COST AND PERFORMANCE REPORT

Multi-Phase Extraction at the Defense Supply Center
Richmond, Virginia

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A treatability study using dual-phase extraction (DPE) technology was conducted at the U.S. Defense Supply Center Richmond (DSCR) Acid Neutralization Pit (ANP) site. The one-year treatability study (July 1997 - July 1998) focused on deriving conclusions with respect to effectiveness of DPE and to make recommendations as to the use of this technology for full-scale remediation. The results indicated that DPE was effective in removing chlorinated and aromatic VOC contamination from the vadose zone and groundwater. The preliminary results also suggested that the DPE system would likely be adequate for groundwater remediation without additional expansion. This case study addresses the results of the one-year treatability study and the performance of DPE technology.

Summary Information

The 640-acre DSCR is a military support, service, and storage facility located approximately 11 miles south of the City of Richmond, VA and 16 miles north of the City of Petersburg, VA. Land use in the area is predominantly residential and wooded, with the James River located approximately one mile east of the site. Since 1942, DSCR has been furnishing and managing general military supplies to the Armed Forces and several federal civilian agencies. Historical and current industrial operations at the DSCR have included repair of small equipment, engine rebuilding, and refurbishment of combat helmets and compressed gas cylinders. Historical and current operational areas consist of indoor and outdoor material storage areas, a motor pool facility, a National Guard training area, fire training areas, and a wastewater treatment system.

The ANP site is located in the northern section of the DSCR in an area used for warehouse storage and light industrial operations. Approximately one-quarter mile east and southeast of the ANP site is an off-base residential area. The ANP site consists of two former concrete settling basins that received wastewater from metal cleaning operations conducted at one of the warehouse buildings. Both tanks were approximately 6.5 feet in depth with the primary tank capacity of 14,600 gallons and a secondary tank capacity of 3,000 gallons. Metal cleaning operations were active from 1958 into the early 1980s. The operations focused on paint and rust removal and repainting of combat helmets and compressed gas cylinders. The cleaning process utilized inorganic acid and base baths. Spent metal cleaning solutions were dispensed to the tanks every one to two months. Wastewater was then discharged from the tanks to the storm sewer between 1958 and the late 1970s. After a secondary tank was added in the late 1970s, wastewater was discharged to the sanitary sewer. The settled solids in the tanks were periodically disposed of at a county landfill. The tanks were closed in 1985 by cleaning the bottoms and filling with clean earth. At the time of closing the sides of the tanks were observed to be cracked and broken. These cracks and holes were suspected migration routes of contaminants to the surrounding soil. The predominant contaminants detected in groundwater at the ANP site were chlorinated solvents, notably tetrachloroethylene (PCE) and trichloroethylene (TCE). Although site records did not indicate the use of solvents at the metal cleaning operations conducted at this portion of the site, it has been proposed that the solvents were transported from other locations at the DSCR and disposed of in the tanks at the ANP site.

Geologic and Hydrogeologic Setting

Impacted soil beneath the DSCR consists of the Eastover Formation extending from the surface to approximately 25 feet below ground surface (bgs). Grain size diameter appears to increase with depth in the Eastover Formation, grading from a silty clay and fine-grained sand into a coarse-grained sand with interlayered gravel. Specifically, the layers can be characterized as: (1) red-brown silty clay and clayey silt; (2) gray mottled, red/yellow interlayered sand and silty clay; (3) red-yellow clayey, fine-grained sand and sandy clay; and (4) light gray, mottled red-brown clayey, coarse-grained sand with gravel.

An unconfined water table aquifer exists in the Eastover Formation beneath the DSCR site. The depth to the water table surface ranges from 10 to 15 feet bgs. The aquifer found in the Eastover Formation can be separated into an upper low permeability zone and a lower high permeability zone. The upper low permeability zone consists of the upper three layers of the Eastover Formation, with occasional localized areas having relatively higher permeabilities. The lower sand and gravel layer is considered the high permeability zone. Transmissivity values for the upper aquifer range from 374 to 504 feet square per day (ft^2/d). The hydraulic gradient is essentially flat at 0.001 ft/ft to 0.002 ft/ft with flow to the northeast direction.

Site Characterization Summary

Soil and groundwater samples were collected and analyzed for the remedial investigation (RI) in 1987 and a supplemental RI in 1992. Soil and groundwater at the ANP site were divided into Operable Units 5 and 8, respectively. Constituents detected in soil consisted of low levels of volatile and semi-volatile organic compounds including PCE, phthalates, naphthalene, and phenanthrene. VOCs were detected at elevated levels in monitor wells screened in the upper aquifer. The highest concentrations of VOCs detected downgradient of the ANP area were 3300 micrograms per liter (μg/L) for PCE and 890 μg/L for TCE. Chlorinated VOCs were not detected in the lower aquifer. This information supported earlier conclusions that a clay confining interval between the upper and lower aquifers was preventing downward migration of contaminants into the lower aquifer. Based on the data collected during the investigations, the plume area was estimated to be 16,000 square feet. A summary of the ANP site information is provided in Table 1.

Table 1. DSCR-ANP Site Summary

Parameter	Characteristics
Geologic Setting of Source Area	Upper Eastover Formation Silty Clay, Fine Sands, Course Sands and Interlayered Gravels 0 to 25 ft bgs
Geologic Setting of Impacted Aquifer	Upper Low Permeability Zone of Eastover Formation Silty Clay, Clayey Silt, Interlayered Sand and Silty Clay 10 to 25 ft bgs
Depth to Groundwater	10 to 15 ft bgs
Hydraulic Gradient	0.001 to 0.002 ft/ft NE
Aquifer Transmissivity	374 to 504 ft^2/d
Constituents of Concern	Tetrachloroethylene (PCE), Trichloroethylene (TCE), 1,2-Dichloroethylene (1,2-DCE)
Groundwater Concentrations Prior to DPE Treatability Study†	3300 μg/L PCE; 890 μg/L TCE; 26 μg/L 1,2-DCE
Plume Area Prior to DPE Treatability Study	Approximately 16,000 square feet

† Maximum detections from RI

Remediation Summary

The Record of Decision (ROD) for operable unit 5 (OU5) included the use of SVE to address soil contamination. An SVE pilot test was conducted in support of the remedial design for OU5. Results from the SVE test resulted in low air flow rates and minor recovery of VOCs. Analysis of samples from borings installed after the SVE test showed that soil VOC concentrations had decreased to below risk-based concentrations. An Explanation of Significant Differences (ESD) was submitted and recommended no further remediation for OU5.

The Feasibility Study (FS) identified dual phase extraction as a potentially viable remediation alternative for groundwater (OU8). Aquifer tests and a DPE pilot test were conducted to gather site-specific data including transmissivity, specific yield, groundwater recovery rates, hydrostatic responses, vadose zone vacuum distributions, intrinsic permeability, air extraction rates, and SVE mass removal rates. Overall the test supported the use of DPE for VOC recovery. The test data supported the design of a larger DPE system. The pilot test also showed the need to employ air injection to facilitate vadose zone air flow.

Several performance goals were established for remediation of groundwater by DPE at the ANP site. The first goal was to remove contaminated groundwater from the upper aquifer for ex-situ treatment by air stripping. In addition, DPE was to lower the groundwater table to increase the volume of semi-saturated soil through which air flow and volatilization of constituents would occur. Based on theory and practice, mass transfer of VOCs from the soil will continue to occur, provided drawdown is maintained. Moreover, DPE was sought to maintain a constant hydraulic gradient toward the DPE wells to prevent off-site migration.

The performance goals for DPE were set to evaluate its effectiveness in achieving remedial action objectives (RAOs) for the site. The RAOs are as follows:

- Reduction of the highest levels of contamination resulting in immediate risk reduction;
- Plume containment of contamination in excess of remedial goals;
- Achievement of remedial goals (PCE $\leq$ 5 μg/L, TCE $\leq$ 5 μg/L), or attainment of an asymptotic trend in contaminant of concern (COC) concentrations in groundwater (whichever occurs first).

It was proposed that DPE would achieve these goals in a more timely manner than could be accomplished by conventional groundwater pumping.

The purpose of the DPE treatability study at the ANP site was to evaluate the effectiveness of a full-scale system. The treatability study also sought to collect additional operational data that may refine system design parameters, if necessary. The study also evaluated the effectiveness of an air injection system to facilitate air flow through soils exposed by drawdown of the groundwater surface. Table 2 presents a timeline of remedial activities related to DPE at the ANP site beginning with the remedial investigation (RI) through the present.

Table 2. Timeline of Remedial Activities at DSCR-ANP Site

Activity	Time of Performance
Remedial Investigation (RI)	January 1987 - November 1988
Supplemental RI	September 1992 - December 1992
ROD for Soils (OU5)	1992
SVE Pilot-Test for Soil	December 1992
Feasibility Study (FS)	November 1994
Aquifer Test/DPE Pilot-Test for Groundwater (OU8)	June - July 1995
ESD† for OU5	September 1995
Work Task Proposal Issued for DPE	July 1996
DPE System Construction Begins	January 1997
Groundwater Extraction Begins	June 1997
SVE and Air Injection Begins	July 1997
12-Month DPE Treatability Study	July 1997 - July 1998
Treatability Study Report Issued/Continued DPE Operation	November 1998

† Explanation of Significant Differences (ESD) for soils at ANP site (OU5) indicated that soil contamination was below risk-based action levels. Recommendation was made to exclude OU5 from further remediation.

Technology Description and System Design

The DPE system consists of 12 dual phase extraction wells and six air injection wells arranged in a rectangular grid. The DPE well configuration is the two pump MPE configuration shown in Figure 1. Each DPE well consists of a sealed casing to maintain SVE vacuum and an electric, submersible (variable-frequency drive) pump for groundwater extraction. The DPE wells are 6-inch diameter polyvinyl chloride (PVC) screen and casing. Well screen was 0.020-inch factory slotted continuous for a depth of 10 feet. A solid cased sump of 2-feet in length was provided at the base of the well for the submersible recovery pump. The wells were installed to be fully penetrating, to depths ranging from 22 to 28 ft bgs. Wells were developed by surging and pumping techniques prior to use. Air injection is achieved by a low pressure rotary-lobe blower through injection wells. The air injection, in conjunction with the SVE portion of DPE, creates air movement through the soil to transfer VOCs. The VOC-laden vapors are extracted by the DPE wells. SVE vacuum is induced by a blower equipped with an air-water separator. Air extracted by the SVE blower is vented to the atmosphere. Extracted groundwater is pumped directly to a low-profile tray type air stripper to remove VOCs. Air stripper off-gas is released to the atmosphere. Effluent water is discharged to a storm sewer that flows to a nearby stream. To date, an exemption from a state administered discharge permit is active while a ROD is completed for the site.

Technology Performance

The DPE treatability study was conducted for one year. During system operation, operational data were routinely collected. This information served as a means of monitoring the performance of system components. A summary of the performance data from the treatability study is provided in Table 3. Figure 1 and Table 4 illustrates the potentiometric surface of groundwater at various times of system operation. The areal extent of drawdown in the water table (radius of influence) during the study period was estimated to be 600 to 800 feet in a down gradient direction and 1,800 to 2,500 feet in an up gradient direction. Drawdown in surrounding monitoring wells ranged from 3.94 feet (400 feet from the nearest dual phase extraction well) to 10.88 feet (in a monitoring well within the perimeter of the extraction wells). Groundwater was extracted at a rate between 22 to 53 gallons per minute (gpm), averaging 37 gpm for the study period.

Figure 1. Comparison of Baseline Groundwater Levels (Law Engineering and Environmental Services, 1998) (Best available copy)

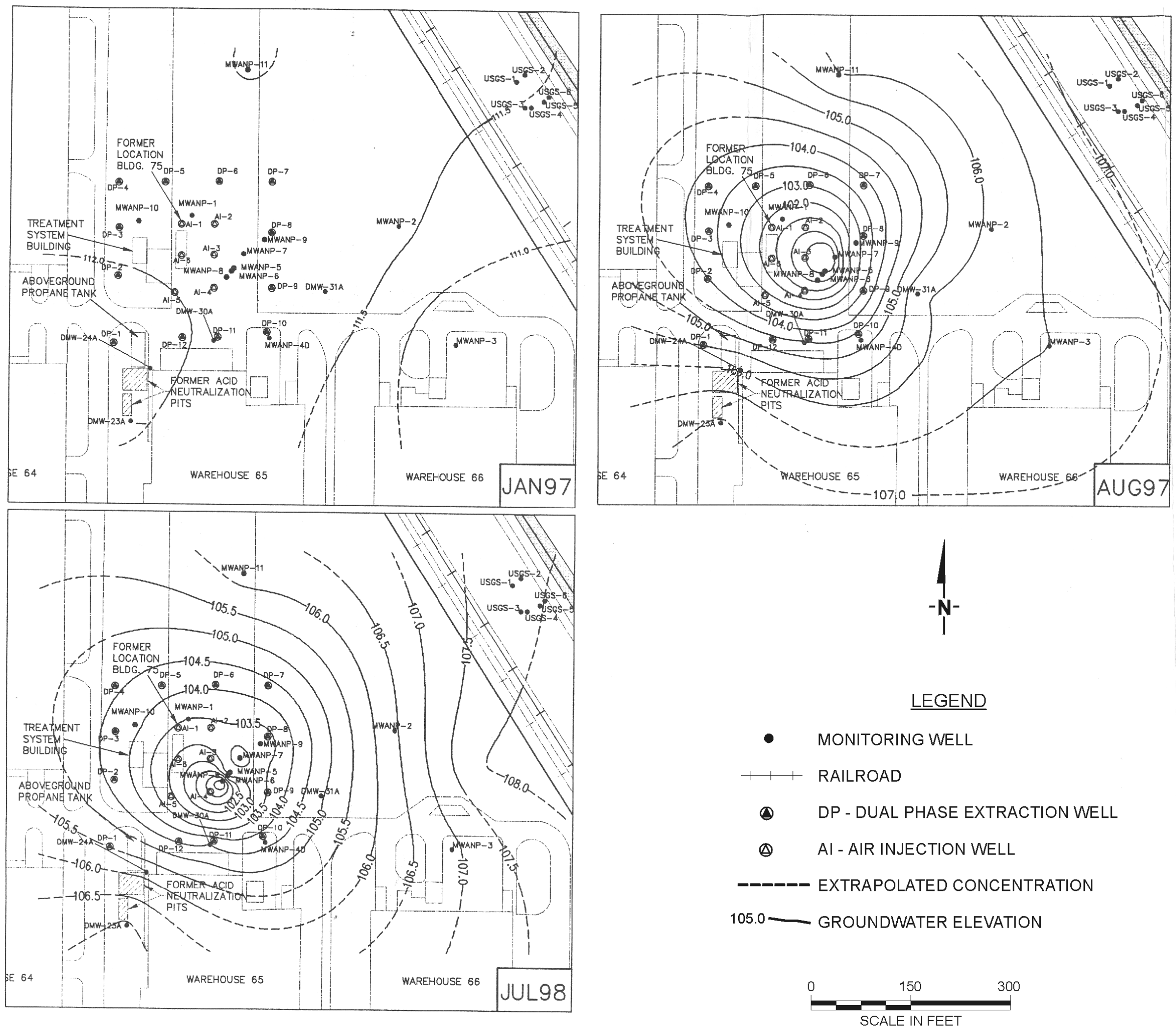


Table 3. Summary of DPE System Performance Data at DSCR

Parameter	Value			
Treatability Study Duration	384 days			
DPE System Operation	7687 hours (320 days)			
SVE Vacuum at Blower	42 in WC, average			
SVE Air Flow Rate	314 cfm, average			
Groundwater Extraction Rate	37 gpm, average			
Cumulative Volume of Extracted Groundwater	17,000,000 gallons			
DPE Radius of Influence	600 to 800 ft, downgradient			
Maximum Drawdown Realized	3.94 ft at 400 ft distance			
Maximum Influent Total VOC Concentrations	1162 μg/L (first month) 90 μg/L (last month)			
Maximum Reduction in VOCs Concentrations in Groundwater	Constituent	Initial Conc.	Final Conc.	% Reduction
	PCE	1300 μg/L	< RAO*	99.6
	TCE	290 μg/L	< RAO	98.3
Soil VOC Mass Removal (Rate)	117 lb (0.37 lb/d), total 70 lb (0.22 lb/d), aromatic 47 lb (0.15 lb/d), chlorinated			
Groundwater VOC Mass Removal (Rate)	28 lb (0.09 lb/d), total 2 lb (<0.01 lb/d), aromatic 26 lb (0.08 lb/d), chlorinated			

Unit notes: in WC = inches of water column; cfm = cubic feet per minute; gpm = gallons per day; μg/L = micrograms per liter; lb = pounds; lb/d = pounds per day

* Remedial action objective (RAO) for groundwater was 5 μg/L for PCE and TCE

Table 4. Potentiometric Surface Elevations

Well I.D.	Potentiometric Surface Elevation		
	January 1997	August 1997	July 1998
DMW-23A	112.04	107.07	107.08
DMW-24A	112.05	106.04	105.86
DMW-30A	111.97	104.55	104.50
DMW-31A	111.88	105.87	104.94
MWANP-1	111.91	102.30	103.50
MWANP-2	111.62	106.88	106.43
MWANP-3	110.51	106.49	106.87
MWANP-5	NA	100.14	103.15
MWANP-6	NA	100.76	103.62
MWANP-7	111.89	101.93	103.81
MWANP-8	NA	100.14	100.40
MWANP-9	NA	NA	103.00
MWANP-10	111.94	103.30	104.13
MWANP-11	111.47	106.03	106.23
USGS-2	NA	107.39	107.89
OS72-1	NA	NA	108.01
OS72-1	NA	NA	107.86

NA=Not Available

SVE flow rates ranged from 150 to 378 cubic feet per minute (cfm) at 40 to 44 inches of water column (in WC). The average extraction air flow rate was 314 cfm with an average vacuum of 42 in WC. SVE emissions were routinely analyzed to support mass removal calculations. Chlorinated VOC concentrations in the extracted vapors increased an order of magnitude within the first 5 days of DPE system operation. This was followed by a steady decrease over the following two weeks. A discrete peak of aromatic VOCs was observed for one sampling event early in system operation. In general, total VOC concentrations in extracted soil vapor remained steady over the last 10 months of the treatability study. These static VOC levels in extracted vapor suggest that VOC removal rates through SVE approached asymptotic levels, or steady-state. Figure 2 plots the time variation of VOCs in SVE air emissions.

Groundwater samples were also analyzed at five events through the treatability study duration plus one, initial round to establish baseline conditions. These data (shown in Table 5) were used to monitor and evaluate the change in VOC concentrations in groundwater affected by DPE. Figure 3 illustrates the VOC distribution in groundwater at several stages in the study time frame. Significant reductions in groundwater VOC concentrations were realized during DPE operation. Most notable were the reductions observed in the plume center where total VOCs were reduced from 1766 μg/L to 3.6 μg/L at one monitor well and from 1980 μg/L to 12 μg/L at another monitor well. Increasing concentrations of chlorinated VOCs were observed at two wells on the outer edge of the DPE influence. The source of this contamination is uncertain. At the conclusion of this study, several wells possessed PCE and TCE concentrations in excess of the remedial goals (<5 μg/L).

Table 5. Summary of Groundwater VOC Data

Well I.D.	Total Chlorinated VOCs (ug/L)					
	January 1997	August 1997	October 1997	January 1998	April 1998	July 1998
DMW-23A	0.53	3.13	2.00	2.28	0.9	2.1
DMW-24A	41.56	18.11	2.26	4.73	5.2	3.6
DMW-30A	1980.5	637.20	21.52	25.28	71.1	11.9
DMW-31A	10.43	30.39	43.71	31.81	20.2	58.6
MWANP-1	21.78	12.63	1.02	1.11	0.6	0.70
MWANP-2	116.14	83.42	28.00	16.65*	25.6	20.5
MWANP-3	2.26	9.60	14.46	43.51	158.6	141
MWANP-7	1765.9	298.95	4.50	3.89	7.7	3.5
MWANP-10	860.7	5.43	ND	0.33	0.3	0.4
MWANP-11	142.74	177.84	15.14	23.30	130.1	55.6
USGS-2	12.78	1.29	18.00	8.27	1.1	0.5

ND = Not Detected
*Collected in February 1998

Figure 2. Plot of VOC Concentrations in SVE Emissions Over Time (Law Engineering and Environmental Services, Inc., 1998) (Best copy available)

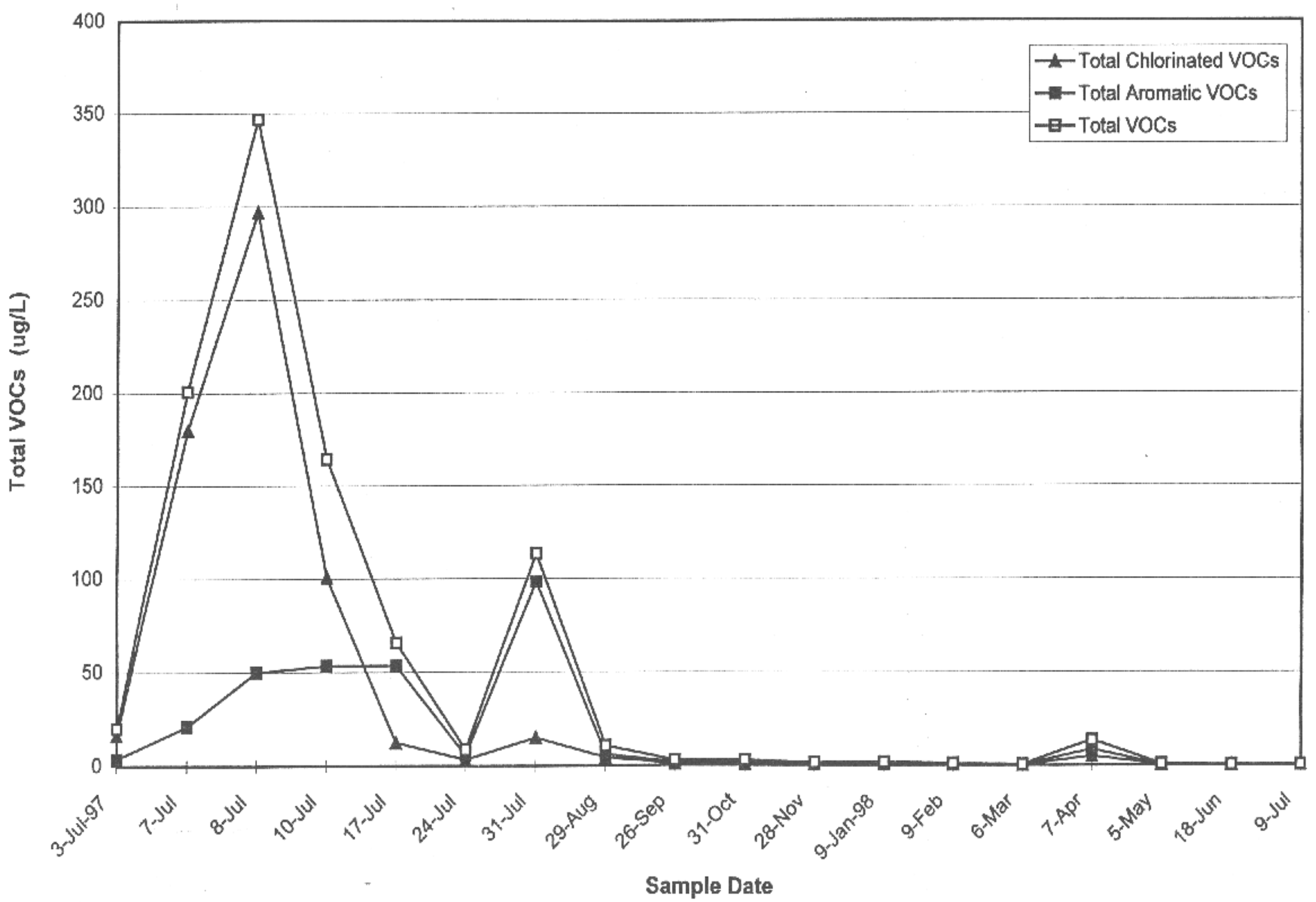
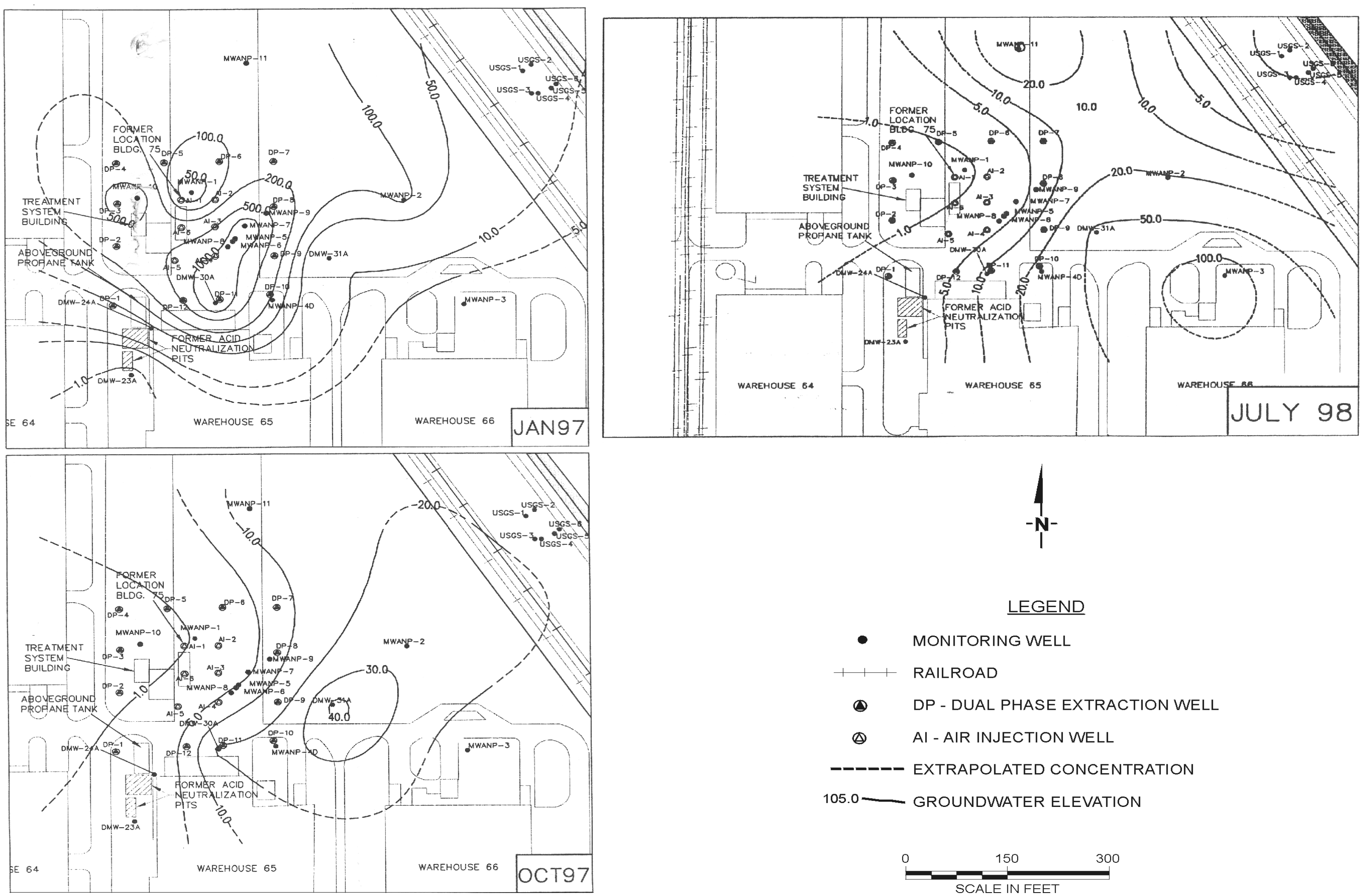


Figure 3. Total VOC Concentrations in Groundwater (Law Engineering and Environmental Services, Inc., 1998) (Best available copy)



Mass removal rates were calculated based on analytical sampling and volumetric flow rates of SVE emissions and groundwater treatment system influent. In total, 145 pounds of VOCs were removed by DPE. SVE accounted for approximately 117 pounds (81 percent) and groundwater extraction for the remaining 28 pounds (19 percent). For SVE, aromatic VOC removal rates outweighed those for chlorinated VOCs through most of the study. Figures 4 and 5 plot the cumulative mass removal of VOCs by groundwater extraction and SVE, respectively.

Technology Cost

The cost for pre-design investigations supporting DPE design, namely pilot and aquifer testing, was $134,092. Engineering design of the DPE system was $73,198. System construction costs (equipment only) were $205,743. Startup costs were $24,309 and the cost for one year of operation and maintenance was $101,148 and includes the cost of sample collection and analysis. Based on 17 million gallons of groundwater recovered during the project, the total cost per unit volume of groundwater recovered and treated is $0.03 per gallon.

Summary of Observations and Lessons Learned

The following conclusions and recommendations were identified by the Army's contractor (Law, 1998) on the performance of the DPE system during the treatability study period.

- Site conditions are favorable for dual phase extraction to be implemented for groundwater remediation.
- The reduction in VOC concentrations in the upper aquifer of the ANP site was affected by DPE and the existing system configuration appears to be adequate for remediating groundwater at OU8.
- Operation of the existing DPE system should be continued until remedial goals or asymptotic levels of contaminants of concern are achieved. If remedial goals are not achieved, then the system should be shut down to monitor VOC rebound. Remaining contamination above remedial goals, if present, should be evaluated and alternatives for remediation, including continued DPE operation and natural attenuation, be considered.
- Additional investigations are recommended to better define the capture zone of the DPE system; to determine the extent of discrete, elevated levels of contamination; and evaluate the ability of the existing DPE system to address contamination present in that area, if necessary.

Figure 4. **Cumulative Mass of VOCs Removed by Groundwater Extraction (Law Engineering and Environmental Services, 1998) (Best available copy)**

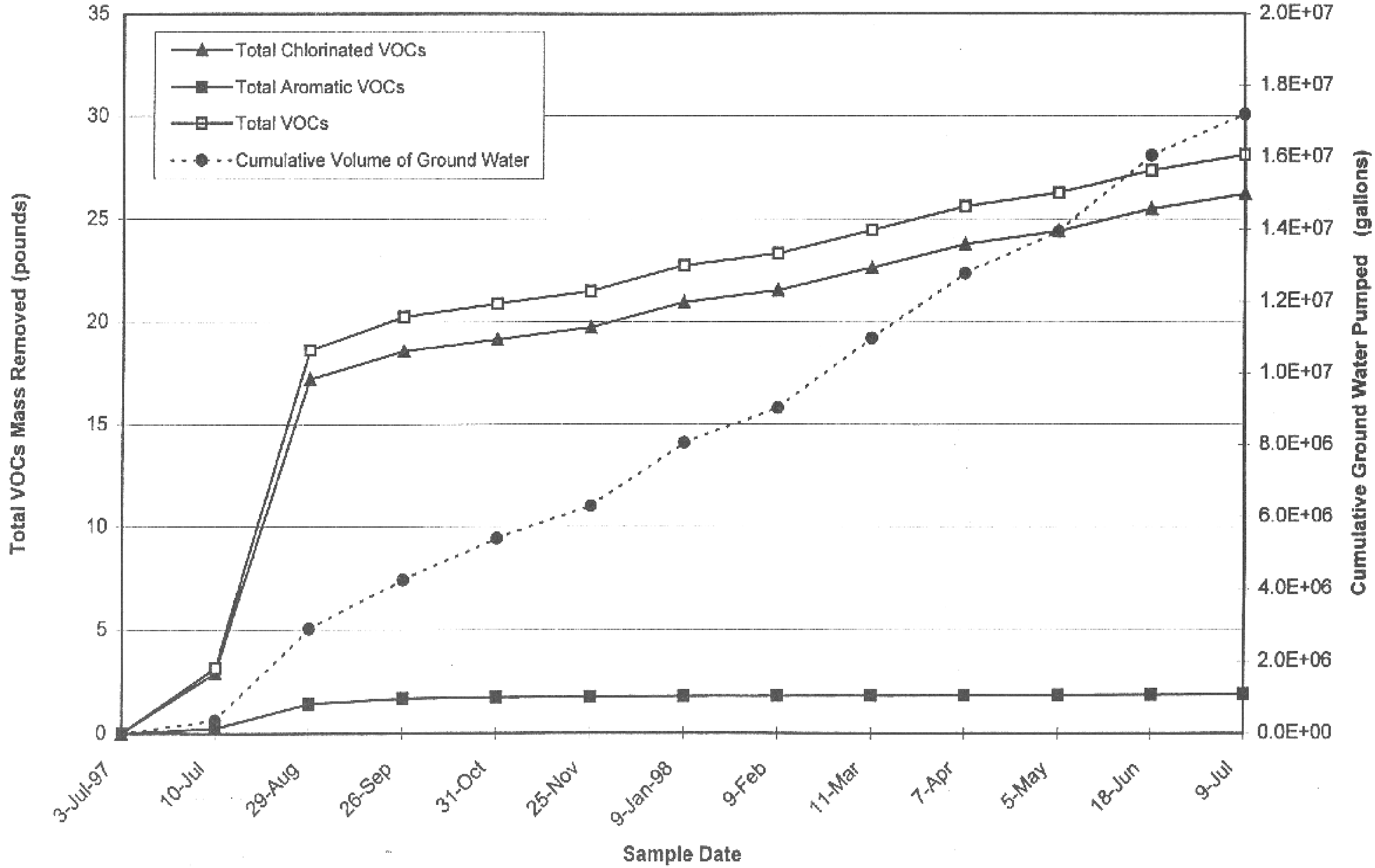
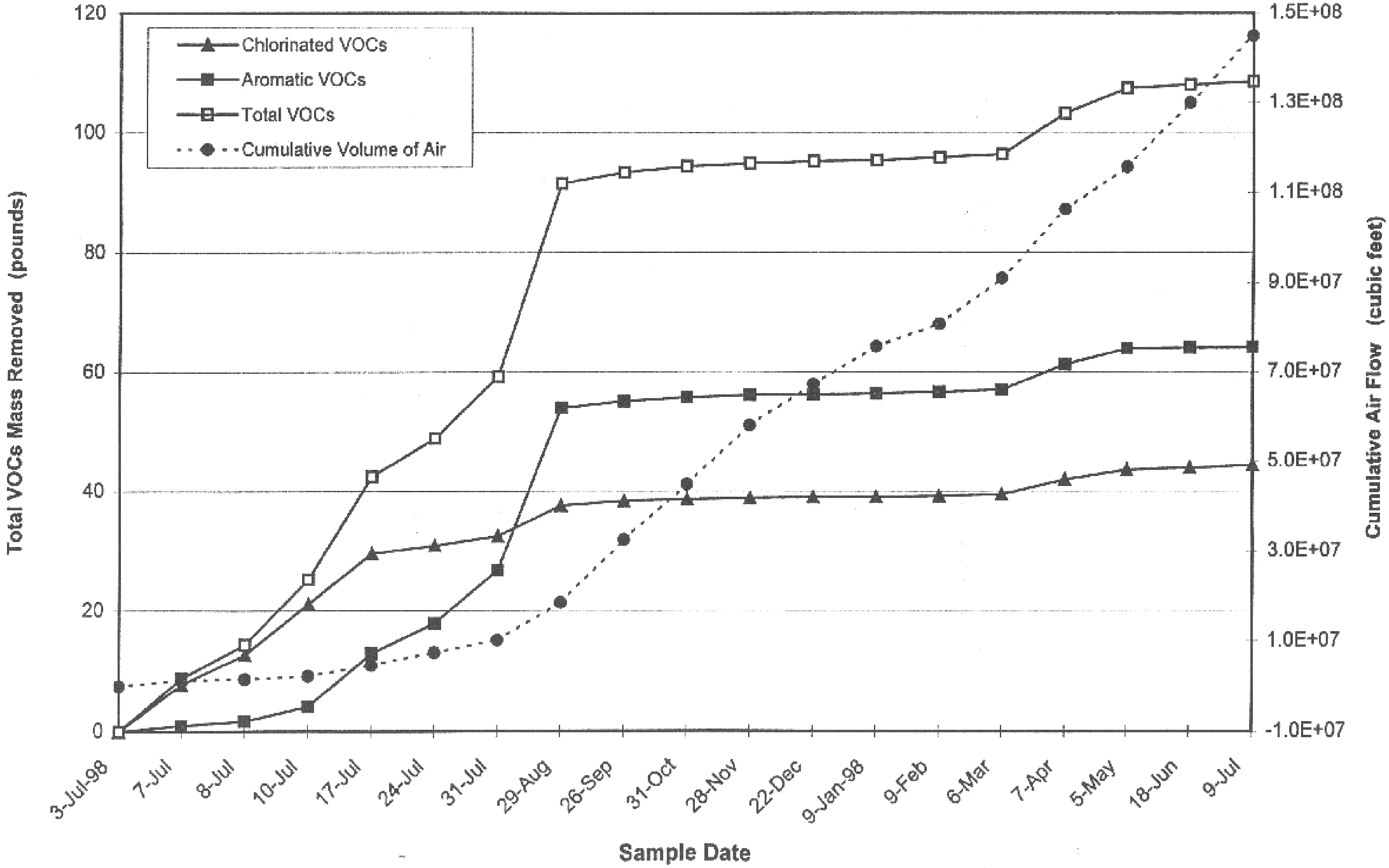


Figure 5. Cumulative Mass of VOC's Removed by SVE (Law Engineering and Environmental Services, 1998) (Best available copy)



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