COST AND PERFORMANCE REPORT

Soil Vapor Extraction
at the
Verona Well Field Superfund Site,
Thomas Solvent Raymond Road (OU-1)
Battle Creek, Michigan

Prepared By:

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

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Notice

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COST AND PERFORMANCE REPORT

EXECUTIVE SUMMARY

This report presents cost and performance data for a soil vapor extraction (SVE) application at the Verona Well Field Superfund site in Battle Creek, Michigan.

This site was the primary well field for potable water for the city of Battle Creek. In 1984, the wells were determined to be contaminated with chlorinated solvents, and several source areas, including the Thomas Solvent Raymond Road (TSRR) area were identified. TSRR was used from the 1960s to the 1980s for storage and packaging of solvents. Spills from these operations, along with leaks from underground storage tanks, resulted in soil and groundwater contamination in this area. The contaminants of concern were volatile organic compounds (VOCs), primarily tetrachloroethene (PCE) and 1,1,1-trichloroethane.

A Record of Decision (ROD), signed in 1985, identified soil vapor extraction (SVE) as the remedial alternative for the TSRR area. Cleanup standards for the area were established in a 1991 ROD. The SVE system included 23 extraction wells, a separator, and offgas treatment. Both carbon adsorption and catalytic oxidation were used with this system, with catalytic oxidation used when the contaminant removal rate was greater than 10 lbs/day. A pilot-scale SVE system was operated in October 1987. Full-scale operation began in March 1988 and continued through May 1992.

The full-scale SVE system removed an estimated 45,000 pounds of VOCs. The soil cleanup standards were achieved for all VOCs with the exception of PCE. While there were several exceedances of the PCE standard, the average concentration of PCE was reported to be below the cleanup standards.

A groundwater pump and treat system was used at the TSRR area from March 1987 to December 1991. The system included nine shallow extraction wells and an air stripper. In addition, a pilot-scale groundwater sparging study was conducted in July 1991 and a sparging test was performed from December 1991 to April 1992.

Approximately $2,180,000 were expended for the SVE application at Verona, including $1,645,281 for activities directly associated with treatment. The $1,645,281 value corresponds to $62/cubic yard of soil treated (estimated as 26,700 cubic yards of soil) and $37/pound of VOC removed. Costs for this application were increased because of the requirement for extensive sampling and analysis. No information is contained in the available references on costs for groundwater cleanup at Verona.

SITE INFORMATION

Identifying Information

Verona Well Field
Battle Creek, Michigan
Thomas Solvent Raymond Road
(Operable Unit #1)

CERCLIS #: MID980793806
ROD Dates: 12 August 1985
28 June 1991

Treatment Application

Type of Action: Remedial
Treatability Study Associated with Application? No
EPA SITE Program Test Associated with Application? No
Operating Period: March 1988 to May 1992
Quantity of Soil Treated During Application: 26,700 cubic yards of soil (Based on an estimate provided by the vendor of a capture zone of 36,000 ft^2 and a depth of contamination of 20 ft.)

SITE INFORMATION (CONT.)

Background

Historical Activity that Generated Contamination at the Site: Solvent storage, blending, repackaging, distribution, and disposal

Corresponding SIC Code: 7389 (Business Services, not elsewhere classified)

Waste Management Practice that Contributed to Contamination: Spill; underground storage tanks

Site History: The Verona Well Field site was the primary well field of potable water for the city of Battle Creek, Michigan, as shown in Figure 1. Routine testing in August 1981 of the water supplies indicated that 10 of the city's 30 wells contained detectable levels of volatile organic compounds. By early 1984, 27 of the 30 supply wells were determined to be contaminated with volatile organic compounds (VOCs). As shown in Figure 2, three areas were identified as the sources of the contamination: the Thomas Solvent Raymond Road (TSRR) area, the Thomas Solvent Annex (TSA), and the Grand Trunk Western Railroad (GTWRR) facility. The TSRR area was used by the Thomas Solvent Company for solvent storage, transfer, and packaging from 1963 to 1984. This area, shown in Figure 3, was found to have the largest mass of contamination among the three source areas. Underground storage tank leakage and surface spills resulted in contamination of the soil and groundwater at the site. [11]

In May 1984, an Initial Remedial Measure was implemented that included converting 12 production wells into blocking wells to control the migration of the plume, installing three new production wells in the well field, and installing an air stripping system to treat extracted contaminated groundwater. [1, 10]

Regulatory Context: In August 1985, a ROD was signed for the TSRR Operable Unit #1 (OU-1) to remediate the soil by soil vapor extraction and the groundwater by pumping to the existing air stripper for treatment. A second ROD was signed in June 1991 to remediate the TSA and GTWRR source areas through soil vapor extraction and groundwater extraction and treatment with air stripping, and continued extraction and treatment of the groundwater at the TSRR source area. The second ROD also established final cleanup goals for the source areas, including the TSRR. [1, 10]

Remedy Selection: Soil vapor extraction (SVE) was selected as the remedial alternative for the TSRR source area. SVE was expected to remediate the contamination to 2% of its original mass (initially estimated as 1,700 lbs) within 2 years of operation. In addition, the installation and operation of SVE would not disturb the soil and cause volatilization of the contaminants to the surrounding area. Other alternatives (capping, soil flushing) were determined to be inconsistent with anticipated future activities at the site or were believed to require too much time to remediate the soil. [1, 12]

Figure 1. Site Location

SITE INFORMATION (CONT.)

Background (cont.)

Figure 2. Vicinity Map [11]

Figure 3. Thomas Solvent Raymond Road [10]

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Management: Fund Lead

Oversight: EPA

Remedial Project Manager:
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U.S. EPA - Region 5
77 W. Jackson Blvd.
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Prime Contractor:
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CH_2M Hill
411 E. Wisconsin Avenue
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Treatment System Vendor:
Robert Piniewski
Terra-Vac
9030 Secor Road
Temperance, MI 48182
(313) 847-4444

MATRIX DESCRIPTION

Matrix Identification

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

Contaminant Characterization

Primary Contaminant Groups: Halogenated and nonhalogenated volatile solvents.

The primary contaminants identified in the soil and groundwater included tetrachloroethene (PCE), trichloroethene, 1,1,1-trichloroethane, acetone and toluene. A light nonaqueous phase liquid (LNAPL) layer was identified in the groundwater. The contamination in the unsaturated zone covered an area of approximately one acre and the groundwater plume in the saturated zone covered an area of approximately one mile by one-half mile at the site. [1]

Data from the remedial investigation, conducted in November 1983, indicated that the total estimated volume of organic compounds, at the TSRR source area in the groundwater to be 3,900 pounds, and in the soil to be 1,700 pounds. These mass estimates were based on sample data obtained using a soil sampling procedure that is now known to produce VOC results lower than actual values. The total VOC mass in groundwater and soils was estimated in 1988 to be 13,000 to 16,500 pounds. This estimate was based on a pre-construction investigation performed prior to the installation of the SVE system. A special sampling technique, involving the use of 3-inch brass liners fitted inside the split spoon sampler, was employed for this soil sampling event to minimize handling and volatilization of the samples. [1, 12]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Cost or Performance [5, 10, 17]

The major matrix characteristics affecting cost or performance for this technology and their measured values are presented in Table 1. A particle size distribution as determined by the Unified Soil Classification System for soil boring W-6 at a depth of 10 feet is shown in Table 2.

Table 1: Matrix Characteristics [5, 10, 17]

Parameter	Value	Measurement Method
Clay Content	< 5 %	USCS
Particle Size Distribution	See Table 2	USCS
Moisture Content	5%	estimated
Air Permeability	10^{3} cm/sec	estimated
Porosity	30-40%	estimated
Total Organic Carbon	Not available	—
Nonaqueous Phase Liquids	Present (LNAPL layer identified)	—
Hydraulic Conductivity	0.0025 cm/sec	Not available

Table 2: Particle Size Distribution [5]

Soil Type	%
Gravel	5.70%
Coarse Sand	4.00%
Medium Sand	21.50%
Fine Sand	64.20%
Silt and Clay	4.60%

Site Geology/Stratigraphy

The geology at the site consists of 10 to 50 feet of relatively permeable Pleistocene and recent glacial and alluvial sand, sometimes gravelly or silty. These deposits overlie the Mississippian-age Marshall Sandstone, primarily a fine- to medium-grained quartz sandstone with interbeds of limestone, siltstone, and shale, particularly at depths of 90 to 100 feet. The sandstone is 100 to 120 feet thick and overlies the Mississippi Coldwater Shale, a gray to dark gray and silty shale. The shale thickness at the site is unknown as rock cores did not fully penetrate the shale. The natural groundwater surface at the site is located between 14 and 16 feet; however, pumping of the extraction wells lowers the water table to between 16 and 25 feet. The groundwater extraction system used in this application created a 50-foot cone of influence in the glacial aquifer. Bedrock beneath the site occurs on the average of 35 feet below the water table. Figure 4 shows the location of geologic cross-sections for the TSRR source area; Figures 5 and 6 show the results from characterizing the geology of the TSRR source area. [10, 13]

Figure 4. Geologic Cross-Section Locations [13]

MATRIX DESCRIPTION (CONT.)

Site Geology/Stratigraphy (cont.)

Figure 5. Geologic Cross-Section C-C' [13]

Figure 6. Geologic Cross-Section D-D' [13]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology Types

Soil Vapor Extraction
Pump and Treat With Air Stripping
Sparging

Supplemental Treatment Technology Types

Post-treatment (Air)—Carbon Adsorption and Catalytic Oxidation

Soil Vapor Extraction and Groundwater Extraction System Description and Operation [9,11]

A description of the soil vapor extraction system (both pilot-scale and full-scale) and the groundwater extraction system is presented in this section.

Soil Vapor Extraction—Pilot-Scale: A pilot-scale SVE system was installed in November 1987 and was operated intermittently over 15 days for a total operation time of 69 hours. The system consisted of 4 wells with individual extracted air flow rates ranging from 60 to 165 standard cubic feet per minute (scfm), and wellhead vacuums of 3 to 4 inches of mercury. The extraction wells were first operated independently to determine their radius of influence and their vapor flow rate/ vacuum pressure relationship, to investigate the effect of the underground tanks on the vacuum pressure distribution in the vadose zone, and to identify the VOC loading rates from the individual wells as a function of vacuum pressure and flow rate. The results were used to determine the optimum process variables and locations of additional wells for the full-scale system.

The total VOC concentrations in the soil vapor ranged from 2 mg/L to 204 mg/L with approximately 3,000 pounds of contaminants being removed. The radius of influence for the wells was determined to be greater than 50 feet, as measured with vacuum piezometers in nearby extraction wells. The average stack gas concentration of VOCs was 0.067 mg/L, at an average combined flow rate of 500 cfm.

Soil Vapor Extraction—Full-Scale: The full-scale soil vapor extraction (SVE) system used at the Verona Well Field TSRR, shown in Figure 7, consisted of 23 extraction wells, an air/ water separator, offgas treatment, and two vacuum blowers. The extraction wells were

Figure 7. Schematic of Soil Vapor Extraction System [10]

TREATMENT SYSTEM DESCRIPTION (CONT)

Soil Vapor Extraction and Groundwater Extraction System Description and Operation [9,11] (cont.)

2- and 4-inch diameter polyvinyl chloride (PVC) screened from approximately 5 feet below the ground surface to 3 feet below the groundwater table. The extraction wells had a sand pack around the screen portion and were also grouted to grade to prevent short circuiting of soil vapor along the side of the extraction wells. The extraction wells were connected together by a surface collection manifold. A throttling valve, sample port, and vacuum pressure gauge were attached to each well. The surface manifold was connected to a centrifugal air/water separator followed by vapor-phase carbon air treatment and 40- and 25-horsepower vacuum units. Following treatment, the off gas was discharged to the atmosphere through a 30-foot stack [9, 11].

During this full-scale operation, 14 of the 23 wells were used at a time to maximize the contaminant loading to the off-gas system. The selection of the 14 wells was determined based on VOC concentrations at the wellhead. This operating scheme produced a combined system air extraction flow rate between 1,400 and 1,600 scfm.

The SVE system was operated from March 1988 to May 1992. Operation of the system was temporarily suspended from November 1990 to February 1991, to dismantle the system, to remove the underground tanks, and to re-install the full-scale SVE system.

According to the vendor, the underground storage tanks were left in place due to health and safety concerns until the level of contamination was reduced. The tanks were removed in January 1991 after the SVE system had removed over 40,000 pounds of contaminants.

In February 1991, the SVE unit resumed operation and consisted of 20 wells, including 10 existing and eight new vapor extraction wells, and two new, dual groundwater/SVE wells, as shown in Figure 8. This re-assembled system operated almost continuously from February 1991 to May 1992 and produced a combined system air extraction flow rate of 1,000 scfm.

Carbon Adsorption— When the SVE system was originally installed, carbon adsorption was used to remove volatile organic compounds (VOCs) from the vapor stream prior to discharge. The carbon adsorption system, which was used from March 1988 to January 1990 and again from February 1991 to May 1992, consisted of two sets of four carbon

Figure 8. SVE System Layout

TREATMENT SYSTEM DESCRIPTION (CONT)

Soil Vapor Extraction and Groundwater Extraction System Description and Operation [9,11] (cont.)

vessels connected in series. Each carbon vessel contained 1,000 lbs of granular activated carbon. The primary set of carbon vessels adsorbed the majority of the VOCs; the secondary set was a backup for contaminant breakthrough from the primary set. The primary carbon was sent off site for regeneration and the secondary carbon placed in the primary position when breakthrough occurred. Carbon adsorption was selected because the contaminant mass was expected to be relatively small; however, full-scale SVE operation indicated that the total VOC mass in the subsurface was approximately 25 times larger than originally estimated, and carbon changeouts were required more frequently than originally anticipated. These changeouts resulted in greater downtime of the extraction system than anticipated, and the carbon system was replaced with a catalytic oxidation (CATOX) unit. Based on the relatively lower mass of VOCs remaining in the subsurface in February 1991 as compared with January 1990 (following the removal of the USTs and surrounding contaminated soil), carbon adsorption was determined to be more cost effective than the CATOX unit to treat the SVE off gas and was re-installed at this time. [9, 11]

CATOX—The CATOX system, which was used from January 1990 to October 1990, consisted of a particulate filter, blower, heat exchanger, a natural gas-fired burner, and catalyst bed. Chlorinated compounds that entered the CATOX unit were converted to carbon dioxide, water vapor, and hydrochloric acid. The catalyst in the system enabled the oxidation reaction to occur at lower temperatures than would be possible without the catalyst. During its use at the site, the CATOX system was run at temperatures between 780°F and 820°F. [9, 11]

Figure 9. Groundwater Extraction System Layout [10]

Groundwater Extraction System:
In addition to the SVE system, a groundwater pump and treat system was used at the TSRR from March 1987 to December 1991. The groundwater extraction (GWE) system, as shown in Figure 9, consisted of nine shallow extraction wells, screened in the unconsolidated aquifer, their associated instrumentation and controls, and approximately 5,000 feet of double-walled HDPE (high-density polyethylene) extraction force main piping. The well depths, screened intervals, and typical pumping rates for the wells are presented in Table

TREATMENT SYSTEM DESCRIPTION (CONT)

Soil Vapor Extraction and Groundwater Extraction System Description and Operation [9,11] (cont.)

Table 3. Verona Well Field (TSRR) Groundwater Extraction Well Characteristics [11]

Extraction Well (EW)	Well Diameter (inches)	Well Depth (feet)	Screen Interval (feet)	Typical Pumping Rate (gpm)
1	8	33	13 to 30	NA*
2	8	40	20.5 to 37	57
3	8	40	20.5 to 37	59
4	8	40	20.5 to 37	37
5	8	40.5	20.5 to 37.5	34
6	8	40	20 to 37	38
7	8	40	20 to 37	24
8**	24	43	12 to 36	50
9	8	40	20.5 to 37	60

**EW-1 was abandoned in 1989.*
***EW-8 is a product recovery well with a 24-inch steel casing. An 8-inch groundwater extraction well is also located within the well.*

3. All but Extraction Well (EW) 8 are 8-inch diameter wells. EW-8 is a 24-inch diameter well that was installed in the vicinity of the LNAPL layer and operates as a dual groundwater/ product recovery well. Groundwater was extracted from the individual wells to the monitoring building, and fed to the extraction force main (common header), which carries the groundwater to the wet well at an existing air stripper in the well field. The extraction wells each discharged between 30 to 70 gallons per minute (gpm) of groundwater for a total combined flow of 300 to 350 gpm. The capture zone of the GWE system is shown in Figure 10.

The GWE system was completed and began operating in March 1987. Through 1988, the product recovery pump in EW-8 removed more than 150 gallons (approximately 1,200 pounds) of the NAPL, which was collected in a holding tank and ultimately disposed off site. EW-1 was removed from service in 1989 because the maximum extraction rate was only 5 to 7 gpm. In 1990, EW-8 was converted to a dual vacuum extraction (DVE)

Figure 10. Approximate Groundwater Extraction Well Capture Zone in Unconsolidated Unit, April 1989 [11]

TREATMENT SYSTEM DESCRIPTION (CONT)

Soil Vapor Extraction and Groundwater Extraction System Description and Operation [9,11] (cont.)

well. The use of the DVE resulted in a 30% increase in vapor phase VOC recovery rates of the SVE system. The use of DVE was limited to the capacity of the existing groundwater treatment system, and consequently, additional DVE extraction wells could not be included because the treatment system could not accommodate the quantity of water that would be generated.

Sparging—In July 1991, a pilot-scale groundwater sparging (GWS) study was conducted using three sparging wells to evaluate sparging as a potential means for improving the performance of the GWE system for remediating the saturated soils. The sparging wells (AW1, AW2, and AW3) were installed at a depth between 30 to 35 feet below ground surface (approximately 10 feet below the dynamic water table) and were constructed of 2-inch PVC pipe with a 2-foot screen. The sparging wells were placed in an arc around EW-8 and were within the zone of influence for both groundwater and vacuum extraction. Each well included a rotameter to measure flow rates, and a pressure gauge to measure injection pressures. Additionally, two piezometer nests were installed to assess the effects of sparging within EW-8. Each nest consisted of a shallow (8 feet above the saturated zone), medium (3 feet above the saturated zone), and deep (2 feet below the dynamic water table) piezometers, constructed of 2-inch PVC pipe with a 2-foot screen. Nitrogen was used as the sparging gas instead of air to minimize formation of iron oxides in the groundwater. Based on the results of the pilot-scale study, a five-month sparging study was conducted from December 1991 to April 1992. [4, 11]

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 presented in Table 4.

Table 4. Operating Parameters [9]

Parameter	Value	Measurement Method
Air Flow Rate	1,400 to 1,600 cfm	Not specified
Operating Pressure/Vacuum	Not available	—

Timeline

A timeline for this application is shown in Table 5.

Table 5. Timeline [1, 2, 10, 11, 12, 13, 16]

Start Date	End Date	Activity
September 1983	—	Verona Well Field added to the National Priorities List
May 1984	—	Initial Remedial Measure implemented
August 1985	—	ROD signed for Operable Unit #1
March 1987	December 1991	Operation of GWE System
October 1987	—	Pilot-scale operation of SVE
March 1988	May 1992	Full-scale operation of SVE
January 1990	October 1990	Catalytic oxidation unit used in SVE system in place of carbon adsorption
November 1990	February 1991	SVE operation temporarily suspended
January 1991	—	Underground storage tanks removed
February 1991	May 1992	SVE operation resumes; carbon adsorption replaces CATOX unit
June 1991	June 1991	Pilot-Scale Sparging Test
June 1991	—	Second ROD Signed
December 1991	April 1992	Sparging Test
June 1992	—	Performance Objective Soil Sampling

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards [10,18]

The 1991 ROD specified the cleanup standards, shown in Table 6 for soil and groundwater at Verona. The 1991 ROD, which addressed and specified the remedy for the TSRR and two other source areas, stated that final soil and groundwater cleanup standards for the TSRR source area were to be the same as those for the TSA and GTWRR source areas. [10] The tetrachloroethene (PCE) cleanup goal shown in Table 6 (0.014 mg/kg , or 14 ppb) was changed from the goal shown in the 1991 ROD (10 ppb) to be consistent with a State of Michigan law (Act 307), which became effective subsequent to the signing of the 1991 ROD. Act 307 established levels for contaminants in soil that correspond to a 10^{-6} risk level.

Table 6. Cleanup Standards [10]

Constitutent	Soil Cleanup Standards (mg/kg)	Groundwater Cleanup Standards (mg/L)
Acetone	N/A	0.7
Benzene	0.02	0.001
Carbon Tetrachloride	0.01	N/A
Chlorobenzene	N/A	0.1
Chloroform	N/A	0.006
1,1-Dichloroethane	0.02	0.001
1,1-Dichloroethene	0.01	0.001
1,2-Dichloroethane	0.01	0.001
cis-1,2-Dichloroethene	0.02	0.001
trans-1,2-Dichloroethene	2	0.1
Ethylbenzene	1.4	0.07
Methylene chloride	0.1	0.005
Tetrachloroethene	0.014	0.001
Tolune	16	0.8
1,1,1-Trichloroethane	4	0.2
1,1,2-Trichloroethane	N/A	0.001
Trichloroethene	0.06	0.003
Vinyl chloride	N/A	0.001
Xylenes	6	0.3

N/A - Cleanup standards not specified for this constituent in this media.

Additional Information on Goals [1,10,11]

Although the 1985 ROD did not specify chemical-specific cleanup goals, contractual documents for the construction, operation, and maintenance of the SVE system, developed following the 1985 ROD, initially specified two performance objectives (1) none of the treated soil samples could have VOC concentrations greater than 10 mg/kg; and (2) less than 15% of the soil samples could have VOC concentrations greater than 1 mg/kg.

As specified in the 1991 ROD (signed during the operational phase for the SVE system), constituent-specific cleanup standards for soil and groundwater were established that superseded the performance objectives stated in the contractual documents.

Treatment Performance Data [2, 3, 4, 9, 12]

Soil Vapor Extraction System

Table 7 presents the analytical results of the performance objective soil sampling effort at the TSRR area. Confirmatory sampling of 26 soil borings was conducted in June 1992 to determine if the SVE system achieved the soil cleanup standards. A total of 115 soil samples were collected at random horizontal and vertical directions within each grid of the grid system established in accordance with the MDNR Guidelines for Verification of Soil Remediation. The soil samples were analyzed for VOCs according to CLP custody and analysis protocols.

The mass of volatile organic compounds (VOCs) removed during this SVE application is shown in Figure 11 as a function of cumulative days of system operation.

An in-line photoionization detection meter was used to monitor and determine breakthrough of the primary carbon system effluent. An on-site gas chromatograph was utilized to analyze vapor samples from individual wellheads and from the carbon system to calculate VOC loading and breakthrough rates.

TREATMENT SYSTEM PERFORMANCE (CONT)

Treatment Performance Data [2,3,4,9,12] (cont.)

Groundwater Pump and Treat System

Dissolved phase VOC concentration data were collected to assess the performance of the nitrogen sparging system. Groundwater sample analyses were performed using EPA Methods 601, 602, 8010, and 8020. Table 8 presents dissolved phase VOC data for selected constituents from EW-8 for ground-water monitoring events both before and during sparging and for two events after sparging. Figure 12 shows the measured concentrations in the extracted vapor (i.e.,

Table 7. Analytical Results of Soil Sampling at the TSRR Source Area [2,3,10]

Constitutent	Soil Cleanup Standard (mg/kg)	Untreated Soil (mg/kg) (Maximum)	Treated Soil (mg/kg) (Range)	Number of Detects	Number of Detects Greater than Cleanup Standard
Acetone	14	130	ND to 0.18	13	0
Benzene	0.02	NA	ND to 0.001	24	0
2-Butanone	8	17	ND to 0.018	3	0
Carbon Disulfide	14	NA	ND to 0.002	4	0
Carbon Tetrachloride	0.01	NA	ND	0	0
Chloroform	0.12	2	ND to 0.007	8	0
Chloromethane	0.06	NA	0.007	1	0
1,1-Dichloroethane	0.02	NA	ND	0	0
1,2-Dichloroethane	0.01	27	ND to 0.005	4	0
1,1-Dichloroethene	0.01	NA	ND	0	0
1,2-Dichloroethene (total)	2	NA	ND to 0.006	14	0
cis-1,3-Dichloropropene	0.004	NA	0.002	1	0
Ehtylbenzene	1.4	78	ND to 0.004	4	0
Methylene chloride	0.1	60	0.002	1	0
Tetrachloroethene	0.014	1800	ND to 0.711	70	20
Toluene	16	730	ND to 0.073	16	0
1,1,1-Trichloroethane	4	270	ND to 0.004	18	0
Trichloroethene	0.06	550	ND to 0.047	38	0
Xylenes (total)	6	420	ND to 0.018	4	0

ND - Not Detected

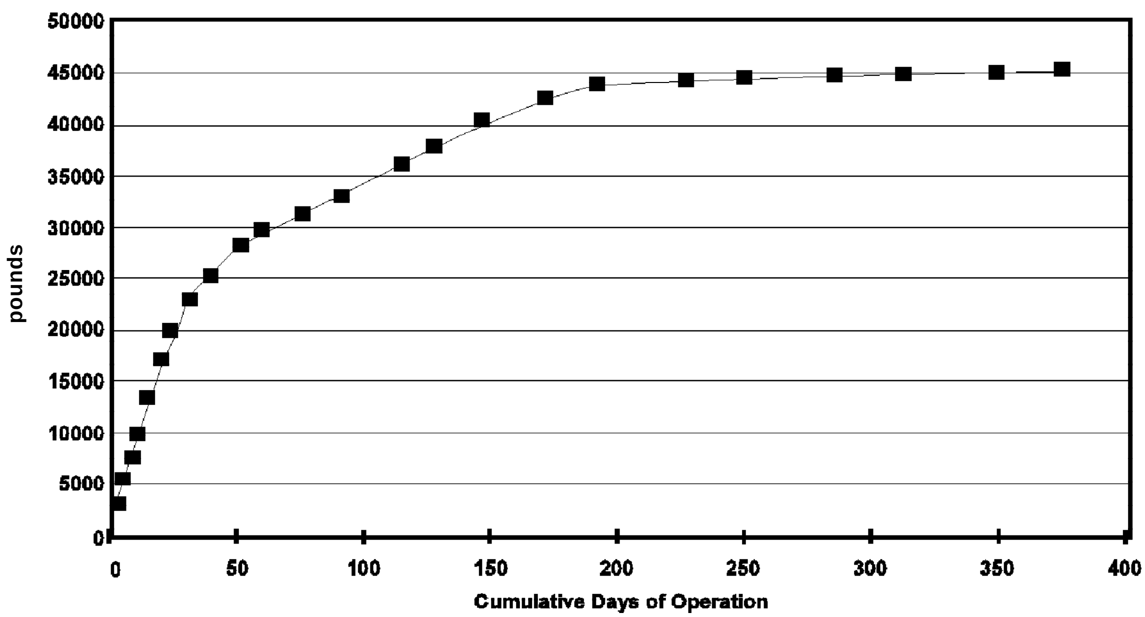

Figure 11. Total VOCs Removed Through Soil Vapor Extraction [11]

TREATMENT SYSTEM PERFORMANCE (CONT)

Treatment Performance Data [2,3,4,9,12] (cont.)

vapor phase VOC concentrations) from EW-8 before sparging (June, September, and November 1991) and during sparging (December 1991 through April 1992).

Table 8. Summary of Dissolved Phase VOC Concentrations (µg/L) at EW-8 [4]

VOC	3/91	5/91	7/91	9/91	11/91	12/91	2/92	2/92	3/92	4/92	6/92	7/92
1,2-Dichloroethene (total)	170	140	300	290	360	370	140	71	130	0	530	90
Tetrachloroethylene	440	430	480	510	310	380	220	160	84	30	250	87
1,1,1-Trichloroethane	100	96	220	140	100	120	0	10	33	10	90	30
Trichloroethylene	290	270	480	350	300	320	84	73	160	60	400	120
Toluene	320	250	20	370	99	580	130	39	48	0	380	130
Xylenes (total)	230	280	430	330	97	390	180	160	19	0	0	75
Ethylbenzenes	14	0	0	41	0	68	22	0	0	0	0	7
Total VOCs	1,564	1,466	1,930	2,031	1,266	2,228	776	513	474	100	1,650	539

NOTE: Sparging started on December 3, 1991, and ended on April 30, 1992.

Figure 12. Vapor Phase VOC Concentrations in EW-8 vs. Time. [4]

TREATMENT SYSTEM PERFORMANCE (CONT)

Performance Data Assessment

The analytical results from the soil sampling in June 1992 shown in Table 7 indicate that the SVE system achieved the cleanup standards for all VOCs with the exception of PCE. PCE was detected at concentrations greater than the cleanup standard of 0.014 mg/kg in 20 of 115 soil samples. According to the prime contractor, the average PCE concentration in the soil samples was less than the 0.014 mg/kg cleanup standard. [19]

Figure 11 indicates that over the course of about 375 days of operation, 45,000 lbs of total VOCs were removed through operation of the SVE system. Total VOCs shown in Figure 11 are the sum of the concentrations for the 19 constituents shown in Table 7. In addition, Figure 11 shows that the VOC removal rate had dropped from a high of 1,000 lbs/day during the first 2 weeks of operation to less than 100 lbs/day after 250 days of operation. According to the vendor, the removal rate had dropped to less than 1 lb/day after 400 days of operation. [17]

According to the remediation contractor, data from the groundwater remediation indicates the following:

- Dissolved phase VOC concentrations remained relatively constant prior to sparging (which began in December 1991);
- Dissolved phase VOC concentrations increased during the initial phases of sparging operation (December 1991);
- Dissolved phase VOC concentrations decreased during the sparging operation from a high of 2.228 mg/L in December 1991 to a low of 0.1 mg/L at the conclusion of sparging; and
- Dissolved phase VOC concentrations increased after the sparging operation was ended (according to the vendor, this increase may be the result of upgradient contamination). [17]

The results for vapor phase VOC concentrations (Figure 12) indicate that the VOC concentrations increased from about 0.04 mg/L to 0.342 mg/L during the first two months of sparging, then decreased to the pre-sparging levels of about 0.05 mg/L in March.

Performance Data Completeness

The available data are suitable for matching the maximum untreated soil concentrations to a range of treated soil concentrations.

Performance Data Quality

CLP protocols used for laboratory analysis of soil boring samples include required QA/QC procedures. The results for the QA/QC efforts are available from the contractor or vendor for this application. [3]

TREATMENT SYSTEM COST

Procurement Process

The remedial activities at the Verona Well Field Site were funded by EPA. Procurement of soil vapor extraction began in March of 1987 and ended seven months later in September 1987. CH_2M Hill was the prime contractor who subcontracted with Terra Vac for the vacuum extraction technology, in a competitive procurement process. [20]

In September of 1990, the contract was switched from a Remedial Planning (REM) IV contract to an Alternative Remedial Contracting Strategy (ARCS) contract. Since there are different requirements under ARCS, CH_2M Hill rebid the subcontract. When the subcontract was rebid under ARCS, CH_2M Hill wrote a sole source justification for Terra Vac to continue the work. [20]

TREATMENT SYSTEM COST (CONT.)

Treatment System Cost

Tables 9 and 10 present the costs for the Soil Vapor Extraction application at Verona Well Field. In order to standardize reporting of costs across projects, costs are shown in Tables 9 and 10 according to the format for an interagency Work Breakdown Structure (WBS). The WBS specifies 9 before-treatment cost elements, 5 after-treatment cost elements, and 12 cost elements that provide a detailed breakdown of costs directly associated with treatment. Tables 9 and 10 present the cost elements exactly as they appear in the WBS, along with the specific activities, and unit cost and number of units of the activity (where appropriate), as provided by the treatment vendor (Terra Vac) and oversight contractor (CH_2M Hill). CH_2M Hill provided costs for contractor oversight and soil sampling and analysis. All other costs were provided by Terra Vac.

As shown in Table 9, the vendor and contractor provided cost data that shows a total of $1,645,281 for cost elements directly associated with treatment of 26,700 cubic yards of soil treated (i.e., excluding before-treatment cost elements). This total treatment cost corresponds to $62 per cubic yard of soil treated, and to $37 per pound of contaminant removed (45,000 pounds). This calculated cost per cubic yard of soil treated is based on an estimate of the zone of influence of the extraction wells. The actual quantity of contaminated media is not available for comparison purposes. In addition, the vendor and contractor provided costs data that show a total of $535,180 for before-treatment costs. The vendor and contractor indicated that there were no costs in this application for after-treatment activities.

No information is contained in the available references on the costs for groundwater cleanup at Verona.

Cost Data Quality

Actual treatment cost data for 11 WBS elements were provided for this application. These costs are broken down into detailed activities completed at Verona, and include costs incurred by both the treatment vendor and oversight contractor.

Table 9. Actual Costs for Activities Directly Associated with Treatment [Adapted from 17, 19]

Activity	Unit Cost	Number of Units	Cost
Vapor/Gas Preparation and Handling			
Activiated carbon (per lb.)	$2.55	14,600	$37,230.00
Catalytic oxidation (per 2 months)	$18,720.00	0.22	$4,118.40
80,000 pounds of carbon	$170,000.00	lump sum	$170,000.00
100,000 pounds of carbon plus additional labor	$285,000.00	lump sum	$285,000.00
CATOX continuous operation	$78,000.00	lump sum	$78,000.00
Carbon Adsorption System	$4,650.00	lump sum	$4,650.00
Mobilization/ Setup			
Submit O&M Manual	$25,000.00	lump sum	$25,000.00
Submittals - Pilot Test	$27,000.00	lump sum	$27,000.00
Set-up Facilities	$49,000.00	lump sum	$49,000.00
Evaluate Well Data	$4,000.00	lump sum	$4,000.00
Pilot Test Design	$15,000.00	lump sum	$15,000.00
Install Pilot test	$43,000.00	lump sum	$43,000.00
SVE Design/Submittals	$29,000.00	lump sum	$29,000.00
Install Manifold	$11,000.00	lump sum	$11,000.00
Install Vacuum System	$115,000.00	lump sum	$115,000.00

TREATMENT SYSTEM COST (CONT)

Treatment System Cost (cont.)

Table 9. (cont.) Actual Costs for Activities Directly Associated with Treatment [Adapted from 17, 19]

Activity	Unit Cost	Number of Units	Cost
Mobilization/ Setup (cont.)			
Install Carbon system	$37,000.00	lump sum	$37,000.00
Mobilize and Setup (CATOX)	$30,000.00	lump sum	$30,000.00
Mobilization for Drilling	$950.00	lump sum	$950.00
Drilling - Level D (150 feet)	$171.00	26.80	$4,582.80
Drilling Mobilization	$475.00	lump sum	$475.00
Vapor Extraction Well Casing and Seal (70 Feet)	$29.50	101.00	$2,979.50
Vapor Extraction Well Screen and Gravel Pack (80 Feet)	$38.70	70.00	$2,709.00
SVE System Hookup (per hookup)	$385.00	11.00	$4,235.00
Construction of Dual Groundwater SVE Well	$7,100.00	lump sum	$7,100.00
Construction of 2 Piezometer Well	$5,350.00	lump sum	$5,350.00
Construction of 3 Air Injection Well Nests	$6,925.00	lump sum	$6,925.00
Construction of EW-6 to Dual Extraction Well	$2,425.00	lump sum	$2,425.00
Installation of 20-ft fence gate	$1,450.00	lump sum	$1,450.00
Set-up and Mobilization of Sparging System	$7,375.00	lump sum	$7,375.00
Startup/Testing/Permits			
Startup and Test SVE	$44,000.00	lump sum	$44,000.00
CATOX Startup	$25,000.00	lump sum	$25,000.00
SVE Well Monitoring System Restart (per day)	$1,500.00	3.00	$4,500.00
Operation (short-term - up to 3 years)			
Operate Pilot Study	$31,000.00	lump sum	$31,000.00
24 Month Operations	$175,000.00	lump sum	$175,000.00
Pilot Study Saturated Zone Sparging	$23,230.00	lump sum	$23,230.00
First Month of Operations	$11,480.00	lump sum	$11,480.00
January Sparging Operations	$9,039.00	lump sum	$9,039.00
February Sparging Operations	$6,526.43	lump sum	$6,526.43
March Sparging Operations	$9,180.00	lump sum	$9,180.00
April Sparging Operations	$8,748.00	lump sum	$8,748.00
Groundwater Extraction System Conncetion to Blower Seal Repair	$4,950.00	lump sum	$4,950.00
HDPE Piping & Conduit Repairs	$8,010.00	lump sum	$8,010.00
Contractor Oversight (per month)	$1,000.00	36.00	$36,000.00
Operation (long-term - over 3 years)			
SVE Sytem Operation (per month)	$6,096.00	16.07	$98,010.00
Contractor Oversight (per month)	$1,000.00	20	$20,000.00
Cost of Ownership			
Contract Execution	$14,000.00	lump sum	$14,000.00
Bond/Insurance	$54,000.00	lump sum	$54,000.00
Bonding	$33,200.00	lump sum	$33,200.00

TREATMENT SYSTEM COST (CONT)

Treatment System Cost (cont.)

Table 9. (cont.) Actual Costs for Activities Directly Associated with Treatment [Adapted from 17, 19]

Activity	Unit Cost	Number of Units	Cost
Dismantling			
Well Abandoment (per well)	$110.00	13	$1,430.00
Demobilization			
SVE Manifold Piping Removal and Replacement (per foot)	$19.10	567	$10,829.70
SVE System Demobilization (per system)	$10,125.00	0.604	$6,118.34
Drilling Demobilization	$475.00	lump sum	$475.00
TOTAL			**$1,645,281.17**

Table 10. Actual Before-treatment Cost Elements [adapted from 17, 19]

Activity	Unit Cost	Number of Units	Cost
Monitoring, Sampling, Testing, and Analysis			
Daily Reporting	$2,000.00	lump sum	$2,000.00
Additional Soil Borings	$23,000.00	lump sum	$23,000.00
Additional Air Sampling	$75,000.00	lump sum	$75,000.00
Split Spoon Sampling During SVE Well Construction (per well)	$50.00	6	$300.00
Soil Sampling and Analysis Performed by ARCS Contractor	$150,000.00	lump sum	$150,000.00
Subsurface Investigation	$42,000.00	lump sum	$42,000.00
Soil Gas Survey	$5,500.00	lump sum	$5,500.00
Geophysical Study	$8,000.00	lump sum	$8,000.00
Site Work			
Bail LNAPL	$2,000.00	lump sum	$2,000.00
Backfill and Compaction of spoils	$24,773.00	lump sum	$24,773.00
Backfill and Compaction of Clean Fill	$23,356.00	lump sum	$23,356.00
Packaging and Handling of Contaminated Soils (per package)	$110.62	2	$221.24
Drums/Tanks/Structures/Miscellaneous Demolition and Removal			
Drum Disposal (per drum)	$950.00	4	$3,800.00
Excavation of USTs	$114,225.00	lump sum	$114,225.00
Tank Removal, Cleaning, and Disposal	$61,005.00	lump sum	$61,005.00
TOTAL			**$535,180.24**

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- A total of approximately $2,180,000 were expended for the SVE application at Verona, including $1,645,281 for activities directly associated with treatment. The $1,645,281 amount corresponds to $62 per cubic yard of soil treated and $37 per pound of VOC removed.
- Costs for this application were increased due to the requirement for extensive sampling and analysis.

OBSERVATIONS AND LESSONS LEARNED (CONT)

Cost Observations and Lessons Learned (cont.)

- Because the actual mass of VOCs removed during the remediation was approximately 25 times greater than the original estimate of 1,700 pounds of VOCs in the soil, the use of carbon adsorption proved to be more costly than originally anticipated during the initial phase of system operation. This higher cost was due to frequent carbon changeouts needed for the larger than expected VOC loadings, and contributed to the decision to replace the carbon system with a catalytic oxidation system. Also, the duration of the cleanup was increased since the extraction vapor system did not operate during carbon changeouts, which also contributed to an increase in costs.
- The use of carbon adsorption during the latter phase of system operation was determined to be more cost-effective than the catalytic oxidation system (CATOX). This decision was attributed to the VOC loadings following UST removal being less than the loadings to the vapor treatment devices during the initial phase of the operation.

Performance Observations and Lessons Learned

- The SVE system achieved the specified soil cleanup standards for all VOCs, with the exception of PCE. Several exceedances of PCE were identified; however, the average concentration of PCE was reported to be below the specified cleanup standard of 0.014 mg/kg.
- The VOC removal rate varied considerably over the course of operating the SVE system, dropping from a high of 1,000 lbs/day during the first 2 weeks of operation to less than 100 lbs/day after 250 days of operation.
- The results from the sparging studies indicated that groundwater sparging had a quick and fairly significant effect in reducing dissolved phase VOC concentrations for selected constituents.
- According to the remediation contractor, dissolved phase VOC concentrations remained relatively constant prior to sparging and increased after the sparging operation ended.
- According to the vendor, air or oxygen could have been used for sparging instead of nitrogen to enhance bioremediation of the nonaqueous phase liquid hydrocarbons. Air or oxygen would have been less expensive than nitrogen.

Other Observations and Lessons Learned

- Naturally-occurring radon gas was detected in the carbon vessels. However, because the levels were not considered to be a public or worker health hazard, there were no additional costs associated with handling the vessels as low level radioactive waste.
- Additional information provided by the RPM and Contracting Officer concerning the procurement and contracting processes at the Verona Well Field Site (and other remedial action sites) is provided in Reference 20. Reference 20 is available from the U.S. EPA National Center for Environmental Publications and Information (NCEPI), P.O. Box 42419, Cincinnati, OH 45242; (fax orders only-(513) 489-8695).

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6. CH_2M Hill Memo dated 22 January 1992, “Operation of SVE System during 1992 at Thomas Solvent Raymond Road”.
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19. Comments received from Paul Boersma, CH_2M Hill, on the draft cost and performance report, Soil Vapor Extraction at Verona Well Field Superfund Site, February 1995.
20. Procuring Innovative Treatment Technologies at Remedial Sites: Regional Experiences and Process Improvements, U.S. EPA, Publication 542/R-92/002, April 1992.

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