In-Situ Soil Vacuum Extraction System
Verona Well Field Superfund Site
Battle Creek, Michigan

Draft Final
Final Report for NATO/CCMS Pilot Study on Remedial Action Technologies for Contaminated Land and Groundwater
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I. INTRODUCTION

Site Description

The Verona Well Field is located in Battle Creek, Michigan in the south central portion of the State. The Verona Well Field (VWF) site consists of four distinct problem areas within approximately 100 acres. The municipal well field is located in the northeast corner of the City and lies on both sides of the Battle Creek River (Figure 1). The well field consists of 30 production wells that supply drinking water for 50,000 residents and several major food industries. The Thomas Solvent Raymond Road (TSRR) facility, the Thomas Solvent Annex (TSA) facility, and the Grand Trunk Western Railroad (GTWRR) have been identified as sources of well field contamination. Figure 1 shows the location of these sources relative to the well field. The site is located in an urban setting which is primarily residential with some light industry.

Site History

The contamination problem at the VWF site was first discovered in August 1981, during testing of the City water supply. Test results revealed that 10 of the City's 30 supply wells were contaminated with volatile organic compounds (VOCs). Concentrations ranged from 1 to 100 ug/l. During the same period, private residential wells were also tested. Several of these wells were found to contain VOCs in excess of 1,000 ug/l. The highest level found in a private well was dichloroethylene at 3,900 ug/l. A bottled water program was implemented in this area and residents were connected to the City's water supply system.

In the Fall of 1983, the first phase of a Remedial Investigation (RI) was initiated to determine the extent of contamination in the well field and potential sources. Sample results from the initial RI work confirmed the existence of a contaminant plume with VOC concentrations ranging from 1 ug/l to 100 ug/l in the well field. The investigation also identified the three major sources of contamination.

Remedial Measures

In May 1984, U.S. EPA signed a Record of Decision (ROD) calling for an Initial Remedial Measure (IRM) to implement a blocking
THOMAS SOLVENT RAYMOND ROAD FACILITY / GRAND TRUNK WESTERN RAILROAD MARSHALLING YARD

VERONA WELL FIELD

MICHIGAN
• BATTLE CREEK

FIGURE 1 VICINITY MAP
well system in the well field. The blocking system consists of a line of converted supply wells that extract contaminated water from the southern end of the VWF. The system prevents contaminants from migrating further into the well field. An air stripper with vapor phase carbon treatment was also installed to treat contaminated water prior to discharge to the Battle Creek River.

In August 1985, U.S. EPA signed a second ROD that addressed the most contaminated of the three sources, the Thomas Solvent Raymond Road facility. The ROD included a groundwater extraction system to remove contaminated groundwater, treatment of extracted water utilizing the existing air stripper at the well field, demolition of the existing warehouse and loading dock, and a soil vapor extraction system to remove VOCs from contaminated soils.

Site Characteristics and Sampling Results

The Thomas Solvent Raymond Road (TSRR) facility is a former solvent repackaging and distribution facility that operated from 1970 to 1984. Solvents were stored in 21 underground storage tanks, of which 19 were later discovered to be leaking. There has also been documented reports of surface spillage during operation. The site contained an office building, a warehouse with a loading dock, and the 21 underground tanks (see Figure 2).

Site geology consists of a fine-to coarse-grained alluvial-glacial sand with traces of silt, clay, and pebbles underlain by a fine-to medium-grained sandstone with minor lenses of shales and limestones. The unconsolidated sand unit ranges in thickness from 10 to 50 feet and the sandstone varies from 100 to 120 feet in thickness. The hydraulic gradient is primarily north to northwest from the identified sources toward the VWF. The depth to water is approximately 20 to 25 feet. The hydraulic conductivity of the unconsolidated material ranges from $2.7 \times 10^{-3}$ to $4.0 \times 10^{-2}$ cm/sec. The hydraulic conductivity of the sandstone ranges from $7 \times 10^{-3}$ to $2 \times 10^{-2}$ cm/sec.

Samples collected at the TSRR facility indicate that both soils and groundwater are highly contaminated with a variety of organic compounds. Table 1 lists organic compounds detected in soils at TSRR. Groundwater samples showed concentrations as high as 100,000 ug/l VOCs. The total estimated volume of organics in groundwater and soils was 3,900 lbs., and 1,700 lbs., respectively.

It should be noted that these total mass estimates were based on sample data obtained using an accepted soil sampling procedure which is now known to produce VOC results lower than actual values. The total mass in groundwater and soils is now estimated
THOMAS SOLVENT BUILDING

TYPICAL UNDERGROUND STORAGE TANKS (APPROXIMATE LOCATIONS)

OFFICE BUILDING

FIGURE 2
LOCATION OF UNDERGROUND TANKS
### TABLE 1

**PRINCIPAL SOIL CONTAMINANTS DETECTED AT TSRR**

<table>
<thead>
<tr>
<th>CHLORINATED HYDROCARBONS</th>
<th>MAX. CONC. (ug/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- METHYLENE CHLORIDE</td>
<td>60,000</td>
</tr>
<tr>
<td>- CHLOROFORM</td>
<td>2,000</td>
</tr>
<tr>
<td>- 1,2-DICHLOROETHANE</td>
<td>27,000</td>
</tr>
<tr>
<td>- 1,1,1-TRICHLOROETHANE</td>
<td>270,000</td>
</tr>
<tr>
<td>- TRICHLOROETHYLENE</td>
<td>550,000</td>
</tr>
<tr>
<td>- TETRACHLOROETHYLENE</td>
<td>1,800,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AROMATICS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- TOluENE</td>
<td>730,000</td>
</tr>
<tr>
<td>- XYLENE</td>
<td>420,000</td>
</tr>
<tr>
<td>- ETHYL BENZENE</td>
<td>78,000</td>
</tr>
<tr>
<td>- NAPHTHALENE</td>
<td>9,400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KETONES</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>- ACETONE</td>
<td>130,000</td>
</tr>
<tr>
<td>- METHYL ETHYL KETONE</td>
<td>17,000</td>
</tr>
</tbody>
</table>
to be significantly greater based on the results of the operating groundwater extraction system and the soil vacuum extraction system.

Conventional subsurface soil sampling procedures involving the use of split spoon samplers require the sampler to be opened and the sample transferred to a bottle prior to shipment to the laboratory. This allows for significant amounts of VOCs to volatilize before analysis. This problem, coupled with the lack of sampling in the capillary zone and beneath the former warehouse building, resulted in estimates of VOC-contaminated soils being considerably lower than actual. This has had a significant effect on the operation of the soil vacuum extraction system. These effects will be discussed in detail in a later section of this report.

Technology Selection

Due to the significant mass of contaminants in the soil and groundwater at the TSRR facility, alternatives that employed both groundwater and soil remediation were developed in the feasibility study. A two step approach to remedial action was used at the TSRR facility in which each alternative developed for the feasibility study included both a groundwater and a soils portion. The selected alternative for the site includes a groundwater extraction (GWE) system and the soil vacuum extraction (SVE) system.

The groundwater extraction system includes 9 extraction wells which pump a total of 300 gallons per minute. The extracted water is pumped to the existing air stripper at the well field and discharged to the Battle Creek River after treatment. Figure 3 shows the layout of the GWE system. Initially, VOC concentrations in groundwater were so high that extracted water was passed through pretreatment carbon units prior to being pumped to the air stripper. The system has been operating since March of 1987.

Several alternatives for soil cleanup were evaluated, including SVE, excavation of soils with on/off site disposal, site capping, and soil washing (flushing water through the unsaturated zone with subsequent groundwater extraction).

SVE was chosen based on a number of reasons. Although it was considered an innovative technology, it was felt that it had a good likelihood of success given the site conditions and contaminants. Excavation was considered unacceptable due to its potential to release high concentrations of VOCs into the air, which would create a health hazard to residents in close proximity to the site, and significantly violate Michigan Air Quality Standards for VOCs. Therefore, alternatives that would
FIGURE 3
GWE SYSTEM LAYOUT
not disturb soils were favored. Capping was not considered to be consistent with future actions because of the high level of contamination present at the site and because the underground tanks would eventually have to be removed.

Of the two soil treatment alternatives, SVE was calculated to take less time to remediate the site than soil flushing. It was estimated that SVE, in conjunction with GWE, would reduce the groundwater contamination to 100 ug/l within three years. The contaminant mass would be reduced to 2% within 1 1/2 years (based on 1700 lbs. of VOCs). Soil washing was estimated to require 8 years to reach 100 ug/l in groundwater and 8 years to reduce contaminant mass to 2%. This was significant in the selection of SVE because it was not less expensive than soil washing. The estimated capital cost of SVE was $413,000, with operation and maintenance (O&M) of $90,000. Soil washing capital cost was estimated at $58,000, with O&M of $6,000. SVE was, however, considerably less expensive than the excavation and capping alternatives.

Since SVE is an innovative technology, the procurement of a SVE contractor was accomplished using a performance specification which contained certain minimum requirements but left the major design details to the discretion of the bidding SVE contractors. Contract documents called for the construction, operation, and maintenance of the SVE system. The performance standards require that the SVE would operate until all soil samples showed VOCs below 10 mg/kg, with no more than 15 percent of the samples above 1 mg/kg total VOCs.

II. TECHNOLOGY

Process Description

The soil vapor extraction process is designed for use in removing VOCs from the unsaturated zone in soils. The mechanism by which SVE operates is fairly simple and straightforward. The system is designed to create negative pressure in the unsaturated zone using wells that are connected to a vacuum extraction unit. The vacuum induces a flow of air through the soils, thereby volatilizing VOCs that are absorbed on soil particles and extracting the contaminants in the vapor phase.

A vacuum extraction system generally consists of several extraction wells screened throughout the unsaturated zone or within discrete units of the unsaturated soils. The wells are connected by transfer pipes which are manifolded to the vacuum extraction unit. The vacuum applied at the wellhead creates a negative pressure or vacuum in the subsurface which cause VOCs to volatilize and migrate to the extraction wells. A vapor/water
separator is also incorporated to remove water from the contaminated air stream.

The materials used for an SVE system are generally readily available and not specialized. Equipment requirements include PVC/stainless steel wells and piping; conventional vapor phase carbon treatment units; a conventional air/water separator; and an induction blower.

The design of the SVE system is critical in order to insure adequate cleanup of the soils. The design requires expertise in modeling vapor flow, understanding site lithology, determining contaminant mass and areal extent of contamination. These factors are used to determine system variables such as well spacing, number of wells, and depth of screened interval.

Site conditions, soil properties, and the contaminant’s chemical properties are the important factors to consider in determining whether to use soil vapor extraction. Information on soil permeability, moisture content, and porosity is needed to make a determination on whether the soils have sufficient air-filled porosity. Insufficient air-filled porosity results from the presence of excess water in the pore spaces which reduces the effectiveness of vacuum extraction. Depth to groundwater is an important cost consideration because if the vadose zone is less than 10 feet, it may not be cost-effective to use SVE (excavation of less than 10 feet may be less costly).

In order for a contaminant to be stripped from the soil using SVE, it must have a Henry’s Constant of 0.001 or greater. The higher the Henry’s Constant, the easier the compound is removed by vacuum extraction. Figure 4 shows relative extraction rates for compounds found at the TSRR facility.

**Design and Construction of the TSRR System**

Prior to full-scale construction of the SVE system at TSRR, a preconstruction investigation was performed. The investigation included a geophysical survey, a soil sampling program, and a soil gas survey.

The geophysical survey was conducted to confirm locations of underground tanks and to check for additional buried objects in the effected area. The soil sampling program was conducted to investigate the horizontal and vertical extent of contamination, and to estimate the mass of VOCs in the vadose zone. As a result of this activity, a revised estimate for VOCs ranging from 13,000 to 16,500 pounds was calculated. This did not include estimates for a floating product layer that was discovered during the sampling. The objective of the soil gas survey was to investigate the extent of VOC contamination in shallow soils in
FIGURE 4
Relative extraction rates.
areas not previously investigated at the site. Results confirmed that the major area of contamination was in the vicinity of the underground tanks and loading dock, however, contamination was also detected along the northeast and southern parameters of the site.

Results of the investigation were used to determine locations of additional SVE wells, revise estimates of the mass of VOCs in the soils, and to make determinations on system parameters.

Following the preconstruction investigation, a pilot phase SVE system was installed. The system consisted of 11 wells that were operated for a total of 70 hours. The objectives of the pilot phase were to verify the radius of influence of the wells and determine the vapor flow rate/vacuum pressure relationship at each well, investigate the effect of the underground tanks on the vacuum pressure distribution in the vadose zone, and identify the VOC loading rates from individual wells as a function of vacuum pressure and flow rate.

Results of the pilot phase were used to determine process variables and locations of wells. Extracted airflow rates range from 60 to 165 standard cubic feet per minute (scfm) from individual wells, with wellhead vacuums of 3 to 4 inches of mercury. VOC extraction rates vary between wells with the highest measured concentration at 4,400 lbs/day during the pilot phase. The radius of influence for the wells was measured to be greater than 50 feet.

The full-scale system consists of a network of 23 4-inch diameter PVC wells with slotted screens from approximately 5 feet below grade to 3 feet below the water table. The wells are packed with silica sand and sealed at the screen/casing interface with bentonite and then grouted to existing grade to prevent short circuiting. Each well has a throttling valve, a sample port, and a vacuum pressure gauge. The wells are connected by an above ground PVC piping manifold system. Figure 5 shows the location of the SVE wells and the piping layout.

The piping manifold is connected to a centrifugal air/water separator. This is connected to the vapor phase carbon absorption system which is followed by the vacuum extraction unit (VEU). The VEU is responsible for inducing extraction of soil vapors from the subsurface, through the extraction wells and into the treatment unit. After treatment, air is discharged through a 30 foot stack located on site. Figure 6 is a schematic of the SVE system.

The carbon absorption system consists of eight stainless steel carbon canisters with four in the primary system and four in the secondary or backup system. The primary carbon system is the main unit for absorption of VOCs, with the secondary carbon...
FENCE LINE
8 INCH HEADER PIPING
MONITORING BUILDING
CONCRETE DECONTAMINATION SLAB
STEAK
TYPICAL SOIL VAPOR EXTRACTION WELL
OFFICE BUILDING
RAYMOND ROAD
GATE
AIR/WATER SEPARATOR
SVE PROCESS BUILDING

FIGURE 5
SVE WELLS AND PIPING LAYOUT
system acting as a backup when breakthrough of the primary system occurs. Each carbon canister holds 1000 pounds of vapor-phase granular activated carbon and are connected to the header piping with flexible hoses and couplings that are easily disconnected for ease in canister change outs. Figure 6 shows the various sample ports, pressure gauges and temperature probes located before, between, and after the carbon units. A carbon monoxide monitor is installed between the carbon units to detect combustion in the primary carbon unit and trigger an automatic system shutoff upon detection.

The carbon system was installed on the negative pressure side of the VEU to minimize leaks and eliminate the potential for emissions to the atmosphere. During the pilot phase of operation it was determined that carbon adsorption efficiency was equivalent under positive and negative pressure.

Breakthrough of the primary carbon system is measured by an in-line HNU photoionization detection meter. Four contaminants are used as indicator compounds, tetrachloroethylene, trichloroethylene, methylene chloride, and benzene. The breakthrough point was determined using the relationship between total VOCs measured by the HNU and the compound-specific concentrations measured in the air flow. When breakthrough occurs, the primary carbon canisters are changed out and replaced with those from the secondary system and a new set of four canisters are put into backup in the secondary system. This allows maximum loading of the primary carbon system prior to rotating the carbon units, while minimizing the possibility of breakthrough in the backup system.

Samples are collected from both carbon systems as well as at the individual wellheads. Results are used to determine VOC loading rates and predict rates of breakthrough. Sample analysis is performed on-site using a gas chromatograph with dual flame ionization detectors and capillary columns.

III. RESULTS

The SVE system began full operation in March 1988. Results discussed in this report are for the period of March 1988 through September 1989.

Vacuum Extraction System Performance

To date, approximately 40,250 pounds of VOCs have been removed from the soils. On-site gas chromatography has been used to monitor VOC concentrations extracted by SVE. Off-site analysis of spent carbon has confirmed that on-site monitoring is accurate to within approximately 5 percent.
The initial loading rate of total VOCs has declined over the period of operation from an initial level of approximately 45 pounds per hour (pph) to below 10 pph. The floating product layer that was detected during preconstruction and during the initial operation period has not been detected since October 1988; however, at that same time, a 0.5- to 1.0 foot increase in the water table was recorded.

The average VOC concentrations measured at the air discharge stack is approximately 1.35 mg/l, with an average flow rate in the stack of 1060 standard cubic feet per minute (scfm). This has dropped from an initial VOC concentration of approximately 23 mg/l. Over the course of operation of the system, an average efficiency rate of greater than 99.8 percent removal has been measured.

**Technology Evaluation and Performance Monitoring**

Since SVE is an innovative technology, careful consideration was given to the method by which the system’s performance would be monitored and to confirm that the performance objectives would be met. A Quality Assurance Project Plan (QAPP) and Sampling Plan were developed for the sampling events. Three soil sampling episodes were planned. One prior to startup, one at the mid-operation point, and the last to confirm that performance objectives have been met.

Since conventional soil sampling methods cause volatilization of VOCs prior to analysis, a special sampling and analysis procedure was developed for collection of samples. Samples are taken by driving a split spoon sampler fitted with four, 3-inch brass liners, through hollow stem augers. To prevent excess handling, and thus volatilization of contaminants, one brass liner is removed from the split spoon, immediately wrapped in aluminum foil, sealed, and sent to the laboratory for analysis. Samples are analyzed using a core of the undisturbed sample for extraction.

To date, the pre-operational and mid-operational sampling events have occurred. The pre-operational samples verified that the volume of VOCs in the soils had been underestimated during the remedial investigation at the site. Based on sample results, VOC concentrations were estimated to be between 12,800 and 16,500 pounds. This did not include estimates for the floating layer of product that was identified during the startup work.

Data from the mid-operational sampling event have not yet been received from the laboratory. It is hoped that this data will be available for incorporation into the final version of this report.
Process factors

Carbon handling requirements have been the limiting factor in performance of the SVE system. Because the estimate of VOCs present in the soils was significantly underestimated, the amount of carbon needed was also underestimated. The amount of contaminants extracted to date has resulted in the use of 250,000 pounds of carbon in the treatment system at a cost of $541,000. It is estimated that a total of more than 400,000 pounds will be needed to complete the project at a cost of approximately $886,000.

In addition to the increased costs, the additional carbon requirements have caused delays in the operation of the system. Although the system has been operational for more than 18 months, actual number of days of operation is approximately 100. This due to the need for frequent carbon change outs and transporting the spent carbon off-site for regeneration. It is estimated that an additional 50 days will be needed to attain the levels required in the performance objectives. It is also expected that carbon change outs will become less frequent as the loading rates decline.

The equipment needed to operate the system has proven to be very reliable and down time due to equipment failure has not been a factor in SVE operation. As discussed, the materials used to operate the SVE system are conventional and easily replaced if necessary. Although Terra Vac, the vendor, has been required to be on site for 8 to 10 days per month due to the frequent need to change out carbon and monitor the system, the system was designed for unattended operation. It is expected that as loading rates decline, Terra Vac will be required to spent less time at the site per month.

Instrumentation and controls have been installed to monitor the system and trigger shut down if necessary. These include the carbon monoxide monitor in the carbon system, a high water-level shut down in the air/water separator, high temperature shut down triggers, and an on-line HNu with a shutdown mechanism for detecting VOC breakthrough of the primary carbon system. In addition, the system contains an automatic dialer that contacts Terra Vac when any of the shutoff mechanisms are triggered.

Costs

A summary of the costs to install and operate the SVE system, current and projected future carbon costs, and the unit costs for operation of the system are listed in Table 2. It was not possible to separate out the cost of the pilot phase portion from the cost of the full-scale system because the bid was received as
### TABLE 2

**SOIL VAPOR EXTRACTION COSTS**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVE Lump Sum Bid - For Construction &amp; Operation (excluding cost of carbon)</td>
<td>$1,265,535</td>
</tr>
<tr>
<td>Cost of SVE/Cubic Yard of VOC-Contaminated Soil (excluding cost of carbon)</td>
<td>$22.50</td>
</tr>
<tr>
<td>Unit Cost/pound for Carbon (removal/transport/regeneration)</td>
<td>$2.16</td>
</tr>
<tr>
<td>Carbon Costs to Date (250,000 pounds used)</td>
<td>$541,000</td>
</tr>
<tr>
<td>Projected Total Carbon Costs (estimated 400,000 pounds)</td>
<td>$886,000</td>
</tr>
</tbody>
</table>
a lump sum for the project. The original cost estimate was revised to account for the additional days per month Terra Vac is required to be on-site, due to the increased contamination at the site.

As previously discussed, carbon costs have been quite high due to the increased level of contamination found at the site. Initially, it was estimated that 20,000 pounds of carbon would be needed to remediate the site. To date, 250,000 pounds have been used and it is estimated that an additional 150,000 pounds more are needed to complete the project. Table 2 lists the actual and projected future carbon costs for project completion. No long term maintenance costs are expected.

Lessons Learned

Vapor Treatment

As has been discussed throughout this report, the underestimation of the total mass of VOCs in the soils at this site has complicated the remediation of the site. The increased levels have affected the project expense, the time to remediate, and the operation of the technology.

During evaluation of the treatment options for the project, it was determined that, based on a total VOC volume of 1,700 pounds, carbon absorption was the least expensive treatment option. If contamination estimates were closer to the actual, carbon absorption would not have been the least costly and would likely not have been considered. In addition, the cost of operating the system is more expensive because Terra Vac must be at the site many more days per month than estimated.

The underestimation of VOC mass has also affected remediation time and the operation of the technology. Due to the frequent number of change outs required during operation, the system is operational as little as five to ten days per month. This has resulted in only 100 days of system operation in a period of 18 months.

In order to prevent this situation, it is imperative that accurate estimates of subsurface contamination be obtained prior to design of the system. Specifically, accurate mass estimates must be obtained for amount of floating product present, and the amount of VOC contamination in the capillary fringe, the zone immediately above the water table, and in the smear zone, the zone within which the water table fluctuates. Based on data collected during operation of the SVE at TSRR, it was estimated that 70 percent of the mass of VOCs occurs as floating product and in VOC saturated soils in the smear zone and capillary fringe.
Radon Gas

A somewhat unexpected contaminant detected was radon gas, which occurs naturally in the site soils. Measurements of the carbon vessels indicate the presence of radioactivity on the spent carbon. The presence of radon gas is not too unusual since it is readily volatilized and activated carbon is a good collection medium for radon. Concentrations measured to date at the TSRR facility are not considered to present a public health or worker hazard. However, the handling, transportation and regeneration of radioactive spent carbon may need to be considered for SVE operation in areas where radon occurs at high levels.

Future Plans

U.S. EPA's contractor, CH_{2}M Hill, is currently evaluating the use of a catalytic oxidation (CATOX) system for the destruction of VOCs in the soil vapor. This would replace the carbon absorption system. While other treatment options have been looked at during the life of the project, the cost for removing the carbon system and installing another treatment system has not been shown to be cost-effective. However, cost-effective CATOX systems have recently been developed that can treat chlorinated VOCs without generating dioxins or suppressing catalyst performance.

In addition to the reduction in cost to treat contaminants, two other major benefits from switching to a CATOX system are the destruction of contaminants on-site, which eliminates the transporting of wastes off-site, and the ability to run the SVE system continuously, thereby attaining site cleanup faster.

IV. CONCLUSIONS

Since the project is still in operation, certain conclusions should not be considered definite. However, based on evaluation of the operating data from the site and on the recent literature regarding SVE, the following conclusions have been drawn:

* SVE is a viable technology for the removal of VOCs in unsaturated soils. The fact that over 40,000 pounds of VOCs have been removed from the soils at TSRR indicates that the technology works.

* SVE will operate in a wide range of soil types. Based on work at the site, SVE is very effective in removing contaminants from sandy soils. Recent literature on SVE performance indicates that it is effective for soils with measured permeabilities of $10^{-4}$ to $10^{-8}$ cm/sec.

* The major considerations in determining the technology's
applicability are soil properties, depth to ground water, and the contaminant's chemical properties. Soils that have a low air-filled porosity and high moisture content may not provide adequate conditions. In addition, at sites where groundwater is encountered at less than 10 feet, it may be more cost-effective to excavate contaminated soils. Chemicals with a Henry's Constant of less than 0.001 may not be sufficiently volatile for the SVE process.

* The SVE system has operated well in all weather conditions at the site. Cold weather operation has not proved to be a problem. The system has operated through an entire winter in the midwest with temperatures that range from 0 degrees celsius to -26 degrees celsius.

* The SVE system can be designed to operate for the majority of the time without an on-site operator. Under most circumstances, the system would be sized to provide unattended operation with vendor personnel on-site 1 to 4 days per month depending on the size of the system and the monitoring requirements.

* Based on experience at the TSRR facility, SVE appears to be the only technology that can effectively remove the VOC saturation remaining after free product is removed from the capillary fringe and smear zone of VOC-contaminated soils.

* The costs of SVE at the site for 1 cubic meter of soil is approximately $50.00 to $60.00. This includes the cost of treatment of vapors using carbon absorption. If treatment of vapors is not required, costs could be as low as $20.00 per cubic meter of soil.

The overall prognosis of the SVE process is that it offers an economical, reliable, and rapid cleanup technology for remediating soils contaminated with volatile organics. The technology enhances groundwater extraction systems and greatly reduces the time and cost for groundwater remediation. The process works on most soil types and has a limited number of factors for consideration in determining applicability. There is no limit on size of the site, or on the level of VOC contamination (except in considering the need for treatment of off-gases). The system is easily installed and removed, and does not require specialized equipment for operation.

V. CONTACTS FOR MORE INFORMATION

Information useful to potential SVE technology users can be provided by the following sources:
VI. REFERENCES

1. Danko, J., Soil Vapor Extraction at a Superfund Site, CH₂M Hill, Corvallis, Oregon, undated.

2. Danko, J., Soil Vapor VOC Removal System at the Verona Well Field Superfund Site City of Battle Creek, Michigan, CH₂M Hill, Corvallis, Oregon, March, 1989.
