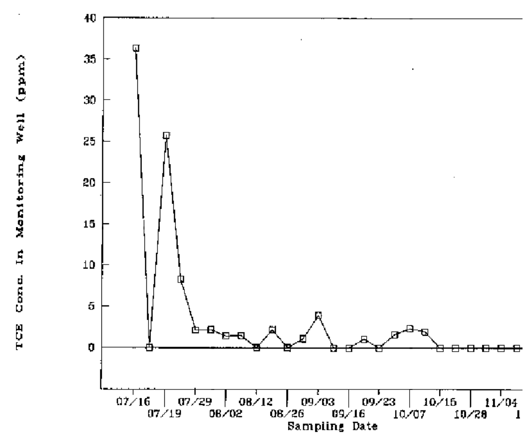

Figure 24. P-7C Deep Monitoring Well [6]

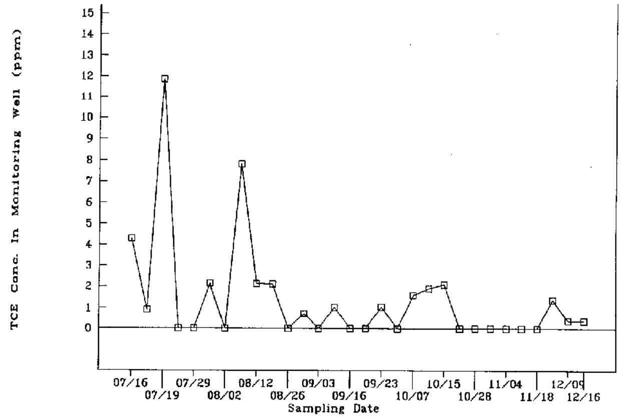

Figure 25. P-8C Deep Monitoring Well [6]

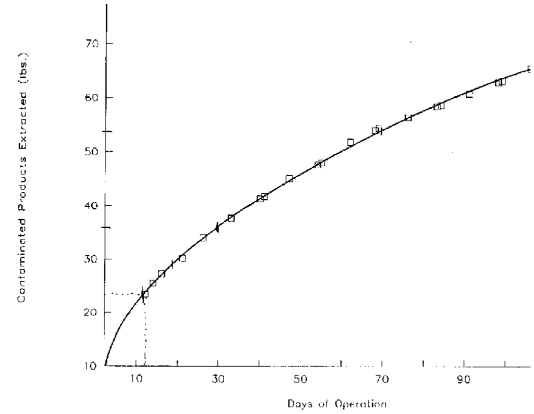

Figure 26. Total Mass TCE Extracted [6]

Table 6. Phase I On-Site GC Results for the Soil Gas Monitoring Wells [5]

Soil Gas Monitoring Well	Trichloroethen Concentration (ppm)	Tetrachloroethen Concentration (ppm)
P5-A	1.400	0.020
P5-B	0.680	<0.015
P5-C	0.600	<0.015
P6-A	3.600	0.030
P6-B	0.790	0.050
P6-C	1.300	0.020
P7-A	5.400	0.020
P7-B	0.670	<0.015
P7-C	0.390	0.060
P8-A	0.300	<0.015
P8-B	0.070	<0.015
P8-C	0.360	<0.015

NOTE: These concentrations were measured prior to the start of the 48-hour test.

- Table 7—TCE and Tetrachloroethene Concentrations Detected by Laboratory Analysis in VES-3 and VES-4.
- Table 8—TCE and Tetrachloroethene Concentrations Measured Onsite in VES-3 and VES-4.
- Table 9—TCE and Tetrachloroethene Concentrations Measured Onsite in the Shallow, Medium, and Deep Monitoring Wells After the 48-Hour Test.

Table 7. Phase II SUMMA Canister Results for the Vapor Extraction Wells During the 48-Hour Test Run [5]

Vapor Extraction Well	Time (hours into run)	Trichloroethen Concentration (ppm)	Tetrachloroethen Concentration (ppm)*
VES-3	0.5	2.410	0.005
VES-3	16	4.150	0.005
VES-3	32	4.410	<0.010
VES-3	47.5	3.940	<0.010
VES-4	0.5	0.945	0.003
VES-4	16	1.800	<0.010
VES-4	32	0.752	<0.010
VES-4	47.5	0.703	<0.010

**Detection limit varies according to required sample dilution.*

Table 8. Phase II On-Site GC Results for the Va Extraction Wells During the 48-Hour Test Run

Vapor Extraction Well	Time (hours into run)	Trichloroethen Concentration (ppm)	Tetrachl Conce (p
VES-3	0.5	4.300	<0
VES-3	4.75	1.400	<0
VES-4	0.5	2.000	<0
VES-4	47.5	0.380	<0

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Solid Waste and Emergency Response
Technology Innovation Office

Table 9. Phase III On-Site GC Results for the Soil Gas Monitoring Wells [5]

Soil Gas Monitoring Well	Trichloroethen Concentration (ppm)	Tetrachloroethen Concentration (ppm)
P5-A	0.160	<0.015
P5-B	0.180	<0.015
P5-C	0.230	<0.015
P6-A	0.230	<0.015
P6-B	0.240	<0.015
P6-C	0.090	<0.015
P7-A	0.430	<0.015
P7-B	0.760	<0.015
P7-C	0.320	<0.015
P8-A	<0.015	<0.015
P8-B	0.020	<0.015
P8-C	0.310	<0.015

TCE concentrations in the vapor extraction, vapor monitoring wells, and in the blower exhaust decreased to non-detectable or low levels during the SVE system's 1991 operation. According to the Rocky Mountain Arsenal Program Manager, the remedial action ended after completion of the 1991 operation periods because the reductions in TCE concentrations detected in the SVE system's exhaust at the end of the study remained low and relatively consistent after rapidly decreasing during the short-term operating period. As shown in Table 5, TCE concentrations in soil vapors collected from the vapor monitoring wells were reduced from concentrations measured as high as 65 ppm at the start of the system's operation to concentrations less than 1 ppm measured at the end of the operating period. The largest quantity of TCE was extracted during the short-term operation of the shallow vapor extraction well (VES-3).

The rate of extraction of TCE by the SVE system during the 1991 operation decreased over time. As shown in Figure 26, approximately 35 pounds of TCE were removed in the first 30 days of operation, compared with approximately 10 pounds of TCE removed during the last 30 days of operation. According to the vendor's project/construction manager, approximately 1,000 pounds of GAC were used to treat the exhaust air from the blower, and approximately 70% of this GAC was used during the system's operation. This estimate is based on the assumption that GAC will typically adsorb approximately 10% of its total weight in contaminants and approximately 70 pounds of TCE were extracted over the course of the system's 1991 operation. [11]

Results of the SVE system's 1993 48-hour verification program test, shown in Tables 6 and 9, indicate that TCE concentrations in th vapor monitoring wells were less than 6 ppı prior to the start of the test and decreased t less than 1 ppm after completion of the test. Soil vapor samples collected from the shallo (VES-3) and deep (VES-4) vapor extraction wells during the 48-hour test are shown in Tables 7 and 8. These results indicate the largest concentrations of TCE, up to 4.4 ppm were detected in the shallow vapor extractic well (VES-3).

The SVE system's 1991 results shown in Tabl 5 are illustrated in Figures 14 through 25. Figures 14, 15, 16, and 17 indicate that the SVE system was effective in reducing TCE concentrations within the short-term operation period to nondetect levels for all four shallow monitoring wells. Intermittent flow operation in the shallow vapor monitoring wells did not cause a rebound in the soil gas concentrations in later recovery periods. Figures 18 through 21 and 22 through 25 illustrate concentrations with respect to time in the medium and deep vapor monitoring wells. As with the shallow region, the TCE concentrations in the medium and deep vadose zones decreased to levels at or near nondetect. The small increases in TCE concentrations shown in these figures during the initial part of the long-term operating period' recovery phases is due to the reduced perme ability of the soil, and possibly deep vadose zones.

While extracting vapors from the shallow vapor extraction well (VES-3) during the 199 operating period, vacuum measured at the medium and deep soil vapor monitoring well remained relatively constant, independent of their distance from the shallow extraction well, as shown in Figure 12. A similar effect occurred during extraction from the deep vapor extraction well (VES-4). Figure 13 shows the vacuum at the shallow soil vapor monitoring wells remained relatively constant independent of their distance from the deep extraction well. These results indicate that the lower permeability of the clay layer found between 32 and 38 feet BGS in the Motor Pool Area was an effective barrier to soil vapor flow. The lower permeability of the clay layer prevented the shallow vapor extraction well from effectively influencing the deeper region, and vice versa.

The vacuum data collected during the initial portion of the treatment application indicated that capping the Motor Pool Area with an asphalt surface was not necessary since a sufficient zone of influence was created with any surface seal. For example, vapor monitor well P-5A was 62.5 feet away from the shall extraction well, and 0.6 inches of water col vacuum was measured in this well.

A review of the soil vapor data for each of th clusters of monitoring wells indicates that th performance of the SVE system was impacte the particle size distribution and permeability the geologic media. The results for the inter ate vapor monitoring wells show that the re air permeability within the clay layer may ha impeded the effectiveness of the SVE syster (compared with the results for the shallow we in terms of reaching and maintaining a nonde level for TCE. The deep wells show results si to those for the intermediate wells.

Performance Data Completeness

Performance data for TCE include results for samples of the untreated vadose zone soil and soil gas, vapor within the vapor extraction and vapor monitoring wells, and the SVE system's exhaust. Spent GAC from the SVE system was not sampled. In addition, because untreated soil samples showed no detectabl concentrations for TCE, no post-treatment so or soil gas sampling was performed. Typical operating conditions are known for the SVE system's 1991 and 1993 operating periods.

Performance Data Quality

Analytical QA/QC procedures included use of trip blanks for charcoal tube samples. No exceptions to the QA/QC protocol were identified by the vendor.

TREATMENT SYSTEM COST

Procurement Process

The U.S. Army was responsible for the site management during this treatment application and paid the associated costs. The U.S. Army retained Woodward-Clyde Consultants to manage the planning, design, implementation, operation, and reporting of the treatment application. [8] Two negotiated delivery orders were established between the U.S. Army Corps of Engineers (USACE) and Woodward-Clyde Consultants. Delivery Order 0003 covered the preparation of pre-pilot study plans, including an architectural/engineering firm (AE) Laboratory Quality Control Plan, an AE Quality Control Sampling Plan, a Site Safety and Health Plan, a Pre-Pilot Study Investigations Plan, and a Pilot Study Progra Document (Implementation Document); and covered associated field investigation activiti [12] Delivery Order 0004 covered the procur ment, installation, and operation of the pilot s vapor extraction system and preparation of a study report. [13 and 14]

The Final Implementation Document (Refere 2), developed under Delivery Order 0003, pr sented estimated total costs of $214,500 to install and operate the SVE pilot system. These treatment cost estimates were disaggregated in Reference 2 into a total capital cost estimate and a total operating cost estimate, as shown in Tables 10 and 11. Elements of the total capital cost estimate presented in Table 11 were obtained from actual costs of similar systems or from vendor quotes. [2]

The actual total costs provided by the vendor for procuring, installing, and operating the SVE pilot system, as well as preparing the pilot study report are shown in Table 12.

In order to standardize reporting of costs across projects, costs provided by the vendor were categorized according to the format for an interagency Work Breakdown Structure (WBS), as shown in Table 13. The WBS specifies 9 before-treatment cost elements, after-treatment cost elements, and 12 cost elements that provide a detailed breakdown of costs directly associated with treatment. Table 13 presents the cost elements exactly they appear in the WBS, along with the specific activities, and unit cost and number (units of the activity (where appropriate). As shown on Table 13, RMA incurred SVE install tion and operation costs of $74,600, which corresponds to $1,100 per pound of contam

Table 10. Estimated Total Capital Cost [2]

Mobilization/Demobilization		$600
Wellhead Installation (VES-3 and VES-4)		6,800
Monitoring Well Installation (3 wells)		12,000
Mechanical Installation		27,700
Blower	$5,500	
Activated Carbon	14,000	
Inlet Separator	500	
Instrumentation	2,200	
Piping & Valving	1,300	
Insulation	200	
Installation	4,000	
Electrical Installation		2,900
NEMA 1 Motor Starter	650	
Cable THW #10 AWG	100	
Conduit ¾-inch RGS	150	
Installation	2,000	
Shed		7,000
	Subtotal	$57,000
	25% Contingency (approx.)	14,300
		$71,300
	15% Contractor OH&P (approx.)	10,700
	TOTAL ESTIMATED COST	**$82,000**

Table 11. Estimated Total Operating Cost [2]

Electrical Power 50,000 KWH @ $0.07/KWH	$3,500
Carbon Changeout 2,000 lbs @ $2.50/lb	5,000
Chemical Analysis 272 samples @ $120/sample	32,600
Technician 520 hours @ $50/hr	26,000
Field Sampling Equipment and Supplies	12,100
Miscellaneous Equipment and Supplies	1,000
Data Analysis and Report Preparation	35,000
Subtotal	$115,200
15% Contingency (approx.)	17,300
TOTAL ESTIMATED COST	**$132,500**

Table 12. Actual Total Treatment Cost as Provided by the Vendor [15]

Activity	Cost (dollars)
Well and Monitor Probe Installation	35,753
Soil Vapor Extraction System Installation	39,450
Soil Vapor Extraction System Operation	65,368
Pilot Study Report Preparation	19,647
Project Management	22,587
Total for Delivery Order 0004	182,805

Table 13. Actual Total Treatment Cost—Intera Breakdown Structure [15]

Cost Element	Cost
Mobilization and Preparatory Work - AE project management and mobilization (lump sum)	23
Monitoring, Sampling, Testing, and Analysis - Monitoring wells (probes) and associated piping (3 @ $5,958)	17
Laboratory Analytical Costs (lump sum)	29
Air Pollution/Gas Collection and Control - vapor wells and associated piping (2 @ $8,938)	17
Soil Vapor Extraction - installation and operating costs, including GAC treatment (excludes laboratory analytical costs) (lump sum)	74
Other - pilot study report (lump sum)	19
Total Contract Award Amounts Reported by the Vendor	182

nant removed (70 pounds removed) and $2.20 per cubic yard of soil treated. The number of cubic yards of soil treated at Rocky Mountain Arsenal is an estimate based on the radius of influence of the extraction wells; the actual amount of soil treated is not available at this time for comparison with the estimate.

The treatment costs shown in Table 13 are based on contract award amounts reported by the vendor. [15] As Tables 12 and 13 illustrate, individual cost elements may be presented in different ways. (The difference in actual total treatment costs presented in Tables 12 and 13 is attributed to rounding.)

The actual total treatment cost of $182,800 for procuring, installing, and operating the SVE pilot system, as well as preparing a pilot study report was approximately 15% less than the $214,500 total of the capital and operating cost estimates provided by the vendor, as shown in Tables 10 and 11. Factors that contributed to the actual total cost being lower than the estimated total cost include: 1 the contractor's mobilization and demobiliza tion costs were less than originally anticipate because the contractor was concurrently engaged in other projects at the RMA; 2) the shed's actual cost was less than the estimat cost; 3) electrical power costs were paid by RMA and not the contractor, as was assume in the original estimate; and 4) GAC changeout was not required during the system's operation, as was assumed in the original estimate. (GAC used in this application is currently located at the RMA.)

Cost Data Quality

Cost data represent actual contract award costs incurred for this project and thus accurately portray the costs for this treatment application.

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- The actual total treatment cost for procuring, installing, and operating the SVE pilot system, as well as preparing the pilot study report was $182,800. This was approximately 15% less than the preliminary cost estimate provided by the remediation contractor. Factors contributing to the actual cost being lower than the estimated cost included lower construction and system operating costs.
- The Rocky Mountain Arsenal Program Manager identified the possible elimination of the GAC treatment of exhaust vapors as a method of potentially reducing costs of soil vapor extraction in future applications. This avenue was not pursued for this project because of regulatory considerations.
- Approximately $74,600 of the total costs were for activities directly related to treatment. This value doe not include costs for disposal of carbon. The $74,600 for treatment activities corresponds to $2.20 per cubic yard of soil treated (for 34,00 cubic yards of soil); the soil treated contained relatively low levels of contaminants.

- TCE levels in the soil vapor at this site were reduced within 5 months of system operation from levels up to 65 ppm to levels of less than 1 ppm.
- Approximately 70 pounds of TCE were recovered during this cleanup action.
- The clay layer inhibited the downward movement of TCE through the vadose zone. The majority of the TCE, approximately 66%, was extracted during operation of the shallow vapo extraction well.
- The results of the pilot study indicat that TCE concentrations in the SVE system's exhaust at the end of the 1991 operating period were low an relatively constant, and a full-scale system was not required for the Motor Pool Area.

Other Observations and Lessons Learned

- This treatment application was completed based solely on soil vapor data collected from soil gas surveys and the SVE system's extraction and monitoring wells.
- Because VOCs were not detected during soil sampling, soil gas surveys were used to delineate the TCE source areas and plume location.
- In lieu of soil data, soil gas and soil permeability studies provided data on the vadose zone parameters at this site. The data provided by the permeability studies was necessary for the SVE system design and contributed to the successful treatment application at this site.
- A 48-hour test completed two years after the treatment application was used to assess the longer-term effectiveness of the SVE system. The 48-hour test indicated little rebound TCE concentrations, with TCE levels measuring <6 ppm in vapor monitoring wells at the start of the 48-hour test, and decreasing to <1 ppm at t end of the 48-hour test.
- According to the Rocky Mountain Arsenal Program Manager, groundwater concentrations of TCE have dropped steadily since completion o the pilot study.

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Solid Waste and Emergency Response
Technology Innovation Office

Response Action at the Motor Pool Area, Version 4.0. Woodward-Clyde Consultants, RIC 900072R04, February 1990.

2. *Implementation Document for the Interim Response Action at the Motor Pool Area, Final Version 3.1.* Woodward-Clyde Consultants, RIC 91052R01, February 1991.

3. *Innovative Treatment Technologies: Annual Status Report, 5th edition.* U.S. Environmental Protection Agency, September 1993.

4. Letter from James D. Smith, Rocky Mountain Arsenal, to Radian Corporation. March 1994.

5. *1993 Motor Pool Area IRA Verification Program Results.* Ebasco Services Incorporated, 1993.

6. *Soil Vapor Extraction Pilot Study Report Version 3.1, Motor Pool Area, Rocky Mountain Arsenal.* Woodward-Clyde Consultants, March 1992.

7. *Superfund Record of Decision: Rocky Mountain Arsenal, (Operable Unit 18), CO, Third Remedial Action.* U.S. Environmental Protection Agency, EPA/ROD/RO8-901038, February 1990.

8. Personal communication, James D. Smith, Rocky Mountain Arsenal. March 29, 1994.

Rocky Mountain Arsenal. April 26, 1994.

10. *Rocky Mountain Arsenal, CO.* NPL Publications Assistance Database, U.S. Environmental Protection Agency, Region 8, EPA ID #C05210020769, March 1992.

11. Personal communication, Richard A. Beyak, Woodward-Clyde Federal Services. November 2, 1994.

12. Letter from Woodward-Clyde Consultants to U.S. Army Corps of Engineers, Omaha District. September 1990.

13. Letter from Woodward-Clyde Consultants to U.S. Army Corps of Engineers, Omaha District. May 1991.

14. Personal communication, John Quander, U.S. Environmental Protection Agency, and Scott Thompson, U.S. Army Corps of Engineers, Kansas City District. October 26, 1994.

15. Cost information for soil vapor extraction at the Motor Pool Area (OU-18), Rocky Mountain Arsenal. U.S. Army Corps of Engineers, Kansas City District. July 1994.

16. Letter from Woodward-Clyde Consultants to U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office. July 1994.

Analysis Preparation

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 Radian Corporation under EPA Contract No. 68-W3-0001.

COST AND PERFORMANCE REPOR

Soil Vapor Extracti
at t
Rocky Mountain Arsenal Superfund Si
Motor Pool Area (OU-18
Commerce City, Colora

Prepared By:

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

March 19

Notice

Preparation of this report has been funded wholly or in part by the U.S. Environmental Protection Agency under Contract Number 68-W3-0001. It has been subject to administrative review by EPA headquarters and Rocky Mountain Arsenal staff and by the technology vendor. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Solid Waste and Emergency Response
Technology Innovation Office