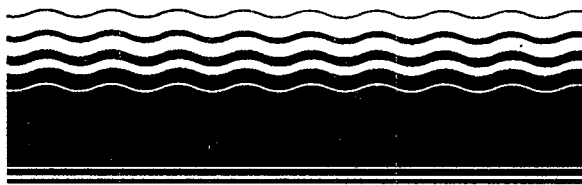




SITE
SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION



Technology Demonstration Summary

Terra Vac In Situ Vacuum Extraction System Groveland, Massachusetts

Terra Vac Inc's vacuum extraction system was demonstrated at the Valley Manufactured Products Company, Inc., site in Groveland, Massachusetts. The property is part of the Groveland Wells Superfund site and is contaminated mainly by trichloroethylene (TCE). Vacuum extraction entails removal and venting of volatile organic constituents (VOCs) such as TCE from the vadose or unsaturated zone in the ground by use of extraction wells and vacuum pumps. The process of removing VOCs from the vadose zone using vacuum is a patented process.

The eight-week test run produced the following results:

- extraction of 1,300 lb of VOCs
- a steady decline in the VOC recovery rate with time
- a marked reduction in soil VOC concentration in the test area
- an indication that the process can remove VOCs from clay strata

This Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the SITE

program demonstration that is fully documented in two separate reports of the same title (see ordering information at back).

Introduction

Environmental regulations enacted in 1984 (and recent amendments to the Superfund program) discourage the continued use of landfilling of wastes in favor of remedial methods that will treat or destroy the wastes. The Superfund program now requires that, to the maximum extent practicable, cleanups at Superfund sites must employ permanent solutions to the waste problem.

The Superfund Innovative Technology Evaluation (SITE) program is one major response to the challenge of finding safe ways to deal with waste sites. Part of the program includes carefully planned demonstration projects at certain Superfund sites to test new waste treatment technologies. These new alternative technologies will destroy, stabilize, or treat hazardous wastes by changing their chemical, biological, or physical characteristics.

Under the SITE program, which is sponsored jointly by the USEPA Office of Research and Development (ORD) and the Office of Solid Waste and Emergency

Response (OSWER), the USEPA selects 10 or 12 Superfund sites each year at which pilot studies of promising technologies can be conducted. Sites are chosen to match the effectiveness and applicability of a particular technology with specific waste types and local conditions. The pilot studies are carefully monitored by the USEPA. Monitoring and data collection determines how effectively the technology treats the waste, how cost-effectively the technology compares with more traditional approaches, and that the operation can be conducted within all public health and environmental guidelines.

The Groveland Wells site was selected for such a demonstration project for 1987. The site is the location of a machine shop, the Valley Manufactured Products Company, Inc., which employs approximately 25 people and manufactures, among other things, parts for valves. The company has been in business at the site since 1964. As an integral part of its building-wide operation of screw machines, the company has used different types of cutting oils and degreasing solvents, mainly trichloroethylene, tetrachloroethylene, trans-1,2-dichloroethylene, and methylene chloride.

The contamination beneath the shop apparently is caused by a leaking storage tank and by former improper practices in the storage and handling of waste oils and solvents. The contamination plume is moving in a northeasterly direction towards and into the Mill Pond.

The USEPA has been involved since 1983, when the Groveland Wells site was finalized on the National Priorities List. The initial Remedial Investigation (RI) of the Valley property was carried out by the responsible party (RP), Valley Manufactured Products Company, Inc. A supplemental RI was conducted by Valley in the fall/winter of 1987 to determine more completely the full nature of contamination at the Valley site. A source control Feasibility Study was performed by USEPA to evaluate various methods for cleaning up or controlling the remaining contaminants. A Record of Decision (ROD) for the site was signed in October 1988 calling for vacuum extraction and groundwater stripping.

The Terra Vac system is being utilized in many locations across the nation. This report is based on monitoring the Terra Vac patented vacuum extraction process (U.S. Patent Nos. 4593760 and 4660639) at the Groveland Wells site during a four-and-one-half-month field operation period, with emphasis on a 56-day

demonstration test active treatment period. The report interprets results of analyses performed on samples and establishes reliable cost and performance data in order to evaluate the technology's applicability to other sites.

The main objectives of this project were:

- The quantification of the contaminants removed by the process.
- The correlation of the recovery rate of contaminants with time.
- The prediction of operating time required before achieving site remediation.
- The effectiveness of the process in removing contamination from different soil strata.

Approach

The objectives of the project were achieved by following a demonstration test plan, which included a sampling and analytical plan. The sampling and analytical plan contained a quality assurance project plan. This QAPP assured that the data collected during the course of this project would be of adequate quality to support the objectives.

The sampling and analytical program for the test was split up into a pretest period, which has been called a pretreatment period, an active period, midtreatment, and a posttreatment period.

The pretreatment period sampling program consisted of:

- soil boring samples taken with split spoons
- soil boring samples taken with Shelby tubes
- soil gas samples taken with punch bar probes

Soil borings taken by split spoon sampling were analyzed for volatile organic compounds (VOCs) using headspace screening techniques, purge and trap, GC/MS procedures, and the EPA-TCLP procedure. Additional properties of the soil were determined by sampling using a Shelby tube, which was pressed hydraulically into the soil by a drill rig to a total depth of 24 feet. These Shelby tube samples were analyzed to determine physical characteristics of the

subsurface stratigraphy such as bulk density, particle density, porosity, pH, grain size, and moisture. These parameters were used to define the basic soil characteristics.

Shallow soil gas concentrations were collected during pre-, mid-, and post-treatment activities. Four shallow vacuum monitoring wells and twelve shallow punch bar tubes were used at sample locations. The punch bar samples were collected from hollow stainless steel probes that had been driven to a depth of 3 to 5 feet. Soil gas was drawn up the punch bar probes with a low-volume personal pump and tygon tubing. Gas-tight 50-ml syringes were used to collect the sample out of the tygon tubing.

The active treatment period consisted of collecting samples of:

- wellhead gas
- separator outlet gas
- primary carbon outlet gas
- secondary carbon outlet gas
- separator drain water

All samples with the exception of the separator drain water were analyzed on site. On-site gas analysis consisted of gas chromatography with a flame ionization detector (FID) or an electron capture detector (ECD). The FID was used generally to quantify the trichloroethylene (TCE) and trans 1,2-dichloroethylene (DCE) values, while the ECD was used to quantify the 1,1,1-trichloroethane (TRI) and the tetrachloroethylene (PCE) values.

The separator drain water was analyzed for VOC content using SW846 8010. Moisture content of the separator inlet gas from the wells was analyzed using EPA Modified Method 4. This method is good for the two-phase flow regime that existed in the gas emanating from the wellhead. See Table 1 for a listing of analytical methods applied.

The posttreatment sampling essentially consisted of repeating pretreatment sampling procedures at locations as close as possible to the pretreatment sampling locations.

The activated carbon canisters were sampled, as close to the center of the canister as possible, and these samples were analyzed for VOC content as a check on the material balance for the process. The method used was P&CAM 127, which consisted of desorption of the carbon with CS₂ and subsequent gas chromatographic analysis.

Table 1. Analytical Methods

Parameter	Analytical Method	Sample Source
Grain size	ASTM D422-63	Soil borings
pH	SW846* 9040	Soil borings
Moisture (110°C)	ASTM D2216-80	Soil borings
Particle density	ASTM D698-78	Soil borings
Oil and grease	SW846* 9071	Soil borings
EPA-TCLP	F. R. 11/7/86, Vol. 51, No. 216, SW846* 8240	Soil borings
TOC	SW846* 9060	Soil borings
Headspace VOC	SW846* 3810	Soil borings
VOC	GC/FID or ECD	Soil gas
VOC	GC/FID or ECD	Process gas
VOC	SW846* 8010	Separator liquid
VOC	SW846* 8010	Groundwater
VOC	Modified P&CAM 127	Activated carbon
VOC	SW846* 8240	Soil borings

*Third Edition, November 1986.

Process Description

The vacuum extraction process is a technique for the removal and venting of volatile organic constituents (VOCs) from the vadose or unsaturated zone of soils. Once a contaminated area is completely defined, an extraction well or wells, depending upon the extent of contamination, will be installed. A vacuum system induces air flow through the soil, stripping and volatilizing the VOCs from the soil matrix into the air stream. Liquid water is generally extracted as well along with the contamination. The two-phase flow of contaminated air and water flows to a vapor liquid separator where contaminated water is removed. The contaminated air stream then flows through activated carbon canisters arranged in a parallel-series fashion. Primary or main adsorbing canisters are followed by a secondary or backup adsorber in order to ensure that no contamination reaches the atmosphere.

Equipment Layout and Specifications

The equipment layout is shown in Figure 1, and specifications are given in Table 2 for the equipment used in the initial phase of the demonstration. This equipment was later modified when unforeseen circumstances required a shutdown of the system. The vapor-liquid separator, activated carbon canisters, and vacuum pump skid were inside the building, with the stack discharge outside the building. The equipment was in an

area of the machine shop where used cutting oils and metal shavings had been stored.

Four extraction wells (EW1 - EW4) and four monitoring wells (MW1 - MW4) were drilled south of the shop. Each well was installed in two sections, one section to just above the clay lens and one section to just below the clay lens. The extraction wells were screened above the clay and below the clay. As shown in Figure 2, the well section below the clay lens was isolated from the section above by a bentonite portland cement grout seal. Each section operated independently of the other. The wells were arranged in a triangular configuration, with three wells on the base of the triangle (EW2, EW3, EW4) and one well at the apex (EW1). The three wells on the base were called barrier wells: Their purpose was to intercept contamination, from underneath the building and to the side of the demonstration area, before this contamination reached the main extraction well (EW1). The area enclosed by the four extraction wells defined the area to be cleaned.

Installation of Equipment

Well drilling and equipment setup were begun on December 1, 1987. A mobile drill rig was brought in and equipped with hollow-stem augers, split spoons, and Shelby tubes. The locations of the extraction wells and monitoring wells had been staked out based on contaminant concentration profiles from a previously

conducted remedial investigation and from bar punch probe soil gas monitoring.

Each well drilled was sampled at 2-foot intervals with a split spoon pounded into the subsurface by the drill rig in advance of the hollow stem auger. The hollow stem auger would then clear out the soil down to the depth of the split spoon, and the cycle would continue in that manner to a depth of 24 feet. The drilling tailings were shoveled into 55-gallon drums for eventual disposal. After the holes were sampled, the wells were installed using 2-inch PVC pipes screened at various depths depending upon the characteristics of the soil in the particular hole. The deep well was installed first, screened from the bottom to various depths. A layer of sand followed by a layer of bentonite and finally a thick layer of grout were required to seal off the section below the clay lens from the section above the clay lens. The grout was allowed to set overnight before the shallow well pipe was installed at the top of the grout. A layer of sand bentonite and grout finished the installation.

VOC Removal From the Vadose Zone

The permeable vadose zone at the Groveland site is divided into two layers by a horizontal clay lens, which is relatively impermeable. As explained previously, each extraction well had a separate shallow and deep section to enable VOCs to be extracted from that

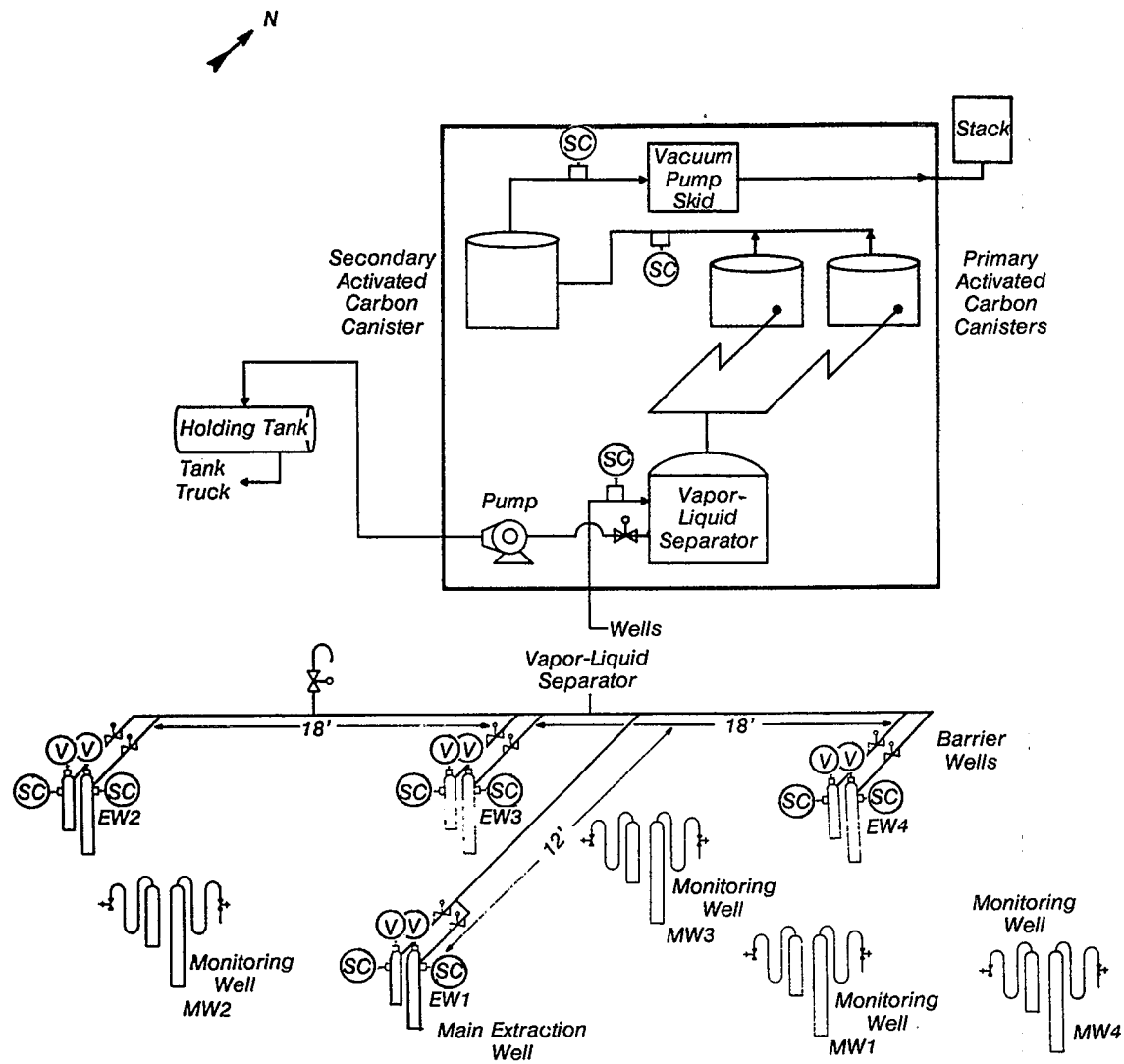


Figure 1. Schematic diagram of equipment layout.

Table 2. Equipment List

Equipment	Number Required	Description
Extraction wells	4 (2 sections each)	2" SCH 40 PVC 24' total depth
Monitoring wells	4 (2 sections each)	2" SCH 40 PVC 24' total depth
Vapor-liquid separator	1	1000-gal capacity, steel
Activated carbon canisters	Primary: 2 units in parallel Secondary: 1 unit	Canisters with 1200 lb of carbon in each canister - 304 SS 4" inlet and outlet nozzles
Vacuum unit	1	Terra Vac Recovery Unit - Model PR17 (25 HP Motor)
Holding tank	1	2000-gal capacity - steel
Pump	1	1 HP motor - centrifugal

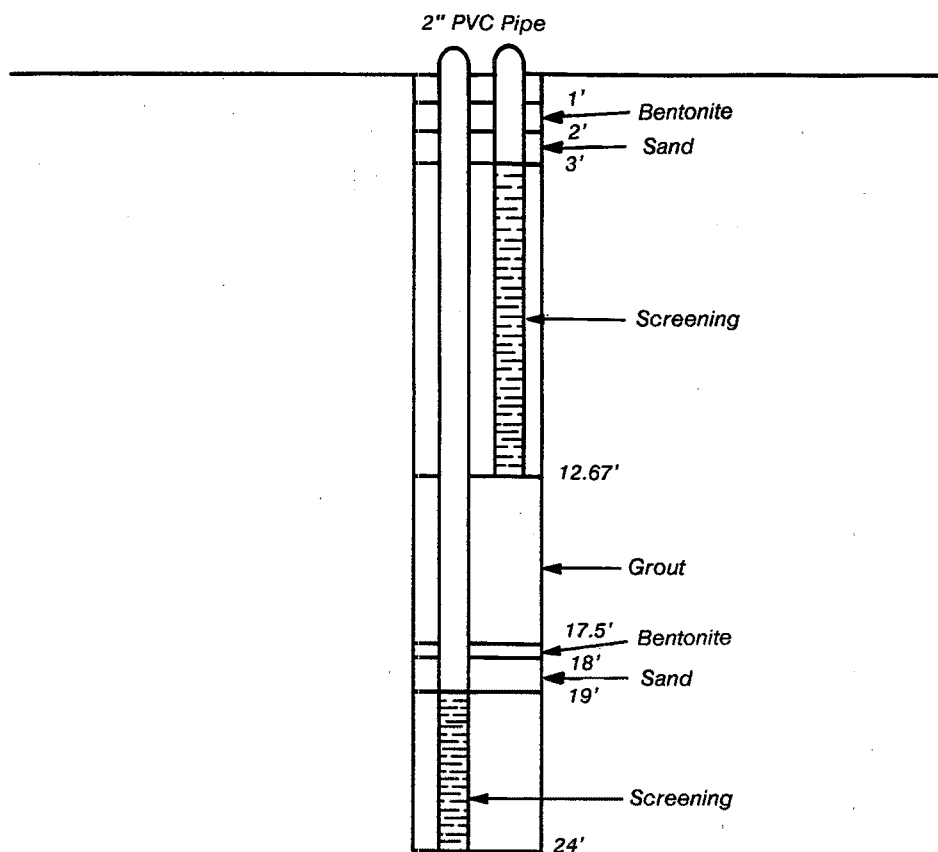


Figure 2. Schematic diagram of an extraction well.

area of the vadose zone above and below the clay lens. The quantification of VOCs removed was achieved by measuring

- gas volumetric flow rate by rotameter and wellhead gas VOC concentration by gas chromatography
- the amount of VOCs adsorbed by the activated carbon canisters by desorption into CS₂ followed by gas chromatography.

VOC flow rates were measured and tabulated for each well section separately. The results of gas sampling by syringe and gas chromatographic analysis indicate a total of 1,297 lb of VOCs were extracted over a 56-day period, 95% of which was trichloroethylene. A very good check on this total was made by the activated carbon VOC analysis, the results of which indicated a VOC recovery of 1353 lb; virtually the same result was obtained by two very different methods.

The soil gas results show a considerable reduction in concentration over the course of the 56-day demonstration period as can be seen from Figures 3 and 4. This is to be expected since soil gas is the vapor halo existing around the contamination and should be relatively easy to remove by vacuum methods.

A more modest reduction can be seen in the results obtained for soil VOC concentrations by GC/MS purge-and-trap analytical techniques. Soil concentrations include not only the vapor halo but also interstitial liquid contamination that is either dissolved in the moisture in the soil or exists as a two-phase liquid with the moisture.

Table 3 shows the reduction of the weighted average TCE levels in the soil during the course of the 56-day demonstration test. The weighted average TCE level was obtained by averaging soil concentrations obtained every two feet by split spoon sampling methods over the entire 24-foot depth of the wells. The largest reduction in soil TCE concentration occurred in extraction

well 4, which had the highest initial level of contamination. Extraction well 1, which was expected to have the greatest concentration reduction potential, exhibited only a minor decrease over the course of the test. Undoubtedly this was because of the greater-than-expected level of contamination that existed in the area around monitoring well 3 that was drawn into the soil around extraction well 1. The decrease in the TCE level around monitoring well 3 tends to bear this out.

Effectiveness of the Technology in Various Soil Types

The soil strata at the Groveland site can be characterized generally as consisting of the following types in order of increasing depth to groundwater:

- medium to very fine silty sands
- stiff and wet clays
- sand and gravel

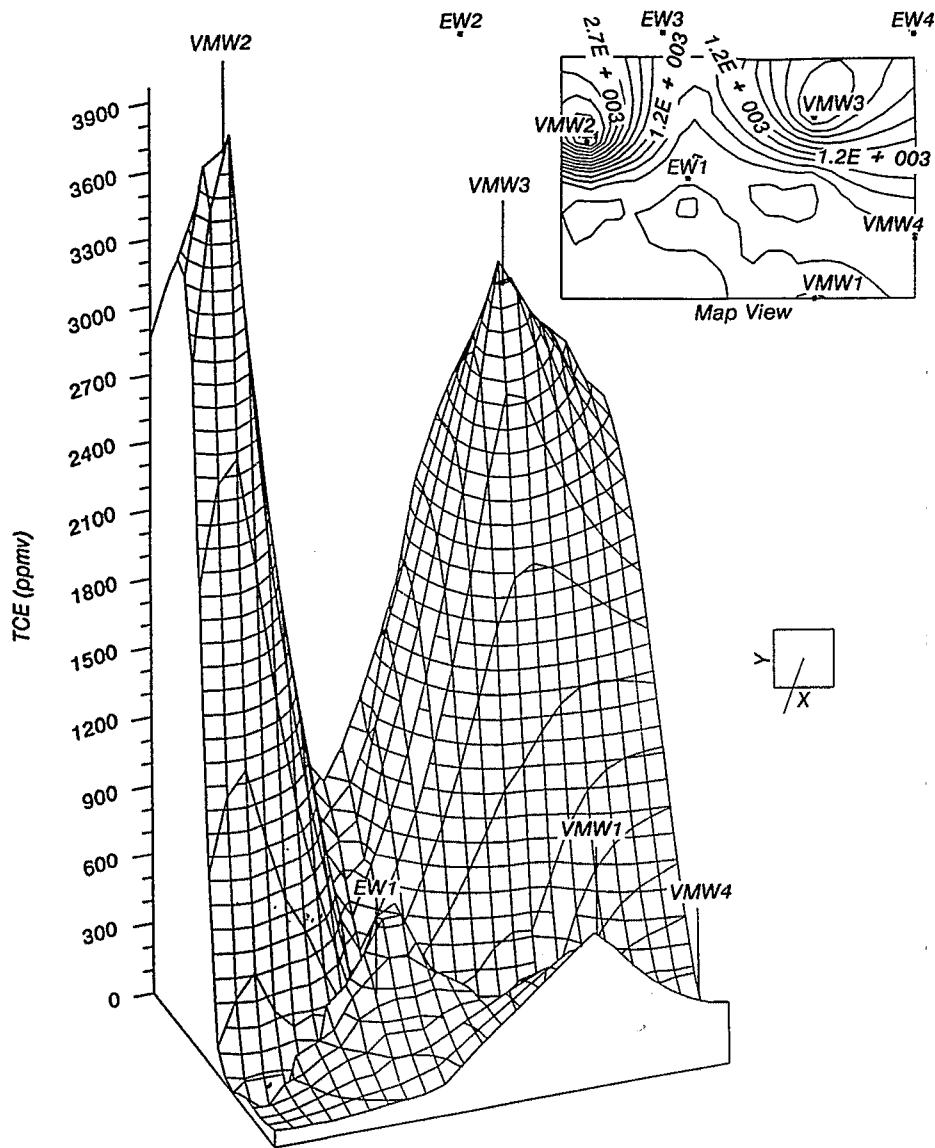


Figure 3. Pretreatment shallow soil gas concentration.

Soil porosity, which is the percentage of total soil volume occupied by pores, was relatively the same for both the clays and the sands. Typically porosity, over the 24-foot depth of the wells, would range between 40% and 50%. Permeabilities, or more accurately hydraulic conductivities, ranged from 10^{-4} cm/sec for the sands to 10^{-8} cm/sec for the clays with corresponding grain sizes equal to 10^{-1} mm to 10^{-3} mm.

Pretest soil boring analyses indicated in general that most of the contamination was in the strata above the clay lens, with a considerable quantity perched on top of the clay lens. This was the case for ex-

traction well 4, which showed an excellent reduction of TCE concentration in the medium to fine sandy soils existing above the clay layer, with no TCE detected in the clay in either the pretest or posttest borings (see Table 4). One of the wells, however, was an exception. This was monitoring well 3, which contained the highest contamination levels of any of the wells, and was exceptional in that most of the contamination was in a wet clay stratum. The levels of contamination were in the 200 to 1600 ppm range before the test. After the test, analyses of the soil boring adjacent to monitoring well 3 showed levels in the

range of ND-60 ppm in the same clay stratum. The data suggest that the technology can desorb or otherwise mobilize VOCs out of certain clays (see Table 5).

From the results of this demonstration it appears that the permeability of a soil need not be a consideration in applying the vacuum extraction technology. This may be explained by the fact that the porosities were approximately the same for all soil strata, so that the total flow area for stripping air was the same in all soil strata. It will take a long time for a liquid contaminant to percolate through clay with its small pore size and

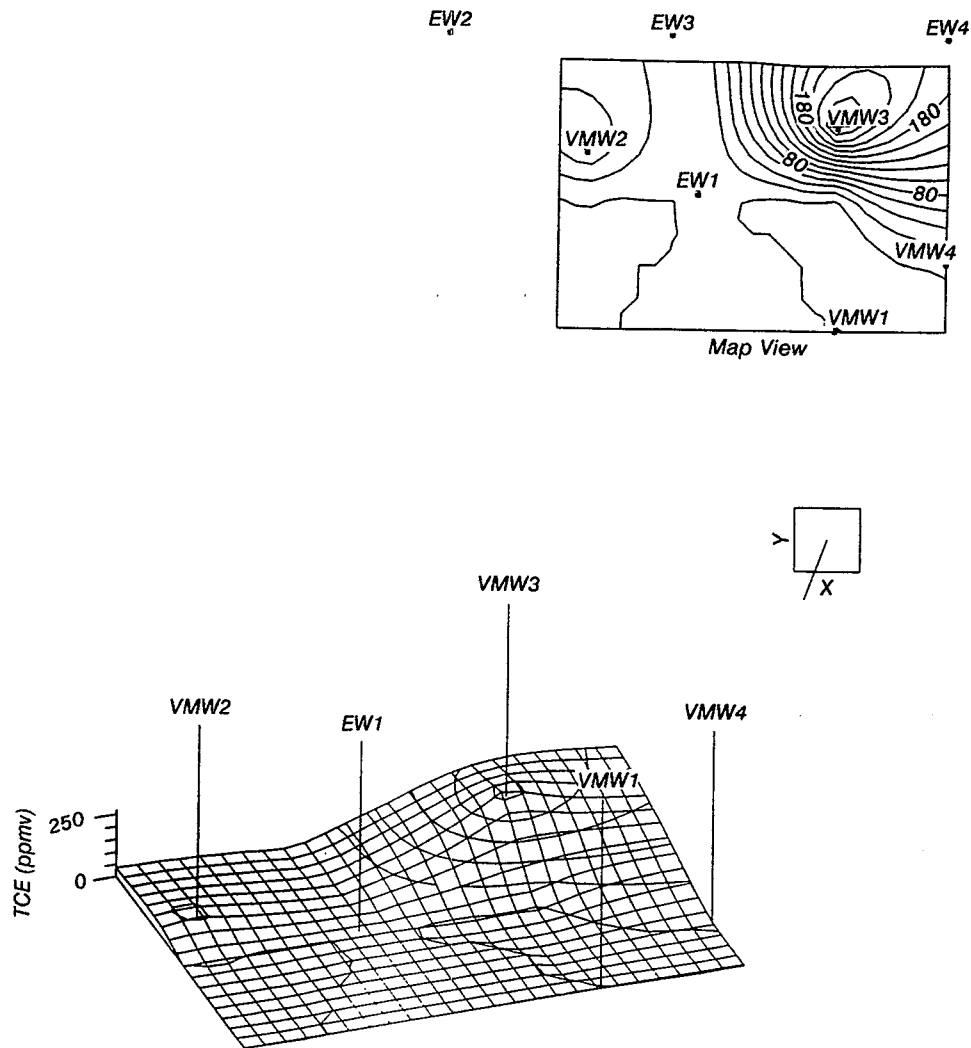


Figure 4. Posttreatment shallow soil gas concentration.

consequent low permeability. However, the much smaller air molecules have a lower resistance in passing through the same pores. This may explain why contamination was generally not present in the clay strata but when it was, it was not difficult to remove. Further testing should be done in order to confirm this finding.

Correlation of Declining VOC Recovery Rates

The vacuum extraction of volatile organic constituents from the soil may be

viewed as an unsteady state process taking place in a nonhomogeneous environment acted upon by the combined convective forces of induced stripping air and by the vacuum induced volatilization and diffusion of volatiles from a dissolved or sorbed state. As such it is a very complicated process, even though the equipment required to operate the process is very simple.

Unsteady state diffusion processes in general correlate well by plotting the logarithm of the rate of diffusion versus

time. Although the representation of the vacuum extraction process presented here might be somewhat simplistic, the correlation obtained by plotting the logarithm of the concentration of contaminant in the wellhead gas versus time and obtaining a least squares best fit line was reasonably good. This type of plot, shown in Figure 5, represents the data very well and is more valid than both a linear graph or one plotting concentration versus log time, in which a best fit curve would actually predict gas concentrations of zero or less.

Table 3. Reduction of Weighted Average TCE Levels in Soil (TCE Conc. in mg/kg)

Extraction Well	Pretreatment	Posttreatment	% Reduction
1	33.98	29.31	13.74
2	3.38	2.36	30.18
3	6.89	6.30	8.56
4	96.10	4.19	95.64
Monitoring Well			
1	1.10	0.34	69.09
2	14.75	8.98	39.12
3	227.31	84.50	62.83
4	0.87	1.05	--

Table 4. Extraction Well 4—TCE Reduction in Soil Strata

Depth ft	Description of Strata	Permeability cm/sec	TCE Conc. ppm	
			pre	post
0-2	Med. sand w/gravel	10 ⁻⁴	2.94	ND
2-4	Lt. brown fine sand	10 ⁻⁴	29.90	ND
4-6	Med. stiff lt. brown fine sand	10 ⁻⁵	260.0	39
6-8	Soft dk. brown fine sand	10 ⁻⁵	303.0	9
8-10	Med. stiff brown sand	10 ⁻⁴	351.0	ND
10-12	V stiff lt. brown med. sand	10 ⁻⁴	195.0	ND
12-14	V stiff brown fine sand w/silt	10 ⁻⁴	3.14	2.3
14-16	M stiff grn-brn clay w/silt	10 ⁻⁸	ND	ND
16-18	Soft wet clay	10 ⁻⁸	ND	ND
18-20	Soft wet clay	10 ⁻⁸	ND	ND
20-22	V stiff brn med-coarse sand	10 ⁻⁴	ND	ND
22-24	V stiff brn med-coarse w/gravel	10 ⁻³	6.71	ND

Table 5. Monitoring Well 3—TCE Reduction in Soil Strata

Depth ft	Description of Strata	Permeability cm/sec	TCE Conc. ppm	
			pre	post
0-2	M. stiff brn. fine sand	10 ⁻⁵	10.30	ND
2-4	M. stiff grey fine sand	10 ⁻⁵	8.33	800
4-6	Soft lt. brn. fine sand	10 ⁻⁴	80.0	84
6-8	Lt. brn. fine sand	10 ⁻⁴	160.0	ND
8-10	Stiff V. fine brn. silty sand	10 ⁻⁴	ND	63
10-12			NR	2.3
12-14	Soft brown silt	10 ⁻⁴	316.0	ND
14-16	Wet green-brown silty clay	10 ⁻⁸	195.0	ND
16-18	Wet green-brown silty clay	10 ⁻⁸	218.0	62
18-20	Wet green-brown silty clay	10 ⁻⁸	1570.0	2.4
20-22	Silt, gravel, and rock frag.	10 ⁻⁴	106.0	ND
22-24	M. stiff lt. brn. med. sand	10 ⁻⁴	64.1	ND

Groveland/Terra-VAC Demonstration

Extraction Well #1
Shallow

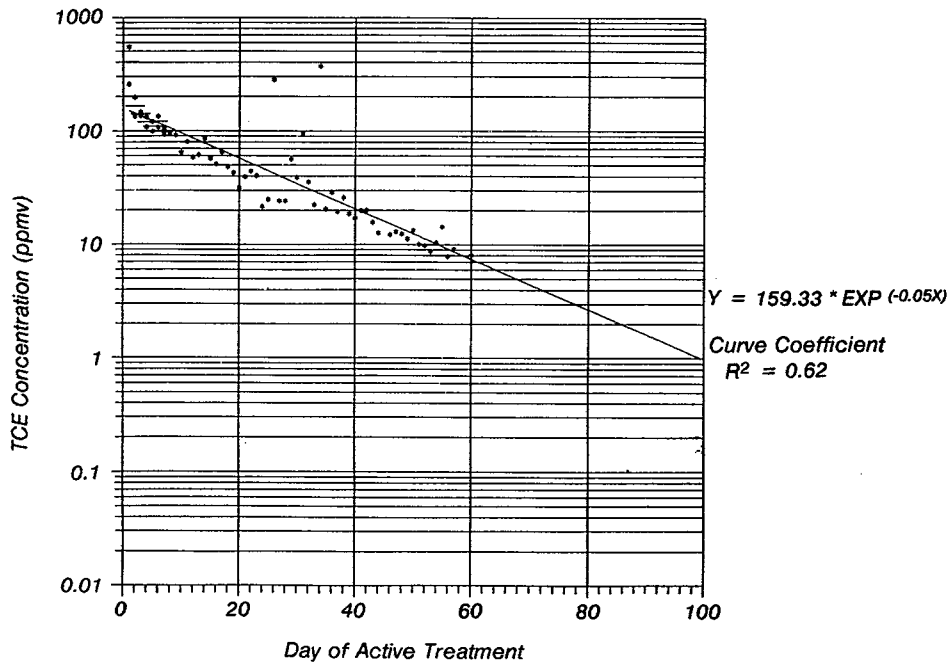


Figure 5. Wellhead TCE concentration vs time.

Looking at the plots for extraction well 1, shallow and deep, equations are given for the least squares best fit line for the data points. If the vacuum extraction process is run long enough to achieve the detection limit for TCE on the ECD, which is 1 ppbv, the length of time required to reach that concentration would be approximately 250 days on the

shallow well and approximately 300 days on the deep well.

Prediction of Time Required for Site Remediation

The soil concentration that would be calculated from the wellhead gas concentration using Henry's Law is in-

cluded in the last column of Table 6. Calculations for the predicted soil concentrations were made assuming a bulk density of the soil of 1761 kg/m³, a total porosity of 50%, and a moisture content of 20%. The calculated air filled porosity of the soil is approximately 15%. Henry's constant was taken to be 0.492 KPa/m³-gmol at 40°F.

Table 6. Comparison of Wellhead Gas VOC Concentration and Soil VOC Concentration

Extraction Well	TCE Concentration in Wellhead Gas ppmv	TCE Concentration in Soil ppmw	Predicted by Henry's Law ppmw
1S	9.7	54.5	0.11
1D	5.6	7.2	0.07
2S	16.4	ND	0.20
2D	14.4	20.4	0.17
3S	125.0	20.9	1.53
3D	58.7	18.0	0.74
4S	1095.6	9.1	12.49

Given the nonhomogeneous nature of the subsurface contamination and interactions of TCE with organic matter in the soil, it was not possible to obtain a good correlation between VOC concentrations in wellhead gas and soil in order to predict site remediation times. Henry's Law constants were used to calculate soil concentrations from wellhead gas concentrations and the calculated values obtained, correcting for air filled porosity, were lower than actual soil concentrations by at least an order of magnitude (see Table 6).

Before one can attempt to make a rough estimation of the remediation time, a target value for the particular contaminant in the remediated soil must be calculated. This target concentration is calculated by using two mathematical models, the Vertical and Horizontal Spread Model (VHS) and the Organic Leachate Model (OLM) (EPA Draft Guidelines for Petitioning Waste Generated by the Petroleum Refinery Industry, June 12, 1987). The mathematical models allow the use of a regulatory standard for drinking water in order to arrive at a target soil concentration.

The VHS model is expressed as the following equation:

$$C_y = C_o \operatorname{erf} (Z/(2(a_z Y)^{0.5})) \operatorname{erf} (X/(a_t Y)^{0.5})$$

where:

C_y = concentration of VOC at compliance point (mg/l)

C_o = concentration of VOC in leachate (mg/l)

erf = error function (dimensionless)

Z = penetration depth of leachate into the aquifer

Y = distance from site to compliance point (m)

X = length of site measured perpendicular to the direction of groundwater flow (m)

a_t = lateral transverse dispersivity (m)

a_z = vertical dispersivity (m)

A simplified version of the VHS model is most often used, which reduces the above equation to:

$$C_y = C_o C_f$$

where:

$C_f = \operatorname{erf} (Z/(2(a_z Y)^{0.5})) \operatorname{erf} (X/(a_t Y)^{0.5})$, which is reduced to a conversion factor corresponding to the amount of contaminated soil

The Organic Leachate Model (OLM) is written as:

$$C_o = 0.00211 C_s^{0.678} S^{0.373}$$

where:

C_o = concentration of VOC in leachate (mg/l)

C_s = concentration of VOC in soil (mg/l)

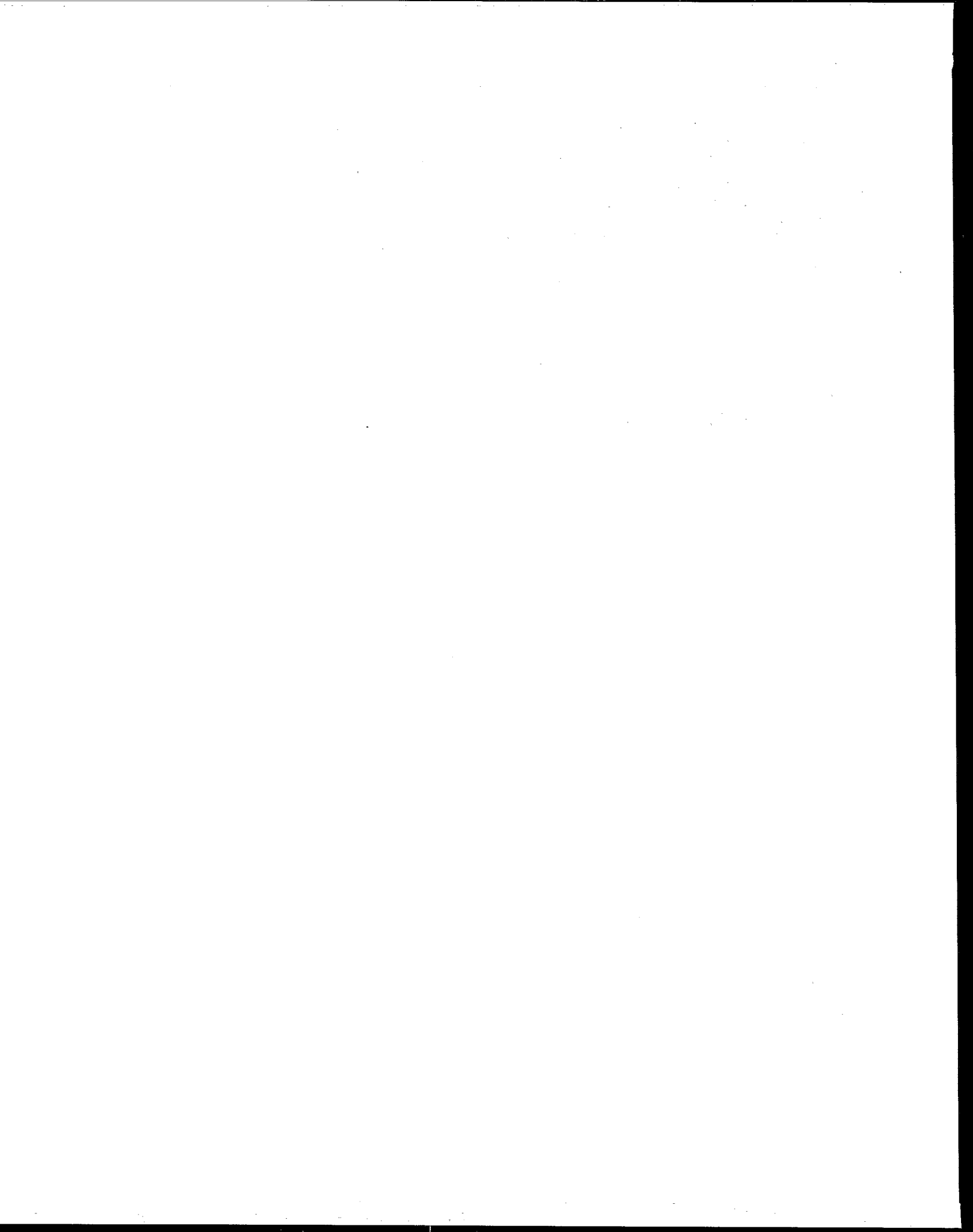
S = solubility of VOC in water (mg/l)

The regulatory standard for TCE in drinking water is 3.2 ppb. This regulatory limit is used in the VHS model as the compliance point concentration in order to solve for a value of the leachate concentration. This value of leachate concentration is then used in the OLM model to solve for the target soil concentration.

Once the target soil concentration is determined, a rough estimation of the remediation time can be made by taking the ratio of soil concentration to wellhead gas concentration and extrapolating in order to arrive at a wellhead gas concentration at the target soil concentration. The calculated target soil concentration for this site is 500 ppbw. This corresponds to an approximate wellhead gas concentration of 89 ppb for EW1S. The equation correlating wellhead gas concentration with time (see Figure 5) is then solved to give 150 days running time.

After 150 days the vacuum extraction system can be run intermittently to see if significant increases in gas concentrations occur upon restarting, after at least a two-day stoppage. If there are no appreciable increases in gas concentration, the soil has reached its residual equilibrium contaminant concentration and the system may be stopped and soil borings taken and analyzed.

The full report was submitted in fulfillment of Contract No. 68-03-3255 by Foster Wheeler Enviresponse, Inc., under the sponsorship of the U.S. Environmental Protection Agency.



The EPA Project Manager, Mary Stinson, is with the Risk Reduction Engineering Laboratory, Edison, NJ 08837 (see below).

The complete report consists of two volumes entitled "Technology Evaluation Report: SITE Program Demonstration Test, Terra Vac In Situ Vacuum Extraction System, Groveland, Massachusetts:"

"Volume I" (Order No. PB 89-192 025/AS; Cost: \$21.95, subject to change) discusses the results of the SITE demonstration

"Volume II" (Order No. PB 89-192 033/AS; Cost: \$36.95, subject to change) contains the technical operating data logs, the sampling and analytical data, and the quality assurance data

Both volumes of this report will be available only from:

National Technical Information Service

5285 Port Royal Road

Springfield, VA 22161

Telephone: 703-487-4650

A related report, entitled "Application Analysis Report: Terra Vac In Situ Vacuum Extraction System," which discusses the applications and costs, is under development.

The EPA Project Manager can be contacted at:

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