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Engineering Forum Issue Paper:
Soil Vapor Extraction Implementation Experiences

Office of Emergency and Remedial Response | Quick Reference Fact Sheet

This fact sheet identifies issues and summarizes experiences with soil vapor extraction (SVE) as a remedy for volatile organic compounds (VOCs) in soils. The issues presented here reflect discussions with over 30 Remedial Project Managers (RPMs) and technical experts. This fact sheet has been developed jointly by the the Engineering Forum and Office of Emergency and Remedial Response, with assistance from the Office of Research and Development. Special thanks are due to Robert Stamnes (Engineering Forum Co-Chair), John Blanchard (OERR), David Becker (USACE), and Dom DiGiulio (ORD). EPA's Engineering Forum is a group of professionals, representing EPA's Regional Offices, who are committed to identifying and resolving the engineering issues related to remediation of Superfund and hazardous waste sites. The Forum is sponsored by the Technical Support Project. The information presented here is advisory in nature, should be verified for its applicability to a given site, and is not intended to establish Agency policy. RPMs should consult their regional management before applying the recommendations cited in this paper for appropriateness at their site.

Soil vapor extraction (SVE) is a commonly used technology for VOCs in soils that EPA has selected as a "presumptive remedy" (see bibliography at the end of this paper). SVE is an *in situ* treatment technology that uses vacuum blowers and extraction wells to strip volatile compounds from unsaturated soil. The extracted vapors are treated at the surface and released to the atmosphere or reinjected into the subsurface. The extraction wells typically are constructed of polyvinyl chloride (PVC) pipe, which is screened through the area of contamination. Emissions from the SVE process often are filtered by activated carbon, or treated either by thermal destruction or condensation refrigeration, before being released into the air. Consult the bibliography at the end of this fact sheet for additional details.

Site Characterization

Before remedial technologies for soil treatment can be evaluated, a site investigation should be conducted to characterize the soils and other site features.

Two major factors determine SVE's effectiveness: soil permeability and constituent volatility. Pertinent soil measures include hydraulic conductivity, soil vapor components, gas permeability, and soil moisture content. SVE is generally less practical in moist, silty or clayey soils. Pertinent measures of volatility include vapor pressure, water solubility, boiling point, and Henry's Law constant (chemicals with a dimensionless vapor pressure of greater than 0.5 mm Hg and a Henry's Law constant greater than 0.01 generally are expected to respond to SVE). Other important factors are depth to the water table, potential for water table upwelling, site structures, subsurface obstructions, and the presence of dense nonaqueous phase liquids (DNAPLs).

Site investigation should begin with geophysical methods (electromagnetic survey or ground-penetrating radar) to determine the presence and location of non-aqueous phase liquids, follow with soil-gas monitoring to locate hot spots, and conclude with soil-matrix sampling to determine the full extent of contamination and establish cleanup levels. Bench- and field-scale studies may be needed to determine treatability. The cost of sampling the soil matrix can be reduced by using a hydropunch or cone penetrometer equipped with sensing devices.

One example illustrates the importance of adequate site characterization in heterogeneous soil conditions. At the site, a continuous rock layer was discovered several years after SVE had been implemented. The rock layer prevented the vacuum from reaching the deep soils. The system was modified by adding horizontal wells, and has reached asymptotic contaminant levels after six years of operation.

At another site, the hydraulic conductivity of soils was low, and varied by an order of magnitude. In the vadose zone, air permeability (which characterizes a soil's resistance to gas flow) was higher than hydaulic conductivity (resistance to liquid flow) and varied by only 30 percent. This information allowed the selection of SVE. Without the air permeability data, SVE would have been ruled out due to the low and widely varying hydraulic conductivity of the site soils.

When a shallow water table is present, it is particularly important to investigate the potential for groundwater upwelling (which can result in removal of less vapor and more water) and its effects on SVE (see the discussion on the effects of moisture on contaminant removal by granular activated carbon (GAC) systems in the *Implementation and Air Emissions Control* section of this fact sheet).

At a wetlands site that had been capped since the early 1980s, a treatability test had to be cut short because of high concentrations of methane in the extracted air. The methane was believed to result from the decomposition of organic matter under the cap. The final design must include appropriate treatment based upon the predicted level of methane. Note that a buildup of methane in a SVE system can pose a serious explosion risk; another remedy may be more appropriate.

A cap covering another site had been in place for some time prior to the SVE system installation. The contaminants initially present at the site were trichloroethane (TCE) and perchloroethane (PCE). Subsequent sampling beneath and along the edges of the cap revealed that anaerobic conditions under the cap had reduced the initial compounds to vinyl chloride. For this reason, the potential for biodegradation of contaminants should be considered when evaluating the use of caps to enhance SVE systems. Vinyl chloride is a very toxic compound that can be released into the air or groundwater.

Determination of Cleanup Levels

Soil criteria and air quality regulations applicable to SVE operations may vary substantially among states, and sometimes between localities within the same state. Accordingly, specific cleanup criteria should be established before SVE or any cleanup technology is chosen.

Some RPMs caution that because SVE is implemented easily and initially may yield good results, it may be selected without adequate attention to setting achievable soil cleanup levels. In many cases, it may be difficult to reach cleanup levels close to background using SVE, because of unsuspected subsurface variability or other limiting factors.

Pilot Testing

Pre-design pilot testing is highly recommended to "fine tune the system" and identify potential problems before final design. Pilot tests may reveal contaminants or areas of contamination that were not identified previously, even at sites where comprehensive remedial investigations have been conducted. Currently, most pilot testing is conducted after the record of decision (ROD) has been signed, at the pre-design stage. Several RPMs believe that advancing the initial pilot test to the remedial investigation stage would be beneficial, and would accord better with the concepts of the Superfund Accelerated Cleanup Model (SACM) and the presumptive remedies initiatives.

Soil-column testing may be useful for SVE implemenation. This laboratory test uses representative soils from a prospective site to determine the minimum time to reduce the concentrations of VOCs in the soil matrix. It measures the number of soil pore volumes of air that must be passed through a column of contaminated soil to achieve the desired contaminant level. That number is divided by the number of soil pore volumes of air that can be extracted from the site in one year, yielding the number of years to clean up the site. The estimated cleanup time is an important factor in determining the cost and effectiveness of any cleanup technology. Column testing can underestimate the time for remediation if the site is heterogenious, and may overestimate the time for remediation due to faster air flow through the column. This can make it difficult to transfer the information from column tests to field situations.

Because the air pollution control system was not pilot-tested at one site at the same time as soil-air permeability, the VOC concentration in the discharge was higher than expected once the system began operations. Due to the higher concentrations, the system could operate at only 10 percent of its design flow capacity and still meet emission standards. Adequate pilot testing would have revealed this design flaw.

System Design

Models can be used during the design stage to predict a system's performance under varying conditions. There are many models available; Air 3D is a commonly used numeric air flow model. Many other models are available, but there is no consistent pattern of use for these models. Several RPMs also suggest modeling be used to troubleshoot an operating SVE system. For example, when actual results did not match the projections at one site, a model was used to locate the source of contaminant loss in the system.

Some models are conservative and may not reflect true site conditions (such as adjacent or overlying buildings or pavement). For example, one commonly used model assumes no cover, thereby overestimating the amount of infiltration that will percolate through the soil for a given rainfall, thus overestimating contaminant migration.

Several RPMs agreed that when models are used to design an SVE system, *the input parameters (air permeability; soil grain size) should reflect site-specific field conditions*. Otherwise, there is a potential for costly errors in the number and placement of wells. At one site, for example, a model programmed with default assumptions resulted in twice as many required wells than when the model was run using field measurements. This information should be collected initially in order to avoid delays later.

Properly designed pilot tests can provide data to optimize SVE system design. A pilot test at one site provided measurements to estimate the radius of influence of an extraction well and the preferential air flow paths. The setup included one vertical extraction well and several soil vapor probe nests. Measurements at some probes indicated that the vacuum was greater farther away from the extraction well than at other probes. These data were helpful in identifying preferential flow paths, which were used to design the layout of the extraction wells. Nests of probes also provided data on the vertical variability of the subsurface, which helped to determine the screening intervals for the extraction wells. Another RPM observed that in certain soils, a small radius of influence for vapor extraction requires the installation of several nested wells for SVE to perform adequately. These wells should be installed with permeable packing materials.

Several RPMs recommend horizontal extraction trenches for SVE at sites with a shallow water table. A larger area is cleaned if the air flow is primarily horizontal. Surface seals are used to avoid drawing air from the atmosphere into the trenches. The potential for vertical short-circuiting is increased, however, by the greater permeability in the trenches after disturbing the soil. "Short-circuiting" is a phenomenon where injection air or extracted gasses follow geological fractures or other highly permeable zones instead of dispersing evenly throughout the target zone.

Depending on the characteristics of the site, different materials can be used to seal the surface. A flexible membrane liner (FML) can be rolled over the site and easily removed when the SVE treatment is complete. FMLs are readily available in a variety of materials, with high density polyethylene (HDPE) being the most common. The life of FMLs can be very short if exposed to sunlight. Alternatives to a synthetic membrane are clay or bentonite, which can be applied in any thickness. Clay liners are not as easily removed as the FMLs, and both types are susceptible to damage from personnel and equipment. A third alternative—the most common at commercial or industrial sites—is the use of a concrete or asphalt cap. This alternative works well at sites that have been paved or will be paved (for example, a gas station).

Air inlet wells, in conjunction with the extraction wells, prevent stagnant zones and improve air flow. At one site, valves on the inlet wells were used to control the air drawn into the soil. At another site, the soil to be treated was not very thick and horizontal extraction wells were used instead of vertical extraction wells. A ground surface seal prevented short-circuiting by ambient air, and air inlet wells were placed in areas of potential stagnation. A surface seal was necessary to eliminate preferential flow paths. To prevent stagnation, one RPM recommend-ed that the SVE system not be shut down for extended periods when a surface seal is installed. Stagnation may lead to anaerobic conditions, which may promote reduction of saturated chlorinated hydrocarbons to vinyl chloride.

SVE systems designed "from the ground up" may be more expensive to design and construct than "packaged" systems. Using a "packaged" system or re-using a successful system may reduce design and construction costs.

It may be beneficial to use a single company, whenever possible, for both the design and operation of the SVE system, because close collaboration is necessary before and during pilot testing. If this is not possible, you might have the designer prepare performance specificiations for the SVE system. The construction company then would be responsible to design and implement the system to meet specific output parameters. Communication and coordination especially are important when the design engineers and the operation engineers work under different contracts. The design engineers must retain responsibility for the system until it is operating smoothly.

System Enhancements

Air sparging injects clean air into the saturated zone, increasing aerobic biodegradation and promoting the physical removal of organics by direct volatilization. Air sparging should be considered when there are high concentrations of VOCs in, or immediately below, the capillary fringe area. Experts caution that air sparging can induce migration of vapors into nearby confined spaces or may cause nearby groundwater monitoring wells to show low levels of dissolved contaminants because of the volatilization of gas immediately around the well. SVE is used sometimes in conjunction with air sparging to remove contaminants from the vadose zone.

At one site, where air sparging was used to supplement SVE, its effectiveness depended upon the depth at which the aquifer was sparged. The results suggested that sparging was effective in the upper few feet of the saturated zone. The test also indicated that spreading of contaminants was not an issue, since the sparged zone was shallow. Pulsed SVE operation was used in conjunction with some of the sparging activities.

Sparging has appeared to be most effective in the mid-range permeability soils. Air sparging is less effective in soils with very high or very low permeability for two reasons: (1) air tends to move around low permeability regions (clay lenses) and (2) sandy soils or sand lenses can short-circuit the sparge influence zone.

Experts have identified several developing technologies that show potential for improving the effectiveness of SVE. These include thermal enhancement, dual phase extraction, pneumatic or hydraulic fracturing for tight soils, and co-metabolic processes. Experiences with system enhancements can be found in the EPA publication, *Soil Vapor Extraction Enhancement Technology Resource Guide* (see bibliography).

Implementation and Air Emissions Control

Implementation

At one site, a "phased" approach was used to implement SVE as an interim measure. Wells were first placed in areas in which the highest levels of contaminants were expected. Additional wells were added over time as the system's behavior became known. This remedial approach also involved using a skid-mounted system that was moved to different extraction locations. This maximized removal by permitting operators to adjust to variations in contamination and hydrogeologic conditions.

RPMs described several actual and potential site-specific problems experienced during SVE implementation. The SVE system at one site was shut down for two weeks during the winter due to unexpected freezing of above-ground piping. The problem was alleviated by installing insulation and explosion-proof heating cable around the piping.

Also, for systems over landfills, heat from subsurface decomposition could increase the potential for landfill fires.

Air Emissions Control

Vapor contaminants from SVE wells or trenches are captured by air pollution control equipment. Granular activated carbon (GAC) units are often used to remove the VOCs. At sites where high removal rates are needed due to high concentration, high flow rate, or both, the carbon absorbers may become saturated quickly; this must be considered during design. Many SVE systems initially exhibit high VOC removal rates due to flushing and evaporation. The VOC removal rate then drops to a constant level in which the mass transfer of the VOC contamination is controlled by diffusion.

The estimated mass of contaminant will influence the size and type of air pollution control system selected for an SVE system. Loadings to the air treatment system are sometimes estimated incorrectly because original concentrations of contaminants are not sustained over time. On the other hand, gross underestimates of the loading rates of contaminants on air pollution control systems may lead to health and safety problems. Excess heat buildup occurs in the GAC if the rate of contaminant accumulation is too great. At one site, carbon adsorption was initially installed as an emission control measure, but, due to a greater contaminant load than originally expected, the frequency of carbon replacement was greater than expected. The carbon adsorption unit had to be replaced by catalytic oxidation. After removal of the sources and the immediately surrounding contaminated soils, VOC concentrations in the remaining soils dropped to lower levels, and the system was switched back to carbon adsorption.

The adsorption capacity of GAC depends on several factors, including the VOC type, concentration, vapor temperature, and relative humidity. Isotherms, which show the mass of contaminants that can be adsorbed per unit mass of carbon at specified temperature intervals, are available from carbon vendors and may be used to predict contaminant-specific adsorption capacity for a specific charcoal-based carbon. GAC generally has a high affinity for volatile molecules, such as lighter hydrocarbons or chlorinated compounds. However, some hydrocarbons such as isopentane have relatively low adsorption capacities.

The relative humidity of the incoming vapor stream may limit the effectiveness of contaminant removal by GAC. Water vapor will occupy adsorption sites preferentially, thereby decreasing the capacity of the carbon to remove contaminants from the air stream. The heat generated by pumping and by the compression of vapors often results in an exhaust stream of elevated temperature. The off-gases from some vacuum systems must be cooled for efficient treatment prior to entering the carbon adsorption units.

Systems using a resin to adsorb VOCs have been reported to attain removal efficiencies similar to GAC. This type of system can be rented, thereby lowering capital costs. Vendors of air pollution technologies that compete with carbon adsorption may provide free technical assistance to ensure that their systems remain operational throughout the cleanup.

For one system that uses a resin, the VOCs are purged from the medium by an inert gas, such as nitrogen, and the contaminant is recovered as a condensate. At one site where this type of system was used, a recycler picked up the condensate for reuse. Storage of the condensate, which in some cases may be concentrated petroleum product, may introduce additional design considerations. For example, air monitoring or explosion-proof facilities in the storage area may be required.

Other technologies that have been used for SVE off-gas treatment are condensation, catalytic oxidation, incineration, cavitation, photo-oxidation, ultraviolet (UV) oxidation, titanium dioxide (TiO_2), internal combustion engines, packed-bed thermal processors, biofilters, reduction processes, and direct discharge.

Monitoring Extracted Vapor

RPMs and experts have recommended monitoring at the emission source by an electron capture device, continuous flame ionization detector, or photo-ionization detector. Periodically, source monitoring should be supplemented with perimeter monitoring. Involving the state's air permit group early in the process will expedite the permit process.

Special attention should be paid to the concentrations of oxygen in the extracted vapor. High levels of oxygen may indicate short-circuiting of the intended air flow through the system. Conversely, high levels of carbon dioxide may stem from biological degradation, which can be exploited by design changes in the SVE system. However, one specialist has stated that in alkaline soils, it may be inadvisable to use changes in concentrations of CO_2 to estimate biodegradation. Alkaline soils can absorb CO_2, and as a result, CO_2 formed as a byproduct of biological activity would not be measured in the vapor extracted from alkaline soils.

One potential source of error in sampling extracted vapors occurs when the sampling syringes used upstream from the air treatment system are diluted with ambient air due to the vacuum inside the SVE. The air entering the syringe can be reduced by capping the syringe immediately after it is withdrawn from the SVE sampling port or by using a stopcock. An alternative is to bring the sample to ambient pressure with filtered air and account for the dilution; this should be done before the syringe is capped. Still another approach is to use canister sampling, which allows the sample to be maintained at the initial pressure until analyzed.

Overall Performance of the SVE System

The growing interest in this *in situ* technology is due in part to its demonstrated effectiveness for removing volatile compounds, relatively low cost, low space requirements, and the apparent "simplicity" of the system's design and operation. However, its success may be limited by overlying structures or heterogeneous soils. Even if the SVE system quickly attains cleanup goals, post-performance monitoring may be required in case the system needs to be reactivated.

At one site, the SVE treatment system reportedly performed better than expected, taking less than one year to achieve cleanup goals rather than the expected two to five years. The initial concentration of PCE in a sandy soil at the site was as high as 1,300 ppm. In less than one year, soil samples demonstrated that the state's interim cleanup standards were reached. The negotiations between the PRP and the state were simplified because the state's interim soil cleanup standards provided a clear endpoint.

The ease with which SVE systems can be installed and operated obscures the complexity of vapor behavior in site-specific subsurface settings. At one site, analyses of SVE air effluent, and analyses of groundwater from wells in the vicinity of the SVE system, indicated that the radius of influence increased over time. The system was designed to extract carbon tetrachloride from the soil. Initially, only carbon tetrachloride was detected in effluent from the SVE system. However, after the system had been in operation for a while, trichloroethane (TCA), dichloroethene (DCE), and trichloroethylene (TCE) were detected in air and groundwater samples. The closest source of TCA, DCE, or TCE was more than 2,000 feet away, well beyond the previously determined radius of influences for the wells. Although the reasons for this phenomenon are not known, one explanation is that the SVE operation desiccated the soil over time, creating a preferential pathway to the second contamination source.

At some sites, there are indications that SVE may be remediating groundwater indirectly. During the time the SVE has operated at one site, for example, the concentrations of contaminants detected in groundwater have dropped significantly. It is uncertain whether this reduction is linked to the SVE or attributable to natural attenuation. At another site, the extent of a contaminated groundwater plume was reduced during SVE operation. The SVE may have contributed to the removal of contaminants from the groundwater by enhancing both partitioning and biodegradation of contaminants.

SVE has not achieved cleanup goals at all sites. The use of other technologies, such as the excavation of hot spots or technological enhancements (see page 4), in conjunction with SVE, may assist in achieving the desired cleanup goals.

Shutting Down the SVE System

Cleanup is usually considered complete when sampling indicates that residual contaminant levels in the soil are at or below those required. Confirmatory soil borings and soil gas samples usually are required prior to closure. Additional criteria for determining when an SVE system should be shut down include: the cumulative amount of contaminant removed, extraction well vapor concentrations, and soil gas contaminant concentration and composition.

When setting cleanup standards for SVE sites, it should be noted that immobile, high-molecular-weight compounds will not be removed by SVE and will remain in the soil.

Measuring extracted vapor concentrations gives an idea of the effectiveness of the system; however, a decrease is not necessarily strong evidence that soil concentrations have decreased. Decreases in vapor concentrations can be attributed also to such other phenomena as water table upwelling and short-circuiting. Monitoring extraction well vapor composition and concentration gives more insight into the effectiveness of the system. If the total vapor concentration decreases without a change in composition, then the decrease is most likely due to one of the phenomena listed above. If the decrease in concentration is accompanied by a shift to less volatile compounds, then there is probably a change in the residual contaminant concentration.

It is sometimes difficult to persuade state agencies to commit to shutting off SVE systems once acceptable levels of cleanup have been reached, because without long-term monitoring it is difficult to determine whether cleanup levels have been achieved permanently. Experts recommend that VOC measurements in the soil matrix be taken again after soil gas measurements have indicated that the SVE system has reached steady-state. If later measurements show that the target risk levels have not been achieved, it may be necessary to reconfigure the system or enhance it with other technologies such as biodegradation or capping.

The SVE system at another site was shut down when VOC levels in the soil gas met the air emission standards, and the groundwater concentrations met the maximum contaminant levels established for drinking water. However, after several months, the concentrations of contaminants rose above standards and the system was reactivated. Such a circumstance may occur because contaminants can diffuse slowly from less permeable soils and interact with soil gas and groundwater.

The operating life of one SVE system was based on its efficiency of removing contaminants relative to groundwater pumping and treatment. An analysis of this SVE system revealed that it was more cost-effective than pump-and-treat systems if it could remove more than 0.001 pounds per hour of the target contaminant. Therefore the decision was made to operate the SVE system until it could no longer exceed this rate of contaminant removal. When this occurred, the system was shut down.

At one site, monitoring of soil vapor indicated that the constant levels of removal of contaminant mass had been met, although pockets of tightly bound contaminant remained in the vadose zone and groundwater. Eventually the state consented to shut down the system, but required that two extraction wells be left in place as a contingency.

Community Involvement

RPMs suggest that cleanup levels should be defined as “goals” for the community early in the process. The community needs to be told that the “law of diminishing returns” may ultimately limit the amount of contamination that can be removed. As more and more contamination is removed from the soil, and as the remaining amounts of concentration of contaminants are lowered, the cost and time necessary to remove additional contaminants increases. For example, the time or cost to remove the last 10 percent of the original mass of contaminants could equal that required to remove the initial 80 to 90 percent of contaminants.

Community involvement at one SVE site was particularly active and innovative. At this site Regional staff provided a hazardous waste health and safety training course to anyone in the community who was interested. This training was attended by approximately 30 people. People from the community were also trained and hired to operate and maintain the SVE system and to collect environmental samples. EPA also established an analytical laboratory in the town for analysis of samples collected at the site. The community involvement effort associated with this site resulted in local acceptance of the system.

While designing SVE pilot studies or SVE systems, care must be taken to determine the effect of the SVE systems on the surrounding communities. For instance, at one site located in a residential area, noise from the blower and its effect on the surrounding residences had to be taken into consideration during the SVE pilot study. To address community concerns at another residential site, the system’s air stripper was housed in a colonial-style building that blended in with the local architecture.

Selected Bibliograpy

Innovative Site Remediation Technology, Vacuum Vapor Extraction
U.S. EPA, OSWER, Technology Innovation Office, April 1995
EPA/542-B-94-002, 222 pp.

This monograph is one of a series of eight on innovative site and waste remediation technologies. It is the cumulation of a multi-organizational effort involving over 100 experts over a two-year period. It provides experienced, practical, professional guidance on the application of this technology.

Abstracts of Remediation Case Studies
Prepared by member Agencies of the Federal Remediation Treatment Technologies Roundtable: U.S. EPA, DOD, DOE, DOI, NASA, TVA, USCG, March 1995
NTIS/PB95/182903,101 pp.

This report is a collection of abstracts summarizing 37 case studies of site remediation projects prepared by federal agencies. The case studies document the results and lessons learned from early technology applications. They help establish benchmark data on cost and performance, which can lead to greater confidence in the selection and use of cleanup technologies.

Soil Vapor Extraction and Bioventing
U.S. Army Corps of Engineers, November 1995. Engineering Manual EM 1110-1-4001.

This manual provides practical guidance for the design and operation of soil vapor extraction and bioventing systems. The manual describes current practices for site characterization, system design, and system startup and operations.

Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites with Volatile Organic Compounds in Soils
Directive 9355.0-48FS, September 1993.
EPA 540-F-93-048, PB 93-963346, 26 pp.

Presumptive remedies are preferred technologies for common categories of sites, based on historical patterns of remedy selection and EPA's scientific and engineering evaluation of performance data. Soil vapor extraction (SVE), thermal desorption, and incineration are the presumptive remedies for Superfund sites with VOC contaminated soil assuming the site characteristics meet certain criteria.

Soil Vapor Extraction Enhancement Technology Resource Guide: Air Sparging, Bioventing, Fracturing, Thermal Enhancements
U.S. EPA, OSWER, Technology Innovation Office, October 1995.
EPA/542-B-95-003, 35 pp.

This reports contains an extensive bibliography of EPA and other agencies' information resources on air sparging, bioventing, fracturing, and thermal enhancements for SVE.

Evaluation for Unsaturated/Vadose Zone Models for Superfund Sites
U.S. EPA, ORD, Robert S. Kerr Environmental Research Laboratory
Ada, OK, March 1994
EPA/600/R-93/184,188 pp.

This manual evaluates several transport models for unsaturated soils and quantifies the sensitivity and uncertainty of model outputs to changes in input parameters.

A Citizen's Guide to Soil Vapor Extraction and Air Sparging
U.S. EPA, OSWER, Technology Innovation Office, Washington, DC, March 1996
EPA/542-F-96-008, 4 pp.

This fact sheet presents in lay terms the technologies, processes, and limitations of soil vapor extraction (SVE) remediation. It may be a very useful handout to communities associated with possible SVE systems.

Soil Vapor Extraction (SVE) Treatment Technology Resource Guide
U.S. EPA, OSWER, Technology Innovation Office, Washington, DC, September 1994
EPA/542/B-94/007, 27 pp.

This report lists an extensive bibliography of EPA and other agencies' information resources focusing solely on soil vapor extraction.

Air Sparging for Site Remediation
Hinchee, R.E., International Symposium on *In Situ* and On Site Bioreclamation, 2nd Ed: 1993
San Diego, CA, Lewis Publishing. 1994, 142 pp.

This book is a collection of papers focusing on air sparging as a useful *in situ* tool for hydrocarbon contamination.

Engineering Forum Issue: Considerations in Deciding to Treat Contaminated Unsaturated Soils *in Situ*
U.S. EPA, OSWER, December 1993
EPA/540/S-94/500, 27 pp.

This issue paper assists in deciding if *in situ* treatment of contaminated soil is a potentially feasible remedial alternative. It also presents reviews of *in situ* technologies. The document contains tables of generic and technology specific critical factors and conditions for the use of *in situ* treatment technologies and addresses soil vapor extraction.

Engineering Bulletin: Technology Preselection Data Requirements
U.S. EPA, OSWER, Office of Emergency and Remedial Response, Washington, DC, October 1992
EPA/540/S-92/009, 9 pp.

This bulletin lists soil, water, and contaminant data elements needed to evaluate the potential applicability of technologies for treating contaminated soil and water. It emphasizes the physical, chemical, soil, and water characteristics for which observations and measurements should be compiled.

Technology Assessment of Soil Vapor Extraction and Air Sparging
U.S. EPA, ORD, Risk Reduction Engineering Laboratory, Cincinnati, OH, September 1992
EPA/600/R-92/173

This document summarizes a substantial body of available information that describes the effectiveness and characteristics of air sparging systems and case studies of practical air sparging applications.

Air/Superfund National Technical Guidance Study Series: Estimation of Air Impacts for Soil Vapor Extraction (SVE) Systems
U.S. EPA, OAR, Office of Air Quality Planning and Standards, RTP, NC, January 1992
EPA/450/1-92/001, 91 pp.

This report provides procedures for estimating the ambient air concentrations associated with soil vapor extraction (SVE). Procedures are given to evaluate the effect of the concentration of the contaminants in the soil-gas and the extraction rate on the emission rates and on the ambient air concentrations at selected distances from the SVE system.

In Situ Soil Vapor Extraction Treatment, Engineering Bulletin
U.S. EPA, OSWER, Office of Emergency and Remedial Response, Washington, DC, May 1991
EPA/540/2-91/006, 12 pp.

This bulletin provides information on the technology applicability, the limitations of the technology, the technology description, the types of residuals produced, the site requirements, the latest performance data, the status of the technology, and sources for further information.

Soil Vapor Extraction Technology: Reference Handbook, Final Report
U.S. EPA, ORD, Risk Reduction Engineering Laboratory, Cincinnati, OH, February 1991
EPA/540/2-91/003, 316 pp.

This report discusses the basic science of the subsurface environmental and subsurface monitoring, emission control, and costs. The report also discusses state-of-the-art technology, the best approach to optimize systems application, and process efficiency and limitations.

How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites
U.S. EPA, OSWER, May 1995
EPA 510-B-95-007

This manual provides technical guidance to state and local regulators in evaluating corrective action plans for remediating underground storage tank releases (and other hazardous waste sites) using “alternative technologies.” The manual describes eight cleanup technologies, including SVE and air sparging, and provides engineering related considerations and parameters for evaluating the feasibility of a given technology.

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Soil Vapor Extraction Sites

Soil vapor extraction is the remedy for VOCs in soils at the sites listed below. At some sites, the treatment is already complete. Some sites are currently operating, and some are in the design phase. This list has been adapted from the *Innovative Treatment Technologies: Annual Status Report (Sixth Edition)*, September 1994 (EPA 542-R-94-005). This list is not comprehensive.

Hamilton-Standard Division, CT
Kellogg-Deering Well Field, CT
Linemaster Switch Corporation, CT
United Technologies Corp., CT
Groveland Wells, MA
Industri-Plex, MA
Silresim, MA
Silresim, MA
Wells G&H OU 1, MA
Union Chemical Co., ME
Mottolo Pig Farm, NH
South Municipal Water Supply Well, NH
Tibbetts Road, NH
Tinkham Garage, NH
Peterson/Puritan Inc., RI
Picillo Farm Site, RI
Stamina Mills, RI
A. O. Polymer, NJ
FAA Technical Center, NJ
Garden State Cleaners, NJ
Naval Air Engineering Center, NJ
South Jersey Clothing, NJ
Swope Oil & Chem. Co., NJ
Applied Environmental Services, NY
Circuitron Corporation, NY
Genzale Plating Company, NY
Mettiace Petrochemicals Company, Inc., NY
Pasley Solvents and Chemicals, Inc., NY
Sinclair Refinery, NY
SMS Instruments, NY
Vestal Water Supply, NY
Janssen Inc., PR
Upjohn Manufacturing Co., PR
Delaware Sand and Gravel, DE
Bendix, PA
Cryochem, PA
Letterkenny Army Depot, PA
Lord-Shope Landfill, PA
Raymark, PA
Saergertown Industrial Area Site, PA
Tyson’s Dump, PA
Arrowhead Associates/Scovill, VA
U.S. Defense General Supply, VA
Hollingsworth Solderless, FL
Robins AFB, GA
ABC Dry Cleaners, NC
Charles Macon Lagoon, NC
JADCO-Hughes, NC
USMC Camp Lejeune Military Base, NC
Medley Farm, SC
SCRDI Bluff Road, SC
Carrier Air Conditioning, TN
Acme Solvent Reclaiming, Inc., IL
American Chemical Services, IN
Enviro. Conservation and Chemical, IN
Fisher Calo Chem, IN
Main Street Well Field, IN
MIDCO, IN
Seymour Recycling, IN
Wayne Waste Reclaimation, IN
Chem Central, MI
Clare Water Supply, MI
Electro-Voice, MI
Kysor of Cadillac Industrial, MI
Peerless Plating, MI
Springfield Township Dump, MI
Sturgis Municipal Well Field, MI
ThermoChem, Inc., MI
Verona Well Field, MI
Long Prairie Groundwater Contamination, MN
Miami County Incinerator, OH
Pristine, Inc., OH
Skinner Landfill, OH
Zanesville Well Field, OH
City Disposal Corporation Landfill, WI
Hagen Farm Source Control, WI
Muskego Sanitary Landfill, WI
Wausau Groundwater Contamination, WI
Prewitt Abandoned Refinery, NM
Petro-Chemical Systems, Inc., TX
Chemplex, IA
McGraw Edision, IA
Coleman Operable Unit, KS
Cleburn Street, NE
Hastings GW Contamination, NE
Lindsay Manufacturing, NE

Waverly Groundwater Contamination, NE
Chemical Sales Company, CO
Martin Marietta, CO
Rocky Flats, CO
Rocky Mountain Arsenal, CO
Sand Creek Industrial, CO
Utah Power and Light/American Barrel, UT
Hassayampa Landfill, AZ
Motorola 52nd Street, AZ
Phoenix-Goodyear Airport Area, AZ
Tucson International Airport, AZ
Williams AFB, AZ
Barstow Marine Corps Logistics Base, CA
Fairchild Semiconductor, CA
Hexcel, CA
IBM, CA
Intel, CA
Intersil/Siemens, CA
Lawrence Livermore Natl. Laboratory, CA
Lorentz Barrel and Drum, CA
Moffett Air Field, CA
Monolithic Memories/AMD, CA
National Semiconductor, CA
Pacific Coast Pipeline, CA
Purity Oil Sales, CA
Raytheon, CA
Signetics, CA
Solvent Service, CA
Spectra Physics, CA
Van Waters and Rogers, CA
Watkins-Johnson, CA
Eielson Air Force Base, AK
Commencement Bay, WA
Fairchild AFB, WA
Fort Lewis Military Res., WA
Hanford, WA
Pondrers Corner (Lakewood), WA