COST AND PERFORMANCE REPORT

Multi-Phase Extraction at the 328 Site
Santa Clara, California

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EPA

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Summary Information

A Dual Phase Extraction (DPE) system was designed, installed, and operated to remove VOCs from silty clay soils and shallow groundwater in a former waste storage area at a large industrial manufacturing facility. Air flow through the soils was enhanced by pneumatic fracturing (PF) between DPE extraction wells and by supplying continuous low flow/low pressure air to the fractured soils. The increased air flow caused by fracturing, within an otherwise tight clay formation, improved capture of VOCs by the vapor extraction system. In addition, concurrent groundwater extraction removed highly impacted shallow groundwater. Over 40 percent of the VOC mass removal occurred from the vadose zone during the first month of operation. Groundwater extraction provided greater mass removal rates than soil vapor extraction by the fifth month of operation. The combination of technologies has allowed soil vapor extraction to be effective in an area that is not well suited for in-situ remediation.

The 328 Site occupies approximately 27.1 acres in a primarily industrial and commercial area of San Jose and Santa Clara, California, near the San Jose Airport. The 328 Site was used for manufacturing military tracked vehicles, including assembly and painting operations, from 1963 through 1998. Manufacturing operations were discontinued in 1998 and the 328 Site is currently being remediated in anticipation of future commercial/industrial redevelopment. This project was conducted by FMC Corporation in accordance with the State of California San Francisco Bay Regional Water Quality Control Board *Final Site Cleanup Requirements Order Number 96-024,* with HSI GeoTrans and Terra Vac as engineer/primary contractor and subcontractor, respectively.

Figure 1 presents the 328 Site plan, including the source area and groundwater containment system. Table 1 provides a summary of the site setting information. The source area was a former waste handling area that is currently covered with asphalt paving. Downgradient migration of impacted groundwater extended to the northeast past the property boundary. A groundwater containment/treatment system was installed at the perimeter of the property in 1993 to prevent further off-site migration of impacted groundwater. The DPE with PF system was installed at the 0.5-acre source area in 1996 to remediate shallow soils and groundwater.

Figure 1. Map of 328 Site (Zahiraleslamzadeh et al., 1998)

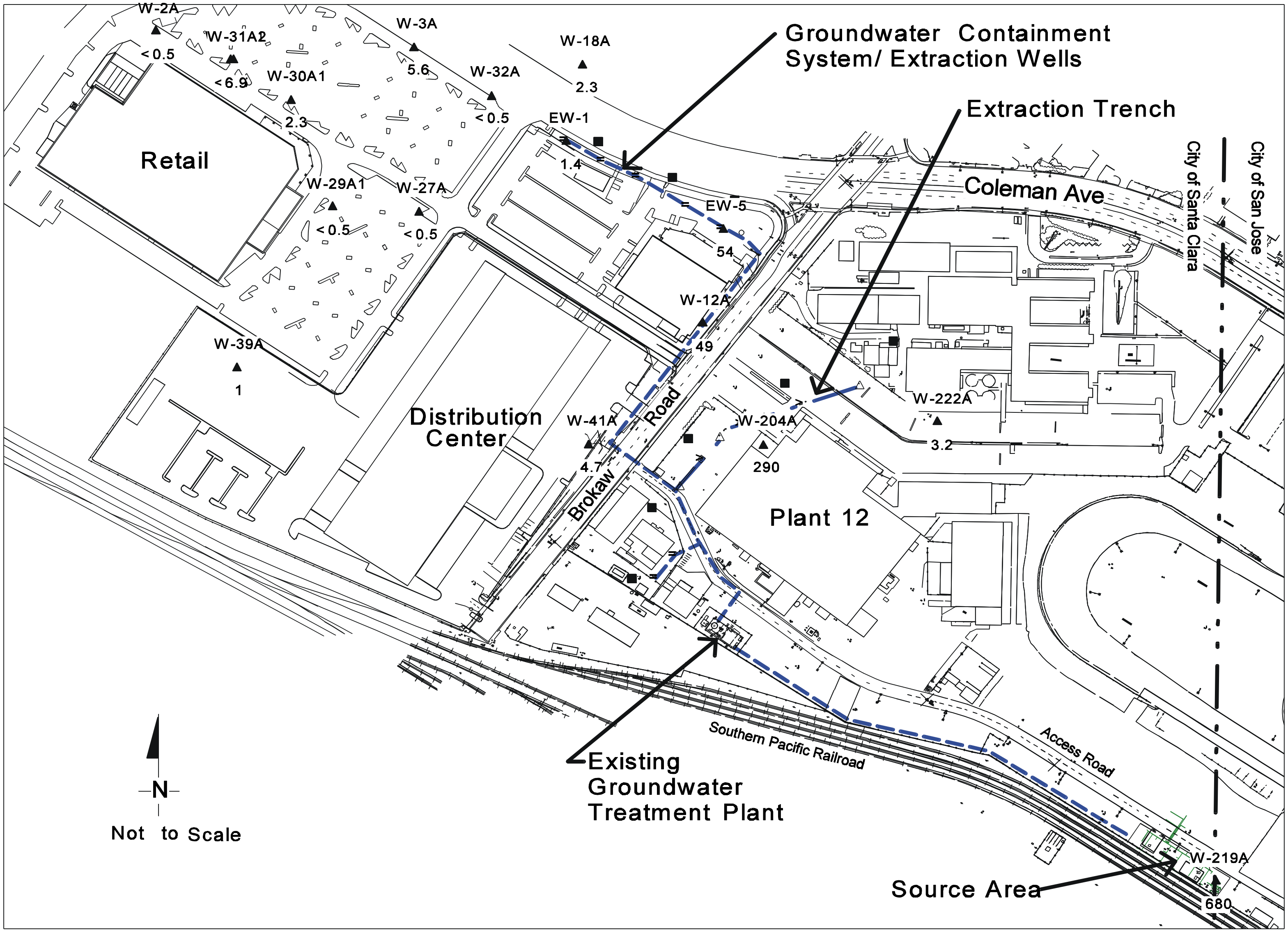


Table 1. 328 Site Setting

Parameter	Characteristics
Geologic Setting of Source Area	Silts and Clays, 0 to 20 feet below ground surface
Geologic Setting of Impacted Aquifers	Sandy Silts, Silty Sands, and Gravelly Sands, 20 to 90 feet below ground surface
Depth to Groundwater	8 feet below ground surface
Constituents of Concern	Trichloroethylene (TCE)
Initial Concentrations	46 mg/kg in Soil; 37,000 ug/L in GW

Sediments underlying the 328 Site include marine or basinal clays, coarse channel deposits, and inter-channel silts and clays. The first extensive lithologic unit encountered at the 328 Site is a dark gray to black silty clay. This unit is immediately below ground surface to depths of approximately 20 feet. Although groundwater is located approximately eight feet below ground surface, the first water-bearing zone (A-level aquifer) underlies the surficial clay, and is observed within a depth interval of approximately 20 to 50 feet below ground surface. The second water-bearing zone (B-level aquifer) is present at depths of 50 to 90 feet below ground surface.

VOCs, predominantly trichloroethylene (TCE), were the primary chemicals of concern. The highest TCE concentration measured in the soil during the remedial investigation was 46 mg/kg, and the highest concentration measured in shallow groundwater during the remediation was 37,000 ug/L. The objective of the DPE with PF system was to remediate shallow soil and groundwater to a depth of 20 feet below ground surface.

Technology Description and System Design

Table 2 provides a summary of the technology used at the 328 site.

Table 2. Technology Summary

Technology	Mechanism
Soil Vapor Extraction	Volatilization of TCE from soil matrix by extracting vadose zone air; air flow increases volatilization processes.
Groundwater Extraction	Air entrainment lifts shallow groundwater droplets with extracted vapors.
Pneumatic Fracturing	Injecting high-pressured air for one to two minutes to create fractures within the clay soil matrix and allow increased air flow through impacted materials.
Air/Water Separator	Gravity separation.
Air Treatment	Vapor-phase carbon removes TCE from air by adsorption.
Groundwater Treatment	Air strippers and vapor-phase carbon at existing downgradient groundwater treatment plant.

Twenty dual phase, single pump extraction wells were installed at the source area based on the results of previous SVE and PF pilot tests. Two pneumatic fracture points, at specific depths, were installed between each pair of extraction wells - a total of 41 fracture locations. Following initial fracturing, a low flow/low pressure compressor provided continuous air injection into each fracture point. A process flow diagram is shown in Figure 2. According to the site owner and their consultant (Zahiraleslamzadeh, 1998) this system offered the following advantages:

1. The pneumatic fracture locations specifically target the low flow regions at the midpoints between extraction wells.

2. The low flow/low pressure air supply maintains open fractures and supplies air to the low flow regions.

3. Air entrained extraction is cost-effective given the shallow groundwater and clay soils.

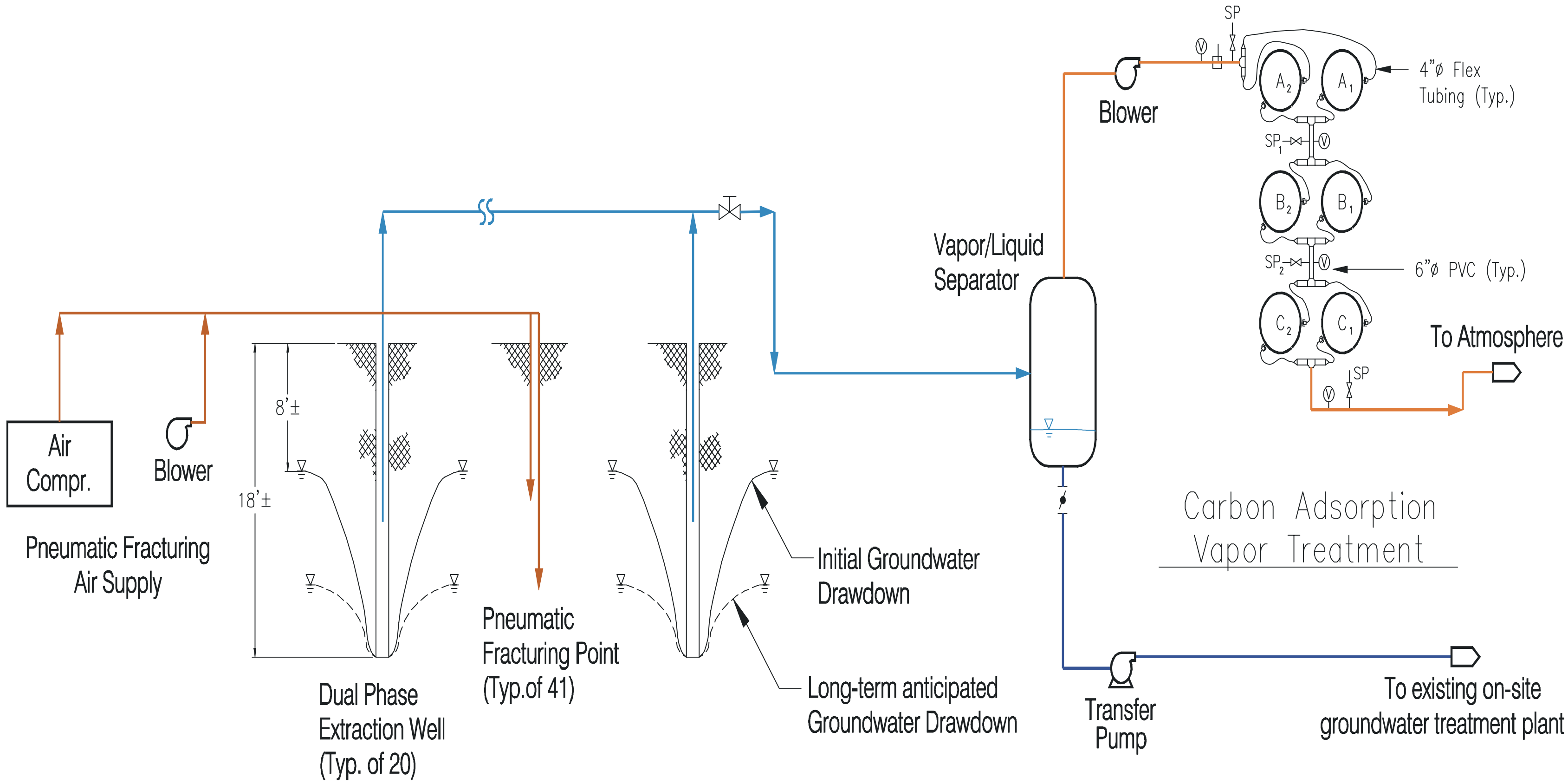
Technology Performance

The DPE with PF system began operating in November 1996; Table 3 provides an overall operations timeline. In theory, the groundwater extraction rate would decrease as the water table was lowered in the vicinity of each well, and additional wells could be brought on-line; however, groundwater production was approximately five gallons per minute (gpm) per well instead of the 0.5 to 2.0 gpm anticipated by the design. This was attributed to the presence of high-permeability lenses in the formation that provided preferential flow paths. Groundwater drawdown a few feet away from operating extraction wells was limited to three to five feet, while drawdown greater than one foot was observed over 100 feet away from the nearest operating DPE wells.

Table 3. Operations Timeline

Dates	Activities
May 1996 – August 1996	Work Plan and Design
September 1996 – November 1996	Construction and Startup
December 1996 – April 1997	Pneumatic Fracturing and Cluster Operations
May 1997 – May 1998	Continued Operations focused in areas of highest impacts
June 1998 – August 1998	Shutdown and Rebound
September 1998 – October 1998	Restart and Continued Operation
November 1998	Confirmation Soil Sampling
January 1999	Final Reports and Preparation for System Shutdown

Figure 2. Process Flow Diagram (Zahiraleslamzadeh et al., 1998)



The DPE system extracted approximately 35 gpm of groundwater on a continuous basis. This limited the number of extraction wells that can operate simultaneously. As such, clusters of extraction wells were operated on a rotating basis to accommodate the unexpected high groundwater production. Cluster operations were focused on areas of higher VOC concentrations.

Pneumatic fracturing of the source area soils was conducted using a portable air compressor and an air supply manifold. The manifold pressure was set at approximately 75 pounds per square inch gauge (psig) and the valve slowly opened to apply an increasing pressure to the pneumatic fracture point. The fracture point pressures ranged from 6 to 60 psig and averaged approximately 19 psig. These fracture pressures were lower than expected for the silty clay soils. The fracturing data also indicates that the formation likely contains high-permeability lenses that provided preferential flow paths.

Extraction vapor flow rates increased significantly following pneumatic fracturing. The average vapor flow rate from the DPE wells increased from approximately 39 scfm to over 65 scfm. In addition, numerous wells experienced order of magnitude increases in vapor flow rate. VOC mass removal, however, remained relatively constant as VOC concentrations were lower in extracted vapors following pneumatic fracturing.

VOC Mass Removal

VOC mass removal followed a typical SVE system decline, as shown in Figure 3. The VOC mass removal rate was approximately 90 pounds per day during the first four days of operation and declined to less than 30 pounds per day by the eighth day of operation. The DPE system removed approximately 1,220 pounds of VOCs from the source area soils and shallow groundwater.

VOC concentrations in groundwater declined similar to VOC mass removal. The average source area VOC concentration in groundwater has declined from over 12,000 micrograms per liter (ug/L) to less than 800 ug/L, during operation of the DPE system. Groundwater monitoring results are shown in Table 4 and illustrated on Figure 4.

Figure 3. VOC Mass Removal

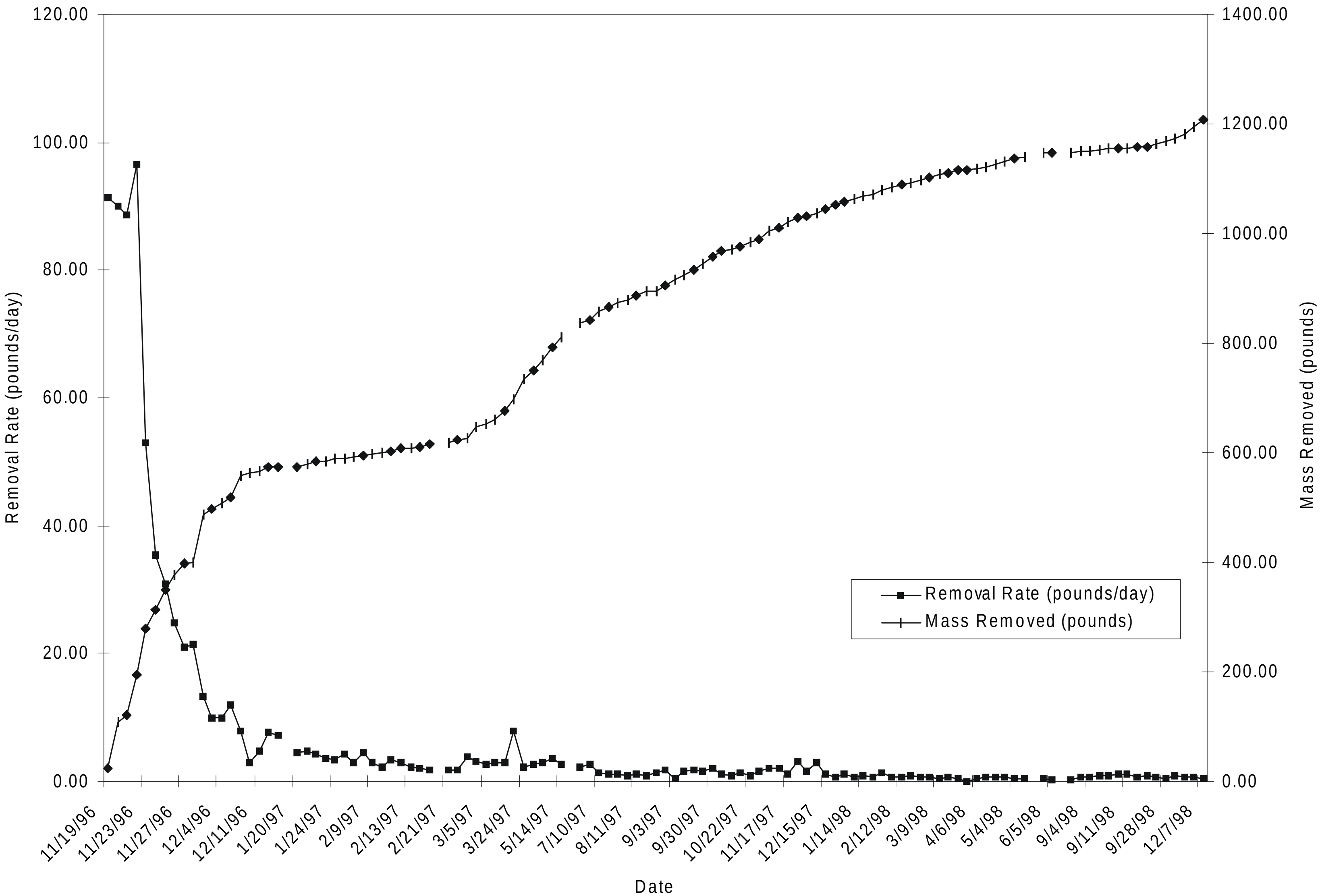


Figure 4. Average VOC Concentrations of Groundwater Over Time

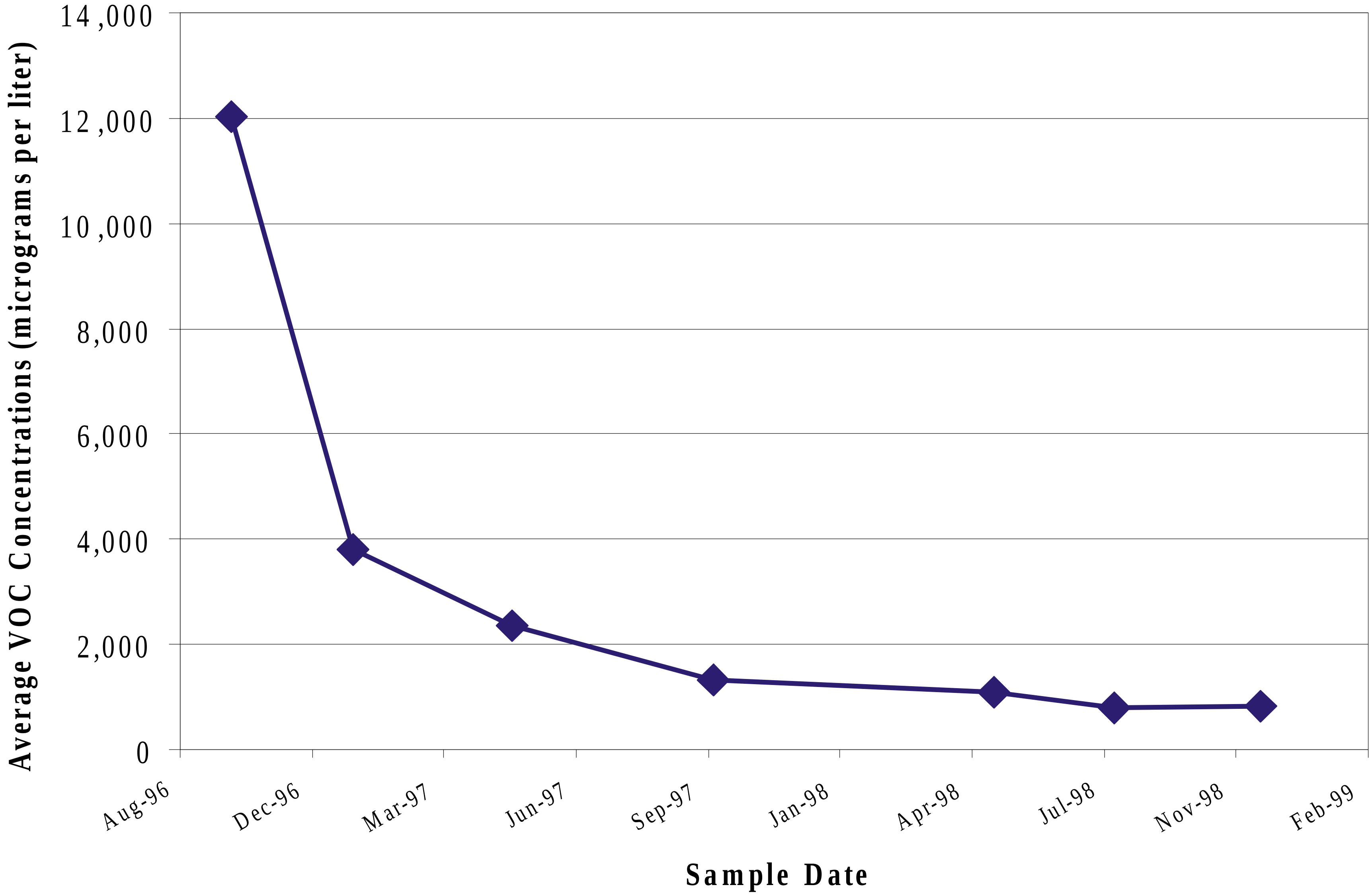


Table 4. VOC Concentrations in Groundwater

DPE Well	Oct-96(1)	Jan-97(2) Feb-97	May-97(3)	Oct-97(4)	May-98(5)	Aug-98(6)
DP-1			1,704	990	954	1,134
DP-2	14,000	9,900	4,700	1,000	1,477	1,039
DP-3		4,300	2,900	920	953	611
DP-4		3,700	2,200	1,500	1,100	1,510
DP-5	8,900	2,100	1,694	1,200	947	956
DP-6		2,000	1,169	770	839	367
DP-7			8,600	6,500	4,200	573
DP-8	23,000	9,300	3,200	3,200	3,400	2,214
DP-9			1,900	2,000	550	1,744
DP-10			512	330	224	237
DP-11			219	95	95	109
DP-12	1,300	2,100	640	270	199	200
DP-13			650	300	220	343
DP-14	800	130	58	41	20	131
DP-15	10,000	3,200	1,671	1,400	913	1,598
DP-16			2,200	1,700	1,294	1,154
DP-17	37,000	3,300	750	260	597	308
DP-18	8,900	4,400	5,500	1,900	1,400	369
DP-19	4,400	1,100	816	470	560	456
DP-20			6,200	1,700	1,600	906
Average	12,033	3,794	2,364	1,327	1,077	798

All concentrations in micrograms per liter (ug/L)
VOC=Volatile Organic Compounds
DP-# = Refers to DPE well designations on site plan
(1) Prior to implementation of dual phase extraction system
(2) Approximately one month after system startup
(3) Approximately six months after system startup
(4) Approximately one year after system startup
(5) Prior to shutdown and rebound period
(6) Following shutdown and rebound period, prior to restart

During initial operation, the VOC concentration in groundwater transferred from the DPE system to the groundwater treatment plant was 380 ug/L. As such, the air entrained extraction process strips nearly 97 percent of the VOCs from the groundwater, based on the initial average VOC concentration in groundwater of 12,000 ug/L. Therefore, the mass of VOCs transferred to the groundwater treatment plant is considered insignificant compared to the mass of VOCs removed through the vapor-phase carbon treatment system.

The mass of VOCs removed from the groundwater and the mass of VOCs removed from soil vapor varied during system operation (see Table 5). Over 40 percent of the VOC mass was removed from the vadose zone during the first month of operation. By the fifth month of operation, however, groundwater extraction was removing more VOC mass than soil vapor extraction. The total mass removed from groundwater is approximately 382 pounds, based on average groundwater VOC concentrations and an average extraction rate of 35 gpm. The total VOC mass removed by soil vapor extraction is approximately 782 pounds. Figure 5 shows the declining removal rate over time, for both groundwater and soil vapor.

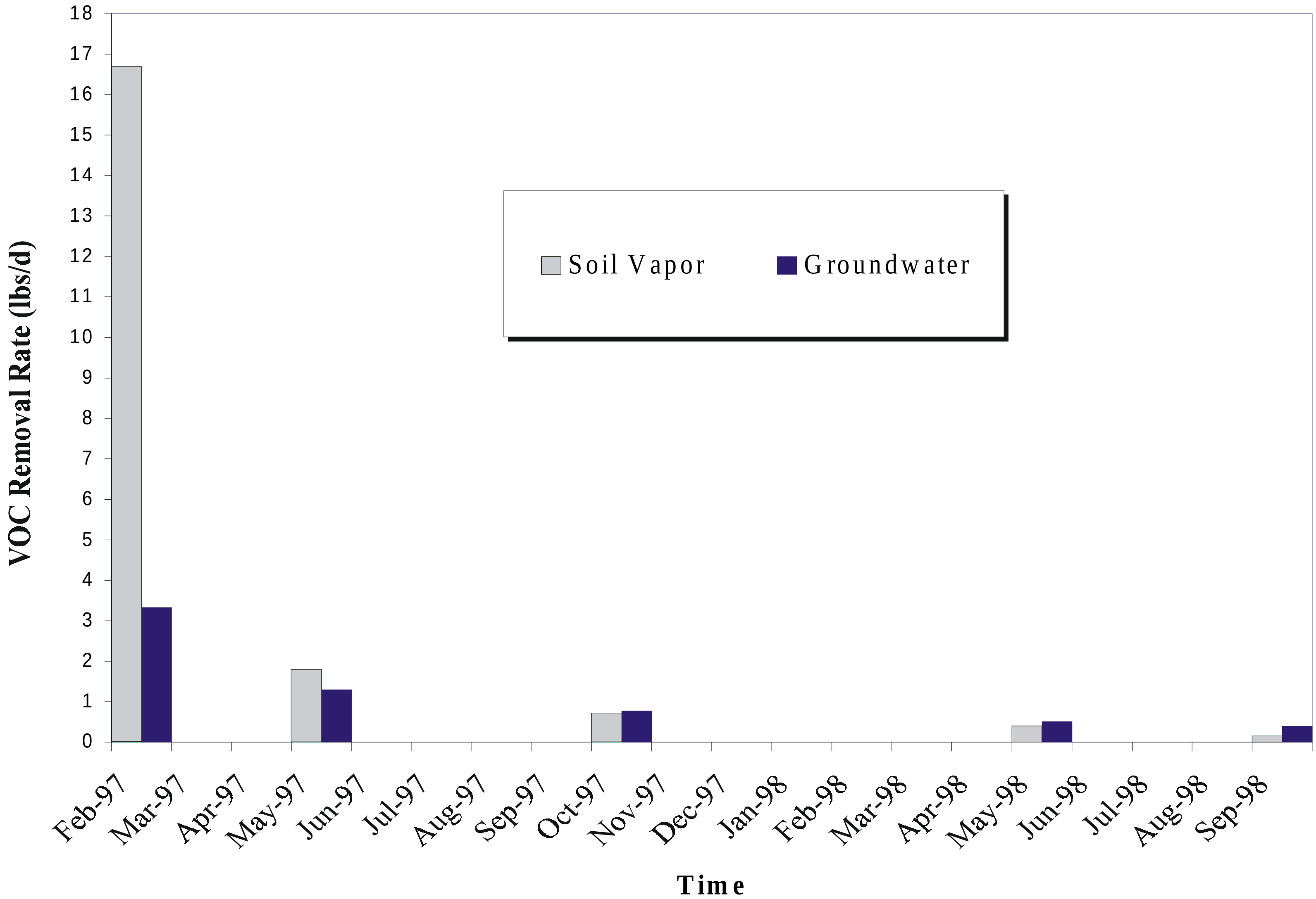
Table 5. Mass Removal of VOCs from Groundwater and Soil Vapor Extraction

Date	Run Time (days)	Total Mass Removed (lbs)[1]	Mass Removed During Operating Interval					
			Total Mass		Mass Removed from GW [2]		Mass Removed from Soil [3]	
			(lbs)	(lbs/day)	(lbs)	(lbs/day)	(lbs)	(lbs/day)
1-Nov-96	0	0	**0**	0	**0**	0	**0**	0
11-Feb-97	30	603	**603**	20.0	**100**	3.3	**503**	16.7
16-May-97	97	810	**207**	3.1	**87**	1.3	**120**	1.8
22-Oct-97	213	984	**174**	1.5	**90**	0.8	**84**	0.7
11-May-98	386	1,139	**155**	0.9	**87**	0.5	**68**	0.4
21-Sep-98	432	1,164	**25**	0.5	**18**	0.4	**7**	0.2
12-Jan-99	544	1,221	**57**	0.5	**38**	0.3	**19**	0.2

1. Based on routine monitoring data of VOC concentrations and flow rates of extracted vapor influent to the carbon treatment units.
2. Based on average VOC concentrations in groundwater from operating DPE wells and an average groundwater extraction rate of 35 gallons per minute.
3. Equal to the Total Mass minus the Mass Removed from Groundwater.

Substantial VOC mass removal by groundwater extraction is likely due to significant groundwater production from a highly impacted area, lack of groundwater drawdown that would create a larger vadose zone, and completion of existing vadose zone remediation. These data illustrate the greater removal efficiency by extracting vapors from the vadose zone rather than groundwater from the saturated zone.

Figure 5. VOC Removal Rates During Operation



Shutdown and Rebound

The DPE system was shutdown from June 5, 1998 through August 31, 1998 to assess any residual impacts that may provide a continuing source of VOCs after the remediation system is removed. Increases in VOC concentrations (rebound effects) were also evaluated to determine if remediation performance could be improved.

Concentrations of VOCs detected in groundwater from the DPE system extraction wells declined during the shutdown and rebound period. Conversely, the VOC concentrations detected in extracted vapor increased slightly during the shutdown and rebound period (Table 6). It is likely that VOCs volatilized from the groundwater to the vadose zone during the shutdown period.

Table 6. VOC Concentrations in Extracted Vapor

DPE Well	May-98 (1)	Sep-98 (2)
DP-7	20	50
DP-8	12	47
DP-18	18	11
DP-20	29	69

VOC = Volatile Organic Compounds
DPE = Dual Phase Extraction
Concentrations in micrograms per liter (ug/L)
Only 4 wells operating during restart
(1) Before shutdown and rebound period
(2) After restart

The VOC mass removed during the month prior to shutdown was approximately 12 pounds. After three months of shutdown, the VOC mass removed during the first month of operation was approximately 19 pounds. Although VOC mass removal increased, it appears that continued operation would have removed more VOC mass over the four month period (three months shutdown plus first month of operation) than system shutdown and restart. The relatively modest increase in VOC mass removal provides further indication that the DPE system has achieved the remediation goals.

Groundwater monitoring well W-219A is located within the source area and screened in the A-level aquifer. VOC concentrations in this well appeared to have stabilized above 4,000 ug/L prior to startup of the DPE system. By use of DPE, VOC concentrations have declined from 4,000 ug/L in November 1996 to 650 ug/L in August 1998.

Technology Costs

The cost to design and install the DPE system with pneumatic fracturing was approximately \$300,000. Approximate costs for two years of operation and maintenance services, reporting, and analytical fees were \$450,000, averaging \$225,000 per year. Approximately \$100,000 was required for the disposal of spent carbon. The unit cost for the 0.5-acre source area from 0 to 20 feet bgs was on the order of \$53 per cubic yard of soil (for treatment of 16,000 yd^3).

Summary of Observations and Lessons Learned

A significant portion of the VOC mass was removed by soil vapor extraction during the first month of operation, while approximately equal VOC mass removals, by soil vapor and groundwater extraction, were achieved during continued operation. This demonstrates the efficiency of soil vapor extraction compared to groundwater extraction, and also demonstrates the benefits of dual phase extraction.

The system reached a steady state with respect to further remediation by the existing DPE system. VOC concentrations in groundwater and extracted vapor remained relatively constant over an extended shutdown period, and these concentrations are substantially less than they were when the DPE system began operation. In addition, VOC concentrations in the A-level aquifer have declined since the source area remediation began.

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