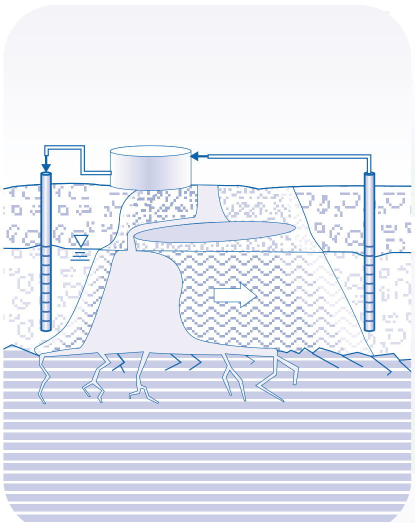
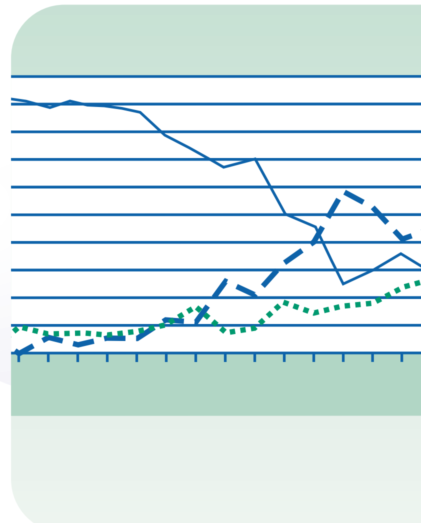
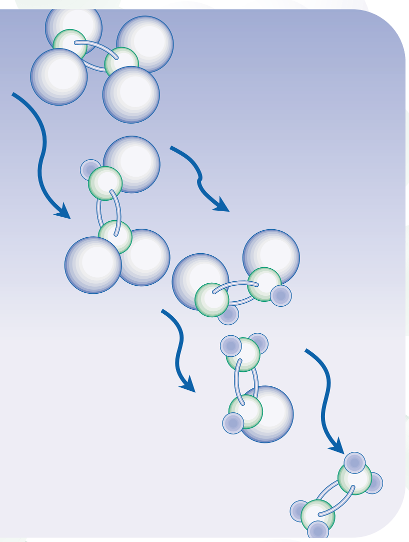
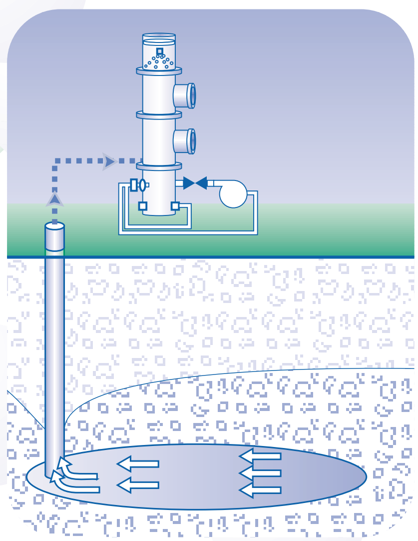
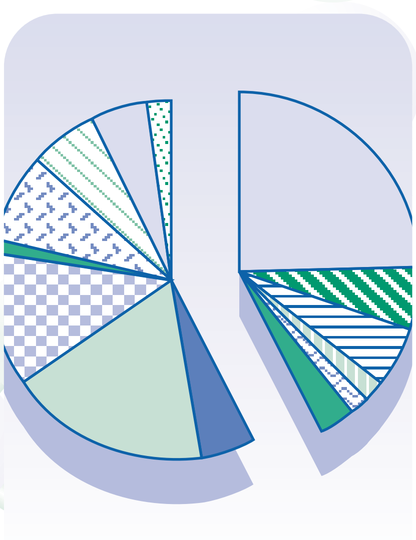
Treatment Technologies for Site Cleanup: Annual Status Report (Eleventh Edition)

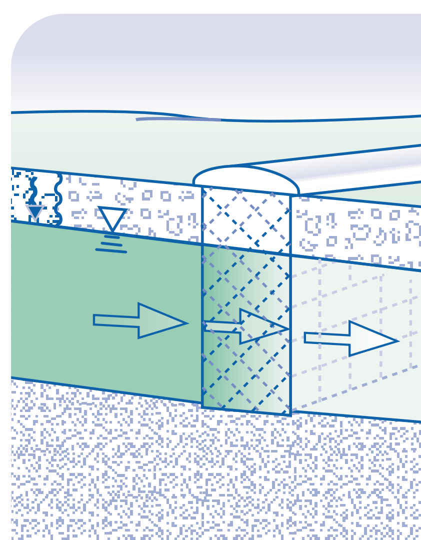












On the Cover

Top row from left to right:

Model of an in situ chemical treatment system for DNAPLs. See page 4 for a description of chemical treatment.

Figure 19. Superfund Remedial Actions: Trends in the Selection of Pump and Treat (FY 1986 - 2002), page 33. See Section 3: Groundwater Remedies for a discussion of this figure.

Middle row from left to right:

Theoretical model of the biodegradation of tetrachloroethene. See page 4 for a description of bioremediation.

Model of a groundwater pump and treat system. See page 7 for a description of groundwater pump and treat systems.

Bottom row from left to right:

Figure 7. Superfund Remedial Actions: Source Control Treatment Projects (FY 1982 - 2002), page 16. See Section 2: Treatment Technologies for Source Control for a discussion of this figure.

Model of a permeable reactive barrier. See page 7 for a description of a permeable reactive barrier.

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Treatment Technologies for Site Cleanup: Annual Status Report (Eleventh Edition)

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Notice

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The data for the ASR are available in a searchable on-line database (the ASR Search System) at *http://cfpub.epa.gov/asr/*. In addition, the data for the ASR have been incorporated into EPA's REmediation And CHaracterization Innovative Technologies (EPA REACH IT) on-line searchable database at *http://www.epareachit.org*.

Acknowledgment

This document was prepared for EPA's Technology Innovation Program under contract number 68-W-02-034. Special acknowledgment is given to the federal and state staffs and other remediation professionals for individual sites, for providing the detailed information presented in this document. Their cooperation and willingness to share their expertise on treatment technologies encourages the application of those technologies at other sites.

List of Acronyms

ASR	Annual Status Report
BTEX	Benzene, toluene, ethylbenzene, and xylene
CCL	Construction Completion List
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CLU-IN	EPA's CLeanUp INformation system
COR	Close-out report
cy	Cubic yard
DCA	Dichloroethane
DCE	Dichloroethene
DNAPL	Dense nonaqueous-phase liquid
DRE	Destruction and removal efficiency
EOU	Excess, obsolete, or unserviceable
EPA	U.S. Environmental Protection Agency
ESD	Explanation of significant differences
FCOR	Final close-out report
FRTR	Federal Remediation Technologies Roundtable
FY	Fiscal year
GW	Groundwater
LNAPL	Light nonaqueous-phase liquid
MNA	Monitored natural attenuation
NA/NFA	No action/no further action
NAPL	Nonaqueous-phase liquid
NPL	National Priorities List
NSCEP	National Service Center for Environmental Publications
OB	Open burn
OD	Open detonation
OSC	On-Scene Coordinator
OSRTI	Office of Superfund Remediation and Technology Innovation
OSWER	Office of Solid Waste and Emergency Response
OU	Operable unit
P&T	Pump and treat
PAH	Polycyclic aromatic hydrocarbons
PCB	Polychlorinated biphenyls
PCE	Tetrachloroethene
PCOR	Preliminary close-out report
PDF	Portable document format
PRB	Permeable reactive barrier
REACH IT	EPA's REmediation And CHaracterization Innovative Technologies on-line searchable database
ROD	Record of Decision
RPM	Remedial Project Manager
RSE	Remediation System Evaluation
S/S	Solidification/stabilization
SARA	Superfund Amendments and Reauthorization Act
SVE	Soil vapor extraction
SVOC	Semivolatile organic compound
TCA	Trichloroethane
TCE	Trichloroethene
UV	Ultraviolet
VC	Vinyl chloride
VEB	Vertical engineered barrier
VOC	Volatile organic compound

Executive Summary

This report documents the status and achievements, as of March 2003, of treatment technology applications for soil, other solid wastes, and groundwater at Superfund sites. The data in this report were gathered from Superfund Records of Decision (ROD) from fiscal year (FY) 1982 - 2002, Close-out Reports (COR) from FY 1983 - 2002, and project managers at Superfund remedial action sites. The report examines:

- *in situ* and *ex situ* treatment technologies for sources (e.g., soil, sludge, sediment, other solid-matrix wastes, and non-aqueous phase liquids [NAPL]).
- *in situ* and *ex situ* (pump and treat [P&T]) groundwater treatment technologies.
- vertical engineered barriers (VEB).
- the selection of monitored natural attenuation (MNA) remedies for groundwater.

This edition of the Annual Status Report (ASR) provides a summary of the 1,811 technology applications identified for Superfund remedial actions. The Tenth Edition of the ASR included information on 934 technologies from RODs from FY 1982 -1999.

- This report adds information from FY 2000, 2001, and approximately 70% of 2002 RODs.
- For the first time, this report includes detailed information regarding 743 groundwater P&T projects.
- For the most frequently selected technologies in the Superfund remedial program, the report analyzes selection trends over time, contaminant groups treated, quantities of soil and groundwater treated, and the status of project implementation.
- The report also focuses on the achievements made at Superfund remedial action sites through the application of treatment technologies, including an analysis of the numbers and types of completed technology applications.
- In addition, more detailed information is provided on the application of chemical treatment, one of several innovative technologies whose use has been increasing in recent years, particularly for the *in situ* treatment of dense nonaqueous-phase liquids (DNAPL), which historically have been difficult to treat.

Major Findings

Overall use of treatment at Superfund remedial action sites:

- At almost two-thirds (62%) of sites on the National Priorities List (NPL), the remedy already implemented or currently planned includes treatment of a source or groundwater (including groundwater P&T remedies).
- The complexity of RODs has been increasing. The proportion of RODs addressing both soil and groundwater contamination has increased from 20% in FY 1997 to 56% in FY 2002.
- Of the 2,610 RODs and ROD amendments signed from FY 1982 - 2002, 1,505 (58%) included treatment remedies.

Use of treatment for source control:

- The percentage of RODs selecting source control treatment as a remedy increased from 40% in FY 2000 to 52% in FY 2002 (about 70% of FY 2002 RODs were available for this report).
- *In situ* technologies make up 42% of all source control treatments at Superfund remedial action sites. Since the inception of the Superfund program in FY 1982, the use of *in situ* source control treatments at these sites has been increasing to the current level of 45% in FY 2002.
- *In situ* soil vapor extraction (SVE) is the most frequently used source control treatment technology (25% of source control projects), followed by *ex situ* solidification/stabilization (18%) and off-site incineration (12%).
- The percentage of completed source control treatment projects increased from 47% in FY 2000 to 54% in FY 2002.
- Innovative applications account for 21% of all source control treatments. Bioremediation is the most commonly applied innovative technology, representing about half of innovative applications for source control treatment.
- Approximately 75% of the source control treatment projects address organic contaminants. Just over 25% address metal or metalloid contaminants. Some of these projects address both organics and metals.
- Since FY 1982, nearly three times as much contaminated soil has undergone remediation by *in situ* treatment (40 million cubic yards [cy]) than by *ex situ* treatment (13 million cy). Approximately 42% (24 million cy) of the total volume of soil undergoing treatment is being treated by *in situ* SVE.

Use of treatment and MNA for groundwater:

- Groundwater treatment was part of the remedy at 71% of Superfund sites that selected a groundwater remedy.
- The percentage of groundwater RODs selecting *in situ* treatment as a remedy increased from none in FY 1986 to 24% in FY 2002.
- At 51% of NPL sites, a groundwater treatment remedy (including *in situ* groundwater treatment and P&T) is currently planned or already being implemented.
- For all remedies selected from FY 1982 - 2001, P&T was the most frequently selected groundwater remedy, followed by MNA and *in situ* treatment.
- The percentage of RODs selecting only MNA as a remedy for groundwater rose from 6% in FY 1986, when MNA was first selected without another groundwater treatment remedy, to a peak of 32% in FY 1998. However, this percentage decreased to 4% in FY 2002.
- The contaminants most commonly treated by groundwater P&T systems were chlorinated volatile organic compounds (VOC), nonchlorinated VOCs, metals, and metalloids.
- More than half of P&T systems use air stripping as a treatment technology. Other commonly used technologies include activated carbon adsorption, filtration, and metals precipitation.
- Most P&T projects (52%) are operational.

Sites achieving construction completion status:

- U.S. Environmental Protection Agency (EPA) has prepared CORs for more than half (57%) of all NPL sites. CORs are prepared for sites when (1) any necessary physical construction is complete, whether or not final cleanup levels or other requirements have been achieved; or (2) EPA has determined that the response action should be limited to measures that do not involve construction; or (3) the site qualifies for deletion from the NPL.
- The most common technologies used at sites for which CORs have been prepared are P&T (32%), SVE (9%), and incineration (9%).

Overview

Introduction

The Eleventh Edition of the Annual Status Report (ASR) updates and expands information provided in the Tenth Edition (February 2001) report. Updated data have been included from the following sources:

- Fiscal year (FY) 2000 Records of Decision (ROD)
- FY 2001 RODs
- FY 2002 RODs available in March of 2003 (an estimated 70% of the total number of FY 2002 RODs that are expected to be signed)
- Close-out Reports (COR) from FY 1983 - 2002

In addition, the scope of the report has been expanded to include groundwater pump and treat (P&T). Information is included on 743 P&T applications selected in RODs from FY 1982 - 2002. A list of sites and an analysis of 1,811 applications of treatment and groundwater containment technologies under remedial actions are also provided. Information has been added about 127 applications of treatment technologies selected by RODs in FY 2000, 75 selected in 2001, and 70 selected in 2002. The U.S. Environmental Protection Agency (EPA) uses RODs to compile baseline information about Superfund remedial actions. At the time of this report's publication, only about 70% of RODs from FY 2002 were available. Therefore, this report does not include information for all of the RODs anticipated for FY 2002.

Box 1. New in the Eleventh Edition

- Information from Close-Out Reports (COR) regarding the construction achievements at Superfund sites and implementation status of treatment technologies.
- Analysis of 743 Superfund pump and treat (P&T) projects.
- A detailed look at an innovative treatment technology, chemical treatment, and construction completion at Superfund sites.

What Treatment Technologies are Addressed in This Report?

Most RODs for remedial actions address the source of contamination, such as soil, sludge, sediments, and solid-matrix wastes; such "source control" RODs select "source control technologies." Groundwater remedial action, also known as "a non-source control action," may be a component of the "source control" ROD and the treatment technologies chosen for groundwater remediation are referred to as "groundwater technologies." Appendix F to this document is a detailed description of the methodology used to identify ROD types, including detailed definitions of "source control," "groundwater technologies," and other remedy types. An example of a ROD selecting both source control and groundwater treatment remedies is summarized in Box 2.

Box 2. ROD Selecting Multiple Remedy Types

A Record of Decision (ROD) issued for the Alaric Inc. site contains both source control and groundwater remedies for the 1.7-acre site in Tampa, Florida. The contamination was the result of degreasing and steam-cleaning processes that used chlorinated solvents. Tetrachloroethene (PCE) and trichloroethene (TCE) have been identified in two areas of the soil. Groundwater contamination is also present.

An interim ROD was issued in July 2002 for remedial action at this site. The ROD specified both source control and groundwater treatment remedies. The treatment portion of the source control remedy is in situ chemical treatment. The groundwater treatment remedy consists of groundwater P&T with air stripping and carbon adsorption. Long-term groundwater monitoring was also selected as part of the groundwater remedy.

For Superfund remedial actions, the ASR documents and tracks the use of both *in situ* and *ex situ* treatment for source control and groundwater, as well as groundwater monitored natural attenuation (MNA) remedies, and groundwater containment using vertical engineered barriers (VEB).

The methodology used to determine ROD and remedy types has evolved over time. As new technologies are developed and innovative techniques for site remediation are implemented, the number of types of remedies has expanded. The methodology and definitions provided in Appendix F were used to classify remedies selected in RODs from FY 1982 - 2002.

The term "treatment technology" means any unit operation or series of unit operations that alters the composition of a hazardous substance or pollutant or contaminant through chemical, biological, or physical means so as to reduce toxicity, mobility, or volume of the contaminated materials being treated. Treatment technologies are an alternative to land disposal of hazardous wastes without treatment (March 8, 1990 Federal Register [55 FR 8819], see 40 CFR 300.5 "Definitions").

Established treatment technologies are those for which cost and performance information is readily available. The most frequently used established technologies are on- and off-site incineration,

Box 3. Summary of Remedy Types

Source Control Remedy Types*

Source Control Treatment

- Treatment of a contaminant source *in situ* or *ex situ*.
- Can include any of the source control treatment technologies described in this report, such as chemical treatment and thermal desorption.

Source Control Containment

- Containment of a contaminant source.
- Can include the use of caps, liners, covers, and landfilling both on- and off-site.

Source Control Other

- Other remedies for contaminant sources.
- Can include institutional controls, monitoring, and population relocation.

Groundwater Remedy Types*

Pump and Treat (P&T)

- Extraction of groundwater from an aquifer and treatment aboveground.
- Extraction usually is conducted by pumping groundwater from a well or trench.
- Treatment can include any of the P&T technologies described in this report, such as air stripping and ion exchange.

In Situ Treatment

- Treatment of groundwater in place without extracting it from an aquifer.
- Can include any of the *in situ* groundwater treatment technologies described in this report, such as air sparging and permeable reactive barriers.

Monitored Natural Attenuation (MNA)

- The reliance on natural attenuation processes (within the context of a carefully controlled and monitored approach to site cleanup) to achieve site-specific remediation objectives within a time frame that is reasonable compared to other alternatives.
- Natural attenuation processes include a variety of physical, chemical, and biological processes.

Groundwater Containment

- Containment of groundwater through the use of a vertical, engineered, subsurface, impermeable barrier.
- Containment of groundwater through a hydraulic barrier created by pumping.

Groundwater Other

- Groundwater remedies that do not fall into the categories of groundwater P&T, *in situ* treatment, MNA, or containment remedies.
- Can include a variety of remedies, such as water use restrictions and alternate water supply.

** - See Appendix F-2 for further definitions of Source Control Remedies and F-6 for Groundwater Remedies.*

solidification/stabilization (S/S), soil vapor extraction (SVE), thermal desorption, and P&T technologies for groundwater. Treatment of groundwater after it has been pumped to the surface usually involves traditional water treatment; as such, P&T groundwater remedies are considered to be established technologies.

Innovative treatment technologies are alternative treatment technologies with a limited number of applications and limited data on cost and performance. Often, these technologies are established in other fields, such as chemical manufacturing or hazardous waste treatment. In such cases, it is the application of a technology or process at a waste site (to soils, sediments, sludge, and solid-matrix waste [such as mining slag] or groundwater) that is innovative, not the technology itself. Innovative technologies for source control are discussed in Section 2 and those for the *in situ* treatment of groundwater are discussed in Section 3.

Both innovative and established technologies are grouped as source control treatment or *in situ* groundwater treatment technologies on the basis of the type of application most commonly associated with the technology. Some technologies may be used for both source control and *in situ* groundwater treatment. These technologies and their respective groupings are listed in Appendix F.

Sources of Information for This Report

EPA verifies and updates the draft information obtained from the RODs through interviews with Remedial Project Managers (RPMs), On-Scene Coordinators (OSCs), and other contacts for each site, along with information from the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS), EPA's Superfund tracking system. For this edition of the ASR, project information and status were also updated using information from Superfund CORs. CORs provide information on the construction achievements at Superfund sites and the implementation status of many technologies tracked in the ASR. For more information regarding CORs, see Section 4. The information collected from these sources is stored and maintained in the ASR Search System. Box 4 summarizes the types of information included in the ASR Search System.

Information about technologies and sites identified in this report may differ from information found in the CERCLIS database. The CERCLIS database includes information from RODs, ROD amendments, and explanations of significant differences (ESDs). This document also includes additional information gathered from other sources, including CORs and contacts with RPMs.

Box 4. Information in ASR Search System

Site Information
- Site name and location (city and state)
- CERCLIS ID
- Description

Project-Specific Information
- Operable unit name
- Cleanup type
- ROD date
- Lead agency/funding information

Contact Information
- Contact name and affiliation
- Address, phone number, and e-mail

Technology Information
- Technology and type (in situ or ex situ)
- Description of technology
- Treatment of residuals, if applicable
- Details (such as type of additives)
- Indicate whether part of a treatment train

Media and Quantity Information
- Media and quantity

Contaminant Information
- Contaminants treated
- Contaminants not treated

Status Information
- Status
- Date began operation
- Date completion is planned

Completed Project Information
- Cost
- Contaminant concentrations before and after treatment

ASR Online Components

To allow users of the ASR access to additional information, EPA maintains several resources online, including:

- Downloadable Spreadsheets - For Tables 1, 2, 7, and 9, and Figure 25 of this report, EPA prepared spreadsheets listing the specific sites names, locations, CERCLIS ID numbers, and types of remedies selected in RODs for those sites. These spreadsheets can be downloaded from *http://clu-in.org/asr.*

- Appendices to the ASR - Appendices B, C, D, and E have expanded over time, and are not available in the printed version of this report. These appendices are available on-line at *http://clu-in.org/asr.*
- ASR Search System - EPA created a searchable, on-line system to allow access to the data that form the basis for this report. See Box 4 for a list of the types of information available from the ASR Search System. This system is available at *http://cfpub.epa.gov/asr/.*
- EPA REACH IT - The ASR data are also available on EPA REACH IT. This system, sponsored by EPA's Technology Innovation Program, lets environmental professionals use the power of the Internet to search, view, download, and print information about innovative remediation and characterization technologies. EPA REACH IT provides information on more than 350 vendors offering 350 remediation and nearly 200 site characterization technologies. EPA REACH IT fosters communication between technology vendors and users by providing information about the availability, performance, and cost associated with the application of treatment and characterization technologies. EPA REACH IT is available at *http://www.epareachit.org.*

Definitions of Specific Treatment Technologies

This section provides definitions of 17 types of source control (primarily soil) treatment technologies, 10 types of *in situ* groundwater treatment technologies, 8 types of groundwater P&T technologies, and 1 groundwater containment technology. Technologies that are applicable to both source control and groundwater treatment are described only once under the source control treatment section. For P&T technologies, the descriptions focus on the treatment portion of the technology. Groundwater pumping technologies are not addressed in this report. Definitions are based on the Remediation Technologies Screening Matrix and Reference Guide, Version 4.0, which can be viewed at the Federal Remediation Technologies Roundtable (FRTR) web site at *http://www.frtr.gov*. Sketches for some of the newer innovative treatment technologies are provided.

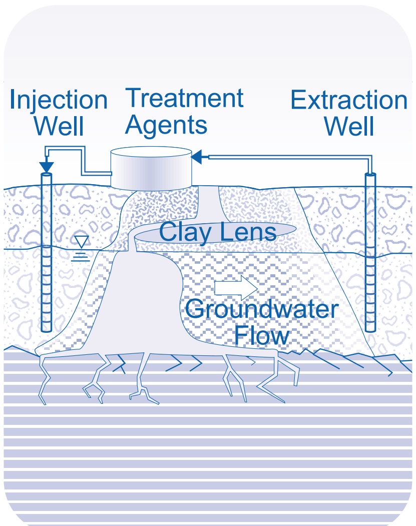
Source Control Treatment Technologies

BIOREMEDIATION uses microorganisms to degrade organic contaminants in soil, sludge, solids, and groundwater either *in situ* or *ex situ*. It can also be used to make metals or metalloids less toxic or mobile. When treating organic contaminants, the microorganisms break down contaminants by using them as a food source or cometabolizing them with a food source. Aerobic processes require an oxygen source, and the end-products typically are carbon dioxide and water. Anaerobic processes are conducted in the absence of oxygen, and the end-products can include methane, hydrogen gas, sulfide, elemental sulfur, and dinitrogen gas. *Ex situ* bioremediation technologies for groundwater typically involve treating extracted groundwater in a bioreactor or constructed wetland. *In situ* techniques stimulate and create a favorable environment for microorganisms to grow and use contaminants as a food and energy source, or to cometabolize them. Generally, this process involves providing some combination of oxygen, nutrients, and moisture, and controlling the temperature and pH. Microorganisms that have been adapted for degradation of specific contaminants are sometimes applied to enhance the process. For the treatment of metals and metalloids, it involves biological activity that promotes the formation of less toxic or mobile species, by either creating ambient conditions that will cause such species to form, or acting directly on the contaminant. The treatment may result in oxidation, reduction, precipitation, coprecipitation, or another transformation of the contaminant.

CHEMICAL TREATMENT, also known as chemical reduction/oxidation, typically involves reduction/oxidation (redox) reactions that chemically convert hazardous contaminants to compounds that are nonhazardous, less toxic, more stable, less mobile, or inert. Redox reactions involve the transfer of electrons from one compound to another. Specifically, one reactant is oxidized (loses electrons) and one is reduced (gains electrons). The oxidizing agents used for treatment of hazardous contaminants in soil include ozone, hydrogen peroxide, hypochlorites, potassium permanganate, Fenton's reagent (hydrogen peroxide and iron), chlorine, and chlorine dioxide. This method may be applied *in situ* or *ex situ* to soils, sludges, sediments, and other solids, and may also be applied to groundwater *in situ* or *ex situ* (P&T).

P&T chemical treatment may also include the use of ultraviolet (UV) light in a process known as UV oxidation.

Model of In Situ Chemical Treatment System for DNAPLs



ELECTROKINETICS is based on the theory that a low-density current will mobilize contaminants in the form of charged species. A current passed between electrodes is intended to cause aqueous media, ions, and particulates to move through the soil, waste, and water. Contaminants arriving at the electrodes can be removed by means of electroplating or electrodeposition, precipitation or coprecipitation, adsorption, complexing with ion exchange resins, or by the pumping of water (or other fluid) near the electrode.

For FLUSHING, a solution of water, surfactants, or cosolvents is applied to the soil or injected into the subsurface to treat contaminated soil or groundwater. When treating soil, the injection is often designed to raise the water table into the contaminated soil zone. Injected water and treatment agents are recovered together with flushed contaminants.

Both on-site and off-site INCINERATION use high temperatures (870 to 1,200°C or 1,600 to 2,200°F) to volatilize and combust (in the presence of oxygen) organics in hazardous wastes. Auxiliary fuels are often employed to initiate and sustain combustion. The destruction and removal efficiency (DRE) for properly operated incinerators exceeds the 99.99% requirement for hazardous waste and can be operated to meet the 99.9999% requirement for polychlorinated biphenyls (PCB) and dioxins. Off-gases and combustion residuals generally require treatment. On-site incineration typically uses a transportable unit; for off-site incineration, waste is transported to a central facility.

MECHANICAL SOIL AERATION agitates contaminated soil, using tilling or other means to volatilize contaminants.

MULTI-PHASE EXTRACTION uses a vacuum system to remove various combinations of contaminated groundwater, separate-phase petroleum product, and vapors from the subsurface. The system typically lowers the water table around the well, exposing more of the formation. Contaminants in the newly exposed vadose zone are then accessible to vapor extraction. Once above ground, the extracted vapors or liquid-phase organics and groundwater are separated and treated.

NEUTRALIZATION is a chemical reaction between an acid and a base. The reaction involves acidic or caustic wastes that are neutralized (pH is adjusted toward 7.0) using caustic or acid additives.

OPEN BURN (OB) and OPEN DETONATION (OD) operations are conducted to destroy excess, obsolete, or unserviceable (EOU) munitions and energetic materials. In OB operations, energetics or munitions are destroyed by self-sustained combustion, which is ignited by an external source, such as a flame, heat, or a detonation wave. In OD operations, explosives and munitions are destroyed by detonation, which generally is initiated by an energetic charge.

PHYSICAL SEPARATION processes use physical properties to separate contaminated and uncontaminated media, or separate different types of media. For example, different-sized sieves and screens can be used to separate contaminated soil from relatively uncontaminated debris. Another application of physical separation is the dewatering of sediments or sludge.

PHYTOREMEDIATION is a process that uses plants to remove, transfer, stabilize, or destroy contaminants in soil, sediment, or groundwater. The mechanisms of phytoremediation include enhanced rhizosphere biodegradation (takes place in soil or groundwater immediately surrounding plant roots), phytoextraction (also known as phytoaccumulation, the uptake of contaminants by plant roots and the translocation/accumulation of contaminants into plant shoots and leaves), phytodegradation (metabolism of contaminants within plant tissues), and phytostabilization (production of chemical compounds by plants to immobilize contaminants at the interface of roots and soil). Phytoremediation applies to all biological, chemical, and physical processes that are influenced by plants (including the rhizosphere) and that aid in the cleanup of contaminated substances. Phytoremediation may be applied *in situ* or *ex situ* to soils, sludges, sediments, other solids, or groundwater.

SOIL VAPOR EXTRACTION (SVE) is used to remediate unsaturated (vadose) zone soil. A vacuum is applied to the soil to induce the controlled flow of air and remove volatile and some semivolatile organic contaminants from the soil. SVE usually is performed *in situ*; however, in some cases, it can be used as an *ex situ* technology.

For SOIL WASHING, contaminants sorbed onto fine soil particles are separated from bulk soil in a water-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, or chelating agent, or by adjusting the pH to help remove contaminants. Soils and wash water are mixed *ex situ* in a tank or other treatment unit. The wash water and various soil fractions are usually separated using gravity settling.

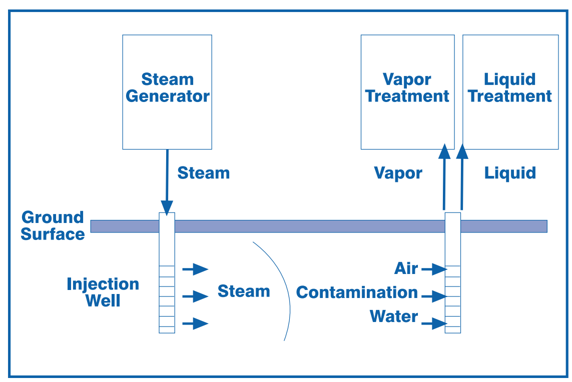
SOLIDIFICATION/STABILIZATION (S/S) reduces the mobility of hazardous substances and contaminants in the environment through both physical and chemical means. The S/S process physically binds or encloses contaminants within a stabilized mass. S/S is performed both *ex situ* and *in situ*. *Ex situ* S/S requires excavation of the material to be treated, and the resultant material must be disposed. *In situ* S/S uses auger/caisson systems and injector head systems to add binders to the contaminated soil or waste without excavation, leaving the resultant material in place.

SOLVENT EXTRACTION uses an organic solvent as an extractant to separate contaminants from soil. The organic solvent is mixed with contaminated soil in an extraction unit. The extracted solution then is passed through a separator, where the contaminants and extractant are separated from the soil.

For THERMAL DESORPTION, wastes are heated so that organic contaminants and water volatilize. Typically, a carrier gas or vacuum system transports the volatilized water and organics to a gas treatment system, typically a thermal oxidation or recovery system. Based on the operating temperature of the desorber, thermal desorption processes can be categorized into two groups: high temperature thermal desorption (320 to 560°C or 600 to 1000°F) and low temperature thermal desorption (90 to 320°C or 200 to 600°F). Thermal desorption is an *ex situ* treatment process. *In situ* thermal desorption processes are discussed below as *in situ* thermal treatment.

IN SITU THERMAL TREATMENT is a treatment process that uses heat to facilitate extraction through volatilization and other mechanisms or to destroy contaminants *in situ*. Volatilized contaminants are typically removed from the vadose zone using SVE. Specific types of *in situ* thermal treatment techniques include conductive heating, electrical resistive heating, radio frequency heating, hot air injection, hot water injection, and steam enhanced extraction. *In situ* thermal treatment is usually applied to a contaminated source area but may also be applied to a groundwater plume.

Model of an In Situ Thermal Treatment System



VITRIFICATION uses an electric current to melt contaminated soil at elevated temperatures (1,600 to 2,000°C or 2,900 to 3,650°F). Upon cooling, the vitrification product is a chemically stable, leach-resistant, glass and crystalline material similar to obsidian or basalt rock. The high temperature component of the process destroys or removes organic materials. Radionuclides and heavy metals are retained within the vitrified product. Vitrification may be conducted *in situ* or *ex situ*.

In Situ Groundwater Treatment Technologies

AIR SPARGING involves the injection of air or oxygen into a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil column, creating an underground stripper that removes volatile and semivolatile organic contaminants by volatilization. The injected air helps to flush the contaminants into the unsaturated zone. SVE usually is implemented in conjunction with air sparging to remove the generated vapor-phase contamination from the vadose zone. Oxygen added to the contaminated groundwater and vadose-zone soils also can enhance biodegradation of contaminants below and above the water table.

BIOREMEDIATION - See Source Control Treatment Technologies.

CHEMICAL TREATMENT - See Source Control Treatment Technologies.

ELECTROKINETICS - See Source Control Treatment Technologies.

FLUSHING - See Source Control Treatment Technologies.

For IN-WELL AIR STRIPPING, air is injected into a double-screened well, causing the volatile organic compounds (VOC) in the contaminated groundwater to transfer from the dissolved phase to the vapor phase in air bubbles. As the air bubbles rise to the surface of the water, the vapors are drawn off and treated by a SVE system.

MULTI-PHASE EXTRACTION - See Source Control Treatment Technologies.

PERMEABLE REACTIVE BARRIERS (PRB), also known as passive treatment walls, are installed across the flow path of a contaminated groundwater plume, allowing the water portion of the plume to flow through the wall. These barriers allow the passage of water while prohibiting the movement of contaminants by employing treatment agents within the wall such as zero-valent metals (usually zero-valent iron), chelators, sorbents, compost, and microbes. The contaminants are either degraded or retained in a concentrated form by the barrier material, which may need to be replaced periodically.

PHYTOREMEDIATION - See Source Control Treatment Technologies.

IN SITU THERMAL TREATMENT - See Source Control Treatment Technologies.

Pump and Treat Technologies (*Ex situ* Treatment)

In ADSORPTION, contaminants concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase. This technology is typically applied by passing extracted groundwater through a column containing granular adsorbent. The most common adsorbent is granulated activated carbon. Other natural and synthetic adsorbents include activated alumina, lignin adsorption, sorption clays, and synthetic resins.

AIR STRIPPING partitions volatile organics from extracted groundwater by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

BIOREMEDIATION - See Source Control Treatment Technologies.

CHEMICAL TREATMENT - See Source Control Treatment Technologies.

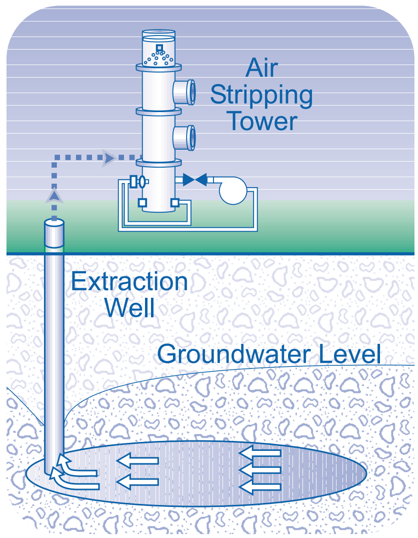
FILTRATION is the physical process of mechanical separation based on particle size, whereby particles suspended in a fluid are separated by forcing the fluid through a porous medium. As fluid passes through the medium, the suspended particles are trapped on the surface of the medium and/or within the body of the medium.

ION EXCHANGE removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are attached.

METALS PRECIPITATION transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. The process usually uses pH adjustment, addition of a chemical precipitant, and flocculation.

MEMBRANE FILTRATION separates contaminants from water by passing it through a semipermeable barrier or membrane. The membrane allows water and other low molecular weight chemicals to pass, while blocking contaminants with a higher molecular weight. Membrane filtration processes include microfiltration, ultrafiltration, nanofiltration, and reverse osmosis.

Model of a Groundwater Pump and Treat Air Stripping



Monitored Natural Attenuation (MNA) for Groundwater

Groundwater MNA is the reliance on natural attenuation processes (within the context of a carefully controlled and monitored approach to site cleanup) to achieve site-specific remediation objectives within a time frame that is reasonable, compared with that offered by other, more active methods. The "natural attenuation processes" include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These *in situ* processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants. Guidance on MNA is available from the document "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites (OSWER Directive 9200.4-17P, EPA, April 21, 1999.").

In Situ Groundwater Containment

VERTICAL ENGINEERED BARRIERS (VEB) are subsurface barriers made of an impermeable material designed to contain or divert groundwater. VEBs can be used to contain contaminated groundwater, divert uncontaminated groundwater from a contaminated area, or divert contaminated groundwater from a drinking water intake or other protected resource.

Section 1: Overview of RODs

As of March 2003, a total of 1,499 sites have been listed on the National Priorities List (NPL). Of these, 269 sites have been deleted leaving 1,230 sites on the NPL. An additional 54 sites are proposed for listing. Updated information on site listings and deletions is available at *http://ww.epa.gov/superfund*. Some sites may cover a large area, include several types of contaminated media, or include areas in which the types of contamination differ. To facilitate the establishment of remedies at a complex site, the site may be divided into operable units (OU), with separate remedies for each. Remedies for NPL sites are documented in RODs. A separate ROD may be developed for each OU. In addition, each OU may require a number of RODs to address different media within it, or to revise the selected remedy; therefore, each site may have multiple RODs.

From fiscal year (FY) 1982 - 2002 (including an estimated 70% of 2002 RODs), 2,610 RODs and ROD amendments were signed. In order to permit an analysis of remedies across the Superfund program, EPA developed a remedy classification system, which is described in Appendix F. Appendix F provides the definitions of the various ROD types, such as source control treatment ROD or groundwater *in situ* treatment ROD, and the methodology used to categorize each ROD. A ROD is assigned a type based on the remedies it contains. Each site is then assigned a type based on the types of RODs issued for that site. For sites with multiple RODs, the hierarchy presented in Appendix F is used to assign a site type. In general, a ROD and site are placed in the treatment category if any portion of the remedy includes treatment.

At almost two-thirds of NPL sites (62%), source control or groundwater treatment has been implemented or is planned as a remedy for some portion of the site. Treatment for both source control and groundwater has been implemented or is planned for 24% of sites. For 27% of sites, the selected remedies do not include treatment. No ROD has been issued for 11% of sites. Figure 1 summarizes the number of NPL sites with each type of remedy.

The remedy selected in a ROD may not be the remedy that is actually implemented at a site. Examples of where a different remedy may be used include a treatment technology that was selected in a ROD based on bench-scale treatability testing that proves to be ineffective in pilot-scale tests conducted during the design phase. Additional contamination may be discovered at the site during the implementation of a remedy. A particular remedy may have been included in a ROD only as a contingent remedy, with future site investigations revealing that implementation of that contingent remedy was not necessary. When significant and fundamental changes are made to remedies selected in the ROD, the changes usually are documented in an ESD or ROD amendment. Box 5 describes a source control remedy that was changed through a ROD amendment.

Box 5. Source Control Remedy Change

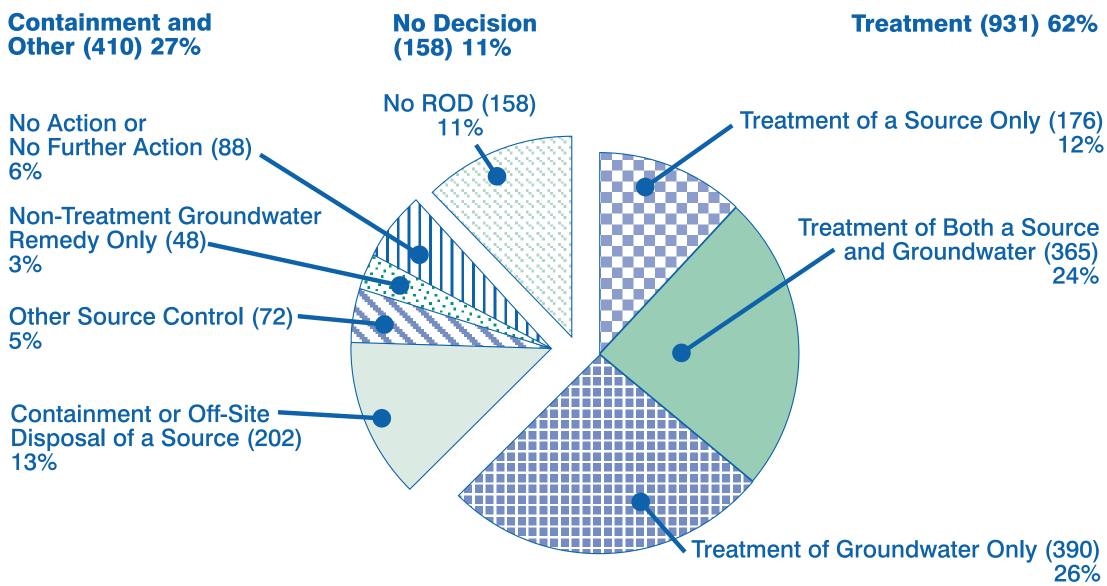
The source control remedy originally selected for the Helena Chemical Company Landfill Superfund Site was changed through a ROD amendment. The Helena Chemical Company Landfill Superfund Site is a 13.5 acre site where pesticides were formulated from the mid 1960's through 1971. The soil was contaminated with halogenated organic pesticides, and groundwater with halogenated and nonhalogenated volatile organic compounds as well as halogenated organic pesticides. This site, located in Fairfax, SC, is currently being operated as a retail sales outlet for agricultural chemicals.

A 1993 ROD selected a treatment train of dechlorination followed by bioremediation as part of the remedy for contaminated soil. However, treatability studies showed that the dechlorination would not achieve performance standards identified in the ROD. A ROD amendment in 1995 changed the source control technology from dechlorination and bioremediation to off-site incineration. The incineration of 5,172 cy of pesticide-contaminated soil was completed in 1999. The groundwater remedy selected in the original ROD (1993) included P&T. The P&T system became operational in 1999 and is expected to treat approximately 250 million gallons of groundwater during its anticipated 12 years of operation.

Figure 1 reflects the current status of remedial actions at NPL sites. The information used to develop Figure 1 reflects the remedies selected in RODs and the remedies actually implemented or currently planned at those sites. Sources for the information include the RODs, ROD amendments, and ESDs published for each site, and contacts with RPMs to identify the most current remedy selected for each site.

Figure 1: Superfund Remedial Actions: Actual Remedy Types at Sites on the National Priorities List (NPL) (FY 1982 - 2002)*

Total Number of Sites[(a)] = 1,499



ROD = Record of Decision
** Includes information from an estimated 70% of FY 2002 RODs.*
(a) NPL sites include current sites and former NPL sites that were deleted or removed from the NPL between FY 1982 and 2002.
Appendix F describes the methodology used to identify remedy types for each site.
Sources: 1, 2, 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

RODs Signed by Fiscal Year

Data from FY 1982 - 2002 RODs are included in this report. The total number of RODs expected for FY 2002 is 106 (about 70% of the FY 2002 RODs were available for this report).

As defined in Appendix F, RODs may select remedies for the source of contamination, such as soil, sludge, sediments, nonaqueous-phase liquids (NAPL), leachate, and solid-matrix wastes; they are referred to as "source control" RODs (see Box 3 on page 2). RODs may also address a contaminated aquifer, and are known as "groundwater" RODs. Because each ROD may include multiple remedies for different media, some RODs contain remedies for both the source and groundwater. Other RODs indicate that no action or no further action (NA/NFA) is necessary at a site, and are known as NA/NFA RODs.

For each FY, Figure 2 shows the number of RODs selecting the following remedies:

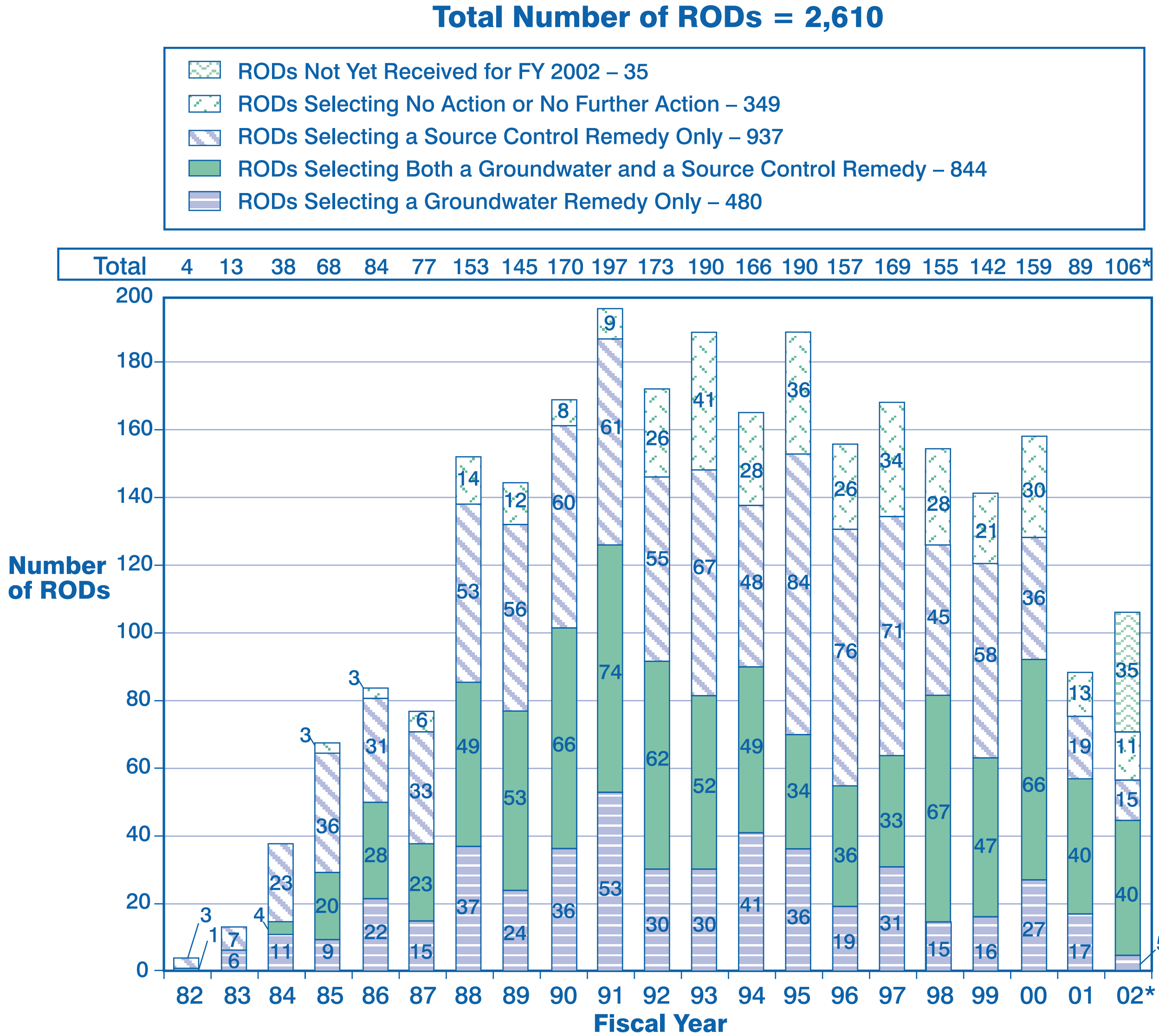
- Only source control remedies
- Both groundwater and source control remedies
- Only groundwater remedies
- NA/NFA remedies

The complexity of RODs has been increasing. The proportion of RODs addressing both soil and groundwater contamination has increased from 20% in FY 1997 to 56% in FY 2002, an indication of the complexity of sites on the NPL still requiring RODs. Although the number of RODs signed in the last two years has dropped, the greatest decrease has been in RODs addressing single media.

From FY 1988 - 2002, the percentage of RODs selecting a source remedy, either alone or in combination with a groundwater remedy, ranged from a low of 58% in FY 1994 to a peak of 77% in FY 2002. The percentages provided are based on the number of RODs shown in Figure 2.

The percentage of RODs selecting a groundwater remedy, either alone or in combination with a source control remedy, peaked in FY 1991 at 64%. This percentage decreased to 35% in FY 1996 and has since risen again to 64% in FY 2001.

Figure 2: Superfund Remedial Actions: RODs Selecting Groundwater and Source Control Remedies (FY 1982 - 2002)*



ROD = Record of Decision

** Includes information from an estimated 70% of FY 2002 RODs. A total of 106 RODs are anticipated for FY 2002.*

Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Superfund Remediation Progress

Information collected and analyzed for this report helps document the progress of remediation technologies implemented at Superfund sites. EPA has developed a better picture of the contribution of remediation technologies to Superfund site cleanup by using additional data. The new data include information from CORs and data on P&T projects. This report also focuses on data collection efforts relating to technology status and treatment accomplishments. This section presents an overview of the progress of treatment technologies at Superfund remedial action sites. Additional information on this topic is presented in Section 4.

The Superfund Amendments and Reauthorization Act of 1986 (SARA) expressed a preference for permanent remedies (that is, treatment) over containment or disposal in the remediation of Superfund sites. Some 58% of all RODs analyzed for the ASR contained provisions for treatment. EPA currently tracks the status of 1,760 projects for the application of treatment technologies at Superfund sites, including *in situ* and *ex situ* treatments for both source control and groundwater. These applications include 499 *ex situ* source control treatments (28% of all projects), 349 *in situ* source control treatments (20%), 743 P&T (42%), 154 *in situ* groundwater treatments

(9%), and 15 *in situ* source control and *in situ* groundwater treatments (1%). Of these projects, 546 have been completed or shut down (31%).

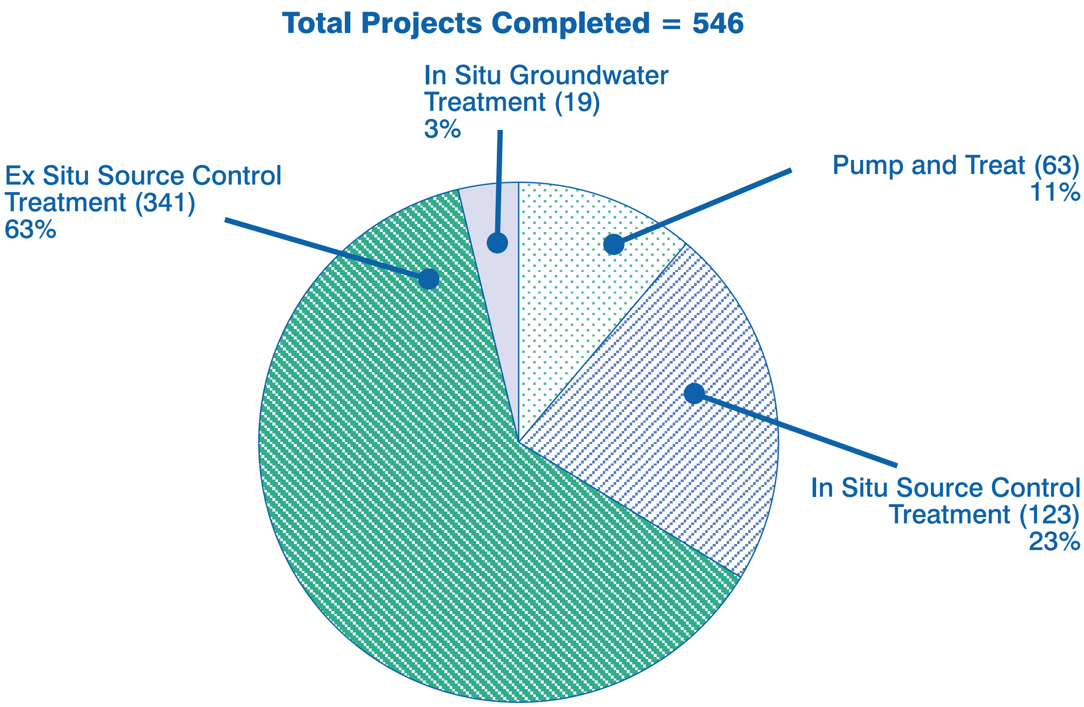
Completed projects are those where the treatment has been performed and is no longer ongoing. For most source control and *in situ* groundwater treatment projects that are no longer ongoing, the technologies achieved their treatment goals. These projects are described as "completed" in this report. The term "completed" has not been used for P&T system projects that are no longer ongoing. Preliminary data indicate that a significant percentage might not have achieved their treatment goals. These projects are provisionally described as "shut down" in this report. Appendix G lists the 63 P&T projects that are shut down, and the reasons that were identified for making that decision. Information about the reason for shut down was not available for all P&T projects from the data sources used for this report. EPA is currently conducting additional data gathering to better understand, across the Superfund Program, the decisions that result in the shut down of P&T systems. In many cases, this appears to be driven by a "treatment train" approach, where P&T is supplemented by a different remedy such as in situ treatment or MNA (see Box 6, Definition of Completed Project).

Figure 3 shows the number and percentage for each type of completed or shut down project at Superfund remedial action sites. For treatment technologies, a total of 546 projects (31%) have been completed or shut down and another 698 (39%) are operational. Most of the completed projects are *ex situ* source control treatments

Box 6. Definition of Completed Project

Project completion and *construction completion* (CC) are different terms used in defining progress in Superfund. The first refers to a specific project (ex: a soil vapor extraction system that is shut down after reaching cleanup levels), whereas CC refers to construction of all remedies being achieved for an entire site (all remedy construction is complete).

Figure 3: Superfund Remedial Actions: Percentages of Completed Source Control and Groundwater Treatment Projects by Remedy Type (FY 1982 - 2002)*

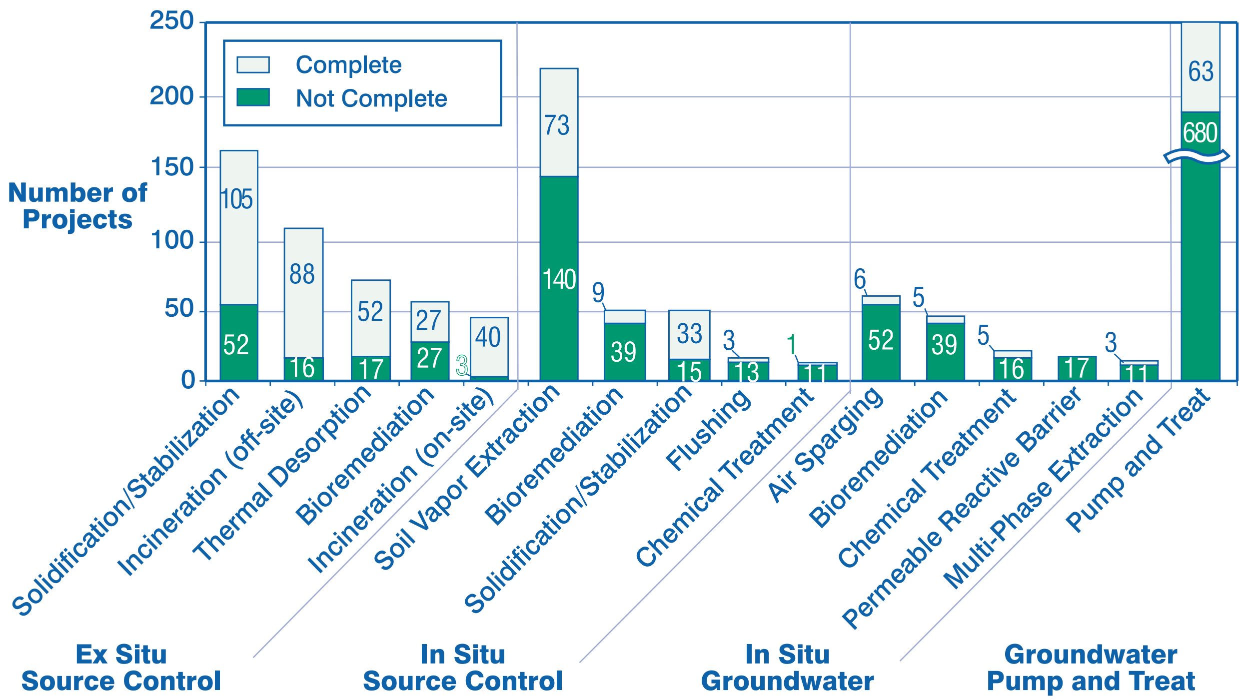


** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

(63%). *Ex situ* source control projects usually involve the excavation of contaminated soil and the application of an aggressive treatment technology in a controlled environment. Therefore, this type of remedy typically requires a shorter amount of time to complete. Additional information on source control projects is presented in Section 2. *In situ* treatments are those that are applied to contaminated media in place, without excavation. These projects typically require longer treatment times because they take place in a less controlled environment, which may limit the treatment rate. P&T projects, which represent the largest number of projects (743), also typically require longer treatment times, and in fact represent only 11% of all completed and shut down projects. The application of P&T is often limited by environmental factors, including the rate at which contaminated groundwater can be extracted from an aquifer and the presence of continuing sources of groundwater contamination such as DNAPLs. Additional information on groundwater projects is provided in Section 3.

Figure 4 shows the number of completed and shut down projects for the most commonly used technologies for *ex situ* source control, *in situ* source control, *in situ* groundwater, and P&T. For *ex situ* source control treatments, nearly all incineration projects have been completed. Approximately 70% of the S/S and thermal desorption projects have been completed. For *in situ* source control treatments, approximately 70% of S/S projects have been completed, as compared to one-third of all SVE projects. Fewer *in situ* groundwater projects have been completed as compared to source control projects. However, these technologies tend to be innovative, and have been selected in more recent RODs. For P&T, 8% of projects have been shut down.

Figure 4: Superfund Remedial Actions: Number of Projects Completed by Technology (FY 1982 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Section 2: Treatment Technologies for Source Control

Source control treatment technologies are designed to treat soil, sediment, sludge, or solid-matrix wastes (in other words, the source of contamination) and are not designed to treat groundwater directly. Source control remedies can be delineated further by the general type of remedy specified (see Box 3 or Appendix F for more detail). Table 1 contains information about the remedy actually implemented or currently planned at sites addressing source contamination. At 70% of all NPL sites, a source control remedy has been implemented or is currently planned. At over one-third (541) of sites, source control treatment has been implemented or is planned as a remedy for some portion of the site. A similar number of sites (576) has containment or off-site disposal of a source. Table 1 includes sites with more than one type of source control remedy in each applicable remedy category. Sites identified in Table 1 as having a source control treatment remedy may also have groundwater remedies. Groundwater technologies are discussed in Section 3.

Source Control Remedies

SOURCE CONTROL REMEDIES

Treatment ↗ | Containment ↑ | ↖ Other

Table 1. Superfund Remedial Actions: Actual Remedy Types at National Priorities List Sites (FY 1982 - 2002)*

Total Numbers of Sites with a Source Control Remedy = 1,046

Remedy Type	Number of Sites
Treatment of a Source	541
Containment or Off-Site Disposal of a Source	576
Other Source Control	650

**Includes information from an estimated 70% of FY 2002 RODs.*
Sites may be included in more than 1 category.
Appendix F describes the methodology used to identify remedy types for each site.
Sources: 1, 2, 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.
Download file containing source data for Table 1.

Source Control RODs

From FY 1988 - 2000, the total number of source control RODs varied between 97 and 135, decreasing to 59 in FY 2001. However, the percentage of source control RODs signed in FY 2001 and 2002 (66% in FY 2001 and 77% in FY 2002) remained similar to that of previous years. Figure 5 shows the number of source control RODs of each type. The information sources used for this report contained only an estimated 70% of RODs signed in FY 2002. Although information on FY 2002 may change as more RODs become available, this report includes FY 2002 ROD data for comparison purposes. Figure 6 shows the percentage of source control RODs of each type for each FY.

As shown in Figure 6, from FY 1988 - 1993, approximately 70% of source control RODs each year contained provisions for treatment of wastes. From FY 1995 to 2001, the percentage mostly decreased with a low of 39% in FY 1999. However, it has recently increased to 52% in FY 2002. For most of the past 13 years (with the exception of FY 1997 and 2000), the percentage of RODs including a source control treatment remedy has equaled or exceeded the percentage with only source control containment.

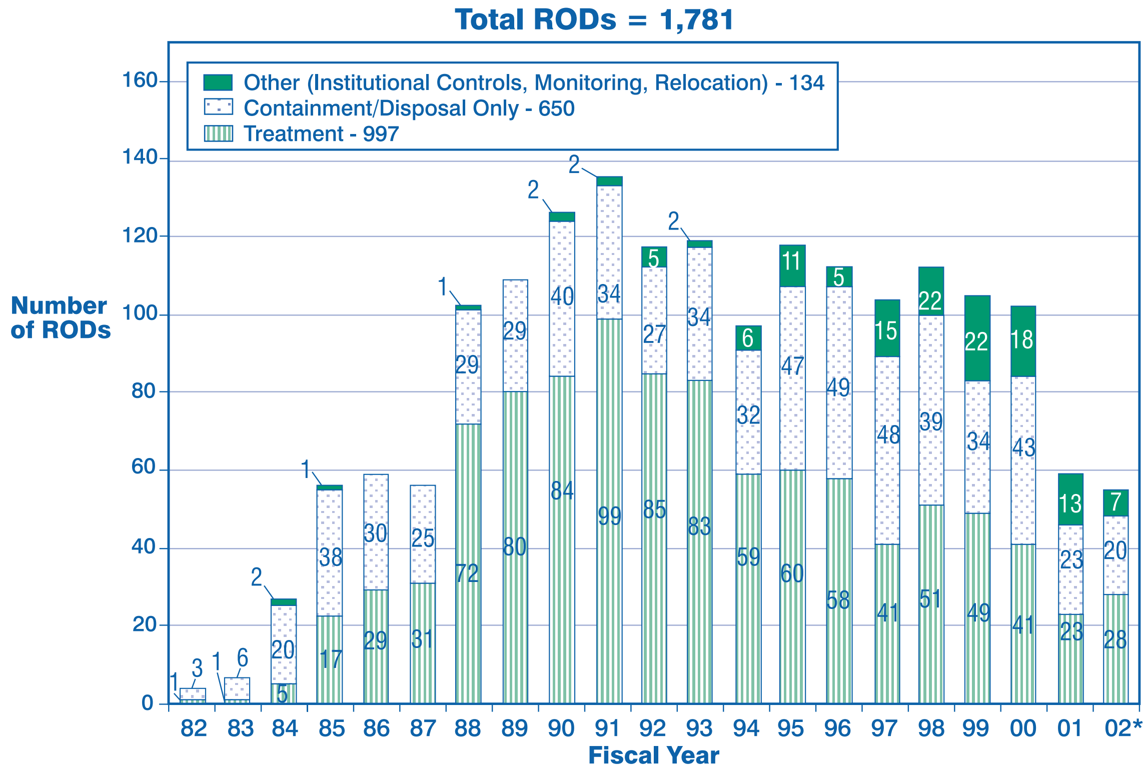
Cumulatively, 50% of source control RODs are of the type "treatment," 43% "containment or disposal," and 6% "other source remedy." From FY 1997 - 2002, the percentage of each type of source control remedy has remained relatively constant, with approximate values of 40% treatment, 40% containment, and 20% other. From FY 1988 - 1996, the percentage of source control treatment RODs was generally higher, ranging from 51% to 73%, while the percentage of containment and other source control remedies was generally lower.

In Situ Versus *Ex Situ* Technologies

In situ technologies for source control are those applications in which the contaminated medium is treated or the contaminant is removed without excavating, pumping, or otherwise moving the contaminated medium to the surface. Implementation of *ex situ* technologies requires excavation, dredging, or other processes to remove the contaminated medium before treatment either on site or off site.

Over FY 1982 - 2002, 863 treatment technologies were selected for source control. Of these, 42%

Figure 5: Superfund Remedial Actions: Source Control RODs (FY 1982 - 2002)*

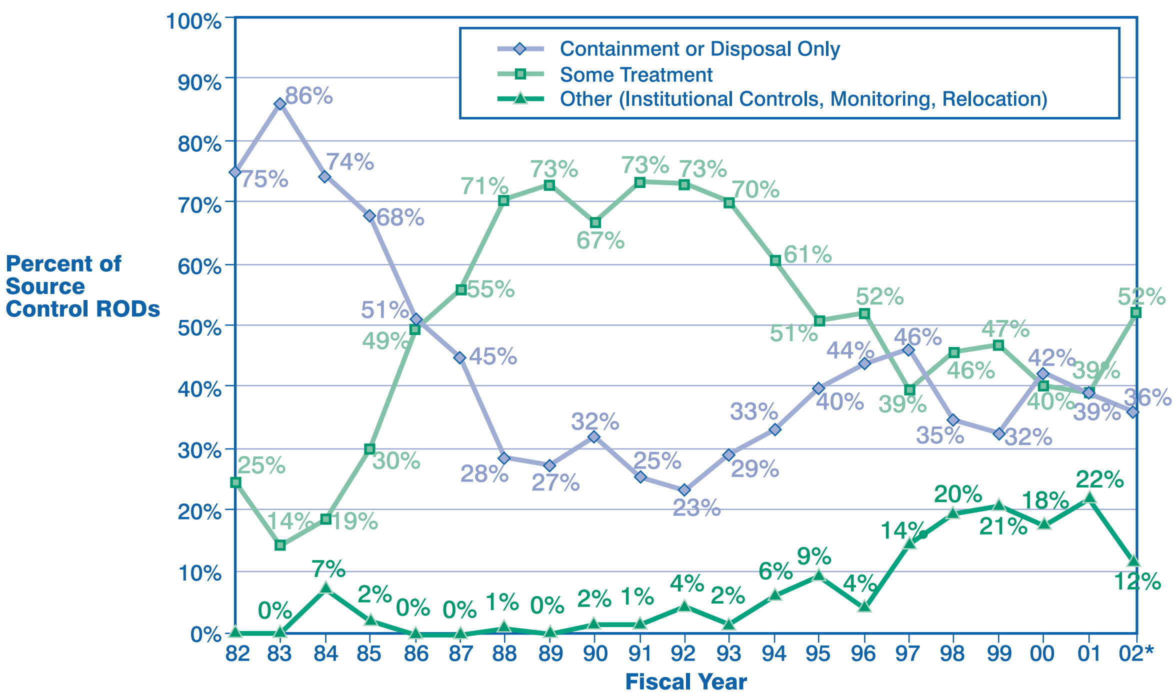


ROD = Record of Decision

** Includes information from an estimated 70% of FY 2002 RODs.*

Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Figure 6: Superfund Remedial Actions: Trends in Types of Source Control RODs (FY 1982 - 2002)*



ROD = Record of Decision

** Includes information from an estimated 70% of FY 2002 RODs.*

Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

were *in situ* technologies and 58% were *ex situ* technologies. Figure 7 provides a cumulative overview of *in situ* and *ex situ* treatment technologies selected for source control.

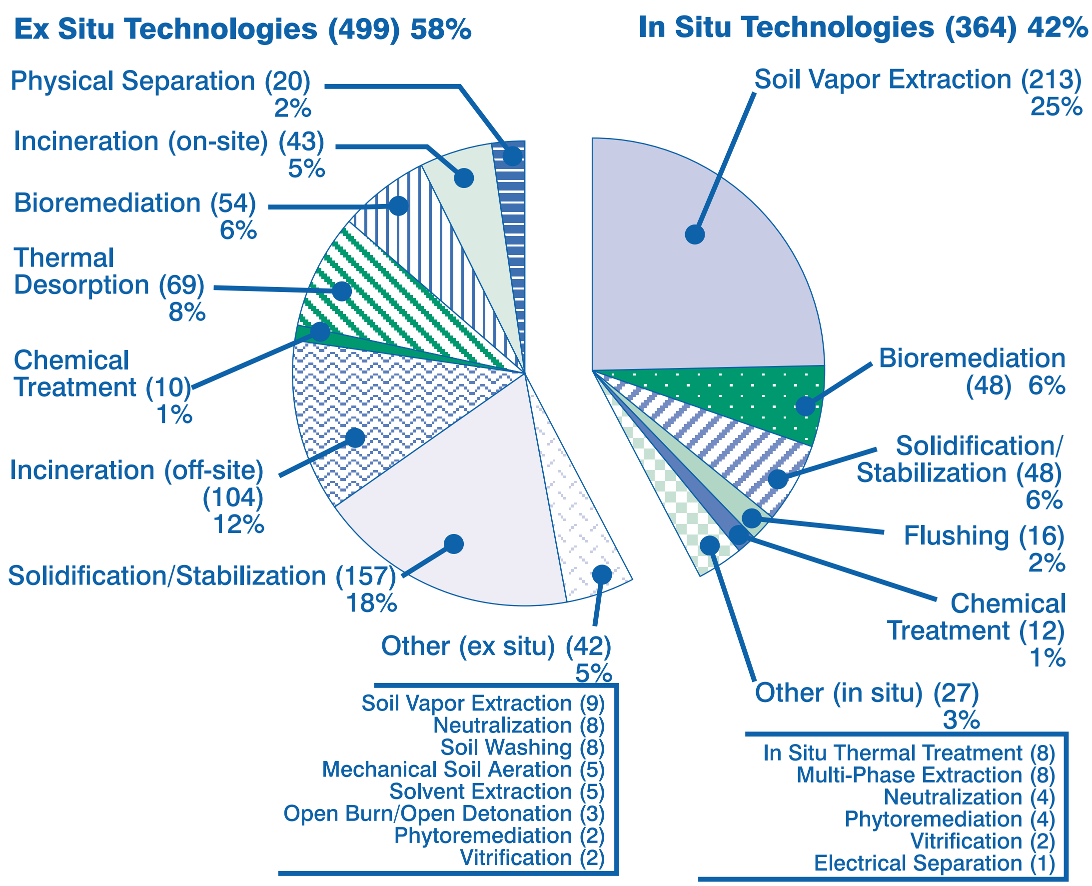
As Figure 7 indicates, SVE (213 projects, 25%), bioremediation (48 projects, 6%), and S/S (48 projects, 6%) are the most common *in situ* technologies, together making up 85% of all *in situ* source control treatment projects.

The most common *ex situ* technologies are S/S (157 projects, 18%), incineration (147 projects, 17%), thermal desorption (69 projects, 8%), and bioremediation (54 projects, 6%). These technologies together represent 86% of *ex situ* source control treatment projects.

Since the Tenth Edition of the ASR (ROD data through FY 1999), an additional 107 source control treatment projects have been selected. As shown in Figure 8, *in situ* SVE and bioremediation and *ex situ* S/S, incineration, and thermal desorption are still the most frequently selected technologies. More than half of all *in situ* chemical treatment projects (7 of 12) have been selected during the last three years. The increased use of this technology is discussed in more detail in Section 4. Bioremediation and thermal desorption also made up a significantly larger percentage of projects in FY 2000 - 2002. Many of the more common conventional technologies were selected with less frequency, including incineration (both on- and off-site), S/S (both *in* and *ex situ*), and SVE. The number of physical separation projects increased primarily because the definition of the technology was expanded to include decontamination of debris and dewatering of sediments for this edition of the ASR.

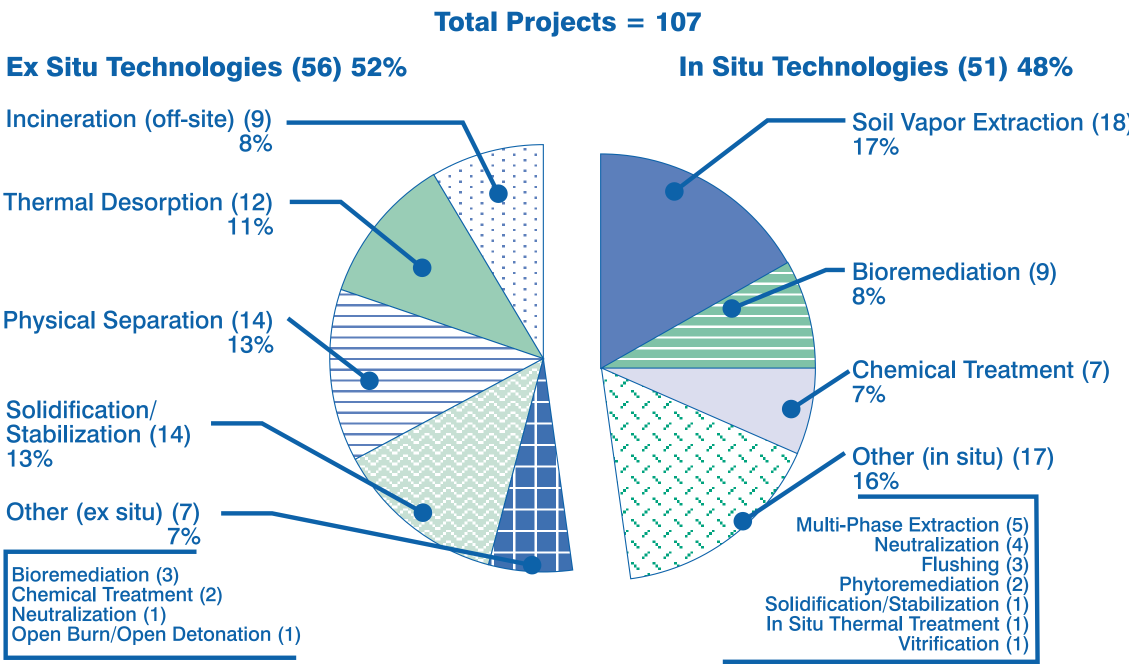
Figure 9 presents the number of *in situ* technologies as a percentage of all treatment technologies for source control by FY. As shown in Figure 9, *in situ* treatment technologies display an increasing trend as a percentage of all treatment technology projects between FY 1985 - 2002. The figure does not include FY 1982 through 1984 because too few RODs were signed during those years to develop accurate information about trends

Figure 7: Superfund Remedial Actions: Source Control Treatment Projects (FY 1982 - 2002)*



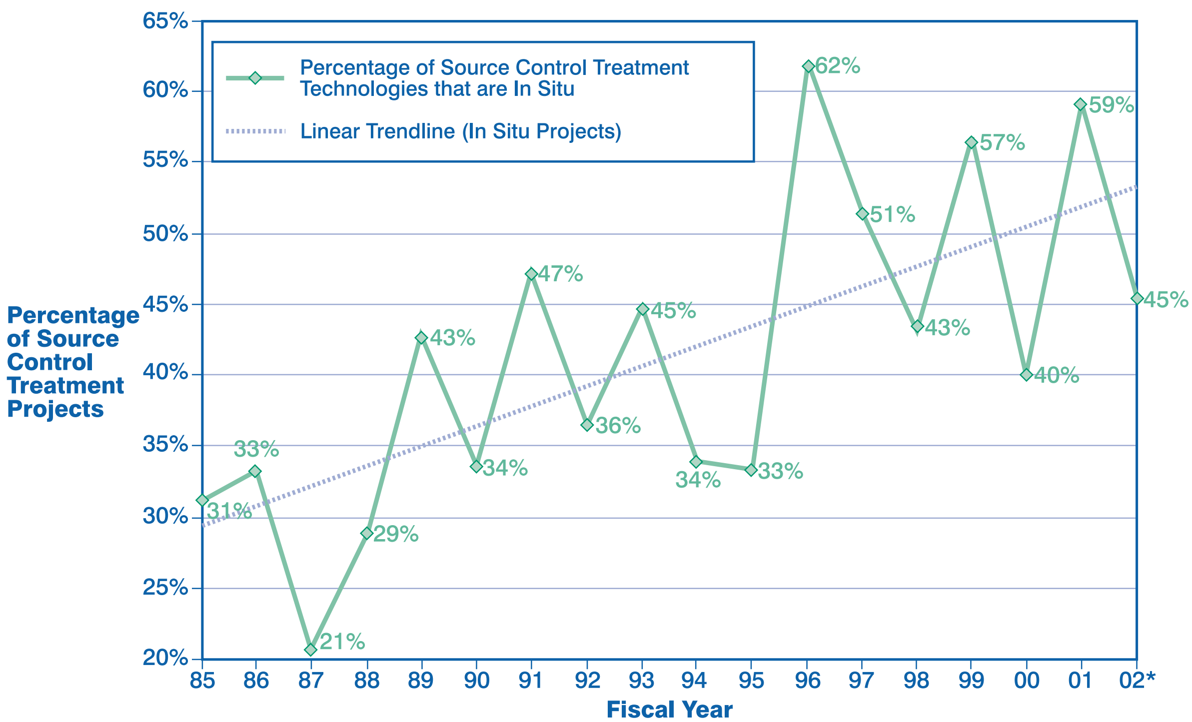
** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Figure 8: Superfund Remedial Actions: Source Control Treatment Projects Selected in FY 2000, 2001, and 2002*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Figure 9: Superfund Remedial Actions: In Situ Technologies for Source Control (FY 1985 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

in remedy selection. A 5-year moving average of the percentage of *in situ* treatment technologies shows a generally steady increase from 31% (FY 1985 - 1989) to 49% (FY 1998- 2002). The factors that may play a role in this upward trend include the following:

- Because *in situ* technologies require no excavation, risk from exposure to contaminated media is reduced, compared with levels of risk associated with *ex situ* technologies that do require excavation.
- For large sites where excavation and materials-handling for *ex situ* technologies can be expensive, *in situ* technologies are often more cost-effective.
- As *in situ* treatment technologies are used more frequently, they are receiving greater acceptance as a reliable technology by site managers, regulators, and other remediation professionals.

Appendix B contains a list of treatment technology projects for source control at remedial sites by EPA Region. The appendix can be accessed at *http://clu-in.org/asr*.

Status of Source Control Treatment Projects

Figure 10 shows the status of *in situ* and *ex situ* source control treatment projects, comparing the projects in the Tenth Edition of the ASR (data collected through August 2000) with the Eleventh Edition of the ASR (data collected through March 2003).

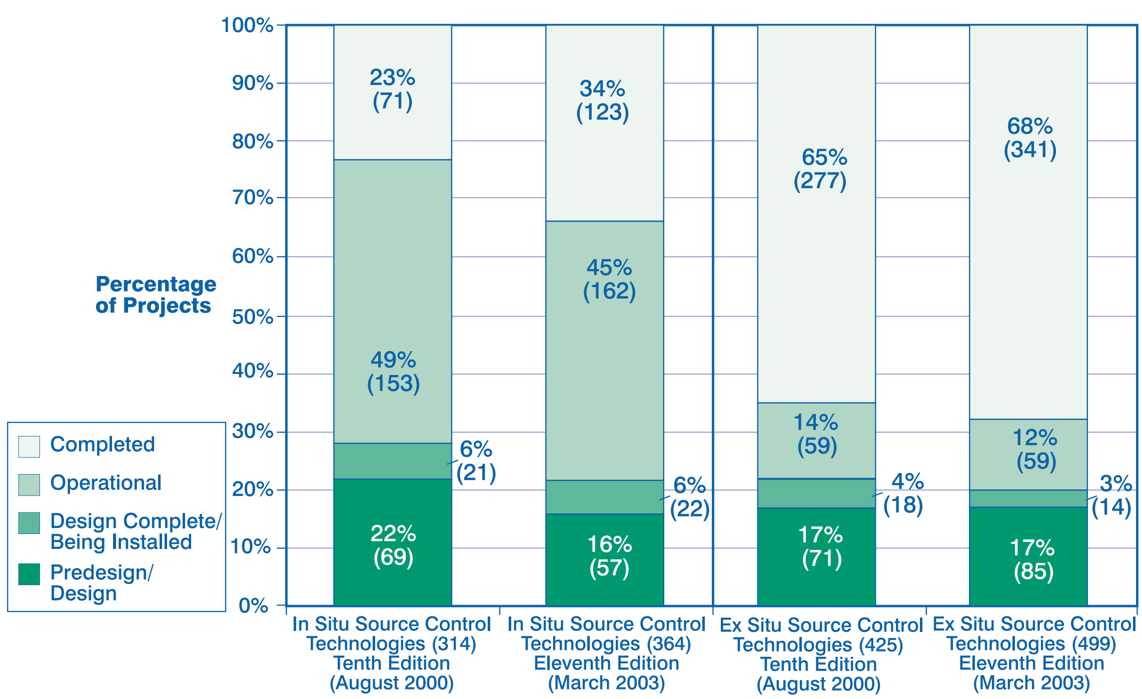
Based on the data in Figure 10:

- For *in situ* and *ex situ* source control projects, the number of completed projects increased by 73% and 23%, respectively. This increase indicates that Superfund sites continue to make progress in treating contaminant sources.
- The percentage of completed *in situ* source control projects increased from 23% in August 2000 to 34% in March 2003.

The status of treatment selected in FY 2000 - 2002 at Superfund remedial action sites includes:

- 107 additional treatment technology projects for source control were selected.

Figure 10: Superfund Remedial Actions: Status of In Situ and Ex Situ Source Control Treatment Projects Comparison Between Tenth and Eleventh Editions of the ASR (FY 1982 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

- Nine projects selected in this period have also been completed, including three off-site incineration projects, two *ex situ* S/S projects, two thermal desorption projects, one SVE project, and one bioremediation project.
- An additional 18 projects selected in the period became operational.

Table 2 provides a summary of project status for each technology type. Some 85% of the SVE projects are in the operational or completed phases. Among *ex situ* technologies, bioremediation has the same number of projects (17) that are operational as S/S, even though bioremediation is only the fourth most common *ex situ* technology (see Figure 7). The high percentage may be the result of the length of time required for bioremediation, compared with other *ex situ* technologies. Bioremediation enhances the ability of microorganisms to degrade contaminants through the addition of nutrients and oxygen. The time required to reach cleanup goals using bioremediation is limited by the degradation processes and depends on many factors such as the specific contaminant, temperature, and moisture. Because of those considerations, treatment by bioremediation (*in situ* or *ex situ*) typically requires a

Table 2. Superfund Remedial Actions: Status of Source Control Treatment Projects by Technology (FY 1982 - 2002)*

Technology	Predesign/ Design	Design Complete/ Being Installed	Operational	Completed	Total
In Situ					
Soil Vapor Extraction	21	10	109	73	213
Bioremediation	10	1	28	9	48
Solidification/Stabilization	7	5	3	33	48
Flushing	3	0	10	3	16
Chemical Treatment	7	2	2	1	12
In Situ Thermal Treatment	2	1	2	3	8
Multi-Phase Extraction	3	1	4	0	8
Neutralization	1	1	2	0	4
Phytoremediation	2	1	1	0	4
Vitrification	1	0	0	1	2
Electrical Separation	0	0	1	0	1
Total	57	22	162	123	364
Percentage of In Situ Technologies	*16%*	*6%*	*45%*	*34%*	—
Percentage of All Source Control Technologies	*7%*	*3%*	*19%*	*14%*	*42%*
Ex Situ					
Solidification/Stabilization	27	8	17	105	157
Incineration (off-site)	9	0	7	88	104
Thermal Desorption	13	0	4	52	69
Bioremediation	9	1	17	27	54
Incineration (on-site)	1	1	1	40	43
Physical Separation	13	1	3	3	20
Chemical Treatment	3	0	0	7	10
Soil Vapor Extraction	0	1	4	4	9
Neutralization	1	0	1	6	8
Soil Washing	4	1	1	2	8
Mechanical Soil Aeration	0	1	0	4	5
Solvent Extraction	2	0	2	1	5
Open Burn/Open Detonation	1	0	1	1	3
Phytoremediation	0	0	1	1	2
Vitrification	2	0	0	0	2
Total	85	14	59	341	499
Percentage of Ex Situ Technologies	*17%*	*3%*	*12%*	*68%*	—
Percentage of All Source Control Technologies	*10%*	*2%*	*7%*	*39%*	*58%*

** Includes information from an estimated 70% of FY 2002 RODs.*

Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Download file containing source data for Table 2.

longer period of time than other *ex situ* technologies, such as incineration, thermal desorption, or S/S, for which the treatment rate is limited primarily by the capacity and throughput of the equipment used.

Time Between ROD Signature and Project Completion

The amount of time required between signature of a ROD selecting a particular source control treatment technology and completion of the project depends on many factors, such as the treatment rate of the technology, the need for mobilization or construction, pilot-scale testing, the amount of media to be treated, contaminant concentrations, and the time needed for permits or other approvals. Table 3 shows the average amount of time between ROD signature and project completion for technologies where completion date information are available for more than 15 completed projects.

Off-site incineration and *in situ* S/S projects have the shortest duration, at about 4 years. Although S/S is an *in situ* treatment, it is an established treatment technology, does not require excavation, and can be completed in relatively short treatment times. *Ex situ* S/S is the technology with the most completed projects, and averages 4.5 years per project. However, the duration ranges significantly, with some projects being completed in the same year as ROD signature, and others requiring up to 10 years. The data presented in Table 3 include only completed projects. *Ex situ* bioremediation projects have the longest duration (6 years). This technology typically requires pilot testing and can be slowed by many site-specific factors, such as climate and soil and contaminant characteristics. Operating dates are available for many of the projects from the ASR Search System at *http://cfpub.epa.gov/asr/*. See Box 4 for more details on the ASR Search System.

Innovative Applications

In the Overview section, innovative technologies were defined as alternative treatment technologies that have a limited number of applications and limited data on cost and performance. Innovative technologies have the potential for providing more cost-effective and reliable alternatives for cleanup of contaminated soils and groundwater.

For example, DNAPLs historically have been difficult to treat because of their behavior in the environment. Because DNAPLs tend to pool below the groundwater table, they may not contact soil vapor, and therefore are not effectively treated by technologies that extract soil vapor, such as SVE, which removes soil vapor from the vadose zone. However, innovative technologies such as *in situ* thermal treatment or *in situ* flushing can effectively treat DNAPLs in some cases. In other cases, an innovative technology may be less expensive than an established technology. It may be expensive to treat soils deep below the ground surface by incineration because of the amount of excavation required to reach the soil. However, an *in situ* chemical oxidation process may work effectively at that depth, resulting in a lower cost. Other reasons for selecting innovative technologies can include reduction in the exposure of workers to contaminated media; reduction in costs for excavation and materials handling (*in situ* technologies); and community concern about off-site releases of contaminants, noise, or odor. Box 7 summarizes an example of an established remedy (incineration) that was changed to an innovative one (bioremediation).

Table 3. Superfund Remedial Actions: Average Number of Years from ROD Signature until Project Completion (FY 1982 - 2002)*

Technology	Average Number of Years from ROD Date until Technology Complete	Number of Completed Projects	Number of Projects with Dates of Completion
Incineration (off-site)	4	88	41
Solidification/Stabilization (*in situ*)	4	33	26
Solidification/Stabilization (*ex situ*)	4.5	105	84
Thermal Desorption	4.5	52	41
Soil Vapor Extraction (*in situ*)	5	73	43
Incineration (on-site)	5	40	37
Bioremediation (*ex situ*)	6	27	15

ROD = Record of Decision
** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

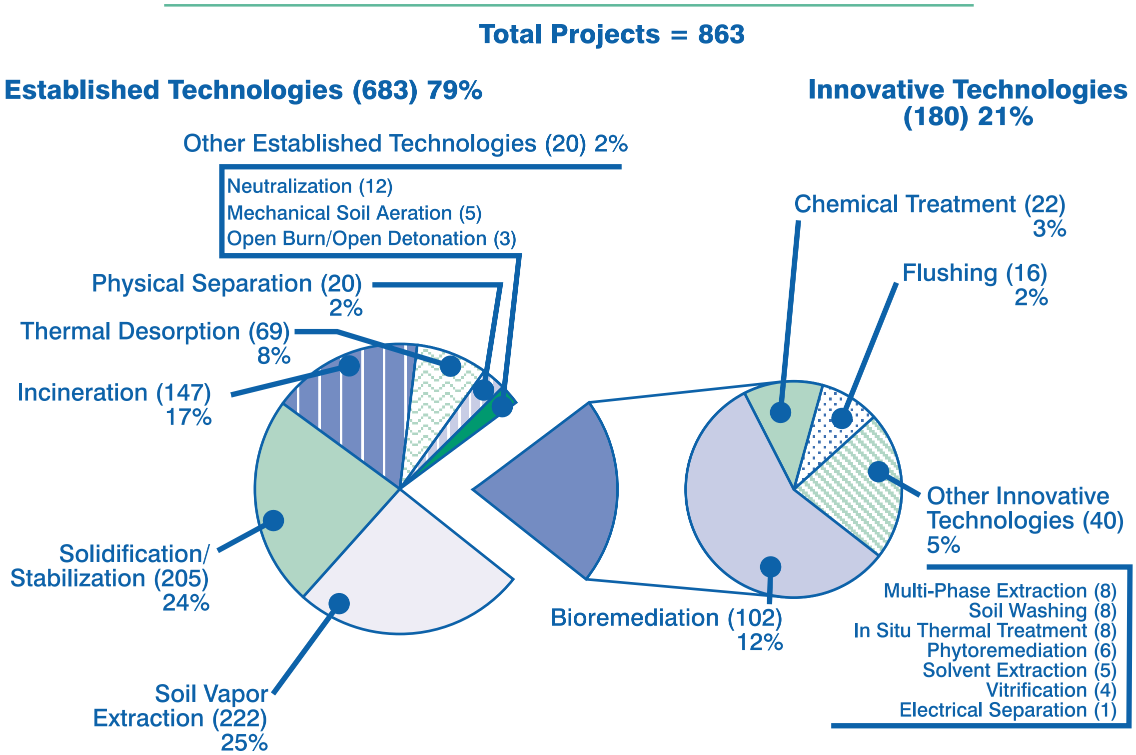
For source control treatment, Figure 11 depicts the number and types of innovative and established technologies used. As shown, innovative treatment technologies represent 21% of all technologies used for source control. Bioremediation makes up more than half of the innovative applications (102). *In situ* chemical treatment and flushing are the second and third most frequently selected innovative technologies. Innovative technologies being used for fewer than 9 projects at Superfund sites are listed under the other innovative technology category, which includes a total of 7 technologies and 40 applications.

The number of applications of a technology is not necessarily indicative of its effectiveness. In some cases, the technology may have only recently become available and has not had time to become widely accepted and used at Superfund sites. In other cases, the technology may be designed for specific types of applications, such as certain contaminants or media. For example, vitrification typically has higher energy costs than other technologies. However, when radioactive contaminants are mixed with other hazardous chemicals, vitrification is often capable of destroying the hazardous chemicals in addition to immobilizing the radioactive contaminants. In three of the four vitrification applications, the contaminants treated included a mixture of radioactive and other contaminants.

Box 7. Innovative Source Control Treatment

An innovative technology, bioremediation, replaced an established technology, incineration, at the MacGillis & Gibbs Co./Bell Lumber and Pole Co. site. This site consists of two adjacent wood preserving facilities in New Brighton, MN. Both facilities have been active since the 1920's. The soil at Operable Unit (OU) 3 has been contaminated with halogenated and nonhalogenated semivolatile organic compounds, including pentachlorophenol, polycyclic aromatic hydrocarbons, dioxins, and furans. A ROD issued for OU 3 in 1994 specified on-site incineration for organic-contaminated soils. In 1999, a ROD amendment was signed, which changed the remedy from on-site incineration to bioremediation. A new remedy was selected because of the high costs associated with incineration and new risk-based determinations for future land use. In addition, EPA issued the document "Presumptive Remedies for Soils, Sediments, and Sludges at Wood Treater Sites" in 1995, which identified bioremediation as a presumptive remedy. Based on these factors, *ex situ* bioremediation was selected for 18,000 cy of soil. This remedy was completed in November 2002.

Figure 11. Superfund Remedial Actions: Innovative Applications of Source Control Treatment Technologies (FY 1982 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*

Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

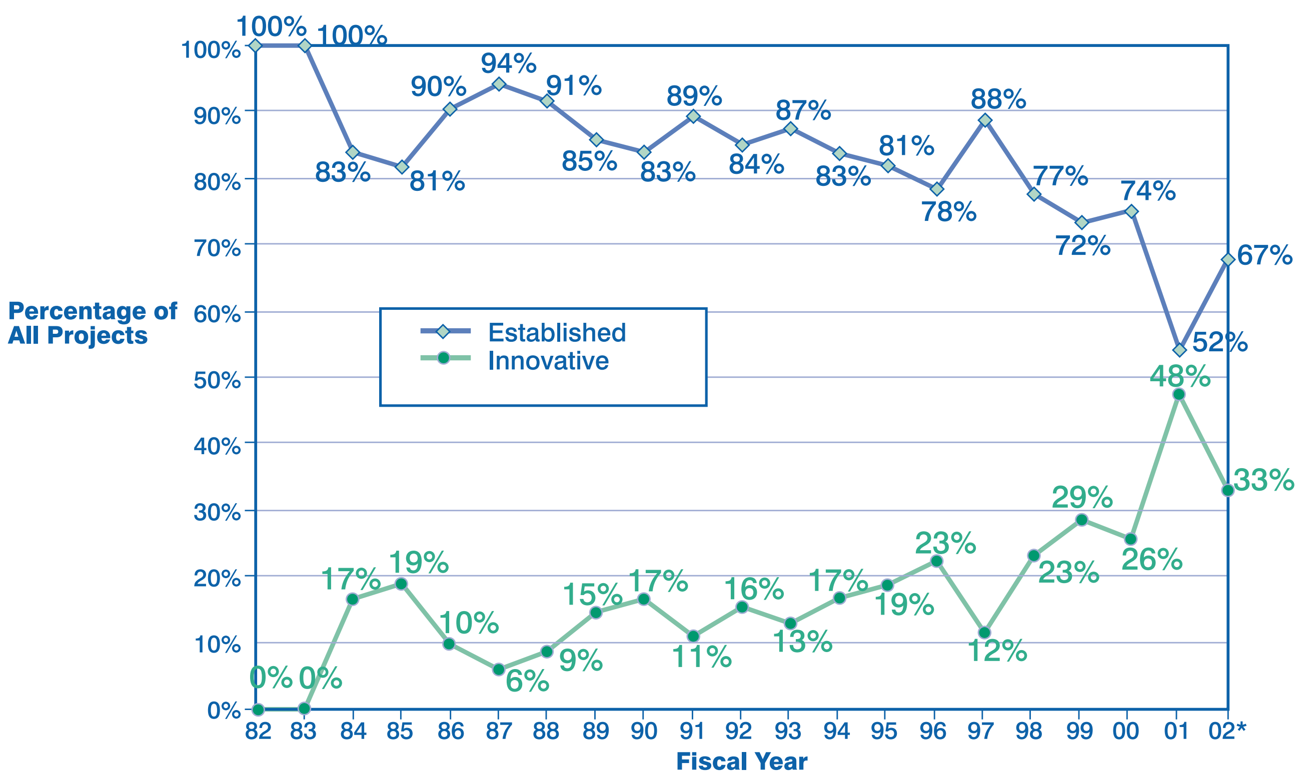
Figure 12 depicts the percentage of projects selected for innovative and established technologies for both source control and groundwater by FY. This figure includes both source control and groundwater projects to provide a broader perspective on the overall trends in innovative technology use. The figure shows that while established technologies historically have been the most frequently used, the frequency of their use relative to innovative technologies has been relatively stable from the mid-1980s through FY 1997. Since FY 1997, the use of innovative technologies has increased and peaked in FY 2001 at 48%. In FY 2001, the percentage of projects using innovative technologies was almost equal to the percentage for established technologies for the first time. This declining trend for established technologies is most dramatic for incineration, which peaked at 18% in FY 1990 and declined to 3% in FY 2002.

The FRTR case studies web site *(http://www.frtr.gov/costperf.htm)* provides detailed information on the cost and performance of both innovative and established technologies applied at Superfund sites. As of June 2003, the FRTR had 342 case studies covering a wide range of treatment technologies that are available for viewing on-line or for downloading from the FRTR website. The case studies were developed by the EPA, Department of Defense, Department of Energy, and National Aeronautics and Space Administration for Superfund and non-Superfund sites. They present available cost and performance information for full-scale remediation efforts and large-scale demonstration projects. They also provide information about site background and setting, contaminants and media treated, technology, cost and performance, and points of contact for the technology application.

Innovative Treatment Trains

Two or more innovative and established technologies may be used together in treatment trains, which are either integrated processes or a series of treatments that are combined in sequence to provide the necessary treatment. Some treatment trains are employed when no single technology is capable of treating all the contaminants in a particular medium. For example, soil contaminated with organics and metals may be treated first by bioremediation to remove organics, and then by S/S to reduce the

Figure 12: Superfund Remedial Actions: Established and Innovative Projects (FY 1982 - 2002)*

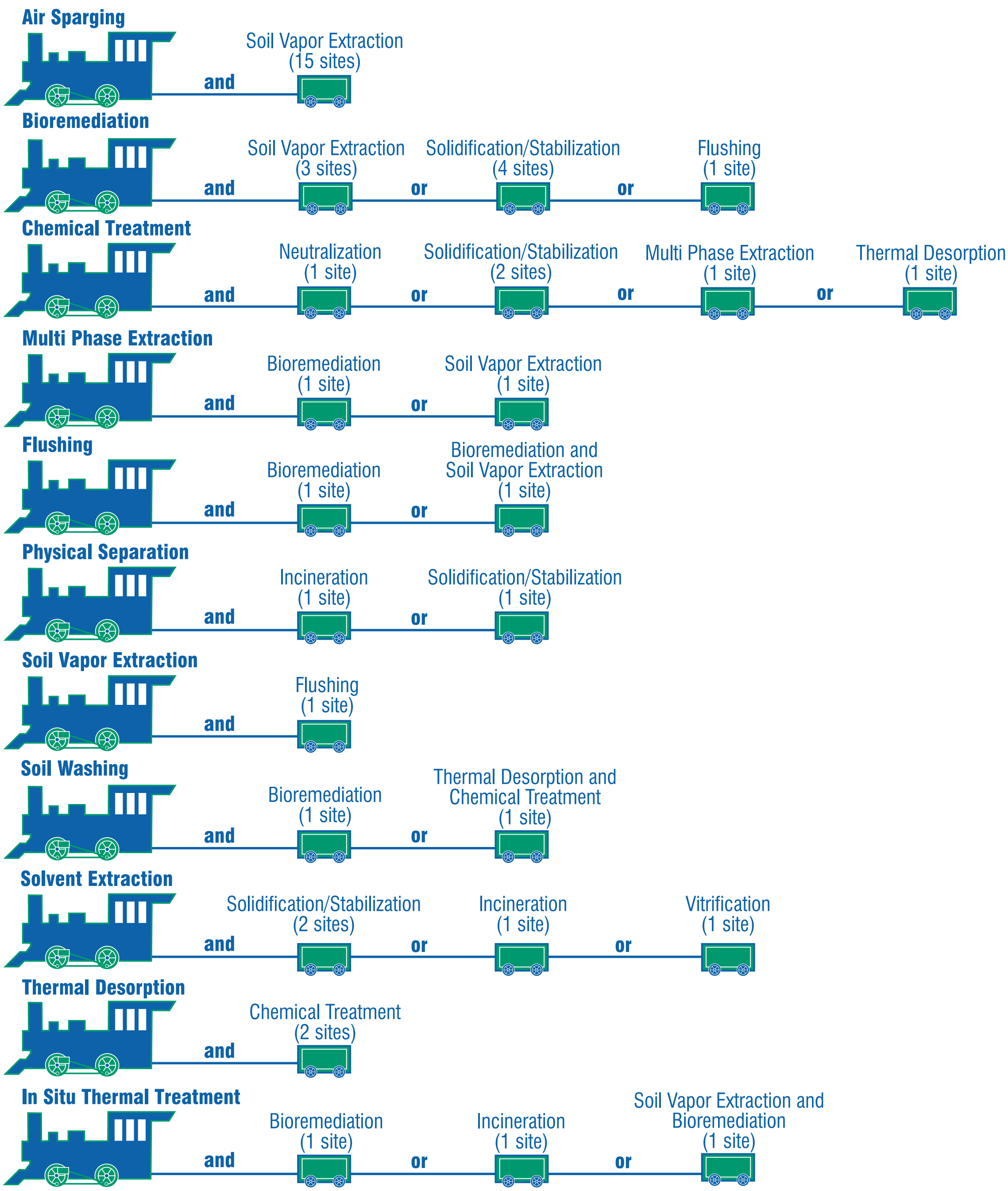


** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

leachability of metals. In other cases, a treatment train might be used to render a medium more easily treatable by another technology, reduce the amount of waste that requires further treatment by a more expensive technology, prevent the emission of volatile contaminants during excavation and mixing, or minimize the overall cost of the treatment.

Treatment trains that include one or more innovative technologies are the selected source control remedy at 46 Superfund sites. Figure 13 identifies specific treatment trains used in remedial actions. Innovative treatment technologies may be used with established technologies or with other innovative technologies. The most common treatment trains are air sparging used in conjunction with SVE, and bioremediation followed by S/S or SVE. In the case of air sparging used with SVE, the air sparging is used to remove contaminants from groundwater *in situ*, while the SVE captures the contaminants removed from the

Figure 13. Superfund Remedial Actions: Treatment Trains with Innovative Treatment Technologies (FY 1982 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

groundwater and removes contaminants from the soil above the groundwater (the vadose zone). A detailed discussion of the volumes of soil for these projects is contained in the Treatment Trains and Their Effects on Quantity of Soil Treated section.

Contaminants Addressed

Table 4 summarizes the contaminants being targeted by specific technologies. Nine major groups of contaminants were analyzed for this report. Compounds were categorized as halogenated VOCs, semivolatile organic compounds (SVOC), or polycyclic aromatic hydrocarbons (PAH) according to the lists provided in EPA's SW-846 test methods 8010, 8270, and 8310, with the exceptions noted in Table 4. Overall, approximately 75% of the source control treatment projects address organics and more than 25% of projects address metals. The number of projects in Table 4 exceeds the total number of projects in Figure 7 because some projects involve more than one type of contaminant. Therefore, such projects are listed in Table 4 multiple times, once for each contaminant type.

The selection of a treatment technology for a site often depends on the physical and chemical properties of the contaminants. For example, VOCs are amenable to treatment by certain technologies, such as SVE, because of their volatility. In other cases, metals, which are not volatile and do not degrade, are not usually amenable to treatment by SVE and thermal desorption. Because metals form insoluble compounds when combined with appropriate additives, such as Portland cement, S/S is most often used for treatment of those contaminants.

As Table 4 shows, halogenated VOCs; benzene, toluene, ethylbenzene, and xylene (BTEX); and non-

Table 4. Superfund Remedial Actions: Contaminants Treated by Source Control Technologies (FY 1982 - 2002)*

Technology	Total number of projects[a]	Polycyclic aromatic hydrocarbons	Other nonhalogenated semivolatile organic compounds[b]	Benzene-toluene-ethylbenzene-xylene	Other nonhalogenated volatile organic compounds[c]	Organic pesticides and herbicides	Other halogenated semivolatile organic compounds[d]	Halogenated volatile organic compounds	Polychlorinated biphenyls	Metalloids and metals
Soil Vapor Extraction	222	14	31	**102**	48	3	27	**183**	0	0
Solidification/ Stabilization	205	16	18	12	13	14	7	14	35	**174**
Incineration	147	28	41	35	23	36	34	**47**	37	6
Bioremediation	102	38	**49**	30	29	25	15	16	1	2
Thermal Desorption	69	20	16	23	15	9	11	**30**	14	2
Chemical Treatment	22	1	2	3	2	2	2	7	4	**11**
Physical Separation	20	6	2	1	0	3	0	0	5	**7**
Flushing	16	3	6	5	4	1	4	**10**	0	5
Neutralization	12	0	0	0	0	0	0	0	0	0
Multi-Phase Extraction	8	1	1	**5**	2	0	2	**5**	1	0
Soil Washing	8	2	1	0	0	2	0	0	1	**3**
In Situ Thermal Treatment	8	**5**	0	2	0	3	2	3	0	0
Phytoremediation	6	1	2	2	2	1	1	3	0	**4**
Mechanical Soil Aeration	5	0	0	1	1	0	1	**4**	0	0
Solvent Extraction	5	2	1	0	1	1	0	2	**3**	1
Vitrification	4	0	0	1	1	0	1	**2**	**2**	1
Open Burn/ Open Detonation	3	0	**2**	0	0	0	1	0	0	0
Electrical Separation	1	0	0	0	0	0	0	**1**	0	0
Total Projects	863	139	172	222	141	100	108	327	103	216

** Includes information from an estimated 70% of FY 2002 RODs.*

[a] Each project may treat more than 1 contaminant group.

[b] Does not include polycyclic aromatic hydrocarbons.

[c] Does not include benzene, toluene, ethylbenzene, and xylene.

[d] Does not include organic pesticides and herbicides.

Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

halogenated VOCs are treated most often by SVE. Non-halogenated SVOCs and PAHs are treated most often by bioremediation. Polychlorinated biphenyls (PCB), organic pesticides/herbicides, and halogenated SVOCs are treated most often by incineration. Metals are treated almost exclusively by S/S. An interesting exception is the use of bioremediation to treat metals in two projects. However, these projects are in the design phase, and the effectiveness of bioremediation for metals at these sites has not yet been demonstrated.

EPA has developed the Hazardous Waste Cleanup Information (CLU-IN) Contaminant Focus area (*http://www.clu-in.org/contaminantfocus/*), which bundles information associated with the cleanup of individual contaminants and contaminant groups. This information is presented in categories including Overview, Policy and Guidance, Chemistry and Behavior, Environmental Occurrence, Toxicology, Detection and Site Characterization, Treatment Technologies, Conferences and Seminars, and Other Resources. Contaminant Focus will be continuously updated with information from federal cleanup programs, state sources, universities, nonprofit organizations, peer-reviewed publications, and public-private partnerships. New contaminants will be added on a periodic basis.

Quantity of Soil Treated

Table 5 shows the results of an analysis of the quantity of soil addressed by the various treatment technologies. Data on the quantity of treated soil are available for 217 *in situ* projects and 325 *ex situ* projects for which source control treatment technologies were selected to treat soil. Typically, *in situ* technologies are used to address larger

Table 5. Superfund Remedial Actions: Estimated Quantities of Soil Treated by Source Control Technologies (FY 1982 - 2002)*

	Total Number of Projects	Number of Projects with Data	Minimum (cubic yards)	Median (cubic yards)	Average (cubic yards)	Maximum (cubic yards)	Total Quantity (cubic yards)
Ex Situ							
Bioremediation	54	46	21	12,750	74,000	1,936,000	3,400,000
Chemical Treatment	10	7	760	21,000	22,000	50,000	154,000
Incineration (off-site)	104	51	5	1,000	4,800	23,000	247,000
Incineration (on-site)	43	34	12	21,000	50,000	330,000	1,714,000
Mechanical Soil Aeration	5	3	2,100	NC	NC	12,000	16,600
Phytoremediation	2	2	850	NC	NC	10,900	11,800
Soil Vapor Extraction	9	7	540	2,400	20,000	81,000	137,000
Soil Washing	8	7	6,400	13,600	26,000	100,000	179,000
Solidification/Stabilization	157	105	18	12,700	51,000	1,071,000	5,322,000
Solvent Extraction	5	4	7,000	NC	NC	300,000	329,000
Thermal Desorption	69	59	250	16,400	32,400	137,000	1,913,000
Average	-	-	1,600	12,600	35,000	368,300	1,220,000
Total	**466**	**325**	**-**	**-**	**-**	**-**	**13,423,400**
In Situ							
Bioremediation	48	26	3,100	24,000	313,000	5,760,000	8,127,000
Chemical Treatment	12	6	2,200	15,800	18,700	41,000	112,000
Multi-Phase Extraction	8	2	77,000	NC	NC	100,000	177,000
Flushing	16	9	2,000	19,000	131,000	1,000,000	1,180,000
Phytoremediation	4	2	60,000	NC	NC	101,000	178,000
Soil Vapor Extraction	213	134	2	31,000	176,000	6,100,000	23,587,000
Solidification/ Stabilization	48	31	180	21,000	99,000	1,920,000	3,063,000
In Situ Thermal Treatment	8	7	200	23,000	567,000	3,528,000	3,969,000
Average	-	-	18,100	22,300	217,500	2,319,000	5,000,000
Total	**357**	**217**	**-**	**-**	**-**	**-**	**40,393,000**
Average for All Technologies	-	-	8,600	16,800	113,000	1,190,000	2,832,000
Total for All Technologies	**823**	**542**	**-**	**-**	**-**	**-**	**53,816,400**

Technologies with data on fewer than two projects were not listed in this table.
** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

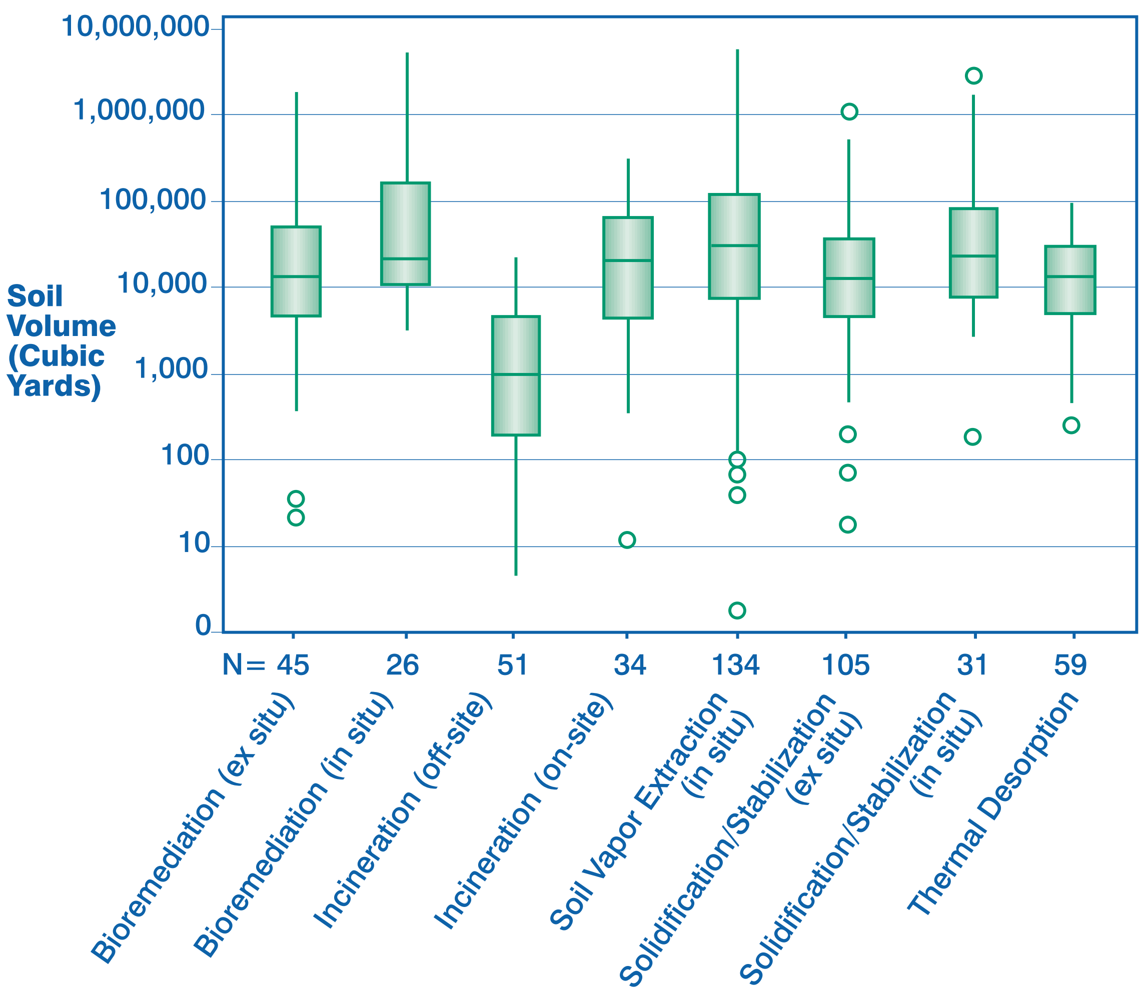
quantities of soil, while *ex situ* technologies are used to treat smaller quantities. Because quantities for *in situ* projects often cannot be determined accurately and many projects have not been completed, the quantities in Table 5 should be considered estimates. Based on the 65% of projects for which data are available, an estimated 82 million cy of soil have been treated.

For *ex situ* technologies, the median volume of soil treated per project ranged from approximately 1,000 cy for off-site incineration to 21,000 cy for both on-site incineration and chemical treatment. After on-site incineration and chemical treatment, thermal desorption had the next highest median (16,400 cy), followed by bioremediation and soil washing (both with approximately 14,000 cy). For *in situ* technologies, the median volume of soil treated per project ranged from almost 16,000 cy (chemical treatment) to 31,000 cy (SVE).

The volume of soil treated by the 8 technologies (for which data on soil volume were available for at least 10 projects) were plotted for comparison purposes. Figure 14 presents a box-and-whiskers plot of the volume of soil treated by technology type to show the distribution of the data. Because of the wide range in volumes of soil treated, the soil volumes are plotted on a logarithmic scale.

Figure 14 shows the median, 25th, and 75th percentiles, as well as the largest and smallest nonoutlier values. In a box plot, the 25th and 75th percentiles are shown as the ends of the box. The largest and smallest nonoutlier values are shown by the lines that extend from the ends of the box, which are known as the "whiskers." Outliers represent values that are between one and one-half and three box lengths from the top or bottom of the box. Extreme values are more than three box lengths from the top or bottom of the

Figure 14. Superfund Remedial Actions: Box-and-Whiskers Plot of Cubic Yards of Soil Treated (FY 1982 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

box. Outliers and extreme values are depicted on Figure 14 by circles.

With the exception of off-site incineration, the median volume of soil treated for all technologies falls between 10,000 and 100,000 cy. The range of values, as shown by the length of the box and whiskers, is much greater for SVE than for all other technologies, ranging from about 100 cy to almost 10 million cy. The 75th percentile value for SVE and bioremediation (*in situ*) is above 100,000 cy, indicating that the volume being treated by these technologies is above 100,000 cy for 25% of the projects for which data are available.

Comparing similar technologies that can be conducted both *in situ* and *ex situ* shows that *in situ* technologies are typically used to treat larger volumes of soil. As Figure 14 shows, the median volume of soil per project for *in situ* bioremediation is greater than that for *ex situ* bioremediation. The range of soil volumes for bioremediation indicate that, when applied *in situ*, it is more applicable to projects with large volumes of soil. For smaller soil volumes, *ex situ* bioremediation is more applicable. S/S, which has both *in situ* and *ex situ* applications, also tends to treat larger volumes *in situ* and smaller volumes *ex situ*.

Off-site incineration is generally treating the smallest volume of soil with a median volume of only 1,000 cy. On-site incineration is used to treat larger volumes, and has a median of 21,000 cy. Off-site incineration costs are typically based on the volume treated, with no start-up costs. On-site incineration typically entails significant start-up costs related to mobilizing equipment to the site and obtaining permits. However, once an on-site incinerator has started up, the treatment cost per unit of material incinerated is typically lower because costs for off-site transportation are eliminated. Therefore, on-site incineration can be more cost-effective than off-site incineration when treatment of a large amount of material is necessary.

Treatment Trains and Their Effect on Quantity of Soil Treated

The ASR Search System contains data on the volumes of soil treated in 26 treatment trains. These data were evaluated to identify treatment trains that may have an effect on the volumes of soil treated.

At 13 sites where treatment trains were used, the volume of soil treated by each technology in the train remained the same. At 10 sites, the volume of soil decreased from 7% to nearly 100% as it moved through the treatment train. The initial technologies with the largest percent decrease were SVE and bioremediation. Both technologies were followed by S/S.

At three sites, the volume of soil increased as it moved through the treatment train. At Robins Air Force Base in Georgia, the treatment train consisted of SVE to remove volatile organics followed by S/S to immobilize metals. The volume of material increased during the S/S step due to the binders added in the S/S process.

When *in situ* technologies are used in a treatment train, a more aggressive technology may be applied to remediate areas with high contaminant concentrations or NAPLs (hot spots), followed by application of a less aggressive technology to remediate a larger area that includes the former hot spot area. This occurred at two of the three sites where the volume of soil increased between the first and second technologies in the treatment train. At the Southern California Edison, Visalia Pole Yard, *in situ* thermal treatment was used to treat 213,500 cy of soil and removed approximately 55,000 pounds of DNAPL (creosote) contamination. Following the *in situ* thermal treatment, bioremediation (biosparging) was implemented to treat approximately 5,760,000 cy of soil and residual groundwater contamination. At the Petro-Chemical Systems Inc. OU 2, *in situ* thermal treatment was used to treat 330 cy of soil to remove BTEX from two hot spots, followed by the application of SVE to 300,000 cy.

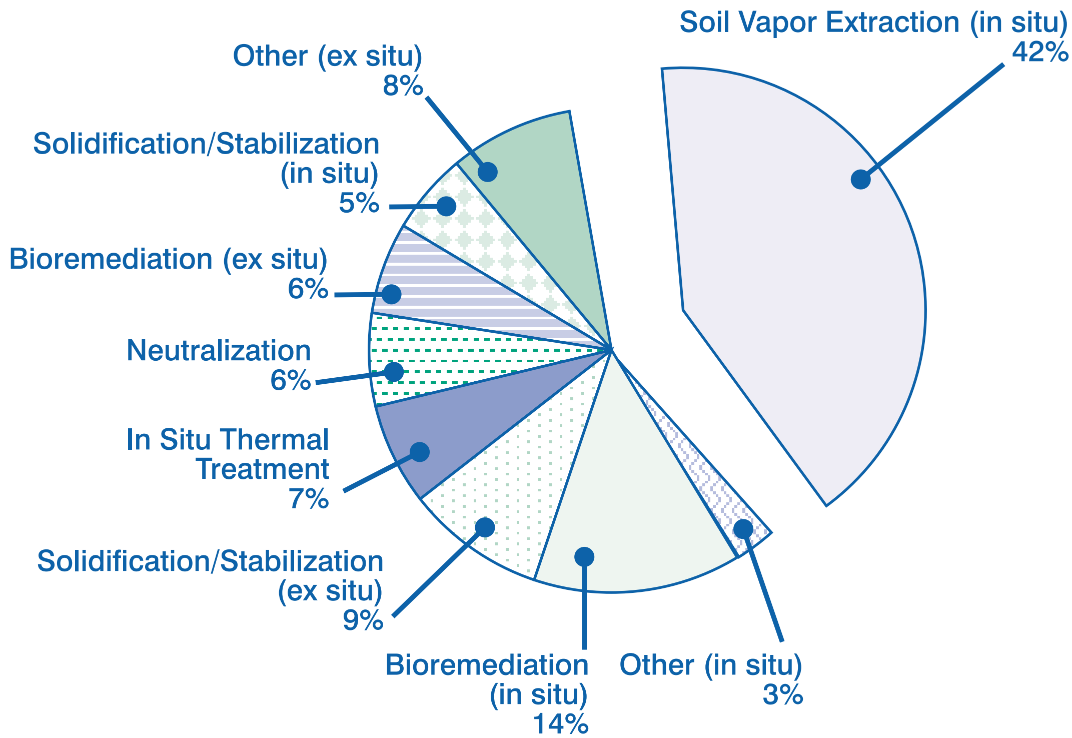
Cumulative Soil Treatment Volumes

Figure 15 shows the percentage of soil volume being treated for each technology type, which indicates SVE treats the largest volume of soil. SVE is the most frequently selected technology at 25% of all source control treatment projects (see Figure 7) and, on average, treats the largest volume of soil (see Figure 14). Those factors explain the large fraction of soil being treated by this technology. Figure 15 is based on the 65% of source control treatments at Superfund remedial action sites where soil treatment data are available.

Remedy Changes

As discussed in Section 1, remedies selected for Superfund remedial actions are documented in a ROD, and changes to the original remedies can

Figure 15: Superfund Remedial Actions: Percentage of Soil Treated by Technology Type (FY 1982 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

be either formally documented or executed through clauses in the original ROD. Remedy changes often occur during the pre-design or design phase of a project when new information about site characteristics is discovered or treatability studies for the selected technologies are completed.

Many of the treatment remedies that were modified involved a change from source control treatment to a remedy that is not source control treatment. Source control treatment remedies have been changed to non-treatment remedies at over 120 Superfund remedial action sites. These remedies are often changed to containment, MNA, or institutional controls. The most commonly cited reason for changing source control treatment to another type of remedy was that further site investigation revealed that the concentration or extent of contamination was less than expected. Other frequently cited reasons included rising groundwater levels making soil treatment impracticable, community concerns about on-site remedies, and high costs.

The Superfund program allows EPA and state environmental regulators the flexibility to modify remedies as site conditions change. The ASR tracks 863 source control treatment projects, not including the 120 that have been changed to non-treatment remedies. Based on a total of 983 source control treatment remedies (863 active plus 120 changed), 12% have been changed.

In 90 instances, one source control treatment technology was replaced with a different treatment technology. Table 6 provides information about the most frequently changed treatment technologies, and the technologies that replaced them, as indicated by cumulative data from FY 1982 - 2002. The source control treatment technologies that were most frequently changed to another source control treatment technology were incineration, bioremediation, and thermal desorption. These technologies are the third, fourth, and fifth most frequently selected treatment technologies (see Figure 7). The most common technologies selected to replace incineration, bioremediation, and thermal desorption were thermal desorption (replacing incineration and bioremediation), S/S, SVE, and incineration (replacing bioremediation and thermal desorption).

Previous editions of the ASR included an appendix (Appendix D) that listed all the technology changes, additions, and deletions made since the previous edition of the ASR. Because the appendix has expanded over time, it is now available on-line at *http://clu-in.org/asr*.

Table 6. Superfund Remedial Actions: Number of Most Commonly Changed Technologies (1982 - 2002)*

	Technology Initially Selected			
New Treatment Technology	Incineration	Bioremediation	Thermal Desorption	Total
Thermal Desorption	9	3	-	12
Solidification/Stabilization	7	3	1	11
Bioremediation	5	-	0	5
Soil Vapor Extraction	3	2	5	10
Solvent Extraction	1	0	0	1
Incineration	-	5	5	10
Air Sparging	0	1	0	1
Chemical Treatment	1	0	1	2
Soil Washing	0	0	1	1
Physical Separation	0	0	1	1
In Situ Thermal Treatment	0	1	0	1
Pump and Treat	0	2	0	2
Total Number of Remedy Revisions	26	17	14	57

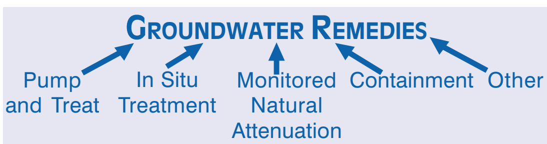
** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Section 3: Groundwater Remedies

In January 2002, EPA published the report Groundwater Remedies Selected at Superfund Sites (EPA 542-R-01-022), which provided information about trends in the selection of P&T, *in situ* treatment, and MNA for groundwater in RODs. This edition of the ASR incorporates and updates the information and analyses from that report. This report focuses on groundwater treatment (P&T and *in situ* treatment) and MNA remedies because they reduce contaminant concentrations or decrease their mobility[1].

Groundwater remedies are delineated by whether the remedy specified: (1) extraction of groundwater followed by aboveground treatment (P&T), (2) *in situ* treatment, (3) MNA, (4) containment using subsurface VEBs, or (5) other actions (such as alternate drinking water supplies or drilling prohibitions), as shown in the box below.

Groundwater Remedy Types



Appendix F defines these remedy types and describes how they are identified. Detailed descriptions of the technologies used to perform groundwater P&T and *in situ* groundwater treatment are presented in the Overview at the beginning of this report.

As shown in Table 7, P&T is the most frequently used groundwater remedy. Because of its prevalence, EPA began an effort to gather more information about P&T remedies and to track the status of P&T projects. For the first time, this report presents detailed information on P&T remedies. See page 39 for a detailed description of the findings.

This report also provides data collected for specific groundwater treatment projects. Detailed information on the status of MNA projects was not collected because it is not a focus of this report. Other groundwater remedies (see Overview), such as well-drilling prohibitions and alternate drinking water supplies, are not a focus of this report because these remedies, while being protective, typically do not directly result in a reduction of contaminant concentrations or a decrease in contaminant mobility.

Groundwater Sites

A groundwater remedy has been implemented or is currently planned at 1,062 sites, 71% of sites on the NPL. As shown in Table 7, P&T has been implemented or is planned at 713 of the sites addressing groundwater. Many sites have more than one type of groundwater remedy. These sites are counted in Table 7 once for each type of groundwater remedy they have. Sites may also have source control remedies in addition to groundwater remedies. Over 700 sites with groundwater remedies also have a source control remedy.

For sites at which several types of groundwater remediation were used, such as a P&T system and *in situ* treatment, the remediation may not have occurred in the same aquifer or groundwater plume. When different types of groundwater remedies are applied to the same contaminant

Table 7. Superfund Remedial Actions: Actual Remedy Types at National Priorities List Sites (FY 1982 - 2002)*

Total Number of Sites with a Groundwater Remedy = 1,062

Remedy Type	Number of Sites
Groundwater Pump and Treat	713
In Situ Treatment of Groundwater	135
MNA of Groundwater	201
Other Groundwater	822

MNA = Monitored natural attenuation
ROD = Record of Decision
**Includes information from an estimated 70% of FY 2002 RODs.*
Sites may be included in more than 1 category. Other groundwater includes sites with groundwater other remedies, as well as groundwater vertical engineered barriers.
Appendix F describes the methodology used to identify remedy types for each site.
Sources: 1, 2, 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.
Download file containing source data for Table 7.

[1] MNA does not generally satisfy the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) preference for treatment because it is not an engineered technology (see Reference 12, on page 50).

plume, they may be used to treat different parts of the plume. For example, an *in situ* groundwater treatment technology may be used for areas that are difficult to treat using P&T, such as hot spots, NAPL source zones, tight clays, fractured rock, and areas with heterogenous hydrogeology. P&T, in turn, may be used to control plume migration and remediate other areas of the plume with lower contaminant concentrations. MNA may be used to treat areas of the plume with relatively low contaminant concentrations that remain above remediation goals. Box 8 describes a site that has selected and implemented groundwater P&T, *in situ* groundwater treatment, and MNA.

Figure 16 shows the use of P&T, *in situ* treatment, and MNA for groundwater, both alone and in combination with other remedies. At least one of these three is a remedy at 851 sites. The most common is P&T only, with 556 sites. The second most common is MNA only at 96 sites. When two types of groundwater remedies were used at the same site, a P&T system was used most frequently with MNA (64 sites) and *in situ* treatment (63 sites). For 30 of the 851 sites, three types of groundwater remedies were used. At most sites where one of these remedies was selected, some form of groundwater treatment was included. P&T or *in situ* treatment was included in the selected remedy at 89% (755) of the sites, while 11% (96) of sites selected only MNA.

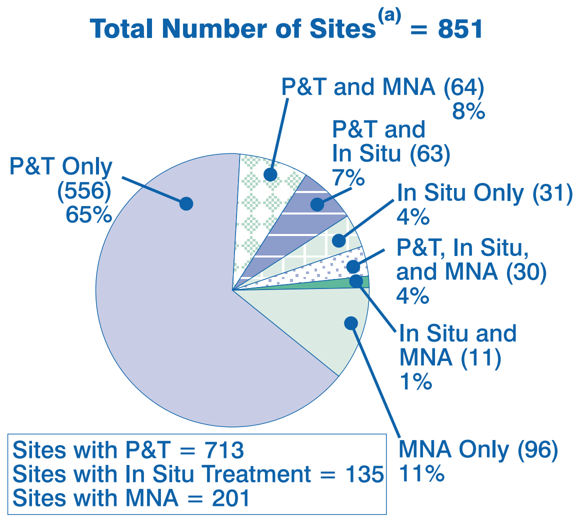
At many of the sites shown in Figure 16, the remedy also includes source control treatment. For example, source control treatment is part of the remedy at 43% of the 556 sites with P&T only. At 41% of the 96 sites with MNA only, source control treatment is also part of the remedy.

Box 8. Site with Multiple Groundwater Remedies

Groundwater contamination at the Naval Air Engineering Station site is being addressed with a combination of P&T, *in situ* treatment, and MNA. The US Navy has used this 7,382 acre site in Lakehurst, NJ since the 1920's for the development and testing of fleet support systems. Fuels, oils, metals, solvents, and other organic compounds have been disposed on-site, and contaminated areas include landfills, open pits, unlined lagoons, and drainage ditches. Petroleum hydrocarbons and volatile organic compounds, including benzene and trichloroethene, have been identified as contaminants of concern in the soil and groundwater.

Several areas (Areas A, B, C, E, H, I, and J) of the site are being remediated with groundwater remedies. At Areas A, B, C, E, and H, groundwater P&T was selected for plume containment through interim RODs in 1991 and 1992. The P&T system is currently operational. In 1997, final RODs were signed, and air sparging was added to Areas A, B, and E to enhance remediation of the most contaminated zone. A ROD was issued in 1999 that selected MNA and *in situ* bioremediation for the higher concentration portions of Areas I and J. Additional groundwater and source control remedies have been selected for other areas at the site.

Figure 16: Superfund Remedial Actions: Sites with P&T, In Situ Treatment, or MNA Selected as Part of a Groundwater Remedy (FY 1982 - 2002)*



MNA = Monitored natural attenuation
P&T = Pump and treat
** Includes information from an estimated 70% of FY 2002 RODs.*
(a) NPL sites include current sites and former NPL sites that were deleted and/or removed from the NPL between FY 1982 and 2002.
Appendix F describes the methodology used to identify remedy types for each site.
Sources: 1, 2, 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Source control is discussed in more detail in Section 2 of this report.

Groundwater RODs

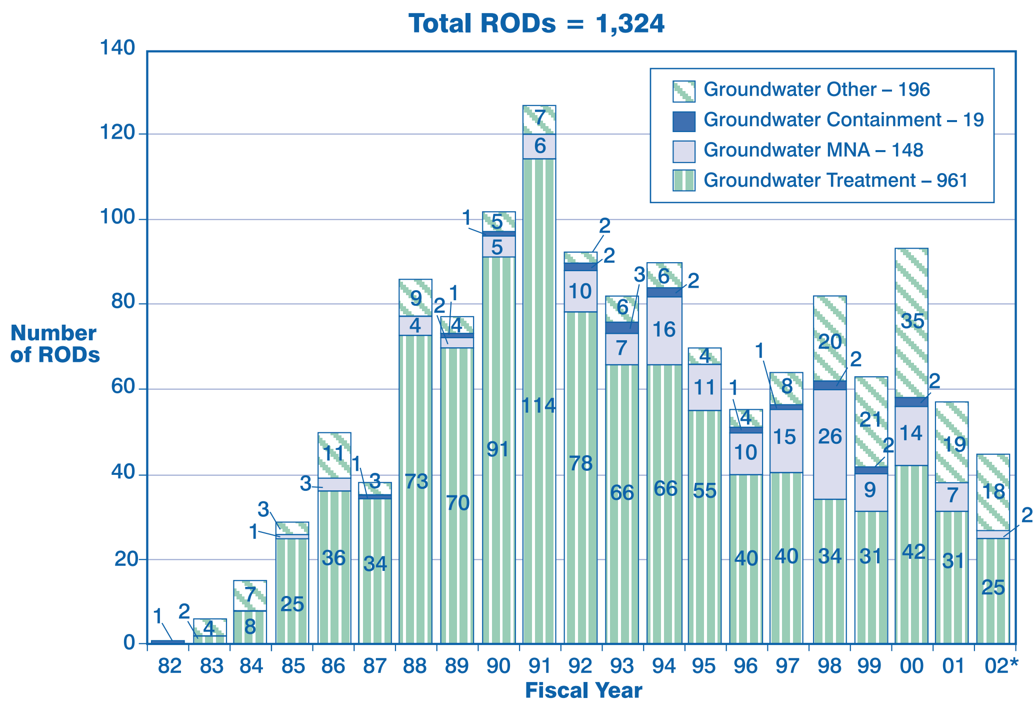
Figure 17 shows the number of groundwater RODs of each type. RODs that select treatment may also include MNA, groundwater containment using VEBs, or other groundwater remedies. The number of groundwater treatment RODs peaked in FY 1991 at 114 and has been generally decreasing, similar to the behavior observed for source control RODS (see Figure 5). This peak matches the peak in the total number of RODs in FY 1991, as shown in Figure 2. From FY 1988 - 1995, the number of groundwater treatment RODs ranged from 55 to 114, while during the period from FY 1996 - 2001, it was between 31 and 42 RODs.

Selection of Groundwater Remedies

Figure 18 shows the percentages of RODs selecting groundwater remedies. Nearly 90% of RODs selected P&T from FY 1987 - 1992. This percentage decreased to 30% in FY 1998, but has since risen to 40% in FY 2002. MNA was selected in less than 10% of RODs from FY 1986 - 1991, but then increased every year until it peaked at 48% in 1998. It was only about half of its peak level in the following three years, and then decreased by an additional two-thirds to 9% in FY 2002. RODs selecting *in situ* groundwater treatment have been generally increasing, from none in 1986 to 24% in FY 2002. The percentage of RODs selecting VEBs has remained relatively consistent, below 10% for all years. RODs selecting other remedies were less than 25% from FY 1986 - 1997, but then increased rapidly. About 90% of RODs selected an other groundwater remedy from FY 2000 - 2002. RODs selecting multiple groundwater remedy types are included in each applicable category. Figures 18 through 21 do not include FY 1982 through 1985 because of the small number of RODs signed.

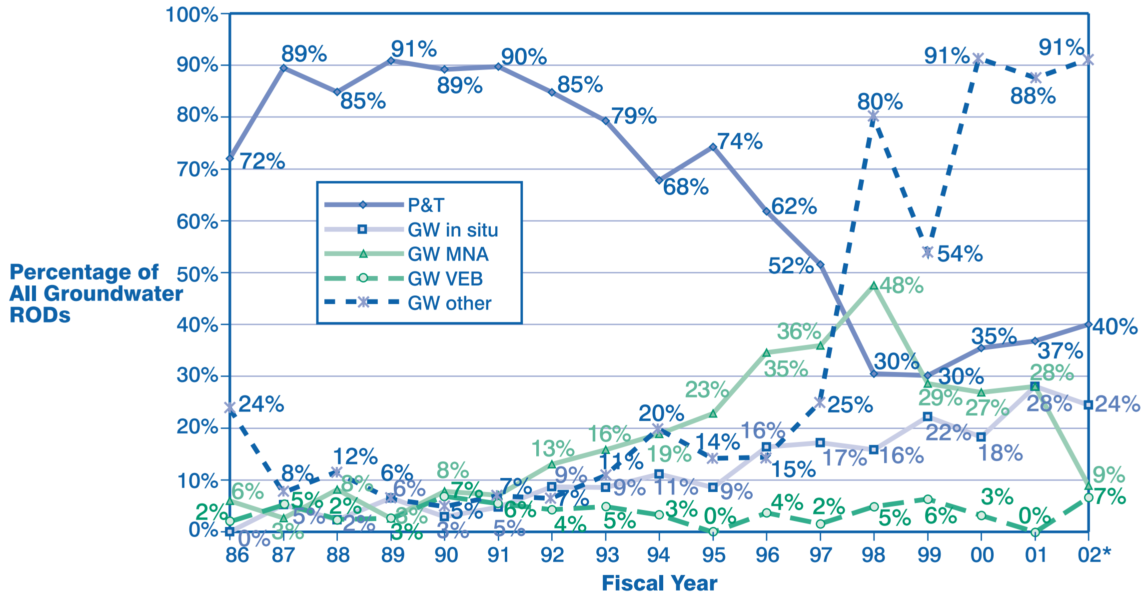
RODs selecting P&T alone have decreased from about 80% prior to FY 1993, to an average of 21% over the last 5 years (FY 1998 - 2002), as shown in Figure 19. In contrast, P&T is being used increasingly with *in situ* treatment or MNA, or not at all. RODs selecting P&T with another remedy generally ranged from 5% to 10% through FY 1995, but increased to an average of 14% from FY 1996 - 2002. Similarly, RODs selecting *in situ* treatment or MNA and not P&T generally ranged from 5% to 10% through FY 1993. However, these RODs

Figure 17: Superfund Remedial Actions: RODs Selecting Groundwater Remedies (FY 1982 - 2002)*



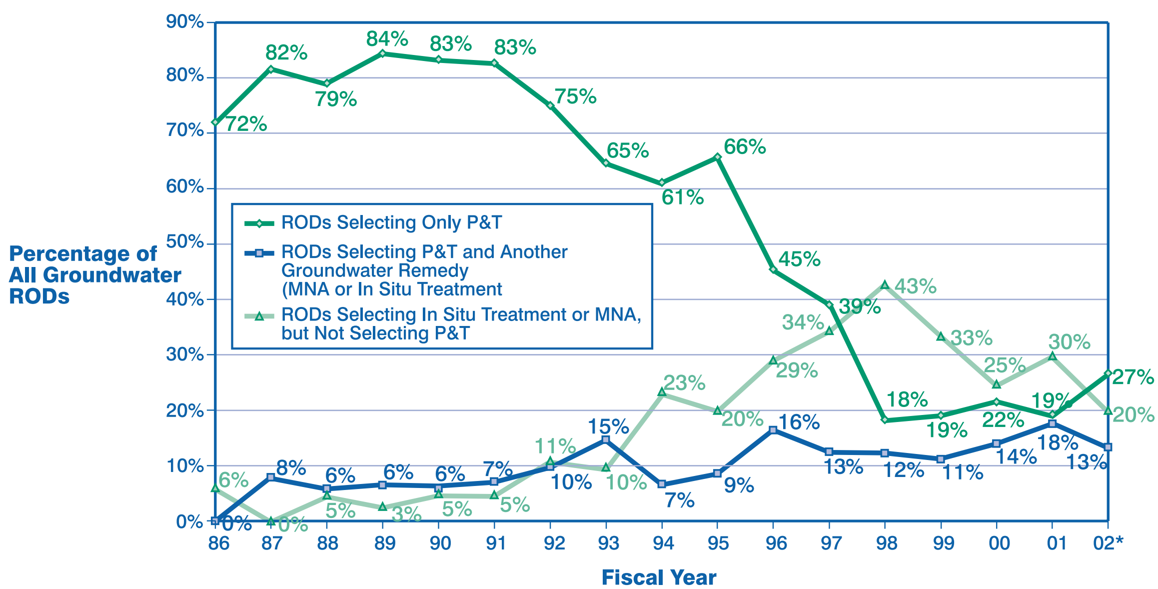
MNA = Monitored natural attenuation
ROD = Record of Decision
** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Figure 18: Superfund Remedial Actions: Trends in Groundwater Remedy Selection (FY 1986 - 2002)*



GW = Groundwater
MNA = Monitored natural attenuation
P&T = Pump and treat
ROD = Record of Decision
VEB = Vertical engineered barrier
** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Figure 19. Superfund Remedial Actions: Trends in the Selection of Pump and Treat (FY 1986 - 2002)*



MNA = Monitored natural attenuation
P&T = Pump and treat
ROD = Record of Decision
** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

then increased to a peak of 43% in FY 1998, and have since decreased to 20% in FY 2002.

The general decrease in the selection of P&T remedies may be due to a variety of factors, including the following:

- More widespread acceptance of innovative *in situ* groundwater treatment remedies
- Reduced operation and maintenance costs from using active *in situ* treatment technologies
- Reduced time to address risk and faster return of sites to beneficial uses by using active *in situ* treatment remedies
- Reduced costs by using MNA

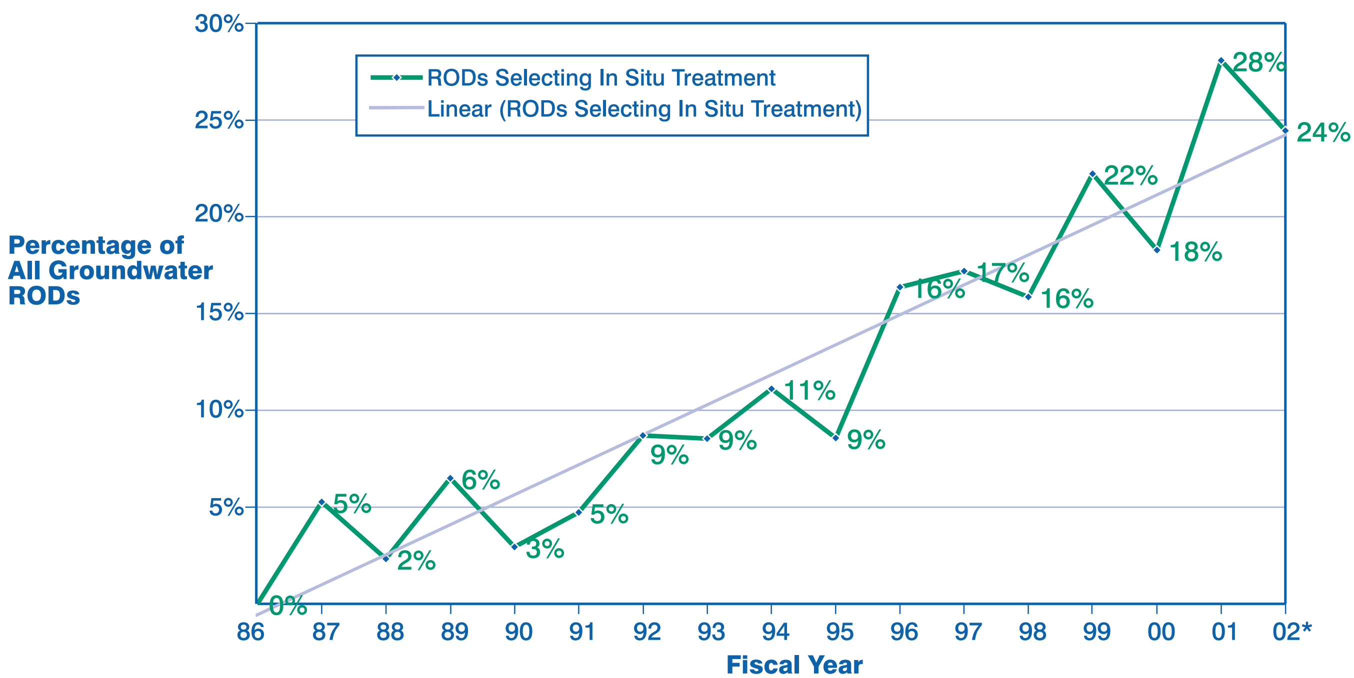
The general increase in the selection of P&T with MNA or *in situ* treatment may be due to a variety of factors, including the following:

- More active *in situ* treatments can reduce P&T treatment times by remediating hot spots and contaminant sources
- MNA can reduce P&T treatment times by allowing P&T systems to be shut down when contaminants reach levels that can effectively be treated by MNA
- MNA can treat areas of a contaminant plume with low concentrations, reducing the amount of the contaminant plume treated by P&T

The percentage of groundwater RODs selecting *in situ* treatment peaked in FY 2001 at 28%. The generally upward trend in the selection of *in situ* treatment, shown in Figure 20, may be due to several factors. The development of these technologies is growing rapidly. They have also begun to be used more frequently in recent years to treat some media and contaminants that are difficult to remediate, such as DNAPL, chlorinated solvents, and fractured bedrock. A detailed discussion of one such technology, chemical treatment, is presented in Section 4. Figure 20 counts all RODs that selected *in situ* groundwater treatment (with or without other remedies).

Groundwater MNA is the reliance on natural attenuation processes (within the context of a carefully controlled and monitored approach to site cleanup) to achieve site-specific remediation objectives within a time frame that is reasonable, compared with that offered by other, more active methods (see Reference 12 on Page 50). The "natural attenuation processes" include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These *in situ* processes include biodegradation; dispersion; dilution; sorption;

Figure 20: Superfund Remedial Actions: Trends in the Selection of In Situ Treatment for Groundwater (FY 1986 - 2002)*



ROD = Record of Decision
** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants.

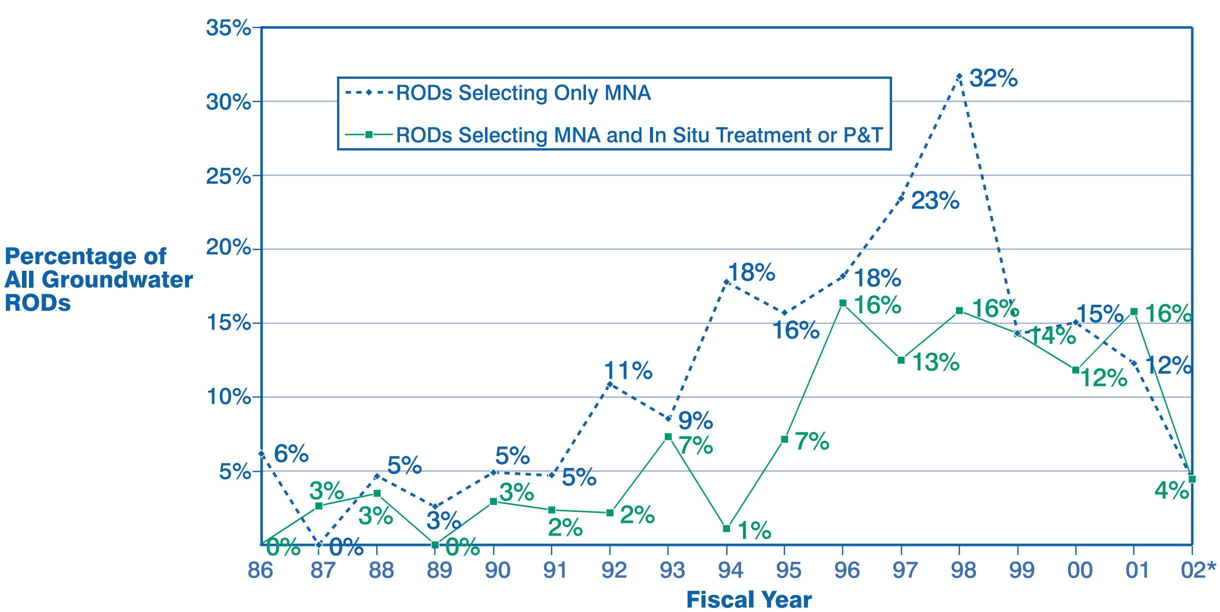
Cumulatively, 234 RODs have selected MNA; of those, 124 selected MNA without a groundwater treatment remedy. Since FY 1986, the fraction of groundwater RODs selecting MNA, both alone and in combination with P&T and *in situ* treatment, has increased. Figure 21 compares the trends in the percentage of groundwater RODs selecting only MNA to MNA in combination with groundwater treatment (P&T or *in situ* treatment). The selection of MNA, both alone and with groundwater treatment remedies, generally increased through 1998. In that year, MNA alone was selected in 32% of RODs, while MNA was selected with P&T or *in situ* treatment in 16% of RODs. From FY 1999 - 2001, MNA alone was half of its peak level, while MNA with a groundwater treatment remedy remained relatively constant. In FY 2002, both types of RODs decreased to 4%.

The decrease in MNA only RODs coincided with the publication of EPA guidance on the use of MNA in 1999 (see Reference 12 on page 50). This directive was issued to clarify EPA's policy regarding the use of MNA for the remediation of contaminated soil and groundwater at sites administered by EPA's Office of Solid Waste and Emergency Response, and contained guidance for the implementation of MNA. The guidance may have influenced remedy identification and selection. For example, the directive provided a more specific definition of MNA than was available in the past. Prior to publication of the directive, some remedies identified as MNA may not have met the definition provided in the directive. Authors of FY 1999 RODs may have identified remedies that they would have previously identified as MNA as another remedy, such as monitoring only or NA/NFA.

In Situ Groundwater Treatment Technologies

In situ technologies for groundwater treatment are those applications in which the contaminated groundwater is treated or the contaminant is removed from the groundwater without extracting, pumping, or otherwise removing the groundwater from the aquifer. Implementation of P&T remedies requires extraction of groundwater from

Figure 21: Superfund Remedial Actions: Trends in the Selection of MNA (FY 1986 - 2002)*



MNA = Monitored natural attenuation
P&T = Pump and treat
ROD = Record of Decision
** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

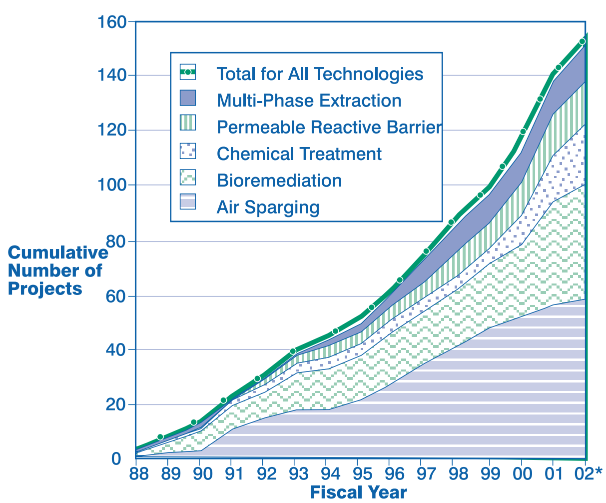
an aquifer, usually through pumping, and treatment aboveground. This section provides additional information about the innovative technologies used for *in situ* groundwater treatment.

Figure 22 shows the cumulative trends in the selection of *in situ* groundwater treatment technologies over time. The most common are air sparging, bioremediation, permeable reactive barriers (PRB), and chemical treatment. Air sparging decreased from 70% of *in situ* projects selected in FY 1996 to 9% in FY 2002. Cumulatively, air sparging continues to represent over 50% of all *in situ* groundwater treatment projects. *In situ* bioremediation has increased in recent years from 8% in FY 1997 to 36% in FY 2002. PRBs ranged from one to three projects in all years since FY 1996, except 1999, when no PRB projects were selected. *In situ* chemical treatment had no more than one project in each year from FY 1988 - 1998, with the number of projects increasing slightly in recent years to an average of four projects per year in the period from FY 1999 - 2002.

The data show that the most commonly selected technologies continue to be selected at high rates. Bioremediation and chemical treatment projects have been selected more frequently over the last three years than in the past. Nearly 50% of the bioremediation projects and 70% of the chemical treatment projects have been selected during the last three years. The number of *in situ* groundwater treatment projects selected in RODs from FY 2000 - 2002 is presented in Table 8.

Figure 23 shows, by technology, eight major groups of contaminants treated in groundwater. Compounds are categorized as VOCs, SVOCs, or PAHs according to the lists provided in EPA's SW-846 test methods 8010, 8270, and 8310, with the exceptions listed in the figure notes. Overall, VOCs, including both BTEX and halogenated VOCs, are the contaminants most commonly treated in groundwater using *in situ* technologies. Halogenated SVOCs (including organic pesticides and herbicides) and metals and metalloids in groundwater are treated least frequently. The number of projects in Figure 23 exceeds the total number of *in situ* groundwater projects because some projects involve more than one type of contaminant. Such projects, therefore, are repeated in Figure 23 under each contaminant type treated by the remedy.

Figure 22: Superfund Remedial Actions: Cumulative Trends for Most Common In Situ Groundwater Technologies (FY 1988 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Table 8. Superfund Remedial Actions: In Situ Groundwater Treatment Projects Selected in FY 2000, 2001, and 2002*

Total Projects = 66

Technology	Number of New Projects
Bioremediation	21
Chemical Treatment	15
Air Sparging	10
Permeable Reactive Barrier	7
Multi-Phase Extraction	4
In-Well Air Stripping	3
Phytoremediation	3
Flushing	2
In Situ Thermal Treatment	1

** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

The selection of a treatment technology for a site depends on the physical and chemical properties of contaminants at the site. For example, VOCs are amenable to air sparging because of their volatility. Metals, which are not volatile and do not degrade, are not amenable to this technology.

The selection of groundwater treatment technologies may also depend on site-specific factors, such as soil type and hydrogeology. For example, air sparging may be an effective treatment for VOCs at a site with sandy soil, but may not be effective at a site with tightly packed clay soil. As Figure 23 shows, BTEX and halogenated VOCs are treated most frequently using air sparging. PAHs and other non-halogenated SVOCs, which are not as volatile as BTEX and halogenated VOCs, but can be destroyed through microbial processes, are treated most frequently by bioremediation. Dissolved-phase halogenated VOCs may be difficult to remove from groundwater in low-permeability matrices using air sparging. Metals and metalloids are typically not amenable to air sparging, bioremediation, and multi-phase extraction. One exception is the use of *in situ* bioremediation to reduce hexavalent chromium to its less toxic trivalent form. This technology, which uses biological activity to create conditions that result in chemical reduction of chromium, is being applied at three sites. At one additional site, bioremdiation to treat arsenic is currently planned. Metals and metalloids may undergo chemical reactions with certain substances to form compounds that are less toxic or mobile. The PRBs were used most often to treat halogenated VOCs, metals, and metalloids.

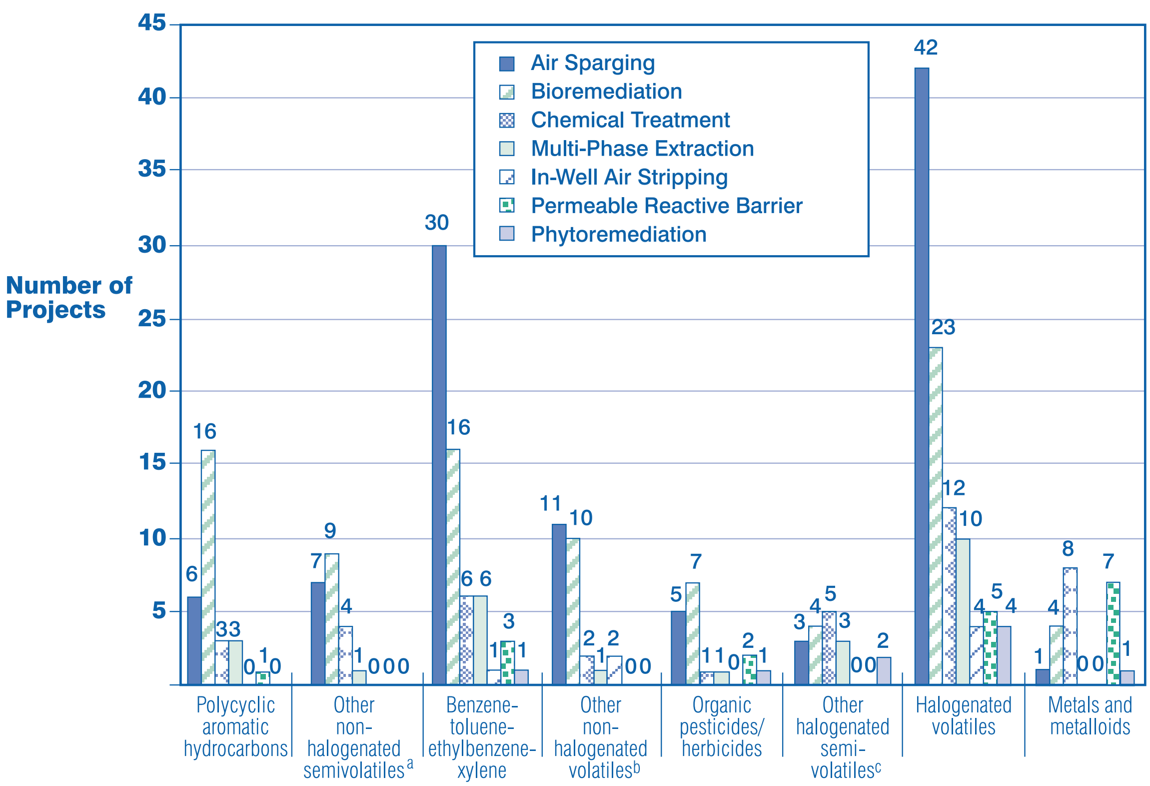
Status of *In Situ* Groundwater Projects

A snapshot of the status of *in situ* groundwater treatment technologies is presented in Figure 24.

The data in Figure 24 show:

- The total number of *in situ* groundwater treatment projects increased by 62%, from 104 to 169 between August 2000 and March 2003.

Figure 23: Superfund Remedial Actions: Contaminants Treated by In Situ Groundwater Technologies (FY 1982 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*

[a] *Does not include polycyclic aromatic hydrocarbons.*

[b] *Does not include benzene, toluene, ethylbenzene, and xylene.*

[c] *Does not include organic pesticides and herbicides.*

Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

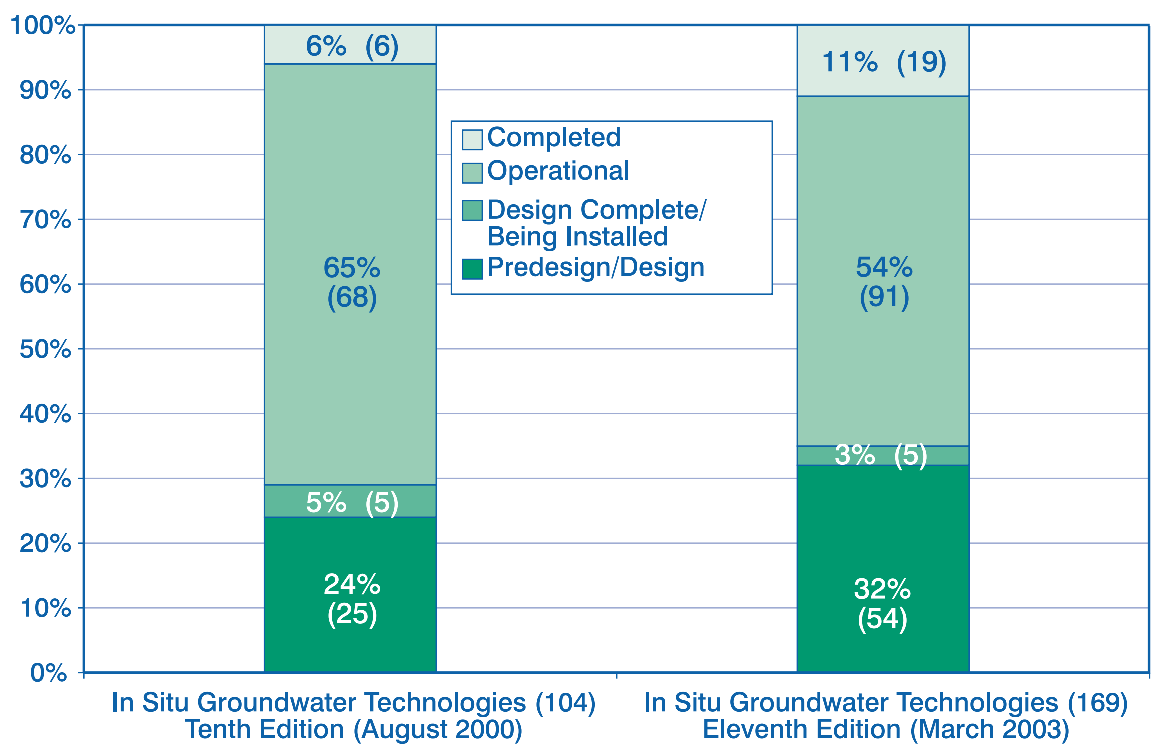
- An additional 13 *in situ* groundwater projects were completed, increasing the percentage of completed *in situ* groundwater projects from 6% to 11%. Completed projects included five chemical treatment, three air sparging, three bioremediation, and two multi-phase extraction projects.
- More than half (54%) of *in situ* groundwater treatment projects are operational.
- Although the percentage of *in situ* groundwater projects that are operational decreased, the total number of operational projects increased from 68 to 91. The technologies with the largest increase in the number of operational projects were air sparging (8 projects) and PRBs (6 projects).
- *In situ* groundwater treatment projects in the design phase increased. The technologies with the largest increase in the number of projects in the design phase were bioremediation (14 projects), chemical treatment (9 projects), and PRBs (4 projects).

The status of *in situ* groundwater treatments selected in FY 2000 - 2002 at Superfund remedial action sites include:

- 66 additional *in situ* treatment technology projects for groundwater were selected (see Table 8 on page 36). Technologies most frequently selected include bioremediation (21 projects), chemical treatment (15 projects), air sparging (10 projects), and PRB (7 projects).
- Three projects selected in the period have been completed, including bioremediation (2 projects) and chemical treatment (1 project).
- An additional 21 projects became operational.
- An additional four projects have progressed beyond the design phase, and the remedies are being installed.

For some projects, the technology treats both sources and groundwater. For example, *in situ* thermal treatment may be applied to treat a DNAPL source and the groundwater contaminated by that source. In previous editions of the ASR, such applications were described only in the source control section. Because remediation professionals may be interested in both the source and groundwater treatment aspects of technologies applied to both contaminant sources and contaminated groundwater, this edition of the ASR presents

Figure 24: Superfund Remedial Actions: Status of In Situ Groundwater Treatment Projects (FY 1982 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

information in both the Source section (Section 2) and Groundwater section (Section 3). To make the August 2000 and March 2003 data comparable, the data in Figure 24 for August 2000 include technologies treating both sources and groundwater, and therefore do not match the information presented for groundwater remedies presented in the Tenth Edition of the ASR.

The specific types of *in situ* treatment remedies and their status at Superfund sites are listed in Table 9. *In situ* treatment of groundwater has been selected 169 times at 135 sites. Among *in situ* technologies, air sparging is the most frequently selected technology, followed by bioremediation. Both of these technologies have a large number of projects in the operational phase. The treatment rate of these technologies is typically limited by site-specific factors. For example, air sparging may require long treatment times when continuing sources of contaminants, such as light nonaqueous-phase liquid (LNAPL) and DNAPL, are present. Bioremediation may be limited by the rate at which microbes can break down contaminants, which can depend on a variety of factors such as climate, soil conditions, contaminant concentrations, and solubility.

The third most frequently selected technology is chemical treatment. Although this technology has approximately half the number of total projects of air sparging and bioremediation, it has the same number of completed projects. Chemical treatment is typically applied as an aggressive treatment technology that requires a relatively short treatment time to achieve cleanup goals. It may also be effective in treating small amounts of DNAPL and LNAPL. Since the Tenth Edition, the number of chemical treatment projects has increased, from only 2 to 21. PRBs rely on natural groundwater flow to carry contaminants into a reactive zone, where they are treated; therefore, this technology does not treat contaminants upgradient of the reactive zone. Most PRBs (10 of 17) are in the operational phase, and none are completed.

Groundwater Pump and Treat

P&T is the extraction of groundwater from an aquifer and treatment aboveground. The extraction step usually is conducted by pumping groundwater from a well or trench. The treatment step can include a variety of technologies. The technologies used at Superfund remedial action sites for the aboveground treatment of contaminated groundwater are described in the Overview section at the beginning of this report.

Table 9. Superfund Remedial Actions: Status of In Situ Groundwater Treatment Projects by Technology (FY 1982 - 2002)*

Technology	Predesign/ Design	Design Complete/ Being Installed	Operational	Completed	Total
In Situ					
Air Sparging	9	3	40	6	58
Bioremediation	18	0	21	5	44
Chemical Treatment	10	1	5	5	21
Permeable Reactive Barrier	6	1	10	0	17
Multi-Phase Extraction	2	0	9	3	14
Phytoremediation	2	0	4	0	6
In-Well Air Stripping	3	0	2	0	5
In Situ Thermal Treatment	2	0	0	0	2
Flushing	2	0	0	0	2
Total	54	5	91	19	169
Percentage of In Situ Technologies	32%	2%	54%	11%	—
Percentage of All Groundwater Technologies	6%	1%	10%	2%	19%

** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.
Download file containing source data for Table 9.

Status of Groundwater Pump and Treat Projects

This report contains information on 743 P&T projects at Superfund remedial action sites. Figure 25 shows the status of these projects, and allows for the following conclusions:

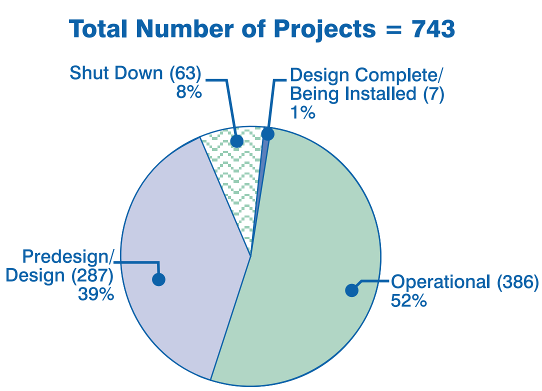
- Most P&T projects (52%) are operational.
- Some 39% are in the predesign/design phase.
- 63 (8%) of P&T projects are shut down (no longer ongoing). Appendix G lists the 63 P&T projects that are shut down, and the reason for the system shut down. Information about the reason for shut down was not available from the data sources used for this report for all P&T projects. EPA is currently gathering additional data to better characterize shut down P&T systems (see Box 6, Definition of Completed Project on page 12).

Pump and Treat Data Sources

Data on P&T remedies were collected from the following sources:

- RODs from FY 1982 - 2002
- The CERCLIS database
- CORs from FY 1983 - 2002
- The EPA P&T Optimization Database
- Contacts with RPMs through March 2003

Figure 25: Superfund Remedial Actions: Status of Groundwater Pump and Treat Projects (FY 1982 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.
Download file containing source data for Figure 25.

The P&T projects were identified primarily from RODs, CORs, and the CERCLIS database. Information collected from these sources on Superfund P&T projects included the contaminants treated, the technologies treating extracted groundwater, the implementation status of these projects, and remedy changes.

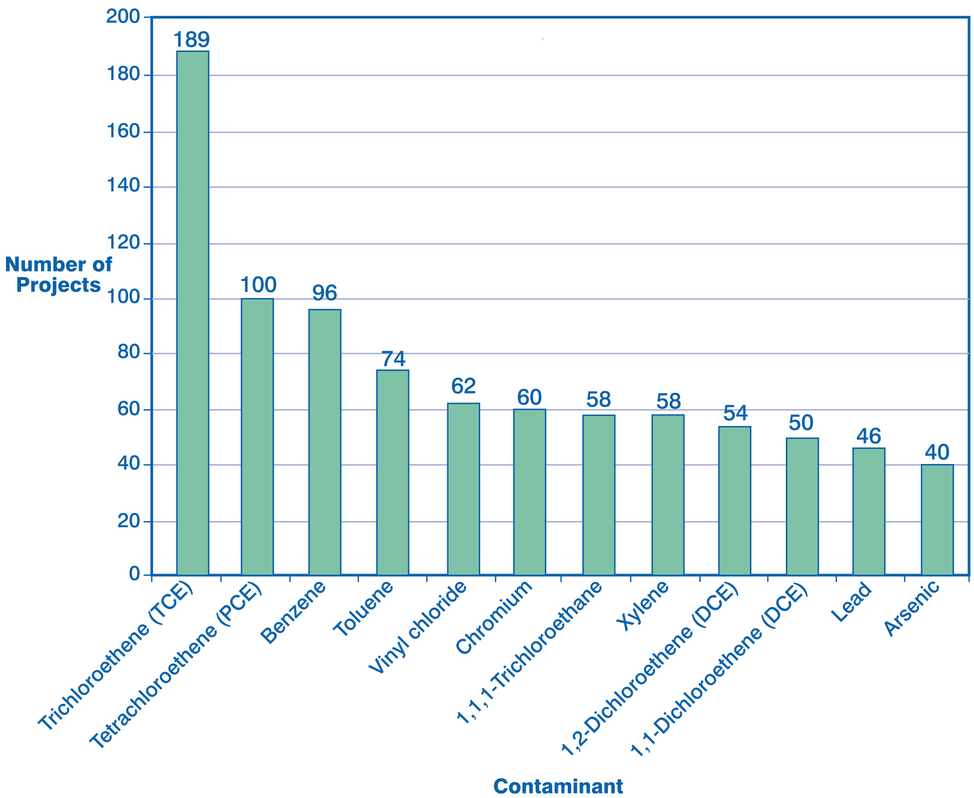
Due to the large number of projects, the diverse sources of information, and the limited resources available for data collection, complete information was not collected for every project from every data source. P&T projects were identified in RODs from FY 1982 to 2002. RPMs were generally not contacted for P&T projects selected in RODs signed after FY 1997, because P&T projects typically require five years to progress to the operational stage, and a higher priority was placed on gathering information on P&T systems that were more likely to be operational.

Information on the specific technologies applied in P&T projects was not collected from RODs. Most RODs do not specify the technologies to be used for P&T projects, and of those that do specify technologies, those technologies are frequently changed before the P&T project begins operation. Technology information was gathered primarily from CORs, contacts with the RPMs, and the P&T Optimization Database. The information on P&T projects presented in this report is as accurate and complete as possible given the limitations on the time and resources available for data collection. Future editions of the ASR may include additional information on more P&T projects.

Contaminants Treated by Pump and Treat

Contaminants treated were identified for 345 P&T projects. Figure 26 shows the 12 most frequently treated contaminants. The contaminant treated most often is trichloroethene (TCE). Other chlorinated VOCs are also frequently treated using P&T, including tetrachloroethene (PCE); vinyl chloride (VC); 1,1,1-trichloroethane (1,1,1-TCA); 1,1-dichloroethene (DCE); and 1,2-DCE. The second most frequently treated contaminants are nonchlorinated VOCs, including benzene, toluene, and xylene. P&T systems are also frequently used to treat heavy metals and metalloids, including chromium, lead, and arsenic. Projects that treat more than one contaminant are counted once for each contaminant listed in Figure 26.

Figure 26: Superfund Remedial Actions: Contaminants Treated by Pump and Treat Systems (FY 1982 - 1997)



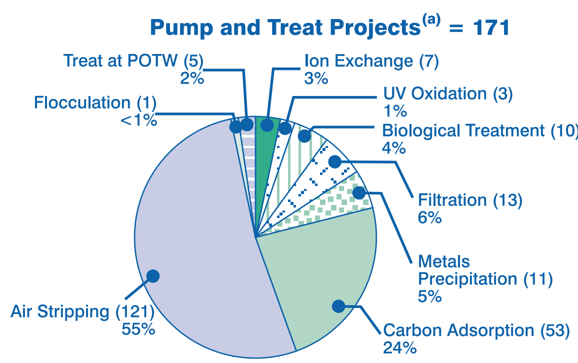
Pump and treat (P&T) projects from FY 1998 through 2002 are not included on this figure, because P&T systems do not generally become operational within 5 years of signing the ROD.
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Aboveground Components of Pump and Treat Projects

Data were available for 171 P&T projects using 224 treatment technologies as shown in Figure 27. More than half of these P&T systems are using air stripping to remove volatile compounds from groundwater. Carbon adsorption is the second most common P&T technology, which also is used to remove organic compounds, including VOCs. These technologies are being used to treat chlorinated and non-chlorinated VOCs, because, as shown in Figure 26, such contaminants make up 9 of the top 12 most frequently treated by P&T. The third and fourth most common technologies are filtration and metals precipitation, respectively. Three of the top 12 contaminants most frequently treated by P&T are metals or metalloids that can be effectively removed using metals precipitation.

Treatment trains are commonly used in P&T systems. Section 2 contains a detailed description of treatment trains and reasons for their use. For the 171 P&T systems for which technology data were available, 35 used a treatment train. The most commonly employed treatment train is air stripping followed by carbon adsorption for the effluent from the air stripper (18 projects). Figure 27 counts projects that use more than one technology once for each technology.

Figure 27: Superfund Remedial Actions: Above Ground Components of Groundwater Pump and Treat Projects (FY 1982 - 2000)



Of 743 pump and treat projects, 171 had a technology selected. Projects may include more than one technology type. POTW = Publicly-owned treatment works
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Data were collected on the amount of groundwater treated by operational and completed P&T projects. Table 10 shows the volume of groundwater treated for 18 P&T projects which used air stripping and carbon adsorption, the two most commonly applied P&T technologies (see Figure 27). The median volumes treated by air stripping and carbon adsorption are 500 million and 25 million gallons, respectively. P&T projects with both air stripping and carbon adsorption had a median volume of 230 million gallons of water treated. Sufficient data were not available to analyze treatment volumes for other technologies.

Table 10. Superfund Remedial Actions: Groundwater Volumes Being Treated Using Pump and Treat Technologies (FY 1982 - 1997)

Aboveground P&T Technology	Number of Projects	Median Volume (gallons)	Total Volume (gallons)
Air Stripping	11	500 million	14 billion
Carbon Adsorption	3	25 million	6 billion
Air Stripping and Carbon Adsorption	4	230 million	6 billion

P&T = Pump and treat
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

Pump and Treat Remedy Changes

One goal of this report is to compile a current list of all P&T projects. As discussed in Section 1, remedies selected for Superfund remedial actions are documented through a ROD, and changes to the original remedies may be formally documented. Remedy changes often occur during the pre-design or design phase of a project when new information about site characteristics is discovered or treatability studies for the selected technologies are completed.

EPA updated the status of 729 P&T projects, primarily by contacting RPMs and reviewing CORs. Of these 729 P&T projects, 80 were changed to other groundwater remedies. These remedies were most often changed to *in situ* groundwater treatment or non-treatment remedies, such as institutional controls and MNA. The most commonly cited reason for changing a P&T remedy was that further site investigation revealed that the concentration or extent of contamination was less than expected. Other frequently cited reasons included problems implementing the remedy due to site conditions such as hydrogeology, implementation of a more effective *in situ* treatment remedy, and high costs.

Pump and Treat Remedy Optimization

Once remediation systems have been functioning for a period of time, opportunities may exist to optimize the system, particularly if they are long-term remedies. The purpose of optimization is to identify potential changes that will improve the effectiveness of a system and reduce operating costs without compromising the effectiveness of the remedy or the achievement of other cleanup objectives.

EPA recognizes that long-term remedial approaches should not remain static, that conditions change over time, and that better technologies, tools, and strategies evolve, which allow for continuous improvement of remedy performance. In OSWER Directive No. 9200.0-33, Transmittal of Final FY00 - FY01 Superfund Reforms Strategy, dated July 7, 2000, EPA outlined a commitment to optimize Superfund-lead P&T systems at Superfund sites.

Information from Superfund-lead sites has been incorporated into the ASR Search System. This information was used to select sites for Remediation System Evaluations (RSE). Superfund-lead P&T systems include systems that are either EPA-lead or state-lead that are funded from the Superfund Program.

EPA performed an RSE on 20 Superfund-lead groundwater P&T systems during 2001. The results of this initiative are documented in the report Groundwater Pump-and-Treat Systems: Summary of Selected Cost and Performance Information at Superfund-Financed Sites. EPA is also preparing additional RSEs for Superfund-financed sites. The report and the RSEs are available at *http://clu-in.org/rse*. Additional information on RSE and optimization of remedies is available at *http://www.frtr.gov/optimization.htm*. This site includes information on optimization tools and techniques, including checklists that can be used to identify optimization opportunities for specific groundwater treatment technologies.

Vertical Engineered Barriers

In the Tenth Edition of the ASR, the scope of the report was expanded to include VEBs, a groundwater containment remedy. Although a

VEB is not a treatment technology, it is an engineered remedy. In addition, VEBs can be constructed using some innovative methods, such as deep soil mixing and geosynthetic walls. The technologies used for VEB construction are also used for *in situ* S/S. VEBs are also an integral part of many PRBs.

VEBs were selected at 49 Superfund remedial action sites for a total of 51 projects (some sites have more than one VEB). More than 80% of the VEBs have been installed (42 of 51). Table 11 indicates the number of each type of VEB. The types of barriers are:

- Slurry wall – Consists of a vertical trench that is filled with a low-permeability slurry of bentonite, soil, or cement.
- Geosynthetic wall – Constructed by placing a geosynthetic liner into a trench.
- Grout – Constructed by injecting a high pressure grout mixture into the subsurface. The grout used is typically cement or a mixture of cement and bentonite.
- Deep soil mixing – Overlapping columns created by a series of large-diameter, counter-rotating augers that mix *in situ* soils with an additive, usually bentonite, cement, or grout, which is injected through the augers.
- Sheet pile – Series of overlapping sheets of impermeable material, such as metal.

Overwhelmingly, slurry walls are the most frequently used type of barrier, with 46 applications. For each of the other types of VEBs, there are fewer than five applications at Superfund remedial action sites. Some VEBs have more than one type of barrier.

Additional information on VEBs is available in the following reports, both of which are available on-line at *http://clu-in.org*:

- Subsurface Containment and Monitoring Systems: Barriers and Beyond
- Evaluation of Subsurface Engineered Barriers at Waste Sites (EPA-542-R-98-005)

Table 11. Superfund Remedial Actions: Types of Vertical Engineered Barriers at 49 Sites Selecting This Technology (FY 1982 - 2002)*

Vertical Engineered Barrier Type	Number of Barriers
Slurry Wall	46
Grout	4
Sheet Pile	3
Geosynthetic Wall	2
Deep Soil Mixing	2
Other - VEB	1
TOTAL	58

** Includes information from an estimated 70% of FY 2002 RODs. Some sites have more than one barrier. Some barriers have more than one barrier type. Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.*

Section 4: Report Focus Areas: Chemical Treatment and Construction Completion

Two areas of interest to the remediation community are the focus of this section: (1) the application and use of chemical treatment, and (2) the remediation achievements at sites on the NPL. As discussed previously, the selection and application of innovative technologies has been increasing in the Superfund program. In particular, the selection and application of chemical treatment has increased significantly since the publication of the Tenth Edition of the ASR. This section provides information on the trends and usage of chemical treatment. In addition, the data sources used to compile this edition of the ASR have expanded to include CORs. This section presents documentation on the remediation achievements at Superfund sites using the information contained in CORs.

Chemical Treatment

Chemical treatment, also known as chemical reduction/oxidation (redox), typically involves redox reactions that chemically convert hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, or inert. Redox reactions involve the transfer of electrons from one compound to another. Specifically, one reactant is oxidized (loses electrons) and one is reduced (gains electrons). The oxidizing agents used for treatment of hazardous contaminants in soil and groundwater include ozone, hydrogen peroxide, hypochlorites, potassium permanganate, Fenton's reagent (hydrogen peroxide and iron), chlorine, and chlorine dioxide. This method may be applied *in situ* or *ex situ*, to soils, sludges, sediments, and other solids, and may also be applied to groundwater *in situ* or *ex situ* (P&T). P&T chemical treatment for groundwater may also include the use of UV light in a process known as UV oxidation. This section focuses on source control and *in situ* groundwater applications of chemical treatment.

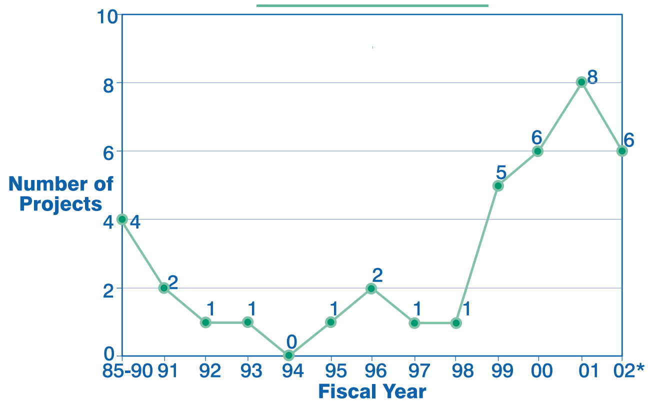
Chemical treatment primarily is used to treat organic contaminants, and is applicable to both halogenated and nonhalogenated VOCs and SVOCs. When organics are treated, these compounds are typically degraded to simpler and less toxic compounds. For example, chlorinated VOCs, such as tetrachloroethene, may be dechlorinated, and oxidized into chlorides, carbon dioxide, and water. When used to treat metals and metalloids, it may be used to change a contaminant's valence state, cause the contaminant to react with other species in the soil, or cause the contaminant to precipitate, rendering it less toxic or mobile. For example, some applications of chemical treatment have reduced chromium (VI) to its less toxic chromium (III) form.

The rate and extent of treatment of a target contaminant are dictated by the properties of the contaminant, its reactions with the chemicals used, concentrations of contaminants and treatment chemicals, and the matrix conditions. Conditions that can impact the effectiveness of chemical treatment include pH, temperature, and the concentration of other chemicals that may react with the treatment chemicals, such as natural organic matter, reduced minerals, carbonate, and free radical scavengers.

Effective *in situ* application of chemical treatment also depends on the method of delivery and distribution of treatment chemicals throughout a subsurface region. Delivery systems often employ vertical or horizontal injection wells or air sparge points with forced advection to rapidly move the chemicals into the subsurface. Chemical treatment can also impact the characteristics of the matrix to be treated. For example, some treatment chemicals can alter the pH if the system is not buffered effectively. Other potential effects that may impact treatment performance include colloid genesis leading to reduced permeability; mobilization of redox-sensitive and exchangeable sorbed metals; possible formation of toxic by-products; evolution of heat and gas; and destruction of microorganisms, leading to reduced potential for future biological treatment.

Chemical treatment is a relatively innovative technology, which has seen increased application in recent years, particularly for *in situ* treatment of recalcitrant remediation problems, such as DNAPLs, LNAPLs, and contaminated groundwater in fractured rock. For *in situ* groundwater treatment, chemical treatment had no more than one project in each year from FY 1988 - 1998. However, the use of this technology has increased in recent years, averaging four projects per year in the period from FY 1999 - 2002. Figure 28 plots the number of chemical treatment projects for source control and in situ groundwater by the FY for which the ROD was signed.

Figure 28: Superfund Remedial Actions: Trend in the Number of Chemical Treatment Projects (FY 1985 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

This section presents detailed information on the *in situ* chemical treatment projects at Superfund remedial action sites, and examines the types of contaminants treated using this technology. Table 12 lists the site name, state, contaminant groups, media, chemical treatment agents, and implementation status for *in situ* source control and groundwater chemical treatment projects.

This report focuses on *in situ* chemical treatment because its use has been increasing in recent years, whereas the use of *ex situ* treatment has not. Historically, chemical treatment has been used for source control treatment but has recently been applied for *in situ* groundwater treatment. Only four projects selected this technology for *in situ* groundwater treatment prior to FY 1998. However, chemical treatment represented 4 of 16 *in situ* groundwater treatment projects in FY 2002. Information about chemical agents is available for implemented projects, because the chemical agents

Table 12. Superfund Remedial Actions: In Situ Chemical Treatment Projects (FY 1982 - 2002)*

Site Name (Operable Unit), State	Contaminant Group	Media Type	Technology Description	Status
Alaric Inc Superfund Site OU 1, FL	Halogenated VOC	Soil (in situ)	Oxidizers may include potassium permanganate, ozone, hydrogen peroxide, or Fenton's reagent.	Pre-design
Battery Tech Duracell Lexington OU 1, NC	BTEX Halogenated SVOC Halogenated VOC Nonhalogenated VOC PCBs Solvents	Soil (in situ)	Mixture of hydrogen peroxide, sodium persulfate, iron II catalyst, sodium permanganate (if needed).	Designed/ Not Installed
Brunswick Wood Preserving Site - OU 1, GA	Halogenated SVOC Nonhalogenated SVOC Organic pesticides/herbicides PAHs	Groundwater (in situ)	Chemical oxidation.	Pre-design
Calhoun Park Area - OU 2, SC	BTEX Nonhalogenated SVOC Nonhalogenated VOC PAHs Solvents	DNAPL (in situ) Groundwater (in situ)	Oxidizing agents may include ozone, hydrogen peroxide, hypochlorites, chlorine, and chlorine dioxide.	Design
Cooper Drum Company, CA	BTEX Halogenated VOC Nonhalogenated SVOC Nonhalogenated VOC PAHs Solvents	Groundwater (in situ)	Potassium permanganate and HRC (a proprietary reductive dechlorination agent).	Design
Dublin TCE Site Remediation OU 2, PA	Halogenated VOC Solvents	DNAPL (in situ)	Chemical oxidation.	Pre-design
Eastern Surplus Company Superfund Site - Entire Site, ME	Halogenated VOC Solvents	Groundwater (in situ)	Permanganate.	Operational

Continued on next page

Table 12. Continued

Site Name (Operable Unit), State	Contaminant Group	Media Type	Technology Description	Status
Eastland Woolen Mill - OU 1, ME	BTEX Halogenated SVOC Halogenated VOC Heavy metals Nonhalogenated SVOC Nonhalogenated VOC Solvents	DNAPL (in situ) Groundwater (in situ)	Chemical reagents such as Fenton's reagent or other oxidizing agents.	Design
Ewan Property - OU 2, NJ	BTEX Halogenated SVOC Halogenated VOC Nonhalogenated SVOC Nonhalogenated VOC Solvents	Groundwater (in situ)	Fenton's reagent.	Pre-design
Frontier Hard Chrome Inc. - OUs 1 and 2, WA	Heavy metals	Soil (in situ) Groundwater (in situ)	Injection of a reducing chemical to convert hexavalent chromium to trivalent chromium.	Design
Frontier Hard Chrome Inc. - OUs 1 and 2, WA	Heavy metals	Groundwater (in situ)	Injection of a reducing chemical to convert hexavalent chromium to trivalent chromium.	Pre-design
Fruit Avenue Plume Site, NM	Halogenated VOC Solvents	Groundwater (in situ)	Chemical oxidation using permanganate.	Design
Halby Chemical Co. - OU 1, Process Plant Area, DE	Nonhalogenated VOC Solvents	Soil (in situ)	Sodium percarbonate.	Completed
Hanford Site - 100 Area - OU 2, WA	Heavy metals	Groundwater (in situ)	In Situ Redox Manipulation involves injecting sodium dithionite to reduce the mobility and toxicity of chromium in groundwater.	Operational
Hanscom Air Force Base - OU 1, Site 1 Source Area, MA	Halogenated VOC Solvents	Soil (in situ) Groundwater (in situ)	Potassium permanganate.	Operational
Jacksonville Naval Air Station - OU 3, FL	Halogenated SVOC Halogenated VOC Nonhalogenated VOC Solvents	Groundwater (in situ)	Oxidant such as potassium permanganate.	Pre-design
Jones Chemicals, Inc., NY	Halogenated VOC Solvents	DNAPL (in situ) Liquids	Oxidizing agent such as potassium permanganate or hydrogen peroxide.	Pre-design
New Hampshire Plating Co. - OU 1, NH	Heavy metals Inorganic cyanides	Soil (in situ)	Phosphate-based proprietary chemical agent addition.	Design
Odessa Chromium II Superfund Site, TX	Heavy metals	Groundwater (in situ)	Ferrous sulfate heptahydrate with hydrochloric acid will be used.	Operational
Peterson/Puritan Inc. - OU 1, PAC Area, RI	Heavy metals	Groundwater (in situ)	Oxygenated water is injected into the vadose zone and shallow groundwater at a rate of 5 gallons per minute to treat and immobilize arsenic.	Completed
Rasmussens Dump, MI	BTEX Halogenated SVOC Halogenated VOC Nonhalogenated VOC Solvents	Groundwater (in situ)	A mixture of ozone/oxygen is injected into the contaminated chlorinated hydrocarbon groundwater plume. Oxidation of the chlorinated hydrocarbons occurs in situ.	Completed
Silver Bow Creek/ Butte Area - Rocker Timber Framing And Treatment Plant OU, MT	Heavy metals	Groundwater (in situ)	Contaminated groundwater was treated with ferrous iron, limestone, and potassium permanganate.	Completed

Continued on next page

Table 12. Continued

Site Name (Operable Unit), State	Contaminant Group	Media Type	Technology Description	Status
Southern Solvents OU 1, FL Installed	Halogenated VOC Solvents	Soil (in situ) Liquids Groundwater (in situ)	Oxidizing agent such as hydrogen peroxide.	Designed/ Not Installed
Tex-Tin OU 1, TX	Heavy metals	Liquids	Sodium hydroxide and hydrochloric acid.	Operational
Townsend Chainsaw Company, Inc., SC	Heavy metals	Groundwater (in situ)	Ferrous sulfate.	Operational
Trans Circuits Site, FL	Halogenated VOC Solvents	Groundwater (in situ)	Perform in situ chemical oxidation of plume via the injection of potassium permanganate, hydrogenperoxide, ozone, or a combinationthereof through injection wells in the surficial aquifer.	Pre-design
Weldon Spring Chemical Plant - OU 2, MO	Halogenated VOC Solvents	Groundwater (in situ)	Permanganate.	Completed
Wright-Patterson Air Force Base Groundwater OU 12, OH	BTEX Halogenated SVOC Halogenated VOC Nonhalogenated VOC Solvents	Groundwater (in situ)	Strong oxidizer such as Fenton's reagent or potassium permanganate.	Completed

** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.
BTEX = Benzene-toluene-ethylbenzene-xylene
DNAPL = Dense nonaqueous-phase liquid
OU = Operable unit
PAH = Polycyclic aromatic hydrocarbon
PCB = Polychlorinated biphenyl
SVOC = Semivolatile organic compound
VOC = Volatile organic compound

are usually identified during bench- and pilot-scale testing. This information is often not available for projects in the design phase. Box 9 contains more detailed information about one of the *in situ* groundwater projects.

In situ chemical treatment is typically used to treat the following:

- Contaminants associated with DNAPLs, including chlorinated VOCs and PAHs
- Contaminants associated with LNAPLs, such as BTEX
- Metals, metalloids, and inorganics, such as chromium, arsenic, and cyanide

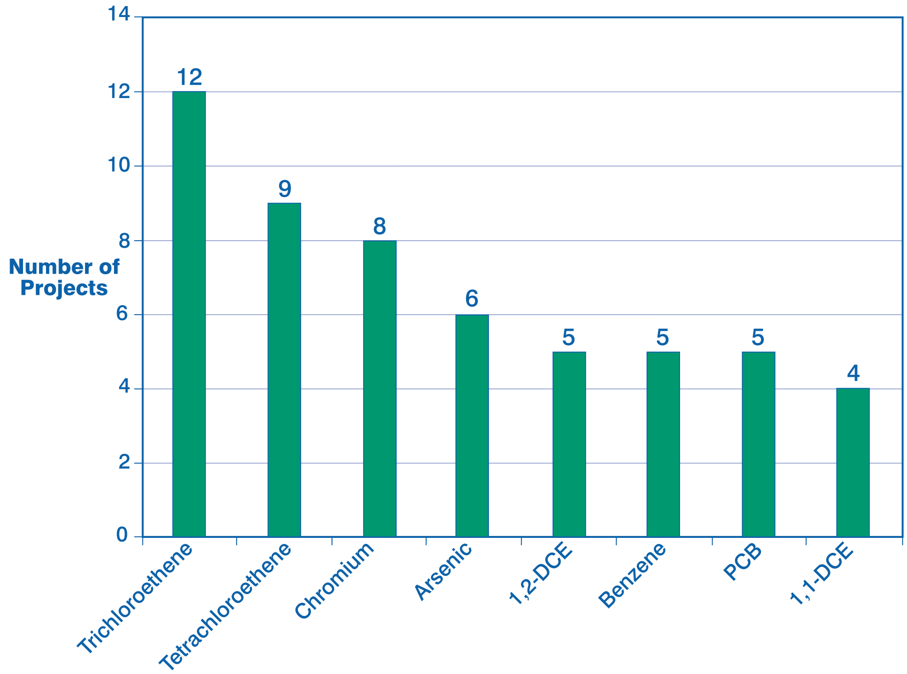
The eight contaminants most frequently treated using chemical treatment either *in situ* or *ex situ* are shown in Figure 29. TCE is the most commonly treated contaminant, followed by PCE, chromium, and arsenic.

Box 9. In Situ Groundwater Chemical Treatment

In situ chemical treatment is being used to treat groundwater contaminated with halogenated volatile organic compounds at the Eastern Surplus Company, a 5-acre site located in Meddybemps, Maine. This site served as a retail location for army surplus and salvage items from 1946 to the early 1980's. During an inspection in 1984, chemical odors, leaking electrical transformers, hundreds of deteriorating drums and containers, and numerous areas of stained soil were observed. Tetrachloroethene (PCE) was identified as the main site contaminant. Trichloroethene, 1,2-dichloroethene, 1,1,2-trichloroethane, methylene chloride, and xylene were also detected in site groundwater. A removal action was conducted, which included soil excavation (completed in 1999) and a groundwater P&T system for plume containment, which became operational in 2001.

A Record of Decision was issued in 2000 for in situ chemical oxidation to restore the site groundwater. Design of the system began in December 2000, and construction was completed in 2001. Several pilot applications were conducted, and the full-scale application began in 2002. This treatment includes permanganate injection for treating PCE.

Figure 29: Superfund Remedial Actions: Most Commonly Treated Contaminants for Chemical Treatment Projects (FY 1982 - 2002)*



** Includes information from an estimated 70% of FY 2002 RODs.*
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.
DCE = Dichloroethene
PCB = Polychlorinated biphenyls

Construction Completion

This edition of the ASR includes information from close-out reports (COR). CORs are prepared when physical construction of all cleanup actions is complete, all immediate threats have been addressed, and all long-term threats are under control. CORs contain information on the actions taken at the site to protect human health and the environment. These reports are prepared for Superfund sites on EPA's Construction Completion List (CCL). For long-term remedies, CORs may be prepared before the remedy is completed. For example, a site with groundwater contamination may achieve construction complete status when a P&T remedy becomes operational. In such cases, a Preliminary COR (PCOR) is prepared. When the groundwater cleanup has been completed, a final close-out report (FCOR) is prepared. This report incorporates both PCORs and FCORs. It is important to note that sites with a COR may not have a completed project, as defined in this report (i.e., the project may still be operating).

One indicator of remediation progress in the Superfund Program is the number of CORs issued. CORs have been prepared for 57% of all NPL sites. Table 13 shows the number of NPL sites with CORs through FY 2002. Figure 30 shows technologies included in CORs from FY 1983 - 2000. The most common technology in CORs is P&T. SVE, S/S, incineration, and bioremediation are other technologies representing a large fraction of CORs. The total number of technologies in Figure 30 exceeds the total number of CORs because CORs discuss all remedies implemented at a site, and many sites have more than one remedy involving a treatment technology.

Construction Complete status is only achieved when the Construction Complete criteria are met for all portions of a site. At sites with multiple areas of contamination, or multiple types of contaminated media, achieving Construction Complete status may require a longer time than simpler sites with fewer contaminated areas or media. The number of treatment projects tracked

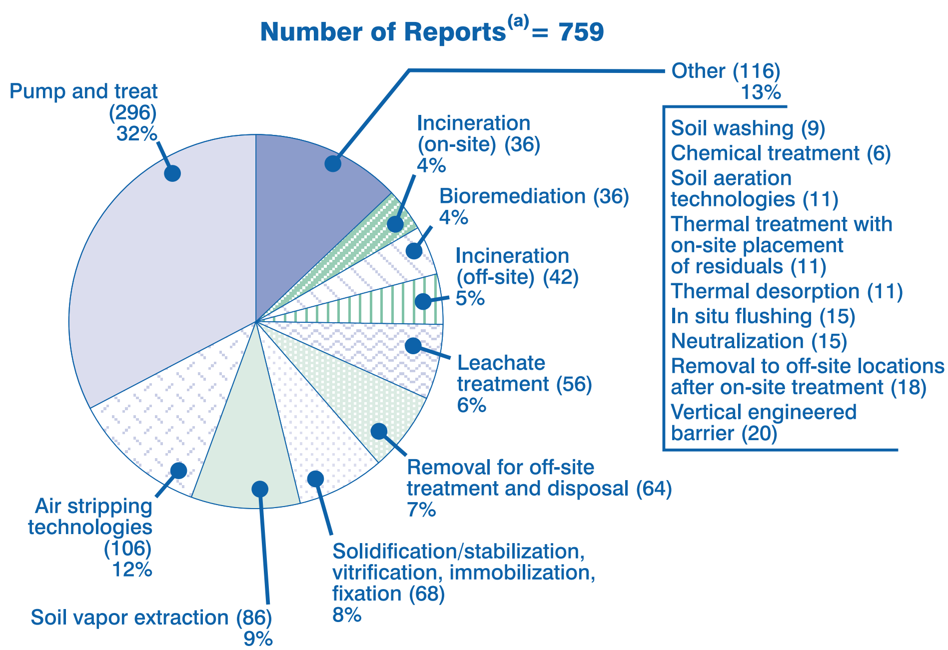
Table 13. Superfund Remedial Actions: Status of Close-out Reports at National Priorities List Sites (FY 1983 - 2002)

Status of Close-out Reports	Number of Sites	Percentage of Sites
Sites with a Close-out Report	846	56%
Sites without a Close-out Report	491	33%
Sites with no ROD (and no close-out report)	158	11%
Sites deleted and referred to another authority	4	1%

ROD = Record of Decision
Sources: 3, 4, 5, 7, 11. Data sources are listed in the References and Data Sources section on page 50.

in the ASR were compared for sites with CORs and sites without CORs. The average number of projects for sites with CORs is slightly less than the average number of projects for sites without them (1.7 compared to 2.2 projects per site). Sites with fewer treatment projects tend to be less complex, with fewer contaminants and smaller volumes of media requiring treatment. These less complex sites are likely to achieve construction complete status more quickly, and therefore have a COR published for them. More complex sites may take longer to identify and implement remedies. For example, 182 of the completed treatment projects identified in this report are at sites that do not have CORs. At these sites, construction of another remedy has not yet been completed.

Figure 30: Superfund Remedial Actions: Technologies Being Used at Sites That Have Achieved Construction Complete Status (FY 1983 - 2000)



(a) Through FY 2000, 759 sites had Close-out reports. Technology information was not available for FY 2001 and 2002. Some close-out reports include more than 1 technology.
Source: 18. Data sources are listed in the References and Data Sources section on page 50.

Section 5: References and Data Sources

1. List of Superfund National Priorities List (NPL) sites that are final. www.epa.gov/superfund/sites/query/queryhtm/nplfina.txt March 2003.
2. List of Superfund NPL sites that have been deleted. www.epa.gov/superfund/sites/query/queryhtm/npldela.txt March 2003.
3. Compilation of Record of Decision (ROD) abstracts, site summaries, and fact sheets for fiscal years (FY) 1982 - 2002. www.epa.gov/superfund/sites/query/advquery.htm March 2003.
4. Records of Decision (RODs), ROD amendments, Explanations of Significant Difference, and ROD abstracts from FY 1982 - 2002.
5. Contacts with remedial project managers, FY 1992 - 2002.
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19. Subsurface Containment and Monitoring Systems: Barriers and Beyond. Leslie Perlman. March 1999.
20. Evaluation of Subsurface Engineered Barriers at Waste Sites (EPA-542-R-98-005). EPA OSWER. August 1998.15. The Role of Cost in the Superfund Remedy Selection Process (EPA 540-F-96-018). EPA. OSWER. September 1996.

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