United States Environmental Protection Agency | Office of Emergency and Remedial Response Washington, DC 20460 | Office of Research and Development Cincinnati, OH 45268

Superfund | EPA/540/2-91/005 | May 1991

EPA

Engineering Bulletin
In Situ Steam Extraction Treatment

Purpose

Section 121(b) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) mandates the Environmental Protection Agency (EPA) to select remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" and to prefer remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants and contaminants as a principal element." The Engineering Bulletins are a series of documents that summarize the latest information available on selected treatment and site remediation technologies and related issues. They provide summaries of and references for the latest information to help remedial project managers, on-scene coordinators, contractors, and other site cleanup managers understand the type of data and site characteristics needed to evaluate a technology for potential applicability to their Superfund or other hazardous waste site. Those documents that describe individual treatment technologies focus on remedial investigation scoping needs. Addenda will be issued periodically to update the original bulletins.

Abstract

In situ steam extraction removes volatile and semivolatile hazardous contaminants from soil and groundwater without excavation of the hazardous waste. Waste constituents are removed in situ by the technology and are not actually treated. The use of steam enhances the stripping of volatile contaminants from soil and can be used to displace contaminated groundwater under some conditions. The resultant condensed liquid contaminants can be recycled or treated prior to disposal. The steam extraction process is applicable to organic wastes but has not been used for removing insoluble inorganics and metals. Steam is injected into the ground to raise the soil temperature and drive off volatile contaminants. Alternatively, steam can be injected to form a displacement front by steam condensation to displace groundwater. The contaminated liquid and steam condensate are then collected for further treatment.

In situ steam extraction is a developing technology that has had limited use in the United States. In situ steam extraction is currently being considered as a component of the remedy for only one Superfund site, the San Fernando Valley (Area 1), California site [1]* [2]. However, a limited number of commercial-scale in situ steam extraction systems are in operation. Two types of systems are discussed in this document: the mobile system and the stationary system. The mobile system consists of a unit that volatilizes contaminants in small areas in a sequential manner by injecting steam and hot air through rotating cutter blades that pass through the contaminated medium. The stationary system uses steam injection as a means to volatilize and displace contaminants from the undisturbed subsurface. Each system has specific applications; however, the lowest cost alternative will be determined by site-specific considerations. This bulletin provides information on the technology applicability, limitations, a description of the technology, types of residuals produced, site requirements, the latest performance data, the status of the technology, and sources for further information.

Technology Applicability

In situ steam extraction has been shown to be effective in treating soil and groundwater containing such contaminants as volatile organic compounds (VOCs) including halogenated solvents and petroleum wastes. The technology has been shown to be effective for extracting soluble inorganics (i.e., acids, bases, salts, heavy metals) on a laboratory scale [3]. The presence of semivolatile organic compounds (SVOCs) does not interfere with extraction of the VOCs [4, p. 12]. This process has been shown to be applicable for the removal of VOCs including chlorinated organic solvents [4, p. 9] [5, p. i], gasoline [6, p. 1265], and diesel [7, p. 506]. It has been shown to be particularly effective on alkanes and alkane-based alcohols such as octanol and butanol [8].

Steam extraction applies to less volatile compounds than ambient vacuum extraction systems. By increasing the temperature from initial conditions to the steam temperature, the vapor pressures of most contaminants will increase, causing them to become more volatile. Semivolatile components can volatilize at significant rates only if the temperature is increased [3, p. 3]. Steam extraction also may be used to remove low boiling point VOCs more efficiently.

* [reference number, page number]

Table 1
RCRA Codes for Wastes Applicable to Treatment by In Situ Steam Extraction

Spent Halogenated Solvents used in Degreasing	F001
Spent Halogenated Solvents	F002
Spent Non-Halogenated Solvents	F003
Spent Non-Halogenated Solvents	F004
Spent Non-Halogenated Solvents	F005

Table 2
Effectiveness of In Situ Steam Extraction on General Contaminant Groups for Soil and Groundwater

	Contaminant Groups	*Effectiveness*		
		Mobile System		*Stationary System*
		Soil	*Groundwater*	*Soil/ Groundwater*
Organic	Halogenated volatiles	■	▼	■
	Halogenated semivolatiles	▼	▼	▼
	Nonhalogenated volatiles	■	▼	■
	Nonhalogenated semivolatiles	▼	▼	▼
	PCBs	❑	❑	▼
	Pesticides	❑	❑	▼
	Dioxins/Furans	❑	❑	▼
	Organic cyanides	❑	❑	▼
	Organic corrosives	❑	❑	▼
Inorganic	Volatile metals	❑	❑	▼
	Nonvolatile metals	❑	❑	▼
	Asbestos	❑	❑	❑
	Radioactive materials	❑	❑	▼
	Inorganic corrosives	❑	❑	▼
	Inorganic cyanides	❑	❑	▼
Reactive	Oxidizers	❑	❑	▼
	Reducers	❑	❑	▼

■ Demonstrated Effectiveness: Successful treatability test at some scale completed
▼ Potential Effectiveness: Expert opinion that technology will work
❑ No Expected Effectiveness: Expert opinion that technology will not work

Table 1 lists specific Resource Conservation and Recovery Act (RCRA) wastes that are applicable to treatment by this technology. The effectiveness of the two steam extraction systems (mobile and stationary) on general contaminant groups for soil and groundwater is shown in Table 2. Examples of constituents within contaminant groups are provided in Reference 9, " Technology Screening Guide for Treatment of CERCLA Soils and Sludges." Table 2 is based on the current available information or professional judgment where no information was available. The proven effectiveness of the technology for a particular site or waste does not ensure that it will be effective at all sites or that the treatment efficiencies achieved will be acceptable at all sites. For the ratings used for this table, demonstrated effectiveness means that, based on treatability studies at some scale, the technology was effective for that particular contaminant and matrix. The ratings of potential effectiveness or no expected effectiveness are based upon expert judgment. Where potential effectiveness is indicated, the technology is believed capable of successfully treating the contaminant group in a particular matrix. When the technology is not applicable or will probably not work for a particular combination of contaminant group and matrix, a no-expected-effectiveness rating is given. The table shows that the stationary system shows potential effectiveness for inorganic and reactive contaminants. This is only true if the compounds are soluble.

Limitations

Soil with high silt and clay content may become malleable and unstable when wet, potentially causing problems with support and mobility of the mobile steam extraction system. Remediation of low permeability soil (high clay content) requires longer treatment times [4, p. 8]. The soil must be penetrable by the augers and free of underground piping, wiring, tanks, and drums. Materials of this type must be relocated before treatment can commence. Surface and subsurface obstacles greater than 12 inches in diameter (e.g., rocks, concrete, wooden piles, trash, and metal) must be removed to avoid damage to the equipment. Substantial amounts of subsurface obstacles may preclude the use of a mobile system. A climate temperature range of 20–100°F is desirable for best operation of the mobile system [4, p. 18].

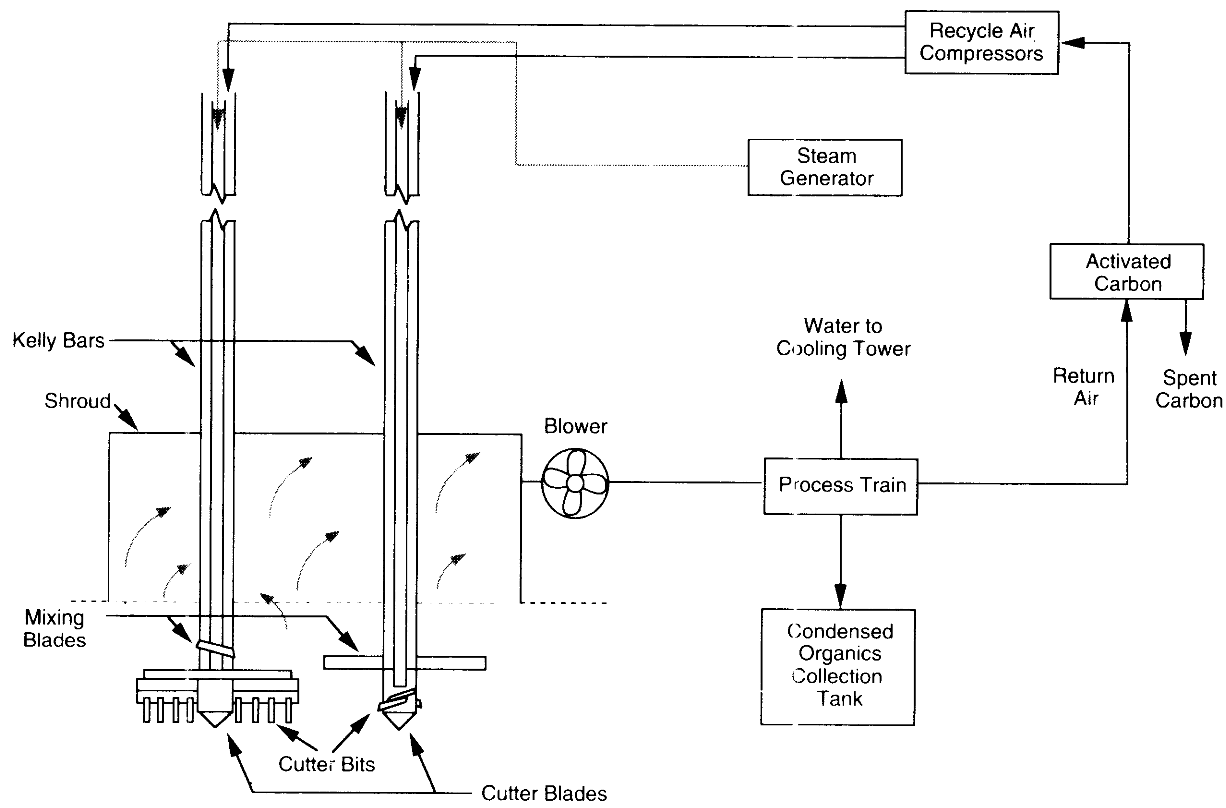
Mobile steam extraction systems can treat large contaminated areas but are limited by the depth of treatment. One system that has been evaluated can treat to a depth of 30 feet.

To be effective, the stationary steam extraction system requires a site with predominately medium- to high-permeability soil. Sites with homogeneous physical soil conditions are more amenable to the system. If impermeable lenses of contaminated soil exist, the stationary system may not remediate these areas to desired cleanup levels [5, p. 19]. However, a combination of steam injection followed by vacuum extraction (drying) may be effective on sites with heterogeneous soil conditions [10]. Steam extraction may be effective for remediation of contaminated groundwater near the source of contamination [5, p. 14] [10].

There may be residual soil contamination after application of in situ steam extraction. Study of a mobile system showed the average removal efficiency for volatile contaminants was 85%; 15% of the volatile compound contamination remained in the soil [4, p. 4]. If other organic or inorganic contamination exists, the cleaned soil may need subsequent treatment by some other technique (i.e., stabilization).

In situ steam extraction may not remove SVOCs and inorganics effectively. The operational costs of steam extraction are greater than ambient vacuum extraction, but may be offset by higher recovery and/or reduction in time required to remediate the site due to more efficient removal of contaminants.

Figure 1
Schematic of the Mobile Steam Extraction System



In situ steam extraction requires boilers to generate steam and a sophisticated process to capture and treat extracted steam and contaminants. Because the mobile system is mechanically complex its equipment may fail and shut down frequently; however, mechanical problems may be corrected fairly quickly. Equipment failure and shutdown are less frequent for the stationary system.

The increase in soil temperature may adversely affect other soil properties such as microbial populations, although some microbial populations can withstand soil temperatures up to 140°F.

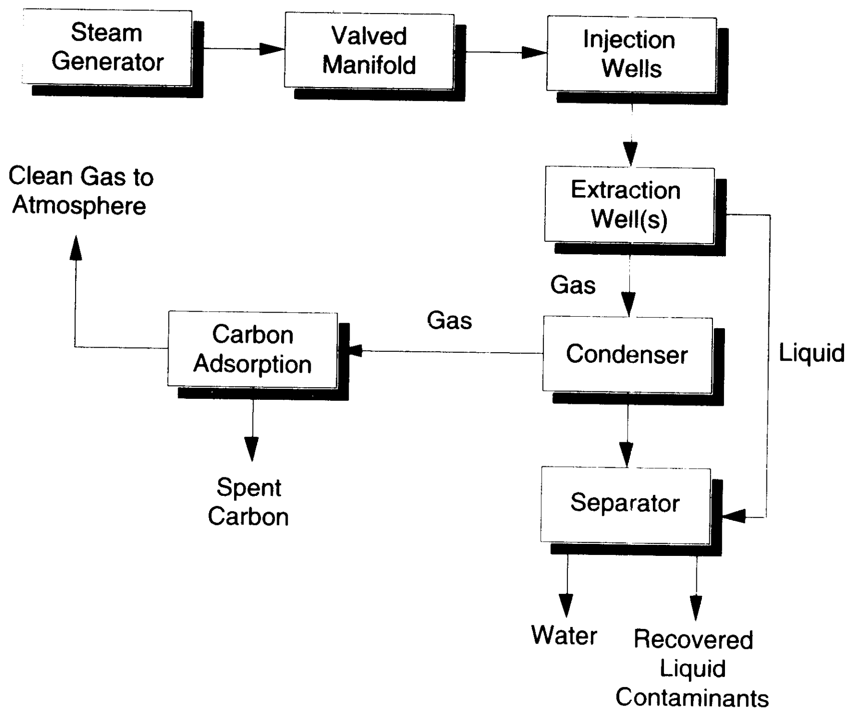
Technology Description

Figure 1 is a general schematic of a mobile steam extraction system [4, p. 48]. A process tower supports and controls a pair of cutter blades which bore vertically through the soil. The cutter blades are rotated synchronously in opposite directions during the treatment process to break up the soil and ensure through-flow of gases. Steam (at 400°F) and compressed air (at 275°F) are piped to nozzles located on the cutter blades. Heat from the injected steam and hot air volatilizes the organics. A steel shroud covers the area of soil undergoing treatment. Suction produced by the blower keeps the area underneath the shroud at a vacuum to pull gases from the soil and to protect against leakage to the outside environment. The offgases are pulled by the blower from the shroud to the treatment train, where water and organics are removed by condensation in coolers. The airstream is then treated by carbon adsorption, compressed, and returned to the soil being treated. Water is removed from the liquid stream with a gravity separator followed by batch distillation and carbon adsorption and is then recycled to a cooling tower. The condensed organics are collected and held for removal and transportation.

Mobile systems treat small areas of contamination until an entire site is remediated. The action of the cutter blades enables the process to treat low-permeability zones (high clay content) by breaking up the soil. Current systems treat blocks of soil measuring 7'4" x 4' by up to 30' deep.

Figure 2 is a schematic of a stationary steam extraction system [5, p. 9]. High-quality steam is delivered through individual valves and flow meters to the injection wells from the manifold. Gases and liquids are removed from the soil through the recovery wells. Gases flow through a condenser and into a separation tank where water and condensed gases are separated from the contaminant phase. Liquid organics are pumped from the separation tank through a meter and into a holding tank. The water may require treatment by carbon adsorption or another process to remove remaining contaminants. Noncondensible gases are passed through activated carbon tanks where contaminants are adsorbed before the cleaned air is vented to the atmosphere. A vacuum pump maintains the subatmospheric pressure on the recovery well and drives the flow of recovered gases. Contaminated liquids are pumped out of the recovery well to a wastewater tank.

Figure 2
Process Schematic of the Stationary Steam Extraction System



Process Residuals

At the conclusion of both processes, the contaminants are recovered as condensed organics in the produced water and on the spent carbon. Residual contamination will also remain in the soil. The recovered contaminants are temporarily stored on site and may require analysis to determine the need for further treatment before recycling, reuse, or disposal.

Separated, cleaned water is used as cooling tower makeup water in the mobile system. Also in this system, cleaned gas is heated and returned as hot air to the soil. Separated water from the stationary system must be treated to remove residual contaminants before disposal or reuse. The cleaned gas from this system is vented to the atmosphere. Both systems produce contaminated granular activated carbon from the gas cleaning. The carbon must be regenerated or disposed. There may be minor fugitive emissions of VOCs from the soil during treatment by the steam stripping systems and from the gas-phase carbon beds [4, p. 2].

Site Requirements

Power and telephone lines or other overhead obstacles must be removed or rerouted to avoid conflict with the 30-foot treatment tower on the mobile steam extraction system. Access roads must be available for transporting the mobile system. Sufficient land area must be available around the identified treatment zone to maneuver the unit and to place support equipment and trailers. The area to be treated by the mobile steam extraction system must be capable of supporting the treatment rig so that it does not sink or tip. The ground must be flat and gradable to less than 1% slope. A minimum treatment area of approximately 0.5 acre (20,000 ft^2) is necessary for economical use of the mobile system. Rectangular shaped treatment areas are most efficient. The mobile system requires a water supply of at least 8 to 10 gpm at 30 psig. Power for the process can be provided by on-board diesel generators [4, p. 18].

Boilers that generate steam for the stationary steam extraction system use no. 2 fuel oil or other hydrocarbon fuels. Water and electricity must be available at the site. The site must have sufficient room for a drilling rig to install the injection and extraction wells and for steam generation and waste treatment equipment to be set up, as well as room for support equipment and trailers.

Contaminated soils or waste materials are hazardous and their handling requires that a site safety plan be developed to provide for personnel protection and special handling measures. Storage should be provided to hold the process product streams until they have been tested to determine their acceptability for disposal, reuse, or release. Depending on the site, a method to store waste that has been prepared for treatment may be necessary. Storage capacity will depend on waste volume.

Onsite analytical equipment capable of determining site-specific organic compounds for performance assessment make the operation more efficient and provide better information for process control.

Performance Data

Toxic Treatments (USA) Inc. used a prototype of its mobile system to remediate a site in Los Angeles, California. The site soil had been contaminated by diesel and gasoline fuel

Table 3
Total Petroleum Hydrocarbons Removed by Toxic Treatments (USA) Inc. at Los Angeles, CA*

Calculated Value	*Initial (mg/kg)*	*Final (mg/kg)*	*Percent Removal*
Mean	2222	191	91

* This information is from vendor-published literature [7]; therefore, quality assurance has not been evaluated.

from underground storage tanks. For this application, the steam stripping was augmented with potassium permanganate to promote oxidation of hydrocarbons in the highly contaminated zones [7, p. 506]. Table 3 summarizes the results of the treatment by steam stripping. The level of petroleum hydrocarbons was reduced overall by an average of 91%. The mobile system was reported to have effectively reduced the level of petroleum hydrocarbon compounds found in the soil at a wide range of concentrations. However, the system's ability to remove the higher molecular weight, less volatile components of the diesel fuel was limited.

Under the Superfund Innovative Technology Evaluation (SITE) program, Toxic Treatments demonstrated an average VOC removal rate of 85 percent for a test area of 12 soil blocks [4, p. 10] as shown in Table 4. The average VOC post-treatment concentration was 71 ppm; the cleanup level for the site was 100 ppm. The primary VOCs were trichloroethene, tetrachloroethene, and chlorobenzene. The test achieved a treatment rate of 3 cu. yds./hr. in soils having high clay content and containing some high-boiling-point VOCs. Toxic Treatments obtained similar results in tests conducted throughout the site; baseline testing demonstrated an average post-treatment concentration of 61 ppm. The mobile technology also demonstrated the ability to diminish the level of SVOCs by approximately 50%, as shown in Table 5, although the fate of these SVOCs could not be determined [4, p. 45]. These tests were conducted on contamination in the unsaturated zone. A follow-up test was conducted on six soil blocks where treatment extended into the saturated zone. Pre-treatment data from the vendor indicated significant VOC contamination in this area. Post-treatment results showed that the average level of VOC contamination in the unsaturated zone was reduced to 53 ppm. Ketones (specifically acetone, 2-methyl-4-pentanone, and 2-butanone) were found to be the primary contaminants in the post-treatment soil. Data from the vendor indicated that similar reduction of VOCs occurred in the saturated zone.

The stationary steam extraction system using steam injection alone decreased soil contaminant concentrations by 90 percent in a recent pilot study [5]. High concentrations of individual contaminants were found in a low permeability zone by use of temperature logs. The residual high contaminant concentrations are thought to have been caused by: 1) retention of highly contaminated steam condensate found ahead of the condensation front in the dry, low-permeability zones and 2) the decreased evaporation rate of the high-boiling-point compounds due to the high water content in the low permeability zones [5, p. 19]. This issue is currently under study at the University of California, Berkeley [10]. Experimental testing has shown that a combination of steam

Table 4
Demonstration Test Results for Volatiles Removed by Toxic Treatments (USA) Inc. [4]

	12-Block Test Area		
Block Number	*Pre-Treatment (µg/g)*	*Post-Treatment (µg/g)*	*Percent Removal*
A-25-e	54	14	73
A-26-e	28	12	56
A-27-e	642	29	96
A-28-e	444	34	92
A-29-e	850	82	90
A-30-e	421	145	65
A-31-e	788*	61	92
A-32-e	479	64	87
A-33-e	1133	104	91
A-34-e	431	196	54
A-35-e	283	60	79
A-36-e	153	56	64

* Only analyses from two of the three sample cores taken were available.

Table 5
Demonstration Test Results for Semivolatiles Removed by Toxic Treatments (USA) Inc. [4]

	12-Block Test Area		
Block Number	*Pre-Treatment (µg/g)*	*Post-Treatment (µg/g)*	*Percent Removal*
A-25-e	595	82	86
A-26-e	1117	172	85
A-27-e	1403	439	69
A-28-e	1040	576	45
A-29-e	1310	726	45
A-30-e	1073	818	24
A-31-e	781	610	22
A-32-e	994	49	95
A-33-e	896	763	15
A-34-e	698	163	77
A-35-e	577	192	67
A-36-e	336	314	7

injection and vacuum extraction can effectively remove volatile contaminants from a heterogeneous soil type [10]. Steam injection followed by vacuum extraction produces an effective drying mechanism. The process achieves greater contaminant removals by enhancing the vapor flow from low- to high-permeability regions.

Performance data may be forthcoming from full-scale stationary system steam extraction projects being conducted by Solvent Service, Inc. and Hydro-Fluent, Inc. Data from laboratory-scale studies are also available [6] [3].

RCRA Land Disposal Restrictions (LDRs) that require treatment of wastes to best demonstrated available technology (BDAT) levels prior to land disposal may sometimes be determined to be applicable or relevant and appropriate requirements for CERCLA response actions. The in situ steam extraction technology produces liquid contaminants which may be recyclable or may require treatment to meet treatment levels set by BDAT. A common approach to treating liquid waste may be to use other treatment techniques in series with in situ steam extraction.

Technology Status

In situ extraction is being considered as a component of the selected remedy for the San Fernando Valley (Area 1) site in Burbank, California. The Area 1 site consists of an aquifer contaminated with VOCs, including TCE and PCE [1, p.145]. Toxic Treatments' mobile steam extraction technology (Detoxifier™) was used in 1986 to remediate 4,700 cu. yds. of soil contaminated with diesel fuel at the Pacific Commerce Center site in Los Angeles, California [7, p. 506].

In 1987, Toxic Treatments' mobile steam extraction system was selected as the remedial action to clean up approximately 8,700 cu. yds. of soil contaminated with VOCs and SVOCs at the GATX Annex Terminal site in San Pedro, California [11, p. I-1]. Treatability testing of the technology at the site has been underway to validate its performance prior to full site remediation. This system also has been evaluated under the SITE program at the site in San Pedro, California. Toxic Treatments expects to have a second generation Detoxifier™ available soon, which will be capable of operating on grades up to 5 percent.

For the mobile technology, the most significant factor influencing cost is the time of treatment or treatment rate. Treatment rate is influenced primarily by the soil type (soils with higher clay content require longer treatment times), the waste type, and the on-line efficiency. Cost estimates for this technology are strongly dependent on the treatment rate and range. A SITE demo indicated costs of $111-317/cu. yd. (for 10 and 3 cu. yd. treatment rates, respectively). These costs are based on a 70% on-line efficiency [4, p. 28].

Solvent Service, Inc. is using and testing its first full-scale stationary Steam Injection Vapor Extraction (SIVE) system at its San Jose, California, facility for remediation to a depth of 20 feet of up to 41,000 cu. yds. of soil contaminated with numerous organic solvents [5, p. 3] [10]. Solvent Service hopes to make the SIVE system available for other applications in the future. The system consists of injection and extraction wells and a gas and liquid treatment process. Equipment for steam generation and extraction and contaminated gas/liquid treatment are trailer mounted.

Hydro-Fluent, Inc. is designing and constructing its first full-scale stationary steam extraction system to be used in Huntington Beach, California for recovery of 135,000 gallons of diesel fuel in soil to a depth of 40 feet at the Rainbow Disposal, Nichols Avenue site [12]. Bench and pilot-scale studies have been conducted.

For the stationary steam extraction system, the most significant factor influencing cost is the number of wells required per unit area, which is related to the depth of contamination and soil permeability. Shallow contamination requires lower operating pressures to prevent soil fracturing, and wells are placed closer together. Deeper contamination allows higher operating pressures and greater well spacing; therefore, fewer wells and lower capital cost. Cost estimates for this technology range from about $50–300/cu. yd., depending on site characteristics [10].

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Acknowledgments

This bulletin was prepared for the U.S. Environmental Protection Agency, Office of Research and Development (ORD), Risk Reduction Engineering Laboratory (RREL), Cincinnati, Ohio, by Science Applications International Corporation (SAIC) under contract No. 68-C8-0062. Mr. Eugene Harris served as the EPA Technical Project Monitor. Mr. Gary Baker was SAIC's Work Assignment Manager. This bulletin was authored by Mr. Kyle Cook of SAIC. The project team included Mr. Jim Rawe and Mr. Joe Tillman of SAIC. The author is especially grateful to Mr. Bob Hillger and Dr. John Brugger of EPA, RREL, who have contributed significantly by serving as technical consultants during the development of this document.

The following other Agency and contractor personnel have contributed their time and comments by participating in the expert review meetings and/or peer reviewing the document:

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