

COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for a soil vapor extraction (SVE) system at the Sand Creek Superfund site, Operable Unit (O.U.) 1, in Commerce City, Colorado. The SVE system was used at the Sand Creek O.U. 1 site to treat soil contaminated with halogenated volatile organic compounds (VOCs), specifically chloroform, methylene chloride, trichloroethene (TCE), and tetrachloroethene (PCE), and nonhalogenated VOCs, including mixed petroleum hydrocarbons.

The Sand Creek O.U. 1 site was the location of pesticide manufacturing companies in the 1960s and 1970s, and prior to that, by a petroleum refinery. The pesticide manufacturing companies had two fires in the period from 1968-1977, and were reported to have unsatisfactory waste management practices. Remedial investigations conducted from 1984 to 1988 showed three subareas of soil contamination at Sand Creek O.U. 1 (referred to as Subareas 1,2, and 3), with the following maximum soil concentrations of halogenated VOCs: chloroform - 0.820 mg/kg, methylene chloride - 5.8 mg/kg, TCE - 0.087 mg/kg, and PCE - 9.34 mg/kg. Based on these concentrations, EPA estimated the total mass of the four target contaminants in the operable unit as 684 pounds. No information was provided in the available references on the concentrations or mass of nonhalogenated VOCs in the three subareas.

A Record of Decision (ROD) addressing Sand Creek O.U. 1 was signed in September 1989 and an Explanation of Significant Differences (ESD) modifying the 1989 ROD was issued in September 1993. The modified ROD specified soil cleanup standards for the four target VOCs as follows: chloroform - 0.165 mg/kg, methylene chloride - 0.075 mg/kg, TCE - 0.285 mg/kg, and PCE - 1.095 mg/kg. No soil cleanup standards were identified for the nonhalogenated VOCs.

The SVE system used in this application was a patented fluid injection/vapor extraction (FIVE) system. In the FIVE technology, pressurized air is injected into vadose zone soils to produce relatively larger subsurface pressure gradients and higher flow rates of extracted vapors than would be achieved solely with using vapor extraction technology. The FIVE system used at Sand Creek O.U. 1 consisted of 32 extraction/injection wells (31 vertical, 1 horizontal), three positive displacement blowers (for extraction), one liquid/vapor separator, one catalytic oxidizer, and two blowers (for injection). The wells were screened up to 32.5 feet below ground surface.

The FIVE system was operated from September to December 1993, and again from January to April 1994, for a total of approximately six months of run time. Confirmatory soil borings collected in April 1994 showed that the concentrations for all four target contaminants were less than the cleanup standards set in the ROD. The maximum concentration of target contaminants measured in the confirmation soil borings was: chloroform - 0.0099 mg/kg, methylene chloride - not detected, TCE - 0.10 mg/kg, and PCE - 0.28 mg/kg. Approximately 176,500 pounds of total VOCs were extracted during this application, including 3,250 pounds of the four target contaminants. The 3,250 pound value was roughly 4.75 times greater than the original estimated mass of target contaminants (685 pounds). An air emissions operating permit was not obtained for this application, however, air emissions were regulated

EXECUTIVE SUMMARY (CONT.)

under an Air Pollution Emission Notice issued by the Colorado Department of Health. Approximately 6,200 pounds of total VOCs were released to the atmosphere through stack emissions.

The total actual costs for this application were approximately \$2,140,000. Of this total, about \$82,000 were expended in before-treatment costs, such as for mobilization and preparatory work, confirmatory sampling, and QA/QC laboratory analyses, and \$2,058,000 were expended for activities directly attributed to treatment, such as subcontractor costs, project management/administrative, SVE remedial work, and cost of ownership. The costs directly attributed to treatment correspond to \$39-65 per cubic yard of soil treated (based on a range of soil quantity treated estimates of 31,440 to 52,920 cubic yards, as provided by the vendor) and \$11.70 per pound of VOC removed (based on 176,500 pounds).

SITE INFORMATION**Identifying Information:**

Sand Creek Industrial Superfund site
 Operable Unit No. 1
 Commerce City, Colorado
CERCLIS # COD980717953
Action Memorandum Date: September 29, 1989

Treatment Application:

Type of Action: Remedial

Treatability Study Associated with Application? Remedial

(see discussion under remedy selection)

EPA SITE Program Test Associated with Application? Remedial

Period of Operation: September 24, 1993 to April 27, 1994

Quantity of Material Treated During Application: There are varying estimates of the quantity of soil treated during this application. These differences are attributed to the different methods used to estimate soil volume for an in-situ application. The following estimates are based on input from the vendor and have been reviewed by the RPM.

The treatment vendor (OHM) provided estimates for quantity of material treated based on (1) the mean (average) groundwater depth and (2) the mean smear zone screen length, as shown below for the three SVE system areas. (Smear zone is the area immediately above the groundwater table, which, in this application, was the area from the top of the well screens to the water table, and which was contaminated by hydrocarbons.) The vendor identified the areal extent of the three SVE areas based on information in their solicitation and used average groundwater depth and smear zone lengths to calculate soil quantity treated. [14]

Treatment Vendor Estimate of Soil Quantity Treated-Mean Depth to Groundwater [14]

SVE Area	Area (ft ²)	Mean (Average) Groundwater Depth (ft)	Volume (ft ³)	Volume (yd ³)
1	29,300	12.4	363,320	13,456
2	30,872	27.2	839,718	31,100
3	7,238	31.2	225,826	8,364
Total (based on mean groundwater depth)				52,920

SITE INFORMATION (Cont.)**Treatment Application (cont.):****Treatment Vendor Estimate of Soil Quantity Treated-Mean Smear Zone Screen Length [14, 16]**

SVE Area	Area (ft ²)	Mean Smear Zone Screen Length (ft)	Volume (ft ³)	Volume (yd ³)
1	29,300	8.1	237,330	8,790
2	30,872	17.7	546,434	20,238
3	7,238	9	65,142	2,412
Total (based on mean smear zone)				31,440

According to the vendor, the estimate based on groundwater depth (52,920 yds³) assumes that all soil in the three SVE areas was contaminated, including the clean backfill in Area 2, while the estimate based on smear zone (31,440 yds³) is a “conservatively low estimate”. [14]

Background

Historical Activity that Contributed to Contamination at the Site: Pesticide Manufacturing, Petroleum Refinery

Corresponding SIC Code: 2879 (Pesticides and Agricultural Chemicals, NEC), 2911 (Petroleum Refining)

Waste Management Practice that Contributed to Contamination: Manufacturing Process

Site History: The Sand Creek Industrial Superfund site (Sand Creek) covers approximately 550 acres and is located in Commerce City, Adams County, Colorado, as shown in Figure 1. O.U. 1, which covers approximately 13 acres of the Sand Creek site, was used by Times Chemical for pesticide manufacturing and petroleum refining from 1960 to 1968. Prior to Times Chemical, the land was used by the Oriental Refinery; no additional information is provided in the available references on Oriental Refinery's operations. Around 1968, Times Chemical changed its name to Colorado International Company (CIC). In 1968, a fire destroyed three buildings at the CIC facility. An inspection of CIC by Tri-County District Health Department personnel in June 1974 indicated unsatisfactory waste management practices and unsatisfactory worker safety conditions. [1, 2, 14, 15]

SITE INFORMATION (CONT.)**Background (cont.)**

In March 1976, the Colorado Department of Health (CDH) conducted a field inspection at CIC. The inspectors observed 55-gallon drums containing pesticides, including parathion, stored in various locations at the CIC facility. In addition, they observed washwater, storm drainage, and boiler feed water draining into a common surface drainage that flowed off property towards Sand Creek. A second fire occurred at CIC in December 1977, releasing parathion fumes over northeast Denver. The state of Colorado issued an Emergency Cease and Desist Order in 1978 against CIC to clean up the property and adjacent areas contaminated by the fire.

CIC declared bankruptcy and re-opened the operations as Colorado Organic Chemical Company (COC). COC operations were essentially the same as CIC operations. [1]

Soil sampling at COC in early 1978 revealed elevated levels of halogenated organic compounds, such as organophosphate pesticides and thermally-altered pesticides, and volatile organic compounds (VOCs). In 1980, COC was cited for unsafe drum storage and improper storage areas. In 1982, a consent agreement and final order were issued for RCRA violations. In March 1983, EPA deferred to the Department of Justice the matter of COC's RCRA violations and violation of the consent agreement. In June 1983, a spill of the herbicide 2,4-dichlorophenoxy acetic acid (2,4-D) resulted in an additional compliance order to clean up the spill and to comply with previous orders. EPA issued a CERCLA 106 order in March 1984 for cleanup of the site. Between April and September 1984, COC removed drummed wastes, product, and contaminated soil from the site and fenced the site. [1]

Initial remedial actions at the site, which were conducted primarily in 1992, involved excavation and incineration of contaminated soils, tank wastes, and pesticides. Approximately 40,000 pounds of material, consisting of several drums of toxaphene and pentachlorophenol and soil contaminated with 2,4-D, were excavated and incinerated off site. Four buildings and four railcars were demolished, and several storage tanks and other debris were removed from the site. [2]

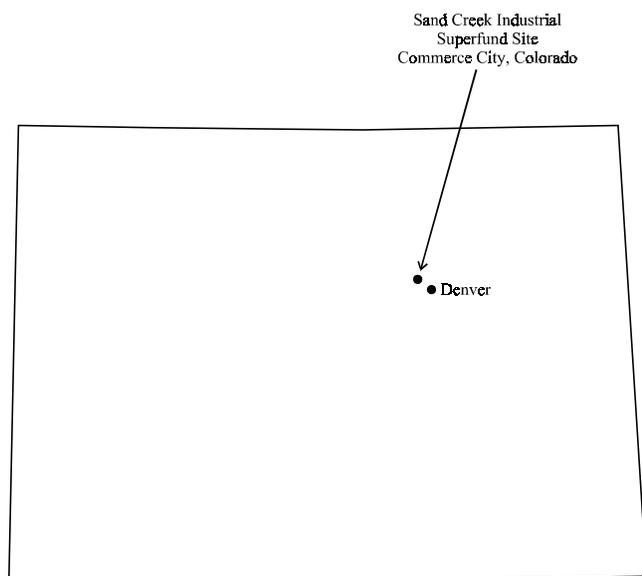


Figure 1. Site Location

SITE INFORMATION (CONT.)

Background (cont.)

Regulatory Context: In September 1989, EPA issued a Record of Decision (ROD) for O.U. 1 at the Sand Creek site. O.U. 1 addressed contaminated soils, buildings, and tanks at the COC facility. The ROD required excavation and off-site incineration for highly contaminated soils (greater than or equal to 1,000 mg/kg of halogenated organic compounds); soil vapor extraction (SVE) for soil contaminated with volatile organic compounds (VOCs); and demolition and treatment of contaminated buildings and tanks in accordance with the RCRA Land Disposal Restrictions. In addition, the ROD required groundwater monitoring at the site for 30 years, and performance of a public health evaluation once every five years following remediation. [1]

In September 1993, EPA issued an Explanation of Significant Differences (ESD) to modify the 1989 ROD for O.U. 1. The ESD modified the ROD by limiting the areal extent for operation of soil vapor extraction technology, and by identifying additional costs for disposal of tanks from the facility. [2]

In July 1994, EPA issued a ROD for Operable Unit No. 4 (O.U. 4) at the Sand Creek site. O.U. 4 involved remediation of a light non-aqueous phase liquid (LNAPL) plume at the site using a combination SVE and dual vapor extraction (DVE) process (SVE/DVE). This treatment was selected because the SVE system was already in place at the site. [12] The application of O.U. 4 is not discussed further in this report.

Remedy Selection: Soil vapor extraction was selected as the remedy for treatment of VOC-contaminated soil in O.U. 1. According to the treatment vendor, the generally permeable nature of the soil matrix indicated that the volatile fractions at Sand Creek, containing the more toxic compounds, could be readily removed with SVE. [14] In 1990, EPA conducted a treatability study to determine if the technology could adequately extract VOCs from O.U. 1 soils and to determine the radius of influence for SVE wells at the site. The study showed that SVE was a feasible remedial technology for the site and that a radius of influence of 60 feet could be achieved at the site. [2,4]

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Management: Federal Lead/Fund Financed

Oversight: EPA

Remedial Project Manager:

Ms. Erna Waterman, 8 EPR-SR
U.S. Environmental Protection Agency
Region VIII
999 18th Street, Suite 500
Denver, Colorado 80202-2466
(303) 312-6762
(303) 312-6897 (fax)

ARCs Contractor:

John Chinnock
URS Consultants, Inc.
1099 18th Street, Suite 700
Denver, Colorado 80202-1907
(303) 296-9700

Remedial Design/Construction/Operation Subcontractor (Treatment Vendor):

Christopher Strzempka
Project Technical Manager for OU-1
OHM Remediation Services Corp.
16406 U.S. Route 224 East
Findlay, OH 45840
(800) 537-9540

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Soil (in situ)

Contaminant Characterization

Primary Contaminant Groups: Volatiles - Halogenated: chloroform, methylene chloride, tetrachloroethene, and trichloroethene; Volatiles - Nonhalogenated: TPH.

EPA conducted a Remedial Investigation (RI) at the site from 1984 to 1988. [3] Soils identified as contaminated with pesticides (e.g., 2,4-D) were excavated and hauled off site for incineration. Additional soil contamination at the site was identified by the vendor as consisting of mixed petroleum and halogenated hydrocarbons, with some of the hydrocarbons classified as semivolatile or non-volatile, including hydrocarbons of aromatic range and heavier hydrocarbons to C-24. [11, 14]

Three subareas of contaminated soil were identified during the RI, labelled Subareas 1, 2, and 3. The maximum concentrations of VOCs in the soil identified by the RI are shown in Table 1. Based on these data, the prime contractor estimated the total mass of chloroform, methylene chloride, TCE, and PCE in the soil as 684 pounds. [4]

Table 1. Maximum Concentrations of Halogenated VOCs in Soil as Identified by RI [2]

Contaminant	Maximum Concentration (mg/kg)
Chloroform	0.820
Methylene Chloride	5.8
Trichloroethene (TCE)	0.087
Tetrachloroethene (PCE)	9.34

In addition to the VOC contamination in the soil, a light non-aqueous phase liquid (LNAPL) plume was identified floating on the groundwater at the COC facility. LNAPL plume thickness was measured at the COC facility in October 1990, April 1991, November 1991, and September 1992. Table 2 shows the LNAPL Plume Thickness in five wells at the COC facility at those times. As shown in Table 2, LNAPL thickness ranged from 1.69 to 4.72 feet in the five wells and averaged from 2.29 to 3.69 feet over the 2-year sampling period. [5]

Figure 2 shows the relative locations of the three contaminated soil areas and LNAPL plume at the Sand Creek site.

MATRIX DESCRIPTION (CONT.)

Contaminant Characterization (cont.)

Table 2. LNAPL Plume Thickness [5]

Well	Measured LNAPL Thickness (ft)			
	10/90	04/91	11/91	09/92
URS-3	4.31	2.25	3.49	2.48
URS-4	3.10	2.43	3.60	3.82
URS-5	3.95	2.26	4.45	4.72
URS-6	3.18	2.43	3.34	1.69
URS-14	2.07	2.07	3.58	3.01
Average	3.32	2.29	3.69	3.14

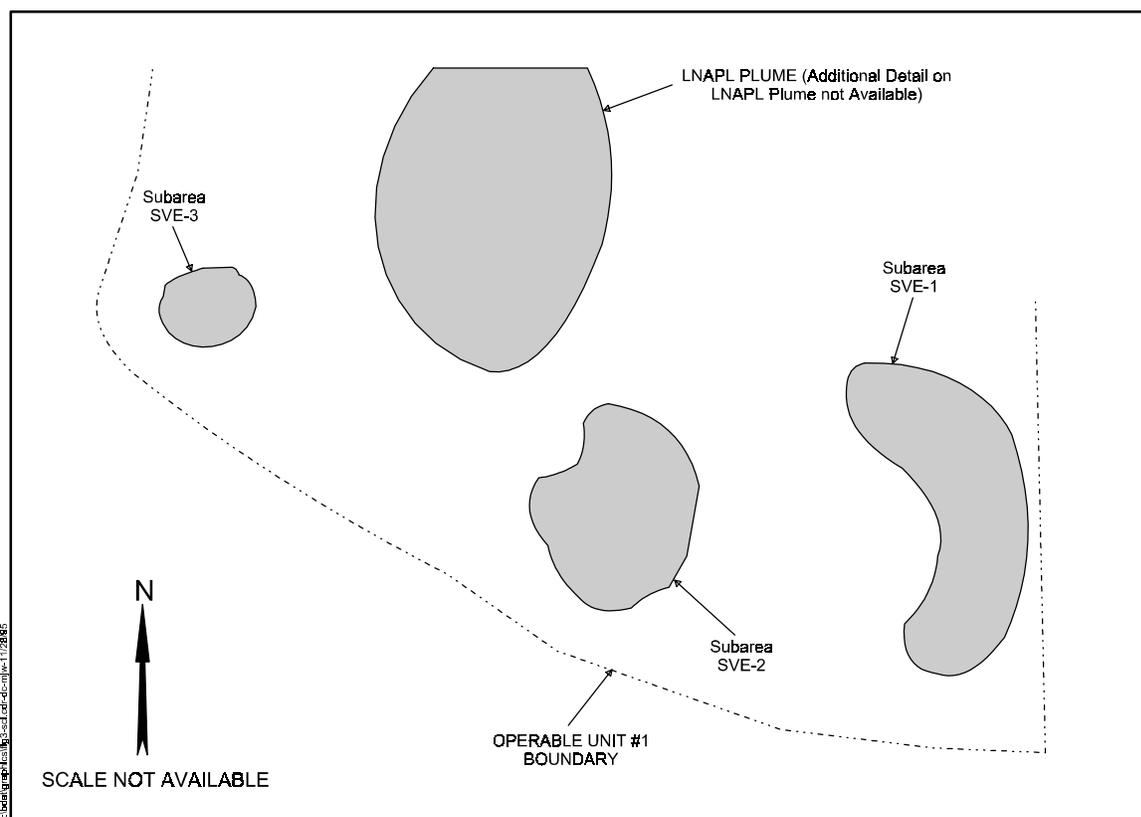


Figure 2. Locations of Contaminated Soil Areas and LNAPL Plume [11]

MATRIX DESCRIPTION (CONT.)**Matrix Characteristics Affecting Treatment Cost or Performance**

The major matrix characteristics affecting cost or performance for this technology and the values measured for each are shown in Table 3.

Table 3. Matrix Characteristics [3, 4, 12, 14]

Parameter	Value	Measurement Method
Soil Classification	Sandy loams, loamy sands	USDA Soil Conservation Service
Clay Content and/or Particle Size Distribution	Larger than 1/4" 0.34 - 3.66% Granules (10 mesh to 1/4") 3.98 - 8.35% Medium to very coarse sand (60 to 10 mesh) 35.48 - 40.38% Very fine to fine sand (200 to 60 mesh) 30.01 - 34.99% Silt and clay (less than 200 mesh) 19.99 - 24.71%	U.S. Standard Sieves
Moisture Content	3.0 - 30.1%	Measured values in 13 observations during well installation
Air Permeability	Not measured*	-
Porosity	Not measured**	N/A
Total Organic Carbon	Not measured***	N/A
Nonaqueous Phase Liquids	LNAPL layer present	Measured on site

*Although air permeability testing was not conducted, the vendor reported the following: (1) the soils were predominantly sandy, and well screens of 5-ft lengths in the vadose zone were producing extraction flows in excess of 100 SCFM at relatively low vacuums; (2) using a simple steady-state facial flow equation for compressible flow described by Johnson et al (1990), air permeabilities in excess of $2 \times 10^{-7} \text{ cm}^2$ (20 darcies) could be expected; and (3) moisture content in the capillary fringe and saturated zones was the chief impediment to flow.

**Porosity measurements were not made during the project. Some interbedded silts and clays were found at O.U. 1, but soils were predominantly sandy with estimated air-filled porosity in the vadose zones of 30 percent. [14]

***TOC analyses of soils were not made. The bulk of the soils were predominantly sands and silts characterized normally by low TOC. [14]

N/A - Measurement method not reported for this parameter because resulting value not expected to vary among measurement procedures.

MATRIX DESCRIPTION (CONT.)

Site Geology/Stratigraphy

The RI indicated that the site is underlain by alluvial deposits consisting of high-permeability sands and gravels, interbedded with low-permeability clayey and silty layers. Two groundwater units underlie the site, separated by a relatively impermeable layer 10 to 20 feet thick. The upper deposit is up to 40 feet thick and is primarily unsaturated (i.e., contains little to no groundwater). The lower deposit is up to 44 feet thick and generally exists under confined conditions. [1] A simplified schematic of the alluvial groundwater system at the Sand Creek site is shown in Figure 3.

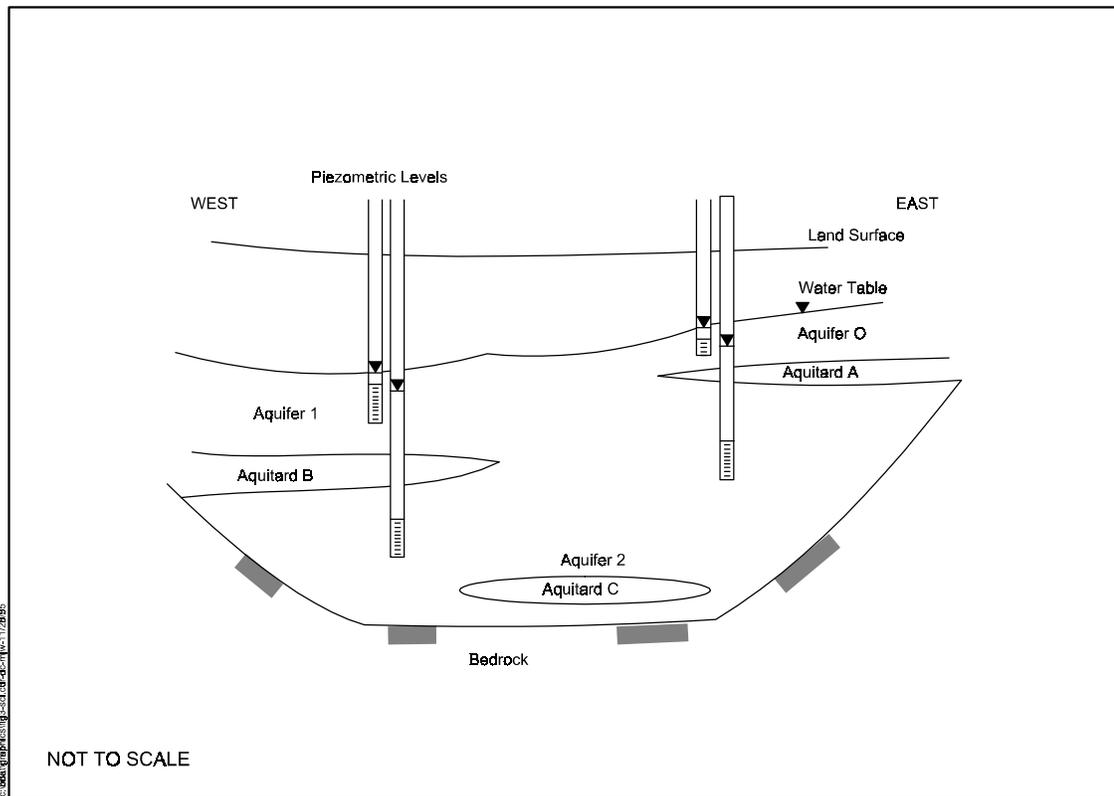


Figure 3. Simplified Schematic of Alluvial Groundwater System at the Sand Creek Site [3]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology Type: Soil Vapor Extraction

Supplemental Treatment Technology Type: Catalytic oxidization

Soil Vapor Extraction System Description and Operation

System Description [4, 8, 10, 12, 14]

The soil vapor extraction system used at Sand Creek consisted of 31 vertical wells and 1 horizontal well, and was thermally-enhanced by fluid injection with vacuum extraction (referred to as the FIVE system). The wells were grouped into three subareas at the site: SVE-1, SVE-2, and SVE-3. Thirteen vertical wells and the horizontal well were located in SVE-1 (wells 101 through 113 and H12). SVE-2 contained 12 wells (wells 201 through 212) and SVE-3 contained 6 wells (wells 301 through 306). The location of these wells at the site is shown in Figure 4. As shown on Figure 4, well H12 is a horizontal well, and all other wells are vertical. For several of the wells in each subarea, operation of the wells was alternated between vacuum extraction and air injection during the course of remediation.

In their bid for the project, the vendor stated that both horizontal and vertical wells would be included in the system, with "preference" given to horizontal wells because the vendor believed such wells would increase the radius of influence. However, only one horizontal well was included in the SVE system at Sand Creek. During installation of the initial horizontal well at Sand Creek, the vendor discovered buried concrete blocks and other construction debris in the subsurface. This created problems of increased friction during installation of the prepackaged well screens resulting in delays. Therefore, after installation of the one horizontal well, the vendor decided to replace the remaining planned horizontal wells with multiple vertical wells.

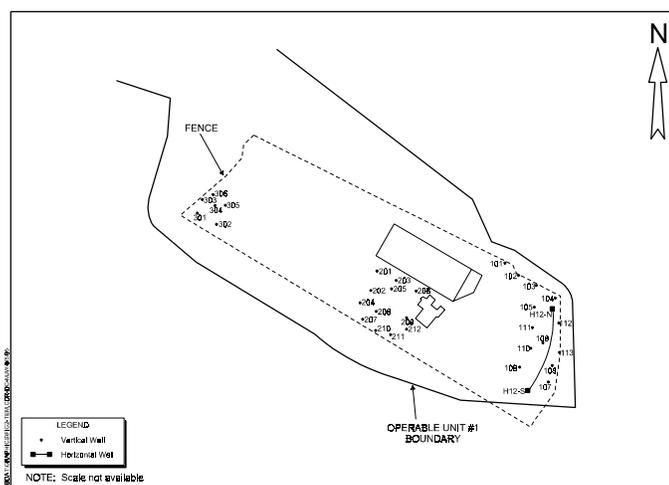


Figure 4. SVE Well Pattern [8]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Soil Vapor Extraction System Description and Operation (cont.)

The screened intervals and depths for the wells at Sand Creek are as follows [14]:

SVE System	Well No.	Screened Interval (ft. bgs)	Total Depth (ft. bgs)
1	SVE-101	4.5 - 11.5	11.5
	SVE-102	6.5 - 11.5	11.5
	SVE-103	4.0 - 11.5	11.5
	SVE-104	4.0 - 11.5	11.5
	SVE-105	4.0 - 11.5	11.5
	SVE-106	3.0 - 10.5	10.5
	SVE-107	5.5 - 13.0	13.0
	SVE-108	5.0 - 12.5	12.5
	SVE-109	5.0 - 12.5	12.5
	SVE-110	5.0 - 12.5	12.5
	SVE-111	5.0 - 12.5	12.5
	SVE-112	5.0 - 12.5	12.5
	SVE-113	4.0 - 11.5	11.5
	H12	10	10
2	SVE-201	8.0 - 15.5	15.5
	SVE-202	8.0 - 20.5	20.5
	SVE-203	7.5 - 17.5	17.5
	SVE-204	11.5 - 21.5	21.5
	SVE-205	10.5 - 20.5	20.5
	SVE-206	10.5 - 20.5	20.5
	SVE-207	9.5 - 24.5	24.5
	SVE-208	8.0 - 25.5	25.5
	SVE-209	10.0 - 22.5	22.5
	SVE-210	15.0 - 30.0	30.0
	SVE-211	13.0 - 30.5	30.5
	SVE-212	14.0 - 32.5	32.5
3	SVE-301	11.0 - 28.5	28.5
	SVE-302	9.5 - 27.5	27.5
	SVE-303	13.5 - 26.0	26.0
	SVE-304	10.5 - 23.0	23.0
	SVE-305	10.5 - 23.0	23.0
	SVE-306	9.0 - 24.0	24.0

TREATMENT SYSTEM DESCRIPTION (CONT.)

Soil Vapor Extraction System Description and Operation (cont.)

Figure 5 shows a schematic of the SVE system. As shown in Figure 5, three 1,500 ACFM positive displacement blowers were used to create a vacuum, with two of the three blowers operated at one time. Extracted water was separated from the vapors using an air/water separator. Following separation, extracted vapors were diluted with ambient air (between 12% and 50% by volume) and treated using a catalytic oxidizer. The emissions from the catalytic oxidizer were either re-injected into the soil through the vertical and horizontal wells, or released to the atmosphere. The system included two blowers for air injection, operated one at a time. The vendor reported that the FIVE system is described in the following reference: Kirk, J.L. and J.R. Ohneck, "A Portable Method for Decontaminating Earth," U.S. Patent No. 4,435,492, U.S. Patent and Trademark Office, Washington, D.C., March 6, 1984.

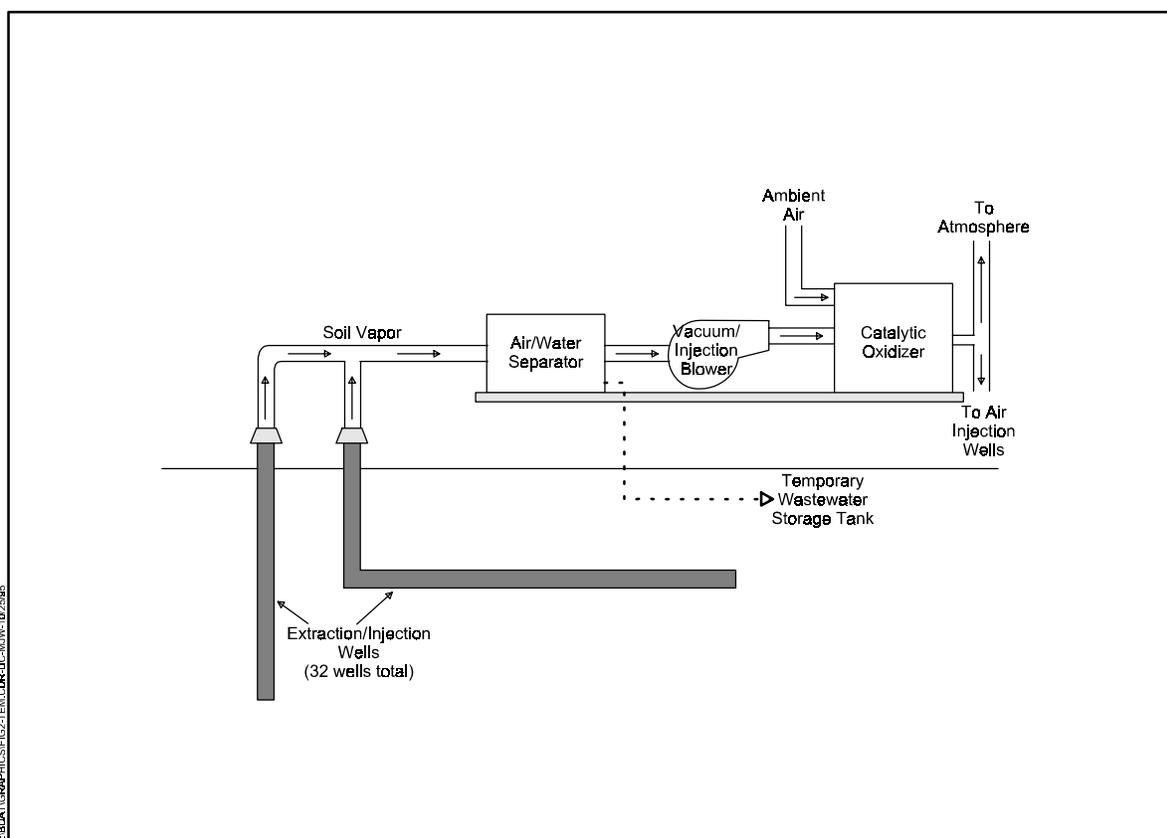


Figure 5. SVE System Schematic [based on 8, 10]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Soil Vapor Extraction System Description and Operation (cont.)

Operation [8, 12, 14]

The SVE system was operated for two periods - September to December 1993, and January to April 1994. SVE system start-up activities began on September 24, 1993 and the system became fully operational by October 12, 1993.

Start-up activities focused on well development (initial purging activities), which took place 24 hours a day. Well development was limited to 2 to 3 wells per day to balance the relatively high concentrations of VOCs in the vapors extracted during development and the capacity of the catalytic oxidizer.

Extraction quantities varied during the remediation based on the capacity of the catalytic oxidation (CATOX) unit (extracted vapors had to be maintained at less than 25% of the lower explosive limit (LEL) of vapors in air). Early in the remedial action, the concentration of VOCs in the extracted vapors was high and few wells could be used for extraction because of "over-heating" of the CATOX unit. Later on, the concentration of VOCs in the extracted vapors was less, and all wells in the system could be used in extraction mode.

Treated vapors were intermittently injected into the soil. In October 1993, approximately 25% of the extracted and treated vapors (i.e., after CATOX) were re-injected into Subareas 2 and 3. In November 1993, approximately 15% of the extracted and treated vapors were re-injected into all three subareas. During December 1993, vapors were re-injected into Subarea 1 for nine days. Treated vapors were released directly to the atmosphere during January through April 1994.

The treatment vendor described their general approach to determining injection quantities as follows: (1) at the start of a remediation (when highly concentrated vapors are being extracted), injection must be limited to prevent fugitive emissions from the ground surface or uncontrolled migration of vapor plumes; (2) later on in the remediation, additional injection wells could be brought into service to thermally enhance volatilization, reduce contaminant liquid viscosity, and improve flushing efficiency between adjacent injection and extraction wells; and (3) towards the end of a remediation (when VOC contaminant concentrations are lowest, and are least amenable to further extraction), lower injection flows (and corresponding lower extraction volumes) would lead to conditions conducive to biodegradation (e.g., oxygen enhancement, elevated temperature, adequate moisture). At Sand Creek, it appears that the vendor used limited injection throughout the remediation (25% in Month 1, 15% in Month 2, limited in Month 3, and none in Months 4-7). No data were provided in the available references on any potential fugitive emissions or uncontrolled migration at Sand Creek, or on how much the use of injection improved treatment system performance through thermally-enhanced volatilization, reduced contaminant liquid viscosity, improved flushing efficiency, or biodegradation.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Soil Vapor Extraction System Description and Operation (cont.)

System operation generally took place without equipment failure or shutdown. However, in March 1994, the system was automatically shut down twice. On March 1, a shutdown occurred because the high temperature set point was exceeded on the catalytic oxidizer. The system was restarted after about 5 hours. On March 8, the system shut down a second time because of flame failure. The system was restarted one-half hour later.

Groundwater Removal and Disposition [8, 12, 14]

From October 1993 through April 1994, the extraction wells removed entrained groundwater from the subsurface, however, no provisions were made for a water treatment system. The water was temporarily stored on site in a storage tank until disposal at an approved facility. On February 21, 1994, approximately 3,750 gallons of entrained water were disposed at Enviroserve, Inc. Between February 21, 1994 and April 27, 1994, approximately 1,700 gallons of entrained water were collected. No additional information was provided on the disposition of water collected between February and April 1994.

The water extraction rate varied with rainfall, and the presence of perched water and fluctuating water tables. The extraction rate of entrained groundwater from October 1993 to February 1994 was estimated as 10 gallons per day. During March 1994, the rate of entrained groundwater extraction increased to approximately 30 gallons per day, possibly due to a spring snow melt. In April, the rate dropped to about 25 gallons per day.

System Shutdown [8, 12]

The soil vapor extraction system was temporarily shut down on April 19, 1994 for soil confirmation sampling and to assess cleanup of the site. Based on these results (presented under treatment performance data), no additional operation of the SVE system was needed and the system was permanently shut down by April 27.

The treatment performance data shown later in this report indicate that cleanup criteria were met in November 1993, however, according to the RPM, system operation was continued until April 1994 because of the structure of the contract and information about non-target VOC removal quantities. According to the RPM, system operation was performed under a fixed-price contract, where the only benefit to an earlier shutdown would be for oversight costs paid to the prime contractor. These oversight costs were less than the estimated costs for demobilization and a possible subsequent remobilization (for example, if vapor headspace concentrations had increased after a shutdown period), and the RPM determined that shutdown in November 1993 would not be "cost efficient." In addition, during the November 1993-April 1994 operating period, the RPM reported that "significant" quantities of non-target VOCs were being removed by the SVE system.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Soil Vapor Extraction System Description and Operation (cont.)

On June 22 and June 23, 1994, the extraction wells were abandoned in place. They were grouted with a 9 to 1 ratio of cement/bentonite. The vacuum extraction/injection blowers, catalytic oxidizer, LEL monitoring control system, and decontamination trailer were reconditioned and reconfigured to be used in remediation of O.U. 4 at the Sand Creek site.

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameters affecting cost or performance for this technology and the values measured for each are shown in Table 4.

Table 4. Operating Parameters [8]

Parameter	September to December 1993	January to April 1994	Measurement Method
Air Flow Rate	2,681 scfm	2,910 scfm	N/A
Operating Pressure/Vacuum	22-24 inches of water column	13.4 to 23.8 inches of water column	N/A
Air Injection Rate	605 scfm under 12 inches of water column pressure	483 scfm under 18.3 inches of water column pressure	N/A

N/A - Measurement method not reported for this parameter because resulting value not expected to vary among measurement procedures.

Timeline

A timeline for this application is shown in Table 5.

Table 5. Timeline [4, 8, 14]

Start Date	End Date	Activity
1982	-	Sand Creek site placed on NPL
1984	1988	Site-wide Remedial Investigation conducted
September 29, 1989	-	ROD signed for O.U. 1
September 8, 1993	-	ESD signed for O.U. 1
September 24, 1993	October 12, 1993	System started up and wells developed
September 1993	December 1993	First period of operations
December 22, 1993	January 5, 1994	System temporarily shutdown for the holiday season
January 1994	April 1994	Second period operations
April 19, 1994	April 27, 1994	System shut down for confirmation soil boring
April 27, 1994	-	Shutdown of SVE system
June 22, 1994	June 23, 1994	Extraction wells abandoned in place
December 20, 1996	-	Sand Creek site removed from NPL (61 FR 67233)

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

The ROD for O.U. 1 specified soil cleanup goals for four VOCs, as shown in Table 6.

Table 6. Soil Cleanup Goals for VOCs at O.U. 1 [1]

Compound	Cleanup Goals (mg/kg)
Chloroform	0.165
Methylene Chloride	0.075
Trichloroethene (TCE)	0.285
Tetrachloroethene (PCE)	1.095

An air emissions operating permit was not obtained for this application, however, air emissions were regulated under an Air Pollution Emission Notice (APEN) effective December 30, 1992, issued by the Colorado Department of Health under Regulation No. 3. The notice required reporting of air emission quantities, but did not limit the emissions. [14]

Addition Information on Goals

The soil cleanup goals for VOCs were developed based on the results of a risk assessment for the site. The risk assessment identified a groundwater ingestion pathway as the most significant route for exposure to VOCs, based on a review of the relatively low partitioning coefficients for the specific contaminants. The cleanup goals were calculated based on this pathway and using a 10^{-6} risk level. [1]

Treatment Performance Data

Treatment performance data for the SVE application at O.U. 1 consists of confirmation soil borings, equilibrium headspace sampling, mass extraction data, and catalytic oxidizer destruction efficiency data.

Confirmation Soil Borings [8]

On April 19, 1994, OHM began confirmation soil boring. Thirty-two confirmation soil borings were performed in O.U. 1. Sixteen soil borings were performed in SVE-1, 11 borings were performed in SVE-2, and 5 borings were performed in SVE-3. Confirmation soil borings were performed using a CME-55 truck mounted drilling rig with 7-inch, outside diameter, hollow-stem augers. Soil samples were collected using a series of 2-inch outside diameter by 2-foot long California Split Spoon Samplers in accordance with ASTM Method D-1586.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Following decontamination of the split spoon samplers, four 6-inch brass sleeves were placed into the sampler.

Once the sampler was retrieved from the boring, the split barrel was opened and the brass sleeves removed. Teflon sheeting was placed over each end of each 6-inch brass sleeve and capped with Teflon caps. For each split spoon sampler retrieved, four soil samples were generated, one for lithology characterization using the Unified Soil Classification System (USCS, ASTM Method D-2488), one for backup, one for on-site analytical screening, and one for off-site laboratory analysis. In addition, QA/QC samples were collected during the field sampling event. These samples included trip blanks, field blanks, and equipment rinse water.

Field analyses of the soil boring samples were performed according to Method 8010B, published in SW-846, "Test Methods for Evaluating Solid Waste," and using a Hewlett Packard Series II Gas Chromatograph (GC), configured with a Tekmar ALS 2016 Purge and a Tekmar LSC 2000 Trap for sample introduction. An OI Corp. 5220 Electrolytic Conductivity Detector (ECD) was used for quantitation of the target compounds.

Off-site laboratory analyses were performed by Great Lakes Analytical Laboratory in Buffalo Grove, Illinois. Trip blanks and equipment blanks also were analyzed by Great Lakes Analytical Laboratory.

Table 7 shows the results from the off-site laboratory analyses for the four target constituents in the confirmation soil borings. Only those borings where at least one constituent was measured at a detectable concentration are shown on Table 7. Samples for off-site analysis were collected between April 19 and May 2, 1994.

Equilibrium Headspace Sampling [8]

Equilibrium headspace sampling was performed in September, November, and December 1993, and in March 1994. Prior to sampling, the SVE system was shut down by closing the valves in the system, including 10-inch headers located in the equipment pad area, 4-inch well head valves, and extraction/injection manifold 4-inch valves. The SVE system was shut down for a minimum of 48 hours to allow sufficient time for the vapors in the wells to reach a state of equilibrium. After equilibration, the SVE system was re-started and operated 5 to 10 minutes, and well head (static vapor) samples were collected.

TREATMENT SYSTEM PERFORMANCE (CONT.)**Treatment Performance Data (cont.)****Table 7. Analytical Results from Off-Site Laboratory for Confirmation Soil Borings* [11]**

Soil Boring	Depth (ft bgs)	Chloroform (mg/kg)	Methylene Chloride (mg/kg)	Trichloroethene (mg/kg)	Tetrachloroethene (mg/kg)
Cleanup Goal	-	0.165	0.075	0.285	1.095
CB-1	5-7	ND	ND	ND	0.200
CB-1	10-12	ND	ND	ND	0.005
CB-2	3-5	ND	ND	ND	0.032
CB-12	11-13	ND	ND	ND	0.280
CB-17	7-9	0.0078	ND	ND	ND
CB-18	15-17	0.0069	ND	ND	ND
CB-18	17-19	0.0099	ND	0.10	ND
CB-19	7-9	ND	ND	ND	0.0063
CB-19	9-11	ND	ND	ND	0.0059
CB-21	19.5-20	0.0071	ND	ND	0.066

ND - Not detected (detection limits not provided).

*Off-site laboratory analyses were performed for 61 samples (i.e., soil borings at specific depths). Only those 10 samples where at least one constituent was measured at a detectable concentration are shown on this table. All other samples were reported as ND for all four target constituents.

Table 8 summarizes the results from equilibrium headspace sampling in Subareas 1, 2, and 3 during September, November, and December 1993, and March 1994. As shown in Table 8, an equilibrium headspace equivalent to the soil cleanup goals was identified for the four VOC target contaminants. This value was calculated using Henry's Law Constant as an indicator of the relationship between headspace soil vapor concentrations and soil concentrations. Headspace equivalent values were calculated with values taken from the technical literature, and field sampling to validate Henry's Constant, porosity, moisture content, temperature, or partition coefficients used to compute headspace equivalent was not conducted.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

**Table 8. Equilibrium Headspace Results for VOCs in O.U. 1 -
Maximum Concentrations (mg/L) [8]**

Sampling Date/Location	Chloroform	Methylene Chloride	Trichloro-ethene	Tetrachloro-ethene	Total VOCs
Equilibrium Headspace Equivalent to Soil Cleanup Goal*	0.139	0.05	0.311	0.856	Not calculated
September 1993					
Subarea 1	BDL	BDL	BDL	0.06	57.7
Subarea 2	0.0178	BDL	0.154	6.9	14.0
Subarea 3	BDL	BDL	BDL	0.3	2.4
November 1993					
Subarea 1	0.001	BDL	0.002	0.001	33.6
Subarea 2	BDL	BDL	BDL	0.078	0.547
Subarea 3	0.001	BDL	BDL	0.002	0.10
December 1993					
Subarea 1	NA	NA	NA	NA	NA
Subarea 2	BDL	BDL	0.001	0.104	1.55
Subarea 3	BDL	BDL	BDL	0.001	0.064
March 1994					
Subarea 1	NA	NA	NA	NA	NA
Subarea 2	NA	NA	NA	NA	NA
Subarea 3	0.001	BDL	0.001	0.005	0.005

*Calculated using Henry's Law - see text.

NA - Data not contained in available references.

BDL - Below detection limit.

Mass Extraction Data [8, 12, 14]

Table 9 summarizes the mass extraction rates and mass removal quantities for the target VOCs and total VOCs during the first and second periods of SVE operation. Removal rates shown in Table 9 represent the average rates measured during the time period.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Treatment Performance Data (cont.)

Table 9. Mass Extraction Rates and Mass Removal Quantities for SVE System Operation [8]

Parameter	September to December 1993	January to April 1994
Average Removal Rate for Target Compounds (lbs/day)	33.86	3.15
Average Removal Rate for Total VOCs (lbs/day)	1,482.6	482.4
Mass Extracted for Target Compounds (lbs)	2,899.7	349.6
Mass Extracted for Total VOCs (lbs)	122,456.6	53,547

NOTE: Total VOCs were analyzed using a modified EPA Method 8015. Non-halogenated VOCs, including the volatile portions of any semivolatiles present were measured, with gasoline range hydrocarbons prevalent in the chromatographs. Average mass extraction rates of contaminants were computed by multiplying the mean concentration by the mean volumetric flow rate between successive sampling episodes and converting to a daily rate (lb/day).

Table 10 shows the cumulative mass of target compounds and total VOCs extracted from the three subareas, released to the atmosphere through stack emissions, and re-injected into the soil. Data in Table 10 represent the cumulative mass over the entire period of system operation, from September 24, 1993 to April 27, 1994.

Total VOCs were analyzed using a modified EPA Method 8015. Non-halogenated VOCs, including the volatile portions of any semivolatiles present were measured, with gasoline range hydrocarbons prevalent in the chromatographs. Average mass extraction rates of contaminants were computed by multiplying the mean concentration by the mean volumetric flow rate between successive sampling episodes and converting to a daily rate (lb/day).

Catalytic Oxidizer Destruction Efficiency Data

The destruction efficiencies for the catalytic oxidizer are shown in Table 11, by operating period. Average destruction efficiencies are shown for target compounds and total VOCs. Destruction efficiency was calculated as follows [14]:

TREATMENT SYSTEM PERFORMANCE (CONT.)**Treatment Performance Data (cont.)****Table 10. Cumulative Mass of Contaminants Extracted, Released to the Atmosphere, and Re-injected - September 24, 1993 through April 27, 1994 (lbs) [8]**

	Target Compounds				Total Target Compounds*	Total VOCs*
	Methylene Chloride	Chloroform	Trichloro-ethene	Tetrachloro-ethene		
Extraction						
Subarea 1	0.0	0.0	0.0	5.2	5.2	69,096.7
Subarea 2	0.0	0.40	35.2	3,130.7	3,166.3	106,232.6
Subarea 3	0.0	13.4	0.0	69.8	83.2	1,175.2
Total	0.0	13.8	35.2	3,205.7	3,254.7	176,504.5
Release to Atmosphere						
Stack Emission	0.0	0.0	0.0	209.6	209.6	6,210.3
Injection						
Total	0.0	0.0	0.0	0.74	0.74	638.9

*Totals reflect rounding.

Table 11. Catalytic Oxidizer [8]

Parameter	September to December 1993	January to April 1994
Target Compounds Destruction Efficiencies (%)	92.9	99.1
Total VOCs Destruction Efficiencies (%)	95.5	98.8

$$\text{Destruction Removal Efficiency} = [1 - [(M_{inj} + M_s)/M_{ext}]] \times 100\%$$

where: M_{inj} = Mass of contaminant injected to the subsurface (lb/day)
 M_s = Mass of contaminant emitted from the stack (lb/day)
 M_{ext} = Mass of contaminant extracted from the subsurface (lb/day)

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment

The treatment performance data shown in Table 7 indicate that the SVE system used at Sand Creek met the soil cleanup goals for VOCs within 6 months of operation. Soil concentrations were reduced from as high as 9.34 mg/kg (the maximum concentration shown in the RI for tetrachloroethene) to less than the cleanup goals. The maximum concentration of target constituents measured by the off-site laboratory for the confirmation soil borings was: chloroform - 0.0099 mg/kg; methylene chloride - not detected; trichloroethene - 0.10 mg/kg; and tetrachloroethene - 0.28 mg/kg. In addition, as discussed in Table 7, less than 20% of the soil boring samples (i.e., soil borings at specific depths) contained at least one target constituent measured at a detectable concentration.

Equilibrium headspace results shown in Table 8 indicate a reduction in contaminant levels over the course of the remediation. For example, these data show a reduction for tetrachloroethene from 6.9 mg/L in September 1993 (Subarea 2) to 0.104 mg/L in December 1993 (Subarea 2), and from 0.3 mg/L in September 1993 (Subarea 3) to 0.005 in March 1994 (Subarea 3). The headspace results also provide an indication of the variations in contaminant levels between subareas. For example, these data show a relatively higher level of contamination in Subarea 2 than in Subareas 1 or 3. The relatively higher concentrations in Subarea 2 are further supported by the cumulative mass extraction data shown in Table 10. For example, Table 10 shows that 3,166.3 lbs of the 3,254.7 lbs (97.3%) of target compounds were extracted from Subarea 2.

Mass extraction rate and mass removal quantity data provided in Table 9 also show a reduction in contaminant quantities over the course of the remediation. For example, the average removal rate for target compounds was reduced ten-fold from the first to second periods, from 33.86 to 3.15 lbs/day.

As shown in Table 10, approximately 3,250 lbs of the four target VOC compounds and 176,500 lbs of total VOCs were extracted from the three subareas at O.U. 1. Tetrachloroethene accounted for approximately 98.5% of the mass of target compounds extracted from the subareas. Table 10 also shows that during the 6 months of SVE operation, approximately 6,200 lbs of total VOCs were released to the atmosphere, including approximately 209.6 lbs of tetrachloroethene. An estimated 0.74 lbs of tetrachloroethene were re-injected into the soil.

As shown in Table 11, the average destruction efficiencies for the catalytic oxidizer ranged from 92.9 to 99.1% during the 7 months of SVE system operation. Treatment performance data are not provided in the available references to compare actual air emissions with regulatory levels.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Completeness

Analytical data are available for the following: 1) the maximum concentrations of contaminants in the soil prior to treatment, as reported in the RI; 2) the range of operating conditions of the SVE system during treatment; 3) analytical data for soil boring confirmation samples; 4) the reduction in equilibrium headspace concentrations over the course of the remediation; and 5) other process parameters, such as rate and mass of extracted VOCs, release of VOCs to the atmosphere, and destruction efficiency of the catalytic oxidizer.

No data are available to characterize the actual soil concentrations in 1993, at the time just prior to treatment system operation. Data are available from the mid-1980s for VOCs in the soil when the RI was performed.

Performance Data Quality

The treatment vendor performed quality assurance/quality control (QA/QC) procedures as part of this application, including use of standard EPA analytical methods, analysis of duplicate samples, trip blanks, and equipment blanks. No deviations to the QA/QC protocols were noted by the vendor. [8]

Soil samples from confirmation soil borings were processed in accordance with the URS-approved Chemical Quality Management/Sampling Plan, Soil Vapor Extraction Remedial Action, Sand Creek Industrial Superfund Site, OU-1 Commerce City, Colorado," dated October 20, 1993, and "Subcontractor Quality Control Plan, OHM Remediation Services Corp.," June 17, 1993. The QA/QC results are contained in OHM's "Cleanup Demonstration Results for Subarea SVE-1, SVE-2 and SVE-3," (Appendix C), dated March 17, 1995. [14]

TREATMENT SYSTEM COST

Procurement Process

The SVE application at Sand Creek O.U. 1 was procured by EPA Region 8 through an ARCs contract with URS Consultants, Inc. (URS). URS prepared detailed bidding and subcontract requirements for the SVE application, including a description of the work, summary of site conditions, and startup, testing, and operating requirements. URS selected OHM Remediation Services Corp. (OHM) under a fixed price subcontract to design, construct, and operate the SVE system in accordance with a URS performance specification. [4, 8, 14] According to the RPM, the remediation was competitively bid, with four bidders. Selection was based on technical criteria and cost, including use of a best and final offer (BAFO) approach. [12]

During the procurement period, EPA revised the air emissions control equipment from activated carbon to catalytic oxidation because of the relatively large quantity of non-target VOCs in the soil (approximately 98% of the total VOCs removed). The ARCs contractor estimated that carbon disposal costs would have exceeded the cost for catalytic oxidation by approximately \$600,000 to \$750,000. [11] The treatment vendor indicated that savings from use of catalytic oxidation rather than carbon with off-site regeneration may have been greater than the estimate of \$600,000 to \$750,000, based on the following analysis: A total of approximately 176,500 lbs of VOC were extracted from site soils. If a carbon adsorption capacity of 10 percent was assumed, 10 lbs of carbon would be needed to adsorb one pound of VOC, and approximately 1,765,000 lbs of carbon costing \$1.50/lb or a total of \$2,647,500 would be required for this application. The vendor stated that this suggested that nearly \$2 million might have been saved by selecting catalytic oxidation. [14]

Treatment System Cost [1, 2, 12]

Actual treatment system costs of approximately \$2.14 million were provided by EPA Region 8 for this treatment application. This value does not include costs for demobilization activities; costs for these activities are not available at this time. [9]

In order to standardize operating costs across projects, costs reported by Region 8 were categorized according to an interagency Work Breakdown Structure (WBS), as shown in Tables 12 and 13. Table 12 shows that \$81,231 in costs for this application were incurred for before-treatment activities such as mobilization and preparatory work, and monitoring, sampling, testing, and analysis. Table 13 shows that \$2,058,564 were incurred for activities directly attributed to treatment, such as short-term operation and cost of ownership. Approximately 82% of the costs directly attributed to treatment were for the treatment vendor for this application.

As discussed under the section on Quantity of Soil Treated, the estimates for the quantity of soil treated during this application varied from 31,440-52,920 cubic yards. Because of this, the cost per cubic yard of soil treated is presented as a range, rather than a single cost number. Therefore, the \$2,058,564 in costs attributed to treatment corresponds to \$39-65 per cubic yard of soil treated (31,440-52,920 cubic yards) and \$11.70 per pound of VOC removed (176,500 lbs).

TREATMENT SYSTEM COST (CONT.)**Treatment System Cost (cont.)****Table 12. Before Treatment Costs [9]**

Cost Element	Unit Cost (\$)	Cost (\$)
Mobilization and Preparatory Work		31,254
- Work plan revisions, addendum, and response to interrogatories	4,117	
- Coordination with Operable Units 4 and 5	27,137	
Monitoring, Sampling, Testing, and Analysis		49,947
- Confirmatory sampling	15,569	
- QA/QC laboratory analyses	34,408	
Total		81,231

Table 13. Treatment Costs [9]

Cost Element	Unit Cost (\$)	Cost (\$)
Operation (short-term - up to 3 years)		2,116,910
- Subcontractor costs	1,693,260	
- Project management/administrative	234,859	
- SVE remedial work (1993)	105,899	
- SVE remedial work (1994)	55,216	
- Other costs (RA, Area 1, 2, 3, SVE, community relations, TSOPs, travel, ODCs, reporting, and closeout)	27,676	
Cost of Ownership		(58,346) ^a
- Overhead adjustment	(55,088) ^a	
- Unallowable costs	(3,258) ^a	
Total		2,058,564

^aValues in parentheses represent credits (i.e., amount that vendor deducted from total treatment cost).

Cost Data Quality

The costs described above represent actual costs for this treatment application as reported by EPA Region 8. Limited information is available on the specific activities included within several of these cost elements. Tables 12 and 13 show the available information.

Vendor Input

URS (the prime contractor) provided the following information on SVE remediation [13]:

There are a number of items that can affect the cost and opportunities for reductions in costs for similar projects to be completed in the future.

- (1) The most important factor is to adequately characterize the site and to identify the aerial extent and the vertical zones of contamination. This is necessary to adequately

TREATMENT SYSTEM COST (CONT.)

Vendor Input (cont.)

remediate the site and prevent cost growth during remediation as a result of "unforeseen site conditions." Change orders during cleanup will substantially impact the ultimate remediation cost. The detailed site characterization should be performed as part of the remedial design phase rather than the RI/FS phase. This will ensure that the design engineers obtain the "design related data" rather than less detailed and specific data required to produce the RI.

- (2) The site must be adequately characterized to ensure that all soil contaminants that will impact the SVE process are quantified. As a case in point, only approximately 2% of the total contaminants removed were target analytes. There are cases where the total quantity of contaminants were not characterized, resulting in large project cost increases because inappropriate air pollution control technologies were specified.
- (3) Innovative contracting strategies can provide opportunities for cost reductions. For example, rather than using a traditional firm fixed price contract, a two step procurement with a fixed price variable quantity contracting strategy could be used. This contracting strategy would provide for a firm fixed price for mobilization, installation and startup of the SVE system. There would also be a firm fixed price for a base period of operation. At the Sand Creek Industrial Superfund Site this could have been two months. The base period of system operation would then be followed by multiple fixed price option time periods. This approach will provide the selection of the best technical approach at the lowest estimated cost. It will also allow EPA to take advantage of cost reductions when a quick site cleanup occurs and pay a reasonable cost if the remediation takes longer. There will also be corresponding reductions to the Remediation Contractor's pricing because of reduced risk for the Contractor.

OHM (the treatment vendor) indicated that cost reduction is directly related to increasing productivity, reducing remediation time, and encouraging innovation. [14]

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- Approximately \$2.14 million were expended for SVE treatment of O.U. 1 at Sand Creek, including \$81,231 in before-treatment costs, and \$2,058,564 in costs directly attributed to treatment.
- The \$2,058,564 in costs directly attributed to treatment corresponds to \$39-65 per cubic yard of soil treated (31,440-52,920 cubic yards) and \$11.70 per pound of VOC removed (176,500 pounds). A range of costs is presented because of the variation in estimates of the quantity of soil treated. Estimates were provided using the average groundwater depth and average smear zone depth to calculate soil quantity treated.
- EPA's decision to revise the air emissions control equipment from activated carbon with off-site regeneration to catalytic oxidation (CATOX) resulted in a cost savings to the government. The prime contractor estimated the savings to be \$600,000 to \$750,000, while the treatment vendor estimated the savings as nearly \$2,000,000. EPA revised the control to CATOX because of the relatively large quantity of non-target VOCs in the soil.
- The RPM stated that there was limited benefit in shutting down the system in November 1993 when the operating data indicated that the cleanup criteria for target contaminants had been met. For example, the system was still removing significant quantities of non-target petroleum hydrocarbons. Although operating data (e.g., wellhead vapors) are becoming more acceptable as an indicator of soil concentrations, the vendor indicated that there was reluctance to perform confirmation soil borings in November 1993, and the system continued to operate until April 1994 when confirmation soil borings indicated the cleanup criteria had been met. Early shutdown would have saved EPA from paying oversight costs to the prime contractor (URS). However, had EPA shut down the system in November 1993, and then found an increase in wellhead vapor concentrations, EPA would have incurred additional costs for demobilization and remobilization.

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned (cont.)

- The prime contractor identified several items that should be considered in future SVE applications for reducing costs:
 - a detailed site characterization should be performed as part of the remedial design rather than the RI/FS, to identify the aerial extent and vertical zones of contamination, and to identify the total quantity of contaminants, including target and non-target contaminants. At Sand Creek, only approximately 2% of the total contaminants removed were target analytes.
 - innovative contracting strategies may provide a potential for cost savings with this technology as alternatives to traditional firm fixed-price contracts. For example, a two-step procurement with a fixed price contract for mobilization, installation, and system startup, followed by multiple fixed price option periods for system operation, would likely result in lower costs for SVE projects.

Performance Observations and Lessons Learned

- Analytical data from off-site laboratory analyses of confirmation soil borings indicate that the SVE system used at Sand Creek met the soil cleanup goals for VOCs within 6 months of operation.
- Soil concentrations were reduced from as high as 9.34 mg/kg (the maximum concentration shown in the RI for tetrachloroethene) to less than the cleanup goals. The maximum concentration of target constituents measured by the off-site laboratory for the confirmation soil borings was: chloroform - 0.0099 mg/kg; methylene chloride - not detected; trichloroethene - 0.10 mg/kg; and tetrachloroethene - 0.28 mg/kg. In addition, less than 20% of the soil boring samples (i.e., soil borings at specific depths) contained at least one target constituent measured at a detectable concentration.
- Equilibrium headspace results, and VOC extraction rate and mass results, indicate a reduction in contaminant levels and quantities over the course of the remediation. For example, equilibrium headspace results show a reduction for tetrachloroethene from 6.9 mg/L in September 1993 to 0.104 mg/L in December 1993 (Subarea 2), and from 0.3 mg/L in September 1993 to 0.005 mg/L in March 1994 (Subarea 3).
- Approximately 3,250 lbs of the four target VOC compounds and 176,500 lbs of total VOCs were extracted from the three subareas at O.U. 1. Tetrachloroethene accounted for approximately 98.5% of the mass of target compounds extracted from the subareas.

OBSERVATIONS AND LESSONS LEARNED (CONT.)

Other Observations and Lessons Learned

- The average quarterly destruction efficiency for the catalytic oxidizer ranged from 92.9 to 99.1% during the 6 months of SVE system operation.
- The mass of target compounds removed from the soil (3,250 pounds) was approximately 4.75 times greater than the original estimated mass of target compounds (684 pounds), determined based on preremedial target compound concentrations and estimated in situ soil volume reported in the remedial design report. According to the RPM, the reason for the difference was based on sampling and analysis for VOCs in the soil prior to remediation. According to the RPM, sampling and analysis of VOCs in soil can often be biased low, because of VOC losses in the sampling processes. In addition, according to the RPM, the pre-remediation VOC results may not have been representative of the zone of influence of the SVE wells.
- The treatment vendor used their patented Fluid Injection/Vapor Extraction (FIVE) technology in this application. The vendor stated that this system “enhanced subsurface volatilization and shortened the period of remediation.”
- The CATOX unit was a limiting factor in determining the number of wells that could be used for extraction. Early in the application, the concentration of contaminants in the extracted soil vapors was high, and the number of wells had to be limited so as not to overheat the CATOX unit. Later in the application, when the vapor concentrations were less, all wells in the system could be used for extraction.
- The vendor’s bid for this application included use of both horizontal and vertical wells, with “preference” given to horizontal wells, because the vendor believed that horizontal wells would increase the radius of influence. At that time, the use of horizontal wells for SVE was not widely practiced, and was considered an emerging technology. However, during installation of the first horizontal well at Sand Creek, the vendor discovered buried concrete blocks and other construction debris in the subsurface, and these items caused an increase in the cost and time required for horizontal well installation. As a result, the vendor abandoned their plan to give preference to horizontal wells. Instead of installing two additional horizontal wells, additional vertical wells were installed.

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