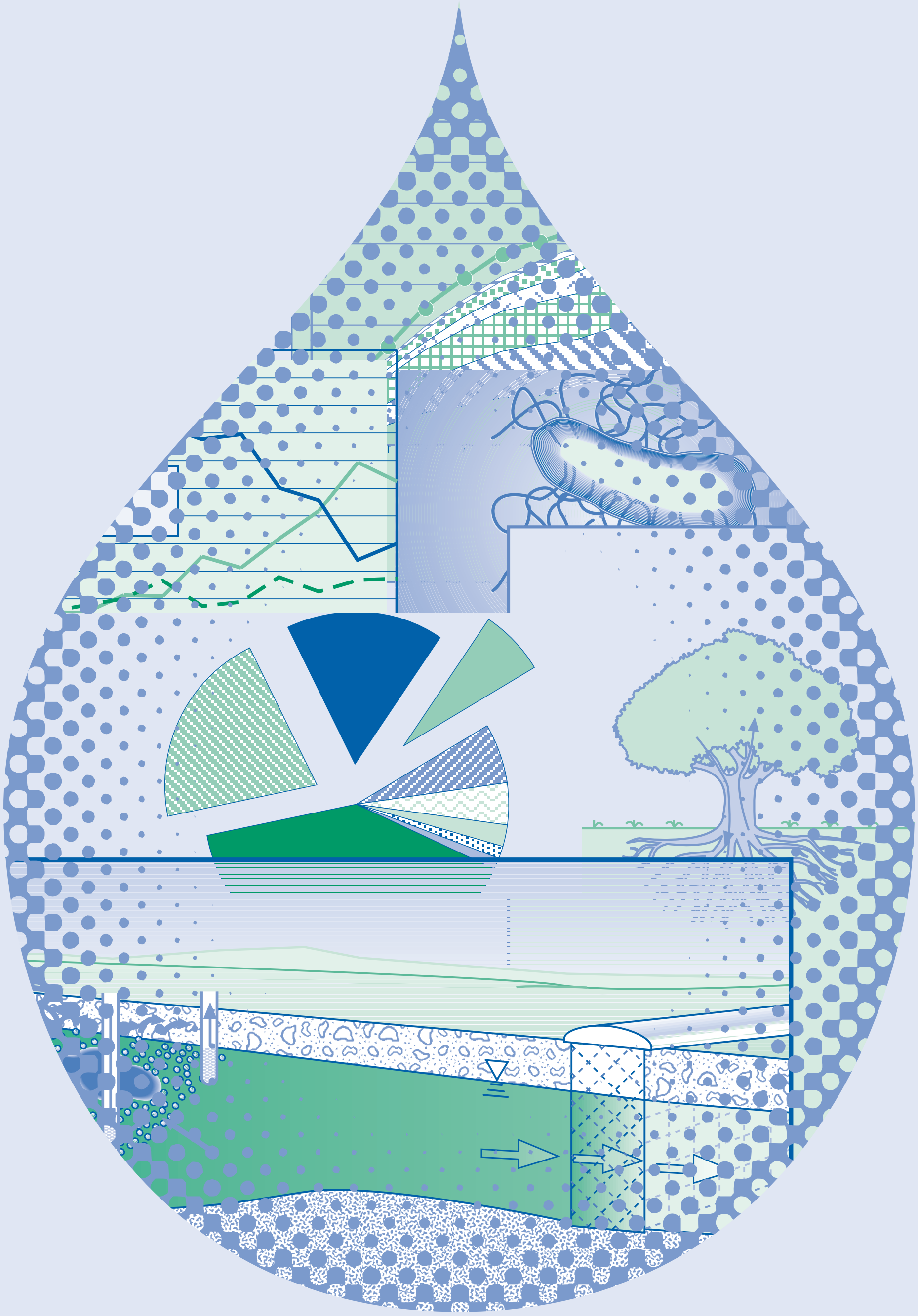
Groundwater Remedies Selected at Superfund Sites



Solid Waste
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clu-in.org/groundwater

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FIGURES

Acronyms

ASR	Annual Status Report
BTEX	Benzene, toluene, ethylbenzene, and xylene
CERCLIS 3	Comprehensive Environmental Response, Compensation, and Liability Information System
CLU-IN	EPA's hazardous waste CLeanUp INformation system
EPA	U.S. Environmental Protection Agency
ESD	Explanation of significant differences
FRTR	Federal Remediation Technologies Roundtable
FY	Fiscal year
MNA	Monitored natural attenuation
NA/NFA	No action/no further action
NAPL	Nonaqueous phase liquid
NPL	National Priorities List
OERR	Office of Emergency and Remedial Response
OSC	On-scene coordinator
OSWER	Office of Solid Waste and Emergency Response
OU	Operable unit
P&T	Pump and treat
PAH	Polycyclic aromatic hydrocarbon
pdf	Portable document format
PRB	Permeable reactive barrier
ROD	Record of Decision
RPM	Remedial Project Manager
RSE	Remedial System Evaluation
SVE	Soil vapor extraction
SVOC	Semivolatile organic compound
TIO	Technology Innovation Office
VEB	Vertical engineered barrier
VOC	Volatile organic compound

Notice

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A portable document format (pdf) version of *Groundwater Remedies Selected at Superfund Sites* is available for viewing or downloading from the Hazardous Waste Cleanup Information (CLU-IN) web site at http://clu-in.org/groundwater. A printed copy can also be ordered directly from CLU-IN.

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Executive Summary

Over a 17-year period from 1982 through 1999 (years discussed in this report are fiscal years [FY]), more than 2,200 Records of Decision (RODs) have been signed for 1,451 Superfund sites, including 989 RODs addressing the remediation of contaminated groundwater at 787 Superfund sites. Groundwater remediation continues to be a priority for the U.S. Environmental Protection Agency (EPA), and remedies that have been specified in RODs for groundwater remediation include treatment (including groundwater pump and treat [P&T] and in situ treatment) and monitored natural attenuation (MNA).

The Technology Innovation Office of the EPA's Office of Solid Waste and Emergency Response (OSWER) prepared this report to document the selection of groundwater treatment and MNA remedies at Superfund remedial action sites. The report presents data on groundwater treatment and MNA remedy decisions and analyzes trends in these decisions over time.

The focus of this report is on groundwater treatment and MNA remedies that result in a reduction of contaminant concentrations or mobility. Groundwater containment and groundwater-other remedies are not addressed in this report.

The findings of this report on the selection of groundwater treatment and MNA remedies are:

Major Findings:

- The selection of P&T as a groundwater remedy has steadily decreased since 1986.
- The selection of in situ treatment and MNA as groundwater remedies has increased since 1986, with the exception of 1999, when selection of MNA remedies decreased significantly.

Remedy Types:

- Between 1982 and 1999, at least one groundwater remedy was selected at more than half (54%) of Superfund sites.
- P&T is the most frequently selected remedy at groundwater remedy sites, followed by MNA and in situ treatment.

Remedy Selection Trends:

- The percentage of groundwater remedy RODs that selected only P&T has decreased from 92% in 1986 to 30% in 1999.
- The percentage of groundwater remedy RODs selecting only MNA has increased from 8% in 1986 to 23% in 1999. In 1998, the percentage of MNA-only RODs peaked at 44% but declined to 23% in 1999.
- The percentage of groundwater remedy RODs selecting in situ treatment increased sharply from 1995 (9%) through 1999 (35%). This rapid growth followed a slow climb from 1986 (0%) to 1995 (9%).

In Situ Treatment Technologies:

- The in situ groundwater treatment technologies most commonly used for Superfund remedial actions are air sparging and bioremediation.
- The in situ groundwater treatment technology used most frequently to treat volatile organic compounds is air sparging, while semi-volatile organic compounds are most frequently treated using bioremediation.

Overview

Introduction

This report presents the results of analyses of:

- the types of groundwater remedies selected at Superfund sites,
- the trends in the selection of groundwater remedies,
- the technologies used to perform in situ treatment of groundwater, and
- the contaminants treated using in situ groundwater treatment technologies.

This report focuses on groundwater treatment or MNA remedies selected in 989 RODs or ROD amendments through 1999. Groundwater treatment and MNA remedies reduce contaminant concentrations or decrease their mobility. However, MNA does not generally satisfy the CERCLA preference for treatment because it is not an engineered technology (Ref. 12, page 17). Detailed information about the technologies used to perform in situ groundwater treatment is presented for 95 treatment projects at 81 sites.

Remedy Selection Background

RODs for Superfund remedial actions may address sources of contamination, such as soil, sludge, sediments, and solid-matrix wastes. Such "source control" RODs select "source control remedies." RODs also may address groundwater. RODs for Superfund remedial actions that address groundwater are "groundwater" RODs. Appendix B to this document is a detailed description of the methodology used to identify ROD types, including detailed definitions of "source control," "groundwater," and other remedy types. Table 1 presents a brief overview of these remedy types.

Table 1. Types of Remedies

Source Control Remedy

- Addresses a contaminant source, such as soil, sludge, sediment, or solid waste.
- Can include source treatment, containment, or other source remedies such as access restrictions and population relocation.

Groundwater Remedy (See Table 2 for more detail on groundwater remedies)

- Remediation of a contaminated aquifer
- Can include pump and treat, in situ treatment, monitored natural attenuation, containment using vertical engineered barriers, or groundwater-other remedies such as providing an alternate drinking water supply.

Throughout this report, the term "groundwater remedies" refers to P&T, in situ treatment, and MNA, and does not include groundwater containment and groundwater-other remedies, unless specified. Table 2 provides brief descriptions of groundwater remedies, including groundwater containment and groundwater-other remedies.

Remedies Addressed in This Report

EPA's Technology Innovation Office (TIO) has historically provided information about innovative and conventional remedies at Superfund sites in the report *Treatment Technologies for Site Cleanup: Annual Status Report (Tenth Edition)* (ASR). The ASR is available on line at *http://clu-in.org/asr*. Currently in its tenth edition, the ASR has focused primarily on source control treatment and in situ groundwater treatment, and has not addressed groundwater P&T or MNA remedies.

TIO continues to advocate more effective, less costly approaches (i.e., "smarter solutions") to cleaning up hazardous waste sites. This report provides information about the use of groundwater treatment and MNA remedies at Superfund sites to site managers, technology service providers, and other stakeholders to assist them in identifying sites where particular groundwater remedies have been selected. In addition, EPA can also use the information in this report to track groundwater remedy selections and assist site managers in their quest to optimize past or future remedies with new information and knowledge acquired from analyzing all remedies in the program.

Groundwater containment and groundwater-other remedies are not addressed in this report. Groundwater containment remedies, such as vertical engineered barriers, are not a focus of this report because these remedies have been discussed in detail in the ASR. Groundwater-other remedies (see Table 2, page 2), 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 in contaminant concentrations or a decrease in contaminant mobility. In addition, the information needed to identify groundwater-other remedies is not currently available. Appendix B contains a complete list of remedies that are considered groundwater-other.

A portable document format (pdf) version of this report is available for viewing or downloading from the Hazardous Waste Cleanup Information (CLU-IN) web site at *http://clu-in.org/groundwater*. To facilitate access to more detailed information about the remedies selected at specific sites and in specific RODs, the online pdf version of this report also contains links to downloadable spreadsheets containing supporting data for figures presented in this report.

Table 2. Types of Groundwater Remedies

Pump and Treat (P&T)

- Extraction of groundwater from an aquifer and treatment above ground.
- Extraction usually is done by pumping groundwater from a well or trench. A variety of technologies may be used in performing treatment.

In Situ Treatment

- Treatment of groundwater in place without extracting it from an aquifer.
- Specific treatment technologies used for in situ groundwater treatment that are discussed in this report are:
  - Air sparging
  - Bioremediation
  - Chemical treatment
  - Dual-phase extraction
  - In-well air stripping
  - Permeable reactive barriers
  - Phytoremediation

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 reasonable time frame.
- 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.
- Groundwater containment may be performed using a variety of barrier materials and barrier construction techniques.

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.

Sources of Information for This Report

For this report, information about remedy selections was gathered from the 2,292 RODs and ROD amendments for Superfund sites that were signed from 1982 through 1999, of which 989 selected groundwater treatment or MNA remedies.

Information about specific technologies used for and contaminants treated by in situ groundwater treatment remedies initially was compiled from RODs, ROD amendments and those Explanations of Significant Differences (ESDs) included in the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS 3), EPA's Superfund tracking system. Data on project status in the CERCLIS 3 provided more detailed information about the specific portion of the remedy involving in situ groundwater treatment technologies. EPA then verified and updated the information on in situ technologies through interviews with remedial project managers (RPMs), On-Scene Coordinators (OSCs), and other contacts for each site. Therefore, information in this report may differ from information in the CERCLIS 3 database. Such differences occur when changes are made in the remedy during the design phase of the project. The changes may not require official documentation (that is, a ROD amendment or ESD), and hence, would not be recorded in CERCLIS 3 but would be obtained from interviews.

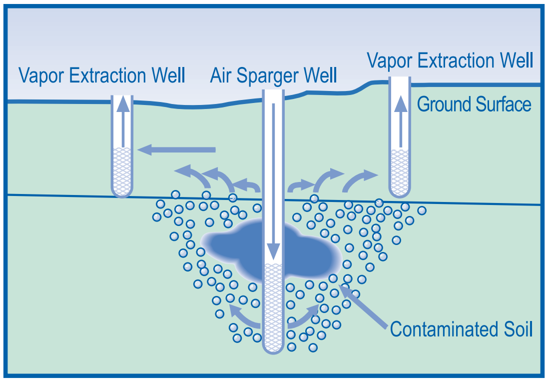
Definitions of Specific Treatment Technologies

This document reports on the selection of groundwater remedies and the use of specific in situ groundwater treatment technologies. This introduction provides brief definitions of seven types of in situ groundwater treatment technologies, as they are discussed in this document. The groundwater treatment technology definitions are based on the introduction to the ASR. The ASR can be viewed at *http://clu-in.org/asr*. Sketches are provided for some of the technologies.

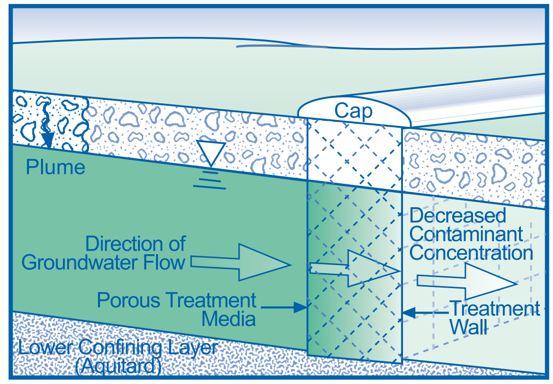
In Situ Groundwater Treatment Technologies

AIR SPARGING involves the injection of air or oxygen through a contaminated aquifer. Injected air traverses horizontally and vertically in channels through the soil, 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. Soil vapor extraction (SVE) usually is implemented in conjunction with air sparging to remove the generated vapor-phase contamination from the vadose zone. Oxygen present in the air added to the contaminated groundwater and vadose-

Model of an Air Sparging System



Model of a Permeable Reactive Barrier



zone soils also can enhance biodegradation of contaminants below and above the water table.

With IN SITU GROUNDWATER BIOREMEDIATION, substrates, nutrients, nonnative bacteria, or an oxygen source (for aerobic processes), are pumped into an aquifer through wells to enhance biodegradation of contaminants in groundwater. Specific types of in situ groundwater bioremediation include biosparging and bioventing.

DUAL-PHASE EXTRACTION, also known as multi-phase extraction, uses a vacuum system to remove various combinations of contaminated groundwater, immiscible contaminants, and vapors from the vadose and saturated zone. The system lowers the water table around the well, exposing more of the vadose zone. Contaminants in the newly exposed vadose zone are then accessible to vapor extraction. The extracted vapors or liquid-phase organics and groundwater are collected, separated, and treated above ground.

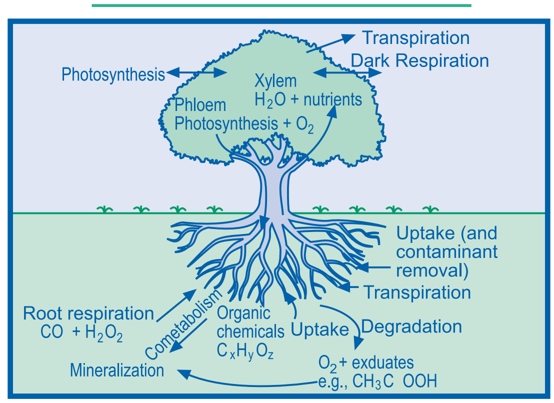
CHEMICAL TREATMENT, also known as chemical reduction/oxidation, typically involves reduction/oxidation (redox) reactions that chemically convert hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, or inert. Redox reactions involve the transfer of electrons from one compound to another. Specifically, one reactant is oxidized (loses electrons) and one is reduced (gains electrons). Cyanide oxidation and dechlorination are examples of chemical treatment.

For IN-WELL AIR STRIPPING, air is injected into a double screened well, lifting the water in the well and forcing it out the upper screen, which causes additional water to be drawn into the lower screen. Volatile organic compounds (VOCs) in the contaminated groundwater are transferred from the dissolved phase to the vapor phase in air bubbles, which rise to the water surface, as vapors are drawn off and treated. The treated groundwater is forced into the unsaturated zone.

PERMEABLE REACTIVE BARRIERS (PRBs), also known as passive treatment walls, are installed across the flow path of a contaminated groundwater plume, allowing the passage of water, while treating the contaminants with zero-valent iron, chelators, sorbents, or microbes. The contaminants are either degraded or retained in a concentrated form by the barrier material, which may require periodic replacement.

PHYTOREMEDIATION is a process that uses plants to remove, transfer, stabilize, or destroy contaminants in soil, sediment, and groundwater. The mechanisms of phytoremediation include enhanced biodegradation in the rhizosphere (soil or groundwater immediately surrounding plant roots), phytoextraction (also known as phytoaccumulation, the uptake of contaminants by plant roots and the translocation and accumulation of contaminants into the shoots and leaves of plants), 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. Plants can be used in site remediation, both through the mineralization of toxic organic compounds and through the accumulation and concentration of heavy metals and other inorganic compounds into aboveground shoots. Phytoremediation may be applied in situ or ex situ, to soils, sludges, sediments, other solids, or groundwater.

Model of Phytoremediation



Section 1: Overview of Remedy Decisions

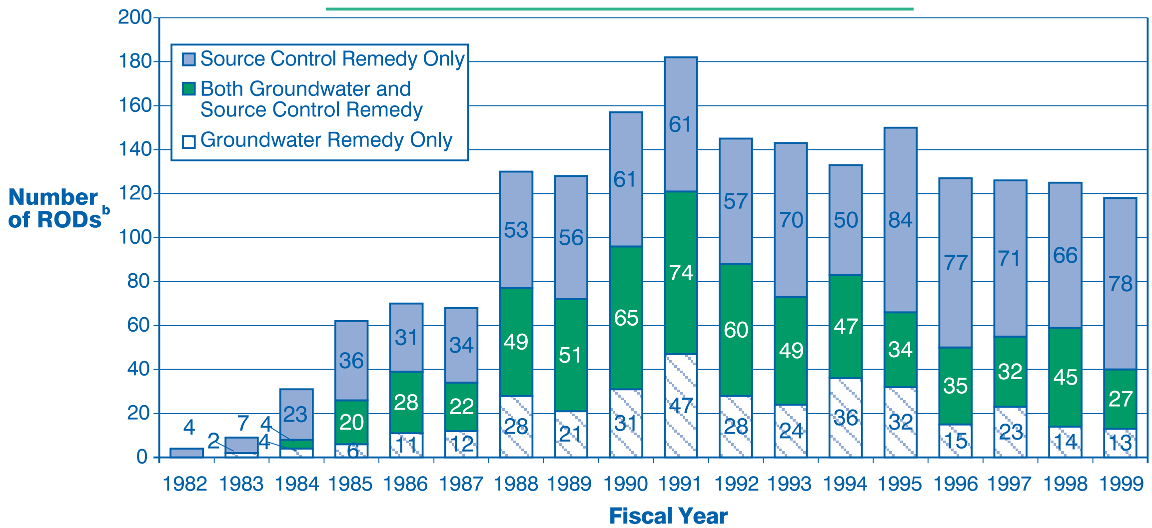
Groundwater Treatment and MNA RODs Signed by Year

As of August 2000, 1,234 sites were on the National Priorities List (NPL); 217 sites had been removed from the NPL. Therefore, 1,451 sites are, or have been, listed on the NPL. An additional 59 sites are proposed for the NPL. Some complex sites may cover a large area, include several types of contaminated media, or include areas in which the types of contamination differ. A complex site may be divided into operable units, each with separate remedies. Remedies for NPL sites are documented in RODs. A separate ROD may be developed for each operable unit. In addition, each operable unit may require a number of RODs to address different media within that operable unit or to revise the selected remedy. Therefore, each site may have multiple RODs.

Through 1999, approximately 2,292 RODs (including ROD amendments) had been signed. Of these, 989 RODs for remedial actions address groundwater treatment or MNA. To support data analysis for this report, a type was assigned to each ROD based on the remedies in the ROD. A type then was assigned to each site based on the types of RODs issued for that site. Appendix B to this report provides the definitions of the various ROD types and describes the methodology used to assign a type to each ROD. For sites for which a number of RODs had been signed, the hierarchy presented in Appendix B was used to assign a site type. This report focuses on groundwater remedies rather than source control treatment remedies; therefore, the hierarchy presented in Appendix B differs from the hierarchy presented in Appendix F of the ASR.

Since 1988, the total number of RODs signed in each year has remained relatively stable, between 142 and 197. For each year, Figure 1 shows the number of RODs selecting only groundwater remedies, both groundwater and source control remedies, and only source control remedies. This figure does not include RODs selecting only no action or no further action (NA/NFA) remedies. Figure 1 shows that the number of RODs addressing groundwater is decreasing. The number of RODs selecting a groundwater remedy, either alone or in combination with a source control remedy, peaked in 1991 at 121 (66% of RODs in 1991). Since 1991, this number has decreased to 40 in 1999 (34% of RODs in 1999). Cumulatively, RODs selecting only a groundwater remedy represent 18% of the total number of RODs (excluding NA/NFA RODs), RODs selecting both groundwater and source control remedies represent 34%, while those selecting only a source control remedy represent 48%.

Figure 1. RODs Selecting Groundwater[a] and Source Control Remedies (FY 1982 - FY 1999)



Sources: 3, 4. Data sources are listed in the References and Data Sources Section on p. 17.

a. Includes groundwater pump and treat, in situ treatment, and monitored natural attenuation remedies. Groundwater containment and groundwater-other remedies are not included.

b. Includes RODs selecting groundwater and source control remedies. RODs selecting only no action or no further action remedies are not included.

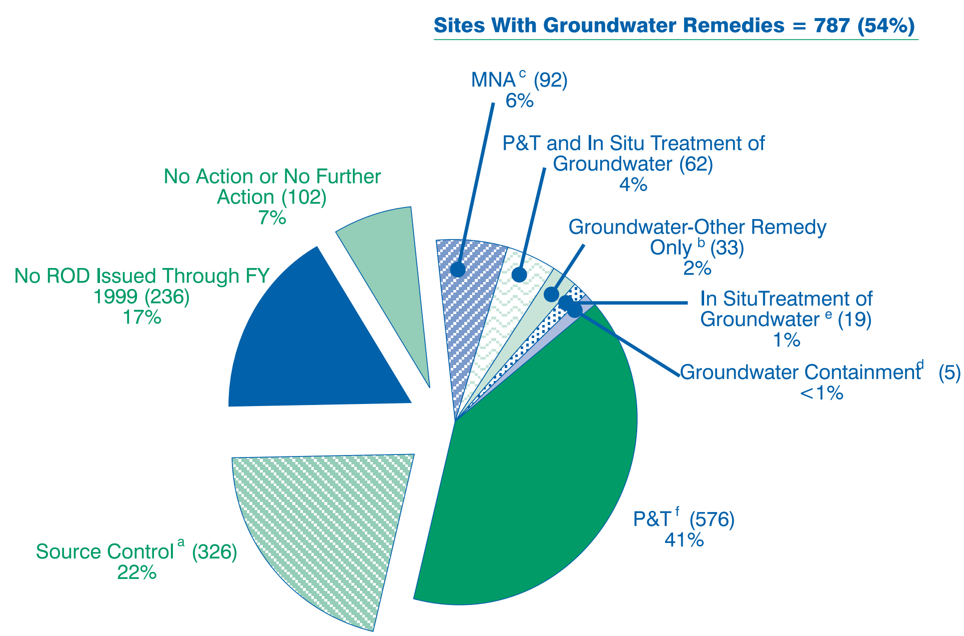
Groundwater containment and groundwater-other remedies were not considered for Figure 1 (page 4) because they are not the focus of this report and the data needed to identify groundwater-other remedies were not available. In addition, RODs selecting only NA/NFA remedies are not included in Figure 1 (page 4). RODs identified as having only source control remedies may in fact have groundwater containment or groundwater-other components to their remedies. For example, a site selecting solidification/stabilization for a source control remedy and an alternate water supply for a groundwater remedy is classified as only having a source control remedy because the groundwater remedy is groundwater-other, which is not discussed in detail in this report.

RODs may have selected only groundwater remedies when the only media requiring a remedy at a site was groundwater or the remediation of contaminant sources was addressed in a separate ROD. RODs selecting both source and groundwater remedies did not necessarily address related source and groundwater media (i.e., remediation of both contaminated groundwater and sources contributing to that groundwater contamination). For example, at the Fort Ord site in Marina, California (CERCLIS ID number CA7210020676) a ROD signed in 1997 selected excavation and on-site disposal of soil and debris from several areas of the site (a source control remedy) and treatment of groundwater contamination in a separate area of the site (a groundwater treatment remedy). In this case, a single ROD selected separate source control and groundwater remedies for portions of the site that were not directly related.

Groundwater Remedy Selection at Sites on the NPL

As shown in Figure 2, over half of all NPL sites (787 of 1,451) selected some type of groundwater remedy, including groundwater treatment (P&T or in situ treatment), MNA, containment, or groundwater-other remedies. Sites for which only a source control remedy was selected comprise 22%

Figure 2. Remedy Types Selected at Sites on the National Priorities List (FY 1982 - FY 1999)



Sources: 1, 2, 3, 4, 5, 6, 8. Data sources are listed in the References and Data Sources Section on p. 17.
P&T = Pump and treat
MNA = Monitored natural attenuation
a. Includes sites where a source control remedy was selected but no groundwater P&T, in situ treatment, MNA, or containment remedy was selected. Insufficient data were available to identify sites selecting both source control and groundwater-other remedies; therefore, some of the 326 source control sites may also have groundwater-other remedies.
b. Includes only sites where groundwater-other remedies were the only remedies selected for the site.
c. Does not include sites selecting both MNA and P&T or in situ treatment of groundwater.
d. Does not include sites selecting P&T, in situ treatment of groundwater, or MNA.
e. Does not include sites selecting both P&T and in situ groundwater treatment.
f. Includes both P&T alone and P&T with any other remedy (except in situ groundwater treatment).

of sites on the NPL (326 sites). NA/NFA was the only remedy selected at an additional 102 sites (7%) and no ROD had been issued through 1999 at 236 sites (17%). This report focuses on the 749 sites (52% of all sites) at which groundwater treatment or MNA was included in the selected remedy. Figure 3 presents greater detail about the 749 sites in Figure 2 (page 5) for which groundwater treatment and MNA remedies were selected.

For this report, a remedy type was assigned to each site on the NPL based on this report's focus on groundwater treatment and MNA remedies. In Figure 2 (page 5), sites with a groundwater treatment remedy were identified as having a P&T remedy, an in situ treatment remedy, or both a P&T remedy and an in situ treatment remedy. Of the remaining sites, a single remedy was identified based on the hierarchy presented in Appendix B. Therefore, for many sites, more remedies were selected than the one identified in the figure.

Appendix A to this report is a table that lists RODs that have been signed and the groundwater remedies selected in those RODs. This table can help site managers, the regulated community, and remediation professionals identify RODs for which a particular remedy type has been selected. The electronic version of this report, which is available on EPA's CLU-IN web site (*http://clu-in.org/groundwater*), includes Appendix A as a downloadable spreadsheet.

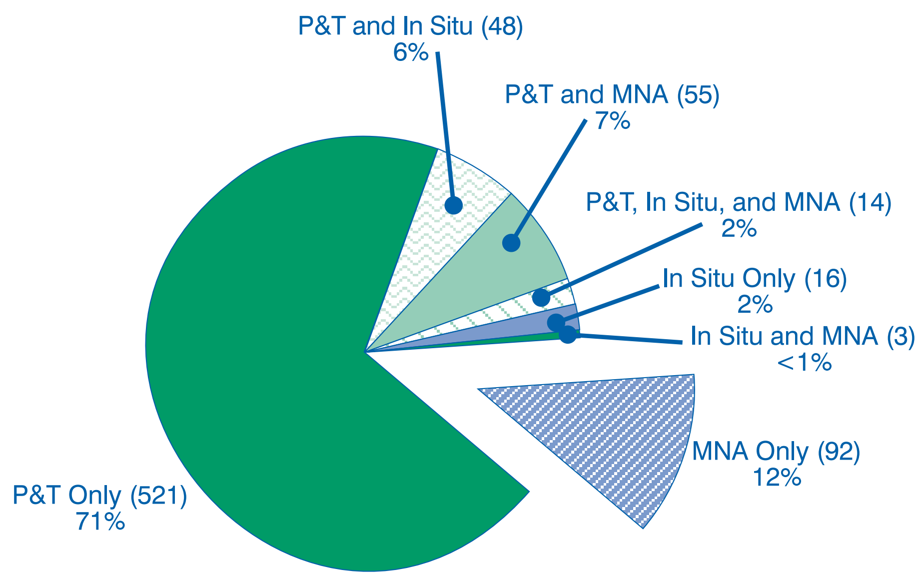
Because previous data gathering efforts focused primarily on source control, groundwater treatment, and groundwater MNA remedies, insufficient data were available to identify groundwater-other remedies when those remedies were selected in conjunction with a source control remedy. Therefore, the sites represented by the "Groundwater-Other Only" wedge of Figure 2 (page 5) are sites at which groundwater-other was the only remedy selected at the site (see Table 2 for remedy definitions). Similarly, some of the sites represented by the "Source Control" wedge of Figure 2 (page 5) may also have groundwater-other remedies. Therefore, the total number of sites with groundwater-other remedies may be higher than the 33 sites indicated in Figure 2 (page 5).

Figure 3 focuses on NPL sites with groundwater P&T, in situ treatment, or MNA remedies. At least one of those groundwater remedies has been selected for 749 of the 1,451 sites in Figure 2 (page 5). The sites in Figure 3 are those sites from the following slices of the pie chart in Figure 2:

- P&T of Groundwater
- P&T and In Situ Treatment of Groundwater
- In Situ Treatment of Groundwater
- MNA

Figure 3. Sites with P&T, In Situ Treatment, or MNA Selected as Part of a Groundwater Remedy (FY 1982 - FY 1999)

Total Number of Sites = 749



Sources: 3, 4, 5, 6, 8. Data sources are listed in the References and Data Sources Section on p. 17.
P&T = Pump and treat
MNA = Monitored natural attenuation

P&T systems alone were selected for 521 sites, MNA alone for 92 sites, and in situ groundwater treatment alone for 16 sites.

When two types of groundwater remedies were used at the same site, a P&T system was used most frequently with MNA (55 sites). Next in frequency of use was a P&T system with in situ treatment (48 sites). For 14 of the 749 sites, three types of groundwater remedies were used at the same site. At the majority of sites where a groundwater remedy was selected, some form of treatment was included. P&T or in situ treatment was included in the selected remedy at 88% (657) of the sites, while sites selecting only MNA comprised only 12% of sites.

The online version of this report includes a downloadable spreadsheet to help site managers, the regulated community, and remediation professionals identify sites at which a particular remedy type has been selected. The spreadsheet contains information for each NPL site where a ROD has been issued, including the site name, location, and site type. The electronic version of this report is available on EPA's CLU-IN web site at *http://clu-in.org/groundwater*.

Groundwater P&T 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 protectiveness of the remedy or achievement of other response 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 Fund-lead P&T systems at Superfund sites.

To fulfill this commitment, EPA is gathering information on Fund-lead P&T systems and selecting sites for a Remediation System Evaluation (RSE). Fund-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 up to 20 Fund-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* (Ref. 10, page 17), which is available on line at *http://clu-in.org*. This report was used to analyze the status and age of P&T systems. Additional information on RSE and optimization of remedies is available at *http://www.frtr.gov/optimization*. This site includes information on optimization tools and techniques, including checklists that can be used to identify optimization opportunities for specific groundwater treatment technologies.

Table 3 shows the number of years the Fund-lead P&T systems have been in operation. The average age of the systems was approximately 5 years. Opportunities for optimization have been found in three areas of P&T systems: long-term monitoring of their performance, well placement and pumping rates, and the effluent stream treatment technology. P&T systems, while performing as designed and being protective, may not always be operating in the most cost effective manner. The longer a remedy has been operating, the richer the performance data set available with which to seek optimization opportunities in any of the areas described in this section.

Table 3. Years in Operation for 67 Superfund Remedial Action P&T Systems

Years in Operation	Number of Systems (Percent of Systems)
0 - 5	35 (52%)
5 - 10	28 (42%)
10 - 15	4 (6%)
Total	67

Sources: 10. Data sources are listed in the References and Data Sources Section on p. 17.

Section 2: Common Groundwater Remedies

Three common groundwater remedies selected at NPL sites are groundwater treatment, including P&T and in situ treatment, and MNA. These remedies are designed to remediate contaminated aquifers and return them to beneficial uses, primarily through a reduction in concentrations of contaminants. The definitions of groundwater, P&T, in situ treatment, and MNA are provided in Appendix B to this report. In this section, each of these remedy types is discussed both independently and in comparison, and analyses of trends in the selection of these remedies over time are presented. Section 3 discusses specific technologies implemented for the in situ treatment of groundwater.

Many of the figures in this section of the report display and compare information about the selection of groundwater treatment and MNA remedies using line graphs that show the percentage of RODs that selected a particular remedy or combination of remedies by year. Figures 5 through 9 do not include 1982 (the year the first ROD was signed) through 1985 because too few RODs were signed during those years to develop accurate information about trends in remedy selection.

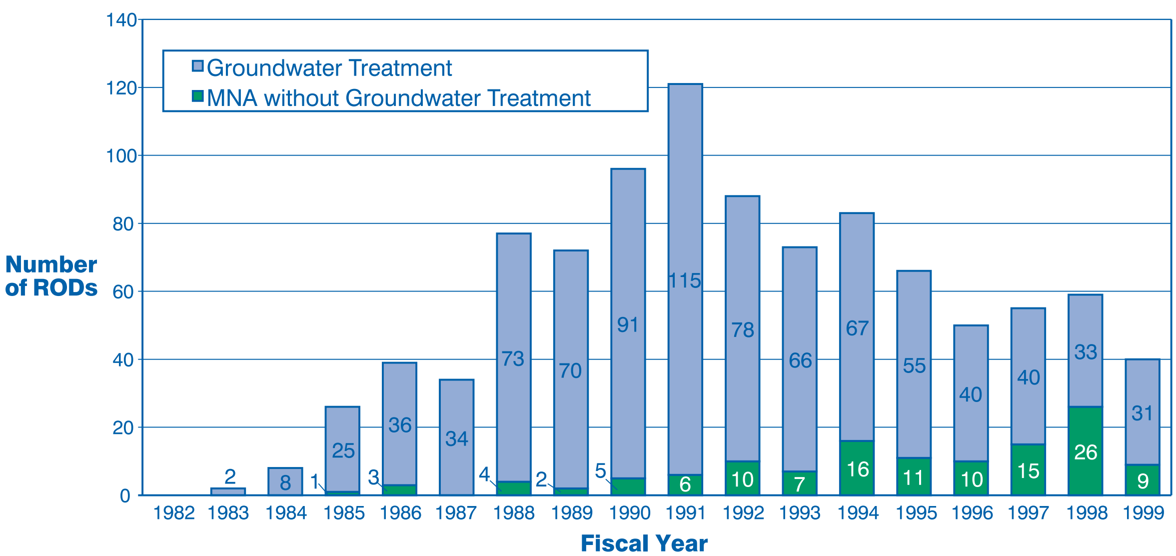
In this report, the term "groundwater RODs" refers to those RODs selecting P&T, in situ treatment, or MNA remedies for groundwater. Where figures in this section show information about RODs as a percentage of groundwater RODs, the total number of groundwater RODs used to calculate those percentages is the sum of RODs selecting P&T, in situ treatment, or MNA of groundwater for each year. Groundwater containment and groundwater-other remedies were not considered when estimating the total number of groundwater RODs. As additional information on groundwater containment and groundwater-other remedies becomes available, EPA may change the basis for estimating the total number of groundwater RODs to include RODs selecting groundwater containment or groundwater-other remedies. Such a change may result in significant changes in the percentages presented in the figures of this section of the report.

Groundwater Treatment RODs

Figure 4 shows the number of RODs in each year selecting a groundwater treatment remedy (including P&T or in situ treatment) and the number selecting only MNA remedies. The total number of groundwater treatment RODs peaked in 1991 at 115 and decreased to the 1999 level of 31.

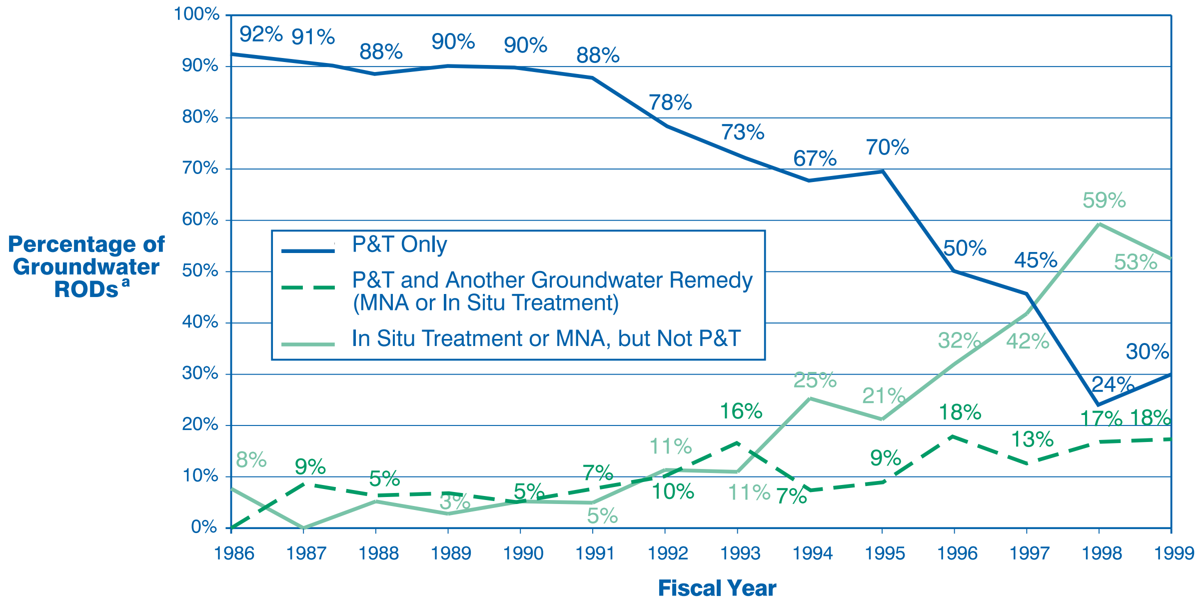
The number of MNA-only RODs increased through 1998, with 26 MNA-only RODs in that year. However, the number of MNA-only RODs declined significantly in 1999 to 9. The number of MNA-only RODs does not represent the total number of RODs selecting MNA because, for Figure 4, RODs selecting both MNA and a groundwater treatment remedy were counted as groundwater treatment RODs.

Figure 4. RODs Selecting MNA-Only and RODs Selecting Groundwater Treatment[a] (FY 1982 - FY 1999)



Sources: 3, 4, 5, 6, 8. Data sources are listed in the References and Data Sources Section on p. 17.
MNA = Monitored natural attenuation
a. Groundwater treatment includes pump and treat and in situ groundwater treatment remedies.

Figure 5. Selection of P&T for Superfund Remedial Actions (FY 1986 - FY 1999)



Sources: 3, 4, 5, 6, 8. Data sources are listed in the References and Data Sources Section on p. 17.
P&T = Pump and treat
MNA = Monitored natural attenuation
a. Includes groundwater P&T, in situ treatment, and MNA remedies. Groundwater containment and groundwater-other remedies are not included.

Groundwater P&T Remedy Selection

As a percentage of RODs selecting groundwater remedies, RODs selecting P&T alone have been decreasing. The percentage of groundwater RODs selecting P&T in combination with another groundwater remedy, and the percentage of groundwater RODs not selecting P&T (i.e., those selecting in situ treatment or MNA) has been increasing. Figure 5 shows trends in the selection of P&T remedies, both alone and in combination with groundwater in situ treatment and MNA remedies. In addition, this figure shows the trend in the selection of groundwater remedies that do not include P&T (i.e., the remedies that include in situ groundwater treatment or MNA without P&T).

In 1986, RODS selecting only groundwater P&T represented 92% of all groundwater RODs. This percentage decreased to 30% in 1999. From 1986 to 1999, the selection of groundwater remedies without P&T has increased. In 1986, groundwater treatment and MNA remedies that did not include P&T were selected in only 8% of RODs. By 1999, that fraction increased to 53%. The percentage of groundwater RODs that did not select P&T exceeded the percentage of RODs selecting P&T-only for the first time in 1998 and again in 1999. Groundwater RODs selecting P&T in combination with either in situ groundwater treatment or MNA also increased from 0% in 1986 to 18% in 1999.

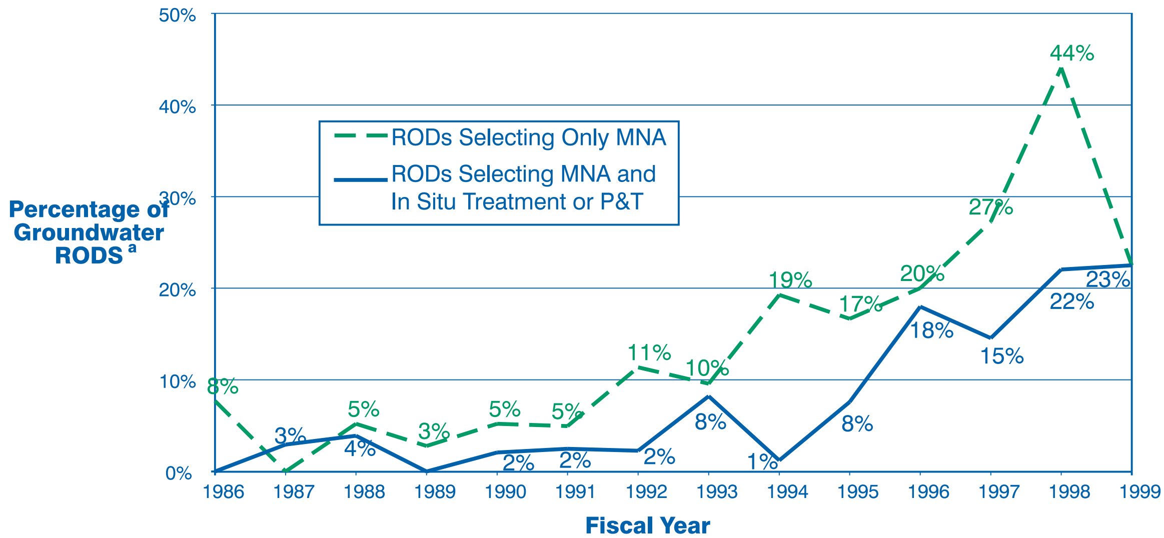
Selection of MNA

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 (Ref. 12, page 17).

Since 1986, the fraction of groundwater RODs selecting MNA, both alone and in combination with P&T and in situ treatment, has increased. Figure 6 (page 10) 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 percentages in Figure 6 add up to less than 100% for each year because groundwater RODs not selecting MNA are not included in this figure. Figures 5 and 6 show that in 1998, the percentage of MNA-only RODs (44%) exceeded the percentage of P&T-only RODs (24%) for the first time. However, the percentage of MNA-only RODs decreased by half to 23% of groundwater RODs in 1999.

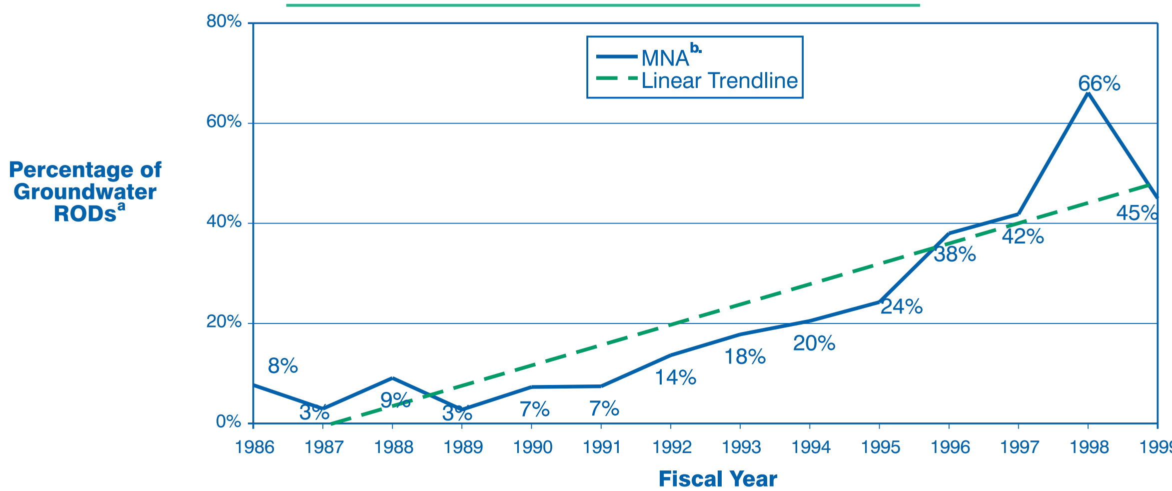
The increase in the selection of MNA can be seen more clearly in Figure 7. This figure shows the percentage of groundwater RODs selecting MNA, either alone or with a groundwater treatment remedy. RODs selecting MNA remedies increased from 8% of groundwater RODs in 1986 to 66% in 1998.

Figure 6. Selection of MNA for Superfund Remedial Actions (FY 1986 - FY 1999)



Sources: 3, 4, 5, 6, 8. Data sources are listed in the References and Data Sources Section on p. 17.
P&T = Pump and treat
MNA = Monitored natural attenuation
a. Includes groundwater P&T, in situ treatment, and MNA remedies. Groundwater containment and groundwater-other remedies are not included.

Figure 7. Trend in the Selection of MNA for Superfund Remedial Actions (FY 1986 - FY 1999)



Sources: 3, 4, 5, 6, 8. Data sources are listed in the References and Data Sources Section on p. 17.
MNA = Monitored natural attenuation
a. Includes groundwater pump and treat, in situ treatment, and MNA remedies. Groundwater containment and groundwater-other remedies are not included.
b. Includes RODs selecting MNA alone and those selecting MNA with any other remedy.

However, in 1999 this percentage decreased to 45%. This decrease coincides with the publication of EPA guidance on the use of MNA during 1999 (Ref. 12, page 17). 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 OSWER, and contained guidance for the implementation of MNA, including guidance for:

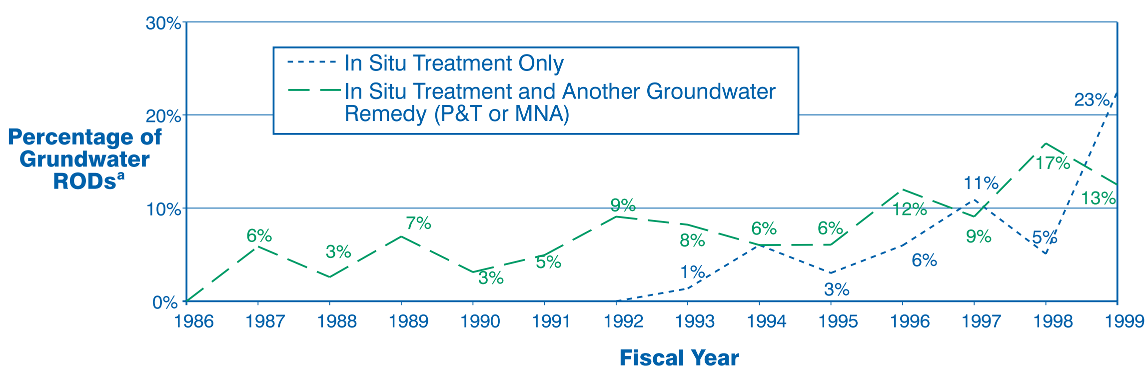
- the role of MNA in OSWER remediation programs
- demonstrating the efficacy of MNA through site characterization
- sites where MNA may be appropriate
- reasonable time frames for achieving cleanup goals using MNA
- remediation of sources using MNA
- performance monitoring and evaluation using MNA
- including contingency remedies as part of an MNA remedy

Although no data that directly link the directive to the decrease in selection of MNA were available, 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 1999 RODs may have identified remedies that they would have previously identified as MNA as another remedy, such as monitoring only or NA/NFA.

Selection of In Situ Treatment

In situ groundwater treatment is usually selected in combination with P&T or MNA. Figure 8 compares the trends in the percentage of groundwater RODs selecting only in situ treatment with in situ treatment in combination with P&T or MNA. The percentages in Figure 8 add up to less than 100% for each year because groundwater RODs not selecting in situ treatment are not included in this figure. Figure 8 shows that the percentage of groundwater RODs selecting in situ

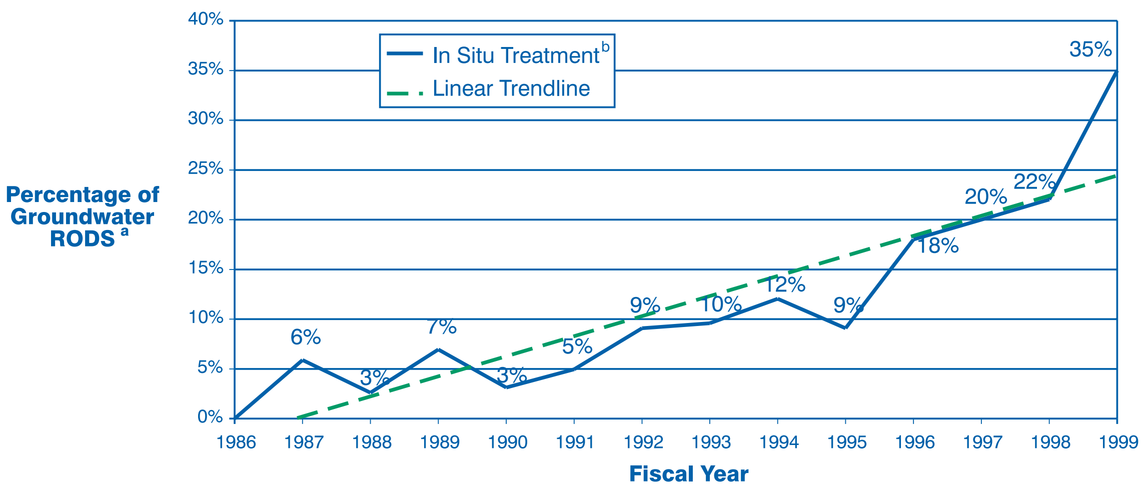
Figure 8. Selection of In Situ Groundwater Treatment for Superfund Remedial Actions (FY 1986 - FY 1999)



Sources: 3, 4, 5, 6, 8. Data sources are listed in the References and Data Sources Section on p. 17.
P&T = Pump and treat
MNA = Monitored natural attenuation
a. Includes groundwater P&T, in situ treatment, and MNA remedies.
Groundwater containment and groundwater-other remedies are not included.

treatment in combination with another groundwater remedy has increased from 0% in 1986 to 13% in 1999. Prior to 1993, no groundwater RODs selected in situ treatment as the sole groundwater remedy. Since then, the percentage of groundwater RODs selecting in situ treatment alone has generally increased. Although the percentage has varied significantly from year to year, the overall trend has been an increase from 1% in 1993 to 23% in 1999. As the trend line in Figure 9 indicates, the percentage of groundwater RODs selecting in situ treatment of groundwater increased from 1986 through 1999. Figure 9 counts all RODs that selected in situ groundwater treatment regardless of the other remedies selected in the ROD.

Figure 9. Trend in the Selection of In Situ Groundwater Treatment for Superfund Remedial Actions (FY 1986 - FY 1999)



Sources 3, 4, 5, 6, 8. Data sources are listed in the References and Data Sources Section on p. 17.

a. Includes groundwater pump and treat, in situ treatment, and monitored natural attenuation remedies. Groundwater containment and groundwater-other remedies are not included.

b. Includes RODs selecting in situ groundwater treatment alone and those selecting in situ groundwater treatment with any other remedy.

Section 3: 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 an aquifer, usually through pumping, and treatment above ground. This section provides additional information about the technologies used for in situ groundwater treatment because they are considered innovative technologies.

Established treatment technologies are those for which information about cost and performance is readily available. P&T groundwater remedies are considered established technologies. Although some groundwater P&T technologies are innovative or apply established technologies in an innovative manner, treatment of groundwater after it has been pumped to the surface usually involves traditional water treatment, such as activated carbon adsorption of organics or precipitation of metals.

Innovative technologies are treatment technologies whose limited number of applications result in a lack of data on cost and performance. Innovative technologies are used for a variety of reasons and have the potential to provide more cost-effective and reliable alternatives for remediation.

In some cases, it may be difficult to treat a particular waste or medium using an established technology. For example, soil containing a high percentage of large particle sizes, such as cobbles, boulders, and large debris, may be difficult to treat using ex situ thermal desorption because many thermal desorption units have limitations on the size of materials that can pass through them. However, in situ bioremediation may effectively treat the soil regardless of its particle size distribution. 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, a thermally enhanced recovery process may work effectively at that depth, at a lower cost. 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.

The *Innovative Remediation Technologies: Field Scale Demonstration Projects in North America, Second Edition* website contains a report and a searchable database with information about demonstrations of innovative remediation treatment technologies in North America. This website can be accessed at *http://clu-in.org/products/nairt*.

As of May 2001, the Federal Remediation Technologies Roundtable (FRTR) has published 270 case studies that cover a wide range of treatment technologies that are available for viewing on line or for downloading from the FRTR website at *http://www.frtr.gov/cost*. Of those case studies, some of which are at Superfund sites, 43 address groundwater P&T systems, 66 address in situ groundwater treatment, and 6 address MNA. Table 4 lists the number of FRTR case studies for these remedy types. The case studies were developed by EPA, Department of Defense, and Department of Energy for Superfund and non-Superfund sites. The case studies present available cost and performance information for full-scale remediation efforts and several large-scale demonstration projects. They provide information about site background and setting, contaminants and media

Table 4. FRTR Case Studies for Groundwater P&T, In Situ Treatment, and MNA

Remedy Type or Technology	Number of FRTR Case Studies
P&T	**43**
In Situ Groundwater Treatment (total)	**66**
Bioremediation	30
Air Sparging	8
Chemical Treatment	7
Permeable Reactive Barrier	7
Dual Phase Extraction	6
Thermally Enhanced Recovery[a]	4
In Situ Flushing[a]	3
Phytoremediation	1
MNA	**6**
Total	**115**

Sources: 11. Data sources are listed in the References and Data Sources Section on p. 17.
FRTR = Federal Remediation Technologies Roundtable
MNA = Monitored natural attenuation
P&T = Pump and treat
[a] *No applications of these technologies to groundwater have been conducted at Superfund sites.*

treated, technology, cost and performance, and points of contact for the technology application. The levels of detail provided in the studies vary, reflecting differences in the availability of data and information.

Most Common Technologies for In Situ Groundwater Treatment

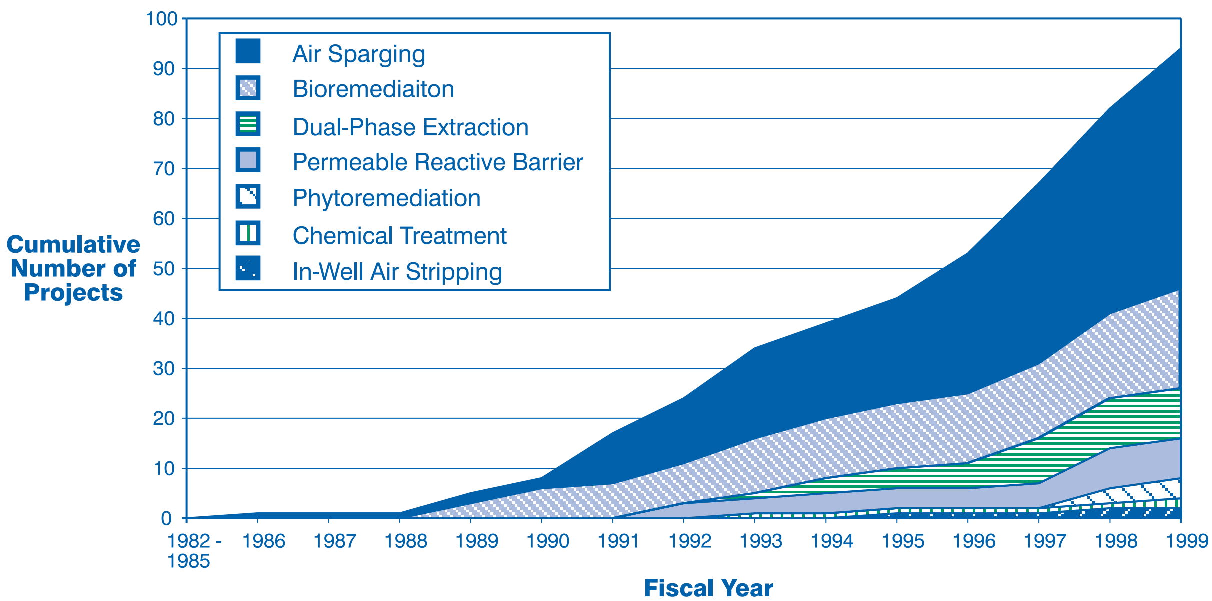
The specific types of in situ treatment remedies for groundwater selected at Superfund sites are shown in Table 5. EPA has selected in situ treatment of groundwater 95 times at 81 Superfund sites. Figure 10 shows the cumulative number of applications of in situ groundwater treatment technologies for each year. As the figure shows, air sparging, bioremediation, dual-phase extraction, and permeable reactive barriers represent most of the applications of in situ groundwater treatment at Superfund remedial action sites. Figure 10 also shows that the total number of applications has increased each year since 1988.

Table 5. Superfund Remedial Actions: In Situ Groundwater Treatment Technologies at 81 Sites[a] Selecting These Technologies (FY 1982 - FY 1999)

Technology	Number of Projects Selected
Air Sparging	48
Bioremediation	21
Dual-Phase Extraction	10
Permeable Reactive Barrier	8
Phytoremediation	4
Chemical Treatment	2
In-Well Air Stripping	2
TOTAL	95

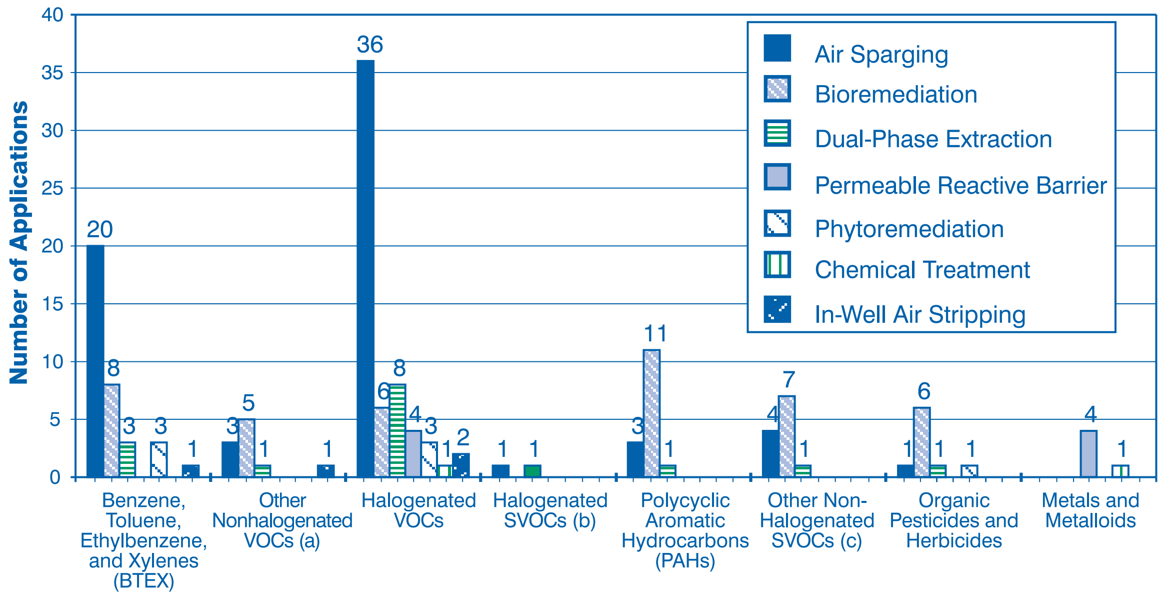
Sources: 3, 4, 5, 6. Data sources are listed in the References and Data Sources section on page 17.
a. Some sites have selected more than one technology.

Figure 10. Superfund Remedial Actions: Cumulative Trends for In Situ Groundwater Treatment Technologies (FY 1982 - FY 1999)



Sources 3, 4, 5, 6. Data sources are listed in the References and Data Sources Section on p. 17.

Figure 11. Contaminants Treated by In Situ Groundwater Treatment Technologies for Superfund Remedial Actions (FY 1982 - FY 1999)



Sources 3, 4, 5, 6. Data sources are listed in the References and Data Sources Section on p. 17.
SVOCs = Semivolatile organic compounds
VOCs = Volatile organic compounds
a. Does not include benzene, toluene, ethylbenzene, and xylene.
b. Does not include halogenated semivolatile pesticides and herbicides.
c. Does not include polycyclic aromatic hydrocarbons.

Contaminants Addressed

The data collected for this report form the basis for an analysis of the classes of contaminants treated by each in situ groundwater treatment technology type applied at remedial action sites. Figure 11 shows that information, by technology, for 8 major groups of contaminants.

For this report, 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 (excluding halogenated semivolatile pesticides and herbicides) and metals and metalloids in groundwater are treated least frequently in situ. The number of projects in Figure 11 exceeds the total number of projects in Table 5 (page 14) because some projects involve more than one type of contaminant. Such projects, therefore, are repeated in Figure 11 under each contaminant type treated by the remedy.

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

The selection of treatment technologies may also depend on site-specific factors, such as 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 11 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. In some cases, halogenated VOCs, metals, and metalloids may be difficult to treat using air sparging, bioremediation, or dual-phase extraction. However, these contaminants may undergo chemical reactions with certain substances to form compounds that are less toxic or mobile. When PRBs are used, their application is most often intended to treat halogenated VOCs, metals, and metalloids.

ROD Sequence

Some sites may encompass 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, with separate remedies for each. A separate ROD may be developed for each operable unit. In addition, each operable unit may require a number of RODs to address different media within that operable unit or to revise the selected remedy. Therefore, each site may have multiple RODs.

For sites with multiple RODs, EPA analyzed the types of remedies selected in the RODs and the chronological order in which the RODs were signed. The remedy types analyzed included the broad remedy categories of source control, groundwater, a combination of source control and groundwater, and NA/NFA. EPA conducted this analysis to determine whether a correlation existed between the sequence of RODs and the types of remedies selected. For example, at sites with both contaminant sources and contaminated groundwater, this analysis was intended to help EPA determine whether contamination sources are usually addressed first.

Among first RODs issued for Superfund sites, RODs selecting only a groundwater remedy represented 19%, RODs selecting only a source control remedy represented 40%, RODs selecting both a source control and a groundwater remedy represented 28%, and RODs selecting NA/NFA represented 13%. For sites where more than one ROD has been issued, subsequent RODs showed similar percentages of remedy type selections. Therefore, no correlation appeared to exist between ROD sequence and the type of remedy selected.

Future Data Needs

Since 1988, an average of 200 RODs have been signed each year. Over one third of these RODs have included groundwater remedies. EPA anticipates that a substantial portion of new RODs will include groundwater remedies.

To provide the users of this report with accurate and current information and to help identify changes in trends in the selection and use of groundwater remedies, EPA may update the information available in this report. Such updates may include summaries of remedy selections in new RODs, additional analyses of groundwater remedies at Superfund sites, or more detail about specific groundwater remedies. The results of these efforts may be made available through future editions of this report or by incorporating such information into future editions of the ASR, which currently focuses primarily on source control remedies.

Some potential areas of additional data reporting and future analyses not included in this report are:

- The ex situ treatment technologies used in groundwater P&T systems.
- The contaminants treated by specific treatment technologies used in groundwater P&T systems.
- The status of groundwater remedies (i.e., whether the remedies are being designed or installed, or are operational or completed).
- Groundwater containment and groundwater-other remedies.
- Further analysis to determine the cause of trends in groundwater remedy selection.

Comments or suggestions regarding this report may be made to EPA at *http://clu-in.org/groundwater*.

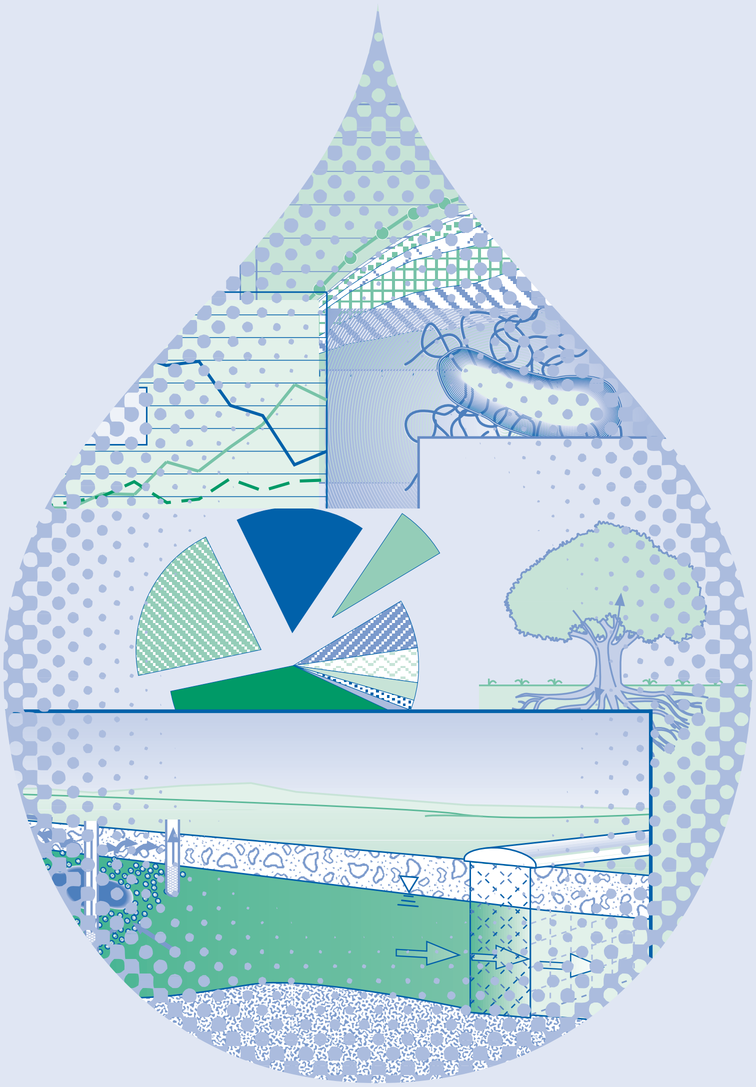
Section 4: References and Data Sources

1. List of Superfund National Priorities List (NPL) Sites. *www.epa.gov/superfund/sites/query/queryhtm/nplfina.txt* September, 2000.
2. List of NPL Sites That Have Been Deleted. *www.epa.gov/superfund/sites/query/queryhtm/npldela.txt* September, 2000.
3. Compilation of Record of Decision (ROD) abstracts, site summaries, and fact sheets for fiscal years (FY) 1982 through 1997. *www.epa.gov/superfund/sites/query/advquery.htm* January, 2000.
4. RODs, ROD Amendments, Explanations of Significant Differences, and ROD abstracts from FY 1982 through FY 1999.
5. Contacts With Remedial Project Managers, FY 1992 through FY 2000.
6. ROD Annual Reports. EPA Office of Emergency and Remedial Response (OERR), 1998 through 1992.
7. Innovative Treatment Technologies: Annual Status Report (ASR) Tenth Edition (EPA-542-R-01-004). EPA. Office of Solid Waste and Emergency Response. *clu-in.org/asr* February 2001.
8. Personal Communication from Ken Lovelace, OERR, to Tom Sinski of Tetra Tech EM Inc., April, 1998.
9. Contacts with EPA Superfund Removal Branch Chiefs and On-Scene Coordinators.
10. Groundwater Pump-and-Treat Systems: Summary of Selected Cost and Performance Information at Superfund-Financed Sites. (EPA-542-R-01-0219). EPA. Office of Solid Waste and Emergency Response. *clu-in.org* December 2001.
11. The Federal Remediation Technologies Roundtable Web Site. *www.frtr.gov* July, 2001.
12. Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, OSWER Directive Number 9200.4-17P, U.S. EPA, April 21, 1999.
13. Innovative Remediation Technologies: Field Scale Demonstration Projects in North America, Second Edition. *clu-in.org/products/nairt* October, 2001.
14. Federal Remediation Technologies Roundtable (FRTR). *www.frtr.gov/cost* May, 2001.
15. Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS 3).

Appendix A

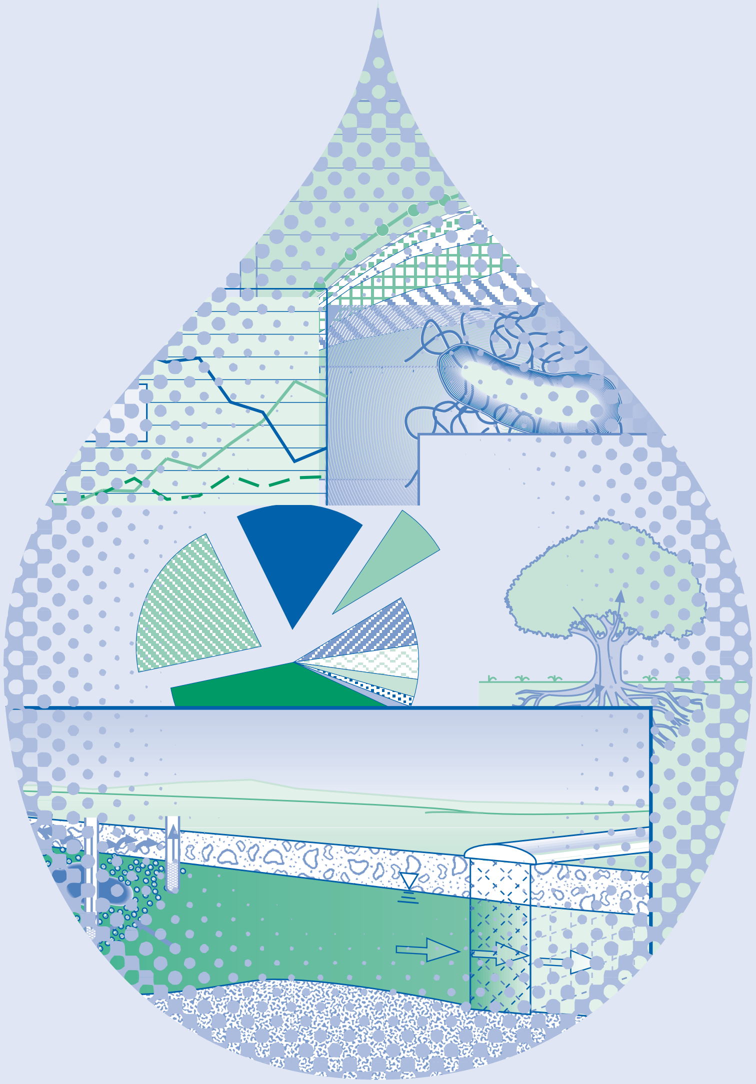
Groundwater Remedies Selected in Records of Decision at Sites on the National Priorities List

This appendix does not appear in the printed version of Groundwater Remedies Selected at Superfund Sites. It is available in the online version of this report at http://clu-in.org/groundwater.



Appendix B

Identification of Remedy and Record of Decision Types for Superfund Remedial Actions



B.1 BACKGROUND

This appendix describes the approach used to identify remedy and ROD types used in the document Treatment and Monitored Natural Attenuation Remedies at Superfund Sites. Please note that this methodology is identical to the one presented in Appendix F of Treatment Technologies for Site Cleanup: Annual Status Report (Tenth Edition) (ASR), with the exception that the hierarchy used to determine ROD and Site types has been modified to reflect the focus of this report on groundwater. In the ASR, source control remedies appeared first in the hierarchy. In this report, groundwater remedies appear first in the hierarchy. The methodology presented here is intended to provide a consistent and comprehensive approach to identifying remedy types, and, based on those remedy types, identifying ROD types. This approach can assist in the transfer of experience and technology among Superfund sites by helping remedial project managers (RPMs), On-Scene Coordinators (OSCs), and other regulatory and remediation professionals identify sites implementing similar remedies. Remedy and ROD types are determined by reviewing the remedies selected in RODs. Although RODs are written using an overall format that is consistent, RODs are prepared by individual RPMs and other staff of the 10 EPA regions. In addition, the management practices and techniques used to remediate sites have evolved over time and continue to evolve. Therefore, the words, phrases, and descriptions applied to the same or similar remedies may differ from ROD to ROD. To facilitate the identification of remedy types, this appendix includes both descriptive definitions of remedy types and lists of key words and phrases that may be used to refer to each remedy type.

The definitions of remedy types provided in this appendix were based on a review of definitions and lists of media, remedies, and technologies provided in the following resources:

- The CERCLA Information System (CERCLIS 3) database
- ROD Annual Reports for fiscal years (FY) 1989 through 1995
- The Federal Remediation Technologies Roundtable (FRTR) Technology Screening Matrix
- The ASR remedy type definitions were reviewed and augmented by a working group of personnel of the U.S. Environmental Protection Agency (EPA) Technology Innovation Office (TIO) and Office of Emergency and Remedial Response (OERR) who are experienced in site remediation and ROD preparation and review.

This appendix includes remedy types and technologies that are not discussed in the ASR. The ASR focuses on source control treatments and in situ groundwater treatments. Additional remedy and technology types are described in this appendix so that it may be used for purposes beyond the limited scope of the ASR.

B.2 IDENTIFICATION OF REMEDY AND ROD TYPES

This appendix describes the methodology used to classify remedies selected at Superfund remedial action sites into specific types. Remedy types were identified by first dividing remedies into three categories (source control, groundwater, and no action) based on the media treated and the type of action. Within each of these categories, the remedies were then further divided into the following 12 specific remedy types, which are also listed in Table B.1 with additional detail:

Groundwater Remedies:

1. Groundwater pump and treat
2. Groundwater in situ treatment
3. Groundwater containment
4. Groundwater other
5. Groundwater monitored natural attenuation
6. Groundwater extraction
7. Groundwater discharge

Source Control Remedies:

8. Source control treatment
9. Source control containment
10. Source control other
11. Source control monitored natural attenuation

No Action Remedies:

12. No action or no further action (NA/NFA)

Each ROD may select multiple remedy types. When multiple remedy types are selected in a single ROD, the overall ROD type is the one that appears first in the list above.

The definitions used to identify each remedy type are provided in the "Definitions" section below. When definitions include specific technologies and those technologies commonly are referred to by more than one word or phrase, the most commonly used word or phrase is listed first, followed by synonyms in parentheses.

B.3 DEFINITIONS USED TO IDENTIFY REMEDY TYPES

Definitions used to identify remedy types are presented below. The definitions of treatment technology and the different types of treatment technologies (physical, chemical, thermal, and bioremediation treatment) apply to both source control and groundwater remedies. Because these definitions apply to both source control and groundwater remedies, they are presented once here rather than being duplicated everywhere they apply.

Treatment Technology - 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. (Federal Register, volume 55, page 8819, 40 CFR 300.5: Definitions). Treatment technologies are grouped into five categories. The definitions for four of the categories (physical treatment, chemical treatment, thermal treatment, and biological treatment) are based on definitions provided in the FRTR Technology Screening Matrix. The fifth category, other or unspecified treatment, includes those technologies that do not fit into the first four categories. The five treatment technology categories are:

Physical Treatment - Uses the physical properties of the contaminants or the contaminated medium to separate or contain the contamination.

Chemical Treatment - Chemically converts hazardous contaminants to non-hazardous or less toxic compounds or compounds that are more stable, less mobile, and/or inert.

Thermal Treatment - Uses heat to: separate contaminants from contaminated media by increasing their volatility; destroy contaminants or contaminated media by burning, decomposing, or detonating the contaminants or the contaminated media; or immobilize contaminants by melting the contaminated media.

Bioremediation Treatment - Stimulates the growth of microorganisms which metabolize contaminants or create conditions under which contaminants will chemically convert to non-hazardous or less toxic compounds or compounds that are more stable, less mobile, and/or inert.

Other or Unspecified Treatment - Treatment that cannot be classified as physical treatment, chemical treatment, thermal treatment, or bioremediation treatment.

B.3.1 Groundwater Remedies

Groundwater Remedy - Management of groundwater. Groundwater remedies can include in situ treatment, pump and treat, containment using vertical engineered barriers, MNA, and other measures to address groundwater.

Groundwater Media - One or more aquifers beneath or proximal to a source of contamination contaminated by migration of a contaminant, such as leachate, or by other sources.

TABLE B.1
REMEDY TYPES FOR SUPERFUND REMEDIAL ACTION SITES

1. Groundwater Pump and Treat

Extraction of groundwater from an aquifer followed by treatment above ground. Key words used in RODs to identify groundwater pump and treat remedies are listed below:

Physical Treatment

- Aeration (air stripping)
- Carbon adsorption
- Clarification (sedimentation)
- Coagulation
- Component separation
- Equalization
- Evaporation
- Filtration
- Flocculation
- Ion exchange
- Oil/water separation

continued on next page

1. Groundwater Pump and Treat (continued)

Metals precipitation

Reverse osmosis (microfiltration and ultrafiltration)

Vapor extraction

Chemical Treatment

Chemical reduction

Chemical oxidation (oxidation, cyanide oxidation, and peroxidation)

Neutralization

Ultraviolet (UV) oxidation

Biological Treatment

Biological treatment

Bioreactors

Fixed film

Oxygen enhancement with H_2O_2

Other or Unspecified Treatment

Pump and treat

Physical/chemical treatment

2. Groundwater In Situ Treatment

Treatment of groundwater without extracting it from the ground. Key words used in RODs to identify groundwater in situ treatment remedies are listed below:

Physical Treatment

Air sparging

Dual-phase extraction

Free product recovery

In-well air stripping (well aeration and air stripping)

Vapor extraction

Chemical Treatment

Chemical oxidation (oxidation and peroxidation)

Chemical reduction

Chemical treatment

Dechlorination

Permeable reactive barrier (chemical reactive barrier, chemical reactive wall, and passive treatment wall)

Thermal Treatment

Thermally enhanced recovery (conductive heating, CROW®, dynamic underground stripping, electrical resistance heating, hot air injection, hot water or steam flushing and stripping, in-situ thermal desorption, microwave heating, radio frequency heating, and steam injection)

Bioremediation

Aeration

Biological treatment

Bioremediation

Biosparging

continued on next page

2. Groundwater In Situ Treatment (continued)

Bioslurping
Bioventing
Co-metabolic treatment
Oxygen enhancement with air sparging
Oxygen enhancement with H_2O_2
Nitrate enhancement
Nutrient injection

Other or Unspecified Treatment

Physical/chemical treatment
Phytoremediation

3. Groundwater Containment

Containment of groundwater, typically through the use of vertical engineered barriers. Key words used in RODs to identify groundwater containment remedies are listed below:

Vertical Engineered Barrier

Deep soil mixing
Geosynthetic wall
Grout (grout curtain)
High-density polyethylene (HDPE) wall
Impermeable barrier
Sheet pile
Slurry wall
Subsurface vertical engineered barrier (subsurface barrier and subsurface vertical barrier)

Other or Unspecified Containment

Plume containment

4. Groundwater Other

Groundwater remedies that do not fall into the categories Groundwater In Situ Treatment, Groundwater Pump and Treat, Groundwater Containment, or Groundwater Monitored Natural Attenuation, including:

Institutional Control

Deed restriction
Drilling restriction
Institutional control
Water supply use restriction

Engineering Control

Extended piping
Engineering control

Groundwater Monitoring

Monitoring
Sampling

continued on next page

4. Groundwater Other (continued)

Water Supply Remedies

Alternate water supply (alternate drinking water and bottled water)

Carbon at tap

Seal well (close well)

Treat at use location

Well-head treatment

5. Groundwater 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 with that offered by other, more active methods. The "natural attenuation processes" that are at work in such a remediation approach 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 (Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, USEPA, Office of Solid Waste and Emergency Response, Directive Number 9200.4-17P, 1999).

A remedy is considered groundwater MNA if it includes "natural attenuation" or "monitored natural attenuation" of groundwater.

6. Groundwater Extraction

The process of removing groundwater from beneath the ground surface, including the following methods of groundwater extraction:

Directional well (horizontal well)

Pumping (vertical well)

Recovery trench (horizontal drain)

7. Groundwater Discharge and Management

A method of discharging or otherwise managing extracted groundwater, including the following discharge methods and receptors:

Centralized waste treatment facility

Deep well injection

Publicly owned treatment works (POTW)

Recycling

Reuse as drinking water

Reuse as irrigation water

Reuse as process water

Surface drain reinjection

Surface water discharge [National Pollutant Discharge Elimination System (NPDES) discharge]

Vertical well reinjection

B.3.2 Source Control

Source control remedy - any removal, treatment, containment, or management of any contaminant source or contaminated medium other than groundwater.

Source Media - "Source material is defined as material that includes or contains hazardous substances, pollutants, or contaminants that act as a reservoir [either stationary or mobile] for migration of contamination to the groundwater, to surface water, to air, [or to other environmental media] or act as a source for direct exposure. Contaminated groundwater generally is not considered to be a source material although non-aqueous phase liquids (NAPLS [occurring either as residual- or free-phase]) may be viewed as source materials." (A Guide to Principal Threat and Low Level Threat Wastes, Superfund publication 9355.3-02FS, USEPA OERR 1991). Source media include soil, sediment, sludge, debris, solid-matrix wastes, surface water, non-aqueous phase liquids (NAPLS), equipment, drums, storage tanks, leachate, landfill gas, and any other contaminated media other than groundwater that can act as a potential source of contamination.

TABLE B.1 (CONTINUED)

8. Source Control Treatment

Any process meant to separate, destroy, or bind contaminants in a source medium. Key words used in RODs to identify these processes are listed below. More detailed descriptions of most of the technologies can be found in the ASR or at http://www.frtr.gov.

Physical Treatment

Acid extraction
Air sparging
Air stripping
Carbon adsorption (liquid-phase carbon adsorption)
Clarification
Decontamination
Dewatering
Dual-phase extraction
Electrical separation (electrokinetic separation)
Evaporation
Filtration
Flocculation
Flushing (soil flushing and surfactant flushing)
Ion exchange
Magnetic separation
Oil-water separation
Physical separation (component separation and materials handling)
Reverse osmosis (membrane separation)
Soil flushing (in situ flushing and surfactant flushing)
Soil vapor extraction (vacuum extraction and vapor extraction)
Soil washing
Solidification/stabilization (asphalt batching, immobilization, and microencapsulation)
Solid-phase extraction
Solvent extraction (chemical stripping)
Super-critical fluid extraction
Volatilization (aeration, mechanical soil aeration, and tilling)

Chemical Treatment

Chemical treatment
Chemical oxidation (cyanide oxidation, oxidation, and peroxidation)
Chemical reduction (reduction)
Dehalogenation (dechlorination)
Neutralization

continued on next page

8. Source Control Treatment (continued)

Metals precipitation

Ultraviolet (UV) oxidation

Thermal Treatment

Flaring

Gas flaring

High energy corona

Open burning

Open detonation

Plasma high-temperature recovery (fuming gasification and high-temperature metals recovery)

Thermal desorption

Thermal destruction (incineration and pyrolysis)

Thermally enhanced recovery (conductive heating, Contained Recovery of Oily Wastes [CROW®], dynamic underground stripping, electrical resistance heating, hot air injection, in situ thermal desorption, microwave heating, radio frequency heating, and steam injection)

Thermal treatment

Vitrification (slagging)

Bioremediation

Aeration

Bioremediation

Biological treatment

Bioreactor

Bioventing

Biopile

Composting

Controlled solid phase

Fixed film

Landfarming

Nitrate enhancement

Nutrient injection

Oxidation enhancement with air sparging

Oxidation enhancement with hydrogen peroxide (H_2O_2)

Slurry-phase bioremediation (bioslurry and activated sludge)

White rot fungus

Other or Unspecified Treatment

Air emission treatment

Gas collection and treatment (off-gas treatment)

Hot gas decontamination

Leachate treatment

Physical-chemical treatment

Phytoremediation

Recycling

Surface water treatment

continued on next page

9. Source Control Containment

Any process or structure designed to prevent contaminants from migrating from a source media into groundwater, to surface water, to air, (or to other environmental media) or acting as a source for direct exposure.

Key words used in RODs to identify source control containment remedies are listed below:

Capping and Cover

Cap
Cover material
Evapotranspiration cover
Revegetation

Bottom Liner

Liner
Clay
Geosynthetic material

Drainage and Erosion Control

Engineering control
Hydraulic control
Impermeable barrier
Subsurface drain
Surface water control (dike, berm, drainage controls, drainage ditch, erosion control, flood protection, and levee)
Water table adjustment

On-Site Landfilling

On-site consolidation
On-site landfilling
On-site disposal

Off-Site Landfilling

Off-site consolidation
Off-site landfilling
Off-site disposal

Vertical Engineered Barrier

(Must apply to source medium. A vertical subsurface engineered barrier used to control or contain groundwater is not source control containment.)

Grout (grout curtain)
Impermeable barrier
Sheet piling
Slurry wall
Subsurface barrier
Vertical barrier

Other or Unspecified Containment

Containment (consolidation, disposal, landfilling, and removal)
Encapsulation

continued on next page

9. Source Control Containment (continued)

Leachate control (leachate collection)
Overpacking
Permanent storage
Repair (pipe repair, sewer repair, and tank repair)

10. Source Control Other

Source control other than treatment or containment.

Institutional Control

Access restriction
Deed restriction
Drilling restriction
Fishing restriction
Guard (security)
Institutional control
Land use restriction
Recreational restriction
Swimming restriction

Engineering Control

Engineering control
Fencing
Wetland replacement

Source Monitoring

Monitoring
Sampling

Population Relocation

Population relocation

11. Source Control 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 with that offered by other, more active methods. The "natural attenuation processes" that are at work in such a remediation approach 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 (Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, USEPA, Office of Solid Waste and Emergency Response, Directive Number 9200.4-17P, 1999).

A remedy is considered source control MNA if it includes "natural attenuation" or "monitored natural attenuation" for a source (e.g., contaminated soil)

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TABLE B.1 (CONTINUED)

12. NA/NFA
The designation used for remedies that indicate no action or no further action will be taken. When determining overall ROD type, the designation is used only for RODs under which NA/NFA is the only remedy selected. If a ROD selects NA/NFA for only part of a site and another remedy for another part of a site, the ROD is given the classification corresponding to that selected remedy and is not given an NA/NFA designation.

B.4 SPECIAL CASES

This subsection provides a list of some special cases and descriptions of how remedy and ROD types should be assigned in those cases:

Decontamination:

- Decontamination of buildings, equipment, tanks, debris, boulders, rocks, or other objects is considered source control treatment. For example, abrasive blasting or scarifying a concrete pad to remove the contaminated surface layer of the pad would be considered source control treatment.
- Decontamination of equipment used to clean up a Superfund site is a normal activity that occurs at many Superfund sites and is not considered a remedy. For example, high-pressure water washing of a front end loader used to excavate contaminated soil would not be considered a remedy and would not be given a remedy type.

Phytoremediation:

- Phytoremediation involves the use of macroscopic plants to destroy, remove, immobilize, or otherwise treat contaminants. The process does not use microorganisms. Processes that use microorganisms are bioremediation.
- The use of plants to control water drainage at a site is not phytoremediation, but is an engineering control (source control other or groundwater other).

Conditional Remedies - If a ROD indicates that a certain remedy will be implemented under specific conditions, the ROD is considered to have selected the conditional remedy. For example, a ROD may specify that, if soils exceed a certain levels of contamination, they will be incinerated, but, if they do not exceed that level, no further action will be taken. In such a case, the ROD is considered to have selected incineration and therefore would be considered a source control treatment ROD.

Vertical Engineered Barriers - Some of the technologies used for vertical engineered barriers are also used to control surface water and surface drainage (for example, slurry walls and sheet piles). The selected remedy should be analyzed carefully to determine whether the containment is source control or groundwater containment.

Solidification/Stabilization - Some of the technologies used for solidification/stabilization are used for containment, as well. For example, encapsulation could mean placing a waste in plastic drums, an approach that would be classified as source control containment. Encapsulation of a waste by mixing it with a monomer and then causing the mixture to polymerize, resulting in microencapsulation, would be classified as source control treatment (solidification/stabilization). In general, containment involves isolating bulk wastes, while solidification/stabilization involves incorporating the waste into a medium so that the leachability of the contaminants is reduced. The selected remedy should be analyzed carefully to determine whether it is a containment or a treatment process.

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