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Engineering Bulletin
In Situ Soil Flushing

EPA

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 soil flushing is the extraction of contaminants from the soil with water or other suitable aqueous solutions. Soil flushing is accomplished by passing the extraction fluid through in-place soils using an injection or infiltration process. Extraction fluids must be recovered and, when possible, are recycled. The method is potentially applicable to all types of soil contaminants. Soil flushing enables removal of contaminants from the soil and is most effective in permeable soils. An effective collection system is required to prevent migration of contaminants and potentially toxic extraction fluids to uncontaminated areas of the aquifer. Soil flushing, in conjunction with in situ bioremediation, may be a cost-effective means of soil remediation at certain sites [1, p. vi] [2, p. 11].* Typically, soil flushing is used in conjunction with other treatments that destroy contaminants or remove them from the extraction fluid and groundwater.

Soil flushing is a developing technology that has had limited use in the United States. Typically, laboratory and field treatability studies must be performed under site-specific conditions before soil flushing is selected as the remedy of choice. To date, the technology has been selected as part of the source control remedy at 12 Superfund sites. This technology is currently operational at only one Superfund site; a second is scheduled to begin operation in 1991 [3][4]. EPA completed construction of a mobile soil-flushing system, the In Situ Contaminant/Treatment Unit, in 1988. This mobile soil-flushing system is designed for use at spills and uncontrolled hazardous waste sites [5].

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

Technology Applicability

In situ soil flushing is generally used in conjunction with other treatment technologies such as activated carbon, biodegradation, or chemical precipitation to treat contaminated groundwater resulting from soil flushing. In some cases, the process can reduce contaminant concentrations in the soil to acceptable levels, and thus serve as the only soil treatment technology. In other cases, in situ biodegradation or other in situ technologies can be used in conjunction with soil flushing to achieve acceptable contaminant removal efficiencies. In general, soil flushing is effective on coarse sand and gravel contaminated with a wide range of organic, inorganic, and reactive contaminants. Soils containing a large amount of clay and silt may not respond well to soil flushing, especially if it is applied as a stand-alone technology.

A number of chemical contaminants can be removed from soils using soil flushing. Removal efficiencies depend on the type of contaminant as well as the type of soil. Soluble (hydrophilic) organic contaminants often are easily removed from so by flushing with water alone. Typically, organics with octanol water partition coefficients (K_{ow}) of less than 10 (log K_{ow}<1) a highly soluble. Examples of such compounds include low molecular weight alcohols, phenols, and carboxylic acids [6]

Low solubility (hydrophobic) organics may be removed selection of a compatible surfactant [7]. Examples of s compounds include chlorinated pesticides, polychlorinated phenyls (PCBs), semivolatiles (chlorinated benzenes and p nuclear aromatic hydrocarbons), petroleum products (gaso

jet fuel, kerosene, oils and greases), chlorinated solvents (trichloroethene), and aromatic solvents (benzene, toluene, xylenes and ethylbenzene) [8]. However, removal of some of these chemical classes has not yet been demonstrated.

Metals may require acids, chelating agents, or reducing agents for successful soil flushing. In some cases, all three types of chemicals may be used in sequence to improve the removal efficiency of metals [9]. Many inorganic metal salts, such as carbonates of nickel, zinc, and copper, can be flushed from the soil with dilute acid solutions [6]. Some inorganic salts such as sulfates and chlorides can be flushed with water alone.

In situ soil flushing has been considered for treating soils contaminated with hazardous wastes, including pentachlorophenol and creosote from wood-preserving operations, organic solvents, cyanides and heavy metals from electroplating residues, heavy metals from some paint sludges, organic chemical production residues, pesticides and pesticide production residues, and petroleum/oil residues [10, p. 13][11, p. 8][7][12].

The effectiveness of soil flushing for general contaminant groups [10, p. 13] is shown in Table 1. Examples of constituents within contaminant groups are provided in Reference 10, "Technology Screening Guide For Treatment of CERCLA Soils and Sludges." Table 1 is based on currently available information or professional judgment where definitive information is currently inadequate or unavailable. The demonstrated 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 efficiency achieved will be acceptable at other sites. For the ratings used in this table, demonstrated effectiveness means that, at some scale, treatability was tested to show that, for that particular contaminant and matrix, the technology was effective. The ratings of potential effectiveness and 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. Other sources of general observations and average removal efficiencies for different treatability groups are the Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions" (OSWER Directive 9347.3-06FS) [13], and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-07FS) [14].

Table 1
Effectiveness of Soil Flushing on General Contaminant Groups

	Contaminant Groups	*Effectiveness*
Organic	Halogenated volatiles	■
	Halogenated semivolatiles	▼
	Nonhalogenated volatiles	▼
	Nonhalogenated semivolatiles	■
	PCBs	▼
	Pesticides (halogenated)	▼
	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.

Information on cleanup objectives, as well as the physical and chemical characteristics of the site soil and its contaminants, is necessary to determine the potential performance of this technology. Treatability tests are also required to determine the feasibility of the specific soil-flushing process being considered. If bench-test results are promising, pilot-scale demonstrations should be conducted before making a final commitment to full-scale implementation. Table 2 contains physical and chemical soil characterization parameters that should be established before a treatability test is conducted at a specific site. The table contains comments relating to the purpose of the specific parameter to be characterized and its impact on the process [15, p. 715] [16, p. 90] [17].

Soil permeability is a key physical parameter for determining the feasibility of using a soil-flushing process. Hydraulic conductivity (K) is measured to assess the permeability of soils. Soils with low permeability ($K < 1.0 \times 10^{-5}$ cm/sec) will limit the ability of flushing fluids to percolate through the soil in a reasonable time frame. Soil flushing is most likely to be effective in permeable soils ($K > 1.0 \times 10^{-3}$ cm/sec), but may have limited application to less permeable soils (1.0×10^{-5} cm/sec $< K < 1.0 \times 10^{-3}$ cm/sec). Since there can be significant lateral and vertical variability in soil permeability, it is important that field measurements be made using the appropriate methods.

Prior to field implementation of soil flushing, a thorough groundwater hydrologic study should be carried out. This should include information on seasonal fluctuations in water level, direction of groundwater flow, porosity, vertical and horizontal hydraulic conductivities, transmissivity and infiltration (data on rainfall, evaporation, and percolation).

Moisture content can affect the amount of flushing fluids required. Dry soils will require more flushing fluid initially to mobilize contaminants. Moisture content is also used to calculate pore volume to determine the rate of treatment [15].

The concentration and distribution of organic contami-

Table 2
Characterization Parameters

Parameter	*Purpose and Comment*
Soil permeability	Affects treatment time and efficiency of contaminant removal
$\geq 1.0 \times 10^{-3}$ cm/sec	Effective soil flushing
$< 1.0 \times 10^{-5}$ cm/sec	Limited soil flushing
Soil structure	Influences flow patterns (channeling, blockage)
Soil porosity	Determines moisture capacity of soil at saturation (pore volume)
Moisture content	Affects flushing fluid transfer requirements
Groundwater hydrology	Critical in controlling the recovery of injected fluids and contaminants
Organics Concentration Solubility Partition coefficient	Determine contaminants and assess flushing fluids required, flushing fluid compatibility, changes in flushing fluid with changes in contaminants.
Metals Concentration Solubility products Reduction potential Complex stability constants	Concentration and species of constituents will determine flushing fluid compatibility, mobility of metals, post treatment.
Total Organic Carbon (TOC)	Adsorption of contaminants on soil increases with increasing TOC. Important in marine wetland sites, which typically have high TOC.
Clay content	Adsorption of contaminants on soil increases with increasing clay content.
Cation Exchange Capacity (CEC)	May affect treatment of metallic compounds.
pH, buffering capacity	May affect treatment additives required, compatibility with equipment materials of construction, wash fluid compatibility.

nants and metals are key chemical parameters. These parameters determine the type and quantity of flushing fluid required as well as any post-treatment requirements. The solubility and partition coefficients of organics in water or other solutions are also important in the selection of the proper flushing fluids. The species of metal compounds present will affect the solubility and leachability of heavy metals.

High humic content and high cation exchange capacity tend to reduce the removal efficiency of soil flushing. Some organic contaminants may adsorb to humic materials or clays in soils and, therefore, are difficult to remove during soil flushing. Similarly, the binding of certain metals with clays due to cationic exchange makes them difficult to remove with soil flushing. The buffering capacity of the soil will affect the amount required of some additives, especially acids. Precipitation reactions (resulting in clogging of soil pores) can occur due to pH changes in the flushing fluid caused by the neutralizing effect of soils with high buffering capacity. Soil pH can affect the speciation of metal compounds resulting in changes in the solubility of metal compounds in the flushing fluid.

Limitations

Generally, remediation times with this technology will be lengthy (one to many years) due to the slowness of diffusion processes in the liquid phase. This technology requires hydraulic control to avoid movement of contaminants offsite. The hydrogeology of some sites may make this difficult or impossible to achieve.

Contaminants in soils containing a high percentage of silt- and clay-sized particles typically are strongly adsorbed and difficult to remove. Also, soils with silt and clay tend to be less permeable. In such cases, soil flushing generally should not be considered as a stand-alone technology.

Hydrophobic contaminants generally require surfactants or organic solvents for their removal from soil. Complex mixtures of contaminants in the soil (such as a mixture of metals, nonvolatile organics, and semivolatile organics) make it difficult to formulate a single suitable flushing fluid that will consistently and reliably remove all the different types of contaminants from the soil. Frequent changes in contaminant concentration and composition in the vertical and horizontal soil profiles will complicate the formulation of the flushing fluid. Sequential steps with frequent changes in the flushing formula may be required at such complex sites [10, p. 77].

Bacterial fouling of infiltration and recovery systems and treatment units may be a problem particularly if high iron concentrations are present in the groundwater or if biodegradable reagents are being used.

While flushing additives such as surfactants and chelants may enhance some contaminant removal efficiencies in the soil flushing process, they also tend to interfere with the downstream wastewater treatment processes. The presence of these additives in the washed soil and in the wastewater treatment sludge may cause some difficulty in their disposal. Costs associated with additives, and the management of these additives as part of the residuals/wastewater streams, must be carefully weighed against the incremental improvements in soil-flushing performance that they may provide.

Technology Description

Figure 1 is a general schematic of the soil flushing process [18, p. 7]. The flushing fluid is applied (1) to the contaminated soil by subsurface injection wells, shallow infiltration galleries, surface flooding, or above-ground sprayers. The flushing fluid is typically water and may contain additives to improve contaminant removal.

The flushing fluid percolates through the contaminated soil, removing contaminants as it proceeds. Contaminants are mobilized by solubilization into the flushing fluid, formation of emulsions, or through chemical reactions with the flushing fluid [19].

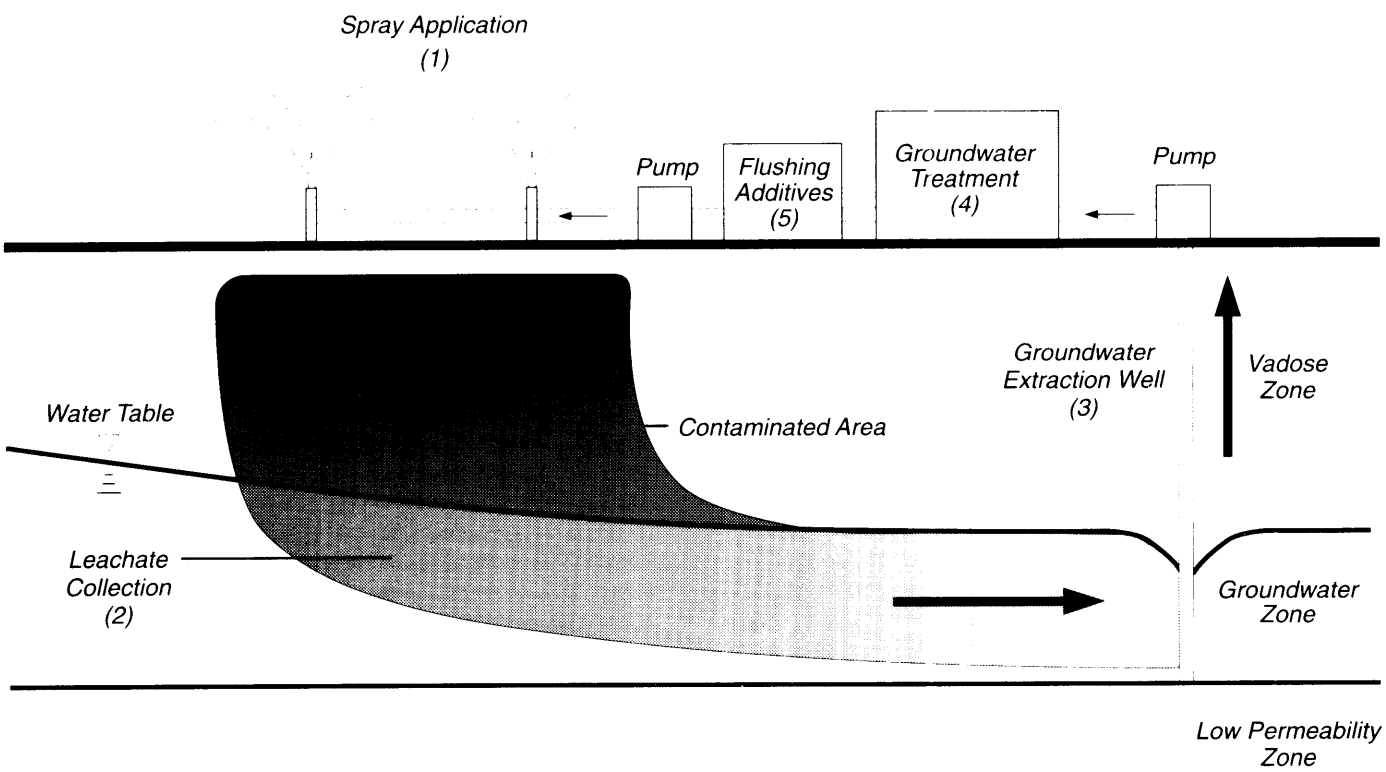
Contaminated flushing fluid or leachate mixes with groundwater and is collected (2) for treatment. The flushing fluid delivery and the groundwater extraction systems are designed to ensure complete contaminant recovery [7]. Ditches open to the surface, subsurface collection drains, or groundwater recovery wells may be used to collect flushing fluids and mobilized contaminants. Proper design of a fluid recovery system is very important to the effective application of soil flushing.

Contaminated groundwater and flushing fluids are captured and pumped to the surface in a standard groundwater extraction well (3). The rate of groundwater withdrawal is determined by the flushing fluid delivery rate, the natural infiltration rate, and the groundwater hydrology. These will determine the extent to which the groundwater removal rate must exceed the flushing fluid delivery rate to ensure recovery of all reagents and mobilized contaminants. The system must be designed so that hydraulic control is maintained.

The groundwater and flushing fluid are treated (4) using the appropriate wastewater treatment methods. Extracted groundwater is treated to reduce the heavy metal content, organics, total suspended solids, and other parameters until they meet regulatory requirements. Metals may be removed by lime precipitation or by other technologies compatible with the flushing reagents used. Organics are removed with activated carbon, air stripping, or other appropriate technologies. Whenever possible, treated water should be recycled as makeup water at the front end of the soil-flushing process.

Flushing additives (5) are added, as required, to the treated groundwater, which is recycled for use as flushing fluid. Water alone is used to remove hydrophilic organics and soluble heavy-metal salts [9]. Surfactants may be added to remove hydrophobic and slightly hydrophilic organic contaminants [12]. Chelating agents, such as ethylenediaminetetra-acetic acid (EDTA), can effectively remove certain metal compounds. Alkaline buffers such as tetrasodium pyrophosphate can remove metals bound to the soil organic fraction. Reducing agents such as hydroxylamine hydrochloride can reduce iron and manganese oxides that can bind

Figure 1
Schematic of Soil Flushing System



metals in soil. Insoluble heavy-metal compounds also can be reduced or oxidized to more soluble compounds. Weak acid solutions can improve the solubility of certain heavy metals [9]. Treatability studies should be conducted to determine compatability of the flushing reagents with the contaminants and with the site soils.

Process Residuals

The primary waste stream generated is contaminated flushing fluid, which is recovered along with groundwater. Recovered flushing fluids may need treatment to meet appropriate discharge standards prior to release to a local, publicly-owned wastewater treatment works or receiving streams. To the maximum extent practical, this water should be recovered and reused in the flushing process. The separation of surfactants from recovered flushing fluid, for reuse in the process, is a major factor in the cost of soil flushing. Treatment of the flushing fluid results in process sludges and residual solids, such as spent carbon and spent ion exchange resin, which must be appropriately treated before disposal. Air emissions of volatile contaminants from recovered flushing fluids should be collected and treated, as appropriate, to meet applicable regulatory standards. Residual flushing additives in the soil may be a concern and should be evaluated on a site-specific basis.

Site Requirements

Access roads are required for transport of vehicles to and from the site. Stationary or mobile soil-flushing process systems are located on site. The exact area required will depend on the vendor system selected and the number of tanks or ponds needed for washwater preparation and wastewater treatment.

Because contaminated flushing fluids are usually considered hazardous, their handling requires that a site safety plan be developed to provide for personnel protection and special handling measures during wastewater treatment operations. Fire hazard and explosion considerations should be minimal, since the soil-flushing fluid is predominantly water.

An Underground Injection Control (UIC) Permit may be necessary if subsurface infiltration galleries or injection wells are used. When groundwater is not recycled, a National Pollution Discharge Elimination System (NPDES) or State Pollution Discharge Elimination System (SPDES) permit may be required. Federal, State, and local regulatory agencies should be contacted to determine permitting requirements before implementing this technology.

Slurry walls or other containment structures may be needed along with hydraulic controls to ensure capture of contaminants and flushing additives. Climatic conditions such as precipitation cause surface runoff and water infiltration. Berms, dikes, or other runoff control methods may be required. Impermeable membranes may be necessary to limit infiltration of precipitation, which could cause dilution of flushing solution and loss of hydraulic control. Cold weather freezing must also be considered for shallow infiltration galleries and above-ground sprayers.

Performance Data

Some of the data presented for specific contaminant removal effectiveness were obtained from publications developed by the respective soil-flushing-system vendors. The quality of this information has not been determined; however it does give an indication of the effectiveness of in situ soil flushing.

Tetrachloroethylene was discharged into the aquifer at the site of a spill in Sindelfingen, Germany. The contaminated aquifer is a high-permeability ($k=5.10 \times 10^{-4}$ m/sec) layer overlaying a clay barrier. Soil flushing was accomplished by infiltrating water into the ground through ditches. The leaching liquid and polluted groundwater were pumped out of eight wells and treated with activated carbon. The treated water was recycled through the infiltration ditches. Within 18 months, 17 metric tons of chlorinated hydrocarbons were recovered [19, p. 565].

Two percolation basins were installed to flush contaminated soil at the United Chrome Products site near Corvallis, Oregon. Approximately 1,100 tons of soil containing the highest chromium concentrations were excavated and disposed of offsite. The resulting pits from the excavations were used as infiltration basins to flush the remaining contaminated soil. The soil-flushing operation for the removal of hexavalent chromium from an estimated 2.4 million gallons of contaminated groundwater began in August 1988. No information on the site soils was provided, but preliminary estimates were that a groundwater equilibrium concentration of 100 mg/L chromium would be reached in 1 to 2 years, but that final cleanup to 10 mg/L would take up to 25 years [20, p. H-1]. Since that time over 8-million gallons of groundwater, containing over 25,000 pounds of chromium, have been removed from the 23 extraction wells in the shallow aquifer. Average monthly chromium concentrations in the groundwater decreased from 1,923 mg/L in August 1988 to 96 mg/L in March 1991 [4].

Waste-Tech Services, Inc. performed two tests of soil-flushing techniques to remove creosote contamination at the Laramie Tie Plant site in Wyoming. The first test involved slowly flooding the soil surface with water to perform primary oil recovery (POR). Soil flushing reduced the average concentration of total extractable organics (TEO) from an estimated initial concentration of 93,000 mg/kg to 24,500 mg/kg, a 74 percent reduction. The second test involved sequential treatment with alkaline agents, polymers, and surfactants. During the 8-month treatment period, average TEO concentrations were reduced to 4,000 mg/kg. This represents an 84 percent reduction from the post-POR concentration (24,500 mg/kg) and a 96 percent reduction from the estimated initial concentration (93,000 mg/kg). The tests were performed in alluvial sands and gravels. The low permeability of adjacent silts and clays precluded soil flushing [22].

Laboratory tests were conducted on contaminated soils from a fire-training area at Volk Air Force Base. Initial concentrations of oil and grease in the soils were reported to be 10,000 and 6,000 mg/kg. A 1.5-percent surfactant solution in water was used to flush soil columns. The tests indicated that 75 to 94 percent of the initial hydrocarbon contamination could be removed by flushing with 12-pore volumes of liquid.

However, field tests were unsuccessful in removing the same contaminants. Seven soil-flushing solutions, including the solution tested in the laboratory studies, were tested in field studies. The flushing solutions were delivered to field test cells measuring 1 foot deep and 1 to 2 feet square. Only three of the seven tests achieved the target delivery of 14-pore volumes. Two of the test cells plugged completely, permitting no further infiltration of flushing solutions. There was no statistically significant removal of soil contaminants due to soil flushing. The plugging of test cells may be related to the use of a surfactant solution. By hydrolyzing in water, surfactants may block soil pores by forming either flocs or surfactant aggregates called micelles. In addition, if the surfactant causes fine soil particles to become suspended in the flushing fluid, narrow passages between soil particles could be blocked. If enough of these narrow passages are blocked along a continuous front, a "mat" is said to have formed, and fluid flow is halted in that area [23] [7].

Resource Conservation Recovery Act (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 (ARARs) for CERCLA response actions. The soil-flushing technology can produce a treated waste that meets treatment levels set by BDAT, but may not reach these treatment levels in all cases. The ability of the technology to meet required treatment levels is dependent upon the specific waste constituents and the waste matrix. In cases where soil flushing does not meet these levels, it still may, in certain situations, be selected for use at the site if a treatability variance establishing alternative treatment levels is obtained. EPA has made the treatability variance process available in order to ensure that LDRs do not unnecessarily restrict the use of alternative and innovative treatment technologies. Treatability variances may be justified for handling complex soil and debris matrices. The following guides describe when and how to seek a treatability variance for soil and debris: Superfund LDR Guide #6A, "Obtaining a Soil and Debris Treatability Variance for Remedial Actions" (OSWER Directive 9347.3-06FS) [13], and Superfund LDR Guide #6B, "Obtaining a Soil and Debris Treatability Variance for Removal Actions" (OSWER Directive 9347.3-07FS) [14]. Another approach could be to use other treatment techniques in conjunction with soil flushing to obtain desired treatment levels.

Technology Status

In situ soil flushing is a developing technology that has had limited application in the United States. In situ soil flushing technology has been selected as one of the source control remedies at the 12 Superfund sites listed in Table 3 [3].

EPA Contact

Technology-specific questions regarding soil flushing may be directed to:

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Table 3
Superfund Sites Using In Situ Soil Flushing

Site	*Location (Region)*	*Primary Contaminants*	*Status*
Byron Barrel & Drum	Genesee County, NY (2)	VOCs (BTX, PCE, and TCE)	Pre-design: finalizing workplan
Goose Farm	Plumsted Township, NJ (2)	VOCs (Toluene, Ethylbenzene, Dichloromethane, and TCE), SVOCs, and PAHs	In design: 30% design phase
Lipari Landfill	Gloucester, NJ (2)	VOCs (Benzene, Ethylbenzene, Dichlormethane, and TCE), SVOCs, PAHs and Chlorinated ethers (bis-2-chloroethylether)	Operational, summer '91
Vineland Chemical	Vineland, NJ (2)	Arsenic and VOCs (Dichloromethane)	Pre-design
Harvey-Knott Drum	_____, DE (3)	Lead	In design: re-evaluating alternative
L.A. Clarke & Son	Spotsylvania, VA (3)	Creosote, PAHs, and Benzene	In design
Ninth Avenue Dump	Garry, IN (5)	VOCs (BTEX, TCE), PAHs, Phenols, Lead, PCBs, and Total Metals	In design: pilot failed
U.S. Aviex	Niles, MI (5)	VOCs (Carbon Tetrachloride, DCA, Ethylbenzene, PCE, TCE, Toluene, TCA, Freon, Xylene, and Chloroform)	Pre-design: re-evaluating alternatives
South Calvacale Street	Houston, TX (6)	PAHs	In design
United Chrome Products	Corvallis, OR (10)	Chromium	Operational since 8/88
Cross Brothers Pail	Pembroke, IL (5)	VOCs (Benzene, PCE, TCE, Toluene, and Xylenes) and PCBs	In desgn: developing workplan
Bog Creek Farm	Howell Township, NJ (2)	VOCs, Organics	In design: treatment plant completed, dump and treat not installed