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Abstracts of Remediation Case Studies

Volume 10

Federal Remediation Technologies Roundtable

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Prepared by the

Member Agencies of the Federal Remediation Technologies Roundtable

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Federal Remediation Technologies Roundtable

Environmental Protection Agency
Department of Defense
- U.S. Air Force
- U.S. Army
- U.S. Navy

Department of Energy
Department of Interior
National Aeronautics and Space Administration

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NOTICE

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FOREWORD

This report is a collection of abstracts summarizing 9 new case studies of site remediation applications prepared primarily by federal agencies. The case studies, collected under the auspices of the Federal Remediation Technologies Roundtable (Roundtable), were undertaken to document the results and lessons learned from technology applications. They will help establish benchmark data on cost and performance which should lead to greater confidence in the selection and use of innovative cleanup technologies.

The Roundtable was created to exchange information on site remediation technologies, and to consider cooperative efforts that could lead to a greater application of innovative technologies. Roundtable member agencies, including the U.S. Environmental Protection Agency (EPA), U.S. Department of Defense, and U.S. Department of Energy, expect to complete many site remediation projects in the near future. These agencies recognize the importance of documenting the results of these efforts, and the benefits to be realized from greater coordination.

The abstracts are organized by technology, and cover a variety of *in situ* treatment technologies and some containment remedies. The abstracts and corresponding case study reports are available through the Roundtable Web site, which contains a total of 383 remediation technology case studies (the 9 new case studies and 374 previously-published case studies). Appendix A to this report identifies the specific sites, technologies, contaminants, media, and year published for the 383 case studies. Appendix A is only available in the online version of this report and can be downloaded from the Roundtable Web site at: *http://www.frtr.gov.*

Abstracts, Volume 10, covers a wide variety of technologies, including full-scale remediations and large-scale field demonstrations of soil, groundwater, and sediment treatment technologies. Previously published versions of the Abstracts Volume are listed below. Additional abstract volumes will be compiled as agencies prepare additional case studies.

Abstracts

Volume 1:	EPA-542-R-95-001; March 1995; PB95-201711
Volume 2:	EPA-542-R-97-010; July 1997; PB97-177570
Volume 3:	EPA-542-R-98-010; September 1998
Volume 4:	EPA-542-R-00-006; June 2000
Volume 5:	EPA-542-R-01-008; May 2001
Volume 6:	EPA-542-R-02-006; June 2002
Volume 7:	EPA 542-R-03-011; July 2003
Volume 8:	EPA 542-R-04-012; June 2004
Volume 9:	EPA-542-R-05-021; July 2005
Volume 10:	EPA-542-R-06-002; August 2006

Accessing Case Studies

All of the Roundtable case studies and case study abstracts are available on the Internet through the Roundtable Web site at: http://www.frtr.gov/costperf.htm. This report is also available for downloading at this address. The Roundtable Web site also provides links to individual agency Web sites, and includes a search function. The search function allows users to complete a key word (pick list) search of all the case studies on the Web site, and includes pick lists for media treated, contaminant types, primary and supplemental technology types, site name, and site location. The search function provides users with basic information about the case studies, and allows users to view or download abstracts and case studies that meet their requirements. Users are encouraged to download abstracts and case studies from the Roundtable Web site.

In addition to being accessible through the Roundtable Web site, a limited number of copies of this document are available free of charge by mail from the National Service Center for Environmental Publications (NSCEP) (allow 4-6 weeks for delivery), at the following address:

U.S. EPA/NSCEP
P.O. Box 42419
Cincinnati, OH 45242
Phone: (513) 489-8190 or
(800) 490-9198
Fax: (513) 489-8695

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INTRODUCTION

Increasing the cost effectiveness of site remediation is a national priority. The selection and use of more cost-effective remedies requires better access to data on the performance and cost of technologies used in the field. To make data more widely available, member agencies of the Federal Remediation Technologies Roundtable (Roundtable) are working jointly to publish case studies of full-scale and demonstration-scale remediation projects. At this time, the Roundtable is publishing 9 new remediation technology case studies to the Roundtable Web site (http://www.frtr.gov/costperf.htm). A total of 383 case studies have now been completed, primarily focused on contaminated soil and groundwater cleanup.

The case studies were developed by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Defense (DoD), and the U.S. Department of Energy (DOE). They were prepared based on recommended terminology and procedures agreed to by the agencies. These procedures are summarized in the *Guide to Documenting and Managing Cost and Performance Information for Remediation Projects* (EPA 542-B-98-007; October 1998).

By including a recommended reporting format, the Roundtable is working to standardize the reporting of costs and performance to make data comparable across projects. In addition, the Roundtable is working to capture information in case study reports that identifies and describes the primary factors that affect cost and performance of a given technology. Factors that may affect project costs include economies of scale, contaminant concentration levels in impacted media, required cleanup levels, completion schedules, and matrix characteristics and operating conditions for the technology.

The case studies and abstracts present available cost and performance information for full-scale remediation efforts and several large-scale demonstration projects. They are meant to serve as primary reference sources, and contain information on site background, contaminants and media treated, technology, cost and performance, and points of contact for the technology application. The case studies and abstracts contain varying levels of detail based on the availability of data and information for each application.

The case study abstracts in this volume describe a wide variety of *in situ* treatment technologies for both soil and groundwater. Contaminants treated included polychlorinated biphenyls; explosives/propellants; petroleum hydrocarbons and benzene, toluene, ethylbenzene, and xylenes; polycyclic aromatic hydrocarbons; pesticides and herbicides; metals; halogenated volatiles and semivolatiles; and nonhalogenated volatiles and semivolatiles.

Table 1 provides summary information about the technology used, contaminants and media treated, and project duration for the 9 technology applications in this volume. This table also provides highlights about each application. Table 2 summarizes cost data, including information about quantity of media treated and quantity of contaminant removed. In addition, Table 2 shows a calculated unit cost for some projects, and identifies key factors potentially affecting technology cost. The column showing the calculated unit costs for treatment provides a dollar value per quantity of media treated and contaminant removed, as appropriate. The cost data presented in the table were taken directly from the case studies and have not been adjusted for inflation to a common year basis. The costs should be assumed to represent dollar values for the time period that the project was in progress (shown on Table 1 as project duration).

Appendix A to this report provides a summary of key information about all 383 remediation case studies published to date by the Roundtable, including information about site name and location, technology, media, contaminants, and year the project began. The appendix also identifies the year that the case study was first published by the Roundtable. All projects shown in Appendix A are full-scale unless otherwise noted. Appendix A is only available in the online version of this report and can be downloaded from the Roundtable Web site.

Table 1. Summary of Remediation Case Studies

Site Name, State (Technology)	Principal Contaminant Groups*											Media (Quantity Treated)	Project Duration	Summary
	PCBs	Pesticides/Herbicides	Explosives/Propellants	Volatiles - Halogenated	Semivolatiles - Nonhalogenated	BTEX	Petroleum Hydrocarbons	PAHs	Volatiles - Nonhalogenated	Semivolatile - Halogenated	Metals			
***In Situ* Soil Treatment**														
Argonne National Laboratory-East, 317/319 Area, Illinois (Phytoremediation)				●		●			●	●		Soil, Groundwater (up to 30 ft bgs)	SITE Evaluation period from July 1999 to September 2001. Treatment period up to 20 years after project started.	Use of phytoremediation to treat soil and groundwater contaminated with BTEX, halogenated and nonhalogenated volatiles, and halogenated semivolatiles.
Jones Island Confined Disposal Facility, Wisconsin (Phytoremediation)	●						●	●				Soil (1,613 cy)	June 2001 to September 2002	Use of phytoremediation to treat dredged soil/sediment contaminated with PCBs, PAHs, and petroleum hydrocarbons.
Cleaners #1 Site, Washington (In Situ Bioremediation, Thermal Desorption)				●								Soil (24,000 cy), Groundwater (6 to 18 ft bgs over a 2,000 ft^2 area)	December 15, 1998 to July 2000	Use of in situ bioremediation and thermal desorption to treat soil and groundwater contaminated with halogenated volatiles.
Rocky Mountain Arsenal, Colorado (In Situ Thermal Desorption)		●								●		Soil (3,200 cy)	October 2001 to March 2002	Use of in situ thermal treatment to treat soil contaminated with pesticides/herbicides, and halogenated semivolatiles.
Onalaska Municipal Landfill Superfund Site, Wisconsin (Pump & Treat, Monitored Natural Attenuation, In Situ Bioventing)				●	●	●	●				●	Soil (NP), Groundwater (2.17 billion gallons)	May 1994 to April 2003	Use of in situ bioventing, pump and treat, and monitored natural attenuation to treat soil and groundwater contaminated with halogenated volatiles, nonhalogenated semivolatiles, BTEX, petroleum hydrocarbons, and metals.

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminant Groups*: PCBs	Pesticides/Herbicides	Explosives/Propellants	Volatiles - Halogenated	Semivolatiles - Nonhalogenated	BTEX	Petroleum Hydrocarbons	PAHs	Volatiles - Nonhalogenated	Semivolatile - Halogenated	Metals	Media (Quantity Treated)	Project Duration	Summary
Sulfur Bank Mercury Mine Superfund Site, California (In Situ Stabilization)											●	Soil (NP)	November 15, 2000 to April 29, 2001	Use of in situ stabilization to treat soil contaminated with metals.
***In Situ* Groundwater Treatment**														
Confidential Site, Maryland (Permeable Reactive Barrier)			●	●								Groundwater (approximately 405,000 gallons)	October 2003 to April 2005.	Use of a permeable reactive barrier to treat groundwater contaminated with halogenated volatiles..
Multiple (3) Naval Facilities (In Situ Chemical Reduction-Nanoscale Zero-Valent Iron)				●								Groundwater (Hunters Point: 1,818 ft^2 [1st treatment]; 8,700 ft^2 [2nd treatment] Jacksonville: NP Lakehurst: 8,470 ft^2 (North plume); 4,350 ft^2 [South plume])	Not Provided	Use of in situ chemical reduction to treat groundwater contaminated with halogenated volatiles at three Naval facilities.
Loring Air Force Base, Maine (In Situ Thermal Treatment)				●								Groundwater (NP)	September 1, 2002 to Spring of 2004	Use of in situ thermal treatment to treat groundwater contaminated with halogenated volatiles.

* Contaminant group focused on for the technology covered in the case study.

Key:
- NP = Not Provided
- bgs = below ground surface
- cy = cubic yards
- SITE = U.S. EPA Superfund Innovative Technology Evaluation Program
- PCBs = Polychlorinated Biphenyls
- PAHs = Polycyclic Aromatic Hydrocarbons
- BTEX = Benzene, Toluene, Ethylbenzene, and Xylene

Table 2. Remediation Case Studies: Summary of Cost Data

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment[1,2]	Key Factors Potentially Affecting Technology Costs
***In Situ* Soil Treatment**					
Argonne National Laboratory-East, 317/319 Area, Illinois (Phytoremediation)	T - $2,382,632 P - $4,592,632 (for 20 years)	Not Provided	Not Provided	Not Provided	The total cost would be affected by the climate, which has a direct impact on the growth of trees, thereby impacting the number of years required to achieve cleanup goals.
Jones Island Confined Disposal Facility, Wisconsin (Phytoremediation)	Corn: D - $47,227 Willow: D - $44,280	1,613 cy	Not Provided	Not Provided	Cost differences may result from changing the methods of grading, tilling and irrigating the plots.
Cleaners #1 Site, Washington (In Situ Bioremediation, Thermal Desorption)	D - $13,680 (for first two applications of HRC®)	Soil: 24,000 cy Groundwater: 6 to 18 ft bgs over a 2,000 ft^2 area	Not Provided	Not Provided	Not Provided
Rocky Mountain Arsenal, Colorado (In Situ Thermal Desorption)	T - $1,900,000	Soil: 3,200 cy	Not Provided	Not Provided	The nature of the waste at the site affected the cost because the wastes contained contaminants with very high boiling points, requiring high operating temperatures and treatment times.
Onalaska Municipal Landfill Superfund Site, Wisconsin (Pump & Treat, Monitored Natural Attenuation, In Situ Bioventing)	With P&T: AO - $200,000 Without P&T: AO - $60,000	Soil: NP Groundwater: 2.17 billion gallons	Area A: 7,780 kg of hydrocarbons Area B: 11,000 kg of hydrocarbons Area C: 1,247 kg of hydrocarbons	Not Provided	Not Provided
Sulfur Bank Mercury Mine Superfund Site, California (In Situ Stabilization)	ENTHRALL: T - $59,807,000 SME: T - $35,690,000 Generic: NP	Not Provided	Not Provided	ENTHRALL: $27.82 per ton SME: $16.60 per ton Generic: NP	The SBMM site has a larger volume of material than most waste sites, resulting in high cost estimates. Cost estimates were also developed independently by the technology vendors with differences in assumptions and cost factors.

Table 2. Remediation Case Studies: Summary of Cost Data (continued)

Site Name, State (Technology)	Technology Cost ($)[1,2]	Quantity of Media Treated	Quantity of Contaminant Removed	Calculated Unit Cost for Treatment[1,2]	Key Factors Potentially Affecting Technology Costs
***In Situ* Groundwater Treatment**					
Confidential Site, Maryland (Permeable Reactive Barrier)	P - $161,400	Approximately 405,000 gallons	Not Provided	$0.02 per gallon treated	Costs associated with the injection process, includes the number and spacing of injection wells, volume of substrate and chase water injected, the time required for injection completion, and the number of injection events.
Multiple (3) Naval Facilities -(In Situ Chemical Reduction-Nanoscale Zero-Valent Iron)	Hunters Point: T - $289,300 (1st treatment); $1,390,000 (2nd treatment) Jacksonville: T - $259,000 Lakehurst: T - $255,500	Hunters Point: 1,818 ft^2 (1st treatment); 8,700 ft^2 (2nd treatment) Jacksonville: NP Lakehurst: 8,470 ft^2 (North plume); 4,350 ft^2 (South plume)	Not Provided	Not Provided	Cost comparisons of the three sites showed that the particle size of the injected iron reagent along with the method of injection affected the demonstration costs.
Loring Air Force Base, Maine (In Situ Thermal Treatment)	Not Provided	Not Provided	Not Provided	Not Provided	Not Provided

1 Actual full-scale costs are reported unless otherwise noted.
2 Cost abbreviation: T = Total costs, AO = Annual operation and maintenance (O&M) costs, C = Capital costs, DI = Design and implementation costs, D = Demonstration-scale costs, P = Projected full-scale costs.

Key:
HRC® = Hydrogen Release Compound
cy = cubic yards
kg = kilograms
NP = Not Provided
bgs = below ground surface
SBMM = Sulfur Bank Mercury Mine

IN SITU SOIL TREATMENT ABSTRACTS

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Deployment of Phytotechnology in the 317/319 Area at Argonne National Laboratory-East, Argonne, Illinois

Site Name: Argonne National Laboratory-East, 317/319 Area	Location: Argonne, Illinois
Period of Operation: Project started in June 1999. SITE Evaluation period from July 1999 to September 2001. Treatment period up to 20 years after project started.	**Cleanup Authority:** RCRA Corrective Action
Purpose/Significance of Application: The objectives of the project are to: • Hydraulically contain the VOCs and tritium plumes south of the 317 Area French Drain and 319 Area Landfill. • Continue the remediation of residual VOCs within the 317 Area French Drain. • Minimize water infiltration into the 317 Area French Drain soils and stabilize the surface to prevent erosion, runoff, and downstream sedimentation. • Protect downgradient surface and groundwater by hydraulically containing the contaminated plume.	**Cleanup Type:** Full Scale
Contaminants: 317 Area: • Soil: – Volatile-halogenated compounds: carbon tetrachloride (maximum of 54,000 µg/kg); chloroform (maximum of 21,000 µg/kg); PCE (maximum of 190,000 µg/kg); TCE (maximum of 47,000 µg/kg). – Volatile-nonhalogenated compounds: benzene (maximum of 3,200 µg/kg); 4-methyl-2-pentanone (maximum of 78,000 µg/kg). • French Drain Groundwater: – Volatile-halogenated compounds: chloroform (maximum of 380 µg/L); PCE (maximum of 50,000 µg/L); TCE (maximum of 8,600 µg/L). • Fence-line Groundwater: – Volatile-halogenated compounds: carbon tetrachloride (maximum of 8 µg/L); chloroform (maximum of 4 µg/L); methylene chloride (maximum of 14 µg/L); TCE (maximum of 6 µg/L); 1,2-DCE (maximum of 6 µg/L). 319 Area: • Landfill Groundwater: – Tritium (maximum of 233,000 pCi/L) – Volatile-halogenated compounds: cis-1,2-DCE (maximum of 240 µg/L); TCE (maximum of 24 µg/L); vinyl chloride (maximum of 5 µg/L). • Fence-Line Groundwater: – Volatile-halogenated compounds: TCE (maximum of 5 µg/L).	**Waste Source:** Solid and liquid waste disposed at the site from various laboratory activities.
Contacts: **SITE Demonstration Contact:** Steven Rock National Risk Management Research Laboratory U.S. Environmental Protection Agency 5995 Center Hill Avenue Cincinnati, OH 45224 Phone: (513) 569-7149 Fax: (513) 569-7879 E-mail: rock.steven@epa.gov	**Technology:** Phytoremediation: • The patented TreeMediation® TreeWell® Treatment System from Applied Natural Sciences was deployed at the site. System is designed to reach groundwater 30 feet below ground surface (bgs). • In the 317/319 Area, approximately 800 trees were planted (approximately 600 hybrid poplars and 200 hybrid willows). • In addition, the 317 Area French Drain area was seeded with a mix of legumes and grasses to minimize water infiltration and to stabilize the soil. • Operational period for the phytoremediation treatment will last for 20 years. Afterwards the trees will be harvested, chipped, and used as landscaping material.

Deployment of Phytotechnology in the 317/319 Area at Argonne National Laboratory-East, Argonne, Illinois (continued)

Contacts (continued):

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SITE Program Contact:
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Type/Quantity of Media Treated:
Soil and groundwater up to 30 ft bgs.

Regulatory Requirements/Cleanup Goals:
Specific contaminant remediation goals are:
317 Area VOC concentrations:

- French Drain Soil (µg/kg): benzene (80); carbon tetrachloride (1,024); chloroform (1,670); PCE (152); TCE (80); 4-methyl-2-pentanone (28,200).
- French Drain Groundwater (µg/L): chloroform (211); PCE (316); TCE (127).
- Fence-line Groundwater (µg/L): carbon tetrachloride (5); chloroform (0.02); methylene chloride (5); TCE (5); 1,2-DCE (5).

319 Area Tritium/VOC concentrations:

- Landfill Groundwater (µg/L or pCi/L): cis-1,2-DCE (70); TCE (5); vinyl chloride (2); tritium (20,000).
- Fence-Line Groundwater (µg/L): TCE (5).

Results:
The phytoremediation technology deployed at the site is ongoing and was evaluated after three growing seasons. The effectiveness of the various plantings was monitored directly through groundwater and soil measurement and samples, as well as indirectly via plant tissue analysis, microbial surveys, geochemical analysis, soil moisture probes, and sap flow monitoring. Groundwater chemical data indicated decreasing concentrations of target VOCs and increasing concentrations of degradation byproducts. Tissue analysis of willows growing at the source area indicated that TCE and PCE were being taken up by the trees and that a portion of the transported contaminants were being degraded in the leaves. TCE and PCE and their degradation byproducts were seen at nearly all groundwater wells throughout the study area, implying that microbial attenuation of some form was occurring.

Costs:
The following conclusions have been drawn based upon the information provided by the Argonne National Laboratory-East:

- The total project cost, which included designing, installing and maintaining the system for the first four years (1999-2002), was $2,382,632.
- The total estimated treatment cost over 20 years of the project is $4,592,632.

Deployment of Phytotechnology in the 317/319 Area at Argonne National Laboratory-East, Argonne, Illinois (continued)

Description:
The 317/319 Area at the Argonne National Laboratory – East (ANL-E) is located on the far southern end of the ANL-E site, immediately adjacent to the DuPage County Waterfall Glen Forest Preserve, an area used for public recreation and as a nature reserve. It covers a surface area of approximately five acres and encompasses several sites used in the past to dispose of solid and liquid waste from various laboratory activities. Releases from the disposal of waste have contaminated the soil and groundwater with VOCs and low levels of tritium. Several interim actions have been implemented at the site in the past to reduce the VOC and tritium releases from this area; however, additional remedial actions are ongoing to further restore the site.

Starting in June 1999, ANL-E planted over 800 hybrid poplars and hybrid willows and a supplemental ground cover of herbaceous plants in the 317/319 Area. Earlier in 1999, EPA expressed an interest in participating with DOE in this study and subsequently included it as a demonstration project under the National Risk Management Research Laboratory (NRMRL) Superfund Innovative Technology Evaluation (SITE) program. ANL-E anticipates operating the phytoremediation system for 20 years. The phytoremediation technologies implemented at ANL-E are intended to eventually replace the existing pump-and-treat system. The project has so far has demonstrated success in decreasing target VOC concentrations and increasing concentrations of degradation byproducts and absorbing TCE and PCE into the plant tissue.

Dredged Material Reclamation at the Jones Island Confined Disposal Facility, Milwaukee, Wisconsin

Site Name: Jones Island Confined Disposal Facility	**Location:** Milwaukee, Wisconsin
Period of Operation: SITE testing period: June 2001 to September 2002.	**Cleanup Authority:** USACE and the Milwaukee Port Authority.
Purpose/Significance of Application: This demonstration was conducted to evaluate the feasibility of using phytoremediation to remediate dredged material at the Jones Island Confined Disposal Facility. The demonstration consisted of comparing and analyzing the results of three different plant species.	**Cleanup Type:** Field Demonstration
Contaminants: Analyte concentrations in individual cells ranged from: • Polycyclic Aromatic Hydrocarbons (PAHs): 77 to161 mg/kg • Polychlorinated Biphenyls (PCBs): 2.0 to 3.6 mg/kg • Reduce diesel range organic (DRO): 24 to 440 mg/kg	**Waste Source:** The dredged material was contaminated from airborne and regulated industrial discharges, spills, and urban run-off.
Contacts: **SITE Demonstration Contact:** Steven Rock EPA SITE Project Manager National Risk Management Research Laboratory U.S. Environmental Protection Agency 5995 Center Hill Avenue Cincinnati, OH 45224 Phone: (513) 569-7149 Fax: (513) 569-7879 E-mail: rock.steven@epa.gov **USACE Project Managers:** Richard Price U.S. Army Engineer Research and Development Center 3909 Halls Ferry Road Vicksburg, MS 39180-6199 Phone: (601) 634-3636 E-mail: Richard.A.Price@erdc.usace.army.mil David Bowman U.S. Army Corps of Engineers Detroit District 477 Michigan Avenue P.O. Box 1027 Detroit, MI 48231-1027 Phone: (313) 226-2223 E-mail: David.W.Bowman@Ire02.usace.army.mil **SITE Program Contact:** Annette Gatchett National Risk Management Research Laboratory U.S. Environmental Protection Agency 26 West Martin Luther King Drive Cincinnati, OH 45268 Phone: (513) 569-7697 E-mail: gatchett.annette@epa.gov	**Technology:** Phytoremediation • Prior to the field demonstration, treatability studies were conducted by the technology developer at the USACE's Engineer Research and Development Center (ERDC) to determine the crops and grasses that would survive in the dredge material. • Four field plots, each containing four treatment cells, were established on the Confined Disposal Facility (CDF) by excavating, screening, and depositing soil in the cells. • Each test plot was 60 ft by 23 ft. The four treatment cells were each 12 ft by 20 ft. The intercell berms separating the treatment cells were 2 ft wide. The outer berms were 3 ft wide. • Each plot had four randomized treatments: corn hybrid, sandbar willow, local grasses, and an unplanted control (plant suppression). • Corn was planted twice during the growing season, from June through September. • The project duration was for two growing seasons.

Dredged Material Reclamation at the Jones Island Confined Disposal Facility, Milwaukee, Wisconsin (continued)

Type/Quantity of Media Treated:
Dredged material containing PAHs, PCBs, and DRO above relevant Wisconsin Department of Natural Resources (WDNR) and USEPA standards.

Regulatory Requirements/Cleanup Goals:
- Reduce PAHs to Category 1 and 2 standards specified in WDNR NR 538.
- Reduce PCBs to less than or equal to 1 mg/kg.
- DRO to less than 100 mg/kg.

Results:
- After two growing seasons, the three treatments plots had PAH concentrations at or below numerical standards for 7 of the 16 PAH compounds listed in Category 1 of the WDNR NR 538. The control plot had 8 compounds at or below Category 1 standards.
- After two growing seasons, the three treatments plots had 8 PAH compounds at or below the Category 2 standards of the WDNR NR 538. The control plot had 11 compounds.
- None of the treatments produced concentrations of PCBs of less than 1 mg/kg.
- None of the treatments produced concentrations of DRO of less than 100 mg/kg.

Costs:
The estimated costs for remediating 1,613 cubic yards (1 acre surface area by 1 foot deep) of dredged material was $47,227 using corn, and $44,280 using willow plants. The costs included equipment costs, direct installation costs, indirect costs, and direct and indirect annual operating costs.

Description:
The Jones Island Confined Disposal Facility (JICDF) is located in Milwaukee Harbor, Milwaukee, Wisconsin. The facility receives dredged materials from maintenance operations of Milwaukee's waterways. USACE, in partnership with the Milwaukee Port Authority, is exploring a range of beneficial reuse options for the dredged material, from building and road fill to landscape material.

A field demonstration was conducted to evaluate the feasibility of using phytoremediation to remediate the dredged material. Treatability studies were conducted to determine suitable crops and grasses. Once the plants were selected, field plots were established on the CDF by excavating, mixing, and depositing soil in test cells. The test plots closely followed established protocols for plot size, sampling, and statistical design. The field demonstration involved four different treatment plots: hybrid corn, an indigenous willow, local grasses, and an unplanted control. The EPA Superfund Innovative Technology Evaluation Program (SITE) and USACE evaluated the demonstration from 2001 to 2002. The effectiveness of the various plantings was monitored directly through soil sampling and indirectly through a variety of assessments.

After two growing seasons, the three plant treatments plots had PAH concentrations at or below numerical standards for 7 of the 16 PAH compounds listed in Category 1 of the WDNR NR 538. The control plot had 8 compounds at or below Category 1 standards. Also, the three plant treatments plots had 8 PAH compounds at or below the Category 2 standards of the WDNR NR 538, with the control plot having 11 compounds at or below the standards. None of the treatments produced concentrations of PCBs of less than 1 mg/kg, and none produced concentrations of DRO of less than 100 mg/kg.

The estimated costs for remediating 1,613 cubic yards (1 acre surface area by 1 foot deep) of dredged material was $47,227 using corn, and $44,280 using willow plants. The costs included equipment costs, direct installation costs, indirect costs, and direct and indirect annual operating costs.

In Situ Bioremediation at the Cleaners #1 Site, Kent, Washington

Site Name: Cleaners #1	Location: Kent, Washington
Period of Operation: • In situ bioremediation – First application (injection application): December 15 to18, 1998 – Second application (excavation application): April 21 to 22, 1999 – Third application (injection application): July 21, 2000 • Mechanical soil aeration – April 1999 • Thermal desorption – April 1999	**Cleanup Authority:** State Corrective Action
Purpose/Significance of Application: Full-scale remediation of VOCs in groundwater and soil using in situ bioremediation.	**Cleanup Type:** Full scale
Contaminants: VOCs – PCE, TCE, DCE, and vinyl chloride	**Waste Source:** Dry cleaning facility operations.

Technology:

In Situ Bioremediation

- Hydrogen Release Compound (HRC®) is a proprietary mixture produced by ReGenesis that consists of ammonium chloride, potassium tripolyphosphate, lactic acid, yeast extract, and sodium hydroxide.
- In the first application, HRC® was injected using 55 Geoprobe boreholes over a 2,000 square foot area, and to a depth of 6 to 18 feet below ground surface (bgs). A total of 1,140 pounds (114 gallons) was injected.
- Following soil excavation to repair a leaky sewer pipe, HRC® was applied to the bottom of two excavations to address any remaining soil contamination. A third application (the second injection application of HRC®) was conducted in July 2000.

Mechanical Soil Aeration and Thermal Desorption

- Soils exceeding the state cleanup level of 0.5 milligrams per kilogram (mg/kg) for PCE were mechanically aerated in an on-site treatment cell, which consisted of a plastic liner with straw bale berms.
- Following mechanical soil aeration, these soils were transported off-site for treatment using thermal desorption.

In addition, approximately 80 cubic yards of soil excavated from the area close to the facility contained low levels of PCE (less than 0.5 mg/kg). These soils were also transported off-site for thermal desorption treatment prior to disposal.

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Type/Quantity of Media Treated:

Groundwater

- 6 to 18 feet bgs over a 2,000 square foot area

Soil

- 24,000 cubic yards using in situ bioremediation (based on dimensions of injection area)
- 86 cubic yards using ex situ thermal desorption (6 cubic yards also treated by mechanical soil aeration prior to thermal desorption)

Regulatory Requirements/Cleanup Goals:
Groundwater cleanup goals are based on Washington State Model Toxic Control Act standards. Cleanup levels for three contaminants are based on residential use as follows: PCE at 5 micrograms per Liter (ug/L), TCE at 5 ug/L, and vinyl chloride at 0.2 ug/L. Cleanup levels for two other contaminants are based on universal use at all sites: cis-1,2-DCE at 80 ug/L and trans-1,2-DCE at 160 ug/L.

The soil cleanup levels for PCE and TCE are both 0.5 mg/kg.

Results:
In Situ Bioremediation:

Following HRC® injection into the groundwater in December 1998, PCE concentrations increased significantly at MW-1 (from 551 up to 67,000 micrograms per liter [ug/L]) in January, February, and March 1999. This increase was attributed to a leaking sewer pipe that allowed PCE-contaminated sewer effluent to seep into the subsurface. Following excavation activities, samples of remaining soils were collected and the results indicated concentrations below cleanup levels (0.5 mg/kg for PCE and 0.5 mg/kg for TCE). After excavation of soil, repair of sewer pipes, and treatment of soil with HRC® at the bottom of the excavations (second HRC® application), PCE and TCE concentrations in groundwater at MW-1 decreased by approximately 99% and 86%, respectively, but cleanup goals were not achieved. Concentrations of vinyl chloride in MW-1 increased due to increased degradation of cis-1,2-DCE. Samples of soil remaining in the excavations were below cleanup levels.

Following the third HRC® application, PCE, TCE, and DCE achieved cleanup goals. These concentrations decreased by 99.9% to less than 2 ug/L for PCE and TCE, and to 0.24 ug/L for DCE. Vinyl chloride also decreased by 99.9% but exceeded the cleanup level of 0.2 ug/L with a concentration of 0.29 ug/L in June 2004. Based on discussions with the project manager in June 2006, subsequent sampling indicated that concentrations of vinyl chloride were eventually reduced to non-detect levels. However, sampling data from the vendor were not available to verify the statement.

Groundwater samples collected from MW-4, MW-5, and MW-6, which are located further downgradient of MW-3, have not shown detectable concentrations of PCE or PCE-degradation by-products.

Mechanical Soil Aeration:

Laboratory analysis of treated soils indicated PCE concentrations ranging from 0.12 to 0.28 mg/kg prior to soil treatment using thermal desorption.

Costs:
The cost of HRC® was $13,860 for the two injection applications (December 1998 and July 2000).

Description:
Cleaners #1 is an operational dry cleaning facility located in a retail strip mall in Kent, Washington. The facility is approximately 1,600 square feet in area and is surrounded by mixed retail, commercial, and residential properties.

Contamination was first discovered at the facility in August 1998, during a Phase II Environmental Site Assessment (ESA). Interior and exterior soil samples were collected from below the facility floor near the dry cleaning machine, and outside the facility near the rear door. Groundwater samples were collected outside the facility. PCE and TCE were found at concentrations above state cleanup levels in groundwater, and PCE slightly exceeded cleanup levels in exterior soil samples. Interior soil samples showed only trace levels of PCE.

Additional soil sampling conducted in September 1998 from six exterior borings and three interior borings indicated that PCE and TCE concentrations were not detected above state cleanup levels. However, groundwater samples collected from three of the six exterior locations showed PCE above the state cleanup levels, with the highest concentration being closest to the rear door of the facility.

In Situ Bioremediation at the Cleaners #1 Site, Kent, Washington (continued)

Description (continued):
Enhanced bioremediation using HRC® was used to primarily address groundwater contamination at the site, while also treating some residual soil contamination. Excavated soil was treated using thermal desorption and mechanical soil aeration. After the first round of HRC® injection at the site, PCE concentrations increased. To determine potential sources of the contamination, sampling of sewer effluent being discharged from the facility to the sanitary sewer system was conducted. Results showed that PCE was being discharged from the facility at levels above state cleanup standards through two potential leaks in the sewer pipe. Following this determination, approximately 86 cubic yards of soil were excavated and the pipes were repaired. HRC® was applied to the bottom of each excavation to address any residual soil contamination. Excavated soil was treated on site using mechanical soil aeration followed by off-site thermal desorption prior to off-site disposal. A third application included HRC® injection in July 2000. Subsequent sampling has shown PCE, TCE, DCE, and vinyl chloride at concentrations below state cleanup levels. The State of Washington is anticipating receipt of a No Further Action letter for this site.

In Situ Thermal Desorption at Rocky Mountain Arsenal Hex Pit, Denver, Adams County, Colorado

Site Name: Rocky Mountain Arsenal	**Location:** Denver, Adams County, Colorado
Period of Operation: October 2001 to March 2002	**Cleanup Authority:** • CERCLA - Remedial Action • Record of Decision issued in June 1996 • Technology evaluated under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program
Purpose/Significance of Application: To evaluate the performance of full-scale application of ISTD to treat soil contaminated with hex and other organochlorine pesticides	**Cleanup Type:** Full scale
Contaminants: Organic pesticides and herbicides (hex, aldrin, chlordane, dieldrin, endrin, and isodrin) Composite soil sample contained the following mean pretreatment contaminant concentrations (expressed in milligrams/kilogram [mg/kg]): hex, 7,600; dieldrin, 3,100; total chlordane, 670; endrin, < 280; isodrin, < 200; and aldrin, < 170.	**Waste Source:** Disposal of distillation products and other residues that were primarily generated during the production of hex, a chemical formerly used in pesticide manufacturing. The waste was disposed in an unlined earthen pit.

Technology:
In Situ Thermal Desorption (ISTD)
- The system design involved a total of 266 thermal wells (210 H-O wells and 56 H-V wells), installed to depths of 12.5 ft below ground surface in a hexagonal arrangement covering an area of 7,194 ft^2
- Dewatering wells were installed several feet below the ISTD thermal well field
- Each thermal well was equipped with an electrical heating element designed to reach maximum temperatures between 1,400 and 1,600 degrees Fahrenheit
- A vacuum pressure of approximately 20 inches of water column was maintained along the boundaries of the treatment area to capture steam and contaminant vapors

The captured off-gas was conveyed to an off-gas treatment system that consisted of a cyclone separator, a flameless thermal oxidizer, a heat exchanger, a knock-out pot, two acid gas dry scrubbers, two activated carbon adsorption beds, and two main process blowers.

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In Situ Thermal Desorption at Rocky Mountain Arsenal Hex Pit, Denver, Adams County, Colorado (continued)

Type/Quantity of Media Treated:
Soil
- The volume of waste in the pit was approximately 3,200 cy, and the waste included solid and semisolid layers of tar-like material

The contaminated portion of the pit extended over an area of approximately 7,000 ft^2 and its depth varied from 8 to 10 ft.

Regulatory Requirements/Cleanup Goals:
- Remediation Goal I: meet or exceed the ROD requirement of 90 percent destruction removal efficiency (DRE) for the six contaminant of concerns (COCs) that include hex, aldrin, dieldrin, endrin, isodrin, and chlordane
- Remediation Goal II: reduce the mean concentration of the six COCs below the ROD human health exceedance criteria

The performance of the technology was also evaluated according to a number of secondary objectives.

Results:
- The ISTD system at the Hex Pit operated for 12 days. The system was shutdown because portions of the aboveground piping had been corroded by hydrochloric acid that was generated during heating of the organochlorine contaminants. Shutdown of the system prevented the evaluation of the effectiveness of the technology at this site.

During operation and post-treatment monitoring, sampling and analysis of air emissions indicated that none of the hourly average air quality standards for off-gas emissions had been exceeded during system operation or during the extended well field cool-down period.

Costs:
The total cost of design and construction of the ISTD system was approximately $1.9 million. Because of the short period of system operation, no operation and maintenance (O&M) costs are available.

Description:
Rocky Mountain Arsenal (RMA) near Denver, Colorado, was established in 1942 as a chemical agent and munitions facility, and was later used in the manufacture of pesticides. The disposal of pesticides in drums that later corroded or ruptured resulted in contamination of soil, surface water, and groundwater at the facility. In 1987, RMA was placed on the National Priorities List. One of the contaminated areas of RMA, the Hex Pit, was an unlined, earthen disposal pit used for the disposal of distillation products that were generated during the production of hex, a chemical formerly used in pesticide manufacturing. In addition, other organochlorine pesticides were disposed of in the pit. The 1996 ROD selected innovative thermal technology for remediation of the Hex Pit. The ROD required the application of specific criteria to evaluate the innovative thermal technology. The criteria included greater than 90 percent DRE for hex, dieldrin, and chlordane, and a cost lower than off-site incineration. Several thermal technologies were evaluated and ISTD was selected as the remedial technology because it could meet the criteria specified in the ROD.

The ISTD system was implemented to treat approximately 3,200 cy of contaminated soil. Installation of the system began in October 2001 and was completed in February 2002. The system design involved a number of H-O wells, H-V extraction wells and dewatering wells. The system was started up on March 3, 2002, and was expected to run for 85 days until the end of May 2002. However, because portions of the aboveground piping became corroded by hydrochloric acid that was generated during heating of the organochlorine contaminants, the system was shut down on March 15, 2002, 12 days after system startup. Following shutdown, the Hex Pit site was buried under approximately 3 ft of imported fill material, and the application was evaluated, and lessons learned noted.

The total cost of design and construction of the ISTD system was approximately $1.9 million. Because of the short period of system operation, no operation and maintenance costs are available.

Pump and Treat and In Situ Bioventing at Onalaska Municipal Landfill Superfund Site, Onalaska, Wisconsin

Site Name:	Location:
Onalaska Municipal Landfill Superfund Site	Onalaska, Wisconsin

Period of Operation:

Groundwater
- Pump and Treat (P&T) – June 1994 through November 2001 [data are available from May 2001 to October/November 2001]
- Monitored Natural Attenuation (MNA) – November 2001 to present [data are available from October 2001 to April 2003]

Soil
- In Situ Bioventing – May 1994 to February 1997

Cleanup Authority:
CERCLA – Remedial Action
ROD Date – August 14, 1990
ESD Dates – September 29, 2000; November 13, 2001
Five-Year Reviews – 1998, 2003

Purpose/Significance of Application:
Full-scale remediation of VOCs, SVOCs, and metals in groundwater and soil using P&T, in situ bioventing, and MNA.

Cleanup Type:
Full scale

Contaminants:
VOCs, SVOCs, and metals
- VOCs (groundwater) – TCE; 1,1-DCA (800 μg/L maximum); 1,1,1-TCA (8 μg/L maximum); 1,1-DCE; 1,2-DCE (27 μg/L maximum); and BTEX.
- SVOCs (soil) – petroleum hydrocarbon solvents, primarily naphtha, at levels as high as 550 mg/kg

Metals (groundwater) – barium, arsenic, iron, manganese, and lead

Waste Source:
Disposal of municipal and chemical wastes in a landfill

Contacts:

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Technology:

Pump and Treat
- Five extraction wells located along the downgradient edge of the landfill with a total design flow rate of 600 to 800 gallons per minute (gpm).
- Treatment system included aeration, clarification, and the addition of sodium hydroxide and polymer for iron removal.
- Air stripping used to remove volatile organic compounds (VOCs).
- Treated water was discharged to the river, and the clarifier sludge was dewatered and disposed in a landfill.
- During its 7.5 years of operation, more than 2 billion gallons of groundwater were extracted and treated.

Monitored Natural Attenuation
- After the P&T system was shut down, MNA was evaluated to address low levels of contamination.
- The monitoring network comprises of 26 monitoring points, including 6 air injection wells, 5 piezometers, 13 monitoring wells, and 2 residential wells.
- Analytes include VOCs; metals; benzene, toluene, ethylbenzene, xylenes (BTEX); naphthalene; and natural attenuation parameters such as oxidation-reduction potential, dissolved oxygen, pH, temperature, and specific conductance.
- Baseline monitoring of natural attenuation was performed in October 2001. The second and third monitoring events occurred in December 2002 and April 2003.

Pump and Treat and In Situ Bioventing at Onalaska Municipal Landfill Superfund Site, Onalaska, Wisconsin (continued)

Contacts (continued):	Technology (continued):
EPA Support Contractor: CH2MHill 135 South 84th St, Suite 325 Milwaukee, WI 53214 Phone: (414) 272-2426 Fax: (414) 272-4408 Web site: www.ch2m.com **State Support Contractor:** Peter Moore ENSR Corporation 4500 Park Glen Road, Suite 210 St. Louis Park, MN 55416 Phone: (952) 924-0117	In Situ Bioventing • Consisted of injecting air into the area of petroleum nonaqueous phase liquid (NAPL) contamination to stimulate naturally-occurring aerobic microbes and to promote biodegradation of the organic compounds. • Area of NAPL contamination targeted was 2.5 acres downgradient of the landfill. • 3- to 5-foot NAPL layer was estimated to be at a depth of 8 to 12 feet below ground surface (bgs). System consisted of 29 vertical air injection wells (each 2 inches in diameter, installed on 40- to 50-foot centers, and screened within the NAPL layer). The wells were connected by a header piping network to a single aeration well blower and operated between 270 and 320 standard cubic feet per minute (scfm).

Type/Quantity of Media Treated:
Groundwater
- 10 to 70 feet below ground surface (bgs); 2.17 billion gallons of groundwater treated soil
- 11 to 15 feet bgs (quantity of soil treated was not reported)

Regulatory Requirements/Cleanup Goals:
- Estimated cleanup goal was 80 to 95 percent reduction of the organic contaminant mass in the soil (ROD did not establish chemical-specific soil cleanup goals).

In 2000, cleanup goals for groundwater were revised to the current state goals in an explanation of significant differences (ESD).

Results:
P&T
- The P&T system operated at an average extraction rate of 563 gpm.
- By May 2001, concentrations for organic contaminants (except benzene and trimethylbenzene) had decreased to below cleanup goals, based on results for samples collected from 14 wells located on- and off-site. Arsenic, barium, iron, and manganese continued to be detected in groundwater at concentrations above the cleanup goals.
- As of October and November 2001, elevated concentrations of organic contaminants were present, primarily in one well. Trimethylbenzenes were present in two wells, with concentrations as high as 670 µg/L.
- As of November 2001, arsenic, barium, and manganese were present in several monitoring wells at levels as high as 14.9, 997 µg/L, and 3,780 µg/L, respectively.

In Situ Bioventing
- The system operated with an air injection rate of 270 to 320 scfm and targeted 3 separate areas of the site (Areas A, B, and C).
- In situ bioventing resulted in aerobic soil conditions, as evidenced by a steady increase in oxygen concentrations at the site, to levels as high as 21 percent. Carbon dioxide concentrations decreased from an average of 10 percent to less than 1 percent, and average methane concentrations decreased from 1.4 to 0.1 percent.
- The average hydrocarbon degradation rate was estimated to be 1 milligram per kilogram per day (mg/kg/day) in Areas A and B and 0.5 mg/kg/day in Area C.
- The total mass of hydrocarbons removed was estimated to be 7,780 kilograms (kg) from Area A; 11,000 kg from Area B and 1,247 kg from Area C.

Pump and Treat and In Situ Bioventing at Onalaska Municipal Landfill Superfund Site, Onalaska, Wisconsin (continued)

Results (continued):

MNA

- The results of the December 2002 and April 2003 sampling events showed that the oxidation-reduction potential (ORP) ranged from 87 to 190 millivolts (mV), indicating that reductive dechlorination may be occurring. Concentrations of dissolved oxygen ranged from 0.23 to 7.07 milligrams per liter (mg/L), indicating aerobic conditions in the groundwater.
- As of April 2003, two organic contaminants, trimethylbenzenes and methylene chloride, remained at concentrations above their respective cleanup goals. In addition, two inorganic compounds, iron and manganese remain at concentrations above their respective cleanup goals.

Monitoring for natural attenuation continues at the site.

Costs:

Operation and maintenance (O&M) costs for the P&T system before the system was shut down (for 1998 through 2001) were about $200,000 per year including groundwater extraction, wastewater treatment plant O&M, sampling and monitoring, monitoring well maintenance, and reporting. After system shutdown, O&M costs were about $60,000 per year for 2002 and 2003.

Description:

The Onalaska Municipal Landfill Superfund Site is located in Onalaska, Wisconsin and was originally used as a sand and gravel quarry from the early to mid-1960s. In the mid-1960s, the Town of Onalaska began using the site as a landfill for both municipal and chemical wastes. Landfill operations stopped in September 1980, and the landfill was capped in June 1982. Subsequent investigations found elevated levels of VOCs and metals in a groundwater plume that extended at least 800 feet from the southwestern edge of the landfill and discharged to nearby wetlands and the adjacent Black River. The aquifer beneath the landfill served as the primary source of drinking water for the residents in the area. In addition, soils above the groundwater table and adjacent to the southwestern edge of the landfill were contaminated with petroleum solvents.

The site was placed on the National Priorities List in September 1984 and remedial investigations were conducted in 1988 and 1989. A record of decision (ROD) was signed in August 1990, which specified a P&T system for groundwater and in situ bioventing for soils. The P&T system operated from June 1994 through November 2001 and was designed to remove VOCs and metals. In situ bioventing operated from May 1994 to February 1997. In 1998, as part of the first 5-year review, EPA concluded that bioventing was no longer affecting biodegradation, and the system was shut down. Based on confirmation of oxygen levels in soil gas, EPA determined that the bioremediation cleanup phase was completed. An ESD was issued in November 2001 that allowed for the temporary shutdown of the P&T system to evaluate the effectiveness of MNA, based on the long-term groundwater monitoring that was being conducted at the site. Monitoring of natural attenuation at the site is ongoing.

Operation and maintenance (O&M) costs for the P&T system before the system was shut down (for 1998 through 2001) were about $200,000 per year including groundwater extraction, wastewater treatment plant O&M, sampling and monitoring, monitoring well maintenance, and reporting. After system shutdown, O&M costs were about $60,000 per year for 2002 and 2003.

Stabilization of Mercury in Waste Material from the Sulfur Bank Mercury Mine, Lake County, California

Site Name:
Sulfur Bank Mercury Mine Superfund Site

Location:
Lake County, California

Period of Operation:
November 15, 2000 to April 29, 2001

Cleanup Authority:
- EPA's Superfund Innovative Technology Evaluation (SITE) program
- Mine Waste Technology Program (MWTP)

Purpose/Significance of Application:
To determine the effectiveness of three stabilization technologies for immobilizing mercury in waste rock material, thereby reducing leachable mobile mercury in the effluent.

Cleanup Type:
Bench Scale

Contaminants:
Heavy Metals
- Mercury: Mercury concentrations ranged from 312 to 1360 milligrams per kilogram (mg/kg) in the mercury ore and 130 to 447 mg/kg in the waste rock

Waste Source:
Historic mining activities at the site.

Contacts:

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Technology:
Three stabilization technologies were used for immobilizing mercury in sulfide mine waste materials from the Sulfur Bank Mercury Mine (SBMM) site. The three technologies are listed below:

- ENTHRALL Technology:
  - Developed by E & C Williams, Inc.
  - Uses inorganic sulfide reagent to target heavy metals. The treatment forms permanent bonds between the reagent surface and heavy metals.
  - Used a proprietary sonic drilling rig to inject the reagent. Two rigs were used concurrently to inject the reagent directly into the waste pile at 15-foot intervals.

- KEECO's Silica Micro Encapsulation (SME) process:
  - Developed by Klean Earth Environmental Company (KEECO).
  - Encapsulates metal in an impervious microscopic silica matrix, which eliminates the adverse effects of the metal on human health and the environment.
  - A modified ex situ process in which material is removed from its location for treatment at an adjacent on-site facility. The material is mixed with the reagent at the on-site facility and then returned to the site where it is replaced and compressed in place.

- Generic Phosphate treatment:
  - Forms insoluble phosphate salts containing the contaminant.
  - Phosphates stabilize metals by chemically binding them into new stable phosphate phases, such as apatites, and other relatively insoluble phases in the soil.

Type/Quantity of Media Treated:
Waste Material (quantity not provided)

Stabilization of Mercury in Waste Material from the Sulfur Bank Mercury Mine, Lake County, California (continued)

Regulatory Requirements/Cleanup Goals:
To achieve a 90% reduction in the total mass of mercury leached from each treatment (relative to the control) over a 12-week continuous column leaching study.

Results:

E&C William's ENTHRALL Technology:
- The ENTHRALL Technology was not effective in reducing levels of mobile mercury in the mercury ore columns.
- The total mass of mercury in both the particulate and dissolved fractions were similar to the control column.

KEECO's SME Technology:
- The SME process was applied both ex situ and in situ and was effective in reducing mobile mercury (< 25µm).
- The in situ process reduced leachability by 88% and the ex situ process by 86%, when compared to the control.
- Both the in situ and ex situ treatments achieved a 99% reduction in particulate-associated mercury, relative to the control.
- There was however a significant increase in the mass of mercury in the dissolved fraction (< 0.45 µm). The in situ applications showed a 198% increase in comparison to the control, and the ex situ showed a 238% increase.

Generic Phosphate:
- The phosphate treatment increased the levels of both the particulate and dissolved fractions (< 0.45 µm) over the course of the 12-week study.
- The mass of mercury leached was high during the first two weeks or monitoring.
- The treatment accelerated the breakdown of the mercury ore material matrix and facilitated the release of particulates.
- The rise in leachable mercury invalidates this treatment as a possible remedial alternative for the materials at the SBMM site.

Costs:

E&C William's ENTHRALL Technology:
- Estimated total operating cost for remediating the SBMM piles was $59,807,000. No cost for residual handling was presented because the technology does not produce residuals.
- The largest cost component, the chemical reagents, was $57,008,000 (93.5% of the total cost).
- The second highest cost, equipment, was $1,633,500 (2.7% of the total cost).
- The remediation cost per ton of material is $27.82.

KEECO's SME Technology:
- Estimated total operating cost for remediating the SBMM piles is $35,690,000. No cost for residual handling was presented because the technology does not produce residuals.
- The largest cost component, the chemical reagents, was $26,700,000 (68% of the total cost).
- The KEECO technology requires residual handling, which costs $1,283,000 and constitutes the second highest cost item.
- The remediation cost per ton of material is $16.60.

Generic Phosphate:
- Full-scale treatment costs were not provided. Based on the study results, further experimentation and product modifications are required before the reagent can be considered for use at the SBMM site.

Description:
The Sulfur Bank Mercury Mine (SBMM) Superfund site is located on the south shore of Oaks Arm of Clear Lake, in Lake County, California. SBMM was mined periodically from 1865 to 1957, with open pit mining beginning in 1915. Starting in the late 1920s, heavy earthmoving equipment was used on a large-scale basis, which dramatically increased the environmental impacts of the mining. Various mining activities over the years have deposited large amounts of mercury in the Clear Lake ecosystem.

Two innovative in situ stabilization technologies and one generic phosphate stabilization treatment were evaluated in a treatability study, using material from the SBMM. The two innovative technologies were the ENTHRALL, developed by E & C Williams, Inc., and the Silica Micro Encapsulation (SME) process, developed by the Klean Earth Environmental Company.

The ENTHRALL technology uses an inorganic sulfide reagent, which forms a permanent bond between the reagent and the heavy metals. The reagent is injected using a proprietary sonic drill. The SME process encapsulates the heavy metals in an impervious microscopic silica matrix. The process can be conducted ex situ by first excavating the material and mixing it with the reagent at an adjacent on-site facility. The material is then returned to the site and compressed into place. The generic phosphate treatment stabilizes the heavy metals by chemically binding them into stable phosphate phases, such as apatites, and other relatively insoluble phases in soil.

The ENTHRALL technology was not effective in reducing levels of mobile mercury in the mercury ore columns. The SME process was applied both ex situ and in situ and was effective in reducing mobile mercury. Both the in situ and ex situ treatments achieved a 99% reduction in particulate-associated mercury, relative to the control, but there was a significant increase in the mass of mercury in the dissolved fraction. The phosphate treatment increased the levels of both the particulate and dissolved fractions. The rise in leachable mercury invalidates this treatment as a possible remedial alternative for the materials at the SBMM site.

The estimated total operating cost for the ENTHRALL and SME process technologies were $59,807,000 and $35,690,000, respectively. Residual handling costs were not included in these costs because the technologies do not produce residuals. Full-scale treatment costs were not provided for the generic phosphate treatment.

IN SITU GROUNDWATER TREATMENT ABSTRACTS

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Edible Oil Barriers for Treatment of Perchlorate Contaminated Groundwater

Site Name:
Confidential Site

Location:
Maryland

Period of Operation:
Demonstration was conducted in October 2003. Monitoring lasted for 18 months (from October 2003 to April 2005).

Cleanup Authority:
Field Demonstration

Purpose/Significance of Application:
The primary objective of the project was to evaluate the cost and performance of an EOS® PRB to control the migration of perchlorate plumes at the Site.

Cleanup Type:
Field Demonstration

Contaminants:
Explosives/Propellants, Volatiles-Halogenated:

- Explosives/propellants: perchlorate: 3,100 to 20,000 μg/L; Volatiles-halogenated: 1,1,1-TCA: 5,700 to 17,000 μg/L; 1,1-DCA: 7 to 62 μg/L; chloroethane: <5 to <20 μg/L; 1,1-DCE: 270 to 1,200 μg/L; PCE: 25 to 110 μg/L; TCE: 28 to 210 μg/L; cis-1,2-DCE: 5.5 to 10 μg/L; trans-1,2-DCE: <5 to <20 μg/L; vinyl chloride <5 to <20 μg/L; ethane: 0.16 to 4.28 μg/L; ethene: 0.04 to 1.94 μg/L.

Waste Source:
Former lagoon that received ammonium perchlorate and waste solvent.

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Technology:
Permeable Reactive Barrier:

- The field demonstration consisted of a one-time injection of emulsified oil substrate (EOS®) and chase water to create a 50-ft long permeable reactive barrier (PRB).
- Approximately 110 gallons of EOS® and 2,070 gallons of chase water were injected into the subsurface.
- The PRB was located approximately 50 ft upgradient of an existing interceptor trench.

Groundwater was extracted from the interceptor trench, treated using an air stripper, and re-injected using an upgradient infiltration gallery.

Type/Quantity of Media Treated:
Groundwater:

- The shallow aquifer (5 to 15 ft below ground surface). Approximately 405,000 gallons of groundwater was treated.

Edible Oil Barriers for Treatment of Perchlorate Contaminated Groundwater (continued)

Regulatory Requirements/Cleanup Goals:
National Primary Drinking Water Regulations and the Maryland Department of the Environment Generic Numeric Cleanup Standards for Groundwater. Also, a reduction of perchlorate concentration by 90% was targeted.

Results:
- Perchlorate concentrations were less than 4 µg/L in all of the injection wells within 5 days of injection.
- 18 months after the injection of EOS, the perchlorate removal rates remained greater than 90 percent of the pre-injection levels in the downgradient wells.
- 1,1,1-TCA was reduced 94 to 98% twenty feet downgradient of the barrier.

The average chlorine number was reduced from 3.0 to 1.5, indicating that biodegradation to less chlorinated daughter products was occurring.

Costs:
Costs for installing a full-scale PRB was compared to that of adding an ion exchange unit to an existing pump-and-treat system. The breakdown of costs is as follows:

- Estimated costs for the installation of a full-scale PRB at the site was $38,000, which is equivalent to $19 per square foot of barrier or $0.02 per gallon treated. The estimated capital cost for ion exchange was $50,000 and $17,000 annual O&M.
- The 30-year life cycle costs for installing an emulsified oil PRB are estimated to be $161,400 compared to $383,600 for adding an ion exchange unit to the existing pump-and treat system.

Description:
A permeable reactive barrier (PRB) field demonstration was conducted at a confidential site in Maryland to remediate mixed perchlorate and 1,1,1-trichloroethane (TCA) in a groundwater plume. The demonstration was conducted in 2003 and monitoring was conducted for 18 months.

The demonstration consisted of a one-time injection of EOS® and chase water to create a 50-ft long PRB. The PRB was located about 50 ft upgradient from an existing interceptor trench. Groundwater was extracted from the interceptor trench, treated using air stripping, and then re-injected using an upgradient infiltration gallery.

EOS® injection resulted in substantial reductions in perchlorate and 1,1,1-TCA concentration within and downgradient of the PRB. Costs for the demonstration were not provided but estimated costs for the installation of a full scale PRB at the site were provided. The estimated initial costs for installation were $38,000. The 30-year cycle costs for were estimated to be $161,400.

Nanoscale Zero-Valent Iron Technology for Source Remediation

<table>
<tr><td colspan="2">Site Name:
Multiple (3) Naval Facilities: Hunters Point Shipyard, Naval Air Station Jacksonville, and Naval Air Engineering Station Lakehurst.</td><td colspan="2">Location:
• Hunters Point Shipyard: San Francisco, California
• Naval Air Station Jacksonville: Jacksonville, Florida
• Naval Air Engineering Station Lakehurst: Lakehurst, New Jersey</td></tr>
<tr><td colspan="3">Period of Operation:
Not Documented</td><td>Cleanup Authority:
• Hunters Point Shipyard: Navy
• Naval Air Station Jacksonville: CERCLA
• Naval Air Engineering Station Lakehurst: Navy</td></tr>
<tr><td colspan="3">Purpose/Significance of Application:
A field demonstration of various NZVI technologies was conducted to determine their effectiveness in treating source areas contaminated primarily with TCE, PCE, DCE, and vinyl chloride.</td><td>Cleanup Type:
Field Demonstration</td></tr>
<tr><td colspan="3">Contaminants:
Hunters Point Shipyard:
• First study (source area, groundwater):
– Volatiles-Halogenated: TCE (88,000 µg/L, maximum); PCE; cis-1,2-DCE; vinyl chloride; total chlorinated ethenes; chloroform; and carbon tetrachloride.
• Second study (downgradient area, groundwater):
– Volatiles-Halogenated: TCE; cis-1,2-DCE; vinyl chloride.

Naval Air Station Jacksonville:
• Soil:
– Volatiles-Halogenated: 1,1,1-TCA (25,300 µg/kg, maximum); PCE (4,360 µg/kg, maximum); and TCE (60,100 µg/kg, maximum).
• Groundwater:
– Volatiles-Halogenated: PCE (173 µg/L, maximum); TCE (5,520 µg/L, maximum); and cis-1,2-DCE (1,350 µg/L, maximum).

Naval Air Engineering Station Lakehurst:
• Groundwater:
– Volatiles-Halogenated: PCE; TCE; 1,1,1-TCA; cis-DCE; and vinyl chloride.</td><td>Waste Source:
• Hunters Point Shipyard: Leakage from an underground storage tank (UST) and the associated floor drain and underground piping; a grease trap and associated cleanout and underground piping; and five steel dip tanks from a former paint shop.
• Naval Air Station Jacksonville: Leakage from two USTs.
• Naval Air Engineering Station Lakehurst: Not provided.</td></tr>
<tr><td>Contacts:
Not Documented</td><td colspan="3">Technology:
Hunters Point Shipyard:
• Two zero-valent iron (ZVI) injection studies were conducted, one in the source area and the other in the groundwater plume.
• In the first study, 16,000 lbs of micron-sized ZVI powder was mixed with tap water to produce an iron slurry (265 grams per Liter [g/L]). The iron slurry was then injected into the dense non-aqueous phase liquid (DNAPL) source zone by pneumatic fracturing, using nitrogen as the carrier gas.
• In the second study, 72,650 lbs of microscale ZVI was made into a 300 g/L slurry with tap water and was injected into a region of less contamination next to the DNAPL source using pneumatic fracturing.</td></tr>
</table>

Nanoscale Zero-Valent Iron Technology for Source Remediation (continued)

Technology (continued):

Naval Air Station Jacksonville:
- 300 lbs of bimetallic nanoscale particles (BNP) was mixed with water drawn from an extraction well to produce an iron slurry (4.5 to 10 g/L).
- The slurry was injected into the subsurface by a combination of direct push and closed-loop recirculation wells.
- Injection was conducted first at 10 "hot spot" locations and the recirculation wells were used to distribute the slurry to the rest of the suspected source zone.

Naval Air Engineering Station Lakehurst:
- 300 lbs of BNP was mixed with water drawn from an extraction well and from a fire hydrant to produce a dilute iron slurry (2 g/L).
- The slurry was injected in to the subsurface using direct push technology.
- Injections were done at 10 locations in the Northern Plume and at five locations in the Southern Plume.

Type/Quantity of Media Treated:
- Hunters Point Shipyard: First study, treatment zone covered an area of 1,818 ft^2. Second study, treatment zoned covered an area of approximately 8,700 ft^2.
- Naval Air Station Jacksonville: Groundwater (Quantity not provided).
- Naval Air Engineering Station Lakehurst: Northern groundwater plume – approximately 8,470 ft^2; Southern groundwater plume – approximately 4,350 ft^2.

Regulatory Requirements/Cleanup Goals:
- Hunters Point Shipyard: Not provided.
- Naval Air Station Jacksonville: Reduce the total site contaminated mass by 40 to 50%.
- Naval Air Engineering Station Lakehurst: Not provided.

Results:

Hunters Point Shipyard:
- *First study:*
  - TCE levels declined sharply in all monitoring wells in the treatment zone without any significant formation of cis-1,2-DCE and vinyl chloride.
  - Sharp declines in oxygen-release potential (ORP) and noticeable increases in pH supported the contention that strongly reducing condition suitable for abiotic reduction of CVOCs was created.
  - Pneumatic fracturing combined with liquid atomization injection of the ZVI slurry was successful in distributing ZVI through most of the target treatment zone.
  - Injecting at shallow depths may lead to nitrogen and slurry seeping up to the ground surface.
- *Second study:*
  - TCE and DCE were reduced rapidly in the treatment zone wells.

Naval Air Station Jacksonville:
- Within five weeks after injection, concentrations of parent VOCs were reduced by 65 to 99%.
- ORP reduction was experienced in most of the source zone monitoring wells, indicating that the direct push and recirculation methods of injection worked relatively well.
- The injection did not create the strongly reducing conditions necessary to generate substantial abiotic degradation of TCE.

Naval Air Engineering Station Lakehurst:
- TCE and PCE concentrations were reduced on average by 79% and 83%, respectively.
- The average decrease in total VOC concentrations was 74%.
- Monitoring data was unable to determine what caused reductions in the CVOC concentrations.

Nanoscale Zero-Valent Iron Technology for Source Remediation (continued)

Costs:

- *Hunters Point Shipyard:*
  - Total cost for the first study was $289,300. This included costs for mobilization, equipment and supplies (ZVI cost $32,500), labor, drilling services, sampling and analysis including waste disposal, and other miscellaneous costs.
  - For the second study the total cost was $1,390,000. This included $770,000 for materials, equipment, field labor for the injection, and waste characterization and disposal; $452,000 for baseline and post-injection groundwater sampling and analysis; and $168,000 for project management, data management, and reporting.

- *Naval Air Station Jacksonville:*
  - The approximate total cost reported for the field demonstration was $259,000 with an additional $153,000 for administrative tasks such as project management, work plan development, and a bench scale study. The field demonstration total cost included cost from mobilization, monitoring well installation, injection/circulation events (NZVI cost $37,000), sampling and analysis as well as waste disposal, and other miscellaneous costs.

- *Naval Air Engineering Station Lakehurst:*
  - The approximate total cost reported for the field demonstration was $255,500 which included monitoring well installation, baseline sampling, nanoscale iron injection, six-month post injection sampling, and reporting results.

Description:

- *Hunters Point Shipyard:*
  - Hunters Point is situated on a long promontory located in the southeastern portion of San Francisco County and extends eastward into the San Francisco Bay. From 1869 through 1986, it operated as a ship repair, maintenance, and commercial facility. In 1991, the Navy designated Hunters Point for closure under the federal Base Closure and Realignment Act. Hunters Point was divided into six separate geographic parcels (Parcels A through F) to facilitate the closure process. The first and second ZVI demonstrations were performed at Site RU-C4 in Parcel C, which is located in the eastern portion of Hunters Point. The groundwater plume at Site RU-C4 had been contaminated with chlorinated solvents, primarily TCE.
  - The first ZVI injection was conducted in the source area of the contamination. The treatment zone covered an area of 1,818 ft^2. The total cost of the first study was $289,300. The second ZVI injection was conducted in the groundwater plume. The approximate treatment area was 8,700 ft^2. The total cost for the second injection project was $1,390,000.

- *Naval Air Station Jacksonville:*
  - Naval Air Station (NAS) Jacksonville is located in Duval County, Florida and has been used for Navy operations since 1940. The demonstration site, H1K, was located in the interior portion of the facility and contained two USTs. The USTs previously received waste solvents and other substances from a wash rack, manhole and other operations. The tanks and associated pipelines were removed and capped in 1994. Cleanup of H1K is managed under CERCLA, and the groundwater monitoring program is managed under RCRA.
  - In 2000 and 2001, an Interim Remedial Action consisting of chemical oxidation was conducted in the source area. In March 2002, a site characterization sampling effort was performed to redefine the extent of contamination. The horizontal extent of contamination is approximately 1,450 ft^2 with a thickness of 18 ft (saturated zone), resulting in a total volume of 967 cubic yards of soil.
  - Iron slurry was injected into the subsurface by a combination of direct push and closed-loop recirculation wells. Within five weeks after injection, concentrations of parent VOCs were reduced by 65 to 99%. The approximate total cost reported for the field demonstration was $259,000, with an additional $153,000 for administrative tasks.

Nanoscale Zero-Valent Iron Technology for Source Remediation (continued)

Description (continued):

- *Naval Air Engineering Station Lakehurst:*
  - Naval Air Engineering Station Lakehurst is located in Jackson and Manchester Townships, Ocean County, New Jersey, 14 miles inland from the Atlantic Ocean. The facility covers 7,383 acres and is within the Pinelands National Reserve.
  - The demonstration project involved two areas with the highest groundwater contaminant concentrations within the northern plume and the southern plume, Areas I and J. The contamination vertically extends 70 ft below the groundwater table. The largest amount of contamination is located in the zone from 45 to 60 ft below the groundwater table.
  - A bench-scale treatability study in 2001 and a pilot test study in 2003 were performed at the facility to evaluate the feasibility of using BNP as an in situ remediation technology to reduce or eliminate the contaminants at Areas I and J. This preliminary testing showed that BNP had the potential to perform better than NZVI without any catalyst coating. 10 injections of BNP were conducted in the northern plume and five injections were conducted in the southern plume. The approximate total cost for the field demonstration was $255,500.

Steam Enhanced Remediation Research for DNAPL in Fractured Rock Loring Air Force Base, Limestone, Maine

<table>
<tr><td colspan="2">Site Name:
Loring Air Force Base</td><td colspan="2">Location:
Limestone, Maine</td></tr>
<tr><td colspan="3">Period of Operation:
September 1 to November 19, 2002. Post-steam injection monitoring: Spring 2003 to Spring 2004.</td><td>Cleanup Authority:
• EPA's Office of Research and Development (ORD) National Risk Management Research Laboratory (NRMRL),
• U.S. EPA Region 1,
• Maine Department of Environmental Protection (MEDEP), the United States Air Force, and EPA's Superfund Innovative Technology Evaluation (SITE) program.</td></tr>
<tr><td colspan="3">Purpose/Significance of Application:
The main objectives of the study were to:
• Develop an improved understanding of the mechanisms controlling DNAPL and dissolved phased contaminant behavior in fractured bedrock systems;
• Evaluate how a remediation technology could be successfully implemented and controlled in a fractured bedrock environment;
• Reduce the mass of contaminants in the subsurface to reduce the overall remediation timeframe; and
• Evaluate characterization needs for fractured bedrock systems.</td><td>Cleanup Type:
Pilot Study</td></tr>
<tr><td colspan="3">Contaminants:
Volatiles-halogenated: 1,1-dichloroethylene; benzene; chlorobenzene; cis-1,2-dichloroethylene; ethylbenzene; tetrachloroethylene; trans-1,2-dichloroethylene; toluene; trichloroethylene; vinyl Chloride; xylenes (total)</td><td>Waste Source:
Past disposal practices of wastes from construction, industrial, and maintenance activities at the Base.</td></tr>
<tr><td>Contacts:
Eva Davis
U.S. Environmental Protection Agency
Robert S. Kerr Environmental Research Center
Ground Water and Ecosystems Restoration
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Ada, OK 74821-1198
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Rob Hoey
Maine Department of Environmental Protection
17 State House Station
Augusta, Maine 04333-0017
E-mail: Rob.Hoey@maine.gov</td><td colspan="3">Technology:
Thermal Treatment (in situ):
• The steam remediation system consisted of a network of vertical wells and borings. 13 boreholes were used as injection or extraction wells and 10 boreholes were used as geophysical and/or temperature monitoring locations.
• Steam was produced in an above ground steam generating unit, which transferred steam using a steam header at 690 kilopascal (kPa) gauge pressure (corresponding to a temperature of 170 °C).
• Steam injection rates varied from 27 to 508 kilograms per hour (kg/hr).
• At the injection wellhead, steam was reduced to pressures between 200 and 620 kPa (corresponding to 135 to 155 °C) depending on the depth of delivery.
• Air was injected in order to help develop fractures for improved steam injection rates, to create a buoyant vapor phase, and to assist in vadose zone flushing.
• During operations, a total of 824,000 cubic meters of non-condenseable vapor was extracted.
• Over the course of the test, a total of 739,000 liters of water was extracted as liquid phase.</td></tr>
</table>

Steam Enhanced Remediation Research for DNAPL in Fractured Rock Loring Air Force Base, Limestone, Maine (continued)

Contacts (continued):

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E-mail: udell@me.berkeley.edu

Type/Quantity of Media Treated:
Groundwater (quantity not documented).

Regulatory Requirements/Cleanup Goals:
None documented.

Results:
- Based on the limited duration of the project it could not be determined conclusively that steam injection would be capable of heating the entire treatment area to the target temperature.
- The vapor and water treatment system employed by the vendor effectively treated these effluent streams to meet discharge limitations.
- For Steam Enhanced Remediation (SER) to be successful for the remediation of the site, extensive characterization would be needed and extremely long injection times would be required.
- Further research is warranted on steam injection remediation in fractured rock at a less complex site.

Costs:
Not documented.

Description:
The former Loring Air Force Base (AFB) is located in the northeastern portion of Maine, approximately 5 km west of the United States/Canadian border. A quarry at the site, located near the northwestern boundary, had historically been used for the disposal of wastes from construction, industrial, and maintenance activities at the Base. The site was added to the Superfund National Priorities List in 1990. During remedial activities in the 1990s, approximately 450 drums were removed from the quarry. The Record of Decision (ROD), signed in 1999, recognized that it was impractical at the time to restore groundwater in fractured rock to drinking water standards. However, an agreement was made between the Air Force, the MEDEP, and EPA Region 1 to use the quarry to conduct a research project to further develop remediation technologies for fractured bedrock. An evaluation of potential technologies to be tested at the site was issued in 2001, and SER was chosen from the proposals received.

Construction was initiated in August 2002 and extraction began on August 30, 2002. Steam injection was initiated on September 1, 2002, and continued until November 19, 2002, when funding for the project was no longer available. Extraction was terminated on November 26, 2002.

Based on the limited duration of the project, it could not be determined conclusively that steam injection would be capable of heating the entire treatment area to the target temperature. The vapor and water treatment system employed by the vendor effectively treated these effluent streams to meet discharge limitations. It was concluded that for SER to be successful for the remediation of the site, extensive characterization would be needed and extremely long injection times would be required. No cost information was provided.

APPENDIX A

SUMMARY OF 383 CASE STUDIES

Appendix A is only available in the online version of this report and can be downloaded from the Roundtable Web site at: *http://www.frtr.gov.*

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Solid Waste and
Emergency Response
(5102P)

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