

DRAFT

# Cost and Performance Report

**Air Sparge/Soil Vapor Extraction  
Mound Plant OU-1 Site  
Miamisburg, Ohio**

**Innovative Treatment  
Remediation Demonstration  
U.S. Department of Energy**

**January 2001**









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## LIST OF ACRONYMS

<i>AS</i>	<i>air sparge</i>
<i>Atm</i>	<i>atmosphere</i>
<i>cfm</i>	<i>cubic feet per minute</i>
<i>cm/sec</i>	<i>centimeters per second</i>
<i>COC</i>	<i>contaminant of concern</i>
<i>DCE</i>	<i>dichloroethene</i>
<i>DOE</i>	<i>Department of Energy</i>
<i>EPA</i>	<i>Environmental Protection Agency</i>
<i>ER</i>	<i>Environmental Restoration</i>
<i>g/mol</i>	<i>grams per mole</i>
<i>GAC</i>	<i>granulated activated carbon</i>
<i>GC</i>	<i>gas chromatograph</i>
<i>ITRD</i>	<i>Innovative Treatment Remediation Demonstration</i>
<i>L/mol</i>	<i>liters per mole</i>
<i>lbs/hr</i>	<i>pounds per hour</i>
<i>mg/L</i>	<i>milligrams per liter</i>
<i>MSL</i>	<i>mean sea level</i>
<i>µg/g</i>	<i>micrograms per gram</i>
<i>µg/L</i>	<i>micrograms per liter</i>
<i>PCE</i>	<i>tetrachloroethene (perchloroethene)</i>
<i>ppbm</i>	<i>parts per billion mass</i>
<i>ppmv</i>	<i>parts per million volume</i>
<i>RCRA</i>	<i>Resource Conservation and Recovery Act</i>
<i>scfm</i>	<i>standard cubic feet per minute</i>
<i>SVE</i>	<i>soil vapor extraction</i>
<i>TCE</i>	<i>trichloroethene</i>
<i>v/v</i>	<i>volume per volume</i>
<i>VOC</i>	<i>volatile organic compound</i>

## FOREWORD

The Department of Energy (DOE) is working to accelerate the acceptance and application of innovative technologies that improve the way the nation manages its environmental remediation problems. The DOE Office of Environmental Restoration (EM-40) established the Innovative Treatment Remediation Demonstration (ITRD) Program to help accelerate the adoption and implementation of new and innovative soil and ground water remediation technologies. Developed as a public-private partnership in cooperation with Clean Sites Inc., the U.S. Environmental Protection Agency (EPA) Technology Innovation Office, and Sandia National Laboratories, the ITRD Program attempts to reduce many of the classic barriers to the use of new technologies by involving government, industry, and regulatory agencies in the assessment, implementation, and validation of innovative technologies.

The ITRD Program is an operational testing and evaluation program that assists DOE facilities in identifying and evaluating innovative technologies that can remediate their sites in the most cost-effective and responsible manner. The technologies considered for evaluation lack the cost and performance information that would otherwise permit their full consideration as remedial alternatives. The technologies have often shown promise in bench- or small-scale applications but have limited pilot or full-scale operational performance data.

Funding is provided through the ITRD Program to assist participating site managers in identifying, evaluating, implementing, and monitoring innovative technologies. The program provides technical assistance to the participating DOE sites by coordinating DOE, EPA, industry, and regulatory participation in each project; providing funds for site-specific treatability and pilot studies for optimizing full-scale operating parameters; coordinating technology performance monitoring; and by developing cost and performance reports on the technology applications.

An ITRD Project was initiated in 1995 with the DOE Mound Facility in Miamisburg, Ohio at the OU-1 Site, a three acre capped landfill. The site is characterized by chlorinated volatile organic compound contamination of ground water in a shallow, high permeability, sandy-gravel, sole source aquifer overlain by volatile organic compound contaminated low permeability glacial till and compacted fill. Advisory groups composed of DOE, EPA, industry, and state and federal regulatory representatives worked with the site Environmental Restoration (ER) Program to review and evaluate approximately 20 potentially applicable innovative remediation technologies that could enhance the cost or performance of the proposed baseline pump-and-treat system. Participants involved in the assessment and evaluation of this technology included Ohio Environmental Protection Agency (OEPA), U.S. EPA National Risk Management Research Laboratory, U.S. EPA Region V, U.S. EPA Superfund Innovative Technology Evaluation (SITE), U.S. EPA Technology Innovation Office, U.S. DOE Office of Environmental Restoration (EM-40), U.S. DOE Ohio Field Office, Sandia National Laboratories, Babcock and Wilcox of Ohio, ICI Americas, Inc., Occidental Chemical, Clean Sites, Inc., and EG&G Mound Applied Technologies.

Based on this technology review the Mound Facility selected two complementary technologies for full scale implementation. The technologies selected were air sparging of the aquifer through 23 air injection wells, and soil vapor extraction through 12 extraction wells and five French drains. The purpose of this Cost and Performance Report is to document these activities, present summary data, and provide evaluation results on the cost and performance of this air sparge/soil vapor extraction system.



## 1. SUMMARY

From mid December 1997 through mid May 2000, the Innovative Treatment Remediation Demonstration (ITRD) Program conducted a performance evaluation at the Mound Plant Operable Unit 1 (OU-1) Site to remediate volatile organic compounds (VOCs) in the landfill vadose (unsaturated) and saturated zones. The treatment system evaluated was a combination of air sparge and soil vapor extraction technologies. The OU-1 Site is characterized by VOC contamination of a 15 to 20 foot thick saturated zone composed of glacial outwash materials, primarily gravel and sandy gravel, and an unsaturated zone, ranging from 24 to 31 feet thick, composed of glacial till and artificial fill. The primary objectives of this study were to 1) evaluate the effectiveness of combining air sparge and soil vapor extraction technologies for the removal of chlorinated VOCs from water and soil matrices simultaneously, and 2) obtain operating and performance data to evaluate the design, operation, and cost of a full-scale system. During the operational period of this study, the emphasis was on reducing contaminants to a specific regulatory level.

The OU-1 Site initial total chlorinated contaminant concentrations in groundwater ranged from 10 to 1200 µg/L (ppbm), with an average of 101 µg/L. The total chlorinated contaminant concentrations of the unsaturated zone generally ranged from 0.001 to 14.4 µL/L. (ppmv). However, one well had a total VOC concentration of 8619 µL/L.

The air sparge/soil vapor extraction system consisted of ten valved extraction wells with various screen intervals, five valved French drains, and twenty-three air injection wells. The valves on the extraction wells and French drains allowed operators to adjust airflow for individual well optimization. Air was pumped into the aquifer through the injection wells, and removed as soil vapor from the extraction wells and French drains. VOC concentrations were monitored at the extraction manifold by an automated onsite gas chromatograph to optimize system performance.

This report covers system operations from start-up on December 16, 1997 through May 30, 2000. During this period, the air sparge system was operational from December 18, 1997 through February 4, 1998. The air sparge system was shut down after seven weeks operation due to fouling of the well screens. The soil vapor extraction system, however, was operational for the entire time except for short maintenance periods. The soil vapor extraction system removed soil gas at rates ranging from 475 to 625 scfm during the evaluation period. As of May 30, 2000 3,433 lbs of VOCs had been removed from the OU-1 Site by the vapor extraction system, and the total VOC concentration in the unsaturated zone decreased from 618.1 µL/L (ppmv) to 4.54 µL/L (ppmv).

The total cost for the full scale AS/SVE system was \$1,439,039, with \$116,773 (8.11%) representing pilot testing, \$221,591 (15.40%) representing design costs, \$398,000 (27.66%) representing construction costs, \$517,958 (35.99%) representing operating costs, and \$184,717 (12.84%) representing sampling and analysis costs. Based on these figures the system costs were \$420 per pound of contaminant removed as of May 2000. If system performance is maintained, the site is anticipated to meet regulatory cleanup levels by December 2002.

## 2. SITE INFORMATION

### *Identifying Information*

*Facility:* Mound Plant  
*Location:* Miamisburg, Ohio  
*OU/SWMU:* OU-1 Site  
*Regulatory Driver:* CERCLA  
*Type of Action:* ITRD Technology Demonstration  
*Technology:* Air sparge/soil vapor extraction  
*Period of operation:* December 1997 to May 2000  
*Treatment volume:* 46,000 cubic yards

### *Site Background*

The Mound Plant is a government owned and contractor operated facility occupying a 306-acre site within the city of Miamisburg, Montgomery County, Ohio. The site is approximately 10 miles south-southwest of Dayton and 45 miles north of Cincinnati. The plant site is bordered on the north by the city of Miamisburg, on the south by the township of Miami, to the south and east by arterial roads, and to the west by railroad tracks (Figure 1). The Mound Facility is situated on an escarpment with topographic elevation ranging from 900 feet MSL, on the east boundary, to 725 feet MSL, along the north, south, and west boundaries. Montgomery County has two distinguishing climatic elements, temperature and precipitation. Precipitation is abundant, with significant amounts occurring year-round. Overall, the county can be described as having warm summers and cold winters.

The OU-1 Site occupies approximately three acres on the western edge of the developed portion of the facility (Figure 2). The operable unit is composed of four sub-units: the historic landfill, the site sanitary landfill, the overflow pond, and three plant production water wells (Figure 3). The OU-1 site sanitary landfill area slopes steeply and is covered with soil and native vegetation.

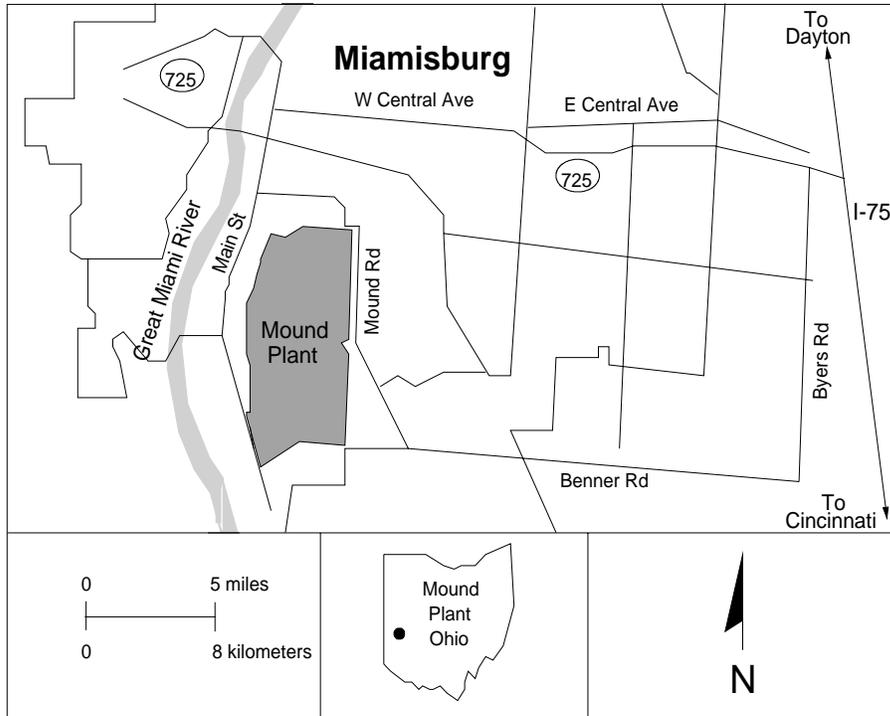
### *Site History*

The Mound Plant, currently owned by the U S Department of Energy, was first occupied in 1948 under the auspices of the Atomic Energy Commission. The site has had three contractors - Monsanto Research Corporation (1948-1988), EG&G Mound Applied technologies (1988-1997), and Babcock & Wilcox Technologies of Ohio (BWXTO), the present contractor. As current site contractor, BWXTO will oversee closure activities and cleanup of the Mound Plant prior to conversion of the facility to private ownership.

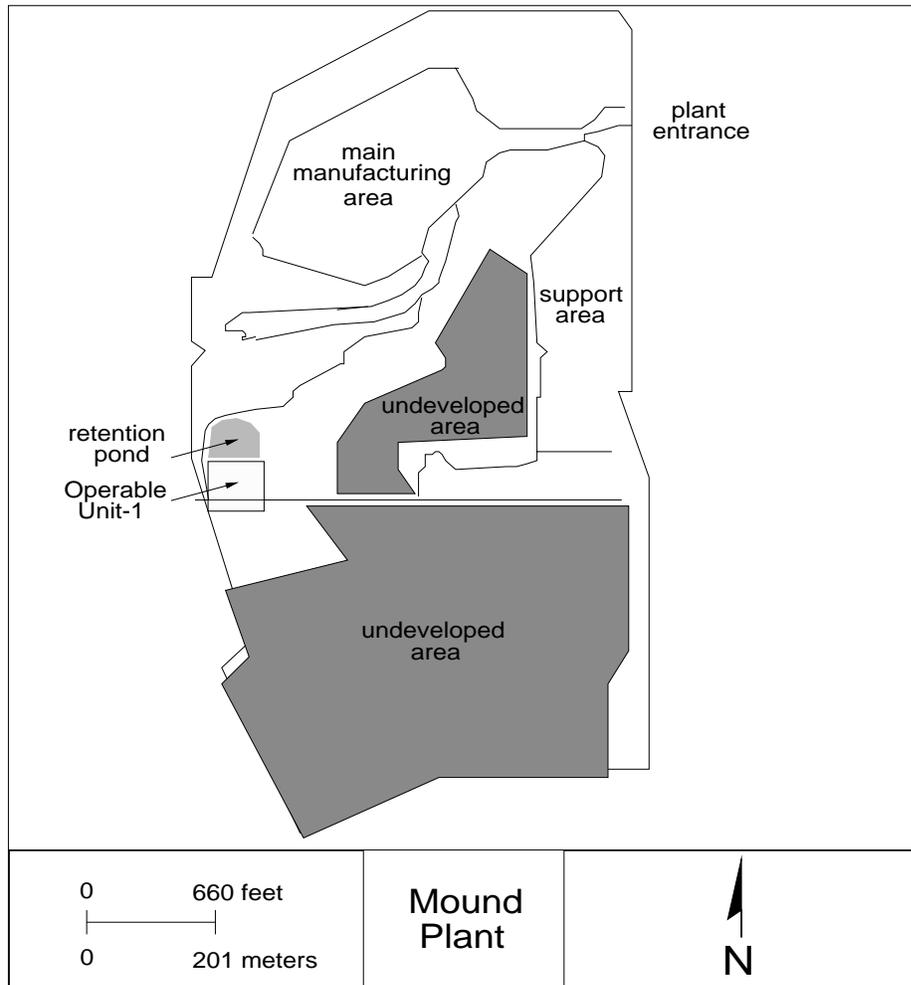
On November 21, 1989, the Mound Plant was placed on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priorities List (NPL) under Section 120 of CERCLA. The Mound Plant site was divided into Operable Units (OUs) to facilitate site investigation and remediation under the environmental restoration program.

The historic landfill in Operable Unit 1 (OU-1) was used between 1948 and 1974 for disposal of general trash, and liquid wastes from Mound Plant operations. Much of the waste was relocated and encapsulated in the site sanitary landfill in 1977. The sanitary landfill was constructed partially within and adjacent to the location of the historic landfill. Both disposal sites have a long history of dumping, burning, moving, reworking, and burying of various plant wastes.

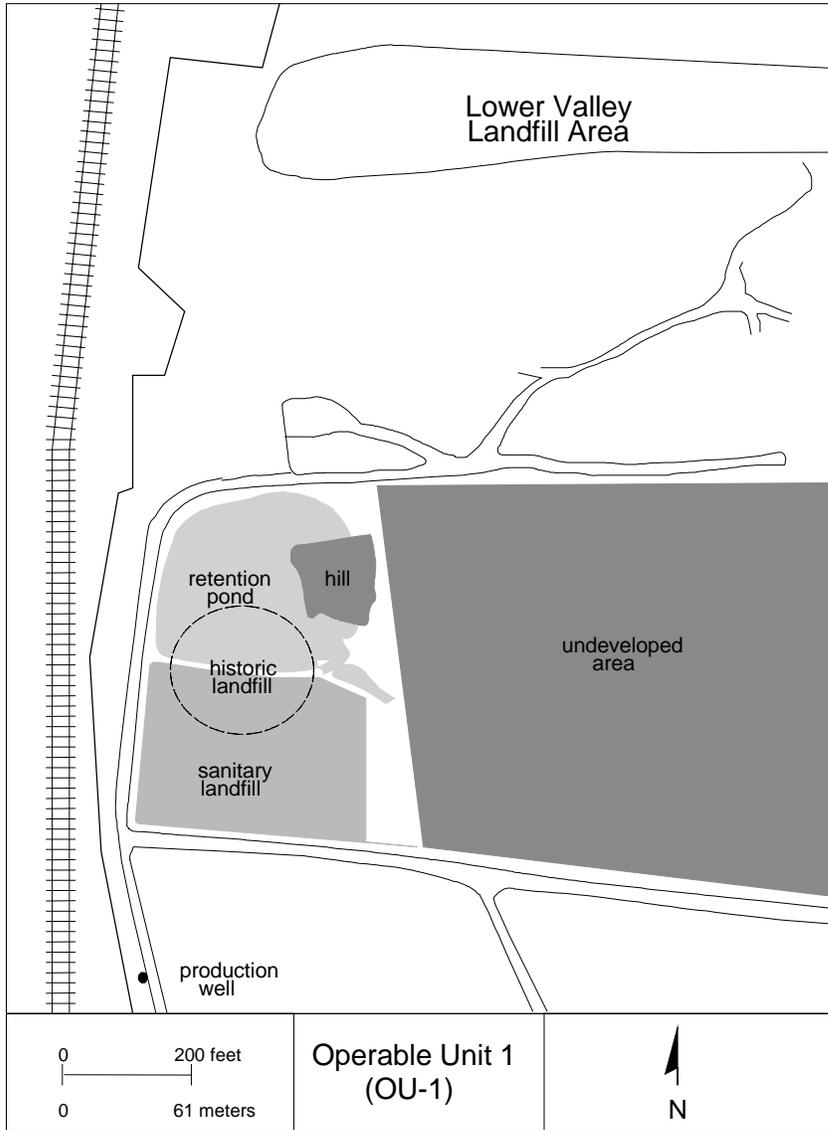
Mound Plant personnel began a periodic water sampling program for volatile organic compounds (VOCs) in 1984. A Phase 1 Preliminary Assessment/Site Inspection was completed in 1986 as part of an Environmental Restoration (ER) Program. The water sampling program and Phase 1 Investigation results indicated the presence of VOCs in both the soil vadose zone and groundwater of OU-1.



**Figure 1. Local and regional setting of the Mound Plant.**



**Figure 2. Location of Operable Unit-1 (OU-1) at Mound Plant.**



**Figure 3. Mound Plant Operable Unit 1 Site.**

### ***Contaminant Inventory***

The VOC contamination was primarily restricted to depths less than 20 feet below grade. The primary VOCs detected in vadose zone soil samples were *cis*-1,2-dichloroethene (DCE), trichloroethene (TCE), toluene, tetrachloroethene (PCE), ethylbenzene, and xylenes. Analysis of soil vapor samples indicated VOC soil concentrations generally less than 10 µL/L (ppmv) with a median concentration of 3.21 µL/L (ppmv). However, a peak concentration of 8619 µL/L was found in one area.

Dissolved VOCs detected in the groundwater at levels above the established regulatory limits included vinyl chloride, trichloromethane, DCE, TCE, and PCE. The aqueous concentrations of individual VOCs were generally less than 1 µg/L (ppbm) with seasonal variability bringing a maximum concentration of 7 µg/L in some areas. The dissolved VOCs in the groundwater appear to be sourced by the vadose zone VOC contamination.

### ***Site Contacts***

Site management was provided by the DOE Miamisburg Environmental Management Project Office (MEMP). The BWXTO Mound OU-1 Environmental Restoration Project Manager was Monte Williams [(937) 865-4543]. The technical contacts for the Mound Air Sparge/Soil Vapor Extraction Project were Dr. Gary Brown, the ITRD technical coordinator at Sandia National Laboratories [(505) 845-8312]; and Mark Spivey, the BWXTO Mound OU-1 Project Engineer [(937) 865-3709].

## **3. MATRIX AND CONTAMINANT DESCRIPTION**

### ***Site Geology/Hydrology***

Based on analysis of soil borings, details of well construction, and environmental studies the OU-1 site is located on a buried bedrock shelf that drops off to the west, north, and south. The surface of the bedrock is a pre-glacial erosional surface that is weathered, but grades rapidly into competent material. The bedrock material is overlain by 15 to 20 feet of glacial outwash materials, primarily gravel and sandy gravel. A surficial deposit ranging from 24 to 31 feet thick, composed of glacial till and artificial fill, caps the site. The fill and glacial till are texturally silty clay to sandy clay.

The principal groundwater aquifer, the Buried Valley Aquifer, is contained in the outwash materials above the bedrock. Only the western portion of the site sanitary landfill overlies the aquifer. The portion of the Buried Valley Aquifer immediately adjacent to OU-1 varies from 0 to 40 feet thick and is relatively free of fine-grained till layers within the outwash. In the main part of the aquifer, to the west of OU-1, gradients are nearly flat with flow from the east and north. Flow is governed by the interrelationships among recharge, river stage, and pumping of the Mound Plant production wells.

The waste materials and contaminated soils within OU-1 are partially isolated from the hydrologic environment, because much of the surface is engineered to provide rapid runoff. The water table is at or above the bedrock interface, leaving most unconsolidated contaminated materials in the unsaturated zone. However, during periods of high seasonal groundwater or enhanced recharge some contaminated soils are exposed to circulating waters. The hydrogeologic setting is shown in Figure 4.

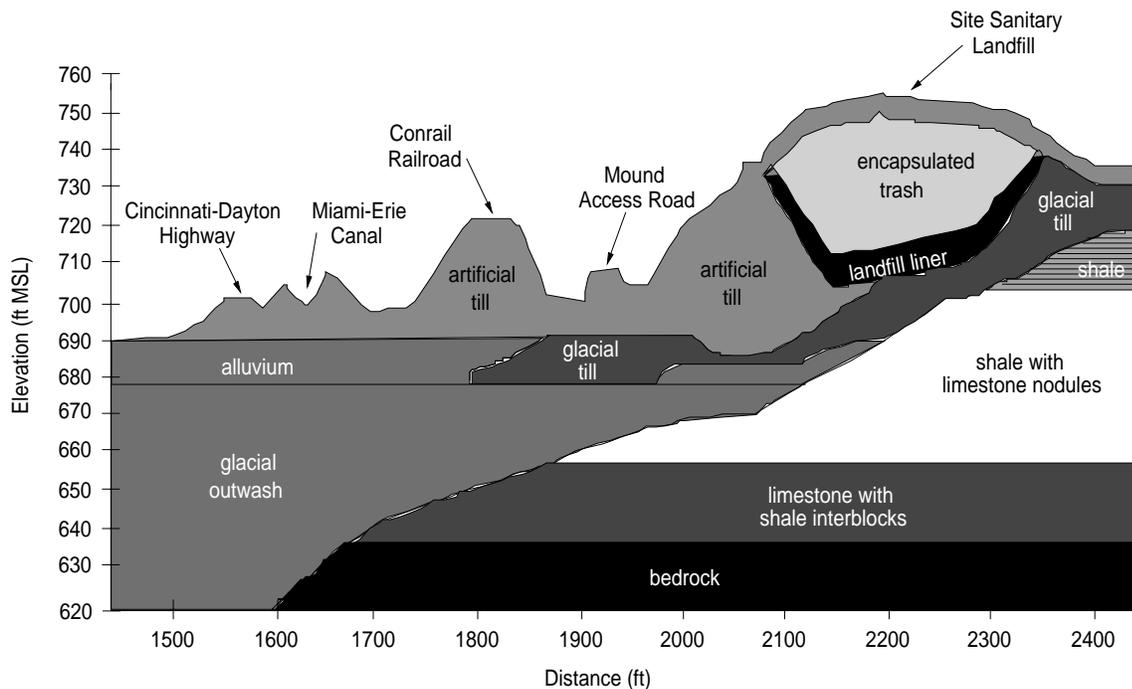


Figure 4. OU-1 geologic setting.

### ***Nature and Extent of Contamination***

The primary contaminant group that the air sparge/soil vapor extraction technology was designed to treat, in this application, was chlorinated VOCs in the Mound OU-1 vadose zone and the Buried Valley Aquifer.

#### ***Soil***

Contaminants of concern (COCs) detected in OU-1 Site subsurface vadose zone included benzene, *cis*-1,2-dichloroethene (DCE), dichloromethane, ethylbenzene, tetrachloroethene (PCE), toluene, trichloroethene (TCE), and xylenes. The vadose zone areal extent of contamination is restricted to the area of past disposal activity and occurs at a depth less than 20 feet. The only discernable pattern for all compounds detected in the soil analyses appear directly related to activities in and around the site sanitary landfill. There appears to be no single major source of contamination, but rather a random pattern of dispersed contamination caused by reworking and transporting of materials. The contaminant concentrations found in extraction wells prior to treatment within the vadose zone treatment area are summarized in Table 1.

*Groundwater*

Contaminants of concern detected in OU-1 Site groundwater included *cis*-1,2-dichloroethene (DCE), tetrachloroethene (PCE), toluene, trichloroethene (TCE), trichloromethane, and vinyl chloride. There is no consistent trend in groundwater VOC concentration with time or depth. The data show no discernible pattern or point source of contamination. However, the source of contamination to the aquifer appears to be the VOCs resident in the site vadose zone suggested by concentration changes correlated to water table depth. The vadose zone contaminants are mobilized by dissolution in precipitation recharge, and by seasonal variations in the groundwater table. The concentrations prior to treatment within the groundwater treatment area are summarized in Table 2.

**Table 1. Pretreatment detectable concentrations of contaminants in soil vadose zone.**

Contaminant	Soil Vapor Concentration (µL/L) *	
	Maximum	Average (n=10)
benzene	16	4
<i>cis</i> -1,2- dichloroethene	3700	290
dichloromethane	28	3
ethylbenzene	4	0.4
tetrachloroethene	75	6
toluene	2000	200
trichloroethene	2800	250
xylenes ( <i>ortho and para</i> )	12	1

\* Summa Analysis Method TO-14 Quanterra 11/11/97

**Table 2. Pretreatment concentration of contaminants in groundwater.**

Contaminant	Groundwater Concentration (µg/L) *	
	Maximum	Average (n=21)
<i>cis</i> 1,2-dichloroethene	640	37
tetrachloroethene	270	34
toluene		
trichloroethene	210	22
trichloromethane	130	8
vinyl chloride	4	1

\* Operable Unit 1 Remedial Investigation Report 5/94

### ***Matrix Description and Characteristics***

The aquifer material consists of glacial outwash materials, primarily gravel and sandy gravel. The outwash material, being the most permeable, has a hydraulic conductivity averaging nearly  $7 \times 10^{-4}$  cm/sec. The unsaturated zone is composed of glacial till and artificial fill. The fill and glacial till are texturally silty clay to sandy clay and are classified under the Unified Soil Classification System as CL-ML, SC-SM, and CH. For these soils, the hydraulic conductivities in the horizontal direction range from  $7 \times 10^{-3}$  to  $9 \times 10^{-5}$  cm/sec, while the estimated vertical hydraulic conductivities range from  $1 \times 10^{-6}$  to  $1 \times 10^{-5}$  cm/sec.

## **4. TECHNOLOGY DESCRIPTION**

Air sparge (AS) and soil vapor extraction (SVE) systems rely on mass transfer of VOC contaminants from the dissolved-, sorbed-, and non-aqueous-phases to a gas phase that is extracted under negative pressure in the subsurface by the soil vapor extraction system. This mass transfer occurs, in accordance with the partitioning laws and vapor densities of the individual contaminant constituents, due to negative pressure created by the soil vapor extraction system.

### ***Air Sparge/Soil Vapor Extraction Technology Description***

#### ***Air Sparge***

The air sparge system operates by injecting air through conventionally constructed wells into the aquifer. The air enters the aquifer from the well at 15 cfm by passing through a diffuser containing 50  $\mu$ m diameter openings. The dissolved-phase and any non-aqueous- and sorbed-phase contamination below the water table will partition into the injected bubbles and be carried up to the vadose zone. In the vadose zone, the gas-phase contaminants mix with the soil gas.

#### ***Soil Vapor Extraction***

The soil vapor extraction system consists of conventionally constructed extraction wells screened at intervals determined in the field to be in till or no-till. These wells are connected via manifold to a vacuum pump that creates negative pressures in the vadose zone. Contaminants, present as non-aqueous- and sorbed phase, are volatilized and mix with any existing soil gas and gas-phase contaminants from the air sparge system. The combined contaminated soil gas is extracted via the soil vapor extraction wells, and transported to the offgas treatment system by a system manifold.

A unique attribute of the vapor extraction system is the use of a relatively high vacuum for extraction to remove volatile organics from a relatively low permeability soil. The vacuum system operates at approximately 13 inches of mercury against a soil permeability of  $1 \times 10^{-6}$  cm/sec, producing a flow rate of 500 scfm. General system design parameters are based on two pilot studies conducted at Mound OU-1. The results of the pilot studies are documented in Radian Corporation and Groundwater Technology reports (1,2). The AS and SVE well design details are shown in Figure 5.

### ***Technology Advantages***

The treatment of VOC-contaminated soils and ground water using air sparge/soil vapor extraction technology offers the following advantages:

- aqueous and vapor phase contaminants are removed simultaneously,
- relatively rapid rate of treatment for large volume of contaminated soil,
- low installation and operating cost,
- high reliability and low maintenance, and

- minimum residuals to other environmental compartments produced.

### ***Technology Limitations***

The treatment of VOC-contaminated soils and ground water using air sparge/soil vapor extraction technology offers the following limitations:

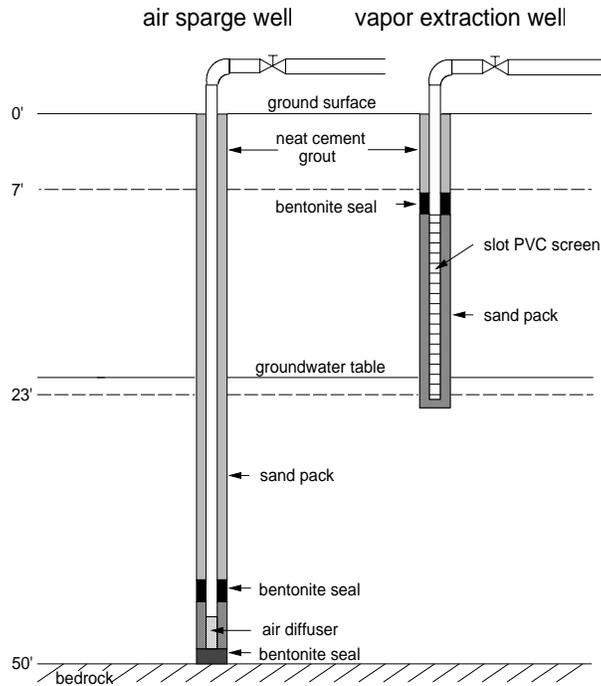
- off gas treatment is required,
- air sparge has a limited area of influence due to lack of horizontal driving force,
- contaminant extraction is limited by soil permeability, channeling, and water content, and
- is favorable only to contaminants with vapor pressure greater than 0.001 atm and Henry's Law Constant less than 0.01.

### ***Mound AirSparge/Soil Vapor Extraction System Description***

The soil vapor extraction system is segregated into two zones. The south zone, Zone 1, includes six wells in the southern portion of the site. The west zone, Zone 2, includes six SVE wells and five French drain vents in the western portion of the site. Table 3 shows the zone assignment, screen length and geologic strata of each well.

SVE wells were located within the areas of identified contamination without penetration on the landfill cell liner. Total airflow from the west SVE wells was 300 scfm under 13 inches of mercury. The south subsystem airflow performance was similar to the west subsystem. The AS injection and the SVE extraction well locations are shown in Figure 6.

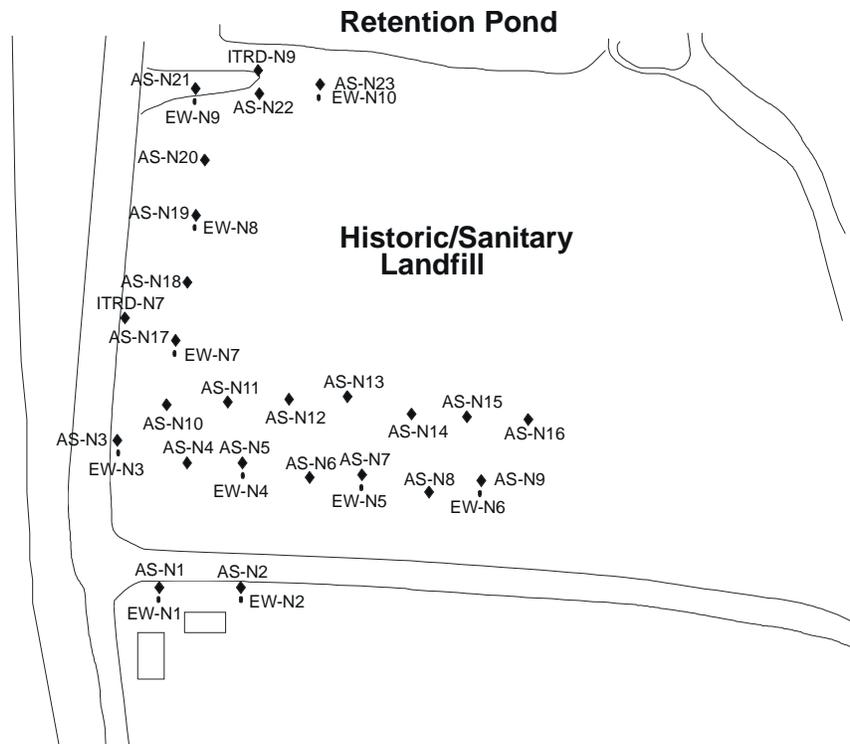
All of the SVE wells in each zone intersect a main manifold that enters Treatment Building 301. The manifolds are connected in series with a water knockout tank, flow through two carbon beds, SVE pumps, and an atmospheric exhaust. A strategy of pulsed treatment was developed to alternate between the two zones, so the system is capable of independent operation of either the west or the south zones for variable time periods.



**Figure 5. AS/SVE well design details.**

**Table 3. Extraction Well Details.**

Extraction Well	Depth to Screen (feet)	Screen Length	Geologic Strata
Zone 1			
EW-N1	17	2	till
EW-N2	10	15	non-till
EW-N3	18	3	Till
EW-N4	10	22	non-till
EW-N5	22.5	2.5	Clay
EW-N6	24	10	non-till
Zone 2			
EW-N7	10	10	non-till
EW-N8	10	10	non-till
EW-N9	15.5	15	non-till
EW-N10	17	12.5	non-till
ITRD-N7			
ITRD-N9			
ED-N1	NA	5	base of French drain
ED-N2	NA	5	base of French drain
ED-N3	NA	5	base of French drain
ED-N4	NA	5	base of French drain
ED-N5	NA	5	base of French drain



**Figure 6. OU-1 Air sparge and vapor extraction well locations.**

The offgas treatment system consists of a water knockout tank, and two granulated activated carbon (GAC) beds connected in series. The treatment system removes both water and volatile organics before discharge to the atmosphere. The water collected in the knockout tank is directed to an air stripper system that operates in conjunction with the previously installed baseline pump-and-treat system. A diagrammatic representation of the AS/SVE injection, extraction, and treatment system components is presented in Figure 7.

***Key Design Criteria***

The air sparge/soil vapor extraction system was designed to meet three main objectives:

- reduce the soil contamination in the west zone to acceptable regulatory levels within three to five years,
- reduce the groundwater contamination to acceptable regulatory levels within three to five years,
- and reach deminimis atmospheric release levels.

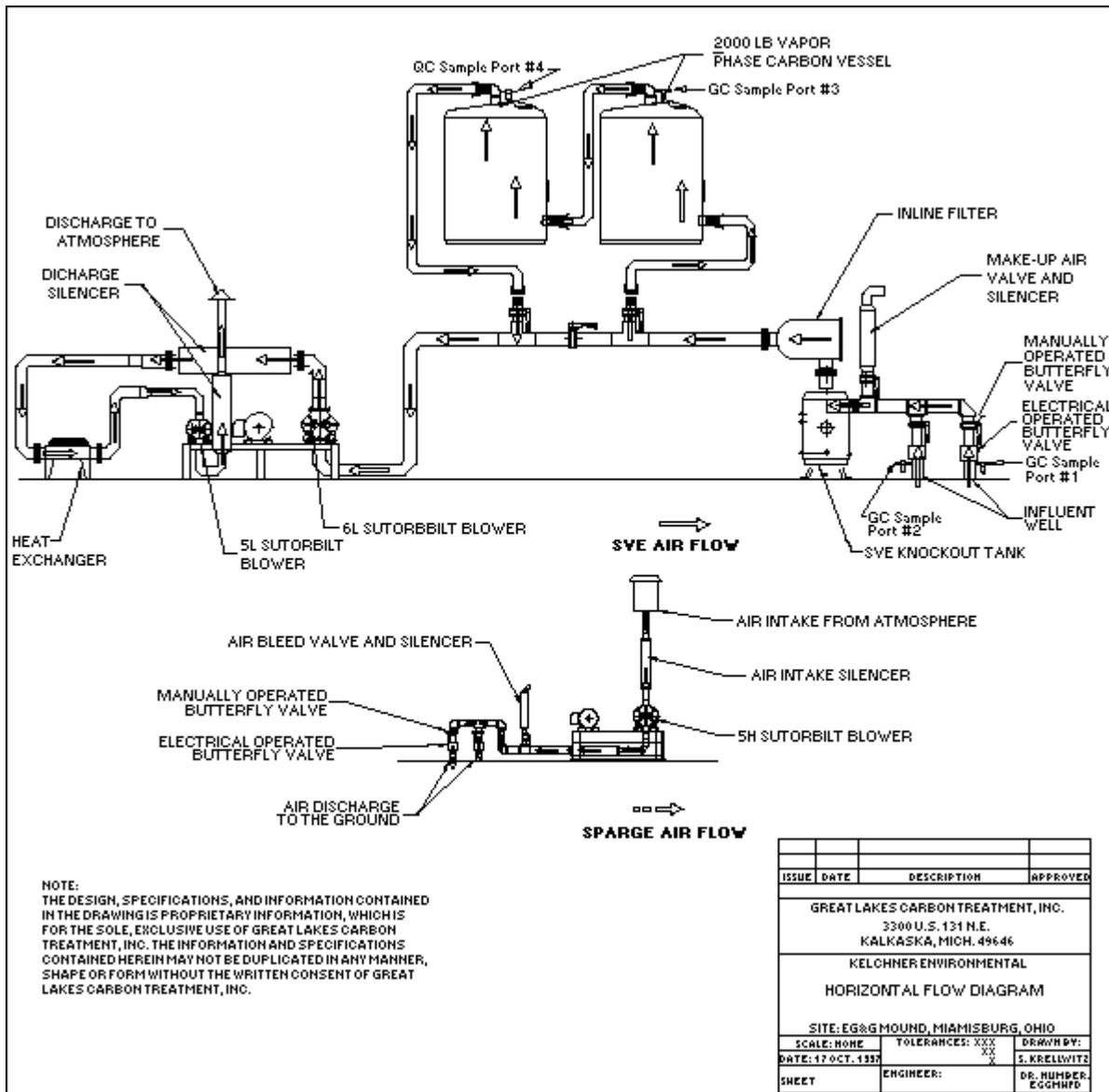


Figure 7. Diagrammatic representation of the AS/SVE injection, extraction, and treatment system components.

## ***Operating Parameters***

The major operating parameters needed to assess the performance and cost of the AS/SVE were considered to be airflow rate, contaminant removal, granular activated carbon renewal, and well redevelopment. Operating parameters were adjusted slightly during the study to optimize operating conditions for the AS/SVE system. The general operating parameters for the system are summarized in Table 4.

**Table 4. Operating parameters affecting treatment cost or performance.**

Parameter	Value or Specification
Optimal airflow from extraction wells	540 scfm
Effluent monitoring	bi-weekly
Frequency of GAC renewal	upon VOC breakthrough
Frequency of redevelopment of extraction well	annually
Frequency of redevelopment of injection well	annually

## **5. AIR SPARGE/SOIL VAPOR EXTRACTION SYSTEM PERFORMANCE**

The air sparge/soil vapor extraction project at the OU-1 Site was conducted to assess the applicability of combined AS/SVE to accelerate the removal of the chlorinated contaminants of concern from the site unsaturated and saturated zones. The information gathered in this project was used to determine the cost and performance of the combined AS/SVE system at the OU-1 Site.

### ***Demonstration Objectives and Approach***

The objectives of the air sparge/soil vapor extraction project were as follows:

1. Remove chlorinated VOCs from the groundwater and soil unsaturated zone at the OU-1 Site,
2. Determine the effectiveness of this technology for site soil and ground water, and estimate the time period needed to meet cleanup objectives,
3. Evaluate the AS/SVE design configuration, such as flow rates, residence times, and flowpaths,
4. Determine optimal operating parameters, and
5. Collect sufficient cost data to estimate site cleanup costs.

### ***Performance Evaluation Criteria***

The performance criteria considered in evaluating the AS/SVE system included:

- system run time,
- contaminant removal rates and the total mass reduction, and
- change in concentration of groundwater and soil contaminants.

The evaluation data were collected by a monitoring program that included: quarterly summa canister sampling and certified laboratory analysis for VOCs, weekly automated sampling and analysis by onsite gas chromatograph, daily operational parameter monitoring and recording, and system maintenance logs, as required.

### **Performance Summary**

#### *Unsaturated Zone Individual Extraction Well Soil Vapor Extraction Performance*

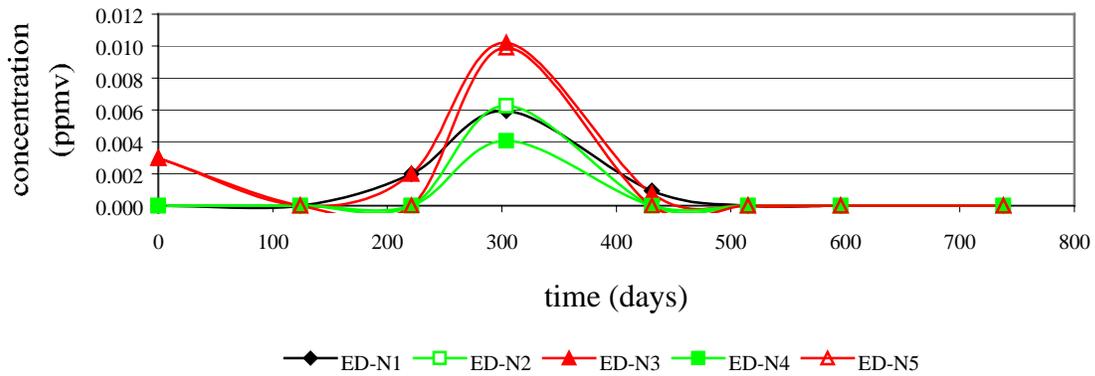
The OU-1 Site initial total chlorinated contaminant concentrations levels encountered at the different extraction wells within the unsaturated zone generally ranged from 0.001 to 75.0 µL/L (ppmv). However, one well, EW-N7, had a total VOC concentration of 8619 µL/L. Contaminant concentration data were collected for individual extraction wells on a quarterly basis to assess the performance of the SVE system on specific pockets of contamination.

Data from the quarterly extraction well sample analyses indicate a reduction in contaminant concentration in all wells. The concentrations of the six primary contaminants found in the extraction well soil gas samples, benzene, *cis* 1,2 dichloroethene, dichloromethane, toluene, tetrachloroethene, and trichloroethene, show a marked decrease over the 17674 hours of soil vapor extraction. Contaminant reduction ranged from 34.8 % to 100 %, and was commonly greater than 80% for the entire contaminant suite and well field. Table 5 shows the contaminant reduction numbers for all soil vapor extraction wells for the principal contaminants. The contaminant removal rates are suggestive of a first order logarithmic reduction, as most contaminant was removed in the first 155 days. Figures 8 through 13 illustrate the removal rate of benzene, *cis* 1,2 dichloroethene, dichloromethane, tetrachloroethene, and trichloroethene, respectively.

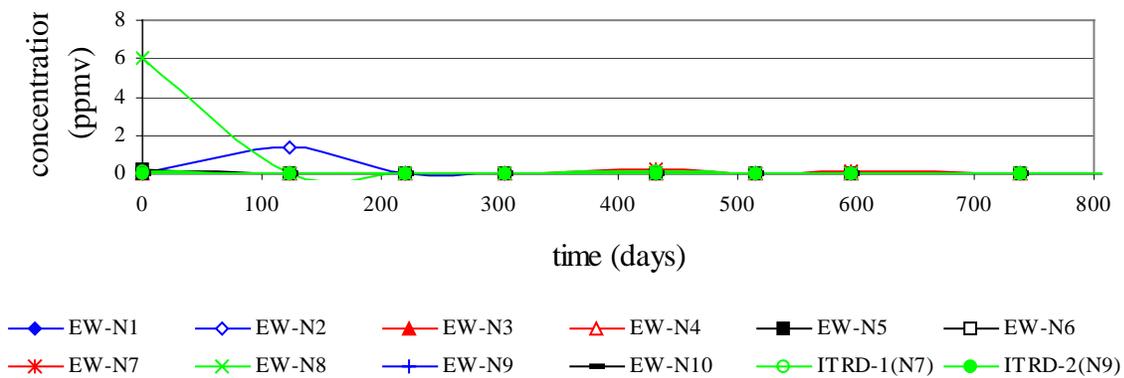
**Table 5. Extraction well contaminant concentration reduction percentage.**

Well	Concentration Reduction (%)				
	benzene	<i>cis</i> 1,2 dichloroethene	dichloromethane	tetrachloroethene	toluene
EW-N1	50.0	48.2	100.0		90.6
EW-N2	100.0	98.8		100.0	100.0
EW-N3	100.0		100.0		
EW-N4		83.2	100.0	96.4	100.0
EW-N5	81.1	80.7	100.0		40.1
EW-N6	66.7	90.3	100.0	87.5	100.0
EW-N7	87.8	100.0	100.0	100.0	100.0
ITRD-1(N7)			100.0		
EW-N8		99.5	100.0	100.0	100.0
EW-N9		99.9	100.0	100.0	100.0
ITRD-2(N9)				89.0	
EW-N10		98.7	100.0	100.0	100.0

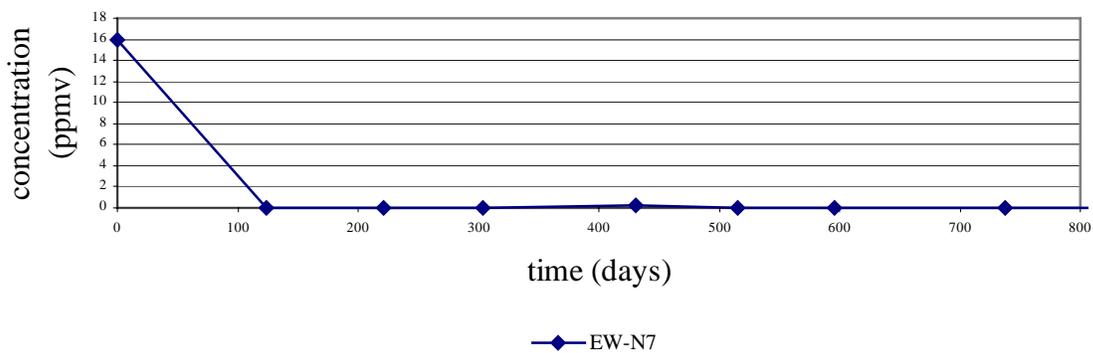
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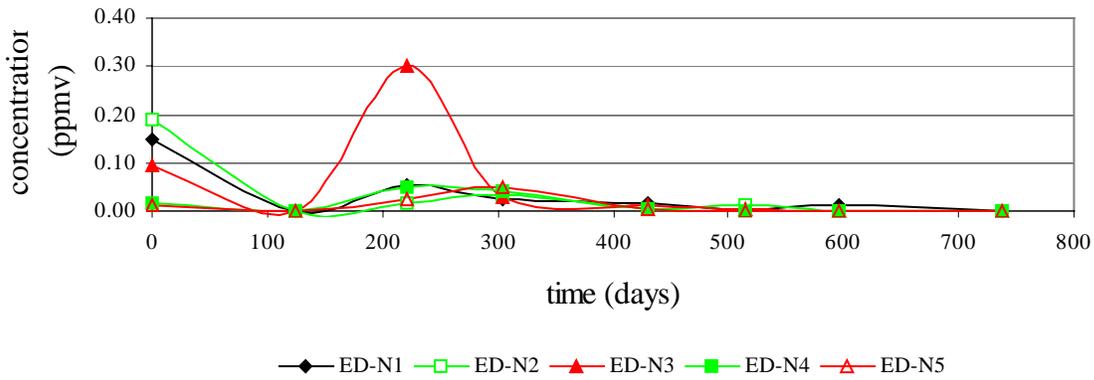


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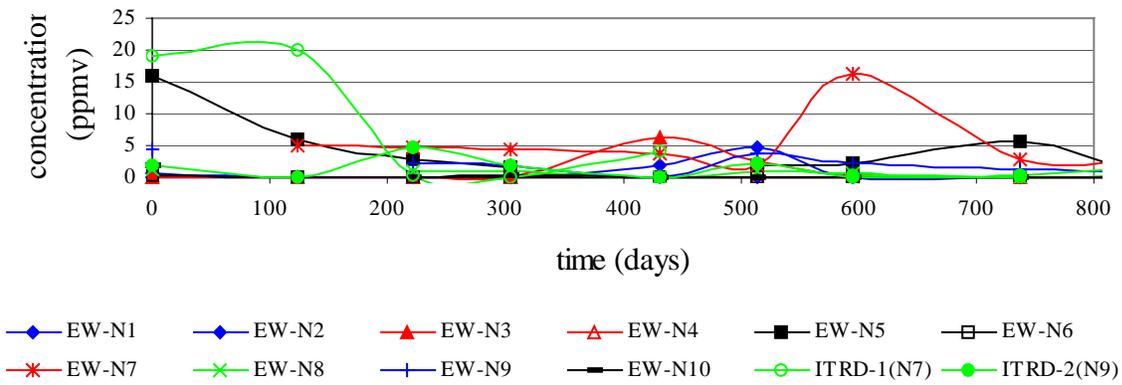


**Figure 8. Extraction well monitoring data for benzene,**  
**a.) french drains, b.) extraction wells including EW-N7 after 125 days, c.) extraction well EW-N7.**

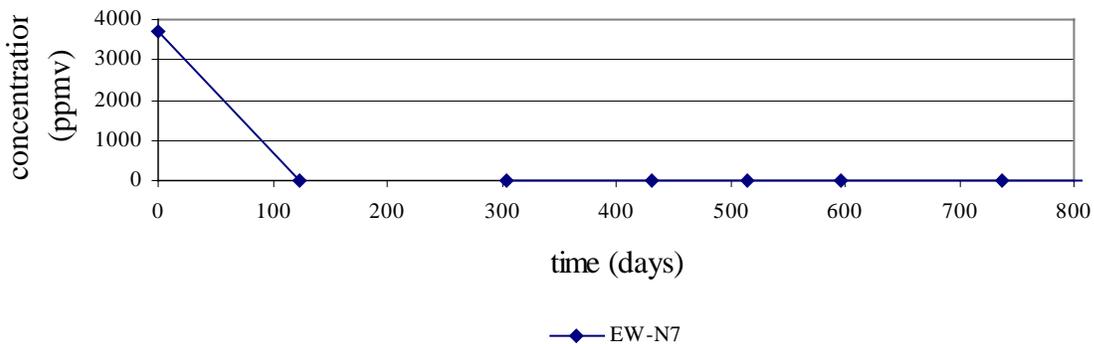
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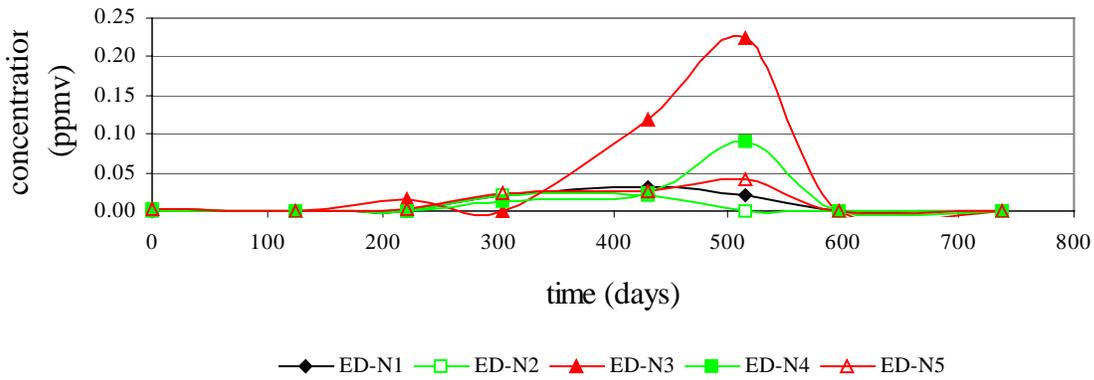


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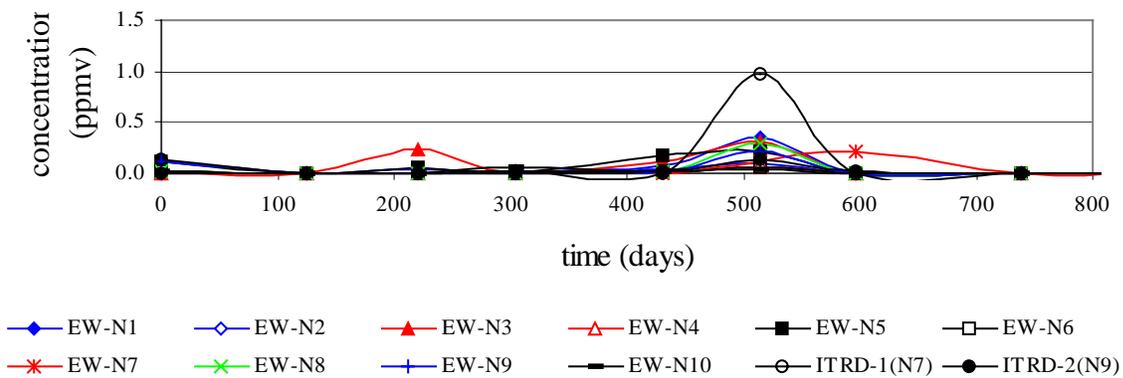


**Figure 9. Extraction well monitoring data for *cis* 1,2-dichloroethene, a.) french drains, b.) extraction wells including EW-N7 after 125 days, c.) extraction well EW-N7.**

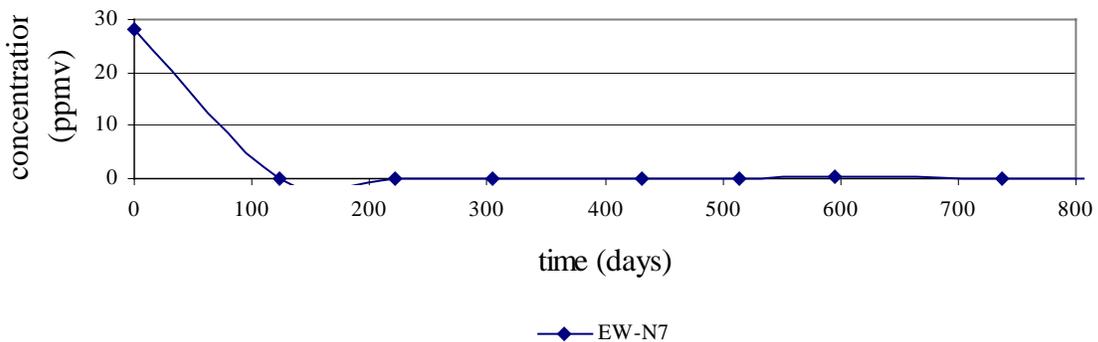
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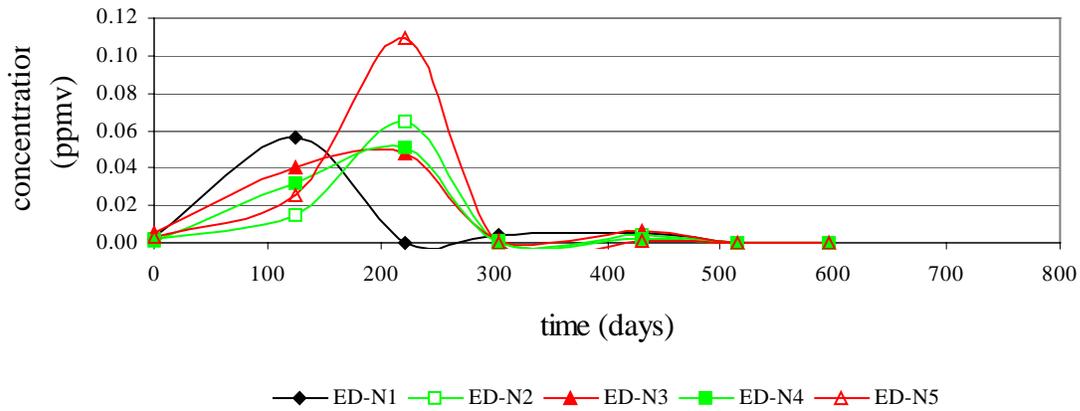


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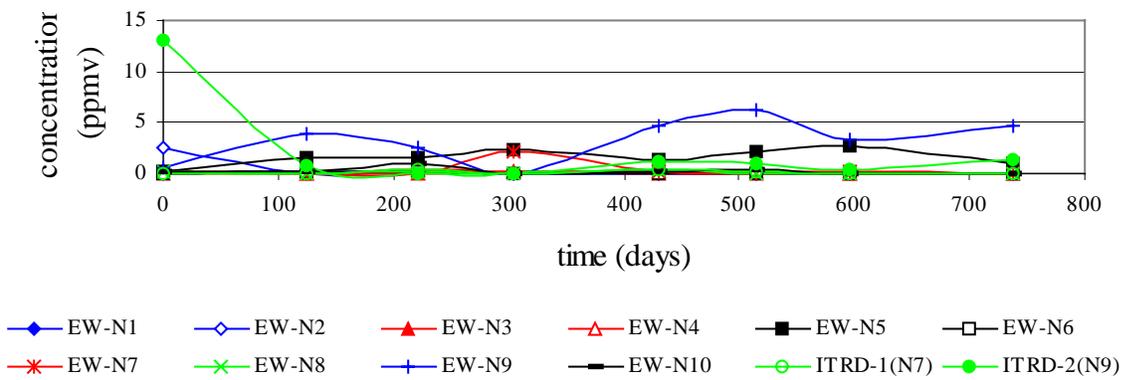


**Figure 10. Extraction well monitoring data for dichloromethane, a.) french drains, b.) extraction wells including EW-N7 after 125 days, c.) extraction well EW-N7.**

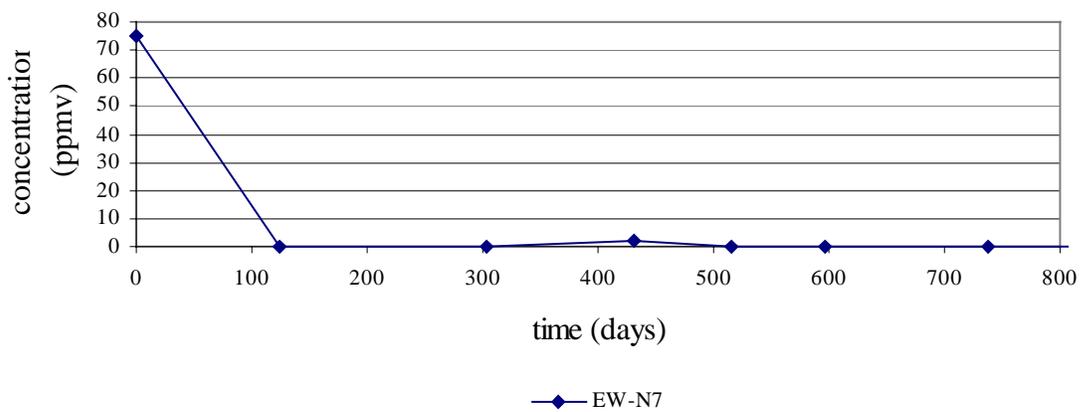
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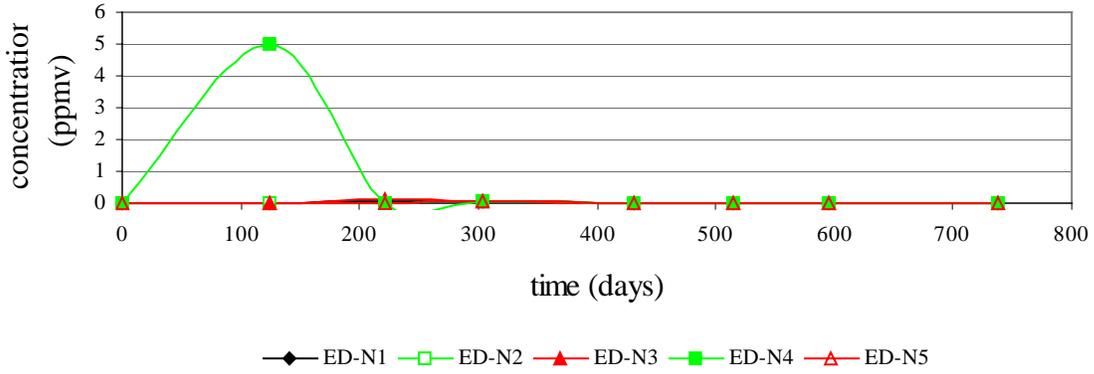


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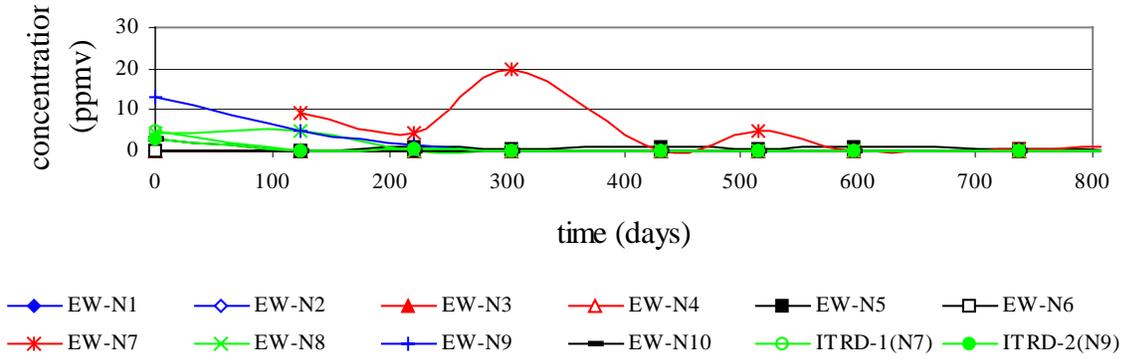


**Figure 11. Extraction well monitoring data for tetrachloroethene, a.) french drains, b.) extraction wells including EW-N7 after 125 days, c.) extraction well EW-N7.**

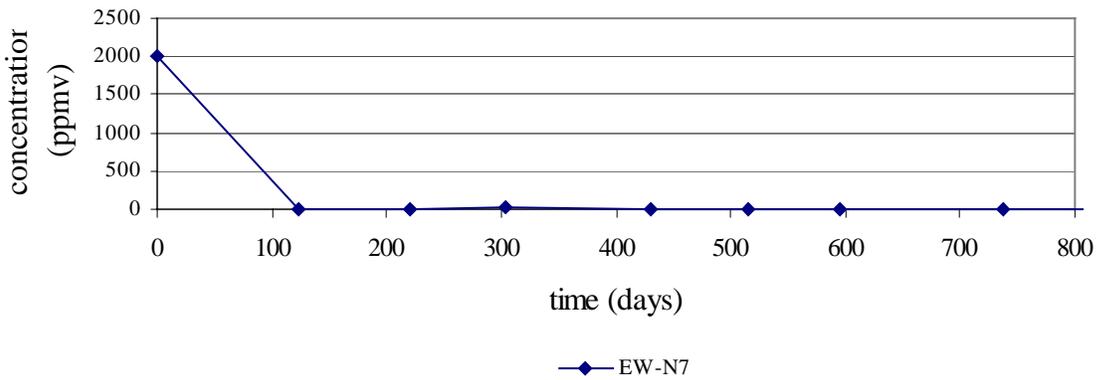
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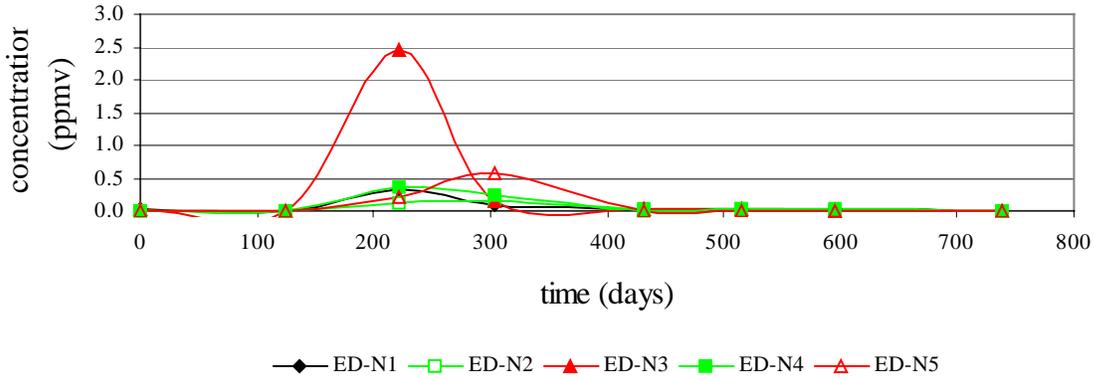


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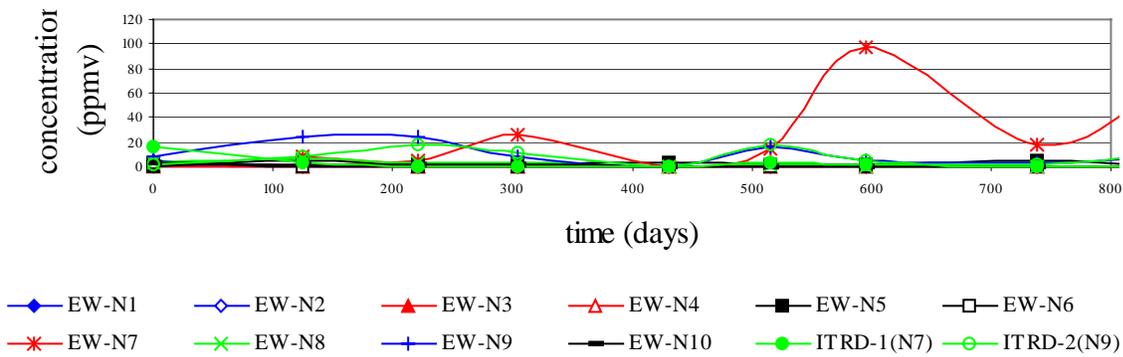


**Figure 12. Extraction well monitoring data for toluene, a.) french drains, b.) extraction wells including EW-N7 after 125 days, c.) extraction well EW-N7.**

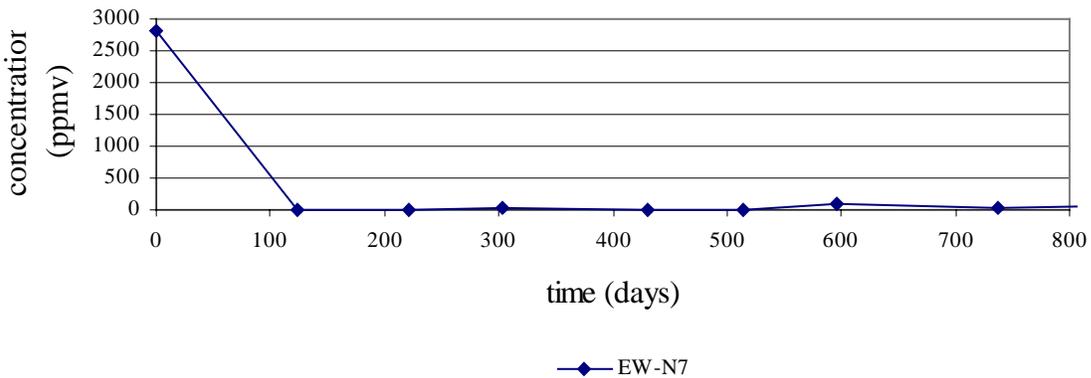
a.



b.



c.



**Figure 13. Extraction well monitoring data for trichloroethene, a.) french drains, b.) extraction wells including EW-N7 after 125 days, c.) extraction well EW-N7.**

### *Unsaturated Zone Soil Vapor Extraction Performance*

To establish a contaminant removal rate for the entire site, contaminant concentrations of the influent and effluent vapors were measured on a regular basis. A combination of Summa canister grab samples, and automated gas sampling and analysis equipment was used to measure the concentrations of volatile organic compounds at the extraction headers of Zone 1 and Zone 2. SVE extraction flow rates were measured by a standard pitot tube and read manually on a quasi-daily basis.

Tables 6 and 7 show the contaminant specific analytical results for Zone 1 and Zone 2, respectively. The concentrations of the six primary VOCs from Zone 1 over time are illustrated in Figure 14 and Zone 2 in Figures 15 and 16. The results of the grab samples for both Zones 1 and 2 show power function declines of the VOCs. Curve fit equations were matched to the data by Table Curve 2D (Ver 4, SPSS, Inc.). The best-fit equation for each compound was used to estimate contaminant concentration between sampling events. Tables 7 and 8 show the equations and correlation factors for the curve fits for each of the VOCs where sufficient evaluation data are available.

Early time concentrations fall very steeply and the curve fit lines may not be representative of the actual concentrations in the first 50 hours before the first sample was obtained on December 18, 1997. Therefore, mass removal estimates have been made starting from the first sample date. To estimate the total mass of each contaminant extracted from the soils, the flow rate from each manifold is used with the concentration data as follows:

$$M_{VOC} = C_{VOC} \frac{MW_{VOC}}{MV_{T,P}} Vt(3.74E - 6)$$

$M_{VOC}$  is the mass of the contaminant removed (lbs),  $C_{VOC}$  is the concentration of the contaminant (ppmv, v/v),  $MW_{VOC}$  is the molecular weight of the VOC (g/mol),  $MV_{T,P}$  is the molar volume of the vapor at a specific temperature and pressure (24.5 L/mol at 25°C and 1 atm),  $V$  is the volumetric flow rate in the extraction manifold (std ft<sup>3</sup>/min),  $t$  is the time interval (min), and 3.74E-6 is for unit conversions.

From time zero to the operating time of 178 hours the system ran on six-hour intervals. The system was switched to four-hour intervals from hour 178 to 552, and to a two-hour interval from hour 552 to 2422. These changes were made to keep automatic shutdowns from occurring when large amounts of water were being extracted from the French drains soon after rainfall events. The system was changed to one hour on Zone 1 and 3 hours on Zone 2 from hour 2422 to 3453. From hour 3453 to date the system was set to only extract from Zone 2.

The early time periods in a SVE system provide much more mass removal than in the later periods due, principally, to the diffusion limitation condition in later time periods where VOCs must move from within dead end pore spaces to the locations experiencing active ventilation. At the time of shutdown on May 7, 1998, the Zone 1 mass removal rate was approximately 0.04 lb/hr. The mass removal rate for Zone 2 was approximately 0.17 lb/hr as of October 15, 1998, giving an estimated mass removal of 4.08 lbs/day, which is below the de minimis regulatory emission level for air of 10 lb/day. The de minimis level was reached in July 1998. At that time, the extracted soil vapor was routed to bypass the carbon tanks and vent to the atmosphere. Subsequent fouling and breakdown of the extraction pumps caused by water and carbonate contamination required that the carbon tanks be brought back on line in August, 1998. As of May 30, 2000, the Zone 2 mass removal rate was 0.04 lb/hr, giving an estimated mass removal of 0.96 lb/day. It is estimated from grab sample and onsite GC contaminant concentration analysis, and measured flow rates that from December 18, 1997 through May 30, 2000 the SVE system extracted a total of 3433 pounds of volatile organics from the unsaturated zone. Zones 1 and 2 contributed 146.75 pounds and 3286.6 pounds of volatile organics, respectively. Table 10 shows the estimated total mass of individual VOCs removed between December 18, 1997 and May 30, 2000 by the system.

**Table 6. Zone 1 Contaminant Concentration Data**

Date	Source	Run Time (hours)	Contaminant Concentration (ppmv)					
			benzene	cis 1,2- dichloroethene	dichloromethane	tetrachloroethene	toluene	trichloroethene
18-Dec-97	Summa	13	0.580	33.000	0.250	8.300	42.000	16.000
22-Dec-97	Summa	56.5	0.220	11.000	0.240	6.100	28.000	8.600
29-Dec-97	Summa	137.5	0.091	4.300	0.160	5.400	19.000	4.600
05-Jan-98	Summa	172.5	0.056	3.200	0.130	5.200	17.000	3.900
12-Jan-98	Summa	255.5	0.026	2.400	0.064	3.500	8.800	2.200
19-Jan-98	Summa	333.5	0.017	1.300	0.015	1.800	3.200	1.600
12-Mar-98	Summa	786.25	0.0056	0.770		0.430	0.062	0.930
19-Mar-98	GC	795.8					5.160	
20-Mar-98	GC	808.3					4.960	3.980
25-Mar-98	Summa	863.75	0.0067	0.750		0.410	0.053	0.930
13-Apr-98	GC	953.8						2.570
22-May-98	Summa	1095.8		0.16		0.26	0.048	0.300
21-Jul-98	GC	1109.8		0.158		0.216	0.016	0.366
21-Jul-98	Summa	1109.8	0.002	0.12		0.18	0.036	0.270
15-Oct-98	Summa	1194.8	0.003	0.2		0.32	0.044	0.430
15-Oct-98	GC	1194.8	0.006	0.161	0.012	0.27	0.057	0.385
17-Feb-99	GC	1204.2	0.003	0.159		0.175	0.014	0.237
11-May-99	GC	1228.1		0.084		0.102	0.011	0.229
12-Jan-00	GC	1284.5	0.001	0.094		0.148		0.187
12-Jan-00	Summa	1284.5	0.002	0.15		0.19	0.028	0.220
03-May-00	Summa	1291.6		0.071		0.11	0.002	0.130
03-May-00	GC	1291.6		0.045		0.046		0.105
11-May-00	GC	1291.7						

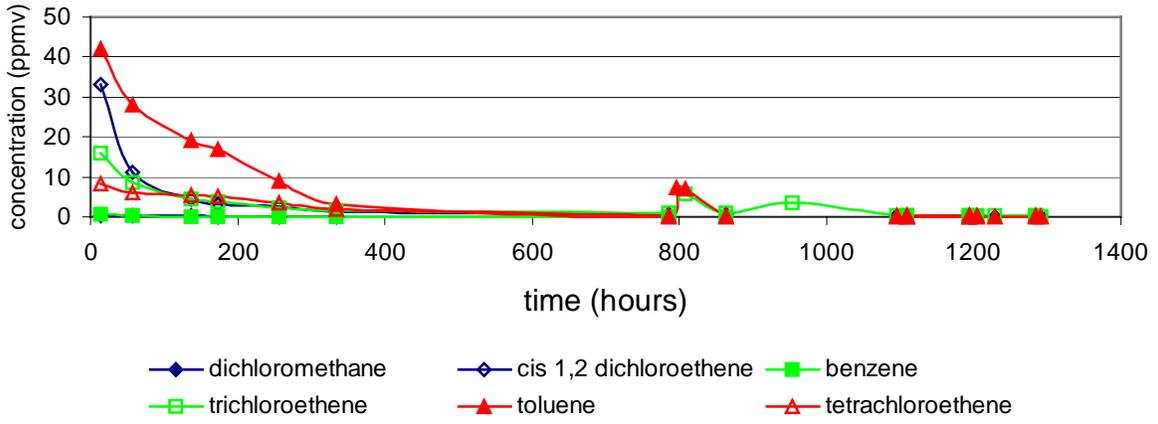
**Table 7. Zone 2 Contaminant Concentration Data**

Date	Source	Run Time (hours)	Contaminant Concentration (ppmv)					
			benzene	cis 1,2- dichloroethene	dichloromethane	tetrachloroethene	toluene	trichloroethene
18-Dec-97	Summa	28.00	2.300	130.000	1.600	10.000	220.000	130.000
19-Jan-98	Summa	351.00	0.540	17.000	0.680	3.300	41.000	50.000
25-Mar-98	Summa	886.25	0.170	8.700		2.000	26.000	36.000
02-Apr-98	GC	1030.25		9.440		0.820	20.400	31.883
13-Apr-98	GC	1155.25		11.990			14.210	19.943
21-Apr-98	GC	1296.25		5.200			7.960	21.094
22-May-98	Summa	1910.22		3.300		0.680	9.900	13.000
24-Jun-98	Summa	2687.81	0.120	4.000	0.160	0.700	12.000	15.000
23-Jul-98	Summa	3327.36	0.037	2.600	0.027	0.580	8.200	9.500
20-Aug-98	GC	3974.59		1.777			3.365	7.509
21-Sep-98	GC	4658.53		1.888			5.068	6.327
05-Oct-98	GC	4989.97		1.713			3.927	6.567
25-Nov-98	Summa	5755.03		1.900		0.560	3.700	8.200
09-Dec-98	Summa	6086.21	0.022	1.900	0.043	0.430	2.600	6.900
18-Dec-98	Summa	6305.46		1.700		0.460	2.600	7.100
30-Dec-98	GC	6575.44		1.857		0.194	2.348	1.145
28-Jan-99	GC	7238.75		2.110	0.06	0.404	4.852	13.688
15-Feb-99	GC	7677.75		1.701	0.062	0.214	3.175	11.826
31-Mar-99	GC L BC	8188.15						1.944
31-Mar-99	Summa	8188.15		1.100	0.043	0.260	0.940	4.300
05-Apr-99	Summa	8308.15		1.100	0.041	0.250	1.100	4.800
28-Apr-99	GC T BC	8853.34	0.009	0.874	0.054	0.183	1.135	7.607

**Table 7. Zone 2 Contaminant Concentration Data (continued)**

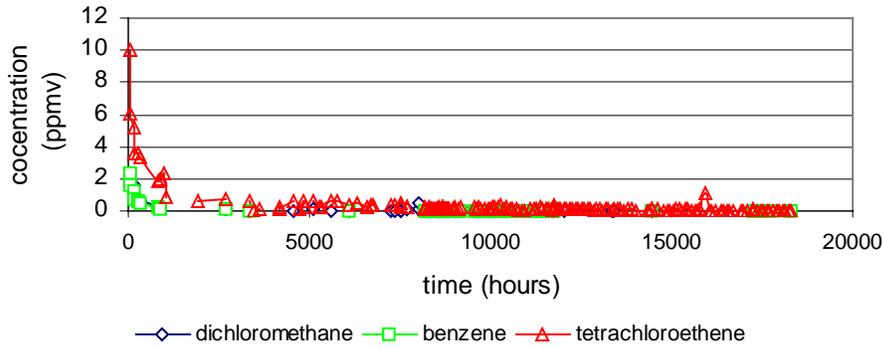
Date	Source	Run Time (hours)	Contaminant Concentration (ppmv)					
			benzene	<i>cis</i> 1,2- dichloroethene	dichloromethane	tetrachloroethene	toluene	trichloroethene
13-May-99	GC T BC	9179.06	0.009	0.841	0.052	0.212	1.301	7.491
24-Jun-99	GC T BC	9823.71	0.003	0.782	0.017	0.119	0.829	6.601
29-Jul-99	GC T BC	10620.00	0.015	0.926		0.103	0.606	7.620
30-Aug-99	GC T BC	11386.62	0.002	0.928	0.018	0.191	0.764	7.266
30-Sep-99	GC T BC	12086.32		0.802		0.151	0.505	6.680
28-Oct-99	GC T BC	12757.01		0.638		0.079	0.278	4.543
24-Nov-99	GC T BC	13404.89		0.634	0.011	0.063	0.208	4.417
20-Dec-99	GC T BC	14005.91		0.594		0.057	0.113	4.086
10-Jan-00	GC T BC	14476.49		0.540		0.067	0.045	3.817
10-Jan-00	Summa	14476.49	0.003	0.780	0.020	0.150	0.100	3.300
31-Jan-00	GC T BC	14966.23		0.186		0.004	0.010	1.355
24-Feb-00	GC T BC	15537.59		0.450		0.028		3.192
27-Mar-00	GC T BC	16278.11		0.099				0.839
24-Apr-00	GC T BC	16896.49		0.474		0.035		3.473
30-May-00	GC T BC	17673.63	0.003	0.687		0.022	0.010	3.619



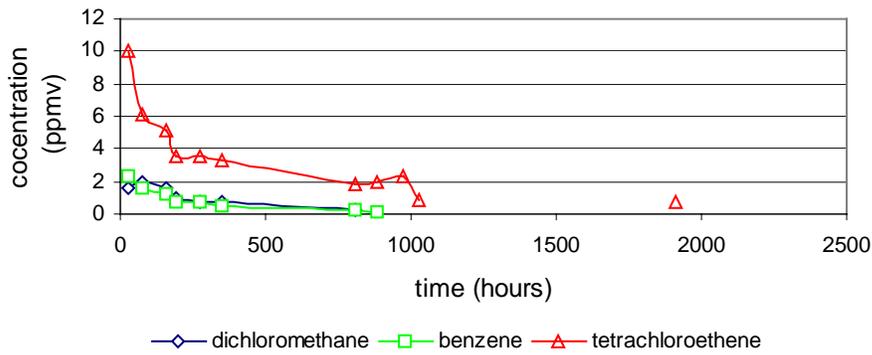


**Figure 14. Zone 1 contaminant concentration data.**

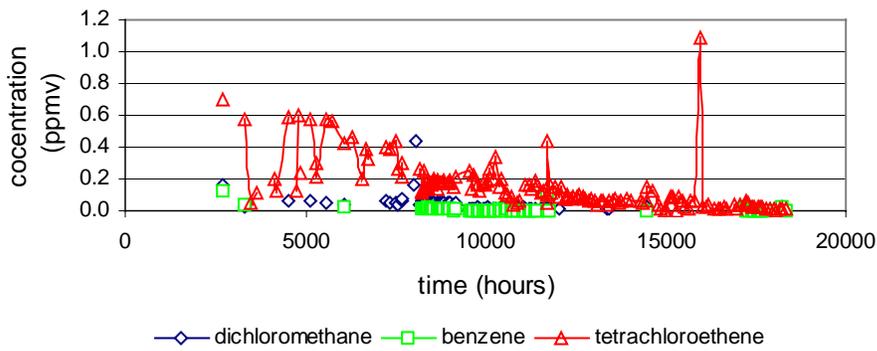
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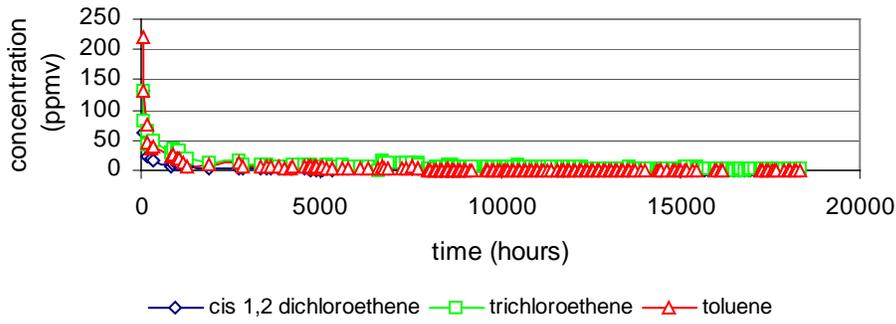


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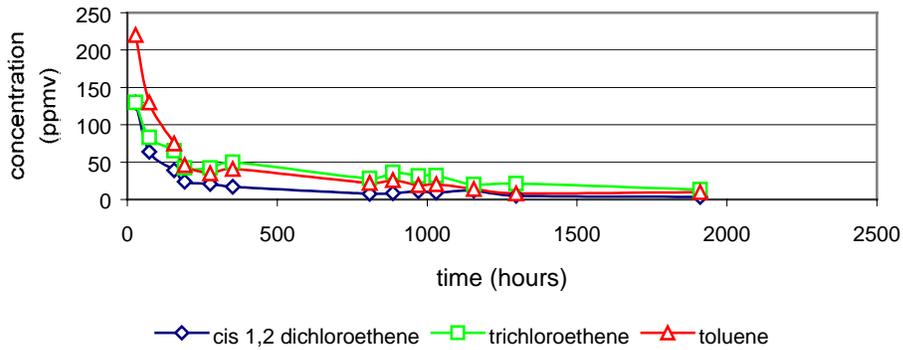


**Figure 15. Zone 2 benzene, dichloromethane, and tetrachloroethene concentration data, a.) 0 to 18000 hours, b.) 0 to 2500 hours, and c.) 2500 to 18000 hours.**

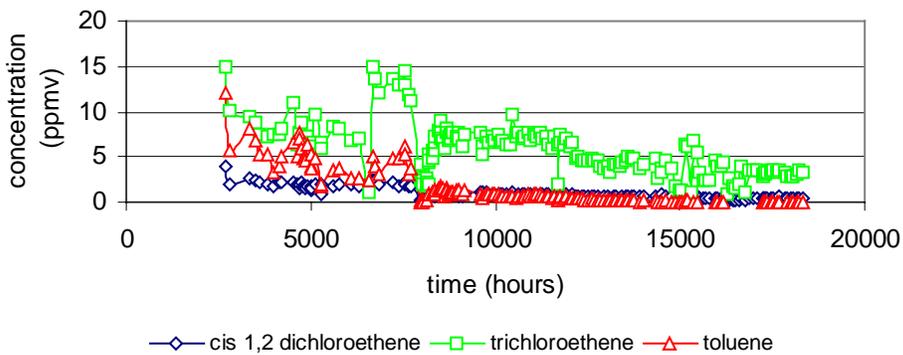
a.



b.



c.



**Figure 16. Zone 2 *cis* dichloroethene, trichloroethene, and toluene concentration data, a.) 0 to 18000 hours, b.) 0 to 2500 hours, and c.) 2500 to 18000 hours.**

**Table 8. Zone 1 Curve Fits and Correlation Factors for VOC Extraction Time History.**

Contaminant	$y = a + bx^c$			Correlation ( $r^2$ )
	a	b	c	
benzene	-0.0046	27.7755	-1.1817	0.993
<i>cis</i> 1,2-dichlorethene	-0.3504	648.6003	-1.0031	0.996
dichloromethane	-0.0719	2.5430	-0.5125	0.912
tetrachloroethene	-83.6993	98.2605	-0.0222	0.960
toluene	-45.0769	129.344	-0.1496	0.966
trichloroethene	-2.4793	52.2583	-0.4025	0.948

**Table 9. Zone 2 Curve Fits and Correlation Factors for VOC Extraction Time History**

Contaminant	$y = a + bx^c$			Correlation ( $r^2$ )
	a	b	c	
benzene	-0.1216	13.5694	-0.5046	0.980
<i>cis</i> 1,2-dichlorethene	-0.6008	1666.3968	-0.7632	0.995
dichloromethane	-0.5566	5.7169	-0.2478	0.893
tetrachloroethene	-0.6464	46.3103	-0.4387	0.973
toluene	-3.5518	2042.1395	-0.6595	0.989
trichloroethene	-5.3955	555.4642	-0.4248	0.952

**Table 10. VOC Mass Removed (lbs).**

Contaminant	Total Mass Removed (lbs)		
	Zone 1	Zone 2	Zone 1 + Zone 2
benzene	0.29	8.99	9.28
<i>cis</i> 1,2-dichloroethene	24.71	360.26	384.97
dichloromethane	0.43	10.17	10.60
tetrachloroethene	31.60	152.89	184.49
toluene	50.04	721.15	771.19
trichloroethene	26.70	1876.16	1902.86
other VOCs	12.98	156.98	169.96
<b>Total</b>	<b>146.75</b>	<b>3286.6</b>	<b>3433.35</b>

A summary of the performance of the soil vapor extraction system is provided in Table 11, relative to stated performance measures and project objectives. Overall, the system met most of the identified system performance objectives.

**Table 11. Soil vapor extraction system performance summary.**

Performance Measures	Values/ Results
system run time	17674 hours of 21465 total hours available (82%)
contaminant removal rates and the total mass reduction	greater than 3400 lbs removed in 29 months
ultimate achievable remediation levels of groundwater and soil contaminants	total contaminants reduced by 1 to 3 orders of magnitude at present removal rate remediation goals will be attained by December 2002

*Saturated Zone Air Sparge Performance*

The air sparge airflow rate for both Zone 1 and Zone 2 initially increased over a ten day period. However, after the initial increase in flow rate, a significant decline was noted as the total flow rate decreased from a peak of 310 cfm to less than 150 cfm in both zones. A steady increase in delivery pressure was also noted as the flow rates decreased. On February 4, 1998 after 40 days of operation and with the system flow rate at approximately 50% of the initial value and the pressure nearly double the start-up value, the system was shut down and an investigation initiated to determine the cause of system performance decline. Potential causes investigated for the decline in performance included microbial biofouling and inorganic iron or carbonate precipitate fouling of the 50 µm diameter well screens. Groundwater analysis reports indicated iron concentrations in the 1 ppm range which essentially eliminated microbial iron oxidation and inorganic iron precipitation as a fouling mechanism, because such low iron concentrations would not be capable of producing enough precipitable mass to plug the well screens. However, the analysis reported alkalinity concentrations ranging from 200 to 300 ppm which suggests that carbonate precipitation may have caused the screen fouling. Because no direct analysis of the fouling substance was possible, any remedy selected must be capable of eliminating the most probable fouling candidates, that is, aerobic microbial growth or carbonate precipitation.

A commercial product produced by Johnson Screens specifically to treat fouled well screens was selected as a treatment method to redevelop the wells. The treatment product was designed to eliminate fouling caused by iron precipitation, carbonate buildup, and microbial biofouling. The treatment is added to the wells as a granular enhancer compound, followed by granular acid, and the addition of water. After addition of the treatment compounds, the system was surged and allowed to set for 96 hours after which the treatment solution was pumped from the wells. The treatment for three air sparge wells, AS-N19, AS-N20, and AS-N21, began on August 26, 1998, and was completed at close of business on August 28. Prior to treatment the wells showed flow rates of 0, 0 and 12 cfm respectively, and 47, 27, and 39 cfm after treatment. Treatment of the remaining air sparge wells in Zone 2 was completed in mid October 1998.

Before the air sparge system was turned back on, a tracer test was proposed to 1) determine connectivity and capture efficiency of the air sparge/soil vapor extraction system, and 2) to establish contaminant containment within site boundaries with air injection. A tracer test plan was developed that included the injection of 10 lbs of Halon 1211 into the Zone 2 AS manifold with subsequent extraction, measurement and monitoring of Halon 1211 concentration at the Zone 2 soil vapor extraction manifold.

In May 1999 the tracer test was conducted at the OU-1 Site. The test indicated a strong subsurface pneumatic connection between the air sparge system and the soil vapor extraction system. Based on Halon 1211 air sparge injection and vapor extraction manifold arrival times, the apparent velocity of Halon 1211 through the system was calculated to be 2.3 cm/sec which indicates that injected air is rapidly migrating into the SVE uptake wells through well formed pathways. The tracer test also indicated that offsite migration induced by the air sparge system was possibly greater than anticipated. The analysis of vapor from three offsite well groundwater samples obtained three hours after injection indicated the presence of significant amounts of Halon. Integration of Halon mass measured in the three wells over 60 hours produced a total mass of approximately 2.5 lbs of Halon 1211 in the offsite wells or 25% of the total mass injected.

Based on the tracer test results, it was decided by the Technical Advisory Group that the air sparge system at the OU-1 Site would not be operated as planned, because of the high probability of increased contaminant movement offsite induced by air injection into the aquifer. However, it was decided that the air sparge system would be utilized in a limited manner to assist in the removal of high contaminant concentrations in isolated areas where the pump-and-treat system was ineffective.

## **6. AIR SPARGE/SOIL VAPOR EXTRACTION SYSTEM COSTS**

The Mound OU-1 air sparge/soil vapor extraction system was designed by R.E. Wright Environmental, Inc., constructed by Kelchner Environmental, Inc., and operated by Babcock and Wilcox Technologies of Ohio under a cost-plus-fee management and operations (M&O) contract with the DOE. Several organizations, including Sandia National Labs and several industry participants, played an important role in the design, operation, and monitoring of the remediation system. These services were often in an advisory or consulting role, though some direct support was provided to the project. Where appropriate, direct support costs are included in Table 12, which shows project costs in accordance with the interagency work breakdown structure adopted by the Federal Remediation Technologies Roundtable.

As can be seen from Table 12, 13% of the overall cost of the system operation was related to the extensive monitoring conducted. This level of monitoring was used in an effort to better understand the operation of the system and to track the contaminant removal through time. The monitoring cost data includes summa sampling and onsite GC analysis. From an operational viewpoint, the system removed an estimated 3433 lbs. of soil vapor contaminant. The direct treatment cost for contaminant removal, excluding the extensive monitoring costs, during the system operations was therefore approximately \$365 per pound of contaminant removed.

**Table 12. Air Sparge/Soil Vapor Extraction Project cost by interagency work breakdown structure.**

Cost element (with interagency WBS Level 2 code)	Description	Costs (\$)	Subtotals (\$)
Mobilization and preparatory work(331 01)			
	Mobilization	5000	
	Site Preparation	10000	
	Demobilization and Site Restoration	7500	22500
Monitoring ,sampling, testing, and analysis (331 02)			
	Sampling Performance Monitoring	7500	
	Sampling Compliance Monitoring	29750	
	Sampling QA/QC	7500	
	Analysis Performance Monitoring	13000	
	Analysis Compliance Monitoring	38000	
	Analysis QA/QC	8000	
	Analysis Data Reduction	5500	
	Geoprobe Sampling	10467	
	On site automated GC	45000	
	Sampling and Analysis Supplies	20000	184717
	Ground water collection and control (331 06)		
Miscellaneous		5000	5000
Soil vapor collection and control			
	GLCT 4,000 lbs. GAC Replacement (LTD)	55000	55000
Air Sparge Treatment			
	Above Ground Equipment Purchase	15000	
	Below Ground Equipment Purchase	8800	
	Above Ground Installation	36200	
	Below Ground Installation	100500	
	Contractor Operating Costs	64750	225250
Soil Vapor Extraction Treatment			
	Above Ground Equipment Purchase	8000	
	Below Ground Equipment Purchase	4200	
	Above Ground Installation	17800	
	Below Ground Installation	50500	
	Contractor Operating Costs	64750	145250
General requirements (331 22)	Project management and engineering (+O&M)	801322	801322
		<b>TOTAL</b>	1439039

## 7. SCHEDULE

**Table 13. Tasks and schedule associated with the air sparge/soil vapor extraction project at the Mound OU-1 Site.**

Date	Milestone
March 1995	Technical Advisory Group formed
April 1995	Technologies selected for demonstration
April 1996	Pilot scale studies completed
April 1997	Construction of full-scale system begun
November 1997	Construction of full-scale system completed
May 1998	Air Sparge system determined to be unsatisfactory halting sparging
May 2000	>3500 pounds VOC removed from unsaturated zone since startup

## 8. OBSERVATIONS AND LESSONS LEARNED

### *Air Sparge Wells*

The sparge points recommended for use, with 50-micron screen openings, fouled within seven weeks of use. This occurred during the initial testing period in which the system was operating as designed, switching between two remediation areas. After treatment by traditional well redevelopment method, well performance was restored to initial levels. The restart of the AS system was delayed due to an EPA request for quantification of additional contaminant removal produced by the AS system. This required the measurement of a stable baseline contaminant level prior to the initiation of the AS. An onsite purge-and-trap GC was required to quantify this VOC baseline concentration and to measure the expected small decrease in contaminant level produced by the AS system. The procurement, testing, and qualification of a purge-and-trap GC added significant cost and time to the project.

### *Soil Vapor Extraction System Components*

During the project the large SVE blower (6LP) experienced two failures, the small SVE blower (5LP) experienced one failure, the 50-hp motor required replacement, and the drive belts required replacement twice. The blower failures were attributed to calcium carbonate encrustation of the blower compressor vanes caused by evaporation of moisture. The moisture reached the blowers because the GAC tanks, which acted as water absorption units, were bypassed after the VOC concentrations in the effluent reached deminimus levels and the GAC was no longer required for effluent treatment. Excess moisture should have been removed by the moisture knockout tank, but the system tank was approximately 1/3 the size required to adequately remove moisture from the system.

The heat exchanger core, due to excessive airflow impedance, was changed. The cause was determined to be carbon fouling of the small passages within the core. This was caused by the system not having post carbon vessel filtration and the carbon within the vessels migrating past the 6LP blower and into the heat exchanger. A filter unit was procured and installed in the 6LP blower intake line.

### *Effluent Treatment System Components*

During the period the installation contractor was operating the system and training Mound personnel, carbon saturation was achieved and went undetected until February 4, 1998. On this date, the system was shut down until the carbon was changed out on February 12, 1998. This reinforces the importance of having the contractor provide an approved monitoring plan prior to system startup.

The SVE system was shut down on multiple occasions for spent carbon removal and replenishment. On each of these occasions, the system was offline for approximately six (6) hours. A design change in plumbing and piping is suggested for future systems to enable changing of carbon in a single vessel without necessitating a system shutdown. Furthermore, the use of traditional PVC well screens for air distribution in the lower portion of the GAC vessel should be avoided as this lead to additional down time for multiple cleanings and has resulted in reduced air flow efficiency.

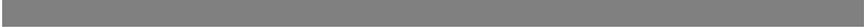
The Grundfos pump, used to transport liquids from the SVE knockout tank to the air stripper, was found inadequate in capacity during rain events exceeding one inch. A pump kit to expand the capacity of the pump was implemented. This only gave marginal relief and did not completely rectify the problem. The major constraint was the one-inch diameter line to the air stripper manifold which limited flow capacity.

## 10. REFERENCES

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1. *2-Phase Extraction Pilot Scale Test Final Report*, Radian International, Rochester, NY, 1996.
2. *Air Sparging and Soil Vapor Extraction Pilot Test and Conceptual Design Report*, Groundwater Technologies, Inc., Cleveland, OH, 1996.

## 10. VALIDATION



Signatories:

“This analysis accurately reflects the performance and costs of the remediation.”

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Oba Vincent, ER Site Program Manager  
U.S. Department of Energy

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Gary Brown, Technical Lead Ohio Projects  
Innovative Treatment and Remediation Demonstration Program  
Sandia National Laboratories

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Brian Nickel, Ohio Environmental Protection Agency