

# **COST AND PERFORMANCE REPORT**

Air Sparging and Soil Vapor Extraction  
at Landfill 4, Ft. Lewis, Washington

October 1998



Prepared by:  
U.S. Army Corps of Engineers  
Hazardous, Toxic, Radioactive Waste  
Center of Expertise

**SITE INFORMATION**



**IDENTIFYING INFORMATION**

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

**TECHNOLOGY APPLICATION**

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

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

**BACKGROUND**

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

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

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

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



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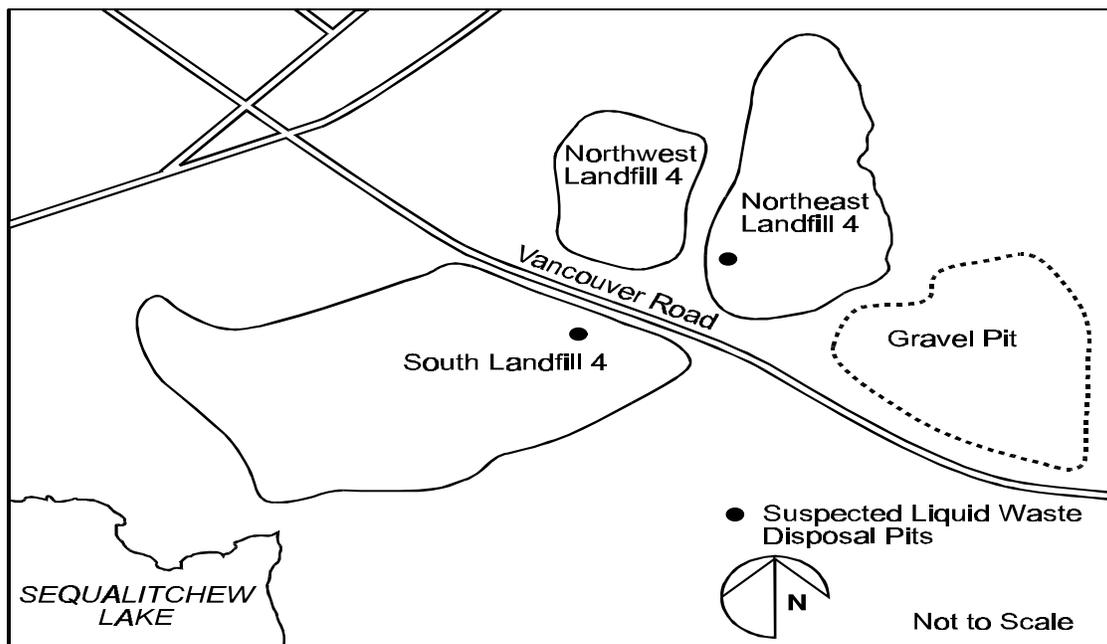


Figure 2: Landfill 4 - Location of Three Cells [6]

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



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

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

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

**SITE LOGISTICS/CONTACTS**

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**MATRIX AND CONTAMINANT DESCRIPTION**

**MATRIX IDENTIFICATION**

Soil (in situ)  
 Groundwater

**CONTAMINANT CHARACTERIZATION**

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

Metals:                                    Manganese (Mn)

**CONTAMINANT PROPERTIES**

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

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



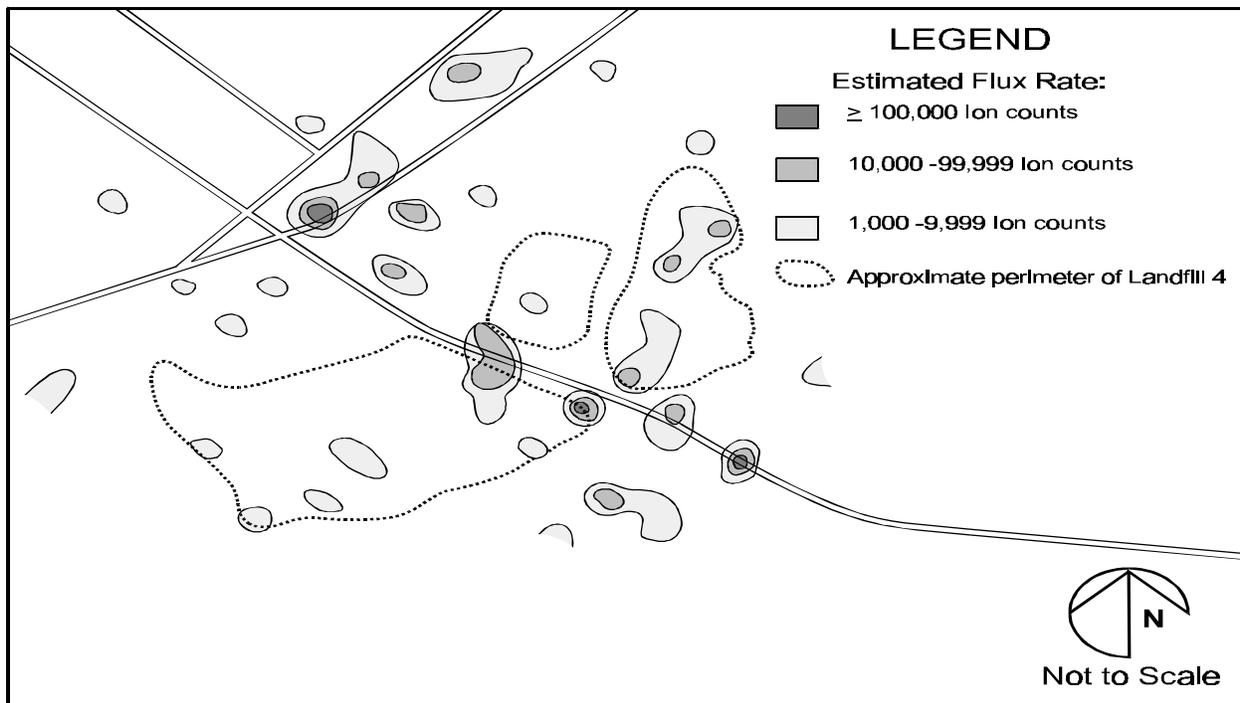
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**CONTAMINANT CONCENTRATIONS (4)**

**Soil [4, 6]**

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



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



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

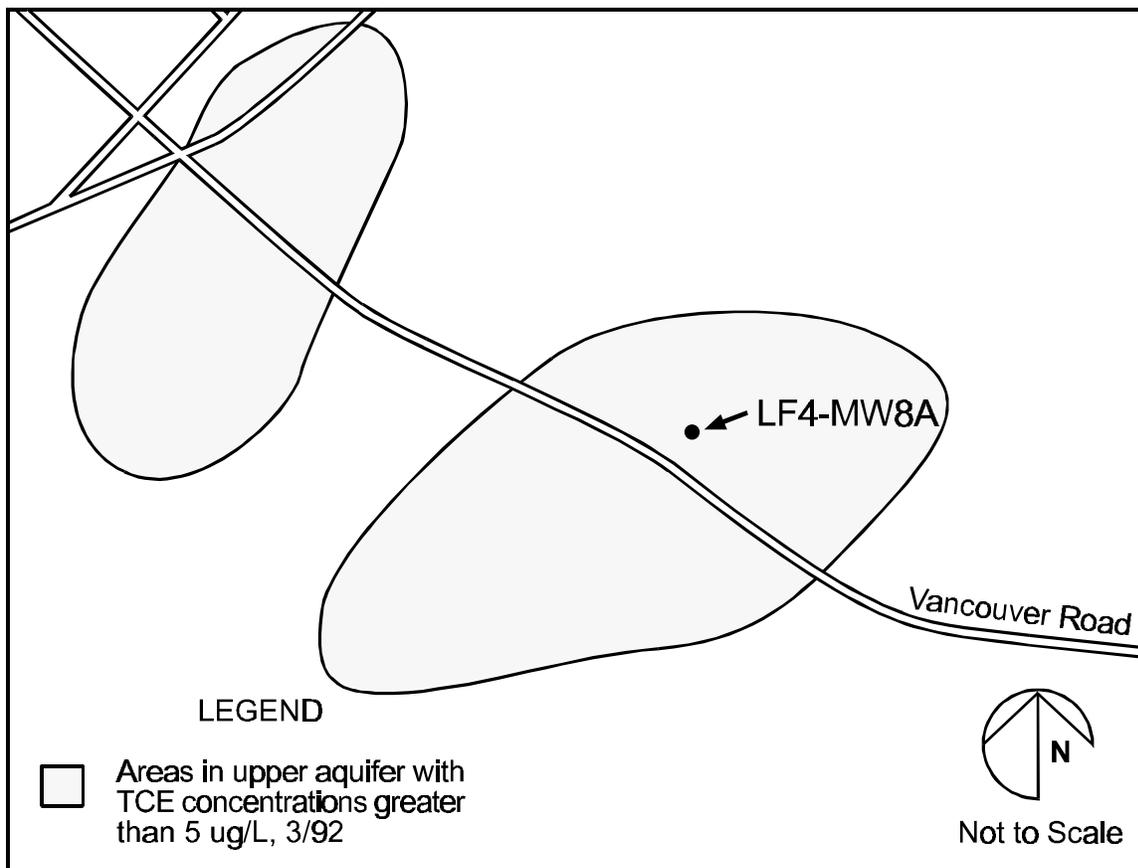
Detected Analyte	Gas Probes Within Landfill	Gas Probes Outside Landfill
	Concentration Range (mg/m <sup>3</sup> )	Concentration Range (mg/m <sup>3</sup> )
Benzene	<0.06-0.17	<0.06-1.6
Chlorobenzene	<0.06-0.09	<0.06
Chloroethane	<0.06-0.79	<0.06
1,4-Dichlorobenzene	<0.06-5.9	<0.06
cis-1,2-Dichloroethene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



**Groundwater [6]**

Table 2 presents a summary of compounds detected during the RI in the upper and lower aquifers at LF4. In the upper aquifer TCE was detected at concentrations as high as 79 ug/L, cis-1,2-DCE at

- Figure 4 shows the area where TCE concentrations greater than 5 ug/L were detected in the upper beneath LF4 as well as in an area to the west of the landfill.
- groundwater to the degradation of this compound.



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



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

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



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

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

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

**GEOLOGY AND HYDROGEOLOGY**

**GEOLOGY (4):**

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



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

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

**Hydrogeology [4,6]**

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



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

**TREATMENT SYSTEM DESCRIPTION**

**PRIMARY TREATMENT TECHNOLOGY TYPE (7)**

Soil - Soil Vapor Extraction  
 Groundwater - Air Sparging

**SUPPLEMENTARY TREATMENT TECHNOLOGY TYPE**

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

**TIMELINE [1, 6]**

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



## TREATMENT SYSTEM SCHEMATIC AND TECHNOLOGY DESCRIPTION AND OPERATION

### Technology Description

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

### PILOT SYSTEM [8]

#### Construction

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



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

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

**Operation**

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

**FULL-SCALE SYSTEM [2]**

**Construction**

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



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

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

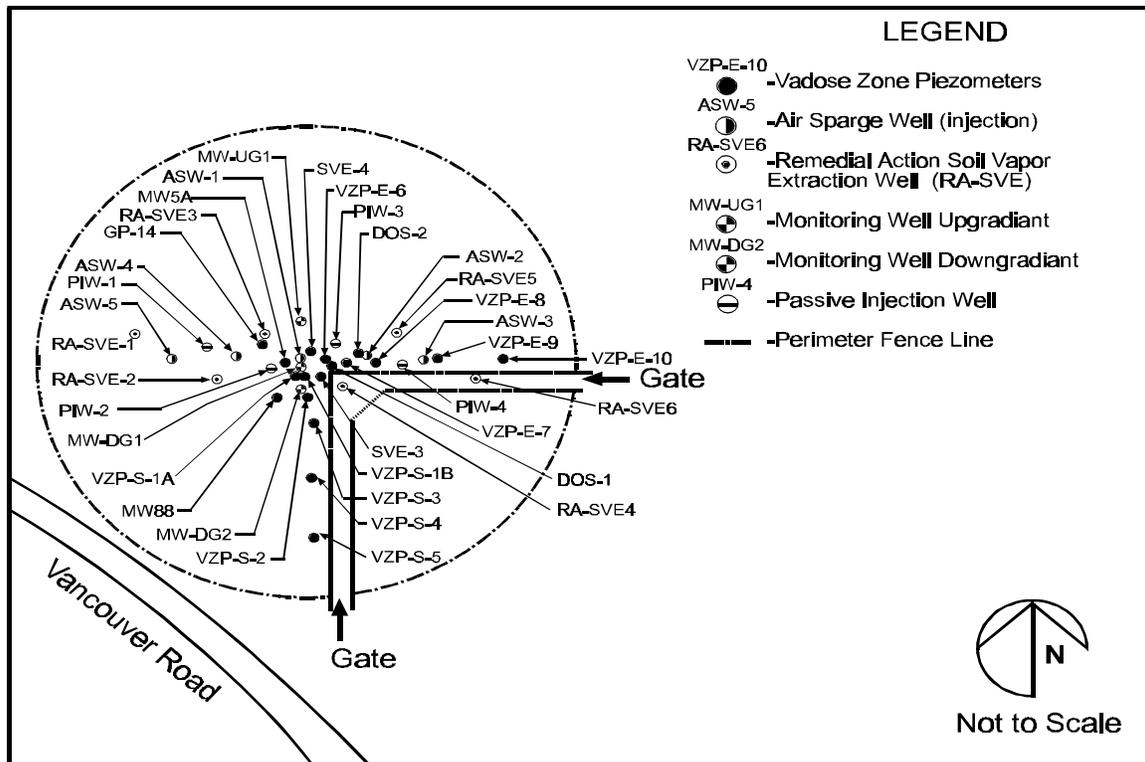


Figure 5: Well Location Map for Landfill 4 [2]



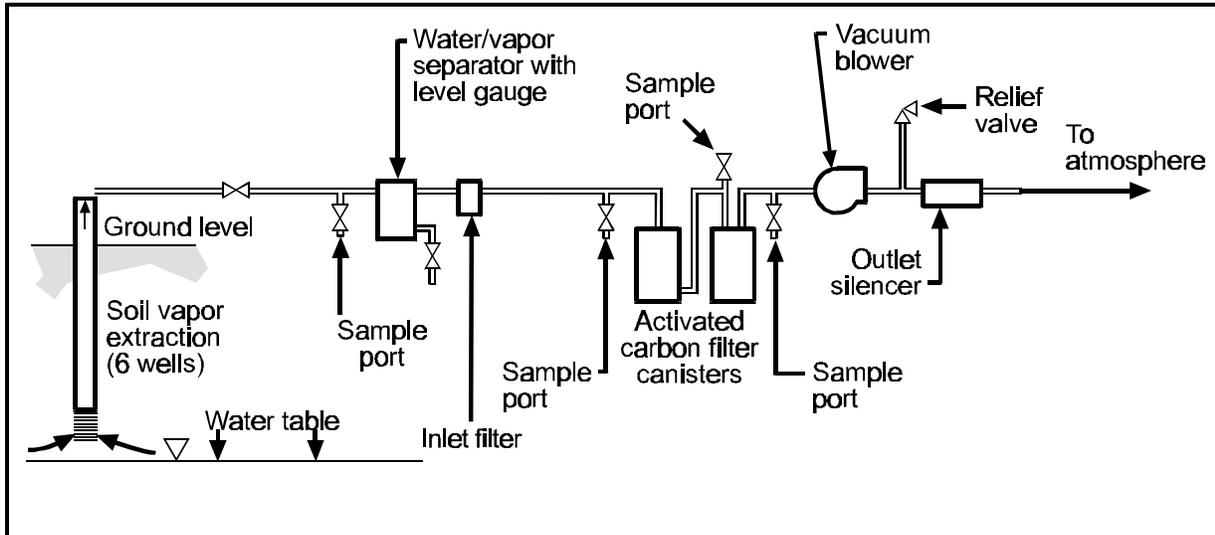


Figure 6: SVE Schematic for Landfill 4 [2]

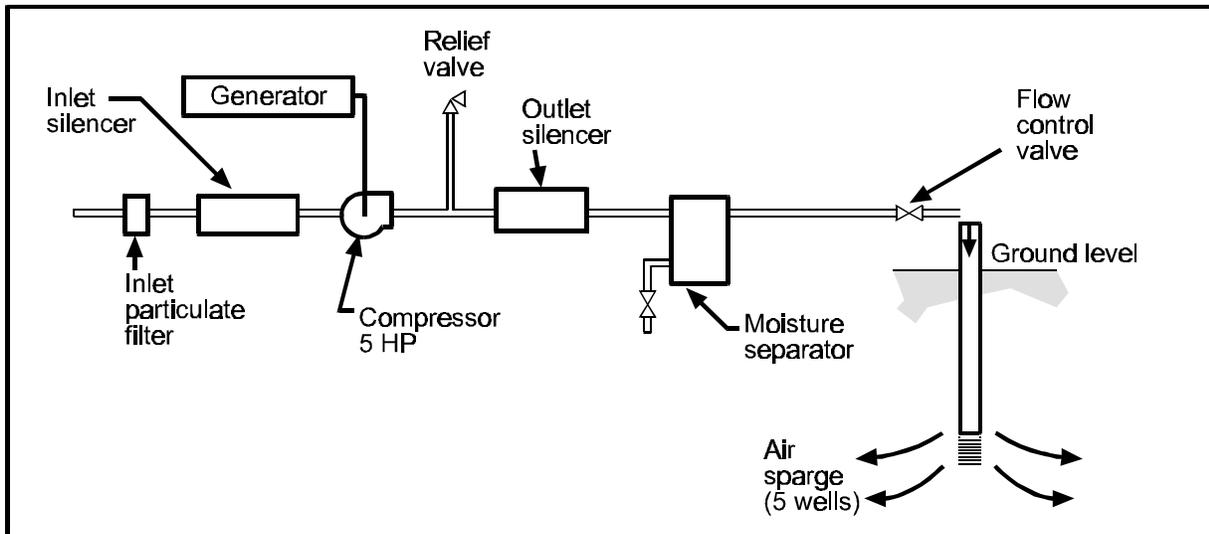


Figure 7: AS Schematic for Landfill 4 [2]



**Operation**

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

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

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

**TREATMENT SYSTEM PERFORMANCE**

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

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



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

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

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

#### **Treatment Plan**

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

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

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



**Soil Gas**

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

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

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

-- - No sample analyzed



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

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

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

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

-- - No sample analyzed



**Groundwater**

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

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

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

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



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

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

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

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

ND - Not detected

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

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

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

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



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



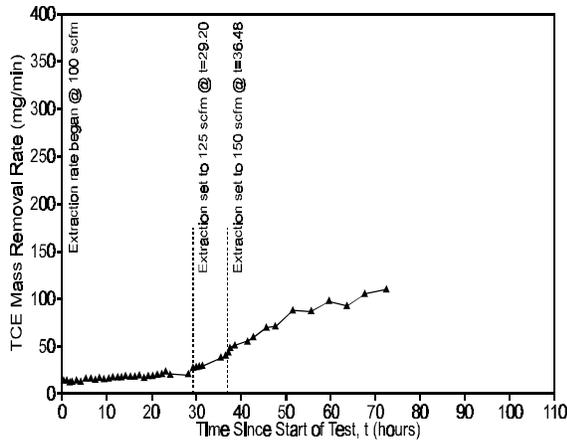


Figure 8: Well SVE-1 TCE Mass Removal Rate vs. Time [1]

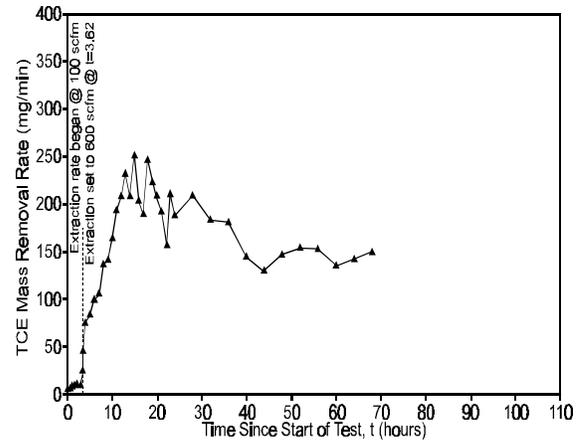


Figure 9: Well SVE-2 TCE Mass Removal Rate vs. Time [1]

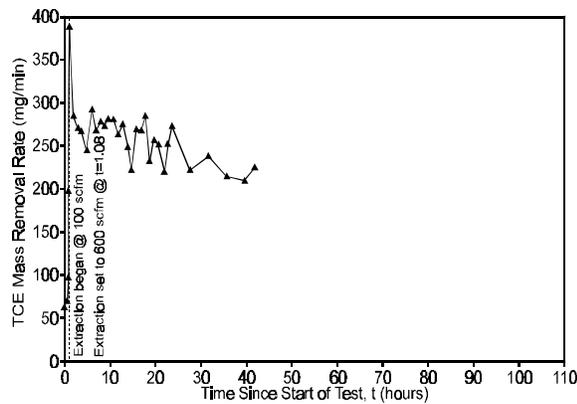


Figure 10: Well SVE-3 TCE Mass Removal Rate vs. Time

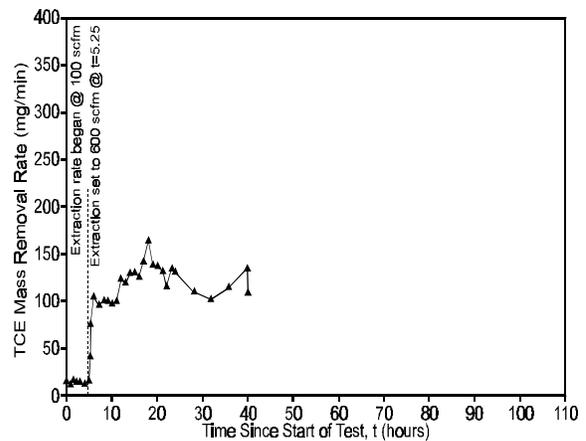


Figure 11: Well SVE-4 TCE Mass Removal Rate vs. Time [1]

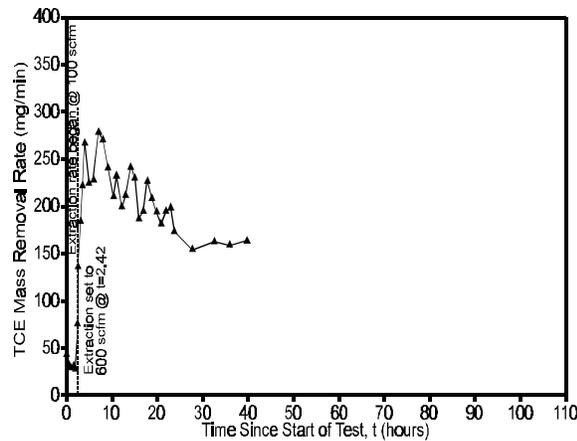


Figure 12: Well SVE-5 TCE Mass Removal Rate vs. Time [1]

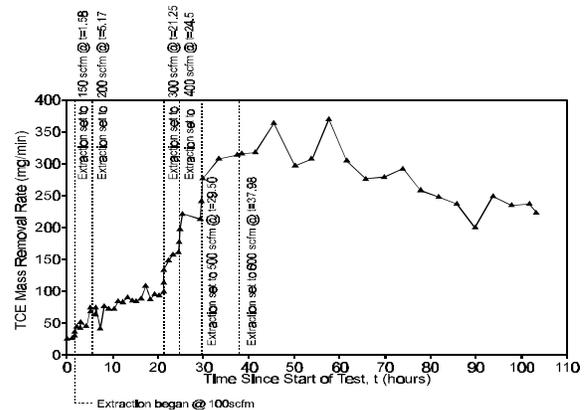


Figure 13: Well SVE-6 TCE Mass Removal Rate vs. Time [1]



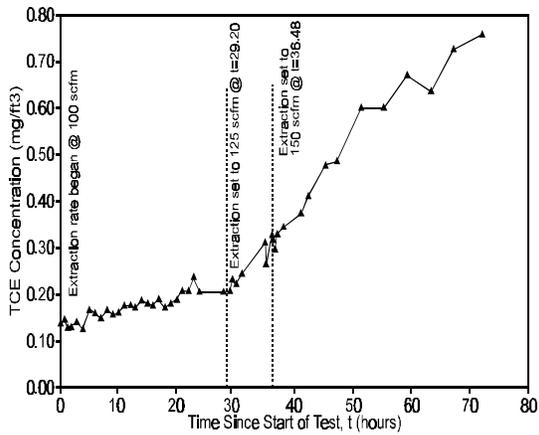


Figure 14: Well SVE-1 TCE Concentration vs. Time [1]

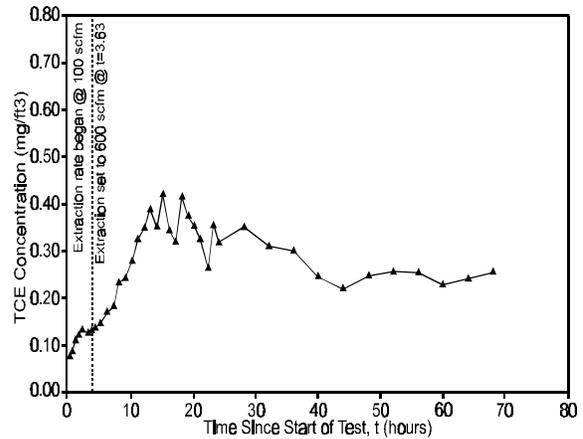


Figure 15: Well SVE-2 TCE Concentration vs. Time [1]

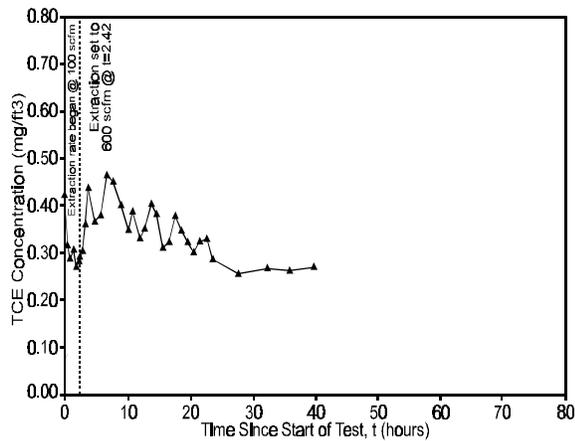


Figure 16: Well SVE-3 TCE Concentration vs. Time [1]

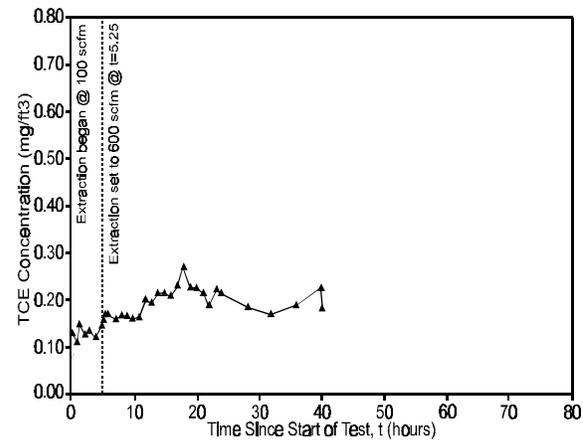


Figure 17: Well SVE-4 TCE Concentration vs. Time [1]

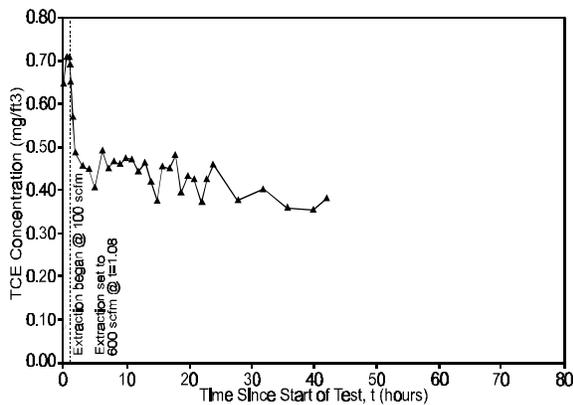


Figure 18: Well SVE-5 TCE Concentration vs. Time [1]

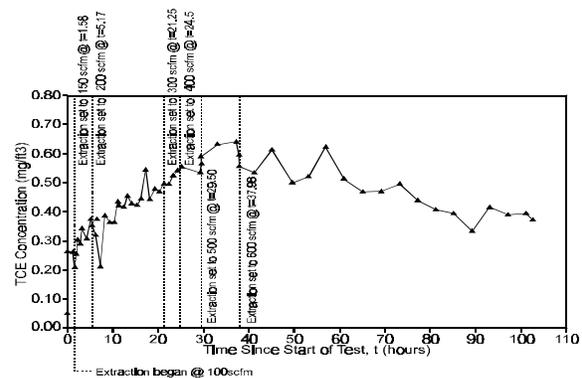


Figure 19: Well SVE-6 TCE Concentration vs. Time [1]



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

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

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



Table 9: Initial Sparge Testing Data [1]

Sparge well	Breakthrough Pressure (psi)	50 scfm [0.70 in of H2O] psi	75 scfm [1.45 in of H2O] psi	100 scfm [2.60 in of H2O] psi
ASW-1	7.0	7.75	9.5	9.5
ASW-2	7.75	8.5	9.0	10.0
ASW-3	6.4	6.5	6.6	6.6
ASW-4	7.0	7.5	8.25	8.25
ASW-5	8.25	8.25	8.5	8.5

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

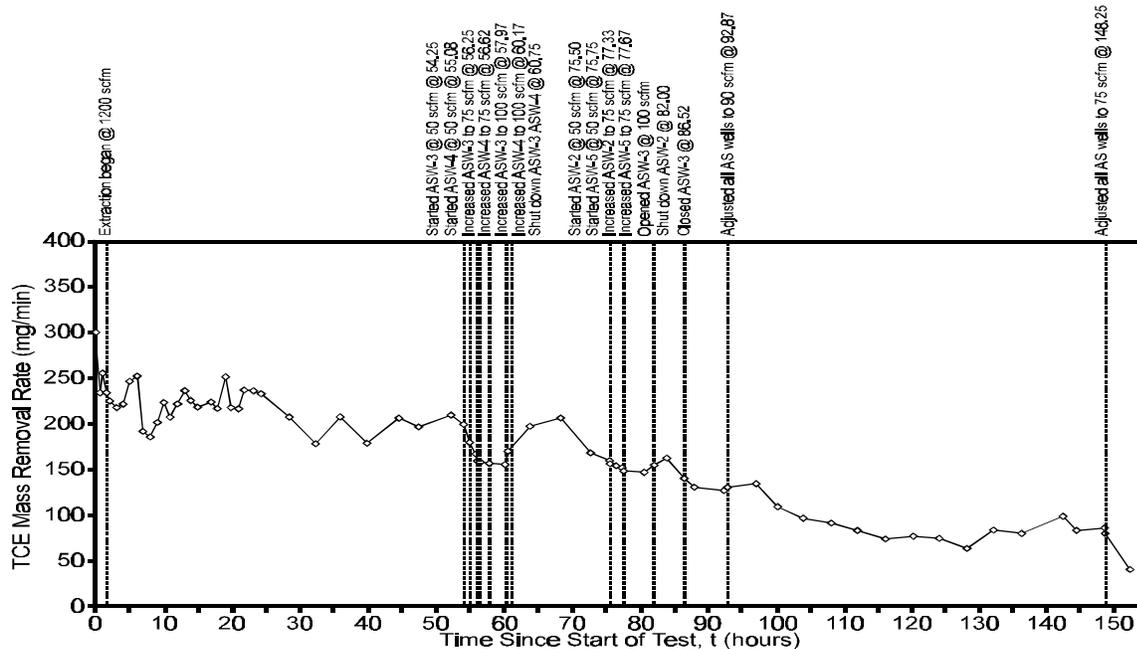
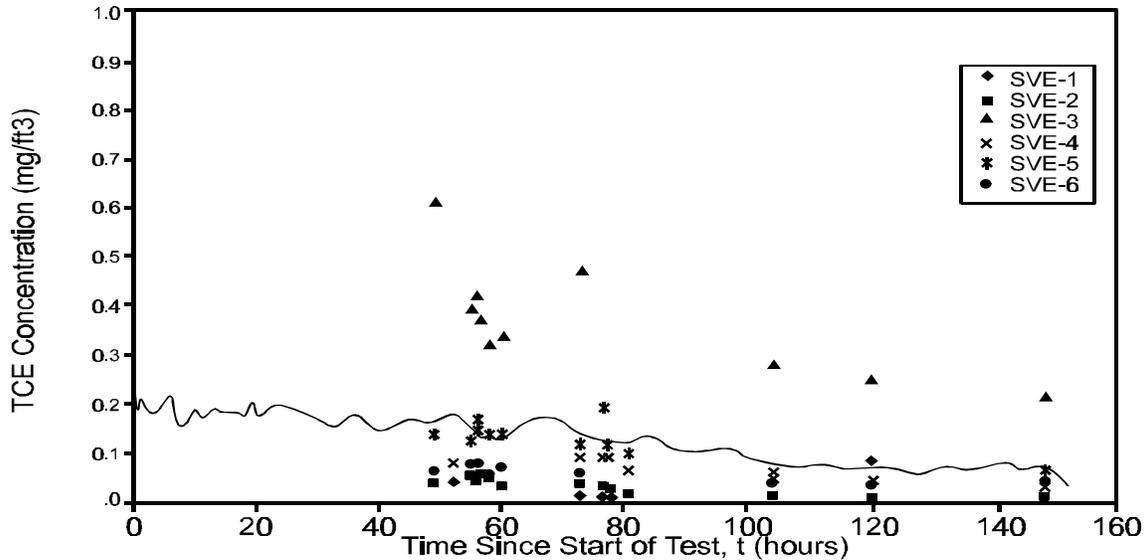


Figure 20: Full system (Phase 1) TCE Mass Removal Rate vs. Time [1]





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

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



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

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



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

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



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

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

- While VC was not measured during startup activities, Chemical Data Report #1 estimated that a maximum of 0.093 lbs of VC were removed from the subsurface during startup activities. This estimate was based on one sample collected from the location where VC levels had been detected. Because this estimate did not account for areas where VC was not detected, it was concluded that the actual quantity of VC removed is likely to be significantly less than the estimate.
- The effect of sparging on the system was reported in Chemical Data Report #1 to be difficult to quantify because of the overall TCE concentration decrease. While TCE concentrations decreased during sparging events, they also continued to decrease when the sparging wells were not operational. For example, from November 21 to 27 when air sparging was conducted, TCE concentrations decreased from 660 ppb to 532 ppb. When the air sparging wells were turned off (December 1), TCE concentrations initially increased to 675 ppb. However, for the next sampling event (December 9), TCE concentrations had decreased to 480 ppb even though the air sparging wells remained closed.
- Sampling data from the period when the passive injection wells were operated (November 27 to December 17) showed TCE concentrations initially increasing from 532 ppb to 675 ppb, then decreasing to 390 ppb. However, the specific effect of the operation of these wells is not evident as the extraction flow rates and use of the AS wells were varied during this time period.
- Because of the significant decreases in TCE concentrations during Phases 2 and 3, the optimal system settings were not determined. The results of the startup activities were used to establish the tentative system settings that were used for the second and third quarters of operation,



during which time the operation of the system was continuously adjusted. These settings include operating SVE wells 1-6 between 210 and 150 scfm; cycling the sparging wells, and leaving the passive injection wells closed.

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

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

### **Groundwater Sampling:**

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



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

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

Notes:

<sup>1</sup> Average concentration from Contaminant Reduction Monitoring wells

<sup>2</sup> Average concentration from Migration Monitoring wells

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

**Air Emissions Sampling:**

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

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

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



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

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

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

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



**TREATMENT SYSTEM COST**

**PROCUREMENT PROCESS**

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

**TREATMENT SYSTEM COST**

**Pilot Study [10]**

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

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

**Full-scale System [11]**

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



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

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

**Notes:**

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

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

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

**REGULATORY/INSTITUTIONAL ISSUES**

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

**OBSERVATIONS AND LESSONS LEARNED**

**COST OBSERVATIONS AND LESSONS LEARNED**

- The total cost for the pilot study of the AS/SVE system at LF4 was \$241,000.
- Subsequent to original negotiations, the contaminant concentrations in system air emissions were determined to be below the allowable air emission standards, and PSAPCA agreed to allow



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USACE to eliminate the need to change the carbon units from the system and to reduce air compliance monitoring requirements. USACE is planning to reallocate money from any savings on air compliance monitoring to increase the system performance air testing. However, several modifications reduced the project costs. The revised costs for this application are \$1,710,303. Because this application is ongoing, the amount of material treated by the system is not known at this time. Therefore, unit costs were not calculated at this time.

## **OTHER OBSERVATIONS AND LESSONS LEARNED**

### **Pilot Study**

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

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

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



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

### **Startup Activities for Full-Scale System**

- The startup activities for the full-scale system were conducted in three phases to provide data for use in optimizing full-scale operations. Phase 1 was designed to collect data on the optimal extraction flow rates for the SVE wells; Phase 2 focused on optimizing the air flow rates for the AS system; and Phase 3 included a number of adjustments to the entire system to determine the optimum system settings for maximum contaminant removal.
- During Phase 1, the first well was tested according to the testing procedures in the LF4 RAMP, which specified a maximum extraction flow rate of 150 scfm. During testing, a five-fold increase in TCE mass removal rate was observed in well SVE-1 when the extraction flow rate was increased from 125 to 150 scfm. Based on these results, the testing procedure was modified to allow wells to be operated at extraction flow rates up to 600 scfm.
- Wells SVE-2 to SVE-6 were operated at the increased extraction flow rates. All five well achieved their highest TCE mass removal rates and highest TCE concentrations in the vapor stream at 600 scfm. However, only well SVE-6 was tested at more than two extraction rates. These data did not provide any additional indication of the optimal extraction flow rates for the individual SVE wells. Therefore, the optimal extraction flow rate was established as a range of between 150 and 600 scfm.
- The total system test performed during Phase 1 included operating all six SVE wells at 200 scfm (1200 scfm for the system) and testing of individual AS wells at varying air flow rates. The addition of the AS wells to the system had little impact on TCE mass removal rates and concentrations. Increasing the air flow rates of an AS well from 50 to 75 scfm resulted in decreased TCE mass removal rates and concentrations for several wells; increasing the air flow rate to 100 scfm generally did not produce mass removal rates higher than that achieved at 50 scfm. However, during the total system test, there was an overall decrease in TCE mass removal rates and concentrations from the start of the test to the end point of the test.
- While TCE concentrations in the groundwater or soil gas were not measured during Phase 1, the results of Phase 2/3 operations (see below) suggest that TCE concentrations at LF4 were trending downward, and therefore, the effects of the operational changes to the system were masked.
- During Phases 2 and 3, a number of adjustments were made to the system including varying injection air flow rates, concentrating extraction in hot spot areas, and concentrating extraction on pairs of wells. Data collected during the system adjustments did not show distinct differences on system operation as a results of the adjustments. During this testing, TCE concentrations in the soil gas were measured and were shown to be decreasing during the period of the testing. In Chemical Data Report #1, the apparent downward trend in TCE concentrations at LF4 were reported to have masked the effects of operational changes made to the system. As a result, the optimal system settings could not be determined during the Phase 2/3 startup activities.
- The results of Phase 2 and 3 activities were used to establish tentative system settings which included operating SVE wells between 150 and 210 scfm; cycling air sparging wells, and leaving the passive injection wells closed.



- The results of the two rounds of groundwater sampling showed a decrease in TCE concentrations in most wells between October 1996 and January 1997; however, TCE concentrations remain above the cleanup goal of 5 ppb.

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

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

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



## REFERENCES

1. Garry Struthers Associates, Inc. 1997. Chemical Data Report #1, Landfill 4 Air Sparging/Soil Vapor Extraction Remediation, Ft. Lewis, Washington. For USACE Contract No. DACA67-95-G-0001-28. June 10.
2. Garry Struthers Associates, Inc. 1996. AS/SVE Workplan, Landfill 4 Remediation, Ft. Lewis, Washington. For USACE Contract No. DACA67-95-G-0001-28. August 26.
3. USACE, Seattle District. Undated. Remedial Action Workplan, Ft. Lewis, LF4, AS/SVE Final Remedial Design.
4. USACE, Seattle District. Undated. Design Analysis, Ft. Lewis, LF4, AS/SVE Final Remedial Design.
5. USACE, Seattle District. Undated. Compliance Monitoring Plan, Ft. Lewis, LF4, AS/SVE Final Remedial Design.
6. Applied Geotechnology, Inc. 1993. Final Feasibility Study Report, Landfill 4 and Solvent Refined Coal Pilot Plant, Ft. Lewis, Washington. Prepared for USACE, Seattle District. May.
7. USACE, Seattle District. 1995. Technical Memorandum, AS/SVE Pilot LF4, Ft. Lewis. March 28.
8. USACE, Seattle District. 1994. Final Management Plan, Pilot Study, Landfill 4, Ft. Lewis, Washington. June.
9. U.S. EPA. 1993. Record of Decision, Ft. Lewis Landfill 4 Remediation. October 15.
10. USACE, Seattle District. 1994. Government Cost Estimate for Cover Air Sparging/Soil Vapor Extraction Pilot Test, Landfill 4, Ft. Lewis, WA, Department of the Army. August.
11. USACE, Seattle District. 1996. Price Negotiation Memorandum. May.
12. K. Lynch, USACE. 1998. Response to questions on LF4 cost data. January 9.
13. Garry Struthers Associates, Inc. 1998. Chemical Data Report #2, Landfill 4 Remediation, Ft. Lewis, Washington. For USACE Contract No. DACA67-95-6-0001-28. March 16.
14. USACE, Seattle District. 1997. Letter from Ronald M. Bush, P.E. to Margaret Corbin, Puget Sound Air Pollution Control Agency. December 5.
15. Puget Sound Air Pollution Control Agency. 1997. Letter from Margaret L. Corbin to Ronald Bush, USACE. December 11.

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

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



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

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



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

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



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