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Baker

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May 2, 1991

Commander
Atlantic Division
Naval Facilities Engineering Command
Norfolk, Virginia 23511-6287

Attention: Ms. Lauri Boucher, P.E.
Code 1822

Re: Contract N62470-89-R-4814
Hadnot Point Industrial Area
Camp Lejeune Military Reservation

Dear Ms. Boucher:

This letter serves to summarize Baker's review of existing groundwater data at the Hadnot Point Industrial Area. The objectives of this technical review were to examine: (1) whether the data and analyses available are sufficient to support the design of an extraction system for groundwater contaminated by VOC and TPH, and (2) whether further investigation of the aquifer properties of the shallow water-bearing layer would be desirable. The materials reviewed include the reports by O'Brien and Gere and Environmental Science and Engineering.

A summary of the background information from these sources indicates:

- The study area is dominated by storage structures and roadways, with little open area for construction.
- A shallow groundwater layer in a coastal formation of silty, clayey sands is present.
- The saturated thickness of the shallow groundwater is about 22 feet.
- A vadose zone or free-board of unsaturated silty sands between the ground surface and the water table is about 12 feet.
- Floating product (diesel fuel) is present on the water table with a thickness of approximately 3 feet.
- VOCs and TPH constituents extend beyond the perimeter of the fuel layer floating on the water table, where contaminants are present in the groundwater and, in all probability, are permeating the vadose zone.
- A second, semi-confined water-bearing layer is present below the surficial aquifer, with similar sediments but having a greater saturated thickness.

- A pump test of the second water-bearing layer calculated a transmissivity of about 7100 gpd/ft and a storativity of about 10^{-3}.

- A pump test of fuel product recovery wells in the surficial aquifer having recalculated (by Baker) values of about or below 100 gpd/ft.

A review of these analyses indicates that:

- The stratigraphic descriptions of the sediments of the surficial aquifer and the underlying semi-confined aquifer are broadly similar; therefore, if sufficient water were available, the aquifer parameters should also be broadly similar.

- The aquifer parameters calculated for the two aquifers are dissimilar; the low value of transmissivity calculated for the surficial aquifer lies below the range expectably available under Darcian (continuous groundwater flow) conditions (predominantly, lateral groundwater movement).

- Given the similarity of the sedimentary layers, the expectable similarity of aquifer parameters between the layers and the lesser saturated thickness of the surficial aquifer compared to the semi-confined lower aquifer, the excursion from Darcian conditions during the pump test of the surficial aquifer appears to have resulted from dewatering of the water table and a transition from Darcian to gravity (vertical) flow of groundwater.

- Given the low pumping rate of the surficial aquifer pump test (3 gpm) and the departure from Darcian conditions, it is unlikely that any pump test will be successful in the surficial aquifer; therefore, further pump tests to support design of a groundwater withdrawal system are not likely to be efficient.

The original perspective of the envisioned interim remedial measure was to extract groundwater contaminated by fuel through pumpage in the water table, and to extract water contaminated by VOC (where found) through a similar means. The review of available information indicates that this approach will succeed in a normal fashion only in the central part of the fuel/VOC layer, where the greatest contamination of groundwater would be expected (i.e., near the source). The cone of depression developed in the water table at the low pumping rate apparently available may not have a radial extent sufficient to reverse the regional flow or to capture water from significant distances; this cone of depression will, however, probably be sufficient to stabilize the migration of the contaminated groundwater in the relatively gentle regional gradient expected in this area.

The improbability of conducting a satisfactory pump test in the surficial aquifer indicates that the orientation of any interim remedial measure may warrant modification. The present orientation is based on design, for which suitable information must be available. The absence of suitable information on the aquifer parameters will not allow a detailed design that can predict the performance of the extraction system. Therefore, the project orientation should shift from a design criterion to a performance criterion. Under the performance criterion, the remedial measure is implemented on the basis of available information, then the design is adjusted during early operation of the measure/system to achieve the desired result or performance.

The probable low recovery rate and limited area of influence of groundwater pumpage indicates that the system of groundwater withdrawal to achieve product movement for product recovery (in fuel/VOC contaminated areas) could be supplemented by vadose extraction (vapor extraction). This hybrid system offers several advantages; principal among these is the ability to simultaneously remediate soils and groundwater. I have attached for your perusal information concerning this technology. Additional field investigation, if this approach to an interim measure is adopted, is anticipated to be minimal.

With respect to whether an interim remedial action is warranted at this time, there are two obvious alternatives: no action and groundwater collection and treatment. The rationale for implementing either of these alternatives are described below.

Considering that a fuel/groundwater extraction and treatment system will be implemented at the site, the sources of the groundwater contamination are being addressed. In addition, there is no immediate threat to human health at the study area caused by the groundwater plume since the area is serviced by the CLEJ base water supply. Thus, there appears to be some justification for not implementing another groundwater remedial alternative at this time. However, implementing an interim groundwater remedial action does have some benefits. The primary benefit would be that performance data could be obtained in support of a final (permanent) remedial alternative, which will most likely involve groundwater pumping and treatment (unless no action could be justified through a risk assessment, which is probably unlikely since the constituents exceed ARARs). Another benefit is that groundwater migration may be stabilized, which may prevent further migration to the lower groundwater flow system.

We would be happy to discuss the contents of this letter with you and/or your staff as soon as possible. If LANTDIV decides that an interim action is warranted or desirable, the details of the interim action could be presented in an interim remedial action feasibility study.

If you have any questions, please feel free to contact me at (412) 269-6036.

Very truly yours,

BAKER ENVIRONMENTAL, INC.

Raymond P Wattras

Raymond P. Wattras
Project Manager

RPW/lmn
Attachment

cc: Mr. D. A. Boucher, P.E. (Code 09A2)

Superfund Site Soil Remediation Using Large-Scale Vacuum Extraction

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ABSTRACT

Full-scale remediation of soils contaminated with various volatile organic compounds (VOCs) was implemented at a Superfund Site in Michigan. The U.S. EPA's ROD specified vacuum extraction for the soil remediation. The site previously had been a facility used for the storage and transfer of industrial solvents. Twenty-one underground storage tanks still exist at the site.

A pilot-phase cleanup project, conducted in late 1987, utilized four soil vacuum extraction wells to verify design parameters for the full-scale system. During the pilot-phase extraction, rates of VOCs (including [illegible], TCE and 20 other identified VOCs) reached a maximum of 4400 [illegible]y, with extracted air flow rates ranging up to 165 cfm per well. Subsurface vacuum measurements indicated a radius of influence of up to 75 ft was achieved.

A full-scale system consisting of 23 vacuum extraction wells, two vacuum extraction units and a vapor phase carbon adsorption emission control system was started up in March 1988. Since remediation of the soils was started, over 28,675 lb of VOCs have been removed from the soils at this site by vacuum extraction.

INTRODUCTION

As part of U.S. EPA's total site remediation strategy, a soil vacuum extraction system (VES) was selected to remediate soils at a Superfund Site in Michigan. The vacuum extraction system removes VOCs from soils by applying negative pressure, volatilizing the contaminant in situ and drawing the vapors towards vacuum extraction wells where they are removed from the subsurface for treatment. Contaminated soils were a continuing source of groundwater contamination for a municipal well field. The soil and groundwater contamination consists of volatile organic compounds. In 1987, Terra Vac was contracted to design, install and operate the VES in conjunction with other ongoing work at the site which includes the recovery and treatment of groundwater.

The well field is located in Central Michigan and supplies potable water to over 35,000 consumers. In 1981, VOCs were discovered in both private and city wells; consequently the well field was placed on the NPL during 1982. Subsequent U.S. EPA investigations revealed soil at a former solvent storage and transfer facility was one source of the groundwater contamination. The site had 21 underground storage tanks, some of which had previously leaked chlorinated and non-chlorinated solvents.

A ROD was signed in 1985 specifying soil vacuum extraction as the [illegible]edial Measure for treatment of soil at the former solvent facility [illegible]iminate one source of groundwater contamination. After evaluation of possible air emissions due to excavation required for underground storage tank removal, the underground storage tanks were scheduled to be removed after soil treatment by vacuum extraction is completed. Design and construction of the VES began in September 1987. Construction was completed in March 1988, with full-scale operations commencing thereafter.

VACUUM EXTRACTION SYSTEM DESIGN

Design and implementation of the VES began with a review of the existing data base and development of a preliminary design based on Terra Vac's modeling of the system, incorporating empirical data and experience from other sites. Factors and design criteria that were addressed are discussed below.

Hydrogeologic Considerations

The geology at this site is composed of unconsolidated material derived from glacial outwash and floodwater channel deposits overlying the Marshall Formation, a sandstone bedrock. The soils at the site consist of fine to coarse grained sand with localized lenses of very coarse sand and silty sand. Groundwater fluctuates between 20 and 25 ft below the ground surface, and a localized cone of depression is present due to groundwater extraction wells both on and off-site.

Nature of Contamination

Previous investigations indicated the presence of VOCs, mainly chlorinated hydrocarbons, aromatics and ketones, in the soils. Soil concentrations as high as 1,800 mg/kg of specific contaminants were reported. Contaminants included TCE, PCE, TCA, methylene chloride, xylenes, 1,1-DCA, acetone, toluene and ethylbenzene.

Contamination was indicated throughout the unsaturated zone, with the possibility of a non-aqueous phase liquid (NAPL) being present. An area of approximately 35,000 ft^2 was addressed by the VES design.

Cleanup Criteria

Achievement of cleanup criteria will be verified by post-treatment soil sampling and analysis. The specified cleanup criteria require all soil samples to be less than 10 mg/kg total VOCs with no more than 15% of the samples above 1 mg/kg total VOCs.

VES Emissions Controls

Air emission limits were placed on several VOCs present, requiring the design and operation of an activated carbon system. Allowable concentrations at the VES discharge stack are shown in Table 1.

Underground Tank Impacts

Twenty-one underground tanks at the site are not scheduled for removal until soil treatment is complete. The impact of the tanks on the subsurface flow regime and on subsurface vacuum levels was evaluated and is reflected in the VES design.

Table 1
Air Emission Limits for VES Discharges

Compound	Stack Concentration (ppm)
Tetrachloroethylene	0.0024
Trichloroethylene	0.0073
Methylene Chloride	0.0406
Chloroform	0.0008
Carbon Tetrachloride	0.0016
Vinyl Chloride	0.0162
Benzene	0.0057

VACUUM EXTRACTION SYSTEM IMPLEMENTATION

A two-phased approach was used for the implementation of the VES design. The first phase was a pilot test during which the preliminary design was confirmed. The second phase of implementation, full-scale system design and construction, started immediately after data from the pilot-phase were evaluated.

The pilot-phase had the following objectives:

- To quantify the subsurface residual VOC profile and compare it to the existing data base
- To verify the radius of influence of individual VES wells predicted by the preliminary design
- To quantify VOC extraction rates
- To evaluate the impact of the underground tanks on the VES
- To obtain data to optimize the VES design to meet performance objectives in the shortest time

Four vacuum extraction wells were installed in October 1987 to serve during the pilot-phase test of the soil remediation. During the installation of the vacuum extraction wells, soils were sampled and analyzed sing an on-site gas chromatograph (GC) and the headspace method quantify the distribution of VOCs in soils in the area of the pilot wells. Residual VOC concentrations in the area of the four pilot test wells were as high as 1380 mg/kg. The soil concentration data were used to confirm the design basis of the vacuum extraction system, to determine screened intervals and, later, to correlate monitoring results with soil concentrations. In addition, a soil gas survey was performed over the complete site, including support areas, to further delineate the areal extent of soils to be treated by the VES.

Each well consisted of a 4-in PVC slotted well screen and riser, a silica sand pack in the annular space and a grout seal to make the wells suitable for vacuum service. Wells later installed as part of the full-scale system included both 4-in wells with slotted screen and 2-in continuous wire-wrapped screen. An aboveground PVC piping manifold was connected to the equipment used during the pilot-phase, which consisted of an air/water separator, a vacuum extraction unit and an emissions control system containing four 1000 lb canisters of vapor phase activated carbon (two in primary service and two in backup service). A 30 ft discharge stack was constructed.

After startup of the pilot-phase VES, each well was developed individually. During the development period of a vacuum extraction well, the soils surrounding the well are dried as air flow paths are developed. In addition, a well's maximum radius of influence is reached, and steady state flows are established. For the wells at this site, the development period for each well was very short, on the order of 1 to 4 hr.

During all phases of operation of the VES, individual wellhead VOC concentrations and other vapor stream concentrations throughout the VES are determined by on-site gas chromatography. Air flow rates are measured using self-averaging pitot tubes or rotameters, depending on the magnitude of the flow rate. The radius of influence for each well is determined by measuring subsurface vacuums using piezometers and her VES wells at different distances from the vacuum extraction well ing developed. The radius of influence for the pilot-phase VES wells was determined to be more than 75 ft.

After intermittent operation of the pilot-phase VES wells for approximately 70 hr over a period of 15 days, construction of the full-scale system was started. The full-scale vacuum extraction system began operation in March 1988. A total of 23 vacuum extraction wells were installed at the site. The location and number of wells reflected pilot-phase experience, accounted for the effect on subsurface airflows of the underground tanks, and provided operating flexibility to ensure that all affected areas would be treated. Figure 1 shows the location of the VES wells and other site features.

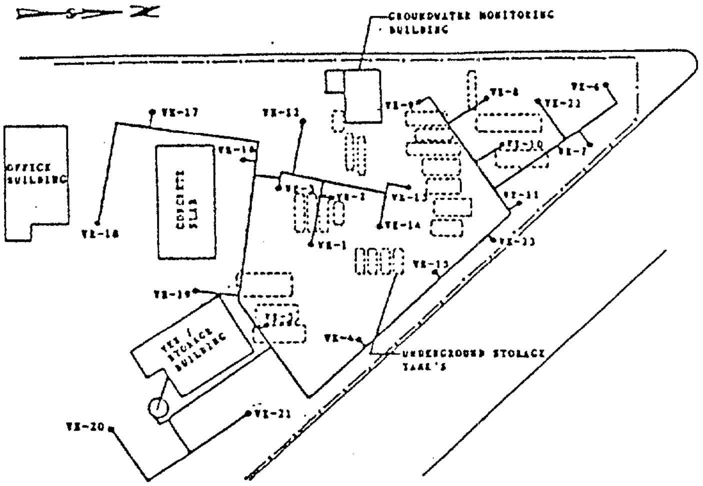

Figure 1
Site Plan

Two vacuum extraction units provided a VES capacity of over 2000 cfm. The pilot-scale vapor phase activated carbon system was scaled up to eight canisters with four in primary service, and four in backup service. Carbon adsorption efficiency was determined to be equivalent under positive pressure and vacuum during the pilot-phase, therefore the full-scale system was constructed with activated carbon under vacuum to minimize leaks and eliminate possible emissions of contaminant-laden air to the atmosphere.

Although the need to frequently change and regenerate activated carbon off-site during the first 10 days of operation dictated attended operation, the VES was designed and constructed for unattended operation. Instrumentation and controls installed included pressure, flow and temperature indicators, a high water level shutdown in the air/water separator, a carbon monoxide monitor and shutdown controller in the activated carbon system, high temperature shutdowns and an on-line PID VOC monitor for detecting primary carbon system breakthrough. Vapor samples were analyzed with the on-site GC at various VOC levels to determine the PID monitor's response to specific compounds. When VOC concentrations entering the backup carbon system reach a predetermined setpoint on the PID monitor, the VES is automatically shut down. The vacuum extraction system is shown schematically in Figure 2.

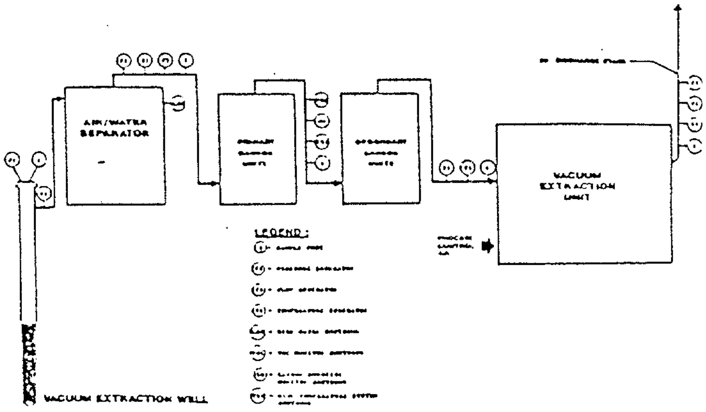

Figure 2
Vacuum Extraction System Schematic

Operating time for the vacuum extraction system through December 1988 was approximately 55 days. On-site GC has been used to monitor lhead VOC concentrations and extraction rates. The logistics of ging, transporting and regenerating activated carbon off-site have n the limiting factor for VES operations.

FIELD ANALYTICAL PROGRAM

An on-site laboratory was established to provide rapid screening of both soil and extracted vapor samples. A Hewlett-Packard 5890A GC with dual flame ionization detectors and capillary columns was coupled with a personal computer and chromatography software. Methodology was developed to analyze for 22 organic compounds. Chlorinated hydrocarbons (including TCA, TCE, PCE and vinyl chloride), aromatics (including benzene, toluene and xylenes) and ketones (acetone, MEK and MIBK) were the three major groups of compounds for which we analyzed.

The minimum detection limits (MDLs) for each compound of interest were determined. The MDLs ranged from 0.0001 mg/l to 0.0080 mg/l and normally showed more sensitivity for aromatic compounds than chlorinated compounds. Calibration was accomplished by injection of a certified standard gas. A QA/QC program was implemented using standards, standard checks, replicates, duplicates and blanks.

During well installation, over 200 soil samples were screened by the on-site GC, providing field data to confirm VES well design. The on-site laboratory routinely analyzed vapor samples for the purposes of tracking VOC extraction rates, verifying activated carbon breakthrough, quantifying stack VOC discharge rates and monitoring the progress of soil treatment.

VACUUM EXTRACTION SYSTEM PERFORMANCE

During the operation of the vacuum extraction system, extracted airflows from individual VES wells have ranged from 50 to 220 cfm, with ad vacuums ranging from 2 to 5 in. of mercury. Extraction rates ermined for individual VES wells by using measured flow rates and VOC concentrations obtained from on-site GC. A total VES extraction rate is routinely determined. Total VES extraction rates are confirmed by off-site analysis of spent carbon.

Individual initial VES well extraction rates ranged from 4400 lb/day to 23 lb/day. The highest individual well extraction rate, 4400 lb/day, was measured at VE-2 during the pilot-phase. TCA was extracted at a rate of 1316 lb/day, with TCE, PCE, toluene, methylene chloride and xylenes all being extracted at rates in excess of 100 lb/day. Figure 3 shows the relative extraction rates for VE-2 for the various VOCs.

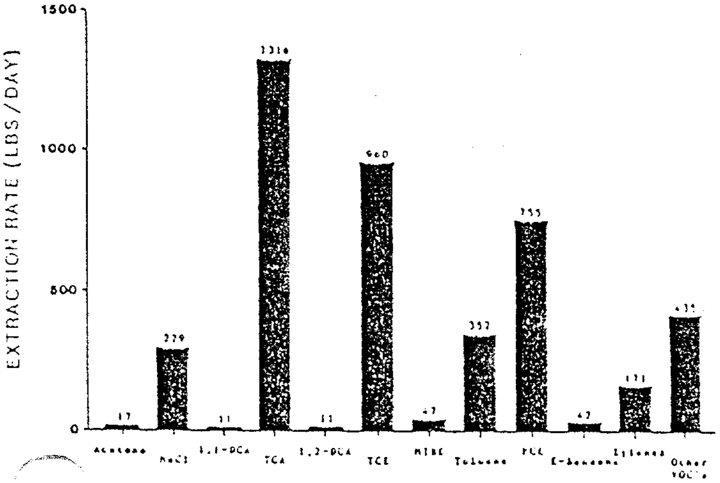

Figure 3
Relative Extraction Rates (Initial)
Extraction Well VE-2

Vacuum extraction well VE-2, located adjacent to a cluster of tanks, in addition to having the highest extraction rate, was the only VES well that accumulated non-aqueous phase liquids (NAPL). At start-up of the full-scale VES, 2.4 ft of NAPL were measured in VE-2. NAPL thickness in VE-2 was routinely monitored. During the 55 days of operation of the VES, NAPL in VE-2 was eliminated. Figure 4 shows the thickness of NAPL over time.

Each time the VES was shut down for carbon changeout, NAPL recharged into VE-2. The total amount of VOCs extracted from VE-2 in 55 days is approximately 8000 lb. The NAPL extracted from VE-2 was extracted in the vapor phase, and it is not possible to quantify how much can be attributed to the liquid phase in the soil. Remediation of NAPL by the VES proved to be less labor intensive compared to other remedial options, such as bailing or pumping, while limiting the migration of NAPL.

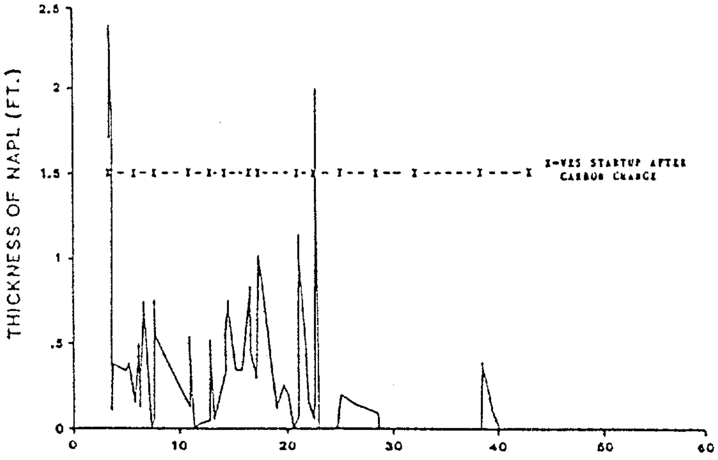

Figure 4
NAPL Thickness vs. VES Run Time

Individual wellhead VOC concentrations declined during the operation of the VES. Since the concentration of VOCs in the airstream extracted from a VES well is representative of the aggregate soil gas concentration within a well's radius of influence, the wellhead concentrations provide an indication of the degree of cleanup being achieved.

Well VE-2 had the highest initial wellhead concentrations, which were measured to be in excess of 250 ppm total VOCs during well development. After approximately 55 days of VES operations, wellhead concentrations have decreased to less than 10 ppm in VE-2. Figure 5 shows

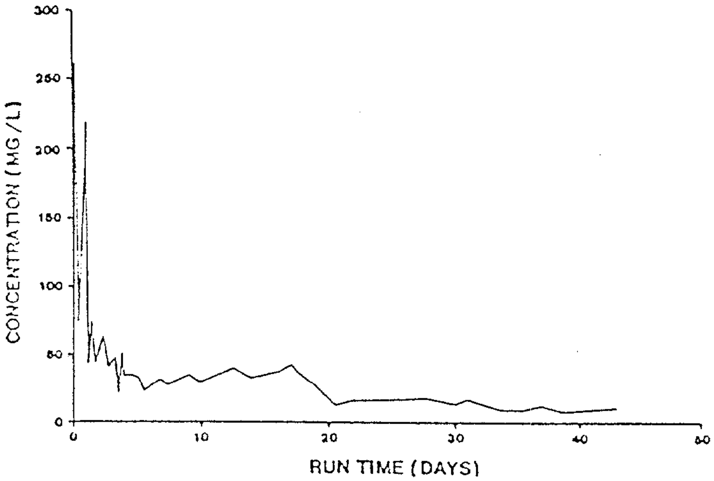

Figure 5
Wellhead VOC Concentrations Extraction Well VE-2

the wellhead concentrations for VE-2 over the VES operating period. Similar declines in wellhead VOC concentration have been quantified in the other VES wells. Figure 6 shows the decline of VOC concentrations from over 40 ppm to approximately 2 ppm in extracted air from VE-8.

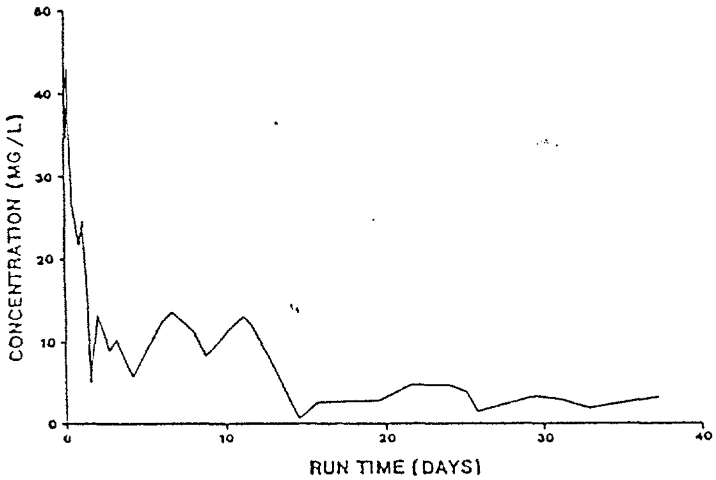

Figure 6
Wellhead VOC Concentration Extraction Well VE-8

At other sites where vacuum extraction has been applied, the wellhead concentration vs. time data follow a characteristic curve. Preliminary evaluation of the data from this Superfund Site indicates that soil cleanup objectives will be attained in approximately 100 days of VES operation.

To date, more than 28,675 lb of VOCs have been extracted by the vacuum extraction system, representing approximately 55 days of operating time for the VES, as shown in Figure 7. The total amount of VOCs extracted is based on monitoring of the system using on-site GC. Off-site analysis of spent carbon confirmed that the on-site monitoring was accurate to within approximately 5% during the pilot-phase.

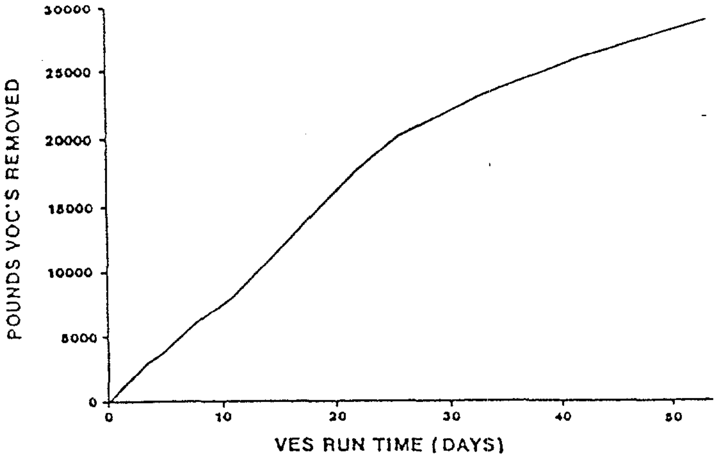

Figure 7
Total Pounds VOCs Extracted

CONCLUSION

Vacuum extraction has been successful in significantly reducing VOC concentrations in the soil at this Superfund Site. Although factors not associated with performance of the VES have resulted in approximately one year of activity at the site, the short VES operating time-frame (approximately 2 mo) has resulted in the safe recovery of VOCs that would take many years to recover using groundwater recovery and treatment or other remedial alternatives.

ACKNOWLEDGEMENTS

The vacuum extraction system was designed, constructed and operated at this Superfund Site under subcontract to CH2M Hill, acting as U.S. EPA's Construction Manager. The authors would like to thank Joseph P. Danko of CH2M Hill for his cooperation throughout the implementation of the VES at the site. Additional thanks are given to James Malot of Terra Vac for his assistance in preparing this paper.

United States
Environmental Protection
Agency

EPA/540/S5-89/003
May 1989

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 ponse (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 d different types of cutting oils and reasing solvents, mainly trichloro- ylene, 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 many locations across the nation. This ort is based on monitoring the Terra c 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 consistec 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 o 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 th ECD was used to quantify the 1,1,1 trichloroethane (TRI) and the tetra chloroethylene (PCE) values.

The separator drain water wa analyzed for VOC content using SW84 8010. Moisture content of the separato inlet gas from the wells was analyze using EPA Modified Method 4. Thi method is good for the two-phase flo regime that existed in the gas emanatin from the wellhead. See Table 1 for listing of analytical methods applied.

The posttreatment sampling essential consisted of repeating pretreatment sar pling procedures at locations as close possible to the pretreatment samplin locations.

The activated carbon canisters we sampled, as close to the center of t canister as possible, and these sampl were analyzed for VOC content as check on the material balance for t process. The method used was P&CA 127, which consisted of desorption of t carbon with CS_2 and subsequent g 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 an from bar punch probe soil gas moni toring.

Each well drilled was sampled at 2-foo intervals with a split spoon pounded int the subsurface by the drill rig in advanc of the hollow stem auger. The hollo stem auger would then clear out the so down to the depth of the split spoon, an the cycle would continue in that manne to a depth of 24 feet. The drilling tailing were shoveled into 55-gallon drums f eventual disposal. After the holes wer sampled, the wells were installed using 2 inch PVC pipes screened at variou depths depending upon the characte istics of the soil in the particular hole. Th deep well was installed first, screene from the bottom to various depths. layer of sand followed by a layer bentonite and finally a thick layer of gro were required to seal off the sectio below the clay lens from the sectio above the clay lens. The grout wa allowed to set overnight before th shallow well pipe was installed at the t of the grout. A layer of sand bentoni and grout finished the installation.

VOC Removal From the Vados Zone

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

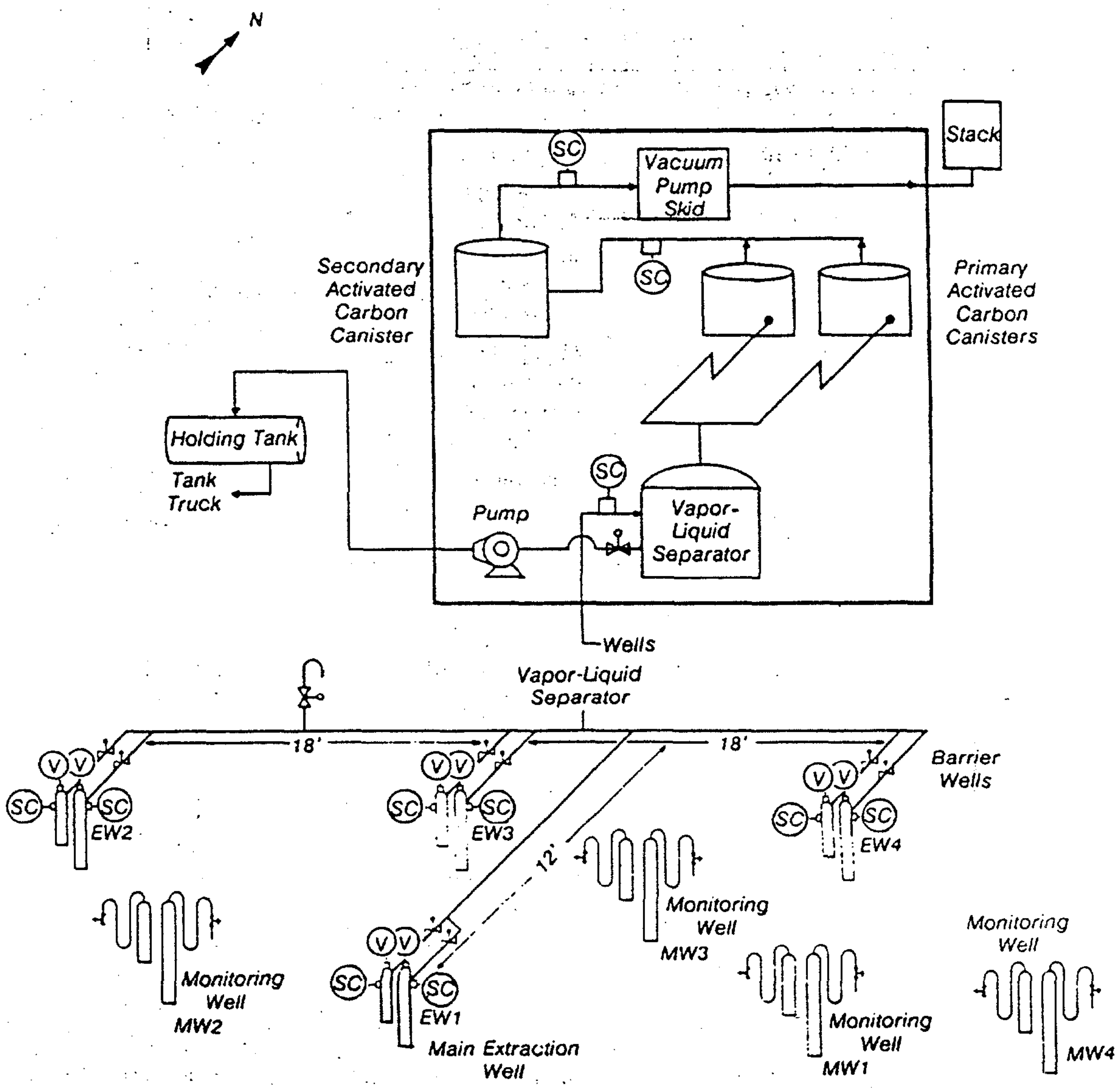

Figure 1. Schematic diagram of equipment layout.

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

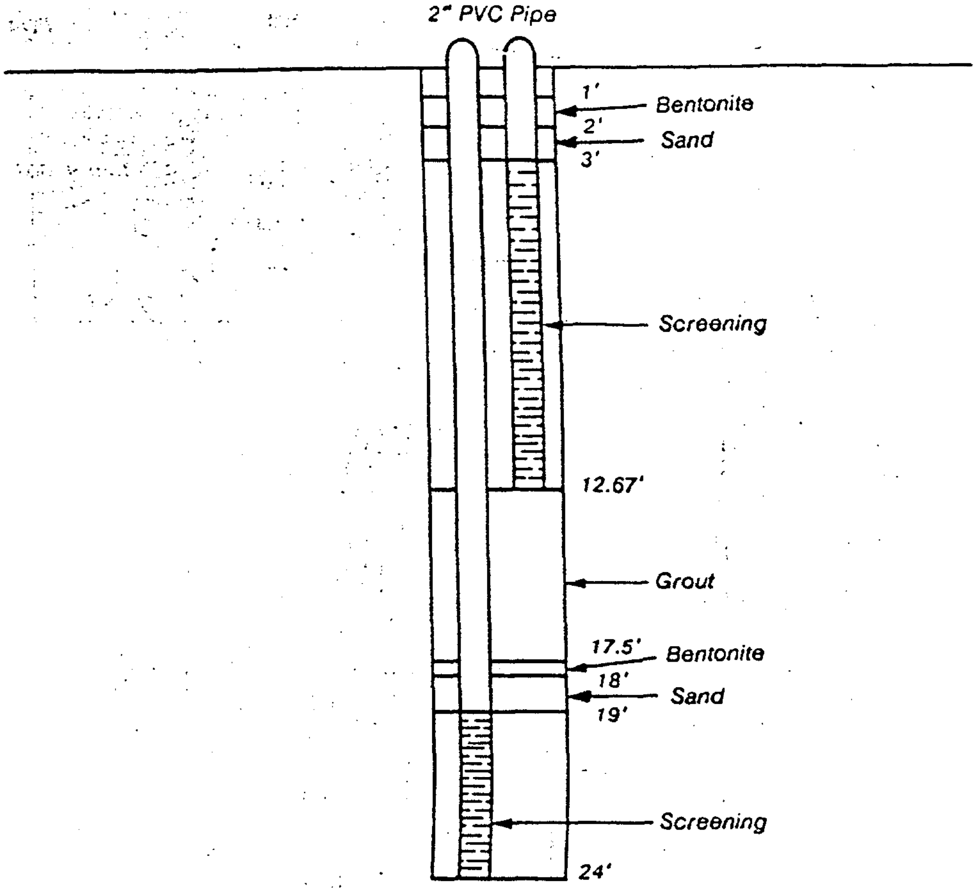

Figure 2. Schematic diagram of an extraction well.

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 CS_2 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. ry good check on this total was e by the activated carbon VOC alysis, 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 leve of contamination. Extraction well 1, whic was expected to have the greates concentration reduction potential exhibited only a minor decrease over the course of the test. Undoubtedly this was because of the greater-than-expecte level of contamination that existed in the area around monitoring well 3 that was drawn into the soil around extraction wel 1. The decrease in the TCE level aroun 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

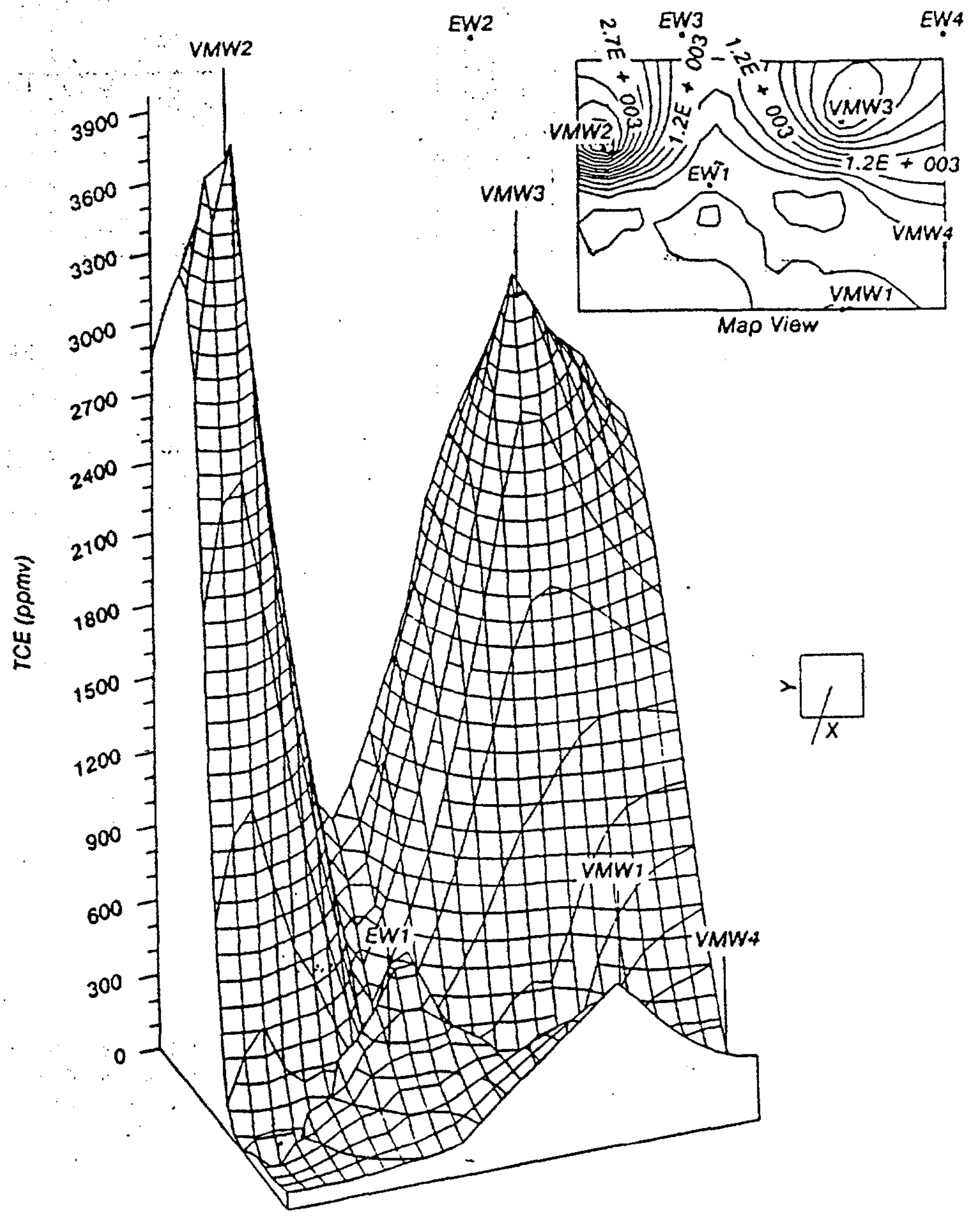

Figure 3. Pretreatment shallow soil gas concentration.

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 extraction 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 stratum. The data suggest that technology can desorb or otherv mobilize VOCs out of certain clays Table 5).

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

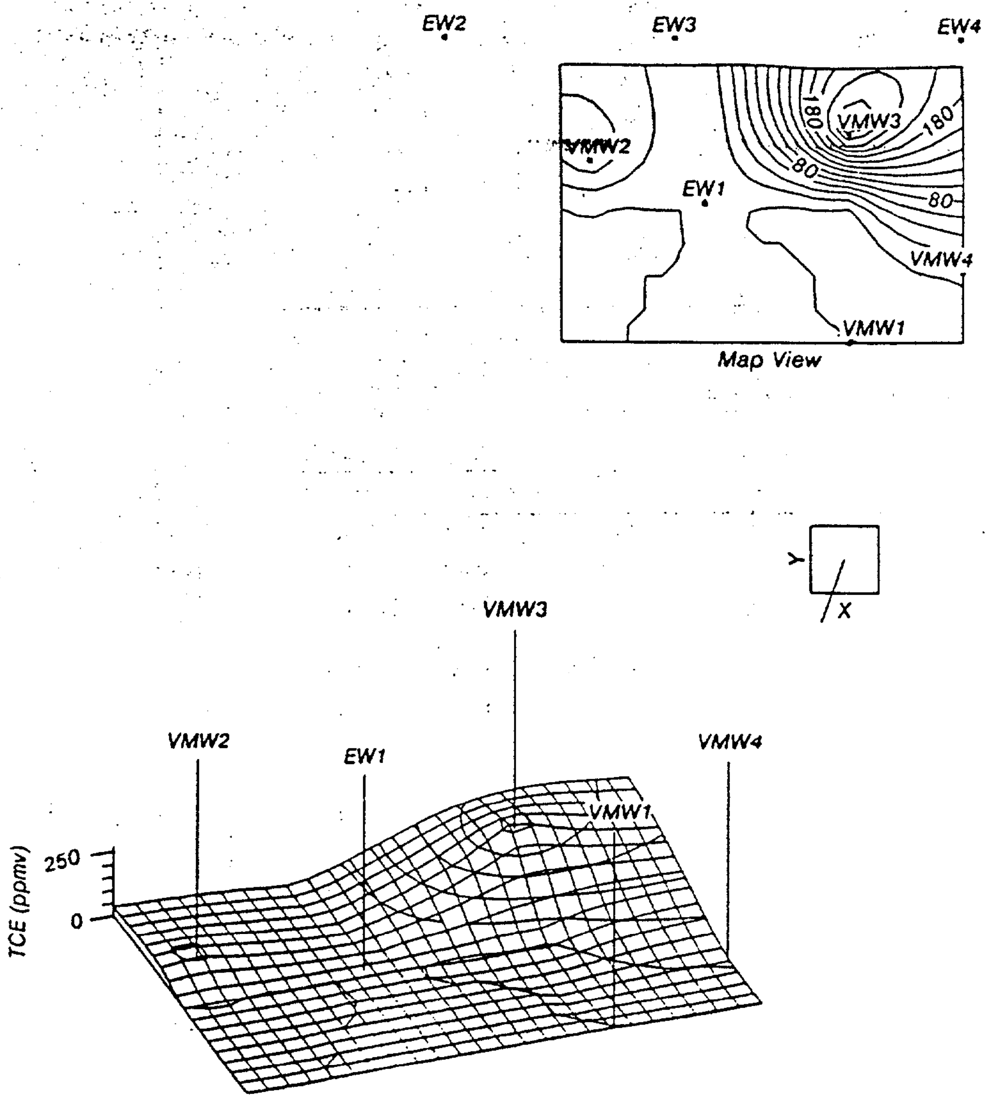

Figure 4. Posttreatment shallow soil gas concentration.

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	Perme-ability cm/sec	TCE Conc. ppm pre	TCE Conc. ppm 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	Perme-ability cm/sec	TCE Conc. ppm pre	TCE Conc. ppm 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

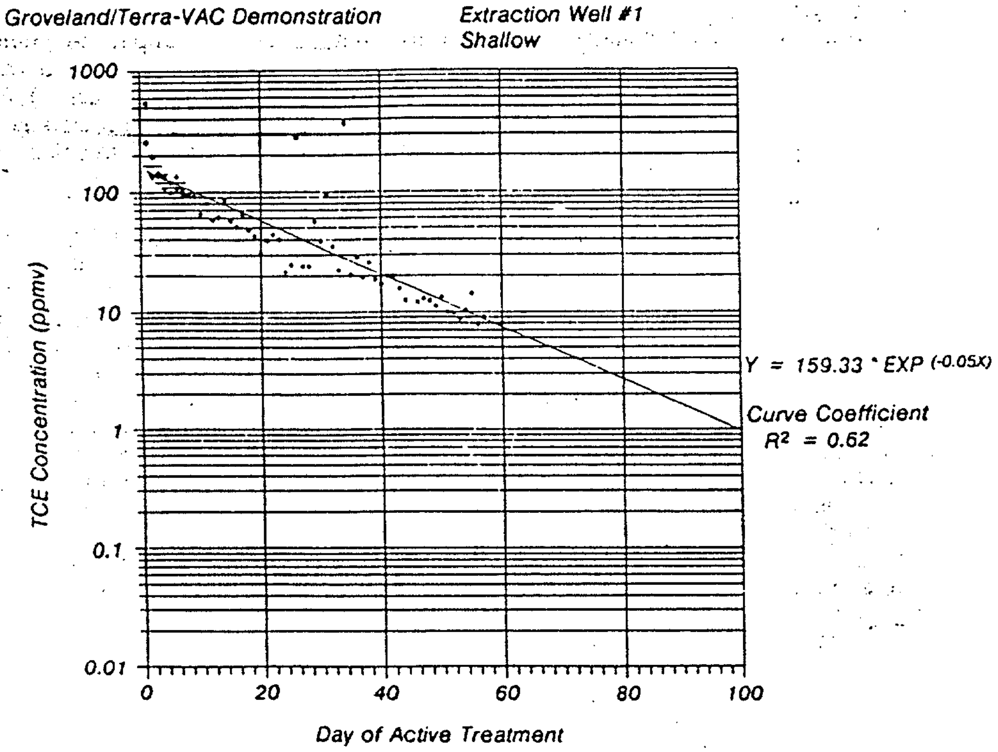

Figure 5. Wellhead TCE concentration vs time.

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 included 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/m^3, 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/m^3-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:

$$C_y = C_o \operatorname{erf}\left(Z/(2(a_zY)^{0.5})\right) \operatorname{erf}\left(X/(a_tY)^{0.5}\right)$$

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:

$$C_y = C_oC_f$$

where:

$C_f = \operatorname{erf}\left(Z/(2(a_zY)^{0.5})\right) \operatorname{erf}\left(X/(a_tY)^{0.5}\right)$, 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 wellhea gas concentration and extrapolating i order to arrive at a wellhead gas concen tration at the target soil concentratio The calculated target soil concentratio for this site is 500 ppbw. This corre sponds to an approximate wellhead ga concentration of 89 ppb for EW1S. Th equation correlating wellhead gas cor centration with time (see Figure 5) is the solved to give 150 days running time.

After 150 days the vacuum extracti system can be run intermittently to see significant increases in gas concentr tions occur upon restarting, after at lea a two-day stoppage. If there are appreciable increases in gas concent tion, the soil has reached its resid equilibrium contaminant concentrati and the system may be stopped and s borings taken and analyzed.

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

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TERRA VAC'S DUAL EXTRACTION PROCESS

In response to the growing demand for a cost effective combined groundwater treatment/vapor extraction technique to simultaneously remediate soils and groundwater, Terra Vac has developed a technical variation of the vacuum extraction process termed 'Dual Extraction'. This technique operates in essentially the same manner as vacuum extraction except that the well is outfitted with a groundwater pump, ejector system, or vacuum water lift system to depress the groundwater table and enhance the flow of contaminants through the induced vadose zone. Thus, a single vacuum extraction well serves a 'dual' purpose, by extracting contaminated groundwater at the same time as soils are being cleaned. Terra Vac has implemented dual extraction at over 70 sites with excellent results.

Terra Vac has shown that the combined effect of groundwater pumping coupled with vacuum extraction can increase the rate of contaminant removal several fold. The added effect of vacuum increases groundwater flowrates toward the well, and in some instances, Terra Vac has recorded up to 15 times the groundwater pumping rates when dual extraction is used compared to simple groundwater pumping alone.