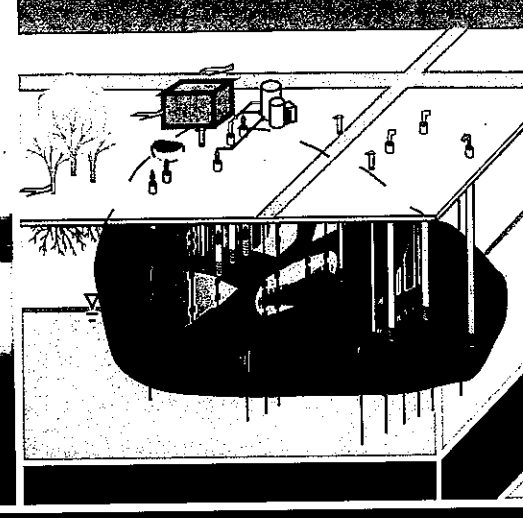
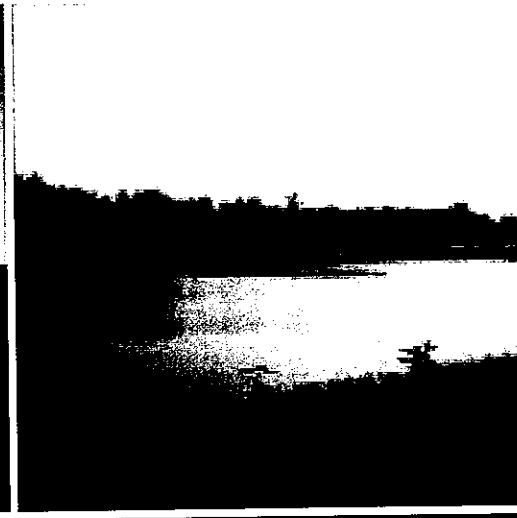
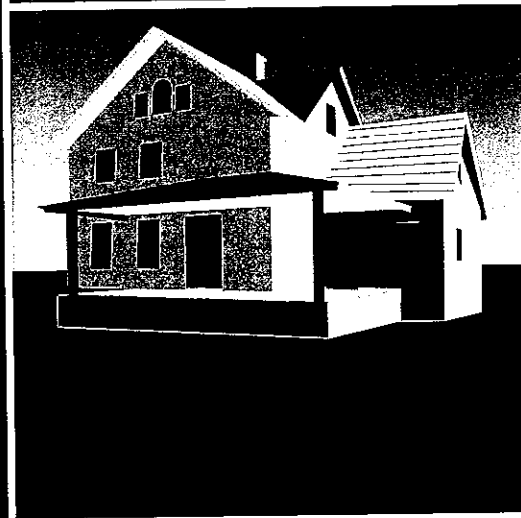
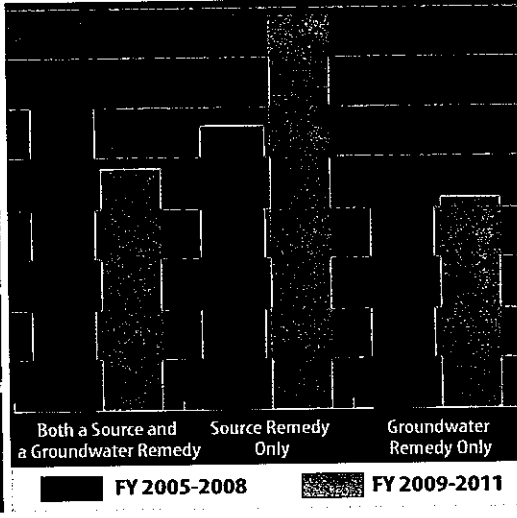
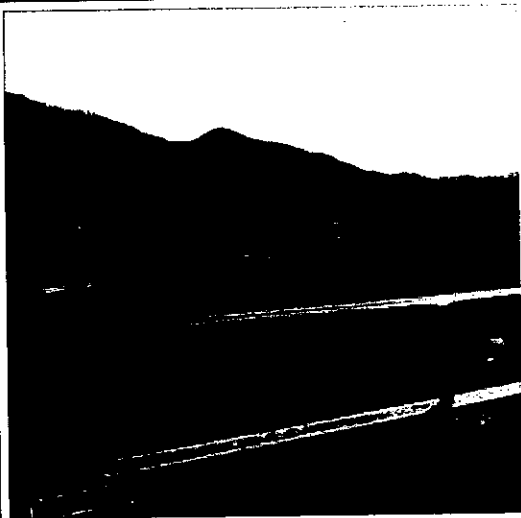
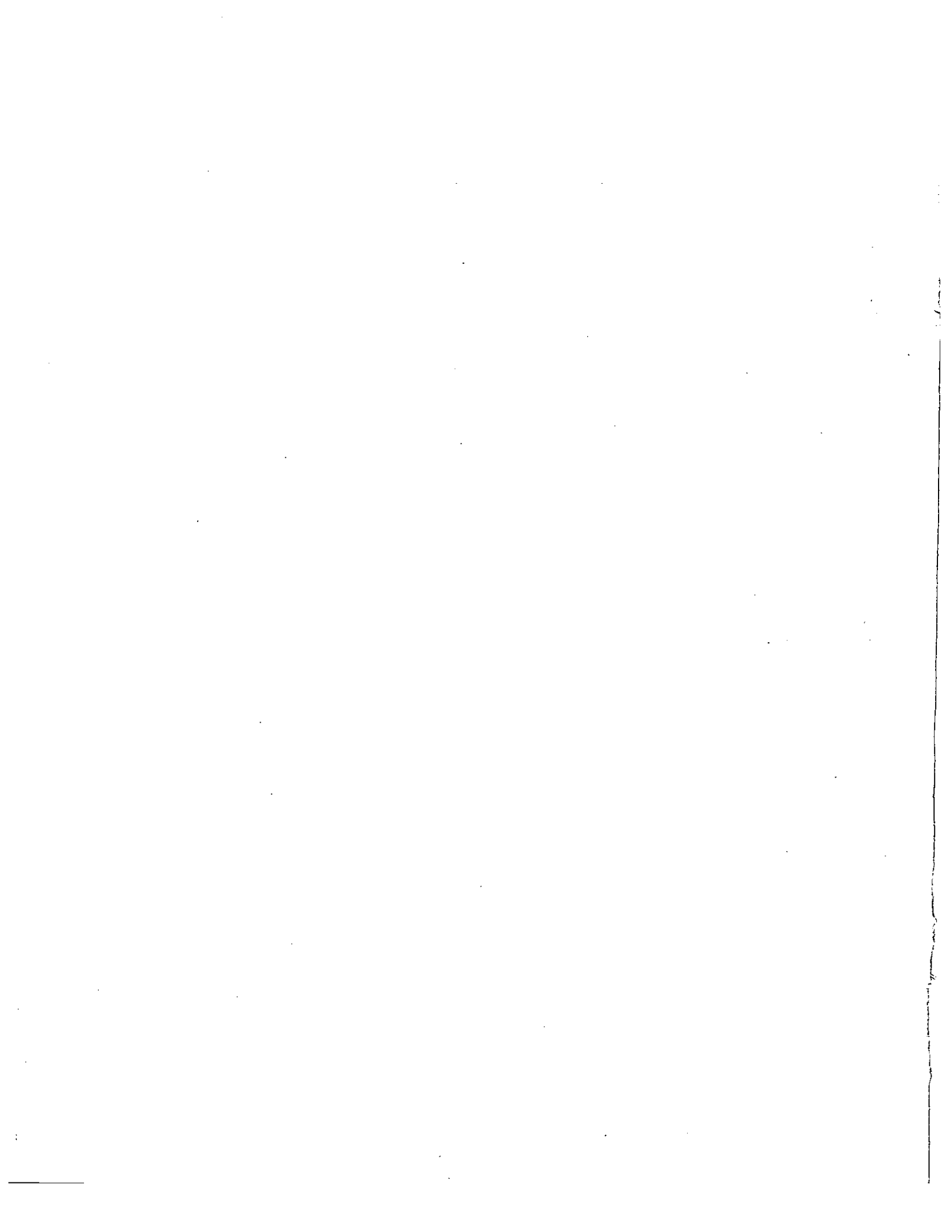


Superfund Remedy Report

FOURTEENTH EDITION







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Solid Waste and Emergency Response
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Superfund Remedy Report

FOURTEENTH EDITION

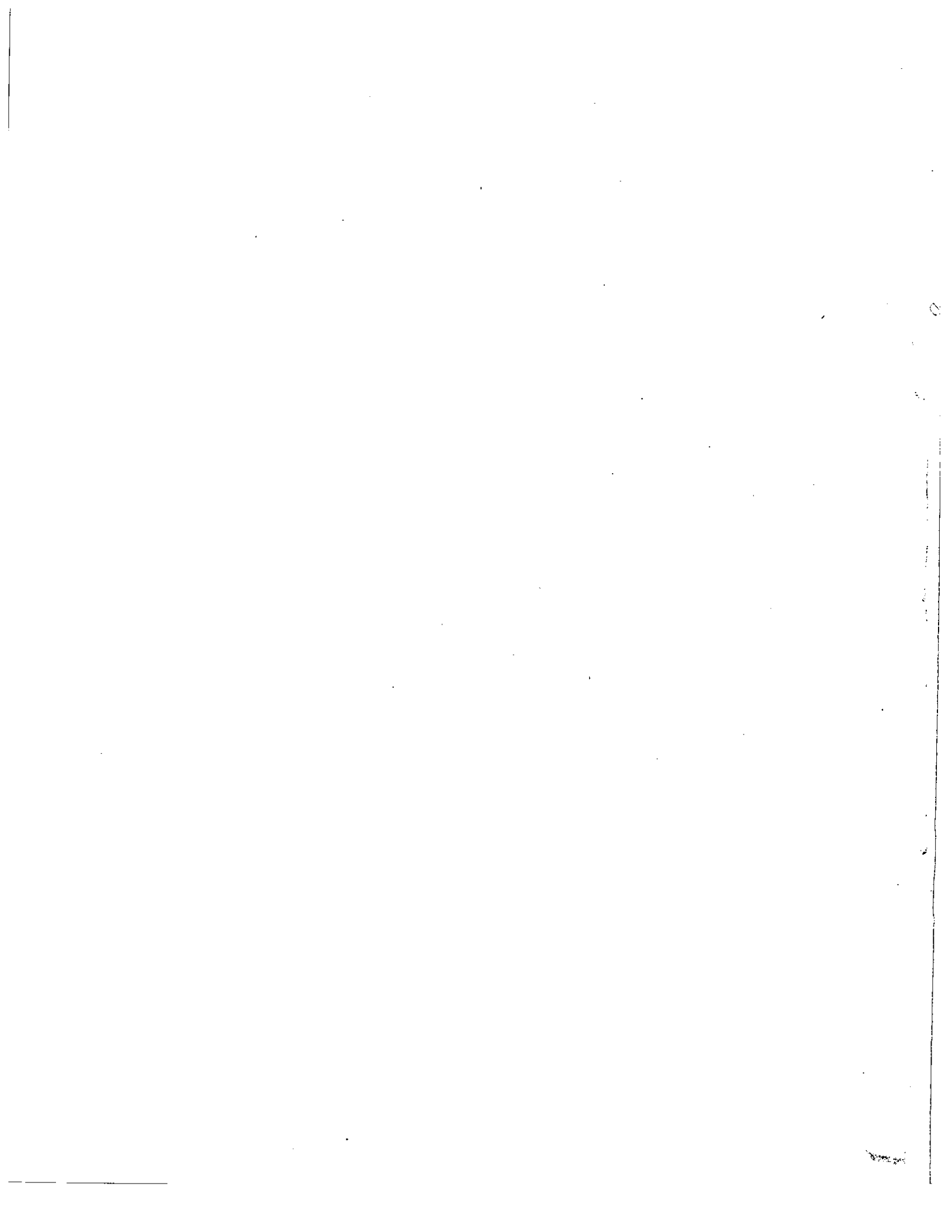


Table of Contents

Notice and Disclaimer	iii
Acronyms and Abbreviations	iv
Executive Summary.....	1
I. Purpose and Introduction.....	3
II. Approach.....	3
III. Use of Treatment at NPL Sites	5
IV. Remedies Selected.....	6
V. Source Remedies	7
VI. Groundwater Remedies.....	12
VII. Vapor Intrusion	15
VIII.Characteristics of NPL Sites in the RI/FS Phase	17
IX. Conclusions.....	20
X. Sources and Electronic Versions.....	21
Appendix A: Definitions of Selected Remedies	A-1
Appendix B: Treatment Technologies Selected by Fiscal Year.....	B-1
Index	Index-1

Figures

Figure 1: Total Number of RODs and ROD Amendments per Year (FY 1982–2011).....	4
Figure 2: ESDs with Remedy Component Changes Included in Analysis (FY 2005–2011).....	4
Figure 3: NPL Sites with Treatment Remedies (FY 1982–2011)	5
Figure 4: Percentage of Decision Documents Addressing Source or Groundwater	6
Figure 5: Remedies Selected in All Decision Documents	6
Figure 6: Types of Remedies in Source Decision Documents (FY 2009–2011).....	7
Figure 7: On-site Containment vs. Off-site Disposal (FY 2009–2011)	8
Figure 8: Selection Trends for Source Remedies (FY 1998–2011).....	8
Figure 9: Top 6 In Situ Source Treatment Remedies in Decision Documents (FY 2005–2011)....	10
Figure 10: Trends in Source Decision Documents Selecting In Situ Treatment (FY 2005–2011).11	
Figure 11: Selection Trends for Groundwater Remedies (FY 1986–2011)	12
Figure 12: Sites with P&T, In Situ Treatment, or MNA Selected as Part of a Groundwater Remedy.....	14
Figure 13: Trends in Groundwater Decision Documents Selecting In Situ Treatment (FY 1986–2011).....	15
Figure 14: Most Frequently Occurring Contaminants at OUs in the RI/FS Phase.....	17
Figure 15: Number of OUs in the RI/FS Phase by Contaminant Group	18
Figure 16: Number of OUs in the RI/FS Phase with Contamination in Selected Media.....	18

Tables

Table 1: Source Treatment Technologies Selected in Decision Documents	9
Table 2: Sediment Remedies in Decision Documents (FY 2009–2011)	11
Table 3: Groundwater Remedy Types Selected in Decision Documents.....	13
Table 4: In Situ Bioremediation and Chemical Treatment Techniques Selected in Groundwater Decision Documents (FY 2009–2011).....	14
Table 5: Vapor Intrusion Remedies Selected in Decision Documents (FY 2009–2011)	16

Available Electronically

- Appendix C:** Remedy Selection Summary Matrix FY 2009–11
- Appendix D:** Source Treatment Technologies Selected in Decision Documents from FY 2009–11,
Organized by Technology
- Appendix E:** Source Treatment Technologies Selected in Decision Documents from FY 2009–11,
Organized by Location
- Appendix F:** Sediment Remedies Selected in Decision Documents from FY 2009–11,
Organized by Technology
- Appendix G:** Sediment Remedies Selected in Decision Documents from FY 2009–11,
Organized by Location
- Appendix H:** Groundwater Remedies Selected in Decision Documents from FY 2009–11,
Organized by Technology
- Appendix I:** Groundwater Remedies Selected in Decision Documents from FY 2009–11,
Organized by Location
- Appendix J:** Vapor Intrusion Remedies Selected in Decision Documents from FY 2009–11,
Organized by Technology
- Appendix K:** Vapor Intrusion Remedies Selected in Decision Documents from FY 2009–11,
Organized by Location
- Appendix L:** Individual Contaminants and Assigned Contaminant Groups in the RI/FS Phase

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format (PDF) version of *Superfund Remedy Report (SRR) Fourteenth Edition* (EPA 542-R-13-016) is available for viewing or downloading from EPA's Hazardous Waste Cleanup Information (CLU-IN) website at www.clu-in.org/asr. For more information about this report, contact Carlos Pachon (pachon.carlos@epa.gov) or Linda Fiedler (fiedler.linda@epa.gov).

Acronyms and Abbreviations

ASD	Active soil depressurization	MNA	Monitored natural attenuation
ASR	Annual Status Report	MNR	Monitored natural recovery
AWS	Alternative water supply	MPE	Multi-phase extraction
BTEX	Benzene, toluene, ethylbenzene, total xylenes	NA/NFA	No action/no further action
CAD	Contained aquatic disposal	NAPL	Non-aqueous phase liquid
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act	NCP	National Oil and Hazardous Substances Pollution Contingency Plan
CERCLIS	Comprehensive Environmental Response, Compensation and Liability Information System	NPL	National Priorities List
CFR	Code of Federal Regulations	nZVI	Nanoscale zero-valent iron
CLU-IN	Hazardous Waste Cleanup Information	OB/OD	Open burn/open detonation
COC	Contaminant of concern	OSWER	Office of Solid Waste and Emergency Response
DNAPL	Dense non-aqueous phase liquid	OU	Operable unit
EMNR	Enhanced monitored natural recovery	P&T	Pump and treat
EOU	Excess, obsolete, or unserviceable	PAH	Polycyclic aromatic hydrocarbon
EPA	U.S. Environmental Protection Agency	PCB	Polychlorinated biphenyl
ERH	Electrical Resistance Heating	PRB	Permeable reactive barrier
ESD	Explanation of Significant Differences	PSV	Passive soil ventilation
ET	Evapotranspiration	RCRA	Resource Conservation and Recovery Act
FRTR	Federal Remediation Technologies Roundtable	RI/FS	Remedial Investigation/Feasibility Study
FY	Fiscal year	ROD	Record of Decision
GAC	Granular activated carbon	S/S	Solidification/stabilization
HRSC	High-resolution site characterization	SEE	Steam enhanced extraction
HVAC	Heating, ventilation and air conditioning	SRR	Superfund Remedy Report
IC	Institutional control	SSD	Sub-slab depressurization
ISCO	In situ chemical oxidation	SVE	Soil vapor extraction
ISCR	In situ chemical reduction	SVOC	Semivolatile organic compound
ITRC	Interstate Technology & Regulatory Council	TCE	Trichloroethene
LNAPL	Light non-aqueous phase liquid	TCH	Thermal conduction heating
		VEB	Vertical engineered barrier
		VOC	Volatile organic compound
		ZVI	Zero valent iron

Executive Summary

The U.S. Environmental Protection Agency (EPA) prepared the *Superfund Remedy Report (SRR) 14th Edition* to provide information and analyses on remedies selected to address contamination at Superfund sites. The EPA is particularly interested in documenting and disseminating information on innovative treatment technologies that advance its mission of protecting human health and the environment at contaminated sites. This report is the latest in a series, prepared since 1991, on Superfund remedy selection.

The *SRR 14th Edition* focuses on the analysis of Superfund remedial actions from fiscal years (FY) 2009 to 2011. The report includes remedies selected in 459 decision documents signed in this three-year period. These documents include 361 Records of Decision (RODs) and ROD amendments, and 98 Explanations of Significant Differences (ESDs). Only ESDs that included changes to remedy components were included in this analysis. The SRR compiles data on overall remedy selection and on remedies for source materials (such as soil and sediments), groundwater and air related to vapor intrusion. The report also analyzes characteristics of sites under investigation that do not yet have a decision document.

In the most recent period (FY 2009 to 2011), about 40 percent of all decision documents addressed only sources, 20 percent addressed only contaminated groundwater, and 25 percent addressed both. The remainder included other remedies, such as mitigation of vapor intrusion or specified no action/no further action. Treatment, on-site containment, and off-site disposal of contaminated source media and groundwater were selected at nearly the same rate as in the previous timeframe evaluated (FY 2005 to 2008). Overall, remedies included a mix of approaches, primarily treatment; on-site containment; off-site disposal; monitored natural attenuation (MNA) or recovery (MNR); and institutional controls (ICs). Decision documents selecting only ICs were found to be for sites that had previous remedial or removal actions. The more recent remedies often addressed complex sites involving more than one contaminated media by selecting remedial strategies with multiple

components to target different site areas, media or both.

Of the nearly 300 decision documents addressing *source* materials, on average Superfund selected somewhat less treatment, on-site containment and off-site disposal in FY 2009 to 2011 than in FY 2005 to 2008 (EPA 2010a). In the recent timeframe, more source decision documents included ICs. The Superfund remedial program continued to select treatment for a large number of source remedies. In situ treatment made up an increasing portion of selected treatment technologies. On average, half of recent source treatment decision documents included in situ treatment. Soil vapor extraction, chemical treatment, solidification/stabilization (S/S), multi-phase extraction, bioremediation and in situ thermal treatment again were the most frequently selected in situ treatment technologies for sources. Physical separation, S/S, off-site treatment and recycling once more were the most common ex situ treatment methods. Off-site incineration was not selected at all, versus six during the previous period.

A new feature in the *SRR 14th Edition* is an analysis of sediment remedies. Overall, 56 source decision documents selected a sediment remedy in FY 2009 to 2011. About three-quarters included dredging, off-site disposal or on-site containment. Some treatment was also selected (for example, ex situ and in situ S/S and subaqueous reactive caps). Examples of other remedies included wetlands restoration or replacement, and enhanced or monitored natural recovery. Nearly two-thirds of sediment decision documents included ICs.

Of the 206 groundwater decision documents evaluated, the recent remedies continue to be a mix of primarily pump and treat (P&T), in situ treatment, and MNA, with most also including ICs. The selection of alternate water supply remedies and other engineering controls was similar to the previous timeframe. The number of P&T remedies selected dropped from an annual average of 21 in FY 2005 to 2008, to an average of 15 in FY 2009 to 2011. MNA decreased from an average of about 30 per year to 20. However, the overall percentage selecting either P&T or MNA decreased only slightly. The selection of in

situ groundwater treatment remedies continued to rise, averaging almost 40 percent of groundwater decision documents. Of these, bioremediation and chemical treatment remained the most frequently selected. The majority of in situ bioremediation remedies specified anaerobic bioremediation, and more than half of chemical treatment remedies were in situ chemical oxidation. Containment technologies (vertical engineered barriers such as slurry walls) were selected at only a few sites.

Since vapor intrusion is being addressed more often in decision documents, the *SRR 14th Edition* for the first time includes an analysis of vapor intrusion mitigation technologies. Twenty-one FY 2009 to 2011 decision documents addressed vapor intrusion. Sub-slab depressurization was the most common mitigation method selected; sealing of openings, sub-membrane depressurization, vapor barriers, enhanced interior ventilation and passive ventilation systems were also selected.

To gain insight on future remedy decisions, this report contains a summary of the characteristics of over 300 sites with operable units currently in the remedial investigation and feasibility study (RI/FS) process. The analysis summarizes preliminary data on the types of contaminants and affected media at these sites. The study shows that the majority of sites may

contain contaminated groundwater; over half may have contaminated soil; and a third, contaminated sediments. All classes of contaminants (that is, volatile organic compounds, semivolatile organic compounds, and inorganic contaminants) may be present at a large number of these sites. Based on initial data, polychlorinated biphenyls, lead, trichloroethene, arsenic, hexavalent chromium and mercury may be among the most frequently occurring contaminants addressed in the future.

The remedy and site information provided in this report can help identify program needs for expanded technical information. For example, the continued increase in the selection of in situ groundwater technologies suggests a role for recently-developed characterization techniques, such as high-resolution site characterization (HRSC)¹, and thus a need for more technical resources and support in this area. The recent selection of vapor intrusion mitigation remedies also highlights the need for technical information and support related to vapor intrusion characterization and mitigation. The preliminary data on sites in the queue for remedy decisions also provide some indication of the future demand for remedial technologies, information of value to stakeholders including technology developers, consulting and engineering firms and public entities managing remediation programs.

¹ For further information, please visit the High-Resolution Site Characterization web page at www.clu-in.org/hrsc

I. Purpose and Introduction

The EPA Office of Superfund Remediation and Technology Innovation prepared this *Superfund Remedy Report, 14th Edition* to share analysis of remediation technologies selected to address contamination at Superfund sites. The EPA is particularly interested in documenting and disseminating information on innovative technologies that advance its mission of protecting human health and the environment at contaminated sites.

The information in this report was extracted from Superfund decision documents. These documents include RODs, ROD amendments and select ESDs issued during FY 2009 to 2011. The data build on the evaluations in 12 editions of *Treatment Technologies for Site Cleanup: Annual Status Report* (which covered the timeframe from FY 1982 through a portion of FY 2005) and *SRR 13th Edition* (which covered FY 2005 to 2008). Remedy data for the most recent period are compared with previous years to evaluate selection trends, when appropriate.²

The SRR includes 10 sections.

- Section I discusses the purpose and introduces the report.
- Section II describes the approach used to collect and analyze data.
- Section III describes the use of treatment at National Priorities List (NPL) sites.
- Section IV analyzes types of remedies selected.
- Section V discusses source remedies, including a breakout of sediment remedies.
- Section VI discusses groundwater remedies.
- Section VII discusses vapor intrusion remedies.
- Section VIII discusses contaminants and media for sites with planned RODs.
- Section IX presents conclusions.
- Section X lists the data sources and provides information on how to access the electronic version of this and previous editions of SRR and ASR, as well as Appendices C through L that are only available electronically.

II. Approach

The EPA used data available in the Comprehensive Environmental Response, Compensation and Liability Information System (CERCLIS) as of June 6, 2012 and reviews of decision documents to compile information about remedy selection in the three-year period between FY 2009 and 2011 (EPA 2012j). Subsequent database or remedy changes are not reflected in this report. The data used include remedies selected in decision documents (RODs, ROD amendments and select ESDs). Only ESDs with changes to remedy components were included in the data set. ESDs were not included if they did not change a remedy component, but instead addressed another aspect of the remedy, such as quantity of material to be addressed, contaminants of concern, cost information, or monitoring requirements.

As of June 6, 2012, 1,652 sites had been finalized on the NPL and of those, 359 sites had been deleted. The report includes only decision documents for these sites currently final on or deleted from the NPL. The current analysis does not include decision documents for non-NPL sites, sites that are proposed for the NPL or Superfund Alternative approach sites.

Figure 1 depicts the number of RODs and ROD amendments issued each year through FY 2011. Figure 2 shows the number of ESDs with changes to remedy components issued each year from FY 2005 to 2011, the only years for which ESDs were analyzed. This report evaluates 459 decision documents signed between FY 2009 and 2011, which includes 361 RODs and ROD amendments, and 98 ESDs.

² Some data in the ASR reports (FY 1982 to 2004) were compiled on a project-specific basis, rather than a decision-document-specific basis. Projects may have consisted of many OUs, or just a small portion of one OU, and project data were updated with each edition of the report. Additionally, decision document data are not revised in the SRR dataset when a decision document is amended. Therefore, it is not always possible to directly compare current data to previous years.

Figure 1: Total Number of RODs and ROD Amendments per Year (FY 1982–2011)

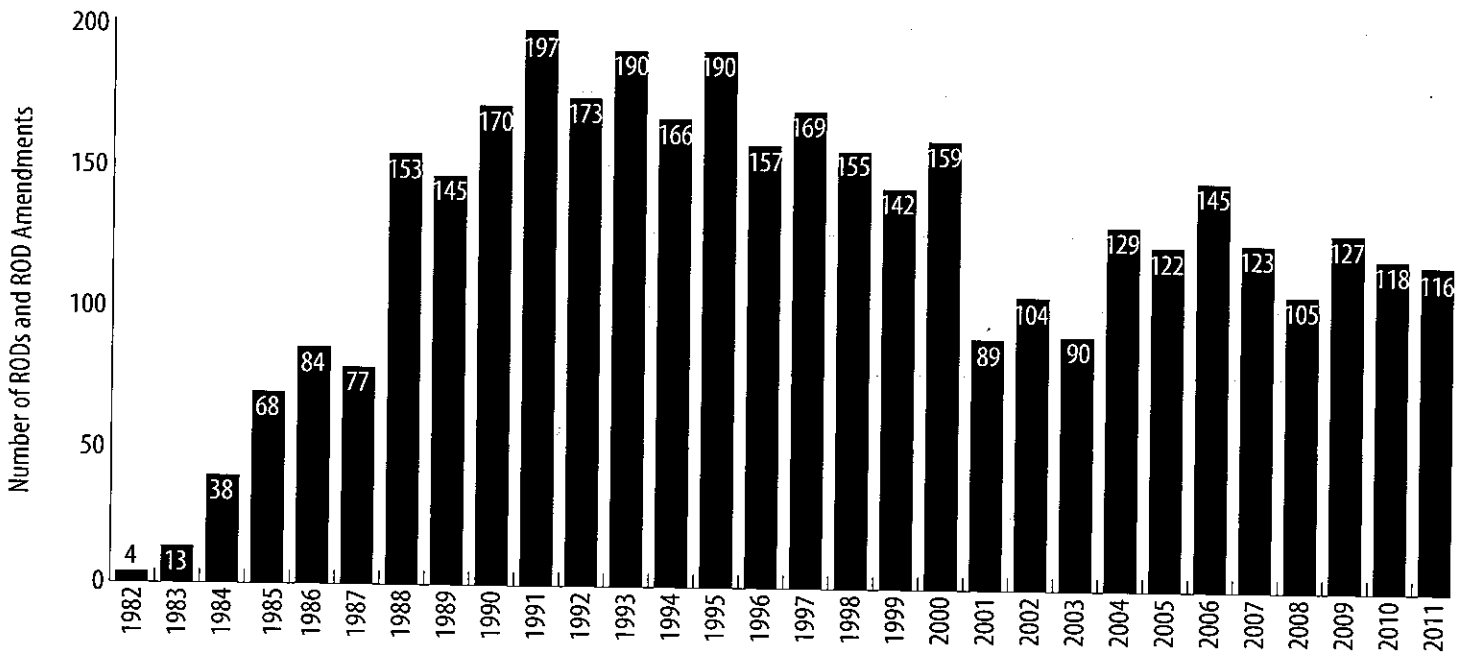
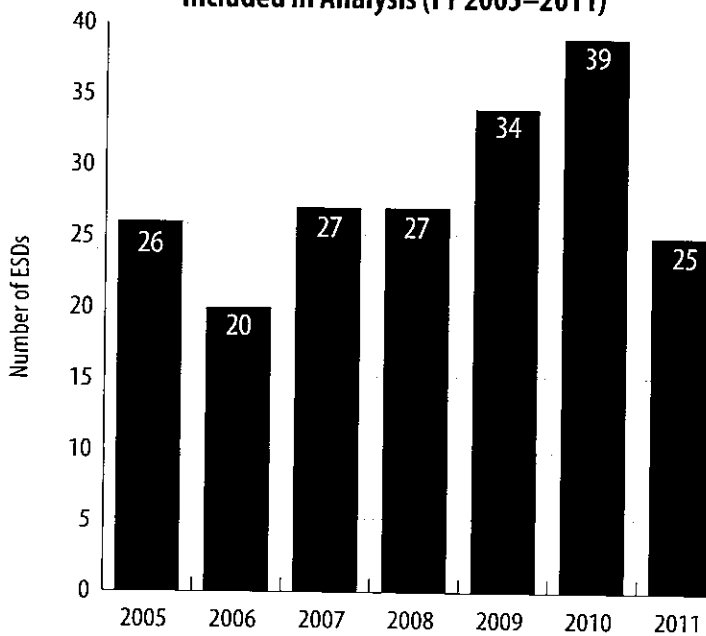


Figure 2: ESDs with Remedy Component Changes Included in Analysis (FY 2005–2011)



of contamination to ground water [sic], to surface water, to air, or acts as a source for direct exposure” (EPA 1991). Source material includes contaminated soil, sludge, sediment, solid waste, debris, drummed waste, leachate and any non-aqueous phase liquid (NAPL) both light (LNAPL) and dense (DNAPL). Groundwater and surface water remedies are considered “non-source material” remedies and are collectively referred to as “groundwater remedies” in this report. Certain surface water remedies like drainage and erosion control were grouped with source containment remedies for the purposes of this report; they are intended to limit the spread of contamination from the source medium to the surface water. In this report, on-site containment and off-site disposal are often combined as ‘containment/disposal.’

All remedies selected in the Superfund remedial program, including treatment, on-site containment, off-site disposal and remedial components such as ICs, are included in this report, with treatment technologies discussed in more detail. “*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

The SRR remedy analysis distinguishes between remediation of contaminated source materials and non-source materials such as groundwater. “Source material” is defined as “material that includes or contains hazardous substances, pollutants or contaminants that act as a reservoir for migration

materials being treated.”³ Definitions of all remedies included in this report can be found in Appendix A.

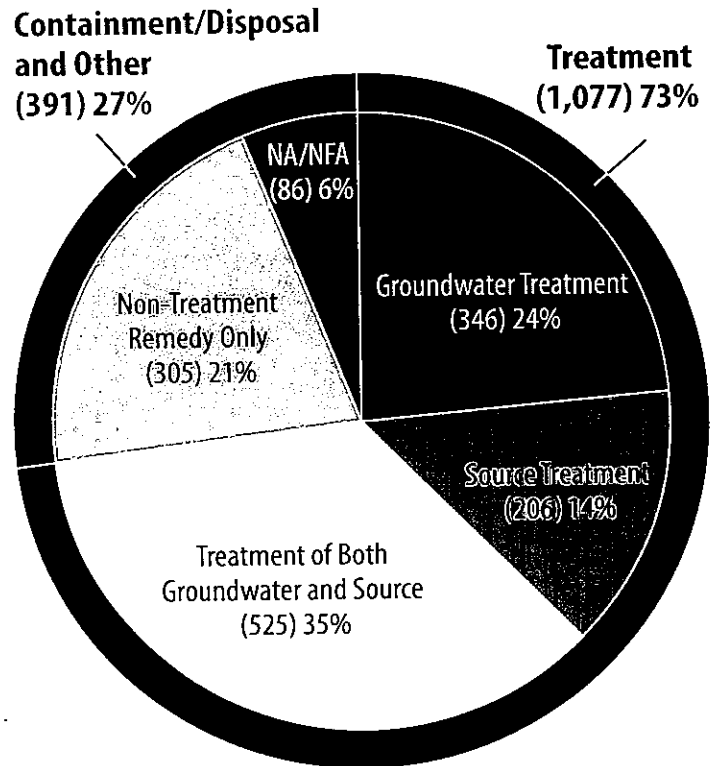
To allow for an analysis of remedy selection trends, the analysis of FY 2005 to 2008 decision documents from the *SRR 13th Edition* was updated to conform to the technology classification scheme used for this report. The subcategories of in situ bioremediation and chemical treatment have been refined. In addition, the new analysis excludes monitoring as a remedy, reducing the number of decision documents counted in the “Other Source Remedies” and “Other Groundwater Remedies” categories. According to EPA guidance, “[a]n alternative may include monitoring only and still be considered ‘no action.’” (EPA 1999a). Thus monitoring is not considered itself a remedy. However, the Superfund program recognizes the importance of effective monitoring and has implemented a long-term monitoring optimization strategy.⁴ As a result of this update, the FY 2005 to 2008 data presented in *SRR 14th Edition* may vary slightly from data for the same period in *SRR 13th Edition*. Data before FY 2005 has not been updated.

III. Use of Treatment at NPL Sites

The EPA evaluated the prevalence of treatment at NPL sites. Of all NPL sites where a remedy has been selected, 73 percent include at least one treatment remedy to address contaminated source, groundwater or both (Figure 3). The EPA’s demonstrated preference for treatment is consistent with CERCLA and the NCP.⁵

The data in Figure 3 follow a hierarchy so that each site is included in only one category. Appendix B lists the type and number of source and groundwater treatment technologies selected by fiscal year.

Figure 3: NPL Sites with Treatment Remedies (FY 1982–2011)



- Number of sites with remedies = 1,468.
- Sites are counted in this figure using the following hierarchy: treatment, non-treatment, no action/no further action (NA/NFA).
- Sites with treatment remedies include in situ or ex situ treatment, and may also include non-treatment remedies.
- Sites with only non-treatment remedies do not include treatment remedies in any decision document. Examples of non-treatment remedies include sediment EMNR, groundwater MNA, sediment MNR, containment/disposal, ICs and vapor intrusion components.
- Sites with only NA/NFA do not have treatment or non-treatment remedies selected in any decision document.

³ CFR, title 40, sec. 300.5

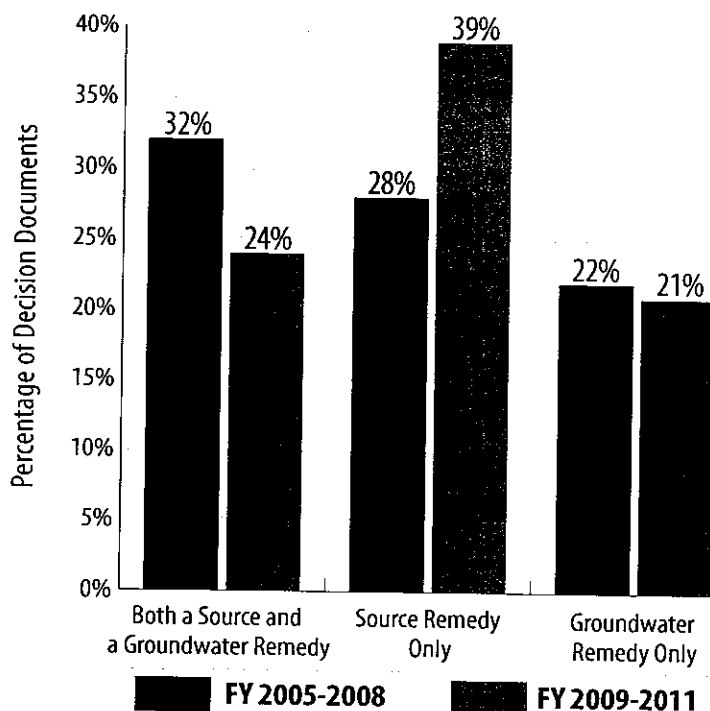
⁴ For further information, please visit the Optimizing Site Cleanups web page at www.clu-in.org/optimization

⁵ USC, title 42, sec. 9621(b)(1); CFR, title 40, sec. 300.430(a)(1)(iii)(A) and (E); CFR title 40, sec. 300.430(f)(1)(ii)(E)

IV. Remedies Selected⁶

Overall, the percentage of decision documents addressing sources, groundwater or both remained relatively constant from the previous reporting period (Figure 4). Of the 459 decision documents issued FY 2009 to 2011, over 60 percent addressed the source of contamination and 45 percent addressed contaminated groundwater. The most prevalent types of remedies selected were treatment, on-site containment, off-site disposal and ICs (Figure 5). The remedial program selected these remedies at nearly the same rate as in the previous timeframe.

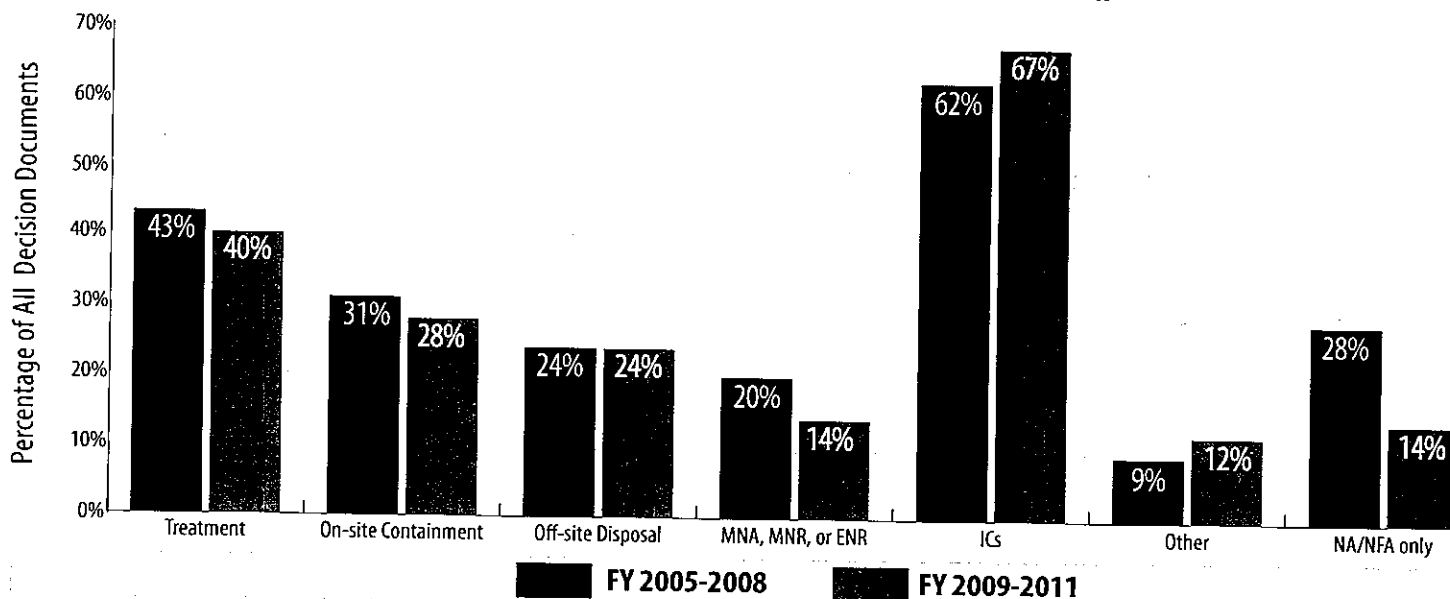
Figure 4: Percentage of Decision Documents Addressing Source or Groundwater



- Total number of decision documents: 595 (FY 2005-08); 459 (FY 2009-11).
- Decision documents are counted in only one category.
- Decision documents with source and/or groundwater may also have a vapor intrusion remedy component.
- Vapor intrusion only: data are not available for FY 2005-08; 2% (FY 2009-11).
- NA/NFA only: 18% (FY 2005-08); 14% (FY 2009-11).

⁶ A summary of all remedies selected for a particular decision document is available in Appendix C. Appendix C is available at www.clu-in.org/asr.

Figure 5: Remedies Selected in All Decision Documents



- Number of decision documents: 595 (FY 2005-08); 459 (FY 2009-11).
- With the exception of NA/NFA only, decision documents may be counted in more than one category.

- "Other" includes vapor intrusion remedies, wetlands replacement, wetland restoration and alternative water supplies.

V. Source Remedies⁷

As stated above, of the 459 decision documents issued FY 2009 to 2011, over 60 percent addressed the source of contamination. Sediments are included in the analysis of source remedies and are discussed in more detail on page 11. Recently, more than 50 percent of decision documents selecting source remedies selected multiple remedial approaches, including various combinations of treatment; on-site containment and off-site disposal; MNR and enhanced monitored natural recovery (EMNR) (for sediments); and other remedies, including ICs (Figure 6). Source treatment was selected in over 40 percent of source documents, either by itself or in some combination with containment/disposal and ICs, a value similar with the previous timeframe (EPA 2010a). An

examination of recent decision documents selecting ICs as the only source remedy found that all were for sites with previous remedial or removal actions. This finding is consistent with the NCP, which includes the expectation that ICs should be used to supplement engineering controls to prevent or limit exposure.⁸

In Figure 6, containment/disposal includes both on-site containment and off-site disposal. On-site source containment includes primarily cap and cover systems. Although some waste sent for off-site disposal is treated prior to disposal, if the treatment is not specified in the decision document, it is not included as treatment in this analysis.⁹

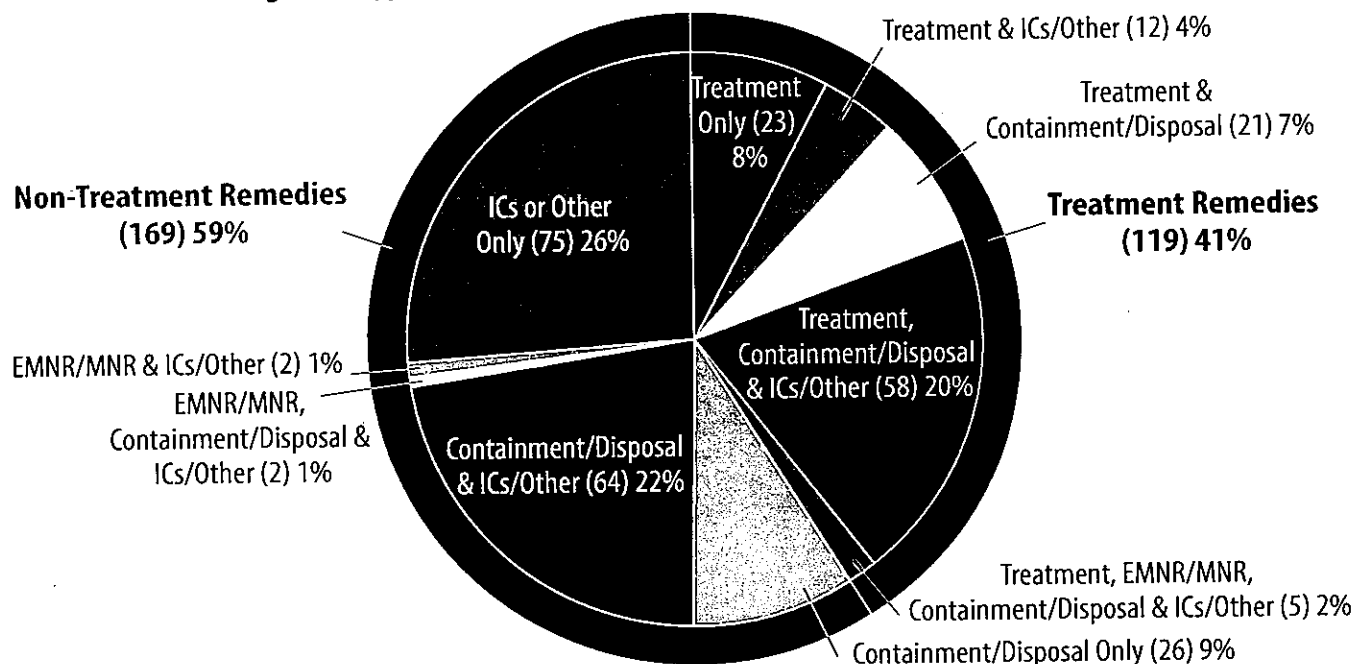
A further analysis of the decision documents selecting on-site containment, off-site disposal or both showed their selection frequency is divided into approximately one-third each (Figure 7).

⁷ Appendix D lists the remedy types in decision documents selecting source remedies from FY 2009 to 2011 by technology, and Appendix E lists by location. Appendix F lists the remedy types in decision documents selecting sediment remedies from FY 2009 to 2011 by technology, and Appendix G lists by location. Appendices D, E, F and G are available at www.clu-in.org/asr.

⁸ CFR, title 40, sec. 300.430(a)(1)(iii)(D)

⁹ See CERCLA off-site rule at CFR, title 40, sec. 300.440.

Figure 6: Types of Remedies in Source Decision Documents (FY 2009-2011)



- Number of source decision documents = 288.
- Each decision document is included in only one category.
- EMNR and MNR categories include: EMNR with no MNR (1), MNR with no EMNR (5), both EMNR and MNR (3).
- "ICs or Other Only" includes: ICs (74), wetlands replacement (1).

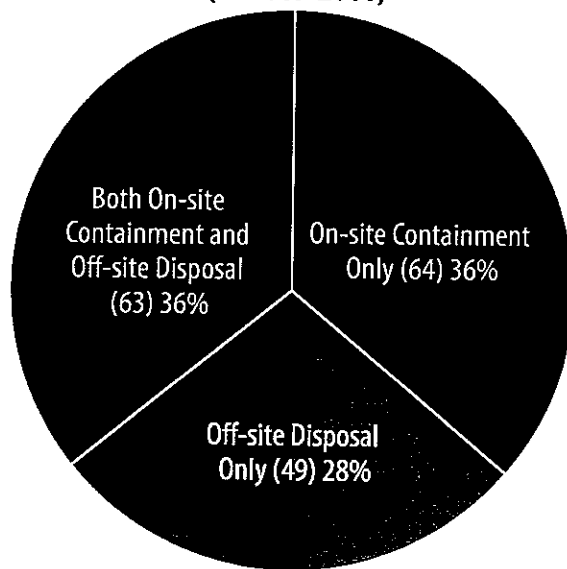
Figure 8 shows the trend in the types of source remedies (treatment, containment/disposal and other) selected in decision documents over a 14-year period. Other source remedies are primarily ICs. On average, the selection of treatment, containment/disposal and ICs has remained relatively stable over the 14-year period.

processes include sifting, sieving and sorting solid media to separate components, dewatering (including dewatering of dredged sediment) and decontamination (for example, cleaning contaminated building surfaces).

Table 1 summarizes the specific types of technologies selected in source treatment decision documents for FY 2009 to 2011 and compares that data to FY 2005 to 2008. The table groups in situ technologies, followed by ex situ. Overall, the selection rate for in situ and ex situ technologies has remained nearly the same for the two time periods and are currently 50 and 67 percent, respectively. Recently, the most frequently selected in situ methods for source were soil vapor extraction (SVE), chemical treatment (including in situ chemical oxidation [ISCO] and in situ chemical reduction [ISCR]), solidification/stabilization (S/S), in situ thermal treatment, bioremediation and multi-phase extraction (MPE). Most notably, the selection of in situ chemical treatment has doubled from 7 to 14 percent.

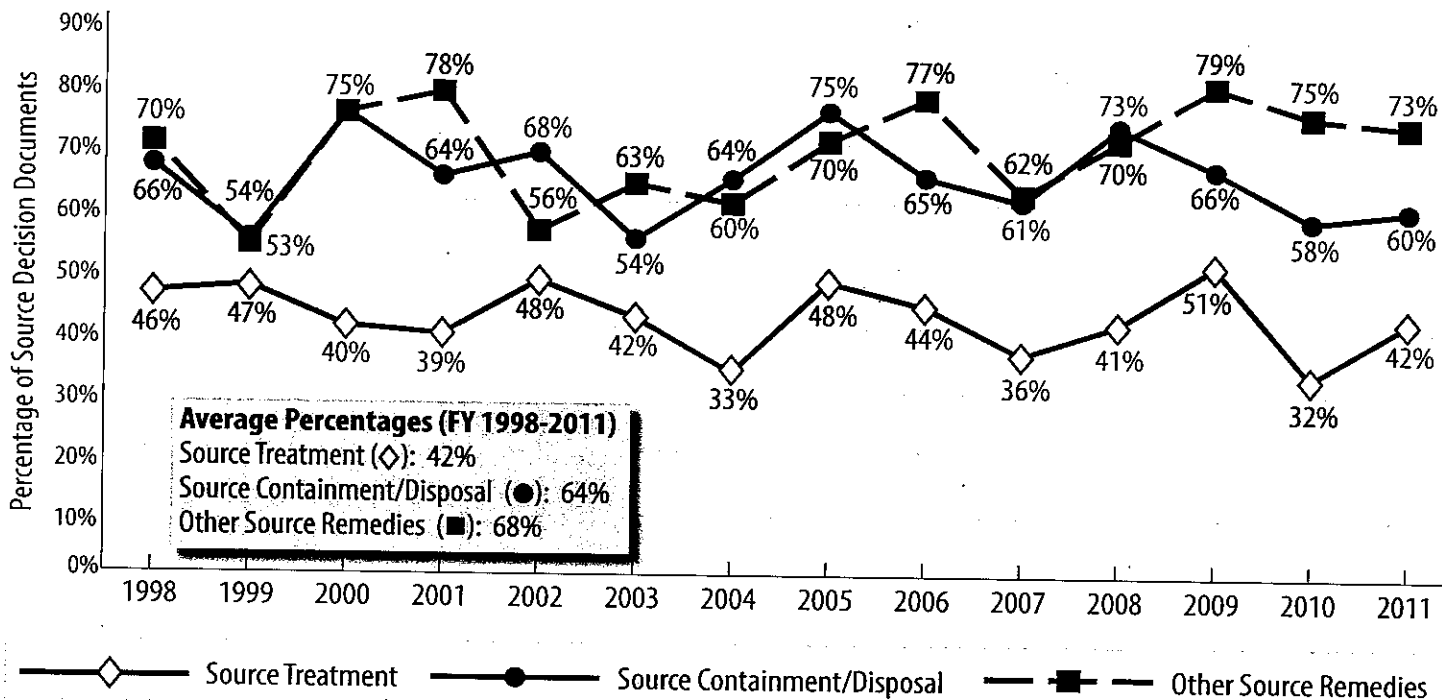
For the recent timeframe, physical separation is the most commonly selected ex situ treatment. For purposes of this report, all types of physical separation are considered treatment. Physical separation

Figure 7: On-site Containment vs. Off-site Disposal (FY 2009-2011)



• Number of decision documents selecting containment or disposal = 176.
• Each decision document is counted only once.

Figure 8: Selection Trends for Source Remedies (FY 1998–2011)



• Number of source decision documents for FY 1998-2011 = 1,293.

• Decision documents may be counted in more than one category.

Of the 33 FY 2009 to 2011 decision documents that selected physical separation, 17 selected dewatering, 12 decontamination, and 6 other physical separation processes such as sieving and mechanical sorting. Recycling is related to physical separation, and thus the two are combined.

The selection of ex situ S/S decreased from 19 to 13 percent for the recent time period but is still the second most commonly chosen ex situ remedial technology for sources. Solidification and stabilization

are separate processes that are often used together; however, stabilization does not always result in solidification. When enough detail was provided in the decision document, stabilization was categorized as chemical treatment rather than as S/S for both FY 2005 to 2008 and FY 2009 to 2011 data. Although usually associated with groundwater, pump and treat is included in Table 1 as an ex situ source treatment technology if selected to extract source material, such as NAPL, leachate or liquid waste.

Table 1: Source Treatment Technologies Selected in Decision Documents

Technology	Total (FY 2005-08)	Percent Source Treatment Decision Documents (FY 2005-08)	Total (FY 2009-11)	Percent Source Treatment Decision Documents (FY 2009-11)
In Situ Treatment	72	48%	59	50%
Soil Vapor Extraction	32	21%	25	21%
Chemical Treatment	11	7%	17	14%
Solidification/Stabilization	14	9%	11	9%
Thermal Treatment	14	9%	7	6%
Bioremediation	10	7%	4	3%
Multi-Phase Extraction	6	4%	3	3%
Constructed Treatment Wetland	0	0%	2	2%
Subaqueous Reactive Cap	0	0%	2	2%
Flushing	2	1%	1	1%
Fracturing	1	1%	1	1%
Phytoremediation	2	1%	0	0%
Ex Situ Treatment	98	65%	80	67%
Physical Separation	31	21%	33	28%
Solidification/Stabilization	29	19%	15	13%
Pump and Treat	18	12%	13	11%
Unspecified Off-site Treatment	11	7%	11	9%
Recycling	15	10%	10	8%
Unspecified On-site Treatment	2	1%	6	5%
Phytoremediation	0	0%	5	4%
Chemical Treatment	5	3%	4	3%
Bioremediation	4	3%	3	3%
NAPL Recovery	1	1%	1	1%
Thermal Desorption	1	1%	1	1%
Unspecified Thermal Treatment	1	1%	1	1%
Other Ex Situ Technologies	13	9%	0	0%

• Number of source treatment decision documents = 150 (FY 2005-08); 119 (FY 2009-11).

• Decision documents may be included in more than one category.

• For unspecified on-site or off-site treatment, decision document indicates on- or off-site treatment but does not specify any particular treatment technology.

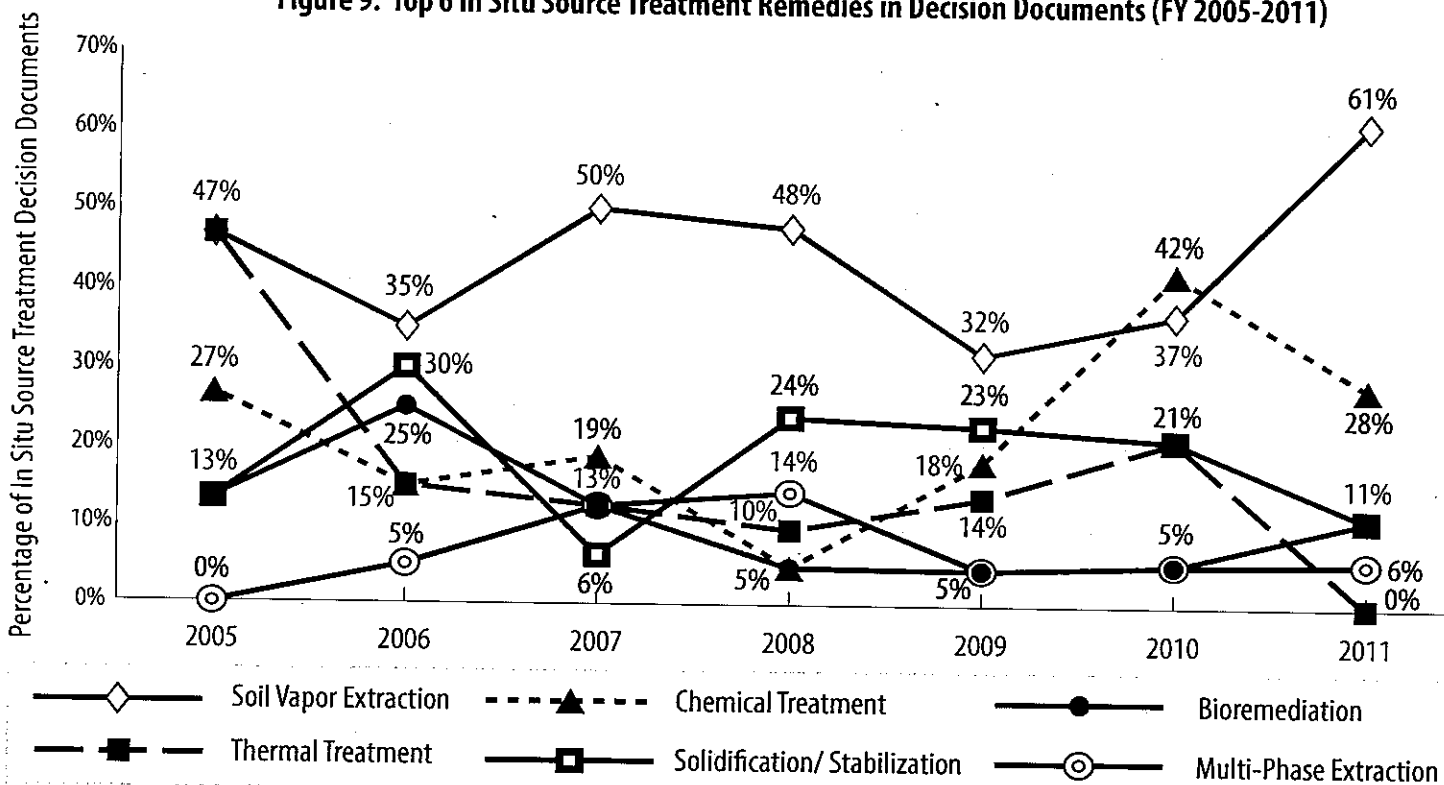
• "Other Ex Situ Technologies" for FY 2005-08 include air stripping (2); evaporation (1); incineration – off-site (6); neutralization (1); open burn/open detonation (1); and ex situ soil vapor extraction (2).

Ex situ incineration was not selected in FY 2009 to 2011, down from 6 selections for off-site incineration in FY 2005 to 2008. Although off-site disposal may include incineration, it cannot be included in Table 1 if off-site incineration is not specified in the decision document.

selecting in situ treatment averages about 19 per year for FY 2005 to 2011. Because of the small sample size, the percentages are heavily dependent on the sites in the pipeline for that year. For instance, the percentage increase in SVE in FY 2011 was partially because one site selected SVE at different operable units in multiple FY 2011 decision documents. Selection trends tend to vary year to year but for this seven-year timeframe the types of in situ remedies selected are fairly consistent. Over the past seven years, the overall selection of in situ source treatment as a percentage of all source decision documents has remained stable at about 20 percent (Figure 10).

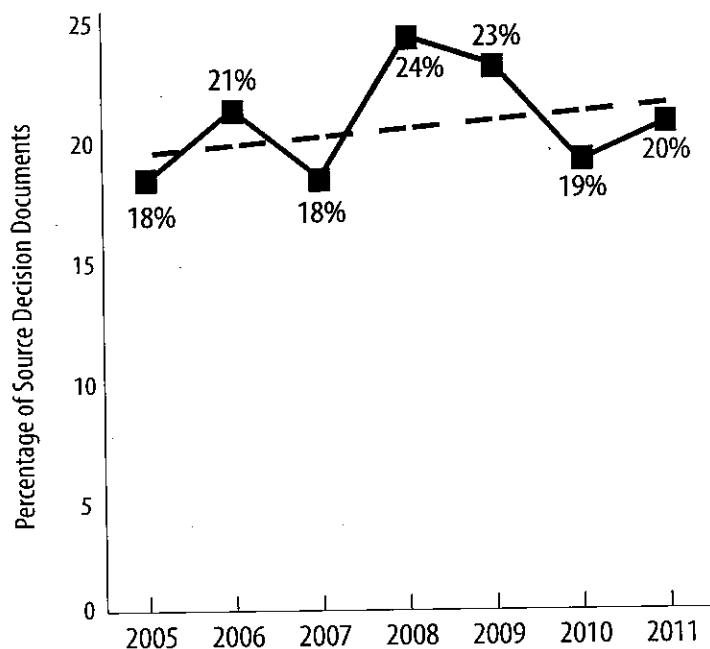
Figure 9 shows trends over a seven-year period for the most commonly selected in situ source treatment remedies. Figure 9 includes percentages as a function of only in situ source treatment decision documents. (Table 1 was based on all source treatment, both in situ and ex situ.) The number of decision documents

Figure 9: Top 6 In Situ Source Treatment Remedies in Decision Documents (FY 2005-2011)



- Number of decision documents selecting in situ source treatment remedies = 131.
- Decision documents may be included in more than one category.

Figure 10: Trends in Source Decision Documents Selecting In Situ Treatment (FY 2005-2011)



• Number of source decision documents = 645.

Sediment Remedies

Fifty-six source decision documents for FY 2009 to 2011 address sediment (Table 2). Three-quarters of these decision documents included dredging, or containment/disposal, while a third selected treatment. Nearly two-thirds of decision documents for sediments also included ICs. The term “constructed treatment wetland” is used to refer to wetlands constructed for the purposes of treatment. “Wetlands replacement” refers to wetlands constructed to compensate for wetlands destroyed by a remedy (such as placement of a cap in a wetland or other habitat area). Rehabilitation of a contaminated wetland is referred to as “wetlands restoration.” The S/S remedies in this table serve to immobilize contaminants in the sediment prior to disposal.

Table 2: Sediment Remedies in Decision Documents (FY 2009–2011)

Technology Treatment	Total	Percent Sediment Decision Documents
Technology Treatment	18	32%
Dewatering	16	29%
Ex Situ Solidification/Stabilization	5	9%
Constructed Treatment Wetland	2	4%
Subaqueous Reactive Cap	2	4%
In Situ Solidification/Stabilization	1	2%
Unspecified On-site Thermal Treatment	1	2%
Unspecified On-site Treatment	1	2%
Enhanced Monitored Natural Recovery	4	7%
Monitored Natural Recovery	8	14%
Dredging, Off-site Disposal and On-site Containment	43	77%
Dredging/Excavation	34	61%
Off-site Disposal	20	36%
Drainage/Erosion Control	19	34%
On-site Containment – Upland Cap or Containment Cell	17	30%
Subaqueous Non-Reactive Cap	6	11%
Subaqueous Containment Cell	2	4%
Stream Realignment	1	2%
Other	40	71%
Institutional Controls	36	64%
Wetlands Restoration	10	18%
Wetlands Replacement	4	7%

• Number of decision documents that address sediment = 83 (56 decision documents include remedy components and 27 are no action/no further action.)

• Decision documents may be included in more than one category.

VI. Groundwater Remedies¹⁰

Of the 459 decision documents from FY 2009 to 2011, 45 percent (over 200) addressed groundwater contamination (Figure 4). The recent remedies continue to be a mix of primarily P&T, in situ treatment, MNA and ICs (Figure 11).

The selection of P&T leveled off at about 25 percent in FY 2005 to 2008 after dropping significantly in the mid-1990s. From FY 2009 to 2011, P&T selection has averaged 22 percent of groundwater decision documents. From FY 2009 to 2011, the selection of MNA varied from 17 to 35 percent of groundwater decisions, and is still down significantly from the FY 2005 level of 45 percent. In contrast, the portion of groundwater decisions that include in situ treatment has steadily increased since FY 1986; in the most recent 3 years it rose to an average of 38 percent from 30 percent in FY 2005 to 2008. Groundwater containment by vertical engineered barriers (VEBs) has steadily increased since FY 1986; in the most recent 3 years it rose to an average of 38 percent from 30 percent in FY 2005 to 2008. Groundwater

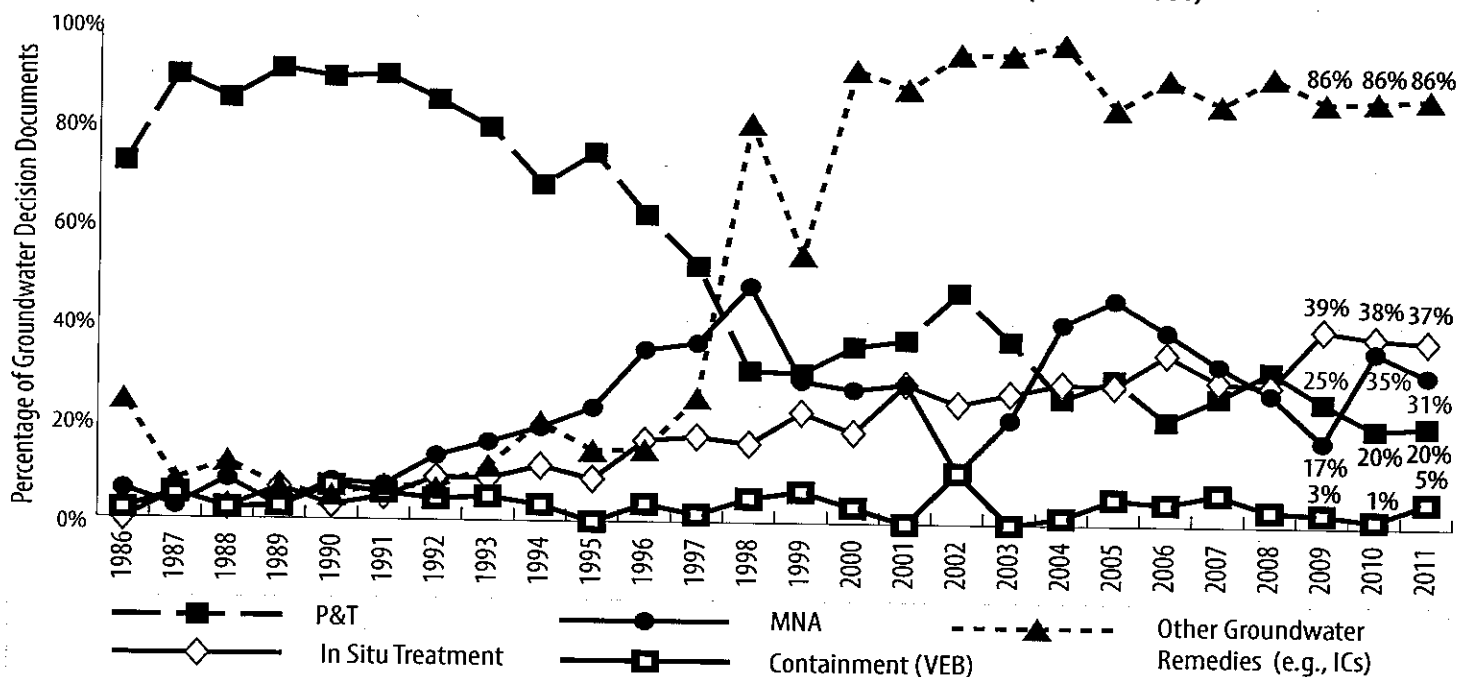
continues to be selected in fewer than 5 percent of decision documents. Almost all recent groundwater remedies included other types of groundwater remedies, primarily ICs. Most (98 percent) of “other groundwater remedies” in Figure 11 include ICs. Some of the increase in the selection of IC remedies may be attributed to changes in program guidance.¹¹ In addition, programmatic data reporting used prior to FY 1998 may have resulted in under reporting of ICs for those years.

The most frequently selected in situ technologies continue to be bioremediation, chemical treatment, air sparging and permeable reactive barriers (PRBs). The selection rate for these increased slightly in the recent time period (Table 3). Bioremediation and chemical treatment made up the majority of in situ technologies selected from FY 2009 to 2011. Of the 79 groundwater decision documents that selected in situ treatment, over half included bioremediation and over a third included chemical treatment.

¹⁰ Appendix H lists the remedy types in decision documents selecting groundwater remedies from FY 2009 to 2011 by technology, and Appendix I lists by location. Appendices H and I are available at www.clu-in.org/asr.

¹¹ Institutional Controls: A Site Manager's Guide to Identifying, Evaluating and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups, EPA 540-F-00-005, OSWER 9355.0-74FS-P, September 2000

Figure 11: Selection Trends for Groundwater Remedies (FY 1986-2011)



• Number of groundwater decision documents = 1,919.
 • Decision documents may be included in more than one category.

• “Other groundwater remedies” include ICs and other remedies not classified as treatment, MNA or containment.

Table 3: Groundwater Remedy Types Selected in Decision Documents

Technologies	Total (FY05-08)	Percent Groundwater Decision Documents (FY05-08)	Total (FY09-11)	Percent Groundwater Decision Documents (FY09-11)
Pump and Treat	85	26%	45	22%
Groundwater Pump and Treat	82	25%	44	21%
Surface Water Collect and Treat	5	2%	1	< 1%
In Situ Treatment	97	30%	79	38%
Bioremediation	60	19%	49	24%
Chemical Treatment	38	12%	28	14%
Air Sparging	10	3%	12	6%
Permeable Reactive Barrier	7	2%	8	4%
In-Well Air Stripping	0	0%	2	1%
Multi-Phase Extraction	1	< 1%	2	1%
Phytoremediation	3	1%	0	0%
Fracturing	1	< 1%	0	0%
MNA of Groundwater	116	36%	56	27%
Groundwater Containment (VEB)	16	5%	6	3%
Constructed Treatment Wetland	1	< 1%	4	2%
For Groundwater Treatment	1	< 1%	3	1%
For Surface Water Treatment	0	0%	1	< 1%
Other Remedies	281	87%	177	86%
Institutional Controls	274	85%	173	84%
Alternative Water Supply	26	8%	13	6%
Engineering Control	4	1%	2	1%

- Number of groundwater decision documents: 322 (FY 2005-08); 206 (FY 2009-11).
- Decision documents may be included in more than one category.
- Engineering Controls for FY 2005-08 include the use of trees for hydraulic gradient control (3) and sewer/sump abandonment (1). Engineering Controls for FY 2009-11 include water table adjustment (1) and wetlands replacement (1).

The majority of decision documents that selected bioremediation remedies specified anaerobic bioremediation (Table 4). Bioaugmentation (addition of bacteria capable of degrading specific chemicals) and aerobic bioremediation were also specified in some

bioremediation remedies. More than half of decision documents that selected chemical treatment specified ISCO, while a quarter selected ISCR.

Table 4: In Situ Bioremediation and Chemical Treatment Techniques Selected in Groundwater Decision Documents (FY 2009–2011)

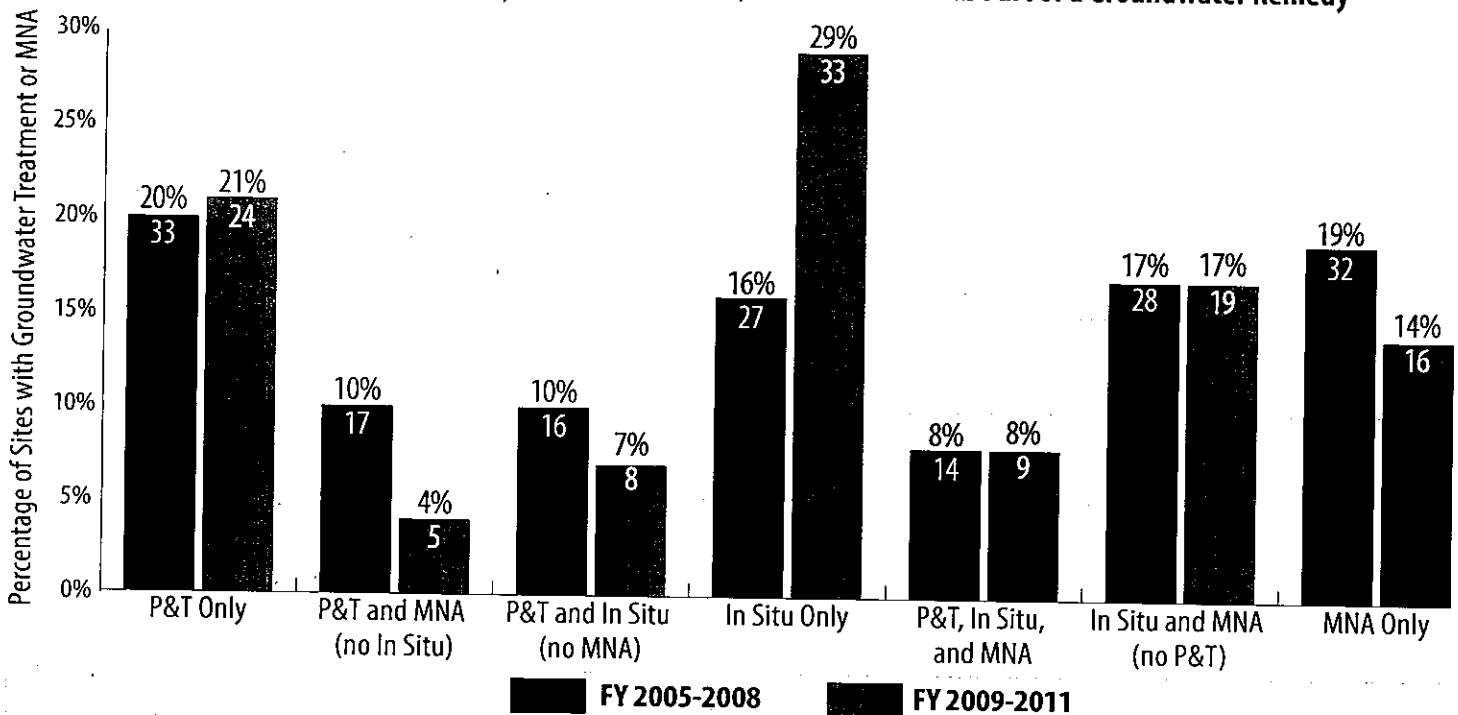
Technology	2009	2010	2011	Total
Bioremediation	21	18	10	49
Anaerobic Bioremediation	15	17	9	41
Bioaugmentation	4	3	3	10
Aerobic Bioremediation	5	1	1	7
Cometabolic Treatment	1	0	0	1
Chemical Treatment	8	10	10	28
In Situ Chemical Oxidation	5	4	7	16
In Situ Chemical Reduction	1	5	1	7
Neutralization	1	1	0	2
Other In Situ Chemical Treatment	1	0	2	3
Ozone Sparging	0	1	2	3

- Number of decision documents selecting in situ groundwater treatment = 79.
- Decision documents may be included in more than one category.

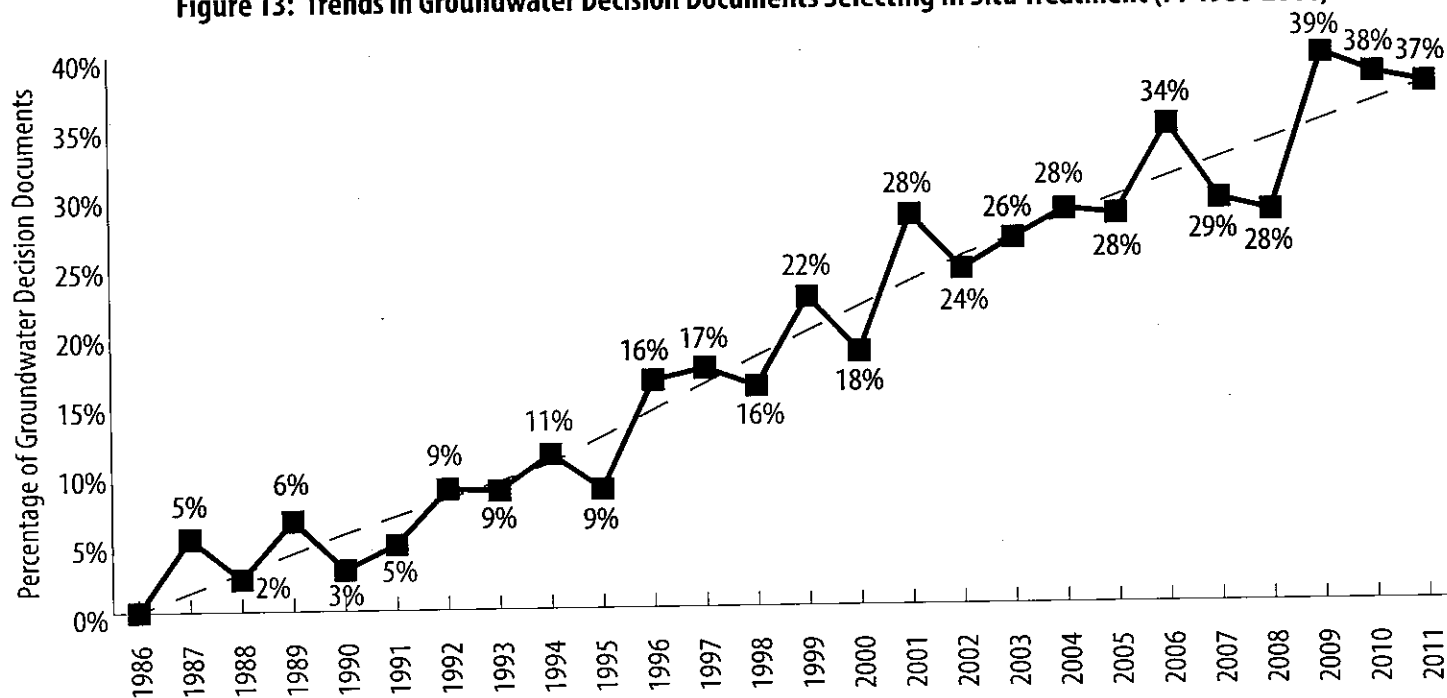
The last seven years of data were also evaluated to determine how often multiple remedial components were selected to address groundwater at a site (Figure 12). For this analysis, remedies are displayed in terms of sites rather than decision documents, so that for each time period decisions in multiple documents can be considered together. For the most recent period, one third of sites with groundwater remedies include more than one cleanup approach. In situ treatment and MNA are the groundwater remedies most often used together. Of the groundwater remedies used alone, in situ treatment was selected most frequently, followed by P&T then MNA. As noted earlier, since the previous period there was a decrease in sites selecting P&T, and an overall increase in sites selecting in situ treatment. Recently, nearly half of sites with P&T or MNA also include an in situ technology.

Figure 13 shows more clearly the trend in selection of in situ treatment as a component of groundwater decision documents since FY 1986.

Figure 12: Sites with P&T, In Situ Treatment, or MNA Selected as Part of a Groundwater Remedy



- Number of sites with groundwater treatment or MNA: 167 (FY 2005-08); 114 (FY 2009-11).
- Sites are counted only once in this figure as appropriate.

Figure 13: Trends in Groundwater Decision Documents Selecting In Situ Treatment (FY 1986-2011)

• Number of groundwater decision documents = 1,919.

VII. Vapor Intrusion¹²

Data for remedies of air media (including vapor intrusion) were not included in past versions of the ASR and SRR. In light of the Superfund program's recent emphasis on vapor intrusion assessment and mitigation, vapor intrusion is being addressed more often in decision documents. The EPA analyzed the selection of vapor intrusion mitigation technologies for existing structures.

Vapor intrusion generally occurs when volatile chemicals migrate from contaminated groundwater or soil into an overlying building. Volatile chemicals emit vapors that may migrate through subsurface soils and into indoor air spaces of overlying buildings in ways similar to radon gas seeping into homes. Volatile chemicals may include volatile organic compounds (VOCs), select semivolatile organic compounds

(SVOCs), some pesticides and some inorganic analytes, such as elemental mercury and hydrogen sulfide. Generally, the main concern in buildings has been that low concentrations of volatile chemicals may pose an unacceptable health risk to building occupants.

Twenty-one FY 2010 and 2011 decision documents addressed vapor intrusion (Table 5). Sub-slab depressurization was the most common mitigation method selected; sealing of openings, sub-membrane depressurization, enhanced interior ventilation, vapor barriers and passive ventilation systems were also selected. Descriptions of the mitigation technologies are found in Appendix A. Institutional controls for vapor intrusion were selected for both existing and future buildings. In FY 2009, some decision documents indicated they would monitor for vapor intrusion and provide mitigation as necessary; however, a mitigation system was not selected in the decision document.

¹² Appendix J lists the remedy types in decision documents selecting vapor intrusion remedies from FY 2009 to 2011 by technology, and Appendix K lists by location. Appendices J and K are available online at www.clu-in.org/asr.

Table 5: Vapor Intrusion Remedies Selected in Decision Documents (FY 2009–2011)

Technology	2009	2010	2011	Total
Vapor Intrusion Mitigation in Existing Structures	0	8	7	15
Sub-Slab Depressurization	0	6	6	12
Sealing Cracks and Openings	0	4	2	6
Sub-Membrane Depressurization	0	4	1	5
Interior Ventilation	0	4	0	4
Vapor Intrusion Mitigation (Unspecified)	0	2	1	3
Passive Barrier (Impermeable Membrane)	0	0	2	2
Passive Soil Ventilation	0	0	1	1
Positive Indoor Pressurization	0	0	1	1
Institutional Controls	0	8	9	17
Future Construction	0	8	9	17
Existing Structures	0	3	2	5

• Number of decision documents selecting vapor intrusion remedies = 21.

• Decision documents may be included in more than one category.

VIII. Characteristics of NPL Sites in the RI/FS Phase

Introduction

The EPA recently collected and analyzed available data on the universe of sites in the Superfund RI/FS phase to evaluate trends in the types of media and contaminants that the program will be addressing in the future. This analysis can help anticipate the need for certain types of remedial technologies and site-specific technical assistance. In the past, the EPA has evaluated the characteristics of Superfund sites undergoing remedial investigation (RI) or feasibility studies (FS) to assess the market for remedial technologies (EPA 2004).

Methodology

This analysis included sites and operable units (OUs) where an RI/FS had been started but had not been completed. The analysis is based on sites and OUs identified in a CERCLIS query conducted on August 24, 2011 that identified 670 OUs at 323 sites with RI/FS actions that had a decision document planned for FY 2012 or later. The EPA collected data for these sites from publicly available sources, including site

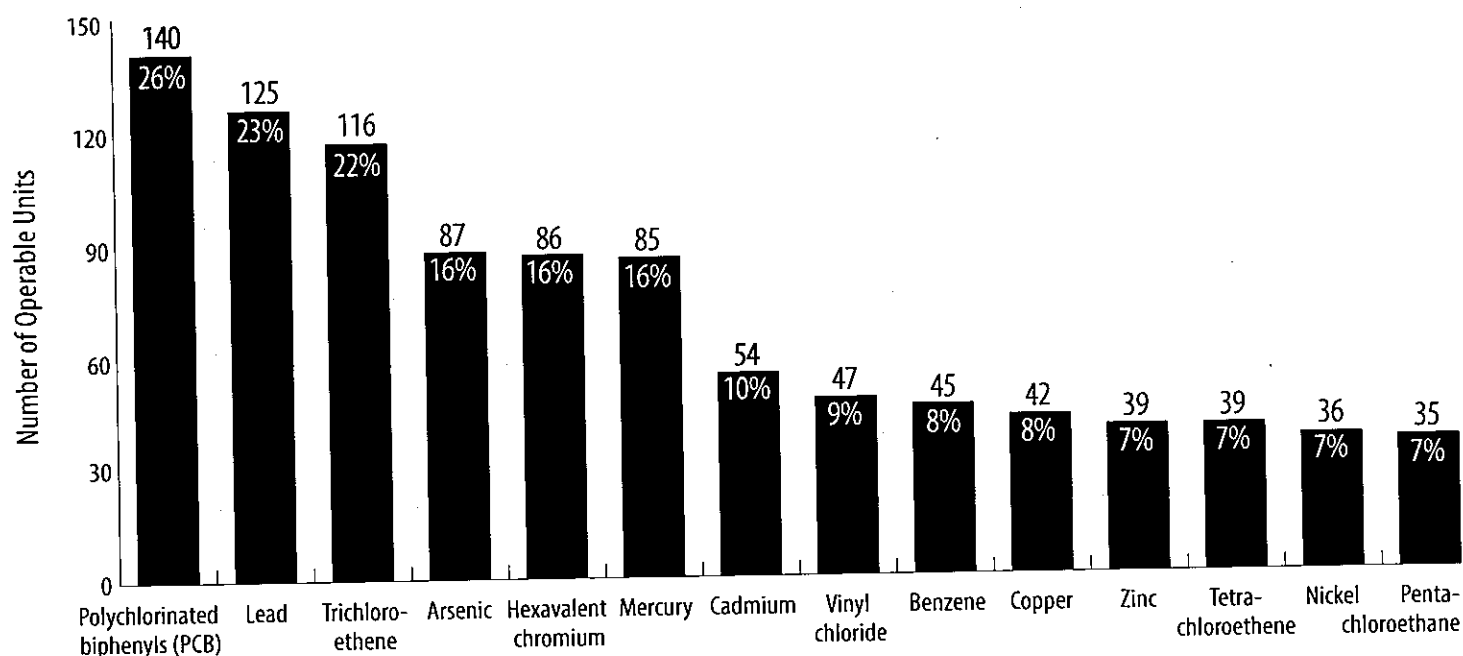
summaries, NPL factsheets and five-year reviews when available (if other OUs at the site were already being addressed). Data were collected about site contamination, media that may be affected, and classes of contaminants that may be of concern. For sites with previous or ongoing cleanup activities, an effort was made to distinguish areas of the site already addressed, from those still under investigation. Because at the time of the analysis, no decision documents had been signed to address these OUs, the contaminants and media identified in the current documentation represent preliminary data on what may be addressed.

Contaminants

The EPA researched contaminant information for the 670 OUs in the RI/FS phase at the 323 sites. Contaminant data was found for 535 OUs of the 670 OUs. Of those, specific contaminant information was available from 447 OUs at 261 sites.

Lead, arsenic, hexavalent chromium, mercury, cadmium, copper, zinc and nickel were the most frequently occurring metals for these OUs (Figure 14). Trichloroethene (TCE) and vinyl chloride were the top VOCs, and polychlorinated biphenyls (PCBs) were the most frequently occurring SVOCs. PCB congeners are considered together in this analysis.

Figure 14: Most Frequently Occurring Contaminants at OUs in the RI/FS Phase



• Total Number of OUs = 447

The OU contaminants were also evaluated by commonly-used groups.¹³ The contaminant groups used are defined below:

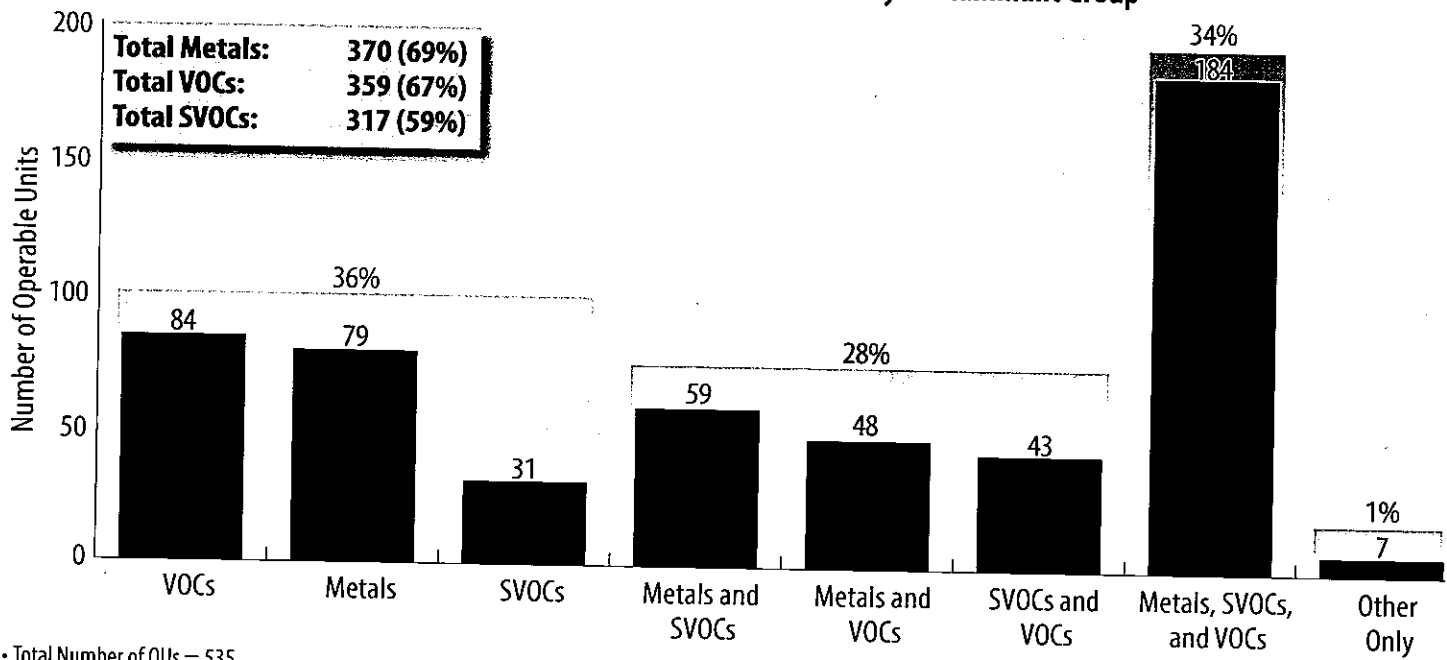
- **Metals** – Metals; metalloids; explosive metals; radioactive metals; and organometallic pesticides and herbicides.
- **VOCs** – Halogenated VOCs; benzene, toluene, ethylbenzene, xylene (BTEX); fuels and distillates; and other nonhalogenated VOCs.
- **SVOCs** – PCBs; polycyclic aromatic hydrocarbons (PAHs); organic pesticides and herbicides; phenols; fuels and distillates; most explosives; and other halogenated and nonhalogenated SVOCs.
- **Other** – nonmetallic inorganics; asbestos; and unspecified organics or inorganics.

Each contaminant is assigned to only one contaminant group, and each contaminant group is counted once per decision document even if it occurs in more than one medium.

Based on this analysis, metals and VOCs are found at almost 70 percent of these OUs, and SVOCs at almost 60 percent (Figure 15). More than 60 percent of OUs were found to have more than one contaminant group.

¹³ The contaminants included in each contaminant group are listed in Appendix L (available online at www.cdu-in.org/asr).

Figure 15: Number of OUs in the RI/FS Phase by Contaminant Group

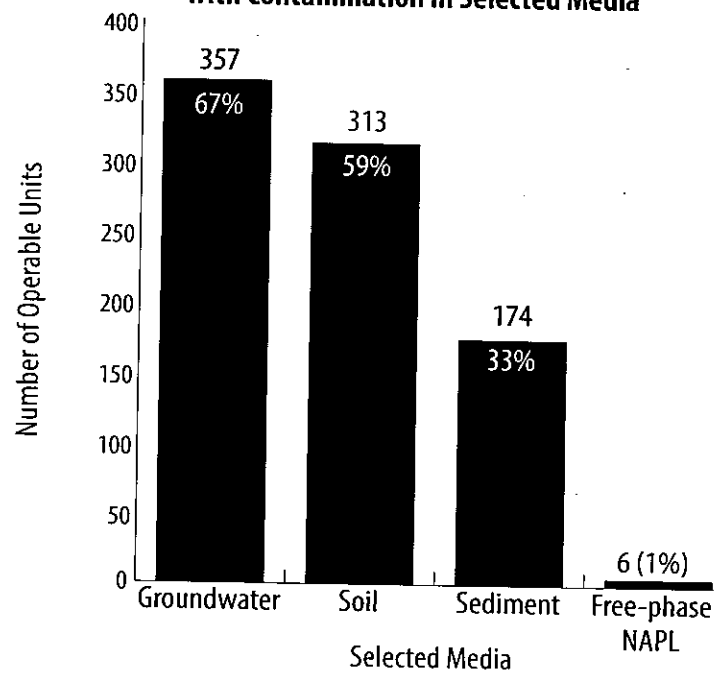


The site summaries often indicated only a general category of contaminant rather than specific contaminants because of the preliminary nature of the data. For example, site summaries noted more than 200 unspecified VOCs, almost 200 unspecified metals, and almost 100 unspecified PAHs. These data were included in the contaminant group analysis, but could not be included in the evaluation of the most frequent contaminants.

Contaminated Media

The evaluation of contaminated media showed that nearly 70 percent of OUs in the RI/FS phase may have contaminated groundwater; almost 60 percent may have contaminated soil; and more than 30 percent, contaminated sediment (Figure 16). NAPLs are specifically identified in only one percent of these OUs, although they may also be present at additional sites with contaminated groundwater.

Figure 16: Number of OUs in the RI/FS Phase with Contamination in Selected Media



- Total Number of OUs = 531
- 4 OUs with contaminant data did not specify media.

IX. Conclusions

The EPA's analysis of remedy selection from FY 2009 to 2011 and a comparison to earlier data shows that the Superfund remedial program continues to select treatment at nearly 75 percent of Superfund sites over the life of the program. The Superfund program also continues to address complex sites involving multiple media. In addition, the data show that multiple technologies are selected to address the same medium, with each technology targeted at a portion of the medium or a particular contaminant. In some cases, the technologies are employed at the same time, while others are employed in series. Based on the multiple types of contaminants at the sites and OUs in the RI/FS phase, future remedies also are likely to include multiple targeted technologies for a single medium.

The data provided in this report can also help identify program needs for improved technical information and support. The successful use of technologies, particularly in situ methods directed at specific areas of contamination, is enhanced by the use of more refined site characterization techniques such as HRSC. HRSC can provide a greater level of detail about subsurface conditions before, during and after the application of subsurface technologies. Therefore the increase of in situ technology use may suggest a need for technical support for the application of these site characterization techniques.

Concerning source remedies:

- The Superfund remedial program continues to select treatment for a large number of source remedies.
- Source remedies continue to include a combination of treatment, containment/disposal and ICs to address contaminated sites.
- Physical separation was recently selected more often for ex situ treatment than S/S, although some chemical stabilization remedies are counted under chemical treatment.
- SVE, chemical treatment, S/S, bioremediation, MPE and in situ thermal treatment continue to be the most frequently selected in situ treatment technologies.
- On average, half of recent source treatment decision documents included in situ treatment.

- A wide range of remedies have been selected to address contaminated sediments. Three-quarters of the decision documents included dredging or containment/disposal, and nearly a third included treatment.

Concerning groundwater remedies in the latest analysis:

- The selection of P&T and MNA decreased slightly while the selection of in situ treatment and ICs has increased.
- Nearly all groundwater decision documents include ICs. The selection of water supply remedies and other engineering controls remains steady.
- The overall selection of in situ bioremediation and chemical treatment remedies for groundwater remains steady.
- The majority of in situ bioremediation remedies specified anaerobic bioremediation. More than half of the chemical treatment remedies were in situ chemical oxidation.
- The selection of in situ treatment for groundwater continues its overall upward trend and averages 38 percent of decision documents addressing groundwater.

Concerning vapor intrusion:

- Sub-slab depressurization was the most frequently selected technology for vapor intrusion mitigation.
- The more recent selection of vapor intrusion mitigation remedies highlights the need for technical information and support related to vapor intrusion site characterization and mitigation technologies.

Concerning sites in the RI/FS process:

- Future decision documents will likely continue to address complex sites with contaminants in multiple groups (VOCs, metals and SVOCs).
- Groundwater contamination may be addressed at two-thirds of these sites, soil in more than half and sediment in about one-third.
- PCBs, lead, TCE, arsenic, hexavalent chromium and mercury may be among the most frequently occurring contaminants addressed in the future.

X. Sources and Electronic Versions

This section lists the sources of information used in this report and provides information on how to access the electronic version of this report and previous versions of the ASR and SRR.

Sources

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Electronic Versions

SRR 14th edition is available electronically at www.clu-in.org/asr. The body of the report and its appendices can be downloaded from the website. In addition, electronic versions of previous ASR and SRR reports can also be downloaded. The list below describes the appendices for the SRR 14th edition.

Appendix A. Definitions of Specific Remedies. This appendix defines the specific remedies selected as part of remedial actions.

Appendix B. Treatment Technologies Selected by Fiscal Year. This appendix lists the ex situ and in situ source treatment technologies, groundwater in situ treatment technologies and groundwater pump and treat remedies selected by fiscal year from 1982 to 2011.

Appendix C. Remedy Selection Summary Matrix FY 2009–11 (only available electronically). This appendix lists the remedy components selected in each decision document analyzed for the SRR 14th edition.

Appendix D. Source Treatment Technologies Selected in Decision Documents from FY 2009–11, Organized by Technology (only available electronically). This appendix lists the source treatment technologies selected from FY 2009 to 2011 and the associated sites and operable units.

Appendix E. Source Treatment Technologies Selected in Decision Documents from FY 2009–11, Organized by Location (only available electronically). This appendix lists the source treatment technologies selected from FY 2009 to 2011 and the associated sites and operable units.

Appendix F. Sediment Remedies Selected in Decision Documents from FY 2009–11, Organized by Technology (only available electronically). This appendix lists the sediment remedies selected from FY 2009 to 2011 and the associated sites and operable units.

Appendix G. Sediment Remedies Selected in Decision Documents from FY 2009–11, Organized by Location (only available electronically). This appendix lists the sediment remedies selected from FY 2009 to 2011 and the associated sites and operable units.

Appendix H. Groundwater Remedies Selected in Decision Documents from FY 2009–11, Organized by Technology (only available electronically). This appendix lists the groundwater technologies selected in decision documents from FY 2009 to 2011 and the associated sites and operable units.

Appendix I. Groundwater Remedies Selected in Decision Documents from FY 2009–11, Organized by Location (only available electronically). This appendix lists the groundwater technologies selected in decision documents from FY 2009 to 2011 and the associated sites and operable units.

Appendix J. Vapor Intrusion Remedies Selected in Decision Documents from FY 2009–11, Organized by Technology (only available electronically). This appendix lists the vapor intrusion remedies selected from FY 2009 to 2011 and the associated sites and operable units.

Appendix K. Vapor Intrusion Remedies Selected in Decision Documents from FY 2009–11, Organized by Location (only available electronically). This appendix lists the vapor intrusion remedies selected from FY 2009 to 2011 and the associated sites and operable units.

Appendix L. Individual Contaminants and Assigned Contaminant Groups in the RI/FS Phase (only available electronically). This appendix lists the individual contaminants from data for operable units in the RI/FS Phase and identifies which contaminant groups the individual contaminants were assigned.

Appendix A: Definitions of Selected Remedies

Background

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

- The CERCLA Information System (CERCLIS3) database
- RODs, ROD amendments, and selected ESDs for fiscal years (FY) 1982—2011
- The Federal Remediation Technologies Roundtable (FRTR) Technology Screening Matrix, Version 4.0
- *A Citizen's Guide to Remedial Technologies* (2012 Editions)
- Other resources.

Definitions Used to Identify Remedy and Media Types

Treatment Technology— “[Any] unit operation or series of unit operations that alters the composition of a hazardous substance, 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 untreated hazardous wastes without treatment” (CFR, title 40, sec. 300.5).

Treatment technologies are grouped into eleven categories. The definitions for four of the categories below (physical treatment, chemical treatment, thermal treatment and biological treatment) are based on definitions provided in the FRTR Technology Screening Matrix (FRTR 2007). Additional categories used in this report include Pump and Treat; Monitored Natural Attenuation (MNA) for Groundwater; Monitored Natural Recovery (MNR) for Sediment; Enhanced Monitored Natural Recovery (EMNR) for Sediment; On-site Containment; Vapor Intrusion Mitigation; and Other or Unspecified Remedies.

Source Media — Source media are defined as “material[s] that includes or contains hazardous substances, pollutants or contaminants that act as a reservoir for migration of contamination to ground

water, to surface water, to air, or acts as a source for direct exposure. Contaminated ground water generally is not considered to be a source material although nonaqueous phase liquids (NAPLs [occurring either as residual- or free-phase]) may be viewed as source materials” (EPA 1991). For purposes of this report, source media include soil, sediment, sludge, debris, solid-matrix wastes, NAPLs, equipment, drums, storage tanks, leachate, landfill gas and any contaminated media other than groundwater that can act as a potential source of contamination.

Source Remedy — Any removal, treatment, containment or management of a contaminant source.

Groundwater Media — One or more aquifers beneath or proximal to a source medium and contaminated or potentially contaminated by migration of contaminants, such as landfill leachate, non-aqueous phase liquids (NAPL), leaching from soil, etc. Because groundwater and surface water are both considered “non-source” media (EPA 1991), for purposes of this report, surface water remedies are counted along with groundwater remedies.

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

Physical Treatment

Physical treatment uses the physical properties of the contaminants or the contaminated medium to separate or immobilize the contamination.

Air Sparging “is a process in which air is injected into the saturated zone below or within the areas of contamination through a system of wells. As the injected air rises through the formation, it may volatilize and remove adsorbed VOC in soils as well as strip dissolved contaminants from groundwater. Air sparging is most effective at sites with homogeneous, high-permeability soils and unconfined aquifers contaminated with VOCs. SVE is commonly used with air sparging to capture the volatiles that air sparging strips from soil and groundwater. The volatile

contaminants are transported in the vapor phase to the vadose zone, where they are drawn to extraction wells and treated using a standard off-gas treatment system” (EPA 1997). Oxygen added to the contaminated groundwater and vadose-zone soils also can enhance biodegradation of contaminants below and above the water table. The injection of ozone into the aquifer is referred to as ozone sparging and is a form of chemical treatment.

Flushing “involves flooding a zone of contamination with an appropriate solution to remove the contaminant from the soil. Water or liquid solution is injected or infiltrated into the area of contamination. The contaminants are mobilized by solubilization, formation of emulsions, or a chemical reaction with the flushing solutions. After passing through the contamination zone, the contaminant-bearing fluid is collected and brought to the surface for disposal, recirculation, or on-site treatment and reinjection.... Flushing solutions may be water, acidic aqueous solutions, basic solutions, chelating or complexing agents, reducing agents, cosolvents, or surfactants” (EPA 2006).

In Situ Geochemical Stabilization — See **Chemical Treatment** (for groundwater) or **Solidification and Stabilization** (for source media).

In-Well Air Stripping systems “create a circulation pattern in the aquifer by drawing water into and pumping it through the wells, and then reintroducing the water into the aquifer without bringing it above ground.... The well is double-cased with hydraulically separated upper and lower screened intervals within the aquifer.... The system can be configured with an upward in-well flow or a downward in-well flow. The most common configurations involve the injection of air into the inner casing, decreasing the density of the groundwater and allowing it to rise.... Through this system, volatile contaminants in the ground water are transferred from the dissolved phase to the vapor phase by the rising air bubbles. Contaminated vapors can be drawn off and treated above ground or discharged into the vadose zone” (EPA 1998a).

Mechanical Soil Aeration agitates contaminated soil, using tilling or other means to volatilize contaminants.

Multi-Phase Extraction (MPE) “is an enhancement of a typical soil vapor extraction (SVE) system that “involves the removal of contaminated vapors and

groundwater from the same borehole. A vacuum applied to the borehole extracts contaminated vapors from unsaturated soils and simultaneously entrains contaminated groundwater. The groundwater is subsequently separated from the vapors and treated using standard aboveground treatment methods. The groundwater table within the zone of influence of a [MPE] well is lowered, exposing the capillary fringe and previously saturated soils to the extraction vacuum and enabling more effective remediation of these soils than traditional SVE systems... [MPE] systems can be implemented to target all phases of contamination associated with a typical NAPL spill site. These systems remove residual vadose zone soil contamination residing in soil gas, dissolved in soil pore-space moisture, and adsorbed to soil particles. [MPE] also effectively removes dissolved and free-phase (both light and dense NAPL [LNAPL and DNAPL]) contamination in groundwater” (EPA 1997). **Dual-phase extraction** and **bioslurping** are types of MPE.

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.

Soil Vapor Extraction (SVE) is “used to remove VOCs from vadose zone soil. Air flow is induced through contaminated soil by applying a vacuum to vapor extraction vents and creating a pressure gradient in the soil. As the soil vapor migrates through the soil pores toward the extraction vents, VOCs are volatilized and transported out of subsurface soil” (EPA 1997). SVE usually is performed in situ; however, in some cases, it can be used as an ex situ technology.

Soil Washing “is a process that uses physical and/or chemical techniques to separate contaminants from soil and sediments. Contaminants are concentrated into a much smaller volume of contaminated residue, which is either recycled or disposed. Washwater can consist of water only or can include additives such as acids, bases, surfactants, solvents, chelating or sequestering agents which are utilized to enhance the

separation of contaminants from soils or sediments” (ITRC 1997). “Hazardous contaminants tend to bind, chemically or physically, to silt and clay. Silt and clay, in turn, bind to sand and gravel particles. The soil washing process separates the contaminated fine soil (silt and clay) from the coarse soil (sand and gravel). When completed, the smaller volume of soil, which contains the majority of the fine silt and clay particles, can be further treated by other methods (such as incineration or bioremediation) or disposed of according to state and federal regulations” (EPA 1996).

Solidification and Stabilization (S/S) reduces the mobility of hazardous substances and contaminants in the environment through both physical and chemical means. “Solidification refers to processes that encapsulate a waste to form a solid material and to restrict contaminant migration by decreasing the surface area exposed to leaching and/or by coating the waste with low-permeability materials. Solidification can be accomplished by a chemical reaction between a waste and binding (solidifying) reagents or by mechanical processes... Examples of inorganic binders include cement, fly ash, lime, soluble silicates, and sulfur-based binders, while organic binders include asphalt, epoxide, polyesters, and polyethylene.

“Stabilization refers to processes that involve chemical reactions that reduce the leachability of a waste. Stabilization chemically immobilizes hazardous materials or reduces their solubility through a chemical reaction. The physical nature of the waste may or may not be changed by this process” (EPA 2000b). Stabilization remedies are classified as S/S whether or not they ultimately involve solidification.

S/S may be performed either *ex situ* or *in situ*. Note that chemical agents added *in situ* for the purpose of binding with contaminants in groundwater (as opposed to soil) is classified as *in situ* **Chemical Treatment**, not S/S.

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.

Chemical Treatment

Chemical treatment chemically converts hazardous contaminants to non-hazardous or less toxic compounds or compounds that are more stable, less mobile, inert, or all three. Even though a chemical reaction is not always involved in chemical precipitation, chemical precipitation is typically included in this category.

Chemical Fixation or Chemical Stabilization— See also **Solidification and Stabilization**.

Chemical 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 chemical to another. Specifically, one reactant is oxidized (loses electrons) and one is reduced (gains electrons). There are several oxidants capable of degrading contaminants. Commonly used oxidants include potassium or sodium permanganate, Fenton’s catalyzed hydrogen peroxide, hydrogen peroxide, ozone, and sodium persulfate. Each oxidant has advantages and limitations, and while applicable to soil contamination and some source zone contamination, they have been applied primarily toward remediating groundwater” (EPA 2006). Chemical oxidation can be conducted either *in situ* or *ex situ*.

Chemical Reduction “involves the placement of a reductant or reductant generating material in the subsurface for the purpose of degrading toxic organic compounds to potentially nontoxic or less toxic compounds, immobilizing metals such as Cr (VI) by adsorption or precipitation, and degrading non-metallic oxyanions such as nitrate” (EPA 2013b).

“Common reducing agents include zero valent metals, which are metals in their pure form. The most common metal used in [*in situ* chemical reduction (ISCR)] is zero valent iron, or ‘ZVI.’ ... Other common reducing agents include polysulfides, sodium dithionite, ferrous iron, and bimetallic materials, which are made up of two different metals. The most common bimetallic material used in ISCR is iron coated with a thin layer of palladium or silver” (EPA 2012d).

In Situ Chemical Oxidation (ISCO) — See **Chemical Oxidation**.

In Situ Chemical Reduction (ISCR)— See **Chemical Reduction**.

Nanoremediation “methods entail the application of reactive nanomaterials for transformation and detoxification of pollutants. These nanomaterials have properties that enable both chemical reduction and catalysis to mitigate the pollutants of concern.... Because of their minute size and innovative surface coatings, nanoparticles may be able to pervade very small spaces in the subsurface and remain suspended in groundwater, allowing the particles to travel farther than larger, macro-sized particles and achieve wider distribution....

“Many different nanoscale materials have been explored for remediation.... Of these, nanoscale zero-valent iron (nZVI) is currently the most widely used.... nZVI particles range from 10 to 100 [nanometers (nm)] in diameter.... The high reactivity of nZVI particles is in part a direct result of their high specific surface area.... nZVI’s small particle size also allows more of the material to penetrate into soil pores, and it can be more easily injected into shallow and deep aquifers, a property that is particularly beneficial when contamination lies underneath a building” (Karn, Kuiken, & Otto 2009).

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.

Permeable Reactive Barriers (PRB) are “in situ, permeable treatment zone[s] designed to intercept and remediate a contaminant plume. The term ‘barrier’ is intended to convey the idea that contaminant migration is impeded; however, the PRB is designed to be more permeable than the surrounding aquifer media so that groundwater can easily flow through the structure without significantly altering groundwater hydrology. The treatment zone may be created directly using reactive materials such as zero-valent iron (ZVI), or indirectly using materials designed to stimulate secondary processes (e.g., adding carbon substrate and nutrients to enhance microbial activity). In this way,

contaminant treatment may occur through physical, chemical, or biological processes” (ITRC 2011).

Subaqueous Reactive Cap refers to an underwater cover in which “[specialized] materials [are] used to enhance the chemical isolation capacity... compared to sand caps. Examples include... reactive/adsorptive materials such as activated carbon, apatite, coke, organoclay, zero-valent iron and zeolite. Composite geotextile mats containing one or more of these materials (i.e., reactive core mats) are becoming available commercially” (EPA 2005).

Biological Treatment

Biological treatment involves adding or stimulating 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. **Phytoremediation**, the use of plants to remove, stabilize, or destroy contaminants, is included in the definition of biological treatment.

Bioaugmentation is “[the] addition of microbes to the subsurface where organisms able to degrade specific contaminants are deficient. Microbes may be ‘seeded’ from populations already present at a site and grown in aboveground reactors or from specially cultivated strains of bacteria having known capabilities to degrade specific contaminants” (EPA 2000a).

Bioremediation “uses microorganisms to degrade organic contaminants in soil, groundwater, sludge, and solids. The microorganisms break down contaminants by using them as an energy source or cometabolizing them with an energy source. More specifically, bioremediation involves the production of energy in a redox reaction within microbial cells. These reactions include respiration and other biological functions needed for cell maintenance and reproduction. A delivery system that provides one or more of the following is generally required: an energy source (electron donor), an electron acceptor, and nutrients” (EPA 2013a).

Constructed Treatment Wetlands are “manmade wetlands built to remove various types of pollutants that may be present in water that flows through them.

They are constructed to recreate, to the extent possible, the structure and function of natural wetlands... They possess a rich microbial community in the sediment to effect the biochemical transformation of pollutants, they are biologically productive, and... they are self-sustaining.... [Constructed wetlands] utilize many of the mechanisms of phytoremediation" (ITRC 2003). Note that the term "constructed wetlands" is used to refer only to wetlands constructed for the purposes of treatment, and not to wetlands constructed to compensate for wetlands destroyed by a remedy (such as placement of a cap in a marsh). Such "compensatory wetlands" are counted as "Wetlands Replacement."

Phytoremediation "uses [macroscopic] plants to extract, degrade, contain, or immobilize contaminants in soil, groundwater, and other contaminated media. The phytoremediation mechanisms used to treat contaminated [media]... are phytoextraction, rhizodegradation, phytodegradation, phytovolatilization, and phytostabilization" (EPA 2006). Phytoremediation may be applied in situ or ex situ.

Note that while phytoremediation may include the use of microorganisms in conjunction with plants, it is distinguished from bioremediation in that bioremediation does not use macroscopic plants or trees. For purposes of this report, the use of plants to control surface water drainage, to influence groundwater movement, or to adjust the water table are not considered phytoremediation. Such remedies are classified as engineering controls.

Thermal Treatment

Thermal treatment uses heat to separate contaminants from contaminated media by increasing their mobility. Thermal treatment includes volatility; destroying contaminants or contaminated media by burning, decomposing, or detonating the contaminants or the contaminated media; or immobilizing contaminants by melting and solidifying the contaminated media.

Electrical Resistance Heating (ERH) "uses arrays of electrodes installed around a central neutral electrode to create a concentrated flow of current toward the central point. Resistance to flow in the soils generates heat greater than 100°C, producing steam and readily mobile contaminants that are recovered via vacuum

extraction and processed at the surface. Electrical resistance heating is an extremely rapid form of remediation with case studies of effective treatment of soil and groundwater in less than 40 days. Three-phase heating and six-phase soil heating are varieties of this technology" (EPA 2013c). ERH is a type of In Situ Thermal Treatment.

Incineration "uses controlled flame combustion to volatilize and destroy organic contaminants and is used to treat a variety of media, including soils, sludges, liquids, and gases. An incinerator consists of a burner, which ignites the supplied fuel and combustibles in the waste feed in a combustion chamber. Efficiency of combustion depends on three main factors of the combustion chamber: temperature, residence time of the waste material in the combustion chamber, and turbulent mixing of the waste material. Thermal destruction of most organic compounds occurs at temperatures between 1,100°F and 1,200°F. The majority of hazardous waste incinerators are operated at temperatures that range from 1,200°F to 3,000°F in the burning zone" (EPA 1998b). On-site incineration typically uses a transportable unit; for off-site incineration, waste is transported to a central facility.

In Situ Thermal Treatment (also referred to as thermally-enhanced SVE) consists of "different methods and combinations of techniques to apply heat to polluted soil and/or groundwater in situ. The heat can destroy or volatilize organic chemicals. As the chemicals change into gases, their mobility increases, and the gases can be extracted via collection wells for capture and cleanup in an ex situ treatment unit. Thermal methods can be particularly useful for dense or light nonaqueous phase liquids (DNAPLs or LNAPLs)" (EPA 2013c). 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 Desorption — See Thermal Conduction Heating (TCH).

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, detonatable explosives and munitions are destroyed by detonation, which is generally initiated by the detonation of an energetic charge” (FRTR 2007).

Steam Enhanced Extraction (SEE) “heats the soil and groundwater and enhances the release of contaminants from the soil matrix by decreasing viscosity and accelerating volatilization. Steam injection may also destroy some contaminants. As steam is injected through a series of wells within and around a source area, the steam zone grows radially around each injection well. The steam front drives the contamination to a system of ground-water pumping wells in the saturated zone and soil vapor extraction wells in the vadose zone” (EPA 2013c). SEE is a type of **In Situ Thermal Treatment**.

Thermal Conduction Heating (TCH) “(also referred to as electrical conductive heating or in situ thermal desorption) supplies heat to the soil through steel wells or with a blanket that covers the ground surface. As the polluted area is heated, the contaminants are destroyed or evaporated. Steel wells are used when the polluted soil is deep. The blanket is used where the polluted soil is shallow. Typically, a carrier gas or vacuum system transports the volatilized water and organics to a treatment system” (EPA 2013c). TCH is a type of **In Situ Thermal Treatment**.

Thermal Desorption “removes organic contaminants from soil, sludge or sediment by heating them ... to evaporate the contaminants. Evaporation changes the contaminants into vapors (gases) and separates them from the solid material.... Thermal desorption involves excavating soil or other contaminated material for treatment in a thermal desorber. The desorber may be assembled at the site for onsite treatment, or the material may be loaded into trucks and transported to an offsite thermal desorption facility. To prepare the soil for treatment, large rocks or debris first must be removed or crushed....If the material is very wet, the water may need to be removed to improve treatment....

“The prepared soil is placed in the thermal desorber to be heated. Low-temperature thermal desorption is used to heat the solid material to 200-600°F [90 to 320°C] to treat VOCs. If SVOCs are present, then

high-temperature thermal desorption is used to heat the soil to 600-1000°F [320 to 540°C].

“Gas collection equipment captures the contaminated vapors. Vapors often require further treatment, such as removing dust particles. The remaining organic vapors are usually destroyed using a thermal oxidizer, which heats the vapors to temperatures high enough to convert them to carbon dioxide and water vapor...” (EPA 2012f). Thermal desorption is an ex situ treatment process. In situ thermal desorption processes are discussed above as **In Situ Thermal Treatment**.

Thermally-Enhanced SVE — See **In Situ Thermal Treatment**.

Vitrification is a thermal treatment process that converts contaminated soil to stable glass and crystalline solids. There are two methods for producing heat for melting the contaminated soil. The older method uses electrodes and electrical resistance to vitrify materials, while the emerging technique uses plasma arc technology.

“In the electrical resistance method, high voltage is applied to electrodes (typically four) placed in the soil. Starter frit (generally graphite) is placed on the soil surface and electrical current heats the soil from the top down to temperatures between 1,400 and 2,000°C [2,550 to 3,650°F].... If the silica content of the soil is sufficiently high, contaminated soil can be converted into glass. Heating vaporizes or pyrolyzes organic contaminants. Most inorganic contaminants are encased in the glass-like monolith that results when the soil cools after treatment” (EPA 2006). Vitrification may be conducted in situ or ex situ.

Pump and Treat

Pump and treat (P&T) “is a common method for cleaning up groundwater [and other aqueous media] contaminated with dissolved chemicals, including industrial solvents, metals, and fuel oil. [Water is extracted and conveyed] to an above-ground treatment system that removes [or destroys/converts] the contaminants. Pump and treat systems also are used to ‘contain’ the contaminant plume. Containment of the plume keeps [the plume] from spreading by pumping contaminated water toward the wells. This pumping helps keep contaminants from reaching drinking water

wells, wetlands, streams, and other natural resources” (EPA 2012e). For the purpose of this report, all P&T systems are considered treatment, even if designed to only contain, rather than restore, a contaminated plume. Also for the purposes of this report, surface water P&T-like remedies, such as collection and treatment of a local creek or stream that receives mine-influenced wastewater, were counted with groundwater P&T.

- **Activated Carbon Treatment** — “Activated carbon is a material used to filter harmful chemicals from contaminated water and air. It is composed of black granules of coal, wood, nutshells or other carbon-rich materials....Granular activated carbon or ‘GAC’ can treat a wide range of contaminant vapors including radon and contaminants dissolved in groundwater, such as fuel oil, solvents, polychlorinated biphenyls (PCBs), dioxins, and other industrial chemicals, as well as radon and other radioactive materials. It even removes low levels of some types of metals from groundwater.

“Activated carbon treatment generally consists of one or more columns or tanks filled with GAC. Contaminated water or vapors are usually pumped through a column from the top down, but upward flow is possible. As the contaminated water or air flows through the GAC, the contaminants sorb to the outer and inner surfaces of the granules....

“The GAC will need to be replaced when the available surfaces on the granules are taken up by contaminants and additional contaminants can no longer sorb to them [sufficiently to prevent breakthrough of contaminants at concentrations that exceed the designed discharge standard for the GAC system]. The ‘spent’ GAC may be replaced with fresh GAC or ‘regenerated’ to remove the sorbed contaminants” (EPA 2012a). GAC can be regenerated on site or off site using steam.

- **Air Stripping** “is the process of moving air through contaminated groundwater or surface water in an above-ground treatment system....

“Air stripping uses either an air stripper or aeration tank to force air through contaminated water and evaporate VOCs. The most common type of air

stripper is a packed-column air stripper, which is a tall tank filled with pieces of plastic, steel, or ceramic packing material.

“Contaminated water is pumped above ground and into the top of the tank and sprayed over the top of the packing material. The water trickles downward through the spaces between the packing material, forming a thin film of water that increases its exposure to air blown in at the bottom of the tank. A sieve-tray air stripper is similar in design but contains [numerous] trays with small holes. As water flows across the trays, a fan at the bottom blows air upwards through the holes, increasing air exposure. Aeration tanks are another type of design that remove VOCs by bubbling air into a tank of contaminated water” (EPA 2012b).

- **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. Ultrafiltration/microfiltration occurs when particles are separated by forcing fluid through a semipermeable membrane. Only the particles whose size are smaller than the openings of the membrane are allowed to flow through” (FRTR 2007). Other filtration methods include nanofiltration and reverse osmosis.
- **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. They also may be inorganic and natural polymeric materials. After the resin capacity has been exhausted, resins can be regenerated for re-use” (FRTR 2007).
- **Metals Precipitation** “from contaminated water involves the conversion of soluble heavy metal salts to insoluble salts that will precipitate. The precipitate can then be removed from the treated water by physical methods such as clarification (settling) and/or filtration. The process usually uses

pH adjustment, addition of a chemical precipitant, and flocculation. Typically, metals precipitate from the solution as hydroxides, sulfides, or carbonates. The solubilities of the specific metal contaminants and the required cleanup standards will dictate the process used. In some cases, process design will allow for the generation of sludges that can be sent to recyclers for metal recovery” (FRTR 2007).

Monitored Natural Attenuation (MNA) for Groundwater

Groundwater MNA is “the reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a timeframe that is reasonable compared to 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. When relying on natural attenuation processes for site remediation, EPA prefers those processes that degrade or destroy contaminants. Also, EPA generally expects that MNA will only be appropriate for sites that have a low potential for contaminant migration” (EPA 1999b).

Monitored Natural Recovery (MNR) for Sediment

Sediment MNR “[relies] on a wide range of naturally occurring processes to reduce risk [from contaminated sediments] to human and/or ecological receptors. These processes may include physical, biological, and chemical mechanisms that act together to reduce the risk posed by the contaminants....Natural processes that reduce toxicity through transformation or reduce bioavailability through increased sorption are usually preferable as a basis for remedy selection to mechanisms that reduce exposure through natural burial or mixing-in-place because the destructive/sorptive mechanisms generally have a higher degree of permanence. However, many contaminants that

remain in sediment are not easily transformed or destroyed. For this reason, risk reduction due to natural burial through sedimentation is more common and can be an acceptable sediment management option. Dispersion is the least preferable basis for remedy selection based on MNR. While dispersion may reduce risk in the source area, it generally increases exposure to contaminants and may result in unacceptable risks to downstream areas or other receiving water bodies....

“The key difference between MNA for ground water and MNR for sediment is in the type of processes most often being relied upon to reduce risk. Transformation of contaminants is usually the major attenuating process for contaminated ground water; however, these processes are frequently too slow for the persistent contaminants of concern (COCs) in sediment to provide for remediation in a reasonable timeframe. Therefore, isolation and mixing of contaminants through natural sedimentation is the process most frequently relied upon for contaminated sediment” (EPA 2005).

Enhanced Monitored Natural Recovery (EMNR) for Sediment

Natural recovery combined with an engineering approach is called **Enhanced Monitored Natural Recovery**. “In some areas, natural recovery may appear to be the most appropriate remedy, yet the rate of sedimentation or other natural processes is insufficient to reduce risks within an acceptable timeframe. Where this is the case, project managers may consider accelerating the recovery process by engineering means, for example by the addition of a thin layer of clean sediment. This approach is sometimes referred to as ‘thin-layer placement’ or ‘particle broadcasting.’ Thin-layer placement normally accelerates natural recovery by adding a layer of clean sediment over contaminated sediment. The acceleration can occur through several processes, including increased dilution through bioturbation of clean sediment mixed with underlying contaminants. Thin-layer placement is typically different than...isolation caps...because it is not designed to provide long-term isolation of contaminants from benthic organisms. While thickness of an isolation cap can range up to several feet, the thickness of the material used in thin layer

placement could be as little as a few inches....Clean sediment can be placed in a uniform thin layer over the contaminated area or it can be placed in berms or windrows, allowing natural sediment transport processes to distribute the clean sediment to the desired areas.

“Project managers might also consider the addition of flow control structures to enhance deposition in certain areas of a site” (EPA 2005).

Note that a layer of clean sediment placed as backfill following dredging or excavation is not considered EMNR.

On-Site Containment Technologies

For the purpose of this report, on-site containment includes several containment technologies, including caps, covers, and vertical engineered barriers (VEBs).

Caps and Cover Systems consist of surface barriers composed of one or more layers of impermeable material designed to contain contaminated source material. Cover systems can be used to prevent direct contact with the source material or minimize leachate creation by preventing surface water infiltration into the contained source material.

Evapotranspiration (ET) Covers are alternatives to conventional cap and cover systems. “ET cover systems are designed to rely on the ability of a soil layer to store the precipitation until it is naturally evaporated or is transpired by the vegetative cover. In this respect they differ from more conventional cover designs in that they rely on obtaining an appropriate water storage capacity in the soil rather than...engineered low hydraulic conductivity [barrier components]. ET cover system designs are based on using the hydrological processes (water balance components) at a site, which include the water storage capacity of the soil, precipitation, surface runoff, evapotranspiration, and infiltration. The greater the storage capacity and evapotranspirative properties are, the lower the potential for percolation through the cover system” (EPA 2011).

Subaqueous Containment Cell (Contained Aquatic Disposal [CAD]) “is a type of subaqueous capping in which the dredged sediment is placed into a natural or excavated depression elsewhere in the

water body. A related form of disposal, known as level bottom capping, places the dredged sediment on a level bottom elsewhere in the water body, where it is capped. [CAD] has been used for navigational dredging projects (e.g., Boston Harbor, Providence River), but has been rarely considered for environmental dredging projects. However, there may be instances when neither dredging with land disposal nor capping contaminated sediment in-situ is feasible, and it may be appropriate to evaluate CADs. The depression used in the case of a CAD should provide lateral containment of the contaminated material, and also should have the advantage of requiring less maintenance and being more resistant to erosion than level-bottom capping” (EPA 2005).

Subaqueous Non-Reactive Cap refers to “the placement of a subaqueous covering or cap of clean material over contaminated sediment that remains in place. Caps are generally constructed of granular material, such as clean sediment, sand, or gravel” (EPA 2005).

Vertical Engineered Barriers (VEB) are “[walls] built below ground to control the flow of groundwater. VEBs may be used to divert the direction of contaminated groundwater flow to keep it from reaching drinking water wells, wetlands, or streams. They also may be used to contain and isolate contaminated soil and groundwater” (EPA 2012h). Common types of VEBs include slurry walls and sheet pile walls.

Vapor Intrusion Mitigation

“[Vapor] intrusion is the general term given to migration of hazardous vapors from any subsurface contaminant source, such as contaminated soil or groundwater, through the vadose zone and into the indoor air, usually of overlying buildings through openings in the building foundation (e.g., through cracks in the slab, gaps around utility lines, or elevator shafts). Contaminants that may result in vapor intrusion include volatile organic compounds (VOCs) and other vapor-forming chemicals, such as some semivolatile organic compounds, elemental mercury, and radionuclides. VOCs typically pose the most common vapor intrusion concerns” (EPA 2012i).

Active Soil Depressurization (ASD) includes a “venting system consisting of a vent pipe (or a series of vent pipes) installed through the slab and connected to a vacuum pump to extract the vapors from beneath the slab” (EPA 2008a). “This approach is the most thoroughly studied and demonstrated approach for mitigating vapor intrusion. This approach consists of a group of methods that site teams can customize to treat different construction features of a building, including sub-slab depressurization (SSD), drain tile depressurization, wall depressurization, baseboard depressurization, and sub-membrane depressurization” (EPA 2012l). An ASD system may be used in conjunction with a vapor barrier.

Passive Soil Ventilation (PSV) “involves installing a venting layer beneath a building. Wind or the build-up of vapors causes vapors to move through the venting layer toward the sides of the building where it is vented outdoors. A venting layer can be installed prior to building construction as well as within existing buildings. It is usually used with a vapor barrier” (EPA 2012g).

Positive Indoor Pressurization “involves adjusting the building’s heating, ventilation, and air-conditioning [HVAC] system to increase the pressure indoors relative to the sub-slab area. This method is typically used for office buildings and other large structures” (EPA 2012g).

Indoor Ventilation — “Some natural ventilation occurs in all buildings. By opening windows, doors, and vents, ventilation increases. This increase in ventilation mixes outdoor air with the indoor air containing VOC vapors, and reduces indoor levels of the contaminants. However, ...if a building is experiencing a ‘stack effect’, which is normal, opening a window only in an upper story above the neutral pressure plane can increase the inflow of soil gas and thus be counterproductive. Moreover, once windows, doors, and vents are closed, the concentration of VOCs most often returns to previous values within about 12 hours” (EPA 2008a).

Sealing Cracks and Openings “involves filling in cracks in the floor slab and gaps around pipes and utility lines found in basement walls” (EPA 2012g).

Passive Barrier (Impermeable Membrane) Installation involves “placing sheets of ‘geomembrane’ or strong plastic beneath a building to prevent vapor entry. Vapor barriers are best installed during building construction, but can be installed in existing buildings that have crawl spaces” (EPA 2012g). Spray-on vapor barriers (rubberized asphalt emulsions or epoxy) may also be used (EPA 2008a).

Other or Unspecified Remedies

Alternative Water Supply (AWS): “In CERCLA, section 101 (34) states that [t]he term ‘alternative water supplies’ includes, but is not limited to, drinking water and household water supplies.’ Also, CERCLA section 118 states that in taking response actions, the President [EPA] shall ‘give a high priority to facilities where the release of hazardous substances or pollutants or contaminants has resulted in the closing of drinking water wells or has contaminated a principal drinking water supply.’...Providing an alternative supply of water to affected users generally is designed to prevent residents from being exposed to contaminated groundwater....Providing an alternative water supply may involve furnishing clean, drinkable water on a permanent or temporary basis. For example, providing a permanent supply of drinking water may include installing a private well, connecting to a municipal water system, drilling of a new community water supply well, or reinstating a previously contaminated water supply well once the groundwater has been cleaned up. Examples of providing a temporary supply of water may involve installing individual treatment units or delivering bottled water. When a [Superfund] response action that provides an alternative water supply involves connecting hundreds of homes to a municipal system (i.e., a residential connection to a water purveyor), it generally means that [residents are connected] to a water supply line that is located relatively close by” (EPA 2010b).

Fracturing for Site Cleanup — “Fracturing creates or enlarges openings in bedrock or dense soil, such as clay, to help soil and groundwater cleanup methods work better. The openings, called “fractures,” become pathways through which contaminants in soil and groundwater can be treated in situ (in place, underground) or removed for above-ground treatment.

Although fractures can occur naturally in soil and rock, they are not always wide or long enough to easily reach underground contamination using cleanup methods. Fracturing can enlarge the cracks and create new ones to improve the speed and effectiveness of the cleanup” (EPA 2012c).

Fracturing for site cleanup is different from fracturing to recover oil and gas. “Oil and gas hydraulic fracturing is used to stimulate the recovery of oil or natural gas from underground geologic formations. Oil and gas hydraulic fracturing works by pumping a mixture of fluids and other substances into the target formation to create and enlarge fractures. Such operations are much larger, use different equipment and chemical additives, occur at greater depths, and use higher volumes of fluid than fracturing for site cleanup. Fracturing to clean up a contaminated site rarely exceeds a depth of 100 feet, and the affected area around the fracturing well usually is less than 100 feet in any direction. However, wells to extract oil and gas often are drilled hundreds or thousands of feet downward and sometimes horizontally into the oil- or gas-bearing rock. Fractures may extend over 500 feet from these wells” (EPA 2012c).

Institutional Controls are defined by the EPA as “non-engineered instruments, such as administrative and legal controls, that help to minimize the potential for exposure to contamination and/or protect the integrity of a response action. ICs typically are designed to work by limiting land and/or resource use or by providing information that helps modify or guide human behavior at a site. ICs are a subset of Land Use Controls (LUCs). LUCs include engineering and physical barriers, such as fences and security guards, as well as ICs” (EPA 2012k). Some common examples of ICs include zoning restrictions, building or excavation permits, well drilling prohibitions, easements, and covenants.

Soil Amendments — “Many soils, particularly those found in urban, industrial, mining, and other disturbed areas, suffer from a range of physical, chemical, and

biological limitations. They include soil toxicity, too high or too low pH, lack of sufficient organic matter, reduced water-holding capacity, reduced microbial communities, and compaction. Appropriate soil amendments may be inorganic (e.g., liming materials), organic (e.g., composts) or mixtures (e.g., lime-stabilized biosolids). When specified and applied properly, these beneficial soil amendments limit many of the exposure pathways and reduce soil phytotoxicity. Soil amendments also can restore appropriate soil conditions for plant growth by balancing pH, adding organic matter, restoring soil microbial activity, increasing moisture retention, and reducing compaction.” (EPA 2007).

Wetlands Replacement — “Compensatory mitigation is required to replace the loss of wetland and aquatic resource functions in [a] watershed. Compensatory mitigation refers to the restoration, establishment, enhancement, or in certain circumstances preservation of wetlands, streams or other aquatic resources for the purpose of offsetting unavoidable adverse impacts [from a specific project (EPA 2008b)]. For the purposes of this report, mitigation performed at the site of the adverse impacts is excluded from the definition of wetlands replacement. For mitigation performed at the site of adverse impacts, see **Wetlands Restoration**. For wetlands constructed as a form of treatment, see **Constructed Treatment Wetlands**.

Wetlands Restoration is defined as “[r]e-establishment or rehabilitation of a wetland or other aquatic resource with a goal of returning natural or historic functions and characteristics to a former or degraded wetland” (EPA 2008b). For the purposes of this report, restoration conducted at a location other than the impacted site is excluded from the definition of wetlands restoration, and is instead considered **Wetlands Replacement**. For wetlands constructed as a form of treatment, see **Constructed Treatment Wetlands**.

Appendix B: Treatment Technologies Selected by Fiscal Year*

Year	82-85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11	Total	
Ex Situ Source Technologies																													
Bioremediation	1	1	0	3	5	2	1	8	3	4	6	6	0	5	6	1	0	1	1	6	1	0	3	0	2	1	0	67	
Chemical Treatment	1	0	1	0	0	0	1	0	0	0	1	1	0	0	1	0	1	0	0	1	3	0	2	0	3	0	1	18	
Incineration (on-site)	4	3	4	6	6	4	3	3	1	1	2	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	
Incineration (off-site)	3	2	3	9	9	15	13	6	8	5	9	5	4	3	2	5	1	2	0	1	1	3	1	1	0	0	0	111	
Mechanical Soil Aeration	0	0	0	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	4	
Neutralization	0	0	0	1	0	0	0	3	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	
Open Burn/Open Detonation	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	8	
Physical Separation	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	0	0	0	0	5	
Phytoremediation	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	9	3	2	1	0	12	13	5	9	18	11	12	99	
Soil Vapor Extraction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	
Soil Washing	0	0	0	0	0	1	2	0	2	1	0	2	0	1	1	0	0	0	0	0	0	1	0	1	0	0	0	9	
Solidification/Stabilization	3	4	6	7	8	14	20	23	13	13	3	7	4	13	8	5	2	6	1	10	6	10	4	9	7	4	4	214	
Solvent Extraction	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	
Thermal Desorption	2	1	4	4	3	6	8	2	4	4	5	1	5	4	2	4	3	6	1	1	1	1	0	0	0	0	0	4	
Vitrification	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72	
Total	14	11	19	31	33	45	47	47	33	29	29	24	18	28	23	24	10	21	4	19	26	27	16	19	32	17	20	666	
In Situ Source Technologies																													
Bioremediation	0	0	1	2	1	3	1	4	4	5	4	6	0	6	4	4	3	2	1	2	2	5	2	1	1	1	2	67	
Chemical Treatment	1	0	0	0	0	0	1	0	0	0	0	0	0	1	3	1	2	5	0	1	4	3	3	1	4	8	5	43	
Electrical Separation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	
Flushing	1	1	0	0	3	1	1	1	1	4	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	1	
Mechanical Soil Aeration	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	1	0	20	
Multi-Phase Extraction	0	1	0	0	0	0	3	4	1	4	0	2	5	3	3	4	2	6	1	3	0	1	2	3	1	1	1	51	
Neutralization	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	2	1	1	0	0	0	0	0	0	0	0	0	8	
Phytoremediation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	8	
Soil Vapor Extraction	4	2	1	8	21	18	34	19	15	8	11	22	16	12	16	8	7	6	11	6	7	7	8	10	7	7	11	301	
Solidification/Stabilization	0	1	3	2	4	2	1	3	5	0	2	4	2	3	3	1	0	3	2	0	2	6	1	5	5	4	2	66	
Thermal Treatment	0	0	0	0	0	1	1	0	0	1	0	2	1	1	1	1	0	0	0	1	7	3	2	2	3	4	0	31	
Vitrification	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	2	
Total	7	5	12	29	25	43	32	25	32	23	17	37	24	29	33	23	17	25	15	15	22	27	18	24	21	26	21	600	
In Situ Groundwater Technologies																													
Air Sparging	0	1	0	0	1	1	8	3	2	0	4	8	6	10	7	8	4	4	1	2	5	2	1	2	7	3	2	92	
Bioremediation	0	0	0	0	4	3	2	2	3	2	2	1	2	3	1	3	12	5	5	5	12	21	15	12	21	18	10	164	
Chemical Treatment	0	0	0	0	0	0	1	1	0	0	0	1	1	0	3	5	6	6	1	7	9	11	14	4	8	10	10	98	
Flushing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	
In-Well Air Stripping	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2	1	0	1	0	0	0	0	2	0	0	10	
Multi-Phase Extraction	0	1	0	0	0	0	1	2	0	2	1	1	5	2	1	2	0	3	0	3	1	0	0	0	1	0	1	27	
Permeable Reactive Barrier	0	0	0	0	0	0	0	1	0	1	1	1	2	2	2	4	3	1	1	4	2	3	1	1	1	3	4	38	
Phytoremediation	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	2	1	0	1	4	0	2	1	0	0	0	0	17	
Total	0	2	0	5	4	11	9	6	5	9	12	18	19	18	26	28	19	10	26	29	39	32	19	40	34	27	447		
Ex Situ Groundwater Technologies																													
Pump and Treat	11	16	7	26	36	26	48	59	56	70	47	48	64	51	43	41	19	23	11	13	22	19	24	20	18	14	13	845	

* Data for FY 1982-2004 are project-level data; data from FY 2005-11 are decision document-level data.

Appendix B: Treatment Technologies Selected by Fiscal Year

Index

A

Activated carbon treatment A-7-A-8
 Active soil depressurization iv, A-10
 Air sparging 13, A-1, B-1
 Alternative water supply iv, 13, 20, A-10
 Annual Status Report iv, 3, 15, 20, 22
 Arsenic 2, 16, 19
 ASD. *See* Active soil depressurization
 ASR. *See* Annual Status Report
 AWS. *See* Alternative water supply

B

Benzene, toluene, ethylbenzene, xylene iv, 17
 Bioaugmentation 13, 14, A-4
 Biological treatment A-1, A-4-A-5
 Bioremediation 1, 2, 5, 8, 9, 10, 12, 13, 14, 19, 20, 21, A-3, A-4, A-5, B-1
 BTEX. *See* Benzene, toluene, ethylbenzene, total xylenes

C

CAD. *See* Contained aquatic disposal
 Caps and Cover Systems A-9
 CERCLA. *See* Comprehensive Environmental Response, Compensation and Liability Act
 CERCLA Information System iv, 3, 16, 21
 CERCLIS. *See* Comprehensive Environmental Response, Compensation and Liability Information System
 CFR. *See* Code of Federal Regulations
 Chemical oxidation A-3-A-4
 Chemical reduction A-3, A-4
 Chemical treatment 9, 10, 13, 14, A-1, A-2, A-3-A-4, B-1
 CLU-In. *See* Hazardous Waste Cleanup Information
 COC. *See* Contaminant of concern
 Code of Federal Regulations iv, 5, 7, 21, A-1
 Comprehensive Environmental Response, Compensation and Liability Act iv, 5, A-1, A-10
 Constructed treatment wetlands 9, 11, 13, A-4, A-5, A-11
 Contained aquatic disposal iv, A-9
 Containment 1, 2, 4, 5, 6, 7, 8, 11, 12, 13, 19, 20, A-1, A-6, A-9-A-10

D

Dense non-aqueous phase liquid iv, 4, A-2
 Depressurization
 sub-membrane 2, 15, 16, A-10
 sub-slab iv, 2, 15, 16, 19, A-10
 Disposal iv, 1, 6, 7, 8, 11, A-1, A-2, A-9

DNAPL. *See* Dense non-aqueous phase liquid
 Dredging 11
 Dual-phase extraction A-2

E

Electrical resistance heating iv, A-5
 Electrokinetic separation A-2, B-1
 EMNR. *See* Enhanced monitored natural recovery
 Engineering controls 13, A-5
 Enhanced monitored natural recovery iv, 5, 6, 7, 11, A-8, A-9
 EOU. *See* Excess, obsolete, or unserviceable
 EPA. *See* U.S. Environmental Protection Agency
 ERH. *See* Electrical Resistance Heating
 ESD. *See* Explanation of Significant Differences
 ET. *See* Evapotranspiration
 Evapotranspiration iv, A-9
 Excess, obsolete, or unserviceable iv, A-5
 Explanation of Significant Differences iv, 1, 3, 4, A-1
 Ex situ treatment 1, 5, 8, 9, 11, 19, A-6

F

Federal Remediation Technologies Roundtable iv, 21, A-1, A-6, A-7, A-8
 Filtration A-7
 Flushing 9, A-2, B-1
 Fracturing 9, 13, 20, A-10-A-11
 FRTR. *See* Federal Remediation Technologies Roundtable

G

GAC. *See* Granular activated carbon
 Granular activated carbon iv, A-7
 Groundwater
 media 1, 2, 3, 4, 5, 6, 12-15, 18, 19, 22, A-1, A-2, A-3, A-4, A-5, A-6, A-7, A-8, A-9
 remedies 1, 3, 4, 5, 12-14, 19, A-1

H

Hazardous Waste Cleanup Information iii, iv, 22
 Hexavalent chromium 2, 16, 19
 High-resolution site characterization iv, 2, 19, 21
 HRSC. *See* High-resolution site characterization
 HVAC. *See* Heating, ventilation and air conditioning

I

IC. *See* Institutional control
 Incineration A-5-A-6, B-1
 Indoor ventilation 2, 15, A-10
 In situ 1, 14, A-5
 chemical oxidation iv, 8, 13, 14, A-4
 chemical reduction iv, 8, 14, 20, A-3, A-4
 treatment 1, 10, 11, 12, 14, 19, 22, A-1

- Institutional control iv, 1, 4, 5, 6, 7, 8, 11, 12, 13, 16, 19, 21, A-11
 Interstate Technology & Regulatory Council iv, 21, A-3, A-4, A-5
 In-well air stripping 13, A-2
 Ion exchange A-7
 ISCO. *See* In situ chemical oxidation
 ISCR. *See* In situ chemical reduction
 ITRC. *See* Interstate Technology & Regulatory Council
-
- L**
- Lead 2, 16, 17, 19
 Light non-aqueous phase liquid iv, 4, A-2
 LNAPL. *See* Light non-aqueous phase liquid
-
- M**
- Mechanical soil aeration A-2, B-1
 Mercury 2, 15, 16, 17, 19, A-9
 Metals precipitation A-7
 MNA. *See* Monitored natural attenuation
 MNR. *See* Monitored natural recovery
- Monitored natural attenuation iv, 1, 5, 6, 12, 13, 14, 19, A-1, A-8-A-9
 Monitored natural recovery iv, 1, 5, 6, 7, 11, A-1, A-8
 MPE. *See* Multi-phase extraction
 Multi-phase extraction iv, 1, 8, 9, 10, 13, 19, A-2, B-1
-
- N**
- NA/NFA. *See* No action/no further action
 Nanoremediation A-4
 Nanoscale zero-valent iron iv, A-4
 NAPL. *See* Non-aqueous phase liquid
 National Oil and Hazardous Substances Pollution Contingency Plan iv, 5, 7
 National Priorities List iv, 3, 5, 16
 NCP. *See* National Oil and Hazardous Substances Pollution Contingency Plan
 Neutralization 14, A-4, B-1
 No action/no further action iv, 5, 6
 Non-aqueous phase liquid iv, 4, 9, 18, A-1, A-2
 NPL. *See* National Priorities List
 nZVI. *See* nanoscale zero-valent iron
-
- O**
- OB/OD. *See* Open burn/open detonation
 Office of Solid Waste and Emergency Response iv, 20, 21
 Open burn/open detonation iv, A-5, B-1
 Operable unit iv, 3, 17
 OSWER. *See* Office of Solid Waste and Emergency Response
-
- OU. *See* Operable unit
 Ozone sparging 14, A-2
-
- P**
- PAH. *See* Polycyclic aromatic hydrocarbon
 Passive barrier 16
 Passive soil ventilation iv, 16, A-10
 PCB. *See* Polychlorinated biphenyl
 Permeable reactive barrier iv, 13, 21, A-4
 Physical separation 8, 9, A-2, B-1
 Physical treatment A-1-A-3
 Phytoremediation 9, 13, A-4, A-5, B-1
 Polychlorinated biphenyl iv, 2, 16, 17, 19, A-7
 Polycyclic aromatic hydrocarbon iv, 17, 18
 Positive indoor pressurization 16, A-10
 PRB. *See* Permeable reactive barrier
 PSV. *See* Passive soil ventilation
 P&T. *See* Pump and treat
 Pump and treat iv, 1, 9, 12, 13, 14, 19, 20, A-1, A-6, A-7
-
- R**
- RCRA. *See* Resource Conservation and Recovery Act
 Record of Decision iv, 1, 3, 4, A-1
 Recycling 9
 Remedial Investigation/Feasibility Study iv, 2, 16, 17, 18, 19, 22
 Remedy selection trends 5, 6
 Resource Conservation and Recovery Act iv, 20
 RI/FS. *See* Remedial Investigation/Feasibility Study
 ROD. *See* Record of Decision
-
- S**
- Sealing cracks and openings 2, 15, 16, A-10
 Sediment 1, 4, 5, 7, 11, 18, 19, 22, A-1, A-5, A-6, A-8, A-9
 media 18, A-8, A-9
 remedies 1, 7
 SEE. *See* Steam enhanced extraction
 Semivolatile organic compound iv, 15, 16, 17, 18, 19, A-6
 Soil
 media iv, 1, 2, 4, 8, 9, 10, 15, 18, 19, A-1, A-2, A-3, A-4, A-5, A-6, A-8, A-9
 Soil vapor extraction iv, 8, 9, 19, A-1, A-2, A-6, B-1
 Soil washing A-2, B-1
 Solidification/stabilization iv, 1, 8, 9, 10, 11, 19, A-2, A-3, B-1
 Solvent extraction A-3, B-1
 Source 1, 3, 4, 5, 7-12, 19, 22, A-1, A-2, A-3, A-4, A-6, A-8, A-9
 media 1, 4, A-1, A-2
 remedies 7-10, 19

SRR. *See* Superfund Remedy Report
S/S. *See* Solidification/stabilization
SSD. *See* Sub-slab depressurization
Steam enhanced extraction iv, A-5, A-6
Stream realignment 11
Subaqueous containment cell 11, A-9
Subaqueous non-reactive cap 11, A-9
Subaqueous reactive cap 9, 11, A-4
Superfund Remedy Report iv, 1, 3, 4, 5, 15, 20, 22
Surface water 13
SVE. *See* Soil vapor extraction
SVOC. *See* Semivolatile organic compound

T

TCE. *See* Trichloroethene
TCH. *See* Thermal conduction heating
Thermal desorption 9, 20, A-5-A-6, B-1
Thermal treatment 9, 10, 11, A-1, A-5-A-7, B-1
Treatment technology 4, 5, A-1
Trichloroethene iv, 2, 16, 17, 19

U

U.S. Environmental Protection Agency iv, 1, 3, 5, 7, 15, 16, 19, 20, 21, A-1-A-11

V

Vapor intrusion 1, 2, 3, 5, 6, 15-16, 19, 22, A-9-A-10
VEB. *See* Vertical engineered barrier
Vertical engineered barrier iv, 12, 13, A-1, A-9
Vitrification A-6, B-1
VOC. *See* Volatile organic compound
Volatile organic compound iv, 15, 16, 17, 18, 19, A-1, A-2, A-6, A-7, A-9

W

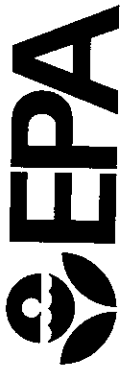
Wetlands replacement 11, A-5, A-11
Wetlands restoration 11, A-11

Z

Zero valent iron iv, A-3, A-4
ZVI iv. *See* Zero valent iron







United States
Environmental Protection
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Washington, D.C. 20460

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