Abstracts of Remediation Case Studies

Volume 8

Federal Remediation Technologies Roundtable
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Prepared by the

Member Agencies of the
Federal Remediation Technologies Roundtable

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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 19 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 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 case study reports and abstracts are organized by technology, and cover a variety of *in situ* and *ex situ* treatment technologies and some containment remedies. The case study reports and abstracts are available on a CD-ROM, which contains a total of 361 remediation technology case studies (the 19 new case studies and 342 previously-published case studies). Appendix A to this report identifies the specific sites, technologies, contaminants, media, and year published for the 361 case studies.

Abstracts, Volume 8, covers a wide variety of technologies, including full-scale remediations and large-scale field demonstrations of soil, groundwater, and sediment treatment technologies. Additional abstract volumes will be prepared as agencies prepare additional case studies.

2004 Series

CD-ROM: FRTR Cost and Performance Case Studies and Related Information, 5th Edition; EPA-542-C-04-004; June 2004

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

Accessing Case Studies

The case studies and case study abstracts are available on the Internet through the Roundtable web site at: http://www.frtr.gov/costperf.htm. The Roundtable web site 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, a limited number of copies of the CD-ROM and Abstracts - Volume 8 are available free of charge by mail from NSCEP (allow 4-6 weeks for delivery), at the following address:

U.S. EPA/National Service Center for Environmental Publications (NSCEP)
P.O. Box 42419
Cincinnati, OH 45242
Phone: (513) 489-8190 or
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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 remediation and demonstration-scale projects. At this time, the Roundtable is publishing a CD-ROM (5th Edition), which contains a total of 361 remediation technology case studies (19 new case studies and 342 previously-published case studies), 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 identify and describe the primary factors that affect cost and performance of a given technology. Factors that may affect project costs include economies of scale, concentration levels in contaminated 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 contain varying levels of detail, reflecting the differences in the availability of data and information about the application.

The case study abstracts in this volume describe a wide variety of *ex situ* and *in situ* soil treatment technologies for both soil and groundwater. Contaminants treated included chlorinated solvents; petroleum hydrocarbons and benzene, toluene, ethylbenzene, and xylenes; polycyclic aromatic hydrocarbons; pesticides and herbicides; metals; and radioactive materials.

Table 1 provides summary information about the technology used, contaminants and media treated, and project duration for the 19 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 be dollars 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 361 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. All projects shown in Appendix A are full-scale unless otherwise noted.

Table 1. Summary of Remediation Case Studies

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated)	Project Duration	Highlights
	Volatiles-Halogenated	BTEX and/or TPH	Pesticides/Herbicides	PAHs	Metals	Radionuclides			
***In Situ* Soil Treatment**									
Soil Vapor Extraction (SVE)									
Multiple (2) Dry Cleaner sites - *In situ* SVE (SVE)							Soil and Groundwater	Various dates from February 1994 - June 2001	Use of *in situ* SVE to treat soil and groundwater contaminated with chlorinated solvents at dry cleaner sites
Multiple (3) Dry Cleaner Sites - *In Situ* Treatment (SVE, *In Situ* Chemical Oxidation)							Soil, Groundwater, and DNAPL	Various dates from April 2002 - August 2002	Use of *in situ* heat SVE and *in situ* chemical oxidation to treat chlorinated solvents in soil and groundwater at dry cleaner sites
Multiple (4) Dry Cleaners - SVE and SVE Used with Other Technologies (SVE, Air Sparging, Chemical Reduction, Pump and Treat, Monitored Natural Attenuation, Multi Phase Extraction)							Soil, Groundwater, and DNAPL	Various dates from June 1998 - August 2003	Use of SVE and SVE used with other technologies to treat groundwater contaminated with chlorinated solvents and BTEX at dry cleaner sites
East Multnomah County Groundwater Contamination Site, OR (SVE, Pump and Treat, Air Sparging)							Soil, Groundwater, and LNAPL	June 1991 - ongoing	Use of SVE, pump and treat, and air sparging to treat soil and groundwater contaminated with chlorinated solvents
Other *In Situ* Soil Treatment									
Castle Airport and Various Sites, CA (Bioventing)							Soil	March - October 1998	Field demonstration of natural pressure-driven passive bioventing to treat soil contaminated with petroleum
Morses Pond Culvert, MA (Chemical Reduction)							Soil (1,025 yd^3)	September - October 2001	Use of *in situ* chemical reduction using calcium polysulfide to treat soil contaminated with chromium
Young-Rainy Star Center (formerly Pinellas) Northeast Area A, FL (ET-DSP™)							Soil and Groundwater	September 2002 - March 2003	Use of steam enhanced extraction and Electro-Thermal Dynamic Stripping Process (ET-DSP™) to treat soil and groundwater contaminated with chlorinated solvents

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated)	Project Duration	Highlights
	Volatiles-Halogenated	BTEX and/or TPH	Pesticides/Herbicides	PAHs	Metals	Radionuclides			
***Ex Situ* Soil/Sediment Treatment**									
Thermal Desorption									
Fort Ord, CA (Thermal Desorption)							Debris/Slag/Solid and Off-gas	October 2002	Field demonstration of thermochemical conversion (thermal treatment) to remediate demolition debris contaminated with heavy metals
Vitrification									
Hazen Research Center and Minergy GlassPack Test Center, WI (Vitrification)							Sediment	January 2001 (dryer evaluation) August 2001 (melter evaluation)	Field demonstration of vitrification to remediate sediment contaminated with PCBs, other organics, and metals
***In Situ* Groundwater Treatment**									
Bioremediation									
Former Industrial Property, CA (Bioremediation - HRC®)							Groundwater	May 2000 - ongoing	Use of enhanced *in situ* bioremediation using HRC® to treat VOC-contaminated groundwater
Moss-American Site, WI (Bioremediation - Permeable Reactive Barrier)							Groundwater	October 2000 - ongoing	Use of a funnel and gate treatment system combined with biotreatment to treat groundwater contaminated with PAH and BTEX
National Environmental Technology Test Site, CA (Bioremediation - Propane Biosparging)							Groundwater	May 2001 - March 2002	Field demonstration of bioremediation (propane biosparging) to treat groundwater contaminated with MTBE

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated)	Project Duration	Highlights
	Volatiles-Halogenated	BTEX and/or TPH	Pesticides/Herbicides	PAHs	Metals	Radionuclides			
Naval Air Station New Fuel Farm Site, NV (Bioremediation - Bioventing, Free Product Recovery)							Groundwater and LNAPL	4 months	Field demonstration of prepump separation technologies to treat groundwater contaminated with LNAPL
Naval Base Ventura County, CA (Bioremediation)							Groundwater	September - December 2002	Use of bioremediation (MTBE biobarrier) to assess reduction in MTBE concentrations
Savannah River Site Sanitary Landfill (SLF), SC (Bioremediation - Biosparging)							Groundwater	October 1999 - ongoing	Use of biosparging using horizontal wells in conjunction with a cap, to treat chlorinated solvents in groundwater beneath a sanitary landfill
Chemical Reduction									
Hunter's Point Ship Yard, Parcel C, Remedial Unit C4, CA (Chemical Reduction - Ferox^{sm})							Groundwater	December 5 - 23, 2002	Field demonstration of chemical reduction using Ferox^{sm} injection to treat groundwater contaminated with chlorinated VOCs
Naval Air Engineering Station (NAES) Site (Area I), NJ (Chemical Reduction)							Groundwater (1,800 ft^3 or 13,500 gals)	February - March 2002 (pilot test)	Use of chemical reduction to conduct a pilot test of Bimetallic Nanoscale Particle injection to remediate groundwater contaminated with chlorinated hydrocarbons

Table 1. Summary of Remediation Case Studies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated)	Project Duration	Highlights
	Volatiles-Halogenated	BTEX and/or TPH	Pesticides/Herbicides	PAHs	Metals	Radionuclides			
Other *In Situ* Groundwater Treatment									
Del Norte County Pesticide Storage Area Superfund Site, CA (Air Sparging and Pump and Treat)							Groundwater	April 1990 - October 1997 March 1994 - November 1996 (Air Sparging)	Use of air sparging, in conjunction with pump and treat, to remediate groundwater contaminated with 1,2-dichloropropane (DCP) and other contaminants at a pesticide storage area
Multiple (2) Dry Cleaners - In Well Air Stripping (In Well Air Stripping and Pump and Treat)							Groundwater and Soil	Various dates from September 1994 - December 10, 1997	Use of in well air stripping and pump and treat to treat chlorinated solvents in groundwater at dry cleaner sites

* Principal contaminants are one or more specific constituents within the groups shown that were identified during site investigations

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**					
Soil Vapor Extraction (SVE)					
Multiple (2) Dry Cleaner sites - *In situ* SVE (SVE)	T - $182,903.63 (Oxboro) D - $34,500 (Eastgate)	Not Provided	Not Provided	Not Provided	Oxboro Cleaners: Clay lens at 10 ft bgs held most of the PCE in place, making SVE easier to implement
Multiple (3) Dry Cleaner Sites - *In Situ* Treatment (SVE, *In Situ* Chemical Oxidation)	OA - $50,000 (Former Market Place)	Not Provided	Not Provided	$39/yd^3 (Denver Colorado Dry Cleaner)	Former Market Place: Chemical oxidation system shut itself down frequently because it was not designed to meet specifications
Multiple (4) Dry Cleaners - SVE and SVE Used with Other Technologies (SVE, Air Sparging, Chemical Reduction, Pump and Treat, Monitored Natural Attenuation, Multi Phase Extraction)	T - $300,000 (Colonial) AO - $300,000 (Long Prairie)	Not Provided	2,313 lbs (MPE and SVE at Midway)	Not Provided	Long Prairie Cleaners: Aggressive source removal led to a decrease in contaminant plume concentrations, making SVE easier to implement
East Multnomah County Groundwater Contamination Site, OR (SVE, Pump and Treat, Air Sparging)	Treatment - $406,000 Groundwater extraction - $2,000,000	Not Provided	958 lbs of VOC	$2,540/lb	Early on-site groundwater extraction provided the greatest annual rate of pounds of mass removed, reinforcing the value of early near source Interim Removal Action Measure (IRAM) actions.

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
Other *In Situ* Soil Treatment					
Castle Airport and Various Sites, CA (Bioventing)	Not Provided	Not Provided	Not Provided	$1.93/yd^3 (estimated for full scale) $2.09/yd^3 (conventional bioventing)	Suitability of lithology/stratigraphy, depth to groundwater, and natural air flow rates
Morses Pond Culvert, MA (Chemical Reduction)	T - $119,719 Calcium polysulfide injection - $69,296 Labor - $13,900 Installation of injection wells & collection of soil borings - $36,523	1,025 yd^3	Not Provided	Not Provided	Soil geology, moisture content, and pH
Young-Rainy Star Center (formerly Pinellas) Northeast Area A, FL (ET-DSP^{TM})	T - $3,800,000	Not Provided	3,000 lbs	Not Provided	Efficiency of vapor recovery system
***Ex Situ* Soil/Sediment Treatment**					
Thermal Desorption					
Fort Ord, CA (Thermal Desorption)	C - $1,950,000 (estimated) AO - $987,00	Not Provided	Not Provided	$117/ton (based on a projection of processing 8,450 tons/year)	Requirement of a relatively simple dry filtration system to treat off-gas
Vitrification					
Hazen Research Center and Minergy GlassPack Test Center, WI (Vitrification)	Not Provided	Not Provided	Not Provided	$38.72/ton (estimated for full-scale)	Amount of moisture contained in the sediment

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**					
Bioremediation					
Former Industrial Property, CA (Bioremediation - HRC®)	Two applications of HRC® - $107,000 Direct push injections - $30,000 Monitoring & analysis (May - July 2000) - $130,000	Not Provided	Not Provided	Not Provided	A one-time application process with no ongoing operation and maintenance activities
Moss-American Site, WI (Bioremediation - Permeable Reactive Barrier)	Not Provided	Not Provided	Not Provided	Not Provided	Low levels of dissolved oxygen in the treatment gates required the installation of well packers and an attempt to install inflatable bladder packers
National Environmental Technology Test Site, CA (Bioremediation - Propane Biosparging)	D - $333,288 (C - $122,311 AO - $184,647) P - $145,600	Not Provided	Not Provided	Not Provided	pH and permeability of saturated zone soils
Naval Air Station New Fuel Farm Site, CA (Bioremediation - Bioventing, Free Product Recovery)	D - $70,000 P - $309,000	Not Provided	Not Provided	$10/gal of fuel removed	High LNAPL production rates require larger liquid traps and production rates to handle the additional flow
Naval Base Ventura County, CA (Bioremediation)	Biobarrier installation - $307,200 AO - $77,486 per year	Not Provided	Not Provided	Not Provided	The conditions at the site showed that biostimulation (aeration only) was a viable option and bioaugmentation was not necessary
Savannah River Site Sanitary Landfill (SLF), SC (Bioremediation - Biosparging)	Installation of two wells - $1 million Construction of pad/well piping - $750,000 AO -$440,000	Not Provided	Not Provided	Not Provided	Clay content of soil, hydraulic conductivity, and depth to groundwater

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
Chemical Reduction					
Hunter's Point Ship Yard, Parcel C, Remedial Unit C4, CA (Chemical Reduction - Ferox^{sm})	D - $146,665	Not Provided	Not Provided	$117/yd^3	Most of the reduction in TCE concentrations occurred during the first 3 weeks of the demonstration, indicating that less monitoring would be needed for future applications
Naval Air Engineering Station (NAES) Site (Area I), NJ (Chemical Reduction)	Not Provided	1,800 ft^3 (13,500 gals)	Not Provided	Not Provided	Concentration of the Bimetallic Nanoscale Particle (BNP) suspension and number of injection points
Other *In Situ* Groundwater Treatment					
Del Norte County Pesticide Storage Area Superfund Site, CA (Air Sparging and Pump and Treat)	AO - $166,518 (1995) AO - $106,928 (1996) AO - $84,211 (1997)	Not Provided	Not Provided	Not Provided	High silt and clay content of the soil, and chemical properties of 1,2-dichloropropane
Multiple (2) Dry Cleaners - In Well Air Stripping, (In Well Air Stripping and Pump and Treat)	T - $773,716 (Schloff)	Not Provided	Not Provided	Not Provided	Schloff Chemicals: system required frequent maintenance Former Base: System was unable to achieve design pumping rates

[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.

IN SITU SOIL TREATMENT ABSTRACTS

In Situ Soil Vapor Extraction (SVE) at Two Dry Cleaner Sites, Various Locations

Site Name:
Multiple (2) Dry Cleaner sites - *In situ* SVE

Location:
Eastgate: Memphis, TN
Oxboro: South Bloomington, MN

Period of Operation:
- Eastgate: February 1994 - November 1996; System reactivation in March 2001 - June 2001 (trial period)
- Oxboro: October 10, 1997 - Not specified

Cleanup Authority:
State

Purpose/Significance of Application:
Use of *in situ* SVE to treat soil and groundwater contaminated with chlorinated solvents at dry cleaner facilities.

Cleanup Type:
Full scale

Contaminants:
1,1-Dichloroethene (1,1 DCE), 1,2-Dichloroethene (1,2 DCE), cis-1,2-Dichloroethene (cis-1,2 DCE), Methylene Chloride, Tetrachloroethene (PCE); Trichloroethene (TCE), Vinyl Chloride, Benzene, Toluene, Acetone, Naphthalene
- Eastgate: Plume size = 120,000 ft^2
  - Halogenated Volatiles - 1,1-DCE- 13 µg/L; 1,2-DCE - 1,300 µg/L; cis-1,2-DCE - 1,000 µg/L; methylene chloride - 0.55 µg/L; PCE - 2,100 µg/L; TCE -1,200 µg/L; vinyl chloride - 1.1 µg/L; PCE soil concentrations - 7,170 µg/kg
  - Non-Halogenated Volatiles - benzene- 1.7 µg/L; toluene - 0.63 µg/L; acetone - 37,000 µg/L
- Oxboro:
  - Halogenated Volatiles - 1,1-DCE - 13 µg/L; 1,2-DCE - 3.4 µg/L; PCE - 37 µg/L; TCE - 58 µg/L
  - Non-Halogenated Volatiles: Naphthalene - 2.2 µg/L; Acetone - 24 µg/L; PCE in soil - 1 µg/kg

Waste Source:
Waste and wastewater from dry cleaning operations

Contacts:
Varied by site

Technology:
In Situ Soil Vapor Extraction
- Eastgate: Between 1994 and 1996, system operated under pulse venting techniques, involving turning off the system for shorter periods of time. The 2001 trial period involved 24-hour per day operations, with an airflow rate of 300 cfm. A 6-hour per day pulse mode was initiated in March and continued until cessation of operations in June. A total of 2,000 lbs of granular activated carbon was used to treat the soil vapor.
- Oxboro: *In situ* SVE system included soil venting wells and a blower system operation checked weekly during first three weeks of operation and monthly thereafter; monitoring included air flow rates, vacuum, and total organic vapor; no specific operating data provided

Type/Quantity of Media Treated:
Soil, Groundwater
- Eastgate:
  - Depth to groundwater - perched groundwater at 40 ft with a basal fluvial aquifer at 70 ft
  - Subsurface geology - Loess deposits of 20 to 25 ft of clayey silts overlying fluvial material (50 to 80 ft) underlain by the Jackson-upper Claiborne confining bed, encompassing the Jackson Clay and the Cockfield Cook Mountain Formations (125 ft thick)
  - Conductivity - $2.55x10^{-5}$ to $3.97x10^{-5}$ ft/day (depths between 8 and 28 ft)
  - Groundwater gradient - 0.001 to the ESE (perched zone)
- Oxboro:
  - Depth to groundwater - 40 ft
  - Subsurface geology - Tan and black gravel/silt (0-2 ft); Dark red sand/gravel (5-35 ft); sand/cobbles (35-40 ft)

Regulatory Requirements/Cleanup Goals:
- Eastgate:
  - Groundwater- PCE - 5 µg/L; TCE - 5 µg/L; 1,1 DCE - 7 µg/L; cis-DCE - 70 µg/L; 1,2 DCE total - 70 µg/L
  - Soil- PCE - 500 µg/kg
- Oxboro: Clean up goals not identified

In Situ Soil Vapor Extraction (SVE) at Two Dry Cleaner Sites, Various Locations (continued)

Results:
- Eastgate:
  - Approximately 1,350 lbs of PCE and TCE were removed during initial operations (1994-1996).
  - During 2001 trial period, approximately 0.16 lbs of total PCE and TCE was recovered from both deep and shallow extraction wells. The system was terminated upon verification that a negligible volume of mass was entering the system; next step is natural attenuation to further reduce contamination.
- Oxboro:
  - Soil - PCE concentration decreased from 160 mg/m^3 on October 20, 1997 to 2.3 mg/m^3 on May 8, 1998.
  - DCE was detected at a concentration of 7.2 mg/m^3 in the October 20, 1998 sample, but was not detected in the remaining samples.
  - Cleanup goals were reported to have been met "within a couple of years"

Costs:
- Eastgate: $34,500 (trial period)
- Oxboro: $182,906.63 (total cost for clean up)

Description:
In situ SVE was conducted at two dry cleaner sites contaminated with chlorinated organic compounds from leaks, spills, or dumping of dry cleaning solvents or waste waters. The concentrations of PCE and TCE contamination varied by site with levels of PCE in groundwater as high as 2,100 : g/L and TCE in groundwater as high as 1,200 : g/L. Levels of PCE in soil were as high as 7,170 : g/kg and 1 : g/kg, respectively. The remediations included full-scale *in situ* SVE and a trial period where the *in situ* SVE system was operated under pulse venting techniques, involving turning off the system for shorter periods of time.

At the Eastgate site, approximately 1,350 lbs of PCE and TCE were removed during the 2-year full-scale operation. An additional 0.16 lbs of contaminants were removed during the trial period. The system operation was terminated in June 2001 based on the negligible amount of contaminant mass entering the system. Natural attenuation is planned to further reduce the contaminant levels.

At the Oxboro site, as of October 1997, soil vapor concentrations of PCE decreased from 160 mg/m^3 to 2.3 mg/m^3. As of October 1998, soil vapor concentrations of DCE decreased to 7.2 mg/m^3 in one sample and was not detected in remaining samples.

In Situ Treatment at Three Dry Cleaner Sites, Various Locations

Site Name:
Multiple (3) Dry Cleaner Sites - *In Situ* Treatment

Location:
- Former Market Place Shopping Center Site, Hilton Head, SC
- Denver Colorado Dry Cleaner, Denver, CO
- United Cleaners Site #1973, Lemont, IL

Period of Operation:
- Former Market Place - June 1, 2002
- Denver Colorado - April 2001
- United Cleaner #1973 - August 26, 2002

Cleanup Authority:
State

Purpose/Significance of Application:
Use of *in situ* treatment technologies to treat chlorinated solvents in groundwater at dry cleaner facilities

Cleanup Type:
Full-scale and field demonstration

Contaminants:
Tetrachloroethene (PCE); Trichloroethene (TCE); Dichloroethene (DCE); Volatiles-Halogenated
- Former Market Place: PCE - 27,000 : g/L; Plume size: 28,600 ft^2
- Denver Colorado - PCE - 18,200 : g/L; TCE - 12,600 : g/L
- United Cleaners #1973 - PCE - 4,300,000 : g/kg; TCE - 170,000 : g/kg; cis-1,2-DCE - 144,000 : g/kg; trans-1,2-DCE - 865 : g/kg; 1,1,1-trichloroethane - 5,610 : g/kg; 1,1-Dichloroethene - 306 : g/kg

Waste Source:
Waste and wastewater from dry cleaning operations

Contacts:
Varied by site

Technology:
In Situ Chemical Oxidation (ISCO); *In Situ* Heat Soil Vapor Extraction (HSVE)
- At the Former Market Place site: ISCO with ozone was implemented; followed by monitored natural attenuation (MNA); technology included ozone air sparge and C-sparging with ozone injection
- At the Denver Colorado site: ISCO using ISOTEC's Modified Fenton's Reagent was implemented; two phases - two injection events for the area inside the former dry cleaner building to treat contaminant source; three injection events to treat the entire groundwater plume; a total of 26,987 gallons of ISOTEC reagents were injected through 244 temporary injection locations; 1st phase: direct push locations (nine points per event) inside former dry cleaner building; direct push locations were on 15-ft centers and shifted laterally between events; 2nd phase: direct push injection points were spaced on 30-ft centers based on a conservative radius of influence of 15 ft determined from a pilot test; direct push locations for second and third injection events shifted laterally from first event locations to ensure complete reagent coverage across the site
- At the United Cleaners #1973 site, *in situ* HSVE was implemented; system used a series of in-ground coils to transfer heat, increase volatility of organic contaminants, and facilitate removal of volatile solvents from the soil using a vapor extraction system; after operation for 120 days, the system was modified slightly, including adding heat points and an extraction well

Type/Quantity of Media Treated:
Groundwater; Soil; DNAPL
- Former Market Place:
  - Depth to groundwater: 10 ft bgs
  - Subsurface geology: fine silty sands, clay and shellhash
- Groundwater gradient: 0.006 ft/ft
- Denver Colorado
  - Depth to groundwater: 9 ft bgs
  - Subsurface geology: sands, silts, and clay overlying siltstone bedrock. Clay, 0-9 ft bgs; permeable sand and gravel, 9-12 ft bgs; siltstone, 12+ ft bgs; subsurface conditions appear to be relatively uniform throughout the plume area; groundwater at the site appears to be confined to the permeable zone overlying the siltstone;
  - Groundwater gradient: 0.121 ft/ft to the east
- United Cleaners #1973
  - Native soils in the vicinity are Wadsworth and Haeger Members of the Wedron Formation; Silty and pebbly drifts containing local areas of sandy to gravely till in outer moraines. Bedrock in the site consists of Silurian-aged dolomite

In Situ Treatment at Three Dry Cleaner Sites, Various Locations (continued)

Regulatory Requirements/Cleanup Goals:
- Former Market Place - Groundwater: <5 : g/L of PCE; <5 : g/L of TCE; <70 : g/L of cis-1,2-DCE, <100 : g/L of trans-1,2-DCE, <2 : g/L of vinyl chloride
- Denver Colorado - None available
- United Cleaners #1973 - site-specific cleanup goals: 1,1-DCA - 1,830,000 : g/kg; cis-1,2-DCE - 1,900,000 : g/kg; PCE - 100,000 : g/kg; TCE - 440,000 : g/kg; vinyl chloride - 250 : g/kg

Results:
- Former Market Place - MW-2I (an intermediate well with the highest initial concentration on site) showed a reduction of PCE from 26,800 : g/L to 704 : g/L
- Denver Colorado:
  - Following final injection event, PCE concentrations ranged from 70 : g/L to non-detect (ND); average PCE concentration across the site was reduced from 3,267 : g/L to 39.6 : g/L, a reduction of 99%. PCE concentration in MW-5 was reduced from 925 : g/L to 51 : g/L, a reduction of 94%.
  - TCE concentrations ranged from 170 : g/L to ND; average TCE concentration across the site was reduced from 1,387.8 : g/L to 64.9 : g/L, a reduction of 95%. TCE concentration in MW-5 was reduced from 550 : g/L to 52 : g/L, a reduction of 90%.
  - Average TCE concentrations in all wells (including source area wells) was reduced by 98%.
- United Cleaners #1973 - PCE soil concentrations reduced from 4,300,000 : g/kg to 2,400,000 : g/kg. Additionally, one of the two areas where the remediation system was installed was completely cleaned up. The vapor extraction system was turned off in this area. Extraction has continued only at those areas where the objectives have not yet been met.

Costs:
- Former Market Place - Cost for operation and maintenance (O&M) - $50,000
- Denver Colorado - $39/cubic yard of saturated soil treated. Costs include pilot scale tests, full-scale treatment, and direct push injection equipment and labor.
- United Cleaners #1973 - Not available

Description:
In situ treatment was conducted at three dry cleaner sites contaminated with chlorinated solvents from dry cleaning operations, with PCE and TCE as the primary contaminants in groundwater. The technologies implemented included ISCO and HSVE. The concentrations of PCE and TCE contamination varied by site with levels of PCE in groundwater as high as 27,000 : g/L and TCE in groundwater as high as 12,600 : g/L. Levels of PCE and TCE in soil were as high as 4,300,000 : g/kg and 170,000 : g/kg, respectively. The remediations, including full-scale and demonstration-scale projects, involved the subsurface injection of ozone and ISOTEC's Modified Fenton's Reagent, and the use of in-ground coils to transfer heat and remove volatile contaminants.

At the Former Market Place site, PCE concentrations were reduced substantially, but still remained above the cleanup goal of 5 : g/L. At the Denver Colorado site, PCE concentrations across the site were reduced by 99%, and TCE concentrations were reduced by 90%. At the #1973 site, PCE soil concentrations were reduced by approximately 50%. Additionally, one of the two areas where the remediation system was installed was completely cleaned up. At the Denver Colorado site, the cost of implementing ISCO was approximately $39/cubic yard of saturated soil treated. At the United Cleaners #1973 site, it was useful to have remote access capability to check the system during operation.

Soil Vapor Extraction (SVE) and SVE Used with Other Technologies at Four Dry Cleaner Sites, Various Locations

Site Name:	**Location:**	**Cleanup Authority:**	**Cleanup Type:**	**Waste Source:**	**Contacts:**
Multiple (4) Dry Cleaners - SVE and SVE Used with Other Technologies	Shorty Cleaners, Stillwater, MN Long Prairie, Long Prairie, MN Colonial Square Mall, MN Midway Plaza, St. Paul, MN	State	Full scale	Waste and wastewater from dry cleaning operations	Varied by state

Period of Operation:
Shorty: SVE - June 1998; ISCO - pending as of August 2003
Long Prairie: SVE - April 1997
Colonial: June 4, 1999
Midway: February 3, 1999

Purpose/Significance of Application:
Use of SVE and SVE used with other technologies to treat chlorinated solvents and BTEX in groundwater at dry cleaner facilities

Contaminants:
Tetrachloroethene (PCE); Trichloroethene (TCE); BTEX; Volatiles-Halogenated; Volatiles-Nonhalogenated; Semivolatiles-Nonhalogenated

Shorty:
- Groundwater - PCE - 50,000 : g/L; TCE - 5,500 : g/L; cis-1,2-dichloroethene - 5,000 : g/L; vinyl chloride - 430 : g/L; benzene - 3.3 : g/L; toluene - 34 : g/L; Naphthalene - 1,500 : g/L
- Soil - PCE - 1,200 mg/kg; TCE - 16 mg/kg; cis-1,2-dichloroethene - 6.1 mg/kg; benzene - 4 mg/kg; naphthalene - 23 mg/kg

Long Prairie:
- Groundwater - PCE - 150,000 : g/L; TCE - 760 : g/L; cis-1,2-DCE - 250 : g/L; vinyl chloride - 3 : g/L.
- Soil - PCE - 7,300,000 : g/kg; TCE - 15 : g/kg; cis-1,2-DCE - 10 : g/kg

Colonial:
- Groundwater - PCE - 3,500 : g/L; TCE - 55 : g/L; cis-1,2-DCE - 62 : g/L
- Soil - PCE - 150,000 : g/kg; cis-1,2-DCE - 110 : g/kg; methylene chloride - 3.6 : g/kg

Midway:
- Groundwater - PCE - 41,000 : g/L; TCE - 840 : g/L; cis-1,2-DCE - 100 : g/L; methylene chloride - 34 : g/L; ethylbenzene - 120 : g/L; benzene - 22 : g/L; acetone - 140 : g/L
- Soil - PCE - 11,000 mg/kg; methylene chloride - 1.3 mg/kg; acetone - 0.32 mg/kg

Technology:
SVE, ISCO, MNA, P&T, MPE, AS

Shorty: Soil Vapor Extraction (SVE), *In Situ* Chemical Oxidation (ISCO), and Monitored Natural Attenuation (MNA)
- SVE system had 6 extraction points, with piping for the system buried 4 ft below grade; soil vents were inserted through old soil boring locations *in situ*; radius of influence was assumed to be 25 ft; air flow operated continuously with exhaust air flow typically around 125 scfm
- The system was turned off after 24 months
- MNA is being assessed through semi-annual groundwater monitoring

Long Prairie: SVE, MNA, Pump and Treat (P&T)

Colonial: SVE, MNA
- SVE system comprised of 5 vents; side-mounted SVE system placed outside the rear of the store; system has a design flow of 300 cfm extracted at 24 inches of water vacuum.

Midway: SVE, Multi Phase Extraction (MPE), Air Sparging (AS)
- MPE implemented in one area of the site; AS/SVE implemented in another area of the site
- Total of 10 MPE extraction wells, 7 SVE wells, and 2 AS wells

Type/Quantity of Media Treated:
Soil, Groundwater, Dense Non-aqueous Phase Liquids (DNAPLs)

Shorty:
- Depth to groundwater - 10 to 12 ft bgs
- Subsurface geology - Complex glacial lithology: 0-11 ft silty sand fill; 11-20 ft sand to silty sand (water bearing unit); 20-40 ft sand to silty sand with clay layers (clay layers are 0.25 to 11 inches thick); 40-60 ft gravelly sand; 60-120 ft bedrock
- Shallow aquifer conductivity - 0.837 to 5.47 ft/day; Deep aquifer conductivity - 0.211 to 33.40 ft/day
- Groundwater gradient: 0.318 ft/ft

Long Prairie:
- Depth to groundwater - 5-5 ft bgs
- Subsurface geology - Series of interbedded glacial till and sand and gravel outwash deposits that extend to at least 200 feet below grade; glacial drift deposits up to 700 ft thick ; western 2/3 of site underlain by sand and gravel outwash deposits that extend from the ground surface to a till layer that is about 60 to 80 feet below grade; eastern 1/3 of site is underlain by upper and lower outwash layers that are separated by an approximately 20-ft thick layer that acts as an aquitard separating the upper and lower outwash layers.

Soil Vapor Extraction (SVE) and SVE Used with Other Technologies at Four Dry Cleaner Sites, Various Locations (continued)

Colonial:
- Depth to groundwater - 36 to 105 ft bgs
- Subsurface geology - 0-10 ft yellow brown sand, dry, fine to coarse fill; 10-15 ft layered silt and sand; 11.5-12 ft Quaternary-aged loamy till, sandy till and lacustrine clay and silt deposits; multiple sand stringers in the predominantly silty soil; sediments overlying bedrock estimated to be 150 to 200 ft in the area; two discrete saturated zones that may be present beneath the site.
- Aquifer conductivity - 1.18 ft/day to 1.29 ft/day
- Groundwater gradient - 0.04 to 0.05 ft/ft

Midway:
- Depth to groundwater - 25.5 to 33 ft bgs
- Subsurface geology - 0-11 ft: fine to medium, red-brown sand; 11-22 ft: silty to clayey moderately stiff, red-brown till; 22-26 ft: silty, fine to medium, tan-brown sand; 26-28 ft: dry, stiff to very dense, clayey, fine to medium, gray sand overlaying a well sorted fine to medium gray sand, which is laterally discontinuous and averages less than 3 ft in thickness; groundwater in the unconsolidated glacial sediments is not hydraulically connected across the entire site; undulations in the bedrock surface appear to be the primary factor controlling the hydrogeology of the unconsolidated sediments at the site
- Aquifer conductivity - 4 to 9 ft/day
- Groundwater gradient - 0.01 ft/ft

Regulatory Requirements/Cleanup Goals:
Shorty: Groundwater - Eliminate hot spot at MW-3; Soil - Reach asymptotic removal rates of VOCs for three consecutive quarters.
Long Prairie: Groundwater - MCLs: 5 : g/L for PCE and TCE; 70 : g/L for DCE; Soil - PCE - 1,200 : g/kg
Colonial: PCE - 3.8 : g/L (ecological criteria due to the presence of wetlands); no numerical standards set for soil
Midway - Groundwater - PCE: 5 : g/L and steady-state in groundwater; soil - PCE: 19,900 : g/kg

Results:
Shorty:
- Concentration of degradation products has increased steadily over time, although the concentration of PCE remains high
- PCE concentration in groundwater decreased by 50% (6,200 : g/L to 3,000 : g/L) during operation of SVE, but spiked up again (10,000 : g/L) after SVE system was shut off

Long Prairie:
- Mass of chlorinated solvent contamination in the plume has been reduced, especially near the source area; concentration of chlorinated solvent contamination in the groundwater has decreased by three orders of magnitude near the source area.
- Soil cleanup goals were met after operation of the SVE system at the source area for approximately three years
- Active remediation will continue until MCLs are met or until data show MNA to be effective to meet MCLs

Colonial:
- Quarterly monitoring from 1997 to 2002 indicates that the groundwater plume is stable
- SVE system operated continuously for 36 months; system was shut down and removed after a year of groundwater monitoring following SVE operation

Midway:
- Mass removal for both MPE and SVE from February 2, 1999 to June 8, 2001 is 2,313 pounds
- Average daily contaminant recovery declined from a high of 22 lb/day to 0.2 lb/day (in January 2001)
- Exponential decay analysis indicates that average daily recovery has reached an asymptotic level
- MPE system was authorized to be shut down on December 11, 2001
- AS/SVE system was shut down after one year of operation
- Soils meet cleanup goal of 19,900 : g/kg, therefore, closure has been requested for the soils

Costs:
Shorty:
Not provided

Long Prairie:
$300,000 annual operation and maintenance (O&M) costs

Colonial:
Total cost was approximately $300,000

Midway:
Not provided

Description:
SVE was implemented together with other technologies at four dry cleaner sites in Minnesota contaminated with chlorinated solvents and BTEX from dry cleaning operations. Initial concentrations of PCE and TCE in groundwater were as high as 150,000 : g/L and 5,500 : g/L, respectively, and 7,300 mg/kg and 16 mg/kg in soil. The remediation involved SVE with other technologies such as air sparging, *in situ* chemical oxidation, pump and treat, and multi phase extraction.

At the Shorty site, PCE concentrations in the groundwater continue to remain high even though the concentration of degradation products has increased steadily over time. At the Long Prairie and Midway sites, soil cleanup goals were met and the SVE system was shut down. At the Colonial site, the groundwater plume was stable and the SVE system was shut down after operating for 36 months.

At the Long Prairie site, source removal was key to reducing contaminant concentrations.

Groundwater Pump and Treat, Air Sparging, and Soil Vapor Extraction at the Cascade Corporation Site, Troutdale Gravel Aquifer, East Multnomah County Groundwater Contamination Site, OU 2, Gresham, Oregon

Site Name:
East Multnomah County Groundwater Contamination Site

Location:
Gresham, Oregon

Period of Operation:
June 1991 to present

Cleanup Authority:
EPA

Purpose/Significance of Application:
Use of multiple technologies to treat chlorinated solvents in soil and groundwater at the site

Cleanup Type:
Full scale

Contaminants:
Tetrachloroethene (PCE), Trichloroethene (TCE), Cis-1,2-dichloroethene (DCE), Halogenated-Volatiles.

- Volatile organic compounds (VOCs) detected in soil at concentrations as high as 0.09 mg/kg (PCE), 5.5 mg/kg (TCE), and 10 mg/kg (1,2-DCE).
- VOCs in groundwater detected at concentrations as high as 920 : g/L (PCE), 11,000 : g/L (TCE), 13,000 : g/L (1,2-DCE), and 106 : g/L (vinyl chloride).
- Chromium detected in groundwater at concentrations as high as 172 : g/L
- Site noted to also have light non-aqueous phase liquids (LNAPLs)

Waste Source:
Suspected releases from site operations, including overflow from an underground storage tank (UST), spills, and on-site land disposal

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Technology:
Technology: Groundwater pump and treat (P&T), air sparging, and soil vapor extraction (SVE)

- Remedy included multiple technologies for the site
- Air sparging was performed in 2 test wells in the same source area as the Total Fluid Extraction (TFE) wells
- An air sparging pilot test was performed using two air sparge wells to determine if sparging would enhance volatilization of VOCs from groundwater, enhance SVE mass removal rates, and enhance the oxygen levels in groundwater
- SVE was performed using 8 SVE wells and the 13 DPE wells
- SVE was shut down from March to October 1999, followed by seasonal SVE shutdown, and permanently ceased operation in December 2001
- Groundwater was extracted from 5 recovery wells and 13 DPE wells; LNAPLs were extracted using TFE in one source area
- Groundwater extraction rates for individual on-site wells in 1998 ranged from 0.01 to 5 gpm; in September and October 1998, total groundwater extraction rates were estimated to range from 8 to 11 gpm
- An off-site control trench was used to intercept the plume and to protect surface water and an underlying aquifer
- Source area groundwater extraction continued through 2002, at which time pulse pump operation began to cyclically desorb contaminants from the soil matrix during off-cycles and extract contaminants during on-cycles

Type/Quantity of Media Treated:
Soil and groundwater

- TGA consists of gravel with sand, silt, and clay, and is approximately 50 ft thick on-site. Upper TGA materials consist primarily of unconsolidated silty, sandy gravel with cobbles and boulders. The lower TGA is typically an indurated sandstone.
- Depth to groundwater - 10 -12 ft bgs

Groundwater Pump and Treat, Air Sparging, and Soil Vapor Extraction at the Cascade Corporation Site, Troutdale Gravel Aquifer, East Multnomah County Groundwater Contamination Site, OU 2, Gresham, Oregon (continued)

Regulatory Requirements/Cleanup Goals:
Groundwater (: g/L): PCE - 5, TCE - 5, cis-1,2-DCE - 70, vinyl chloride - 2, and chromium (VI) - 100
Soil (mg/kg): PCE - 0.3, TCE - 0.4, cis-1,2-DCE - 4.0, vinyl chloride - 0.008 mg/kg, chromium (VI) - 1,5000 (total waste analysis), 0.86 mg/L (TCLP)

Results:
As of 2003, a total of 958 pounds of VOCs were removed over the 13 year period, consisting of 561 pounds removed from groundwater, 377 pounds removed from soil, and 20 pounds removed as LNAPL. In addition, the TCE plume in the TGA groundwater was significantly reduced.
While the concentrations of the contaminants were reduced, they remained above cleanup levels as of 2003.

Costs:
- Total cost for treatment (without disposal of residues) was approximately $406,000.
- Total cost for groundwater extraction (without disposal of residues) was approximately $2,000,000.
- For the 958 pounds of VOC removed by the system during this time, the unit cost amounts to $2,540 per pound of VOC removed.

Description:
The East Multnomah County (EMC) Groundwater Contamination site covers three square miles in Multnomah County, east of Portland, Oregon, and includes multiple facilities. The Cascade site (OU 2), located within the EMC site consists of those portions of Cascade Corporation's property containing soil or groundwater contamination at levels requiring remedial action. Soil and groundwater at the Cascade site are contaminated with chlorinated solvents, primarily PCE, TCE and cis-1,2-DCE, as well as LNAPL. The Record of Decision (ROD), signed for OU 2 in December 1996, specified the use of multiple technologies, including SVE with destruction of VOCs using catalytic oxidation or equivalent; continued operation of on- and off-site IRAMs (using P&T); expansion of the off-site groundwater extraction trench; extraction of LNAPL by co-pumping LNAPL and groundwater; additional on-site groundwater extraction using existing and new wells; and air sparging using approximately 25 on-site wells.

Performance data available through 2003 showed that a total of 958 pounds of VOCs have been removed over a 13 year operating period, consisting of 561 pounds removed from groundwater, 377 pounds removed from soil, and 20 pounds removed as LNAPL. While contaminant concentrations and plume sizes have decreased, concentrations remain above cleanup levels. Operation of the control trench and groundwater extraction are continuing. A pilot test of bioaugmentation is planned for the source area. In addition, 850 poplar trees were planted in 2000 for future use in treating VOCs in groundwater north of the control trench.

Natural Pressure-Driven Passive Bioremediation at Castle Airport, Merced, CA

Site Name:
Castle Airport and Various Sites

Location:
Merced, CA and Various Locations

Period of Operation:
March 1998 - October 1998 (Castle Airport); varying times for other locations

Cleanup Authority:
Not identified

Purpose/Significance of Application:
Field demonstration of natural pressure-driven passive bioventing of petroleum-contaminated soil

Cleanup Type:
Field demonstration

Contaminants:
Total Petroleum Hydrocarbons (TPH), BTEX
- TPH concentrations in soil as high as 28,000 mg/kg
- BTEX concentrations in soil as high as 12 mg/kg benzene, 80 mg/kg toluene, 40 mg/kg ethylbenzene, and 180 mg/kg total xylenes

Waste Source:
Spills and leaks of jet fuels and gasoline

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Technology:
Natural Pressure-Driven Passive Bioventing
- Uses the force generated by normal daily fluctuations in atmospheric conditions for injecting air into the subsurface; primary advantage over conventional bioventing is that no electrical blower is needed
- 15 DoD sites across the country were screened as possible demonstration sites for passive bioventing; screening criteria included evaluating suitability of lithology/stratigraphy, depth to groundwater, and natural air flow rates, with a minimum criteria for air flow into existing vent wells of at least 1 cfm; report includes summary of information by site and a description of selection process
- Report focuses on Castle Airport, which was selected for the demonstration
- One vent well - 4-in inside diameter, PVC casing, screened between 25 and 85 ft bgs, with three isolated 10-foot screened sections to evaluate airflow rates in three different lithologic zones
- 8 vapor monitoring points, installed at radial distances of 4, 8, 12, and 16 ft
- The radius of influence of the bioventing well was estimated at 42 feet after seven weeks
- The daily airflow rates ranged from 27 to 9,300 cubic ft per day and averaged 3,400 cubic feet per day; peak airflow rates ranged from 5.1 to 15 cfm
- During the 6-month demonstration, six tests conducted to evaluate the technology, including establishing radius of influence and *in situ* respiration; conditions were varied, such as vent well open or closed

Type/Quantity of Media Treated:
Soil
- Three main layers - upper 20 to 25 ft of subsurface comprised of silty sands/sand; underlain by sand to 35 ft; underlain by sand/silty sand
- Air permeability of sands below 25 ft, ranged from 38 to 200 darcies
- Soil moisture - average about 6%

Regulatory Requirements/Cleanup Goals:
- Goals of the demonstration included achieving consistent air flow rate to vadose zone greater than 1 cfm and 1,200 cubic feet per day and a radius of influence greater than 10 feet
- No specific cleanup levels were identified for the demonstration

Natural Pressure-Driven Passive Bioremediation at Castle Airport, Merced, CA (continued)

Results:
- Air supply during demonstration consistently exceeded goals of 1 cfm and 1,200 cubic feet per day; ranged from 27 to 9,300 cubic feet per day and averaged 3,400 cubic feet per day
- The radius of influence was estimated to be 42 feet after seven weeks, exceeding the goal of 10 feet.

As areas near the well are remediated and the oxygen demand is satisfied, the predicted radius of influence would be expected to be 85 feet, comparing favorably to conventional bioventing radius of influence of 110 feet.

Costs:
- The estimated cost of a full-scale passive bioventing system was $1.93 per cubic yard of soil treated; the cost of conventional bioventing was estimated at $2.09 per cubic yard
- Passive bioventing would require the use of 1.5 times as many wells as conventional bioventing, and a treatment time of 4 years instead of 3 years at the Castle Airport Site, however an overall reduction in costs would be achieved by eliminating the capital cost of blowers and the O&M cost of powering the blowers
- A cost comparison between the installation and operation of a full scale passive bioventing and a conventional bioventing system at Castle Airport suggests that the passive system would save approximately $31,300; this cost saving would be significantly greater if electricity were not already available at the site to operate electric blowers for a conventional bioventing system.

Description:
15 DoD sites across the country were screened as possible demonstration sites for passive bioventing; screening criteria included evaluating suitability of lithology/stratigraphy, depth to groundwater, and natural air flow rates, with a minimum criteria for air flow into existing vent wells of at least 1 cfm. A demonstration of natural pressure-driven passive bioventing was performed at Castle Airport in Merced, CA. The petroleum oil and lubricants fuel farm area was the bulk fuel storage and distribution facility for the former AFB located at the site. Soil and groundwater contamination resulted from leaking underground storage tanks and fuel distribution lines and surface spills. The Department of Defense Environmental Security Technology Certification Program (ESTCP), the Air Force Research Laboratory, and Naval Facilities Engineering Service Center, and the Air Force Center for Environmental Excellence (AFCEE) cooperated in conducting the demonstration.

Natural pressure-driven passive bioventing is similar to conventional bioventing with the exception that it uses the force generated by normal daily fluctuations in atmospheric conditions to replace a powered blower for injecting air into the subsurface. During the demonstration, six tests of natural pressure-driven passive bioventing were performed over a six month period. A single well installed to a depth of 65 feet achieved an average daily air flow rate to the vadose zone of 3,400 cubic feet and a radius of influence of 42 feet. As areas near the well are remediated and the oxygen demand is satisfied, the predicted radius of influence would be expected to be 85 feet, comparing favorably to conventional bioventing radius of influence of 110 feet. The projected cost of a full-scale passive bioventing system was $1.93 per cubic yard of soil treated, compared to $2.09 per cubic yard for conventional bioventing.

In Situ Chemical Reduction at the Morses Pond Culvert, Wellesley, Massachusetts

Site Name:
Morses Pond Culvert

Location:
Wellesley, Massachusetts

Period of Operation:
September - October 2001

Cleanup Authority:
EPA

Purpose/Significance of Application:
In situ treatment of chromium-contaminated soils at a railroad embankment where excavation of soils deeper than 4 ft was determined not to be practical or safe due to slope stability and structural concerns.

Cleanup Type:
Full scale

Contaminants:
Chromium, zinc, and lead
1994: Soil chromium concentrations of 100,000 mg/kg, and surface water hexavalent chromium concentration of 210 : g/L. Zinc concentrations above ambient water quality criteria.
1999: Total chromium in soil as high as 129,000 mg/kg and hexavalent chromium as high as 31,000 mg/kg in surface soils located on residential property, the embankment, and areas adjacent to the pond, and levels of total chromium as high as 10,800 mg/kg in soils and sediments in the culvert and cove areas.

Waste Source:
Chromium-laden pigment from former paint factory used as fill material for improving railroad embankment around the culvert.

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Technology:
In situ chemical reduction using calcium polysulfide
- Total of 40 injection well points installed along an embankment, each 10 ft apart to allow for a 5-ft radial distribution of reagent from each well.
- Wells installed to depths ranging from 5 to 25 ft.
- Treatment performed first in western portion of embankment area, followed by eastern portion.
- Total of 56,800 gallons of calcium polysulfide reagent (18% solution) injected.
- Additional area (4 injection points) on western embankment added to *in situ* treatment area.
- Post-treatment soil borings collected from locations of pre-treatment borings and analyzed for total chromium and lead (off-site laboratory) and field screened for hexavalent chromium.

Type/Quantity of Media Treated:
Soil; approximately 1,025 cubic yards treated in total.

Regulatory Requirements/Cleanup Goals:
Non-binding goals for treatment: hexavalent chromium - 200 mg/kg (total) and 1 mg/kg using the Toxicity Characteristic Leaching Procedure (TCLP).

In Situ Chemical Reduction at the Morses Pond Culvert, Wellesley, Massachusetts (continued)

Results:
Post-treatment concentrations in the western portion of the embankment:
Hexavalent chromium: zero to 5,600 mg/kg (with pre-treatment concentrations as high as 11,400 mg/kg)
Total chromium: 140 to 67,000 mg/kg (with pre-treatment concentrations as high as 97,000 mg/kg)
Total lead: 24 to 11,000 mg/kg (with pre-treatment concentrations as high as 32,3000 mg/kg)
Post-treatment concentrations in the eastern portion of the embankment:
Hexavalent chromium: zero to 5,000 mg/kg (with pre-treatment concentrations as high as 11,700 mg/kg)
Total chromium: 92 to 35,000 mg/kg (with pre-treatment concentrations as high as 59,000 mg/kg)
Total lead: 23 to 220 mg/kg (with pre-treatment concentrations as high as 440 mg/kg)

Costs:
- Total cost of approximately $119,719
  - EPA noted that cost for calcium polysulfide injection was $69,296, plus about $13,900 for ERRS contractor labor (injecting reagent), in addition to $36,523 paid to GZA Geoenvironmental, Inc., for installing the injection wells and collecting pre- and post-treatment soil borings.

Description:
The Morses Pond Culvert Site is located in Wellesley, Massachusetts. The southern portion of the site includes an earthen railroad embankment, divided by a culvert into eastern and western portions. It is suspected that chromium-laden pigment from a former paint factory was used as fill material for improving the embankment and was the source of chromium contamination at the site. Due to slope stability and structural concerns with the steep embankment area, *in situ* chemical reduction using calcium polysulfide was selected as the remedy for treating chromium-contaminated soil at the site.

The injection system consisted of a total of 40 well points installed to depths ranging from 5 to 25 ft bgs. A total of 56,800 gallons of calcium polysulfide reagent was injected, treating 1,025 cubic yards of soil. The non-binding goals of treatment for hexavalent chromium were 200 mg/kg and 1 mg/kg using the TCLP. Post-treatment hexavalent chromium concentrations ranged from zero to 5,600 mg/kg in the western embankment, and from zero to 5,000 mg/kg in the eastern embankment. Total chromium concentrations after treatment ranged from 140 to 67,000 mg/kg in the western embankment, and from 92 to 35,000 mg/kg in the eastern embankment. According to the work plan for the site, calcium polysulfide was selected over ferrous sulfate for this application for several reasons, including that less calcium polysulfide would be needed compared to the ferrous sulfate. The total cost for the treatment was approximately $119,719, including $69,296 for the calcium polysulfide, $13,900 in labor costs, and $36,523 for installing the injection wells and collecting pre- and post-treatment soil borings.

Steam Enhanced Extraction and Electro-Thermal Dynamic Stripping Process (ET-DSP™) at the Young-Rainy Star Center (formerly Pinellas) Northeast Area A, Largo, Florida

Site Name: Young-Rainy Star Center (formerly Pinellas) Northeast Area A	**Location:** Largo, Florida
Period of Operation: September 2002 to March 2003	**Cleanup Authority:** RCRA Corrective Action
Purpose/Significance of Application: Steam Enhanced Extraction and ET-DSP™ were combined to treat NAPL contamination in soil and groundwater	**Cleanup Type:** Full scale
Contaminants: Halogenated Volatile Organics, Petroleum Hydrocarbons, DNAPL, and LNAPL • TCE and toluene present as free product; concentrations in soil boring samples were as high as 2,900,000 : g/kg for TCE and 1,000,000 : g/kg for toluene • Dissolved phase VOCs included TCE, cis-1,2-DCE, vinyl chloride, methylene chloride, and toluene; methylene chloride detected as high as 12,000,000 : g/L and TCE as high as 26,000 : g/L	**Waste Source:** Past operation and disposal activities

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Technology:

Steam Enhanced Extraction and Electro-Thermal Dynamic Stripping Process (ET-DSP™)

- Steam Enhanced Extraction and ET-DSP™ were combined to deliver energy to the subsurface, optimize the heating patterns, and maximize contaminant removal during pressure cycling operations; system consisted of:
  - 15 steam injection wells around the perimeter of the treatment cell
  - 28 extraction wells with ET-DSP™ electrodes located below the screened interval for heating of clay of the Hawthorn Group (Hawthorn) and the base of the surficial aquifer
  - 21 combined steam injection-ET-DSP™ wells for heating of the surficial aquifer
  - 2 deep ET-DSP™ electrodes, located in the Hawthorn and without extraction screens
  - 36 temperature-monitoring boreholes distributed across Area A; 8 monitoring wells (in four well pairs) installed outside Area A
- 12 additional shallow steam injection wells were installed based on results of additional soil sampling
- ET-DSP™ was used to preheat the perimeter of the remediation area, the upper Hawthorn, the bottom of the surficial sands, and an interval of the upper sand located above the depth of the steam injection screens; steam injection was used to form a steam barrier around the perimeter of Area A, and to deliver steam energy to heat the site
- When the Hawthorn clay and the outside perimeter were heated sufficiently, the inside upper electrodes and steam injection wells were turned on to heat the entire target volume to temperature; pressure cycling was then induced by creating temporal changes in downhole pressure by varying the steam injection pressures and the electrical heating rate
- Steam injection rates varied between 100 and 5,000 lb/hr; ET-DSP™ delivered a total of 4,700 million British Thermal Units (BTU) to the subsurface
- After heating ceased, extraction was continued during the initial cool-down
- All effluents from the system, including vapors, liquids, and solids were treated; treatment included heat exchange, separations, and carbon adsorption

Steam Enhanced Extraction and Electro-Thermal Dynamic Stripping Process (ET-DSP™) at the Young-Rainy Star Center (formerly Pinellas) Northeast Area A, Largo, Florida (continued)

Type/Quantity of Media Treated:
Soil and Groundwater
- Site hydrogeology at Area A consists of 30 ft of a surficial, unconfined aquifer composed of relatively fine-grained sand, underlain by Hawthorn clay, which acts as a local aquitard; surficial sands range in thickness from 26 - 34 feet (ft) and typically consist of fine-grained, moderately to well-sorted sand, with variable amounts of silt and clay
- Local water table ranges in depth from 1- 6 ft bgs; ground water flows toward the east-southeast at a very low gradient
- Horizontal hydraulic conductivity ranges from $3.5x10^{-4}$ to $3.5 x10^{-3}$ centimeters per second (cm/sec); vertical hydraulic conductivity ranges from $1.06 x10^{-6}$ to $1.06x10^{-4}$ cm/sec.

Regulatory Requirements/Cleanup Goals:
- Soil cleanup goals: TCE - 20,400 : g/kg; DCE - 71,000 : g/kg; methylene chloride - 227,000 : g/kg; toluene - 15,000 : g/kg; TPH - 2,500,000 : g/kg
- Groundwater cleanup goals: TCE - 11,000 : g/L; DCE - 50,000 : g/L; methylene chloride - 20,000 : g/L; toluene - 5,500 : g/L; TPH - 50,000 : g/L

Results:
- Target temperature of greater than 84 /C established across entire treatment cell at a depth of 14 - 34 ft below ground surface (bgs) within 35 days; bulk of the site (14 - 34 ft bgs) was maintained at or above 100 /C for a period of at least 70 days until the beginning of active cooling
- All soil and groundwater samples were below the cleanup goals; many groundwater samples met the more stringent MCLs; an estimated 3,000 lbs of VOCs were removed

Costs:
- The total project subcontract cost was approximately $3,800,000, including all aspects of the project from design, permitting, drilling, construction, operations, sampling, waste disposal, demobilization, and reporting; no additional cost data were provided

Description:
The Young-Rainy Star Center (formerly Pinellas) Northeast Area A, located in Largo, Florida, was the site of NAPL contamination in soil and groundwater. NAPL constituents included TCE, DCE, methylene chloride, toluene, and petroleum range organics. Contaminant concentrations were as high as 2,900,000 : g/kg for TCE in soil and 12,000,000 : g/L for methylene chloride in groundwater. Area A covered approximately 10,000 ft^2 by 35 ft deep, for an estimated cleanup volume of 13,000 cubic yards. A combination of steam-enhanced extraction and ET-DSP™ was chosen by DOE to remediate the site because of the challenges at the site including low permeability sediments and the suspected presence of TCE, DNAPL, and oily LNAPL. The initial system of 66 wells included steam injection, ET-DSP™, and combined wells. Results from additional soil sampling resulted in the installation of 12 shallow steam injection wells to improve the steam delivery and heat distribution in the subsurface in Area A.

After 4.5 months of operation, all soil and groundwater cleanup goals had been met, with many groundwater samples showing contaminant levels having been reduced to below the more stringent MCLs. During this application, several ways to improve system efficiency were identified. These included more rapid heating or flushing of the upper 10 ft of the treatment cell, lowering the water discharge rate, and using a more robust GAC system.

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EX SITU SOIL/SEDIMENT TREATMENT ABSTRACTS

Thermochemical Conversion of Demolition Debris from Fort Ord, California

Site Name:
Fort Ord

Location:
Monterey, California

Period of Operation:
October 2002

Cleanup Authority:
Not applicable

Purpose/Significance of Application:
Field demonstration of thermochemical conversion to treat demolition debris

Cleanup Type:
Field Demonstration

Contaminants:
Heavy Metals (lead) (evaluated for recycling or stabilization after thermal treatment of debris)

Waste Source:
Demolition of 26 World War II-era wooden military buildings located at Fort Ord

Contacts:

Navy
Commanding Officer
(specific name not provided)
Naval Facilities Engineering Service Center
1100 23rd Avenue
Port Hueneme, CA 93043

Technology:
Thermochemical Conversion (thermal treatment)

- Wood waste processed at three different scales: small, intermediate, and large
  - Small scale-test conducted in a tube furnace (a horizontal electrically heated chamber that houses a refractory tube in which the sample is placed)
  - 2 series of tests conducted, the first on wood shavings, and the second on ash produced from the intermediate-scale processing of wood shavings to test the sintering properties of the fluxed ash
  - Intermediate scale test conducted in a 4.7 ft^2-area rotary hearth furnace
  - Four of five burners operated during the test, with the hearth maintained at a negative pressure via an induced draft fan
  - Large-scale test conducted at contractor's test facility; operating temperature of hearth was about 1500°F
  - Following system shutdown, ash samples from various parts of hearth and off-gas system collected and analyzed
- Leach performance of ash produced from test was evaluated including ash as-produced, fluxed and sintered ash, and ash to which Portland cement and water had been added

Type/Quantity of Media Treated:
Demolition debris

- Wood siding coated with lead-based paint (LBP)
- Wood shavings and LBP generated from attempts to remove LBP and recycled lumber

Regulatory Requirements/Cleanup Goals:

- Conduct a series of thermal treatment tests to collect data that would facilitate designing and estimating capital/operational costs for a transportable treatment system that could process such waste on site during demolition activities at current and former military installations
- Toxicity Characteristic Leaching Procedure (TCLP) target for lead: 5.0 parts per million (ppm)

Results:

- 97% volume reduction and 90% reduction in mass of waste
- Over 99.9% of lead released to off-gas system during processing was in particulate form >0.7 microns in effective diameter
- Concentrations of lead in residual ash ranged from about 7 - 12% from the processing of whole boards to about 25% from the processing of wood and paint shavings.
- Data collected from off-gas monitoring and sampling suggest that emission control for processing lead-based paint (LBP) waste will be relatively simple and consist of a dry filtration system. There will not be a need for a wet off-gas system thus eliminating issues surrounding management of wastewater.
- Data produced from the tests facilitated development of a design for a transportable processing system for LBP-coated materials.

Costs:
Estimated capital cost: $1,950,000
Estimated average annual operating costs - $987,000 (for a system with capacity to process 1.5 tons/hour)
Estimated unit cost - $117/ton (based on the processing of 8,450 tons/year)

Thermochemical Conversion of Demolition Debris from Fort Ord, California (continued)

Description:
Fort Ord, located near Monterey, California, is a former military facility that has undergone decommissioning and demolition. Due to the application of LBP on many of the buildings at the site, the demolition debris has been shown to exhibit hazardous properties. A series of *in situ* thermal desorption tests (at three different scales) was conducted on debris from the site, to collect data that would facilitate the design and capital/operational cost estimates for a transportable treatment system that could process such wastes on site during demolition activities at current and former military installations. The large-scale test was performed at a test facility in Tacoma, Washington. Leach performance of ash produced from the tests were evaluated, including ash as-produced, fluxed and sintered ash, and ash to which Portland cement and water had been added.

The results showed that the technology was able to effect a 97% reduction in volume and a 90% reduction in mass of waste. Analyses of the chemistry and recyclability of the ash showed that concentrations of lead ranged from about 7-12% from the processing of whole boards, to about 25% from the processing of wood and paint shavings. Data collected from off-gas monitoring and sampling suggest that a combination of a bag house and HEPA filter in a dry off-gas system will be capable of meeting regulatory standards. Based on these tests, a design for a transportable processing system for LBP-coated materials was developed. The estimated unit cost for a system that can process 8,450 tons of waste per year at the rate of 1.5 tons/hour is $117/ton.

The tests also showed that hearth ash typically passed leach tests for lead, while bag house ash did not, and the addition of Portland cement tended to improve leach characteristics but relatively large quantities of cement will be required to immobilize lead in bag house ash. Fluxing and sintering of ash impaired leach performance because of the lack of glass forming ions in the ash.

Glass Furnace Technology (GFT) Demonstration at the Hazen Research Center in Golden, Colorado and the Minergy GlassPack Test Center in Winneconne, Wisconsin

Site Name: Hazen Research Center and Minergy GlassPack Test Center	**Location:** Golden, CO and Winneconne, WI
Period of Operation: January 2001 (dryer evaluation); August 2001 (melter evaluation)	**Cleanup Authority:** EPA SITE Program
Purpose/Significance of Application: Demonstration of GFT to treat river sediment contaminated with PCBs, other organics, and metals	**Cleanup Type:** Field Demonstration
Contaminants: Polychlorinated Biphenyls (PCBs), Heavy Metals, Dioxins/Furans • Total PCB concentration in sediments in the 20 to 30 ppm range • Other contaminants included mercury, dioxins and furans	**Waste Source:** Contaminated river sediment dredged from the Lower Fox River

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Technology:

Ex Situ Glass Furnace Technology (GFT) (Vitrification)

- Demonstration process - two steps: sediments drying (dryer) and dried-sediment vitrification (melter)
- Sediment dryer - Holoflite® dryer that was a small batch, bench-scale unit with a capacity of 14 lb/hr of dewatered sediment (45-55% by weight); portions of the sediment were dried and mixed with the dredged and dewatered sediment to create better flow characteristics of the feed material; unit was 30-in long with two hollow, oil-filled augers; oil heated to about 180°C; dried sediment had a moisture content of <10%; steam from dryer condensed and collected;
- Melter - pilot-scale glass furnace designed to simulate full-scale production - 8 split-stream, oxygen-fuel burners; fired with oxygen and natural gas to control nitrogen-related and particulate emissions; refractory brick; charger was a standard screw feeder, retrofitted with a small screw barrel and flights for the demonstration
- Melter characteristics - melter area was 10 ft^2 ; length/width aspect ratio of 2:1; melting rate - 5.4ft^2/ton; dwell time - 6 hrs; gas usage - 1.7 MM Btu/hr; oxygen usage - 35 cubic ft/hr; output - 2 tons/day
- Process controls - thermocouple signals to maintain constant temperature and automatically adjust gas and oxygen in each zone

Type/Quantity of Media Treated:

Sediments

- Dredged sediments - dewatered form (45-55% solids by weight)
- The report stated that because GFT is not designed to be used on one particular site, information about site location and hydrogeology are not needed for demonstration purposes

Regulatory Requirements/Cleanup Goals:

- Primary objectives of the demonstrations were to determine the treatment efficiency of GFT in treating PCB-contaminated dredged-and-dewatered sediment, and to determine whether GFT glass aggregate product met relevant regulatory criteria for beneficial reuse

Glass Furnace Technology (GFT) Demonstration at the Hazen Research Center in Golden, Colorado and the Minergy GlassPack Test Center in Winneconne, Wisconsin (continued)

Results:
- Total PCBs - 99.9995% of total PCBs were removed or destroyed
- Mercury - reduced from concentrations slightly less than 1 ppm to non-detect in the glass aggregate; report stated that if mercury was not removed thermally, it was likely inactivated within the glass matrix
- Dioxins and furans - >99.9995% reduction
- Glass aggregate met the state of Wisconsin requirements for beneficial reuse
- Leach test results of glass aggregate, including Synthetic Precipitate Leaching Procedure (SPLP) - no contaminants detected in leachate

Costs:
- Report includes detailed cost analysis for the technology
- Estimated unit cost for full-scale GFT is $38.72 per ton of dredged-and-dewatered sediment, based on 50% moisture and a 15 year project life expectancy
- Costs may depend on location of treatment facility, amount of moisture in the sediment, and the potential end use of the product

Description:
Glass Furnace Technology (GFT), developed by Minergy Corporation, was evaluated by the EPA SITE Program. The demonstration included an evaluation of the drying process at the Hazen Research Facility in Golden Colorado in January 2001 and an evaluation of the melter at Minergy's GlassPack Test Center in Winneconne, WI in August 2001. The primary objectives of the demonstration were to evaluate the effectiveness of GFT in treating PCB-contaminated sediments that had been dredged and dewatered and to determine if the glass aggregate product met relevant requirements for beneficial reuse. Sediment dredged from the Little Fox River in Green Bay, WI was used for the demonstration; the sediment was dewatered to a moisture content of 50% by weight.

Results of the demonstration showed that GFT removed or destroyed contaminants in the sediment including 99.9995% of the PCBs (measured as total PCBs), >99.9995% of dioxins and furans, and appeared to be capable of reducing mercury concentrations. In addition, the glass aggregate met the Wisconsin Administrative Code Chapter NR 538 Category 2 criteria and qualified for beneficial reuse. Projected full-scale unit costs of GFT are $38.74 per ton of sediment treated (50% moisture), with costs dependent of factors such as location of the treatment facility, sediment moisture content, and potential end use of the product. According to the vendor, GFT is designed to treat contaminated river sediment at any location and can be scaled to accommodate a wide range of sediment projects. The report indicates that possible areas where scale-up economies could be realized include lower energy costs per ton of sediment treated, reduced sampling and analysis requirements once the treatment efficiencies for the technology are established, and the potential to automate some of the processes.

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IN SITU GROUNDWATER TREATMENT ABSTRACTS

In Situ Bioremediation Using HRC® at a Former Industrial Property, San Jose, CA

Site Name:
Former Industrial Property

Location:
San Jose, CA

Period of Operation:
May 2000 to Ongoing (data available through July 2003)

Cleanup Authority:
State

Purpose/Significance of Application:
Use of enhanced *in situ* bioremediation using HRC® to treat VOC-contaminated groundwater at a site with an active business

Cleanup Type:
Full scale

Contaminants:
Volatiles-Halogenated; Trichloroethene (TCE)
- Volatile organic contaminants (VOCs), primarily TCE
- TCE concentrations as high as 10,000 µg/L in groundwater and 10,000 µg/kg in soil

Waste Source:
Released from manufacturing operations

Contacts:

State Contact:
Michelle Rembaum-Fox
The California Regional Water Quality Control Board, San Francisco Bay Region
1515 Clay Street, Suite 1400
Oakland, CA 94612
Telephone: (510) 622-2387

Prime Contractor:
Catherine McDonald
GeoTrans Inc.
3035 Prospect Park Drive, Suite 40
Rancho Cordova, CA 95670
Telephone: (916) 853-1800

Vendor:
Stephen S. Koenigsberg
Regenesis Bioremediation Products
1011 Calle Sombra
San Clemente, CA 92673
Telephone: (949) 366-8000
E-mail: *steve@regensis.com*

Technology:
In Situ Bioremediation Using HRC®
- HRC® is a proprietary, food quality, polylactate ester that slowly degrades to lactic acid upon hydration; the lactic acid is metabolized to a series of organic acids and hydrogen, which serve as electron donors for reductive dechlorination of chlorinated VOCs
- Two applications - first in May 2000 with1,329 gal injected in 103 injection points from 8 to 28 ft bgs using a bottom-up injection method; second in November 2001 in 105 injection points with 575 gal injected from 10 to 30 ft bgs using a top-down injection method
- HRC® applied on a 5 ft by 10 ft grid within the 1,000 µg/L TCE in groundwater contour(about two-thirds of the injection points), and on a 5 ft by 5 ft grid within the 5,000 µg/L TCE contour (about one third of the injection points)

Type/Quantity of Media Treated:
Groundwater
- Depth to groundwater - 7 to 10 ft bgs

Regulatory Requirements/Cleanup Goals:
- Groundwater cleanup goals based on state and EPA MCLs, including TCE - 5 µg/L; cis-1,2-DCE - 6 µg/L; trans-1,2-DCE-10 µg/L; vinyl chloride - 0.5 µg/L
- No soil cleanup goals established as initial concentrations were below EPA Region 9 Preliminary Remediation Goals for residential soils

In Situ Bioremediation Using HRC® at a Former Industrial Property, San Jose, CA (continued)

Results:
- Data are available for May 1999 to July 2003, with analytical data presented for four wells, including wells upgradient, in the center of the plume, and along the perimeter of the plume
- After the first injection of HRC® in May 2000, concentrations of TCE decreased, with corresponding increase in degradation products cis-1,2-DCE and vinyl chloride
- After the second injection in November 2001, TCE concentrations continued to decrease, concentrations of cis-1,2-DCE and vinyl chloride decreased, and concentrations of degradation product ethene increased
- As of July 2003, TCE concentrations were below cleanup goals in selected wells; while concentrations of cis-1,2-DCE and vinyl chloride continued to decrease, they remained above the cleanup goals in most of the selected wells
- Currently, groundwater monitoring and natural attenuation monitoring are being performed on a semiannual basis at the site

Costs:
- Costs for two applications of HRC® were $107,000
- Direct push injection costs totaled approximately $30,000 including the two HRC® applications and soil sampling
- Groundwater monitoring costs averaged approximately $8,000 per monitoring round for nine wells, including field costs (low-flow purging) and laboratory costs for the full suite of in-situ bioremediation monitoring parameters
- Estimated budget for the in-situ monitoring and analyses conducted from May 2000 through July 2003 totaled approximately $130,000

Description:
The site is a 4.1 acre property, located in San Jose, California, that is occupied by a 76,000 square foot building that is currently being used for light industrial retail. From the 1960s to the 1980s, the site was used for various manufacturing. Site investigations, conducted in the late 1980s, showed the presence of volatile organic compounds (VOCs) in the subsurface, with TCE concentrations detected as high as 5,000 : g/L in groundwater and 10,000 : g/kg in soil. Cleanup activities at the site are being conducted under a State of California Regional Water Quality Control Board, San Francisco Bay Region order. In late March 1997, the site was proposed for a pilot under a state research and development project to develop methods for setting site cleanup objectives. In March 1999, the Board approved the "In-Situ Remedial Alternatives Evaluation Report" for the site where the proposed remedy was to stimulate anaerobic degradation activities. Results of bench-scale testing during the Spring of 1999 showed that the use of an electron donor could stimulate microbial activity and biodegradation. HRC® and a benzoate-lactate mixture were considered. HRC® was selected because it offered a one-time application process with no ongoing operations and maintenance (O&M) activities, while the benzoate-lactate application used a continuous feed system that would require daily O&M activities. Therefore, it was concluded that HRC® could stimulate the microbial community and the biodegradation process without disrupting the business activities being conducted at the site.

Two applications of HRC® were performed. HRC® was applied on a 5 ft by 10 ft grid within the 1,000 : g/L TCE in groundwater contour (about two-thirds of the injection points), and on a 5 ft by 5 ft grid within the 5,000 : g/L TCE contour (about one third of the injection points). The first application in May 2000 involved injecting 1,329 gal injected in 103 injection points. TCE concentrations decreased, with a corresponding increase in degradation products cis-1,2-DCE and vinyl chloride. A second application of HRC® was performed in November 2001 to complete the degradation process and involved injecting 575 gal into 105 injection points. As of July 2003, TCE concentrations had decreased to below cleanup goals in selected wells. Concentrations of cis-1,2-DCE and vinyl chloride decreased, with a corresponding increase in ethene concentrations; however, these contaminants remain above the cleanup goals in selected wells. Currently, groundwater monitoring and natural attenuation monitoring are being performed on a semiannual basis at the site.

Biotreatment Funnel and Gate at the Moss-American Site, Milwaukee, Wisconsin

Site Name:
Moss-American Site

Location:
Milwaukee, Wisconsin

Period of Operation:
October 2000 - Ongoing (Data available through June 2003)

Cleanup Authority:
CERCLA

Purpose/Significance of Application:
Use of a funnel and gate treatment system combined with biotreatment to treat PAH and BTEX groundwater contamination at the site

Cleanup Type:
Full scale

Contaminants:
Volatiles-Nonhalogenated, Polycyclic Aromatic Hydrocarbons (PAHs), Benzene Toluene Ethylbenzene Xylenes (BTEX)
- Contaminants from creosote and No.6 fuel oil; creosote present as free product

Waste Source:
Wastes generated from wood preserving operations

Contacts:

Russell Hart
Remedial Project Manager
U.S. EPA Region 5
Telephone: (312) 886-4844
E-mail: *hart.russell@epa.gov*

Binyoti Amungwafor
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PRP Contractor
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Telephone: (847) 918-4142
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Technology:
Funnel and Gate System with Biotreatment
- System consists of six treatment gates, constructed in three rows of two gates each; Waterloo sheet piling located on both sides of gates to direct groundwater flow through gates
- Biotreatment includes injection of air and nutrients into the gates; air injection began in October 2000, with air injected into all six gates; nutrient injection was performed at Gate 1, using a solution that contained potassium nitrate and potassium phosphate from late June 2001 to October 2002
- As of June 2003, flow of groundwater was directly through treatment Gates 1 and 2, but at an obtuse angle through Gates 3-6
- Free product sumps are used to collect free product creosote prior to its entering the treatment gates
- Groundwater monitoring is performed using 7 shallow groundwater monitoring wells and 8 containment performance monitoring wells
- System expected to be in place approximately 20 years

Type/Quantity of Media Treated:
Groundwater
- Depth to groundwater - 3.6 to 7.3 ft bgs
- Hydraulic gradients vary across the site; within the treatment gate area, the hydraulic gradient is approximately 0.0009 ft/ft in an easterly direction
- Groundwater flow velocities within the treatment gates were estimated to range from 0.0076 to 0.14 ft/day

Regulatory Requirements/Cleanup Goals:
- Groundwater cleanup goals based on the Wisconsin Department of Natural Resources Preventative Action Limit for BTEX and PAH constituents, including benzene - 0.5 : g/L; benzo(a)pyrene - 0.02 : g/L; benzo(b)fluoranthene - 0.02 : g/L; chrysene - 0.02 : g/L; naphthalene - 8 : g/L

Results:
- Results are available through June 2003
- As of June 2003, groundwater concentrations for the contaminants of concern had been reduced to below detection limits in several wells; however, concentrations of all five contaminants remained above the cleanup goals in one or more monitoring wells
- With the exception of naphthalene, detected concentrations ranged from about 1.4 to 7.9 : g/L; naphthalene concentrations were as high as 6,100 : g/L
- Naphthalene concentration data for September 2000 to June 2003 provided for one monitoring well show that concentrations of this contaminant have remained relatively constant over a three-year period (in the range of 5,000 to 7,000 : g/L, with a concentration of 6,100 : g/L as of June 2003)
- The concentration of microbial degraders has been decreasing in Gates 1 and 2 over a period of 2 1/3 years, indicating that the biodegradation may be decreasing

Biotreatment Funnel and Gate at the Moss-American Site, Milwaukee, Wisconsin (continued)

Costs:
- No cost data were provided for the biotreatment funnel and gate system

Description:
The Moss-American Site, located in Milwaukee, Wisconsin, is approximately 88 acres in size, and consists of a former wood preserving facility, portions of the Little Menomonee River, and adjacent flood plain soils. The discharge of wastes from wood preserving operations resulted in the contamination of groundwater at the site with PAHs, including creosote, and BTEX from No. 6 fuel oil. A mixture of creosote and fuel oil were present as free product in the subsurface at the site. The site was added to the National Priorities List in 1984, and a record of decision (ROD) was signed in 1990, with an Explanation of Significant Difference (ESD) signed in 1997 changing soil treatment to thermal desorption and groundwater treatment to a biotreatment funnel and gate system. Free product recovery was performed from 1996 to 1999, with about 12,500 gallons of liquid extracted. In addition, contaminated soil was excavated and treated using thermal desorption.

The biotreatment funnel and gate system consists of six treatment gates, with Waterloo sheet piling located on both sides of the gates to direct groundwater flow. Operation of the system began in October 2000, with the injection of air, followed by the addition of nutrients in Gate 1 in June 2001. In addition, sumps are being used to collect any free product prior to its entering the treatment gates. During the three years of operation for which data are available, the concentration of benzene, benzo(a)pyrene, benzo(b)fluoranthene, and chrysene have been reduced to near or below cleanup goals in most monitoring wells. As of June 2003, naphthalene concentrations were as high as 6,100 : g/L. The concentration of microbial degraders has been decreasing in Gates 1 and 2 over a period of 2 1/3 years, indicating that biodegradation may be decreasing. The PRP contractor suggested that the relatively fine-grained soil and low groundwater flow rates have lead to low oxygen conditions and inhibited the ability to introduce nutrients and other additives. To address the low levels of dissolved oxygen, well packers were installed in Treatment Gate 5 injection wells in June 2000. However, this did not lead to substantial increases in DO levels in those wells. The contractor is continuing to evaluate alternatives for air injection into the treatment gates.

In Situ Remediation of MTBE Contaminated Aquifers Using Propane Biosparging at the National Environmental Technology Test Site, Port Hueneme, CA

Site Name: National Environmental Technology Test Site	**Location:** Port Hueneme, CA
Period of Operation: May 2001 to March 2002	**Cleanup Authority:** State
Purpose/Significance of Application: Field demonstration of propane biosparging to treat MTBE-contaminated groundwater	**Cleanup Type:** Field Demonstration : g/L
Contaminants: MTBE and TBA • Groundwater contaminant concentrations as high as - 6,300 : g/L for MTBE; TBA detected in one well only at 470 : g/L	**Waste Source:** Leaks from a gasoline distribution system

Contacts: ***Navy*** Commanding Officer (specific name not provided) Naval Facilities Engineering Service Center 1100 23rd Avenue Port Hueneme, CA 93043	**Technology:** *In Situ* Bioremediation (Propane Biosparging) • Test plot and control plot (90 ft by 60 ft) • Test plot - network of 8 oxygen injection points (OIP), 7 propane injection points (PIPs), and 7 bacteria injection points (BIPs) installed along a line perpendicular to groundwater flow; groundwater monitoring network of 15 dual-level (shallow and deep), nested wells • Control plot - 8 OIPs installed along a line perpendicular to groundwater flow; no PIPs or BIPs; groundwater monitoring network of 10 dual-level (shallow and deep), nested wells • 2 oxygen cylinders per plot; oxygen delivery - 40-60 psig; one propane cylinder for test plot; propane delivery - 20-30 psig; oxygen and propane control manifold assemblies, and a control panel • Oxygen system - operated for four, 6-minute cycles per day, yielding approximately 5 lb/day of oxygen in the test and control plots • Propane system operated for four, 10-minute cycles per day and yielded approximately 0.5 lb/day of propane at the test plot; after several months of operation and a review of the geochemical data, the propane flow was decreased from 1 scfh to between 0.3 and 0.4 scfh (yield of approximately 0.17 to 0.2 lb/day of propane)

Type/Quantity of Media Treated:
Groundwater
- Unconsolidated sediments composed of sands, silts, clays, and small amounts of gravel and fill material
- Upper-most water-bearing unit - shallow, semi-perched, unconfined aquifer (upper silty sand, underlain by fine to coarse grain sand, and a basal clay layer)
- Depth to groundwater - 6 to 8 ft bgs; saturated aquifer thickness - 16 to 18 ft

Regulatory Requirements/Cleanup Goals:
- Treatment goal for the demonstration was to reduce MTBE and TBA concentrations to <5 : g/L for MTBE (California secondary MCL) and <12 : g/L for TBA (California Action Level)
- Primary objectives of the demonstration were to: (1) demonstrate the safe application of propane biosparging for *in situ* remediation of MTBE and (2) evaluate the ability of this technology in reducing MTBE concentrations in groundwater to below 5 : g/L

Results:
- MTBE concentrations were reduced in both the test plot and the control plot, as expected based on the results of microcosm studies and previous demonstrations at the site; however, MTBE concentrations were reduced to <5 : g/L in only 3 of the 30 monitoring wells in the test plot; in the control plot, MTBE concentrations remained above 5 : g/L in all wells; most active MTBE degradation appeared to occur near the oxygen injection points
- MTBE concentrations - in test plot, in shallow wells decreased 62-88% and in deep wells decreased 86-97%; in control plot, decreased 86-97% and in deep wells decreased 88-90%; results indicate that indigenous bacteria at this site are capable of aerobically degrading MTBE
- TBA concentrations - in test plot, generally <25 : g/L in shallow and deep wells; reduced to below 12 : g/L in some wells

In Situ Remediation of MTBE Contaminated Aquifers Using Propane Biosparging at the National Environmental Technology Test Site, Port Hueneme, CA (continued)

Costs:

- Costs for the demonstration were $333,288, including $122,311 in capital costs, $184,647 in O&M costs, and $26,329 for treatability studies
- Projected full scale costs are $145,600, reflecting improved efficiencies of technology implementation and reduced monitoring and reporting requirements than those required for a demonstration project

Description:

The National Environmental Technology Test Site, Port Hueneme, CA was the location of a field demonstration of propane biosparging to (1) demonstrate the safe application of propane biosparging for *in situ* remediation of MTBE and (2) evaluate the ability of this technology in reducing MTBE concentrations in groundwater to below the California secondary MCL of 5 : g/L. Leaks from a gasoline distribution system resulted in the groundwater at the site being contaminated with MTBE and its degradation product, TBA. BTEX was present at low levels only. The demonstration, conducted from May 2001 to March 2002, included a test plot and a control plot, with oxygen injected in both. The technology was also evaluated under the EPA SITE Program.

MTBE concentrations were reduced in both the test plot and the control plot. This was expected based on the results of microcosm studies and previous demonstrations at the site. However, in the test plot, MTBE concentrations were reduced to <5 : g/L in only 3 of the 30 monitoring wells and were not reduced below this level in any wells in the control plot. The most active MTBE degradation appeared to occur near the oxygen injection points. The results of a cost assessment indicated that full-scale application would be up to 44% less costly than the demonstration project, reflecting improved efficiencies of technology implementation and reduced monitoring and reporting requirements than those required for a demonstration project. Observations and lessons learned from the demonstration included: propane biosparging can be applied safely and economically; system designs must ensure sufficient delivery of oxygen; indigenous microbes in some aquifers can effectively degrade MTBE if supplied the appropriate nutrient or oxygen; and propane biosparging can support the growth or activity of indigenous or added propane oxidizing bacteria.

Prepump Separation Technologies to Enhance Bioslurping at the Naval Air Station, New Fuel Farm Site, Fallon, NV

Site Name: Naval Air Station New Fuel Farm Site	**Location:** Fallon, NV
Period of Operation: Long term demonstration conducted over a 4-month period	**Cleanup Authority:** State
Purpose/Significance of Application: Field demonstration of prepump technologies to enhance the cost-effectiveness of bioslurping to treat LNAPL-contaminated groundwater	**Cleanup Type:** Field Demonstration
Contaminants: Petroleum Hydrocarbons, LNAPL • Demonstration site was selected because it appeared to contain sufficient LNAPL to support a four month demonstration	**Waste Source:** Leaks from JP-5 fuel storage tanks

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Technology:
Separation
- Demonstration of prepump separation technologies to enhance biosplurper systems; prepump separation of LNAPL prevents the formation of emulsions and floating solids in the bioslurper process effluent, thereby minimizing/eliminating the need for downstream waste treatment and decreases the concentrations of contaminants in the process off-gases
- Evaluated in-well and above-ground prepump (knockout tank) separation technologies in short-term single-well and long term multiple well demonstrations; compared to conventional bioslurper
- Various configurations tested including use of dual drop tubes for in-well prepump system to extract the LNAPL and water/soil gas in two separate streams and use of a knockout tank to separate LNAPL from the liquid stream prior to entry into the liquid pump ring; report included detailed information about configurations tested and testing sequence
- Primary components of the bioslurper system (liquid ring pump, oil/water separator and piping) were the same for all tests; operating conditions of the system were held constant
- Baseline data included depth to groundwater, LNAPL thickness, lateral extent of the plume, TPH concentrations and subsurface vacuum
- System performance parameters included petroleum hydrocarbon concentrations in effluents, emulsions and floating solids formed, LNAPL recovery rates, groundwater recovery rates, and stackgas flow rates

Type/Quantity of Media Treated:
Groundwater
- Soils - fine sand and clay loam, underlain by alternating layers of clay, silty/clayey sand, and sand
- Vadose zone - primarily clay loam
- Depth to groundwater - 7 to 15 ft bgs
- Demonstration site selected based on soils being sufficiently permeable to allow LNAPL flow while still being “tight” enough to allow the bioslurper to create a vacuum-induced pressure gradient (no specific data were provided)

Regulatory Requirements/Cleanup Goals:
- The objectives of the demonstration included quantifying the cost effectiveness of prepump LNAPL separation methods in controlling effluent emulsion formation and reducing the concentrations of petroleum hydrocarbons in the aqueous and off-gas streams from the bioslurper

Prepump Separation Technologies to Enhance Bioslurping at the Naval Air Station, New Fuel Farm Site, Fallon, NV (continued)

Results:
- Assessment of performance was based primarily on aqueous and vapor TPH concentrations; production of floating solids and emulsions formed by the different configurations was also assessed, along with information of LNAPL and groundwater recovery
- Average TPH concentration reduction in the seal tank water compared to conventional bioslurper - 98% for in-well and 82% for the knockout tank (report includes data for each configuration)
- LNAPL recovery and groundwater recovery rates generally remained constant
- Dual drop and knockout tank configurations reduced the formation of milky emulsions; site did not produce floating solids during the demonstration
- While TPH concentrations in the off-gas were not affected during the long term demonstration, average TPH concentrations were observed in other demonstrations by both prepump configurations

Costs:
- Total cost of the long term demonstration was about $70,000 with a unit cost of $10 per gallon of fuel removed; total cost for the demonstration program (seven demonstrations) was $480,000
- Estimated cost for full-scale implementation at a 2-acre site - in-well separation bioslurping - about $309,000; more cost-effective than conventional systems (bioslurping with a DAF unit for postpump treatment - about $519,000; bioslurping with manual removal of floating solids - about $554,000)
- Costs for prepump separation systems at a site are affected primarily by the potential for emulsion formation, free product recovery rates, and groundwater recovery rates

Description:
The NAS in Fallon Nevada was selected by the Navy for a demonstration of prepump separation technologies to enhance the cost-effectiveness of bioslurping to treat LNAPL in groundwater. The New Fuel Farm, located in the northwestern portion of the NAS Fallon, is used for the storage of jet propulsion (JP) jet fuel in underground and aboveground storage tanks, and historically has been used for the storage of jet fuel, aviation gasoline, diesel, and motor gasoline. An LNAPL plume is located beneath the site. According to the Navy, this site was selected for the demonstration based on soils being sufficiently permeable to allow LNAPL flow while still being "tight" enough to allow the bioslurper to create a vacuum-induced pressure gradient, and because it appeared to contain sufficient LNAPL to support a four month demonstration (long term demonstration). The prepump separation technologies were evaluated in both short-term, single well configurations and in long-term, multiple well configurations. This report focuses on the long-term demonstration.

Two prepump separation technologies were evaluated - in-well and knockout tanks. These technologies were compared to conventional bioslurper systems. The results of the demonstrations showed that the in-well and knockout systems were effective in reducing TPH concentrations in the seal tank water and in the off-gas, and are more cost effective than conventional bioslurper systems (including manual separation and DAF). Costs for prepump separation systems at a site are affected primarily by the potential for emulsion formation, free product recovery rates, and groundwater recovery rates. According to the Navy, the results of the short-term and long-term demonstrations show that the dual drop configuration worked well at a variety of sites that include tidal influence, varied geologic conditions, and varied LNAPL type and thickness. Scale-up considerations include proper sizing of components for full-scale operations; pilot-scale testing is recommended to determine the feasibility of bioslurping and the scale-up engineering evaluation for a specific site.

In Situ Bioremediation at Naval Base Ventura County, Port Hueneme, California (Field Demonstration)

Site Name:
Naval Base Ventura County

Location:
Port Hueneme, California

Period of Operation:
September 2000 to December 2002 (biostimulation began in September 2000 and bioaugmentation began in December 2000)

Cleanup Authority:
California Regional Water Quality Control Board (CARWQCB)

Purpose/Significance of Application:
- To install and operate a full-scale MTBE biobarrier across a mixed MTBE-BTEX dissolved plume and to assess the reductions in MTBE and BTEX concentrations achieved over time, and effectiveness of air delivery to the treatment zone

Cleanup Type:
Field Demonstration

Contaminants:
MTBE, BTEX and TBA
- Dissolved MTBE plume 5,000 ft long and 500 ft wide
- MTBE concentrations ranging from 1,000 µg/L to 10,000 µg/L and BTEX concentrations about 1,000 µg/L in the vicinity of the source zone soils
- TBA concentrations approximately 1,000 : g/L

Waste Source:
Leaking Underground Storage Tanks (USTs) from the Naval Exchange service station located on-site

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Technology:
In Situ Bioremediation
- A 500 ft wide biobarrier (biologically reactive groundwater flow-through biobarrier) installed downgradient of the source zone in the mixed MTBE-BTEX dissolved plume
- Biobarrier comprised of two different bioaugmented plots (oxygenated and seeded with two MTBE-degrading cultures), and two different types of biostimulated plots (one aerated and one oxygenated)
- Seeding done using two cultures: MC-100 microbial culture and also a MTBE-degrading isolate identified as SC-100 (*Rhodococcus aetherovorans*)
- Aeration/oxygenation system consisted of 21 modules; each module with a satellite gas injection tank and 6 solenoid valves, connected to the gas injection wells; Injection wells screened at 14-15 ft bgs for shallow wells and 18-20 ft for deep wells; Air used for oxygenation
- Over 400 wells installed; 225 for monitoring and 175 for gas injection
- Monitoring wells were screened over 4-ft intervals

Type/Quantity of Media Treated:
Groundwater
- The shallow aquifer of interest is unconfined and the depth to ground water is approximately 8 ft bgs, varying seasonally to about a foot
- Minor amounts of gravel and fill material
- Unconsolidated clay, silt, and sand to 30 ft bgs, and a clay aquitard at approximately 20 ft bgs

Regulatory Requirements/Cleanup Goals:
MTBE, BTEX, and TBA concentrations - <10 µg/L

Results:
- MTBE concentrations in groundwater exiting the treatment system were below the cleanup goal of 10 : g/L within 7 months of operation
- Downgradient benzene concentrations reached the cleanup goal by December 2000 (prior to start of bioaugmentation)
- TBA concentrations measured in March 2002 were below the cleanup goal
- The aeration/oxygenation system achieved dissolved oxygen levels above 4 mg/L

In Situ Bioremediation at Naval Base Ventura County, Port Hueneme, California (Field Demonstration) (continued)

Costs:

- Biobarrier installation costs totaled approximately $307,200, and included $186,519 for air and oxygen delivery system, $29,716 for field laboratory, and $90,964 for culture injection
- Annual O&M costs were $77,843 per year, and included $19,000 for oxygen generator O&M, $44,400 for sampling and analysis, and $14,443 for utilities

Description:

The Naval Exchange service station at Naval Base Ventura County in Port Hueneme, CA, contained USTs that leaked MTBE-containing gasoline between September 1984 and March 1985. The leak resulted in contamination of soil and groundwater at the site, and caused a mixed MTBE-BTEX plume measuring 5,000-ft long and 500-ft wide to develop. Laboratory and pilot field testing of *in situ* bioremediation were carried out at the site in 1998, with the addition of oxygen and MC-100 microbial culture. The success of these tests prompted a large field demonstration of the technology using a 500-ft wide biobarrier containing MC-100 and another MTBE-degrading isolate, SC-100, for *in situ* bioremediation of the mixed MTBE-BTEX plume.

The biobarrier was installed down-gradient of the source zone and began operation in September 2000. It consisted of two different bioaugmented plots (oxygenated and seed with MC-100 and SC-100), and two different types of biostimulated plots (one aerated and one oxygenated). Biostimulation began in September 2000, and bioaugmentation began in December 2000. Approximately 225 wells were used for regular performance monitoring on a monthly to quarterly basis for dissolved oxygen (DO), MTBE, and BTEX, and 175 wells were used for gas injection. The operation ended in December 2002.

The results showed that the biobarrier was able to reduce effluent MTBE concentrations to below the cleanup goal of 10 : g/L within 7 months of operation. Concentrations of benzene were reduced to the cleanup goal using bioaugmentation alone. Biostimulation was not required for the reduction of benzene levels to acceptable levels. The biobarrier system was able to reduce TBA concentrations to the cleanup goal by March 2002. The aeration/oxygen system was successful in achieving dissolved oxygen levels above 4 mg/L, the level determined necessary to stimulation and support aerobic degradation. The biobarrier installation costs were $307,200, with the annual O&M costs being $77,843. A lesson learned from this demonstration is that biostimulation (aeration only) was successful where the influent MTBE concentration was as high as 1,000 µg/L, and that biostimulation could be a viable option at some sites.

Biosparging at the Savannah River Site Sanitary Landfill, Aiken, South Carolina

Site Name:
Savannah River Site Sanitary Landfill (SLF)

Location:
Aiken, SC

Period of Operation:
October 1999 to ongoing (data available through 2003)

Cleanup Authority:
RCRA Corrective Action

Purpose/Significance of Application:
Biosparging, using horizontal wells, in conjunction with a cap, to treat chlorinated solvents in groundwater beneath a sanitary landfill

Cleanup Type:
Full scale

Contaminants:
Halogenated VOCs
- Primary contaminants of concern are TCE, cis-1,2-DCE, and vinyl chloride

Waste Source:
Disposal of waste in unlined sanitary landfill

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Technology:
Biosparging
- Biosparging system includes two horizontal wells; injection pad - a compressor, a header for each well, NO_2 cylinder and triethyl phosphate drum, and methane vents that discharge directly into the air
- Horizontal wells - installed to depth of 60 ft bgs; screened to length of 800 ft and 900 ft; 6-inch diameter outer casing of carbon steel with holes (0.17% open area); 4-inch inner HDPE casing with varied slit spacing to distribute injectate (0.28% open area); system operated on pulsed injection schedule
- Groundwater monitoring network includes 90 monitoring wells
- Initially, one well used to inject methane, air, and nutrients (nitrous oxide and triethyl phosphate) to stimulate the growth of methanotropic (methane oxidizing) organisms to complete the mineralization of TCE; second well used to inject air and nutrients to aerobically degrade and volatilize vinyl chloride
- Methane injection stopped in January 2001 after TCE concentrations decreased
- Air and nutrients continue to be injected in both wells; system operations to continue until cleanup goals are met

Type/Quantity of Media Treated:
Groundwater
- The estimated volume of water that has moved through the treatment zone is 9.4 billion gallons
- Depth to groundwater - ranges from 30 to 60 ft bgs
- Contamination occurs in the uppermost hydrogeologic unit - Steel Pond Aquifer; water table/unconfined aquifer consisting of interbedded sands and clayey/silty sands

Regulatory Requirements/Cleanup Goals:
- Savannah River Site (SRS) negotiated with the state for Alternate Concentration Limit/Mixing Zone Concentration Limits (ACL/MZCLs)
- ACL/MZCLs include: TCE (21 : g/L), cis-1,2-DCE (287 : g/L), and vinyl chloride (12 : g/L)

Results:
- As of 2001, the TCE plume had diminished and methane injection was stopped; DOE determined that TCE concentrations had decreased substantially and the results of numerical modeling predicted that further methane injection would not be beneficial
- As of FY2003, the maximum TCE concentrations ranged from not detected at wells in the interior of the landfill to a maximum of 8 : g/L at point of compliance wells upgradient of the treatment system; in the monitoring wells downgradient from the horizontal treatment wells, TCE was not detected at a quantifiable concentration (< 2 : g/L)
- Vinyl chloride concentrations have continued to decrease over the past year, with maximum concentrations during FY 2003 reaching 80 : g/L in an interior landfill monitoring well, and 14 : g/L in a point of compliance well at the base of the landfill (upgradient from the treatment system); vinyl chloride was not detected in wells downgradient from the treatment system
- Westinghouse Savannah River Company indicated that biosparging reduced concentrations in a well in the treatment zone by 99 percent for vinyl chloride and 75 percent for TCE.

Biosparging at the Savannah River Site Sanitary Landfill, Aiken, South Carolina (continued)

Costs:

- The actual costs to date for the biosparging application are: installation of two horizontal injection wells – $1 million; construction of the injection pad/well piping – $750,000; operation of the biosparging system – $225,000/year; and cost of groundwater monitoring – $215,000/year

Description:

The U.S. Department of Energy (DOE) Savannah River Site (SRS) is a 310 square-mile facility located near Aiken, South Carolina. From 1974 to 1994, a variety of wastes from SRS were disposed of in the unlined SRS Sanitary Landfill (SLF), which includes a main section (33 acres) and two expansion areas – a 22-acre southern expansion area and a 16-acre northern expansion area. In 1988, results of groundwater monitoring showed elevated levels of chlorinated solvents at the SLF, including TCE, 1,2-DCE, and vinyl chloride. In 1996, the South Carolina Department of Health and Environmental Control (SCDHEC) approved a closure plan for the SLF, which included the installation of a low-permeability geosynthetic cap (engineered RCRA cap). From 1996 to1997, the cap was installed over the main section and southern expansion area of the SLF, which were certified closed in October 1997. Installation of the cap minimized infiltration and produced anaerobic conditions in the subsurface, facilitating reductive dechlorination of TCE.

In 1999, two horizontal biosparging wells were installed with one well used to inject methane, air, and nutrients to stimulate the growth of methanotropic organisms to complete the mineralization of TCE, and the second well used to inject air and nutrients to promote the aerobic degradation and volatilization of vinyl chloride. In January 2001, methane injection was stopped as TCE concentrations had decreased substantially and the benefits of additional injections were determined to be limited. Air and nutrient injection is ongoing. As of 2003, biosparging reduced concentrations in a well in the treatment zone by 99 percent for vinyl chloride and 75 percent for TCE. SRS negotiated with the state for Alternate Concentration Limit/Mixing Zone Concentration Limits, and the system will continue to operate until these levels are met. According to the State, reducing conditions below the landfill helped degrade trichloroethene, but caused the vinyl chloride groundwater contaminant plume to increase. The current rate of growth of the vinyl chloride groundwater contaminant plume is insignificant. Future increases in the concentration of vinyl chloride in groundwater below the SLF are limited by the small mass of dissolved trichloroethene, its precursor, remaining and by the presence of the landfill cap, which prevents additional leaching of contamination from above.

Ferox[sm] Injection at Hunter's Point Shipyard, Parcel C, Remedial Unit C4, San Francisco, CA

Site Name: Hunter's Point Ship Yard, Parcel C, Remedial Unit C4	**Location:** San Francisco, CA
Period of Operation: December 5 - 23, 2002	**Cleanup Authority:** Not identified
Purpose/Significance of Application: Field demonstration to evaluate use of Ferox[sm] injection to treat chlorinated VOCs	**Cleanup Type:** Field Demonstration
Contaminants: Volatiles-Halogenated, Trichloroethene (TCE), DNAPL - Volatile organic compounds (VOCs), primarily TCE; TCE concentrations in groundwater as high as 88,000 : g/L	**Waste Source:** Leaks from underground storage tanks, and wastes from painting and degreasing operations

Contacts:

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Technology:
Chemical Oxidation using Ferox[sm] Injection
- 4 injection boreholes; 32 ft deep (below where DNAPL expected to be observed); injections performed from the bottom up to minimize potential DNAPL displacement downward and horizontally; injections conducted sequentially in each of the 4 boreholes; 3-ft intervals starting at 30 ft bgs, going to 10 ft bgs
- Injection process integrated pneumatic fracturing and Ferox[sm] delivery, with nitrogen gas used as both the fracturing and injection fluid; zero valent ion (ZVI) slurry (1 kg ZVI powder to 1 gal water) injected at pressures ranging from 40 to 180 psig; about 16,000 lbs of ZVI injected during the demonstration

Type/Quantity of Media Treated:
Groundwater
- Estimated subsurface volume treated was 1,683 cubic yards (based on a treatment area of about 1,818 ft^2 and extending from the top of the water table of 7 ft bgs to 32 ft bgs
- Two aquifers (A and B) and one bedrock water-bearing zone; hydrogeology characterized by shallow bedrock overlain predominantly by artificial fill material with variable hydraulic conductivity; Aquifer A hydraulic conductivity ranged from 26.6 to 43 ft/day
- Groundwater flow directions are variable, generally trend south to southwest; depth to groundwater ranged from 6.2 to 6.8 bgs

Regulatory Requirements/Cleanup Goals:
- Primary objective of the demonstration was to evaluate the cost and performance of Ferox[sm] injection in treating chlorinated VOCs in source areas at Hunter's Point
- Other objectives included evaluating the percent reduction of TCE, PCE, 1,2-DCE, vinyl chloride, total chlorinated ethenes, chloroform, and carbon tetrachloride; no specific cleanup goals were identified

Results:
- Groundwater sampling conducted prior to the injections and at 2, 6, and 12 weeks after injection
- The overall reduction percentages within the treatment zone for the VOCs were: TCE (99.2 percent), PCE (99.4 percent), cis-1,2-DCE (94.2 percent), vinyl chloride (99.3 percent), total chlorinated ethenes (99.1 percent), chloroform (92.6 percent), and carbon tetrachloride (96.4 percent)
- Horizontal zone of influence (based on ORP and other parameters) - extended at least 15 ft from the injection boreholes

Costs:
- Total cost of the field demonstration was $289,274 or $172 per cubic yard of the treatment zone
- Excluding costs for sampling, analysis, and management of demonstration-derived wastes, the total cost was $196,665, or $117 per cubic yard
- Economies of scale for certain cost elements, such as mobilization and demobilization, could result in somewhat lower unit costs for larger-scale applications

Ferox[sm] Injection at Hunter's Point Shipyard, Parcel C, Remedial Unit C4, San Francisco, CA (continued)

Description:
Hunter's Point Shipyard (HPS) is located in the southeastern portion of San Francisco. The 928-acre facility operated from 1869 through 1986, as a ship repair, maintenance, and commercial facility; in 1991 the facility was designated Navy for closure under the federal Base Closure and Realignment Act.

Parcel C, located in the eastern portion of HPS, was identified as having several groundwater plumes, with a chlorinated solvent plume (primarily TCE) located beneath Remedial Unit-C4 (RU-C4). Ferox injection is a patented technology of ARS Technologies, Inc. for *in situ* subsurface remediation of source areas of chlorinated VOCs. The Ferox[sm] technology involves injection of liquid atomized zero-valent iron (ZVI) powder into targeted subsurface zones, using a packer system to isolate discrete depth intervals within open boreholes.

A field demonstration of Ferox[sm] injection was conducted at HPS RU-C4 to evaluate the use of the technology to treat chlorinated solvents in groundwater. The demonstration involved the use of 4 boreholes and the use of an injection process that integrated pneumatic fracturing and Ferox[sm] delivery (nitrogen gas used as both the fracturing and injection fluid). Results of the demonstration showed reductions in concentrations of chlorinated solvents, including DNAPL, of as high as 99.4 percent. It was noted that most of the reduction in TCE concentrations occurred during the first 3 weeks of the demonstration. For future applications, it was suggested that less monitoring would be needed than was performed for the demonstration.

In Situ Bimetallic Nanoscale Particle (BNP) Treatment at the Naval Air Engineering Station Site (Area I), Lakehurst, New Jersey

Site Name: Naval Air Engineering Station (NAES) Site (Area I)	**Location:** Lakehurst, New Jersey
Period of Operation: February to March 2002 (pilot test)	**Cleanup Authority:** Not applicable
Purpose/Significance of Application: Pilot test of *in situ* BNP injection to treat groundwater contaminated with chlorinated hydrocarbons	**Cleanup Type:** Field Demonstration
Contaminants: Volatiles-Halogenated Tetrachloroethene (PCE), trichloroethene (TCE), 1,1,1-trichloroethane (1,1,1,-TCA), cis-dichloroethene (cis-DCE), and vinyl chloride. • Contamination extends vertically 70 feet below groundwater table • Largest amount of contamination in the zone from 30 to 50 feet below groundwater table • In February 2000, total volatile organic compound (VOC) concentrations in groundwater approximately 900 : g/L	**Waste Source:** Various facility operations and releases

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Technology:

In Situ Bimetallic Nanoscale Particle (BNP) treatment (categorized as *in situ* chemical reduction)

- BNP consists of submicron particles of zero valent iron (Fe^0) with a trace coating of palladium (approximately 0.1% by weight) that acts as a catalyst; treatment of contaminants is based on a redox process where the zero valent iron serves as the electron donor
- Pilot test of *in situ* BNP conducted at Area I; groundwater recirculation initiated one day prior to injection of BNP to enhance *in situ* mixing and achieve hydraulic control of pilot test area
- BNP pressure injection performed from February 5-7, 2002, using three injection points; piston pump used with open probe rods using a bottom up injection procedure
- Injection point -1 (IP-1):
  - String of probe rods retracted from 65 to 43 feet bgs at injection rate of approximately 2.5 gpm
  - Total of approximately 2,260 liters of 1.4 g/L BNP suspension (average concentration) injected
- IP-2:
  - String of probe rods retracted from 65 feet below grade to ground surface at injection rate of approximately 2.5 gpm; due to problems with grout pump (likely from pressure build-up) rods had to be pulled up to ground surface
  - Total of approximately 2,070 liters of 1.5 g/L BNP suspension (average concentration) injected
- IP-3:
  - String of probe rods retracted from 65 to 34 feet below grade at injection rate of approximately 2.5 gpm
  - Total of approximately 2,315 liters of 1.4 g/L BNP suspension (average concentration) injected
- Groundwater monitoring performed on day 1, 7, 14, and 28 following BNP injection and analyzed for VOCs, chloride, iron, and geochemical parameters

In Situ Bimetallic Nanoscale Particle (BNP) Treatment at the Naval Air Engineering Station Site (Area I), Lakehurst, New Jersey (continued)

Type/Quantity of Media Treated:
Groundwater: 1,800 cubic feet or 13,500 gallons; based on an assumed treatment area of 300 ft^2, an impacted groundwater thickness of 20 ft, and porosity of 0.3

- Average hydraulic conductivity of aquifer - 88.31 ft/day
- Estimated hydraulic gradient - 0.002 ft/ft
- Estimated groundwater velocity - 0.59 ft/day
- Geology: unconsolidated sediments characterized as a fairly uniform, brown-yellow, fine to coarse sand; grain size analyses characterized sediments as 0.5 to 5.9% gravel, 85.8 to 93.6% sand, and 5.4 to 8.6% clay; total organic carbon levels ranged from 40 to 800 mg/kg

Regulatory Requirements/Cleanup Goals:
The primary objective of the pilot test was to assess the feasibility of using BNP to treat chlorinated hydrocarbons in groundwater in Area I at the site. The remedial goal was to reduce, but not completely degrade, chlorinated hydrocarbons in the treatment area. Changes in groundwater chemistry (for example, oxidation-reduction potential (ORP)) following the application of BNP were also evaluated. No specific cleanup goals were identified.

Results:

- Results from the BNP pilot test are based on data collected from February 8 to May 6, 2002
- Average reductions of concentrations for PCE, TCE, and cis-DCE in the treatment area were approximately 67% to 87%. The total reduction of VOCs within the treatment area during this period was approximately 74%.
- Within specific wells, reductions were as high as 100% for PCE, 74% for TCE, 89% for cis-1,2-DCE, and 88% for total VOCs
- During the pilot test, ORP levels in groundwater were reduced from a range of +170 to +311 mV to a range of -100 to -400 mV. Reducing conditions were observed two months following the completion of the pilot test.
- Based on the results of the pilot test, a larger scale pilot test of BNP in Area I was recommended

Costs:
Not provided

Description:
NAES Lakehurst, located in Orange County, New Jersey, is approximately 7,300 acres in size. Groundwater in Area I at the site was determined to be contaminated with chlorinated hydrocarbons, including PCE, TCE, 1,1,1-TCA, and vinyl chloride, with levels of VOCs as high as 900 : g/L. A pilot test of *in situ* BNP was conducted at the site from February to March 2002. BNP consists of submicron particles of zero valent iron with a trace coating of palladium that acts as a catalyst. The treatment of contaminants using BNP is based on a redox process where the zero valent iron serves as the electron donor. The objective of the pilot test was to assess the feasibility of using BNP to treat chlorinated hydrocarbons in groundwater in Area I at the site, and to evaluate changes in groundwater chemistry following the application of BNP. A BNP-water suspension was injected into the groundwater at three injection points using pressure injection through open probe rods. A total of approximately 7,000 liters of BNP suspension was injected from February 5 to 7, 2002, and groundwater sampling was performed through May 2002.

The average reductions of PCE, TCE, and cis-DCE in the treatment area were approximately 67% to 87% from February 8 to May 6, 2002. The total reduction of VOCs within the treatment area during this period was approximately 74%. ORP data showed that reducing conditions were achieved during the pilot test and two months after completion of the test. Based on these results, a larger scale pilot test of BNP in Area I was recommended. Suggestions for improvement in the larger scale test included increasing the amount of BNP injected into the groundwater by increasing the concentration of the suspension and increasing the number of injection points, and injecting BNP in a grid pattern to create a reaction zone.

Air Sparging and Pump and Treat at the Del Norte County Pesticide Storage Area Superfund Site, Crescent City, California

Site Name: Del Norte County Pesticide Storage Area Superfund Site	**Location:** Crescent City, California
Period of Operation: April 1990 - October 1997 (Air Sparging: March 1994 - November 1996)	**Cleanup Authority:** EPA
Purpose/Significance of Application: Use of air sparging, in conjunction with pump and treat, to enhance the removal of DCP in groundwater	**Cleanup Type:** Full scale
Contaminants: 1,2-Dichloropropane (DCP), 2,4-Dichlorophenoxyacetic acid (2,4-D), chromium DCP concentrations prior to start up of air sparging: 15 - 40 : g/L	**Waste Source:** Residues and rinse water disposed of in an unlined sump

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Technology:

Technology: Air Sparging and Pump and Treat

- A pump and treat system was installed in 1990 and operated until October 1997; no details of this system were provided
- Air sparging was added in 1994 in an attempt to enhance contaminant removal
- The air sparging system included:
  - 10 air sparge points initially installed within the 1,2-dichloropropane (DCP) plume; after one year of operation, 15 additional sparge points installed
  - Points consisted of ½-inch diameter PVC tubes placed to bottom of aquifer; tubes were plumbed to air compressor to force air through tubes to bottom of aquifer
  - System was shut off in November 1996 after no discernable changes in DCP concentrations were noted

Type/Quantity of Media Treated:

Groundwater

- Groundwater depth - ranged between 3 and 10 feet bgs
- Groundwater flow direction - southeast
- Thickness of uppermost aquifer - approximately 30 feet
- Hydraulic conductivity - approximately 10^{-3} cm/s

Regulatory Requirements/Cleanup Goals:

- 1985 ROD specified 10 : g/L for DCP (health-based standard)
- 2000 ROD Amendment - included a TI Waiver and changed the groundwater remedy to plume containment through natural attenuation, groundwater monitoring, and institutional controls

Air Sparging and Pump and Treat at the Del Norte County Pesticide Storage Area Superfund Site, Crescent City, California (continued)

Results:

- The pump and treat system operated from 1990 to 1997; the air sparging system operated from 1994 to 1996; DCP data are available for 1994 to 2003
- The areal extent of the DCP plume (greater than 5 : g/L) was reduced from approximately 12,000 ft^2 to 5,000 ft^2 (as of 1998)
- An estimated 3.75 gallons DCP removed from groundwater between 1990 and 1997 (95% of this amount was estimated to have been removed by the pump and treat system between 1990 and 1994)
- Operation of the air sparging system resulted in no discernable changes in groundwater DCP concentrations; the system was shut down in 1996
- Continued operation of the pump and treat system resulted in no discernable changes in groundwater DCP concentrations; the system was shut down in 1997
- As of March 2003, groundwater DCP concentrations ranged from 2.4 to 6.6 : g/L

Costs:

- EPA provided actual costs for O&M for 1995 to 1997: 1995 - $166,518; 1996 - $106,928;

1997 - $84,211; no additional details were provided regarding the O&M costs; no capital cost data were provided

Description:

Del Norte County Pesticide Storage Area Superfund Site is located in Crescent City, California, and operated from 1970 to 1981 as a county-wide collection point for the interim and emergency storage of pesticide containers generated by local industry. Pesticide containers were rinsed on site, with residues and rinse water improperly disposed of in a unlined sump. This resulted in groundwater at the site becoming contaminated with pesticides, herbicides, and volatile and semi-volatile compounds. Contaminants of concern at the site included DCP, 2,4-D, and chromium. The site was listed on the NPL in 1983. The 1985 ROD specified pump and treat as the groundwater remedy for the site.

The pump and treat system was installed in 1990. In 1994, EPA determined that while DCP concentrations had decreased in monitoring wells, asymptotic levels of between 15 and 40 : g/L had been reached. In an attempt to enhance contaminant removal, an air sparging system was added, and after one year of operation, expanded to include additional sparge points. EPA noted that there were no discernable changes in DCP concentrations and the air sparging system was shut down in November 1996. Continued operation of the pump and treat system did not result in discernable changes in DCP concentrations and the system was shut down in 1997. EPA concluded that neither the pump and treat remedy nor any other technology available at the time would be able to treat DCP to below the cleanup level and a TI waiver was issued based on these findings. In August 2000, a ROD Amendment was signed amending the groundwater remedy for the site to include plume containment through natural attenuation, continued monitoring of the groundwater, and institutional controls. Final site cleanup and equipment removal was completed in December 2000, and the site was deleted from the NPL in September 2002.

During operation of these systems between 1990 and 1997, an estimated 3.75 gallons of DCP were removed from the groundwater, with 95% of this amount removed by the pump and treat system between 1990 and 1994. O&M costs available for 1995 to 1997 were: $166,518 in 1995, $106,928 in 1996, and $84,211 in 1997. Results of groundwater monitoring after system shut down showed DCP concentrations in groundwater ranging from 2.4 to 6.6 : g/L.

In Well Air Stripping at Two Dry Cleaners, Various Locations

Site Name:
Multiple (2) Dry Cleaners - In Well Air Stripping

Location:
- Schloff Chemicals and Supply Company, Inc., St. Louis Park, MN
- Former Base Laundry & Dry Cleaning Facility, Orlando, FL

Period of Operation:
- Schloff: September 1994
- Former Base: December 10, 1997

Cleanup Authority:
State

Purpose/Significance of Application:
Use of in well air stripping (IWAS) to treat chlorinated solvents in groundwater at dry cleaner facilities

Cleanup Type:
Full scale

Contaminants:
Tetrachloroethene (PCE); Trichloroethene (TCE); Volatiles-Halogenated
- Schloff: PCE - 7,800 : g/L; TCE - 240 : g/L
- Former Base: Groundwater - PCE - 34,000 : g/L; TCE - 15,000 : g/L; Soil - PCE - 430 : g/kg; TCE - 27 : g/kg; plume size - 245,000 ft^2

Waste Source:
Waste and wastewater from dry cleaning operations

Contacts:
Varied by site

Technology:
IWAS - UVB; Pump & Treat (P&T)
- Schloff:
  - Two UVB wells installed
  - Water being pumped into the UVB-200-1 reactor at 4 m^3/h, and back into the two UVB-200-2 stripping reactors at 2 m^3/h
- Former Base:
  - Two UVB wells installed 300 ft downgradient of the facility, approximately 85 ft apart; wells constructed of 10-inch diameter schedule 80 PVC with two stainless steel screens (0.01-inch slots)
  - Contaminated groundwater was extracted through the upper screen (3.5 -12.5 ft bgs - upper surficial aquifer)
  - Water was treated in an in-well stripping unit installed on the top of the wellhead
  - Treated water was injected through the lower screen interval (39-45 ft bgs - lower surficial aquifer)
  - Design flow rate for each submersible pump was 40 gpm
  - VOC emissions from the system were estimated to be approximately 2.0 lbs/day; therefore no emissions treatment was installed

Type/Quantity of Media Treated:
Groundwater, Soil
- Schloff:
  - Depth to groundwater: 8 - 12 ft bgs
  - Subsurface geology: 0-27 ft fine to coarse grained sand; 27-75 ft bedrock
  - Aquifer conductivity: 0.5 - 25.2 ft/day
  - Groundwater gradient: 0.004 - 0.005 ft/ft
- Former Base:
  - Depth to groundwater: 3.3 - 10.1 ft bgs
  - Subsurface geology: (Upper surficial aquifer) 0-17 ft bgs fine-grained sand; 17-20 ft bgs moderately to well indurated silty, fine-grained sand. (Lower surficial aquifer) 20-54 ft bgs fine-grained sand; 54-71 ft bgs silty, fine, fine to coarse sand with phosphate nodules and shells; 71 - depth of investigation silty, clayey sand with clay interbeds
  - Aquifer conductivity: Upper surficial aquifer - 10 ft/day; Lower surficial aquifer - 40 ft/day
  - Groundwater gradient: 0.008 ft/ft

Regulatory Requirements/Cleanup Goals:
Schloff: Not provided
Former Base: Groundwater (MCLs) PCE - 3 : g/L; TCE - 3 : g/L; cis 1,2-DCE - 70 : g/L

In Well Air Stripping at Two Dry Cleaners, Various Locations (continued)

Results:
- Schloff: Not provided
- Former Base: Results not available because the system could not achieve design pumping rates and therefore, did not achieve capture of the downgradient portion of the contaminant plume.

Costs:
Schloff: $773,716 (total cost as of 1999)
Former Base: Not available

Description:
In Well Air Stripping (IWAS) - UVB was implemented at full scale at Schloff Chemicals in Minnesota and Former Base Laundry in Florida. The contaminants at the sites were mainly halogenated volatiles, including PCE and TCE. PCE was found in groundwater at concentrations as high as 34,000 : g/L, and TCE as high as 15,000 : g/L. In the soil, concentrations of PCE and TCE were 430 : g/kg and 27 : g/kg, respectively.

The application of UVB technology at Schloff was the first application of its kind in the state of Minnesota. However, results were not provided for the project. At Former Base, results were not available because the system could not achieve design pumping rates. The system had many operational and maintenance problems including silt/sand entering the well screens, failed packers, biofouling, precipitation, and problems associated with equalizing influent and effluent pumping rates.

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APPENDIX A

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EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Soil Vapor Extraction (40 Projects)						
Basket Creek Surface Impoundment Site, GA	18	SVE	Soil	TCE; Volatiles-Halogenated; Ketones; Volatiles-Nonhalogenated; Heavy Metals	1992	1997
Camp Lejeune Military Reservation, Site 82, Area A, NC	32	SVE	Soil	BTEX; PCE; TCE; Volatiles-Halogenated; Volatiles-Nonhalogenated	1995	1998
Commencement Bay, South Tacoma Channel Well 12A Superfund Site, WA	45	SVE	Soil; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	1992	1995
Davis-Monthan AFB, Site ST-35, AZ	51	SVE	Soil	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1995	1998
Defense Supply Center Richmond, OU 5, VA	52	SVE (Field Demonstration)	Soil	PCE; TCE; Volatiles-Halogenated	1992	1998
East Multnomah County Groundwater Contamination Site, OR	370	SVE; Air Sparging; Pump and Treat	Soil; Groundwater; LNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	1991	2004
Fairchild Semiconductor Corporation Superfund Site, CA	68	SVE	Soil	PCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1989	1995
Fort Greely, Texas Tower Site, AK	82	SVE; Air Sparging; Bioremediation (*in situ*) Enhanced Bioremediation	Soil; Groundwater	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1994	1998

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Fort Lewis, Landfill 4, WA	84	SVE; Air Sparging	Soil	TCE; DCE; Volatiles-Halogenated; Heavy Metals	1994	1998
Fort Richardson, Building 908 South, AK	88	SVE	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated; Volatiles-Halogenated	1995	1998
Hastings Groundwater Contamination Superfund Site, Well Number 3 Subsite, NE	104	SVE	Soil	TCE; Volatiles-Halogenated	1992	1995
Holloman AFB, Sites 2 and 5, NM	108	SVE	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1994	1998
Intersil/Siemens Superfund Site, CA	117	SVE	Soil	TCE; Volatiles-Halogenated	1988	1998
Luke Air Force Base, North Fire Training Area, AZ	145	SVE	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated; Ketones	1990	1995
McClellan Air Force Base, Operable Unit D, Site S, CA	154	SVE (Field Demonstration)	Soil	PCE; TCE; DCE; Volatiles-Halogenated	1993	1995
Multiple (2) Dry Cleaner Sites - *In situ* SVE, Various Locations	366	SVE	Soil; Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1994	2004
Multiple (3) Dry Cleaner Sites - *In Situ* Treatment, Various Locations	363	SVE; Chemical Oxidation/Reduction (*in situ*); Thermal Treatment (*in situ*)	Soil; Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	2001	2004

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Multiple (3) Dry Cleaner Sites - SVE/Air Sparging, Various Locations	317	SVE; Air Sparging	Soil; Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	Various years - starting 1995	2003
Multiple (3) Dry Cleaner Sites - SVE/MNA, Various Locations	320	SVE; Monitored Natural Attenuation; Pump and Treat	Soil; Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	Various years - starting 1996	2003
Multiple (4) Dry Cleaners - SVE and SVE Used with Other Technologies, Various Locations	365	SVE; Air Sparging; Chemical Oxidation/Reduction (*in situ*); Pump and Treat; Monitored Natural Attenuation; Multi Phase Extraction	Soil; Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Semivolatiles-Nonhalogenated	1997	2004
Multiple (6) Dry Cleaner Sites, Various Locations	345	SVE	Soil; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	Various years - starting 1992	Various years - 2002, 2003
Multiple (7) Dry Cleaner Sites	176	SVE; Pump and Treat	Soil; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	Various years - starting 1998	Various years - 2001, 2002
Multiple (7) Dry Cleaner Sites - P&T/SVE/MPE, Various Locations	349	SVE; Multi Phase Extraction; Pump and Treat	Soil; Groundwater; DNAPLs; Off-gases	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	Various years - starting 1991	Various years - 2002, 2003
NAS North Island, Site 9, CA	183	SVE (Photolytic Destruction) (Field Demonstration)	Soil	PCE; TCE; DCE; BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated	1997	1998
Patrick Air Force Base, Active Base Exchange Service Station, FL	215	SVE (Internal Combustion Engine) (Field Demonstration)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1993	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Patrick Air Force Base, Active Base Exchange Service Station, FL	214	SVE (Biocube™) (Field Demonstration)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1994	2000
Rocky Mountain Arsenal Superfund Site (Motor Pool Area - Operable Unit #18), CO	237	SVE	Soil	TCE; Volatiles-Halogenated	1991	1995
Sacramento Army Depot Superfund Site, Burn Pits Operable Unit, CA	240	SVE	Soil	PCE; TCE; DCE; Volatiles-Halogenated	1994	1997
Sacramento Army Depot Superfund Site, Tank 2 (Operable Unit #3), CA	241	SVE	Soil	Ketones; BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated	1992	1995
Sand Creek Industrial Superfund Site, Operable Unit 1, CO	242	SVE	Soil; LNAPLs	PCE; TCE; Volatiles-Halogenated; Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1993	1997
Seymour Recycling Corporation Superfund Site, IN	258	SVE; Containment - Caps; Bioremediation (*in situ*) Enhanced Bioremediation	Soil	PCE; TCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1992	1998
Shaw AFB, OU 1, SC	261	SVE; Free Product Recovery	Soil; Groundwater; LNAPLs	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1995	1998
SMS Instruments Superfund Site, NY	264	SVE	Soil	Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1992	1995

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Stamina Mills Superfund Site, RI	273	SVE; Multi Phase Extraction (Field Demonstration)	Soil; Off-gases	TCE; Volatiles-Halogenated	1999	2001
Tyson's Dump Superfund Site, PA	285	SVE	Soil	PCE; TCE; DCE; Volatiles-Halogenated	1988	1998
U.S. Department of Energy, Savannah River Site, SC	295	SVE (Flameless Thermal Oxidation) (Field Demonstration)	Soil; Off-gases	PCE; TCE; Volatiles-Halogenated	1995	1997
U.S. Department of Energy, Savannah River Site, SC, and Sandia, NM	251	SVE; In-Well Air Stripping; Bioremediation (*in situ*) ALL; Drilling (Field Demonstration)	Soil; Groundwater	Volatiles-Halogenated	1988	2000
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH	292	SVE; Chemical Oxidation/Reduction (*in situ*); Solidification/Stabilization; Thermal Treatment (*in situ*) (Field Demonstration)	Soil	TCE; DCE; Volatiles-Halogenated	1992	1997
Vandenberg Air Force Base, Base Exchange Service Station, CA	306	SVE (Resin Adsorption) (Field Demonstration)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1994	2000
Verona Well Field Superfund Site (Thomas Solvent Raymond Road - Operable Unit #1), MI	307	SVE	Soil Light Non-aqueous Phase Liquids	Ketones; BTEX; Volatiles-Nonhalogenated; PCE; Volatiles-Halogenated	1988	1995
Other *In Situ* Soil/Sediment Treatment (38 Projects)						
Alameda Point, CA	5	Electrokinetics (Field Demonstration)	Soil	Heavy Metals	1997	2001
Argonne National Laboratory - West, Waste Area Group 9, OU 9-04, ID	12	Phytoremediation (Field Demonstration)	Soil	Heavy Metals	1998	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Avery Dennison, IL	329	Thermal Treatment (*in situ*)	Soil; DNAPLs	Volatiles-Halogenated	1999	2003
Beach Haven Substation, Pensacola, FL	20	Electrokinetics (Field Demonstration)	Soil	Arsenic	1998	2000
Brodhead Creek Superfund Site, PA	24	Thermal Treatment (*in situ*)	Soil; DNAPLs	PAHs; Semivolatiles-Nonhalogenated; BTEX; Volatiles-Nonhalogenated; Arsenic	1995	1998
Castle Airport, CA	35	Bioremediation (*in situ*) Bioventing (Field Demonstration)	Soil	BTEX; Volatiles-Nonhalogenated	1998	1999
Castle Airport and Various Sites, CA	361	Bioremediation (*in situ*) Bioventing (Field Demonstration)	Soil	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated;	1998	2004
Confidential Chemical Manufacturing Facility, IN	330	Thermal Treatment (*in situ*)	Soil; DNAPLs; Off-gases	PCE; TCE; DCE; Volatiles-Halogenated	1997	2003
Crooksville/Roseville Pottery Area of Concern (CRPAC), OH	327	Solidification/Stabilization (Field Demonstration)	Soil	Heavy Metals	1998	2002
Dover Air Force Base, Building 719, DE	57	Bioremediation (*in situ*) Bioventing (Field Demonstration)	Soil	TCE; DCE; Volatiles-Halogenated	1998	2000
Eielson Air Force Base, AK	64	Bioremediation (*in situ*) Bioventing (Field Demonstration)	Soil	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1991	1995
Ensign-Bickford Company - OB/OD Area, CT	66	Phytoremediation	Soil	Heavy Metals	1998	2000
Former Mare Island Naval Shipyard, CA	75	Thermal Treatment (*in situ*) (Field Demonstration)	Soil	PCBs; Semivolatiles-Halogenated	1997	2000
Fort Richardson Poleline Road Disposal Area, OU B, AK	89	Thermal Treatment (*in situ*); SVE (Field Demonstration)	Soil	PCE; TCE; Volatiles-Halogenated	1997	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Hill Air Force Base, Site 280, UT	106	Bioremediation (*in situ*) Bioventing	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1990	1995
Hill Air Force Base, Site 914, UT	107	Bioremediation (*in situ*) Bioventing; SVE	Soil	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1988	1995
Idaho National Engineering and Environmental Laboratory, ID	114	Bioremediation (*in situ*) Bioventing (Field Demonstration)	Soil	Volatiles-Halogenated	1996	2000
Koppers Co. (Charleston Plant) Ashley River Superfund Site, SC	350	Solidification/Stabilization	Sediment; DNAPLs	PAHs; Semivolatiles-Nonhalogenated	2001	2003
Lowry Air Force Base, CO	143	Bioremediation (*in situ*) Bioventing	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1992	1995
Magic Marker, NJ and Small Arms Firing Range (SAFR) 24, NJ	146	Phytoremediation (Field Demonstration)	Soil	Heavy Metals	Magic Marker - 1997; Fort Dix - 2000	2002
Missouri Electric Works Superfund Site, MO	160	Thermal Treatment (*in situ*) (Field Demonstration)	Soil	PCBs; Semivolatiles-Halogenated	1997	1998
Morses Pond Culvert, MA	351	Chemical Oxidation/Reduction (*in situ*)	Soil	Heavy Metals	2001	2004
Multiple Air Force Test Sites, Multiple Locations	180	Bioremediation (*in situ*) Bioventing (Field Demonstration)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1992	2000
Naval Air Weapons Station Point Mugu Site 5, CA (USAEC)	188	Electrokinetics (Field Demonstration)	Soil; Sediment	Heavy Metals	1998	2000
Naval Air Weapons Station Point Mugu Site 5, CA (USEPA)	189	Electrokinetics (Field Demonstration)	Soil	Heavy Metals	1998	2000
Paducah Gaseous Diffusion Plant (PGDP) Superfund Site, KY	328	Lasagna™	Soil	TCE; Volatiles-Halogenated	1999	2002

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Parsons Chemical/ETM Enterprises Superfund Site, MI	212	Vitrification (*in situ*)	Soil; Sediment	Pesticides/Herbicides; Semivolatiles-Halogenated; Heavy Metals; Dioxins/Furans	1993	1997
Portsmouth Gaseous Diffusion Plant, X-231A Site, Piketon, OH	225	Fracturing (Field Demonstration)	Soil; Groundwater	TCE; Volatiles-Halogenated	1996	2001
Sandia National Laboratories, Unlined Chromic Acid Pit, NM	246	Electrokinetics (Field Demonstration)	Soil	Heavy Metals	1996	2000
Savannah River Site 321-M Solvent Storage Tank Area, GA	337	Thermal Treatment (*in situ*) (Field Demonstration)	Soil; DNAPLs	PCE; TCE; Volatiles-Halogenated	2000	2003
Twin Cities Army Ammunition Plant, MN	283	Phytoremediation (Field Demonstration)	Soil	Heavy Metals; Arsenic	1998	2000
U.S. Department of Energy, Hanford Site, WA, Oak Ridge (TN) and Others	289	Vitrification (*in situ*)	Soil; Sludge; Debris/Slag/ Solid	Pesticides/Herbicides; Heavy Metals; Arsenic; Dioxins/Furans; Semivolatiles-Halogenated PCBs; Radioactive Metals	Not Provided	1997
U.S. Department of Energy, Multiple Sites	288	Drilling (Field Demonstration)	Soil; Sediment	-	1992	1997
U.S. Department of Energy, Paducah Gaseous Diffusion Plant, KY	291	Lasagna™ (Field Demonstration)	Soil; Groundwater	TCE; Volatiles-Halogenated	1995	1997
U.S. Department of Energy, Portsmouth Gaseous Diffusion Plant, OH and Other Sites	293	Fracturing (Field Demonstration)	Soil; Groundwater; DNAPLs	TCE; Volatiles-Halogenated	1991	1997
U.S. Department of Energy, Savannah River Site, SC, and Hanford Site, WA	296	Thermal Treatment (*in situ*) (Field Demonstration)	Soil; Sediment	PCE; TCE; Volatiles-Halogenated	1993	1997
White Sands Missile Range, SWMU 143, NM	313	Chemical Oxidation/Reduction (*in situ*) (Field Demonstration)	Soil	Heavy Metals	1998	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Young-Rainy Star Center (formerly Pinellas) Northeast Area A, FL	355	Thermal Treatment (*in situ*)	Soil; Groundwater	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated DCE; PCE; TCE; Volatiles-Halogenated	2002	2004
Incineration (on-site) (18 Projects)						
Baird and McGuire, MA	15	Incineration (on-site)	Soil; Sediment	Dioxins/Furans; Semivolatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated; Arsenic; Heavy Metals; Volatiles-Halogenated	1995	1998
Bayou Bonfouca, LA	19	Incineration (on-site)	Soil; Sediment	PAHs; Semivolatiles-Nonhalogenated	1993	1998
Bridgeport Refinery and Oil Services, NJ	23	Incineration (on-site)	Soil; Debris/Slag/Solid; Sediment; Organic Liquids; Sludge	PCBs; Semivolatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Heavy Metals; Volatiles-Halogenated	1991	1998
Celanese Corporation Shelby Fiber Operations, NC	36	Incineration (on-site)	Soil; Sludge	PAHs; Semivolatiles-Nonhalogenated; TCE; Volatiles-Halogenated; Volatiles-Nonhalogenated; Heavy Metals; BTEX	1991	1998

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Coal Creek, WA	43	Incineration (on-site)	Soil	PCBs; Semivolatiles-Halogenated; Heavy Metals	1994	1998
Drake Chemical Superfund Site, Operable Unit 3, Lock Haven, PA	59	Incineration (on-site)	Soil	Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1998	2001
FMC Corporation - Yakima, WA	72	Incineration (on-site)	Soil; Debris/Slag/ Solid	Pesticides/Herbicides; Semivolatiles-Halogenated; Heavy Metals	1993	1998
Former Nebraska Ordnance Plant - OU 1, NE	76	Incineration (on-site)	Soil; Debris/Slag/ Solid	Explosives/Propellants	1997	1998
Former Weldon Springs Ordnance Works, OU 1, MO	79	Incineration (on-site)	Soil; Debris/Slag/ Solid	Explosives/Propellants; Heavy Metals; PCBs; Semivolatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated	1998	2000
MOTCO, TX	165	Incineration (on-site)	Soil; Sludge; Organic Liquids	PCBs; Semivolatiles-Nonhalogenated; Heavy Metals; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1990	1998
Old Midland Products, AR	206	Incineration (on-site)	Soil; Sludge	Semivolatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated; Volatiles-Nonhalogenated; Volatiles-Halogenated	1992	1998

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Petro Processors, LA	217	Incineration (on-site)	Soil; Organic Liquids; DNAPLs	PAHs; Semivolatiles-Nonhalogenated; Heavy Metals; Volatiles-Halogenated	1994	1998
Rocky Mountain Arsenal, CO	236	Incineration (on-site)	Soil; Organic Liquids	Pesticides/Herbicides; Heavy Metals; Arsenic	1993	1998
Rose Disposal Pit, MA	238	Incineration (on-site)	Soil	PCBs; Semivolatiles-Halogenated; TCE; Volatiles-Halogenated; Volatiles-Nonhalogenated	1994	1998
Rose Township Dump, MI	239	Incineration (on-site)	Soil	PCBs; Semivolatiles-Halogenated; Heavy Metals; BTEX; Volatiles-Nonhalogenated; Semivolatiles-Nonhalogenated; PAHs; Ketones	1992	1998
Sikes Disposal Pits, TX	262	Incineration (on-site)	Soil; Debris/Slag/ Solid	PAHs; Semivolatiles-Nonhalogenated; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1992	1998
Times Beach, MO	280	Incineration (on-site)	Soil; Debris/Slag/ Solid	Dioxins/Furans; Semivolatiles-Halogenated	1996	1998
Vertac Chemical Corporation, AR	308	Incineration (on-site)	Soil; Debris/Slag/ Solid; Organic Liquids	Dioxins/Furans; Semivolatiles-Halogenated; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1992	1998

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Thermal Desorption (29 Projects)						
Anderson Development Company Superfund Site, MI	8	Thermal Desorption (*ex situ*)	Soil; Sludge	PAHs; Semivolatiles-Nonhalogenated; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Heavy Metals	1992	1995
Arlington Blending and Packaging Superfund Site, TN	13	Thermal Desorption (*ex situ*)	Soil	Pesticides/Herbicides; Semivolatiles-Halogenated; Arsenic	1996	2000
Brookhaven National Laboratory (BNL), NY	325	Thermal Desorption (*ex situ*) (Field Demonstration)	Soil	Heavy Metals	Not provided	2002
Cape Fear Superfund Site, NC	33	Thermal Desorption (*ex situ*)	Soil	PAHs; Semivolatiles-Nonhalogenated; Arsenic; Heavy Metals; Volatiles-Nonhalogenated; BTEX	1998	2002
FCX Washington Superfund Site, NC	69	Thermal Desorption (*ex situ*)	Soil	Pesticides/Herbicides; Semivolatiles-Halogenated	1995	1998
Fort Lewis, Solvent Refined Coal Pilot Plant (SRCPP), WA	86	Thermal Desorption (*ex situ*)	Soil	PAHs; Semivolatiles-Nonhalogenated	1996	1998
Fort Ord, CA	354	Thermal Desorption (*ex situ*) (Field Demonstration)	Debris/Slag/Solid; Off-gas	Heavy Metals	2002	2004
Industrial Latex Superfund Site, NJ	348	Thermal Desorption (*ex situ*)	Soil; Off-gases	Pesticides/Herbicides; Semivolatiles-Halogenated; PAHs; PCBs; Arsenic	1999	2002
Letterkenny Army Depot Superfund Site, K Areas, OU1, PA	135	Thermal Desorption (*ex situ*)	Soil	TCE; Volatiles-Halogenated; Heavy Metals	1993	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Lipari Landfill, Operable Unit 3, NJ	137	Thermal Desorption (*ex situ*)	Soil	TCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Arsenic; Heavy Metals; Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1994	2002
Longhorn Army Ammunition Plant, Burning Ground No. 3, TX	138	Thermal Desorption (*ex situ*)	Soil	TCE; Volatiles-Halogenated	1997	2000
McKin Superfund Site, ME	155	Thermal Desorption (*ex situ*)	Soil	BTEX; Volatiles-Nonhalogenated; PAHs; Semivolatiles-Nonhalogenated	1986	1995
Metaltec/Aerosystems Superfund Site, Franklin Borough, NJ	156	Thermal Desorption (*ex situ*)	Soil	TCE; DCE; Volatiles-Halogenated; Heavy Metals	1994	2001
Naval Air Station Cecil Field, Site 17, OU 2, FL	182	Thermal Desorption (*ex situ*)	Soil	BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated	1995	1998
New Bedford Harbor Superfund Site, New Bedford, MA	197	Thermal Desorption (*ex situ*) (Field Demonstration)	Sediment	PCBs; Semivolatiles-Halogenated	1996	2001
Outboard Marine Corporation Superfund Site, OH	209	Thermal Desorption (*ex situ*)	Soil; Sediment	PCBs; Semivolatiles-Halogenated	1992	1995
Port Moller Radio Relay Station, AK	223	Thermal Desorption (*ex situ*)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1995	1998
Pristine, Inc. Superfund Site, OH	227	Thermal Desorption (*ex situ*)	Soil	Pesticides/Herbicides; PAHs; Semivolatiles-Nonhalogenated; Heavy Metals	1993	1995

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Re-Solve, Inc. Superfund Site, MA	230	Thermal Desorption (*ex situ*)	Soil	PCBs; Semivolatiles-Halogenated; Ketones; BTEX; Volatiles-Nonhalogenated; TCE; Volatiles-Halogenated	1993	1998
Reich Farm, Pleasant Plains, NJ	228	Thermal Desorption (*ex situ*)	Soil	Volatiles-Halogenated; Volatiles-Nonhalogenated; Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1994	2001
Reilly Industries Superfund Site, Operable Unit 3, IN	229	Thermal Desorption (*ex situ*)	Soil	PAHs; Semivolatiles-Nonhalogenated; BTEX; Volatiles-Nonhalogenated	1996	2002
Rocky Flats Environmental Technology Site, Mound Site, Golden, CO	234	Thermal Desorption (*ex situ*)	Soil	PCE; TCE; Volatiles-Halogenated	1997	2001
Rocky Flats Environmental Technology Site, Trenches T-3 and T-4, CO	235	Thermal Desorption (*ex situ*)	Soil; Debris/Slag/ Solid	TCE; Volatiles-Halogenated; Ketones; BTEX; Volatiles-Nonhalogenated; Radioactive Metals	1996	2000
Sand Creek Superfund Site, OU 5, CO	243	Thermal Desorption (*ex situ*)	Soil	Pesticides/Herbicides; Arsenic	1994	2000
Sarney Farm, Amenia, NY	248	Thermal Desorption (*ex situ*)	Soil	TCE; DCE; Volatiles-Halogenated; Ketones; BTEX; Volatiles-Nonhalogenated	1997	2001

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Site B (actual site name confidential), Western United States	333	Thermal Desorption (*ex situ*)	Soil; Off-gases	Pesticides/Herbicides; Semivolatiles- Halogenated; Semivolatiles-Nonhalogenated	1995	2003
TH Agriculture & Nutrition Company Superfund Site, GA	277	Thermal Desorption (*ex situ*)	Soil	Pesticides/Herbicides	1993	1995
Waldick Aerospaces Devices Superfund Site, NJ	310	Thermal Desorption (*ex situ*)	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated; PCE; Volatiles-Halogenated; Heavy Metals	1993	1998
Wide Beach Development Superfund Site, NY	314	Thermal Desorption (*ex situ*); Chemical Oxidation/Reduction (*ex situ*)	Soil	Semivolatiles-Halogenated; PCBs	1990	1995
Other *Ex Situ* Soil/Sediment Treatment (33 Projects)						
Bonneville Power Administration Ross Complex, Operable Unit A, WA	22	Bioremediation (*ex situ*) Land Treatment	Soil	PAHs; Semivolatiles-Nonhalogenated; Semivolatiles-Halogenated	1994	1998
Brookhaven National Laboratory, NY	25	Physical Separation	Soil	Radioactive Metals	2000	2001
Brown Wood Preserving Superfund Site, FL	27	Bioremediation (*ex situ*) Land Treatment	Soil	PAHs; Semivolatiles-Nonhalogenated	1989	1995
Burlington Northern Superfund Site, MN	29	Bioremediation (*ex situ*) Land Treatment	Soil; Sludge	PAHs; Semivolatiles-Nonhalogenated	1986	1997
Dubose Oil Products Co. Superfund Site, FL	60	Bioremediation (*ex situ*) Composting	Soil	PAHs; Semivolatiles-Nonhalogenated; BTEX; Volatiles-Nonhalogenated; Semivolatiles-Halogenated	1993	1997

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Fort Greely, UST Soil Pile, AK	83	Bioremediation (*ex situ*) Land Treatment	Soil	BTEX; Volatiles-Nonhalogenated; Semivolatiles-Halogenated	1994	1998
Fort Polk Range 5, LA	87	Acid Leaching; Physical Separation (Field Demonstration)	Soil	Heavy Metals	1996	2000
French Ltd. Superfund Site, TX	91	Bioremediation (*ex situ*) Slurry Phase	Soil; Sludge	PAHs; Semivolatiles-Nonhalogenated; Volatiles-Halogenated; PCBs; Semivolatiles-Halogenated; Arsenic; Heavy Metals	1992	1995
Hazen Research Center and Minergy GlassPack Test Center, WI	358	Vitrification (*ex situ*) (Field Demonstration)	Sediment	PCBs; Dioxins/Furans; Semivolatiles-Halogenated; Heavy Metals	2001	2004
Idaho National Environmental and Engineering Laboratory (INEEL), ID	116	Physical Separation	Soil	Radioactive Metals	1999	2001
Joliet Army Ammunition Plant, IL	121	Bioremediation (*ex situ*) Slurry Phase (Field Demonstration)	Soil	Explosives/Propellants	1994	2000
King of Prussia Technical Corporation Superfund Site, NJ	125	Soil Washing	Soil; Sludge	Heavy Metals	1993	1995
Los Alamos National Laboratory, NM	141	Physical Separation	Soil; Debris/Slag/ Solid	Radioactive Metals	1999	2000
Lowry Air Force Base, CO	144	Bioremediation (*ex situ*) Land Treatment	Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1992	1995
Massachusetts Military Reservation, Training Range and Impact Area, Cape Cod, MA	152	Solidification/Stabilization	Soil	Heavy Metals	1998	2001

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Naval Construction Battalion Center Hydrocarbon National Test Site, CA	190	Bioremediation (*ex situ*) Composting (Field Demonstration)	Soil	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1996	1998
New Bedford Harbor Superfund Site, New Bedford, MA	196	Solvent Extraction (*ex situ*) (Field Demonstration)	Sediment	PCBs; Semivolatiles-Halogenated	1996	2001
New Bedford Harbor Superfund Site, New Bedford, MA	198	Vitrification (*ex situ*) (Field Demonstration)	Sediment	PCBs; Semivolatiles-Halogenated	1996	2001
New Bedford Harbor Superfund Site, New Bedford, MA	195	Solidification/Stabilization (Field Demonstration)	Sediment	PCBs; Semivolatiles-Halogenated	1995	2001
Novartis Site, Ontario, Canada	199	Bioremediation (*ex situ*) Land Treatment (Field Demonstration)	Soil	Pesticides/Herbicides; Semivolatiles-Halogenated	1996	1998
Oak Ridge National Laboratory, TN	201	Vitrification (*ex situ*) (Field Demonstration)	Sludge	Heavy Metals; Radioactive Metals	1997	2000
Pantex Plant, Firing Site 5, TX	211	Physical Separation	Soil; Debris/Slag/ Solid	Radioactive Metals	1998	2000
Peerless Cleaners, WI; Stannard Launders and Dry Cleaners, WI	216	Bioremediation (*ex situ*) Composting	Soil	PCE; TCE; DCE; Volatiles-Halogenated; Semivolatiles-Nonhalogenated	Not Provided	2001
RMI Titanium Company Extrusion Plant, OH	231	Solvent Extraction (*ex situ*) (Field Demonstration)	Soil	Radioactive Metals	1997	2000
Sandia National Laboratories, ER Site 16, NM	245	Physical Separation	Soil	Radioactive Metals	1998	2000
Sandia National Laboratories, ER Site 228A, NM	244	Physical Separation	Soil	Radioactive Metals	1998	2000
Scott Lumber Company Superfund Site, MO	254	Bioremediation (*ex situ*) Land Treatment	Soil	PAHs; Semivolatiles-Nonhalogenated	1989	1995

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Southeastern Wood Preserving Superfund Site, MS	270	Bioremediation (*ex situ*) Slurry Phase	Soil; Sludge	PAHs; Semivolatiles-Nonhalogenated	1991	1997
Sparrevohn Long Range Radar Station, AK	272	Solvent Extraction (*ex situ*)	Soil	PCBs; Semivolatiles-Halogenated	1996	1998
Stauffer Chemical Company, Tampa, FL	275	Bioremediation (*ex situ*) Composting (Field Demonstration)	Soil	Pesticides/Herbicides	1997	2001
Tonapah Test Range, Clean Slate 2, NV	282	Physical Separation	Soil; Debris/Slag/ Solid	Radioactive Metals	1998	2000
Umatilla Army Depot Activity, OR	300	Bioremediation (*ex situ*) Composting (Field Demonstration)	Soil	Explosives/Propellants	1992	1995
Umatilla Army Depot Activity, OR	301	Bioremediation (*ex situ*) Composting	Soil	Explosives/Propellants	1994	1997
Pump and Treat (50 Projects)						
Amoco Petroleum Pipeline, MI	7	Pump and Treat; Air Sparging	Groundwater; LNAPLs	BTEX; Volatiles-Nonhalogenated	1988	1995
Baird and McGuire Superfund Site, MA	16	Pump and Treat	Groundwater	BTEX; Volatiles-Nonhalogenated; PAHs; Semivolatiles-Nonhalogenated; Pesticides/Herbicides; Semivolatiles-Halogenated	1993	1998
Bofors Nobel Superfund Site, OU 1, MI	21	Pump and Treat	Groundwater	BTEX; Volatiles-Nonhalogenated; Semivolatiles-Halogenated; Volatiles-Halogenated; Semivolatiles-Nonhalogenated	1994	1998

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Charnock Wellfield, Santa Monica, CA	37	Pump and Treat; Chemical Oxidation/Reduction (*ex situ*) (Field Demonstration)	Drinking Water	MTBE; Volatiles-Nonhalogenated	1998	2001
City Industries Superfund Site, FL	41	Pump and Treat	Groundwater	BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated; Ketones; Semivolatiles-Nonhalogenated	1994	1998
Coastal Systems Station, AOC 1, FL	44	Pump and Treat (Field Demonstration)	Groundwater	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated; Heavy Metals	1997	1998
Commencement Bay, South Tacoma Channel Superfund Site, WA	47	Pump and Treat; SVE	Groundwater; Soil; DNAPLs; LNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	1998	2001
Commencement Bay, South Tacoma Channel Well 12A Superfund Site, WA	46	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1988	1995
Des Moines TCE Superfund Site, OU 1, IA	54	Pump and Treat	Groundwater	TCE; DCE; Volatiles-Halogenated	1987	1998
Former Firestone Facility Superfund Site, CA	73	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1986	1998
Fort Lewis Logistics Center, WA	85	Pump and Treat	Groundwater	TCE; DCE; Volatiles-Halogenated	1995	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Ft. Drum, Fuel Dispensing Area 1595, NY	81	Pump and Treat; Free Product Recovery	Groundwater; LNAPLs	BTEX; Volatiles-Nonhalogenated	1992	1995
JMT Facility RCRA Site (formerly Black & Decker RCRA Site), NY	119	Pump and Treat	Groundwater	TCE; DCE; Volatiles-Halogenated	1988	1998
Keefe Environmental Services Superfund Site, NH	122	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1993	1998
King of Prussia Technical Corporation Superfund Site, NJ	126	Pump and Treat	Groundwater	BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated Heavy Metals	1995	1998
Lacrosse, KS	127	Pump and Treat	Drinking Water	BTEX; Petroleum Hydrocarbons; MTBE; Volatiles-Nonhalogenated	1997	2001
Langley Air Force Base, IRP Site 4, VA	128	Pump and Treat	Groundwater; LNAPLs	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1992	1995
LaSalle Electrical Superfund Site, IL	129	Pump and Treat	Groundwater	PCBs; Semivolatiles-Halogenated; TCE; DCE; Volatiles-Halogenated	1992	1998
Lawrence Livermore National Laboratory (LLNL) Site 300 - General Services Area (GSA) Operable Unit, CA	134	Pump and Treat	Groundwater; Soil; DNAPLs	TCE; Volatiles-Halogenated	1991	1998
Marine Corps Base, Campbell Street Fuel Farm, Camp Lejeune, NC	150	Pump and Treat	Groundwater; Soil	BTEX; Volatiles-Nonhalogenated	1996	2001

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Marine Corps Base, OU 1 and 2, Camp Lejeune, NC	149	Pump and Treat	Groundwater	PCBs; Semivolatiles-Nonhalogenated; Pesticides/Herbicides; Heavy Metals; BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated	1995	2001
McClellan Air Force Base, Operable Unit B/C, CA	153	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1988	1995
Mid-South Wood Products Superfund Site, AR	158	Pump and Treat	Groundwater	Semivolatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated; Heavy Metals; Arsenic	1989	1998
Mystery Bridge at Hwy 20 Superfund Site, Dow/DSI Facility - Volatile Halogenated Organic (VHO) Plume, WY	181	Pump and Treat; SVE	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1994	1998
Naval Air Station, Brunswick, Eastern Groundwater Plume, ME	185	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1995	2001
Odessa Chromium I Superfund Site, OU 2, TX	203	Pump and Treat	Groundwater	Heavy Metals	1993	1998
Odessa Chromium IIS Superfund Site, OU 2, TX	204	Pump and Treat	Groundwater	Heavy Metals	1993	1998
Offutt AFB, Site LF-12, NE	205	Pump and Treat	Groundwater	BTEX; Volatiles-Nonhalogenated; TCE; DCE; Volatiles-Halogenated	1997	1998

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Old Mill Superfund Site, OH	207	Pump and Treat	Groundwater	TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1989	1998
Ott/Story/Cordova Superfund Site, North Muskegon, MI	208	Pump and Treat	Groundwater	PCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; PCBs; Semivolatiles-Halogenated; Pesticides/Herbicides	1996	2001
Paducah Gaseous Diffusion Plant, KY	344	Pump and Treat (Field Demonstration)	Groundwater	Radioactive Metals	1999	2002
Pinellas Northeast Site, FL	219	Pump and Treat (Membrane Filtration - PerVap™) (Field Demonstration)	Groundwater	TCE; DCE; Volatiles-Halogenated	1995	1998
Pope AFB, Site FT-01, NC	221	Pump and Treat; Free Product Recovery	Groundwater; LNAPLs	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1993	1998
Pope AFB, Site SS-07, Blue Ramp Spill Site, NC	222	Pump and Treat; Free Product Recovery	Groundwater; LNAPLs	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	1993	1998
Rockaway, NJ	233	Pump and Treat	Drinking Water	MTBE; BTEX; Volatiles-Nonhalogenated; TCE; Volatiles-Halogenated	1980	2001
SCRDI Dixiana Superfund Site, SC	255	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1992	1998

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Shaw AFB, Site OT-16B, SC	259	Pump and Treat	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	1995	1998
Shaw AFB, Sites SD-29 and ST-30, SC	260	Pump and Treat; Free Product Recovery	Groundwater; LNAPLs	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated; Volatiles-Halogenated	1995	1998
Sol Lynn/Industrial Transformers Superfund Site, TX	265	Pump and Treat	Groundwater	TCE; Volatiles-Halogenated	1993	1998
Solid State Circuits Superfund Site, MO	266	Pump and Treat	Groundwater; DNAPLs	TCE; DCE; Volatiles-Halogenated	1993	1998
Solvent Recovery Services of New England, Inc. Superfund Site, CT	267	Pump and Treat; Containment - Barrier Walls	Groundwater	Semivolatiles-Nonhalogenated; PCBs; Semivolatiles-Halogenated; Heavy Metals; TCE; DCE; Volatiles-Halogenated	1995	1998
Sylvester/Gilson Road Superfund Site, NH	276	Pump and Treat; Containment - Barrier Walls; Containment - Caps; SVE	Groundwater; LNAPLs	Volatiles-Halogenated; Ketones; BTEX; Volatiles-Nonhalogenated; Heavy Metals	1982	1998
Tacony Warehouse, PA	278	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1998	2000
Twin Cities Army Ammunition Plant, MN	284	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1987	1995

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
U.S. Aviex Superfund Site, MI	286	Pump and Treat	Groundwater; DNAPLs	Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1993	1998
U.S. Department of Energy Kansas City Plant, MO	290	Pump and Treat	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; Semivolatiles-Halogenated PCBs; Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated; Heavy Metals	1983	1995
U.S. Department of Energy Savannah River Site, A/M Area, SC	297	Pump and Treat	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	1985	1995
Union Chemical Company Superfund Site, ME	302	Pump and Treat; Chemical Oxidation/Reduction (*in situ*); SVE	Groundwater; Soil	TCE; DCE; Volatiles-Halogenated	1996	2001
United Chrome Superfund Site, OR	303	Pump and Treat	Groundwater	Heavy Metals	1988	1998
Western Processing Superfund Site, WA	312	Pump and Treat; Containment - Barrier Walls	Groundwater; LNAPLs; DNAPLs	TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; PAHs; Semivolatiles-Nonhalogenated; Heavy Metals	1988	1998
***In Situ* Groundwater Bioremediation (42 Projects)**						
Abandoned Manufacturing Facility - Emeryville, CA	2	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	TCE; Volatiles-Halogenated; Heavy Metals	1997	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Altus Air Force Base, Landfill 3 (LF 3), OK	338	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated	2000	2003
Avco Lycoming Superfund Site, PA	14	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	TCE; DCE; Volatiles-Halogenated; Heavy Metals	1997	2000
Balfour Road Site, CA; Fourth Plain Service Station Site, WA; Steve's Standard and Golden Belt 66 Site, KS	17	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1995	1998
Brownfield Site, Chattanooga, TN (specific site name not identified)	28	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	MTBE; BTEX; Volatiles-Nonhalogenated	1999	2001
Contemporary Cleaners, Orlando. FL	49	Bioremediation (*in situ*) Enhanced Bioremediation (HRC)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001
Cordray's Grocery, Ravenel, SC	50	Bioremediation (*in situ*) Enhanced Bioremediation (ORC)	Groundwater	BTEX; MTBE Volatiles-Nonhalogenated; Semivolatiles-Nonhalogenated	1998	2001
Dover Air Force Base, Area 6, DE	56	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1996	2000
Dover Air Force Base, Area 6, DE	55	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	TCE; DCE; Volatiles-Halogenated	1996	2002
Edwards Air Force Base, CA	63	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated	1996	2000
Former Industrial Property, CA	372	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	TCE; Volatiles-Halogenated	2000	2004

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
French Ltd. Superfund Site, TX	92	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	BTEX; Volatiles-Halogenated; Volatiles-Nonhalogenated	1992	1998
Gas Station, Cheshire, CT (specific site name not identified)	94	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	BTEX; MTBE Volatiles-Nonhalogenated	1997	2001
Hanford Site, WA	96	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	Volatiles-Halogenated	1995	2000
Hayden Island Cleaners, Portland, OR	105	Bioremediation (*in situ*) Enhanced Bioremediation (HRC)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001
Idaho National Engineering and Environmental Laboratory, Test Area North, ID	115	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	1999	2002
ITT Roanoke Site, VA	118	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	DCE; Volatiles-Halogenated	1998	Not Provided
Lawrence Livermore National Laboratory, CA	133	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater; Soil	MTBE Volatiles-Nonhalogenated	Not Provided	2001
Libby Groundwater Superfund Site, MT	136	Bioremediation (*in situ*) Enhanced Bioremediation; Pump and Treat	Groundwater	Semivolatiles-Halogenated; PAHs; Semivolatiles- Nonhalogenated	1991	1998
Moffett Field Superfund Site, CA	162	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	Volatiles-Halogenated	1986	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Moss-American Site, WI	369	Bioremediation (*in situ*) Enhanced Bioremediation; Permeable Reactive Barrier	Groundwater	PAHs; Semivolatiles-Nonhalogenated; BTEX; Volatiles-Nonhalogenated,	2000	2004
Multiple (4) Dry Cleaner Sites - *In Situ* Bioremediation, Various Locations	346	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; Volatiles-Nonhalogenated; BTEX; MTBE	Various years - starting 2002	2003
Multiple Dry Cleaner Sites	174	Bioremediation (*in situ*) Enhanced Bioremediation (HRC)	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	Not Provided	2001
National Environmental Technology Test Site, CA		Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	MTBE	2001	2004
Naval Air Station New Fuel Farm Site, NV	360	Bioremediation (*in situ*) Bioventing; Free Product Recovery	Groundwater	Petroleum Hydrocarbons; LNAPL	Not Provided	2004
Naval Base Ventura County, CA	352	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	TCE; DCE; Volatiles-Halogenated	1999	2004
Naval Weapons Industrial Reserve Plant (NWIRP) , TX	315	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	TCE, Volatiles-Halogenated	1999	2002
Naval Weapons Station Seal Beach, CA	194	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater; Soil; LNAPLs	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1997	2000
Offutt Air Force Base, NE	339	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated	Not provided	2003
Pinellas Northeast Site, FL	218	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater; DNAPLs	TCE; DCE; Volatiles-Halogenated	1997	1998

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Savannah River Site, SC	250	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater; Sediment	PCE; TCE; Volatiles-Halogenated	1992	2000
Savannah River Site Sanitary Landfill (SLF), SC	362	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	TCE; DCE; Volatiles-Halogenated	1999	2004
Service Station, CA (specific site name not identified)	256	Bioremediation (*in situ*) Enhanced Bioremediation (ORC)	Groundwater	BTEX; MTBE; Volatiles-Nonhalogenated	Not Provided	2001
Service Station, Lake Geneva, WI (specific site name not identified)	257	Bioremediation (*in situ*) Enhanced Bioremediation (ORC)	Groundwater	BTEX; MTBE; Volatiles-Nonhalogenated	Not Provided	2001
Site A (actual name confidential), NY	263	Bioremediation (*in situ*) Enhanced Bioremediation; Pump and Treat; Air Sparging; SVE	Groundwater	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1995	1998
South Beach Marine, Hilton Head, SC	268	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	PAHs; Semivolatiles-Nonhalogenated; BTEX; MTBE; Volatiles-Nonhalogenated	1999	2001
Specific site name not identified	304	Bioremediation (*in situ*) Enhanced Bioremediation (Bench Scale)	Groundwater; Soil	MTBE; Volatiles-Nonhalogenated	Not Provided	2001
Texas Gulf Coast Site, TX	279	Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	TCE; Volatiles-Halogenated; Heavy Metals	1995	2000
U.S. Department of Energy Savannah River Site, M Area, SC	298	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater; Sediment	PCE; TCE; Volatiles-Halogenated	1992	1997

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
U.S. Navy Construction Battalion Center, Port Hueneme, CA	299	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	MTBE; BTEX; Volatiles-Nonhalogenated	1998	2001
Vandenberg Air Force Base, Lompoc, CA	305	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater	MTBE; BTEX; Volatiles-Nonhalogenated	1999	2001
Watertown Site, MA	311	Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater; Soil	PCE; TCE; Volatiles-Halogenated	1996	2000
Other *In Situ* Groundwater Treatment (76 Projects)						
328 Site, CA	1	Multi Phase Extraction; Fracturing	Groundwater; Soil	TCE; Volatiles-Halogenated	1996	2000
A.G. Communication Systems, IL	332	Thermal Treatment (*in situ*)	Groundwater; Soil	TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1995	2003
Aberdeen Proving Grounds, Edgewood Area J - Field Site, MD	3	Phytoremediation (Field Demonstration)	Groundwater	TCE; DCE; Volatiles-Halogenated	1996	2002
Amcor Precast, UT	6	In-Well Air Stripping; SVE	Groundwater; Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated; PAHs; Semivolatiles-Nonhalogenated	1992	1995
Brookhaven National Laboratory, NY	26	In-Well Air Stripping (Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1999	2002

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Butler Cleaners, Jacksonville, FL	30	Chemical Oxidation/Reduction (*in situ*) ($KMnO_4$)	Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	Not Provided	2001
Camp Lejeune Marine Corps Base, Bldg 25, Camp Lejeune, NC	31	Flushing (*in situ*) (SEAR and PITT)	Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	1999	2001
Cape Canaveral Air Force Station, Launch Complex 34, FL	341	Chemical Oxidation/Reduction (*in situ*) (Field Demonstration)	Groundwater; DNAPLs	TCE; Volatiles-Halogenated	1999	2002
Cape Canaveral Air Force Station, Launch Complex 34, FL	340	Thermal Treatment (*in situ*) (Field Demonstration)	Groundwater; Soil; DNAPLs	TCE; Volatiles-Halogenated	1999	2003
Carswell Air Force Base, TX	34	Phytoremediation (Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated	1996	2002
Clear Creek/Central City Superfund site, CO	326	Phytoremediation (Field Demonstration)	Groundwater	Heavy Metals	1994	2002
Confidential Manufacturing Facility, IL	48	Thermal Treatment (*in situ*)	Groundwater; Soil; DNAPLs	TCE; DCE; Volatiles-Halogenated	1998	2000
Defense Supply Center, Acid Neutralization Pit, VA	53	Multi Phase Extraction (Field Demonstration)	Groundwater; Soil	PCE; TCE; DCE; Volatiles-Halogenated	1997	2000
Del Norte County Pesticide Storage Area Superfund Site, CA (Air Sparging and Pump and Treat)	359	Air Sparging; SVE	Groundwater	Pesticides/Herbicides; Semivolatiles-Halogenated; Heavy Metals	1990	2004

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Eaddy Brothers, Hemingway, SC	61	Air Sparging; SVE	Groundwater; Soil	BTEX; MTBE Volatiles-Nonhalogenated; Semivolatiles-Nonhalogenated	1999	2001
Edward Sears Site, NJ	62	Phytoremediation (Field Demonstration)	Groundwater	PCE; TCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1996	2002
Eight Service Stations, MD (specific sites not identified)	65	Multi Phase Extraction	Groundwater; Soil; LNAPLs	BTEX; MTBE Volatiles-Nonhalogenated	1990	2001
Fernald Environmental Management Project, OH	70	Flushing (*in situ*) (Field Demonstration)	Groundwater	Heavy Metals	1998	2001
Former Intersil, Inc. Site, CA	74	Permeable Reactive Barrier; Pump and Treat	Groundwater	TCE; DCE; Volatiles-Halogenated	1995	1998
Former Nu Look One Hour Cleaners, Coral Springs, FL	77	In-Well Air Stripping (NoVOCs™)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001
Former Sages Dry Cleaners, Jacksonville, FL	78	Flushing (*in situ*) (Ethanol Co-solvent)	Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001
Fort Devens, AOCs 43G and 43J, MA	80	Monitored Natural Attenuation	Groundwater; Soil; LNAPLs	BTEX; Volatiles-Nonhalogenated	1997	2000
Fort Richardson, AK	331	Thermal Treatment (*in situ*) (Field Demonstration)	Groundwater; Soil; DNAPLs; Off-gases	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1999	2003

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Four Service Stations (specific site names not identified)	90	Air Sparging	Groundwater	BTEX; MTBE Volatiles-Nonhalogenated	1993	2001
Fry Canyon, UT	93	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Radioactive Metals; Heavy Metals	1997	2000
Gold Coast Superfund Site, FL	95	Air Sparging; Pump and Treat	Groundwater; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1994	1998
Hanford Site, 100-H and 100-D Areas, WA	101	Chemical Oxidation/Reduction (*in situ*) (Field Demonstration)	Groundwater	Heavy Metals	1995	2000
Hunter's Point Ship Yard, Parcel C, Remedial Unit C4, CA	357	Chemical Oxidation/Reduction (*in situ*)	Groundwater; DNAPLs	TCE; Volatiles-Halogenated	2002	2004
ICN Pharmaceuticals, OR	334	Thermal Treatment (*in situ*); SVE	Groundwater; Soil; DNAPLs	TCE; DCE; Volatiles-Halogenated	2000	2003
Johannsen Cleaners, Lebanon, OR	120	Multi Phase Extraction	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001
Keesler Air Force Base Service Station, AOC-A (ST-06), MS	123	Monitored Natural Attenuation	Groundwater; Soil	BTEX; Volatiles-Nonhalogenated; Heavy Metals	1997	2000
Kelly Air Force Base, Former Building 2093 Gas Station, TX	124	Monitored Natural Attenuation	Groundwater; Soil	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1997	2000
Lawrence Livermore National Laboratory Gasoline Spill Site, CA	130	Thermal Treatment (*in situ*) (Field Demonstration)	Groundwater; Soil	BTEX; Volatiles-Nonhalogenated	1992	1995
Louisiana Army Ammunition Plant, LA	142	Monitored Natural Attenuation	Groundwater	Explosives/Propellants	Not Provided	2001

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Marshall Space Flight Center, AL	336	Chemical Oxidation/Reduction (*in situ*); Fracturing; Permeable Reactive Barrier (Field Demonstration)	Groundwater	Tetrachloroethene (TCE); Volatiles-Halogenated	2000	2003
Massachusetts Military Reservation, CS-10 Plume, MA	159	In-Well Air Stripping (UVB and NoVOCs) (Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1996	2002
McClellan Air Force Base (AFB), OU A, CA	151	Air Sparging; Bioremediation (*in situ*) Enhanced Bioremediation (Field Demonstration)	Groundwater; Soil	TCE; DCE; Volatiles-Halogenated	1999	2001
Miamisburg, OH	343	Air Sparging; SVE	Groundwater; Soil	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1997	2001
Milan Army Ammunition Plant, TN	157	Phytoremediation (Field Demonstration)	Groundwater	Explosives/Propellants	1996	2000
Moffett Federal Airfield, CA	161	Permeable Reactive Barrier (Field Demonstration)	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	1996	1998
Moffett Field Superfund Site, CA	163	Permeable Reactive Barrier (Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1996	2000
Monticello Mill Tailings Site, Monticello, UT	164	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Metals	1999	2001
Multiple (2) Dry Cleaner Sites, Various Locations	324	Chemical Oxidation/Reduction (*in situ*)	Groundwater; Dense Non-aqueous Phase Liquids (DNAPLs)	PCE; TCE; Volatiles-Halogenated	Various years - starting 1998	2003

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Multiple (2) Dry Cleaners - In Well Air Stripping (In Well Air Stripping and Pump and Treat)	364	In-Well Air Stripping	Soil; Groundwater	PCE; TCE; Volatiles-Halogenated	1994	2004
Multiple (10) Sites - Air Sparging, Various Locations	342	Air Sparging	Groundwater; Soil	TCE; PCE; DCE; Volatiles-Halogenated; PAHs; Semivolatiles-Nonhalogenated; BTEX; Volatiles-Nonhalogenated; MTBE; Petroleum Hydrocarbons	Various years	2002
Multiple Air Force Sites	177	Multi Phase Extraction (Field Demonstration)	Groundwater; LNAPLs	Petroleum Hydrocarbons; BTEX; Volatiles-Nonhalogenated	Not Provided	2001
Multiple Air Force Sites	178	Monitored Natural Attenuation (Field Demonstration)	Groundwater	TCE; DCE; Volatiles-Halogenated	1993	1999
Multiple Air Force Sites	179	Monitored Natural Attenuation (Field Demonstration)	Groundwater	BTEX; Petroleum Hydrocarbons; Volatiles-Nonhalogenated	1993	1999
Multiple DoD Sites, Various Locations	347	Permeable Reactive Barrier (Field Demonstration)	Groundwater	Volatiles-Halogenated	Various years	2003
Multiple Dry Cleaner Sites	172	Flushing (*in situ*); Thermal Treatment (*in situ*); In-Well Air Stripping (Field Demonstration)	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	Not Provided	2001
Multiple Dry Cleaner Sites	171	Air Sparging; SVE	Groundwater; Soil; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated	Not Provided	2001, 2002

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Multiple Dry Cleaner Sites	175	Chemical Oxidation/Reduction (*in situ*) (Field Demonstration)	Groundwater; DNAPLs	PCE; TCE; Volatiles-Halogenated	1999	2001, 2002
Multiple Dry Cleaner Sites	173	Multi Phase Extraction; Pump and Treat	Groundwater; Soil; DNAPLs	PCE; TCE; Volatiles-Halogenated	Not Provided	2001, 2002
Multiple Sites	167	Permeable Reactive Barrier (Full scale and Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1991	2002
Multiple Sites	166	Permeable Reactive Barrier (Full scale and Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated; Heavy Metals; Radioactive Metals; Arsenic	1997	2002
Multiple Sites	169	Permeable Reactive Barrier (Full scale and Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Heavy Metals; Radioactive Metals; Arsenic	1995	2002
Multiple Sites	170	Permeable Reactive Barrier (Full scale and Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated; Heavy Metals; Radioactive Metals; Pesticides/Herbicides	1995	2002

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Multiple Sites	168	Permeable Reactive Barrier (Full scale and Field Demonstration)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated; Heavy Metals; Radioactive Metals	1995	2002
Naval Air Engineering Station (NAES) Site (Area I), NJ	353	Chemical Oxidation/Reduction (*in situ*)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	2002	2004
Naval Air Station, North Island, CA	186	In-Well Air Stripping (NoVOCs) (Field Demonstration)	Groundwater	TCE; DCE; Volatiles-Halogenated	1998	2000
Naval Air Station, Pensacola, OU 10, FL	184	Chemical Oxidation/Reduction (*in situ*) (Field Demonstration)	Groundwater	TCE; Volatiles-Halogenated	1998	2000
Naval Air Station, Pensacola, FL	187	Chemical Oxidation/Reduction (*in situ*)	Groundwater	TCE; DCE; Volatiles-Halogenated	1998	2001
Naval Submarine Base, Kings Bay, GA	193	Chemical Oxidation/Reduction (*in situ*); Monitored Natural Attenuation	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1999	2001
Naval Submarine Base, Kings Bay, GA	192	Chemical Oxidation/Reduction (*in situ*)	Groundwater	PCE; TCE; DCE; Volatiles-Halogenated	1998	2000
Oak Ridge National Laboratory, TN	202	Permeable Reactive Barrier - Funnel and Gate Configuration and Trench (Field Demonstration)	Groundwater	Radioactive Metals	1997	2002

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Pinellas Northeast Site, FL	220	Thermal Treatment (*in situ*) - Dual Auger Rotary Steam Stripping (Field Demonstration)	Groundwater; Soil; DNAPLs	PCE; TCE; DCE; Volatiles-Halogenated; BTEX; Volatiles-Nonhalogenated	1996	1998
Portsmouth Gaseous Diffusion Plant, X-701B Facility, OH	226	Chemical Oxidation/Reduction (*in situ*) (Field Demonstration)	Groundwater; DNAPLs	TCE; Volatiles-Halogenated	1988	2000
RMI Titanium Plant, Ashtabula Environmental Management Project, OH	232	Flushing (*in situ*) (WIDE) (Field Demonstration)	Groundwater; Soil	TCE; Volatiles-Halogenated; Radioactive Metals	1999	2001
Scotchman #94, Florence, SC	253	Multi Phase Extraction; Air Sparging; SVE	Groundwater; Soil	Polycyclic Aromatic Hydrocarbon (PAHs); Semivolatiles-Nonhalogenated; BTEX; MTBE; Volatiles-Nonhalogenated	1998	2001
Site 88, Building 25, Marine Corps Base Camp Lejeune, NC	147	Flushing (*in situ*) (SEAR) (Field Demonstration)	Groundwater; DNAPLs; LNAPLs	Petroleum Hydrocarbons; Volatiles-Nonhalogenated; PCE; Volatiles-Halogenated	1999	2001
South Prudence Bay Island Park, T-Dock Site, Portsmouth, RI	269	Air Sparging; Bioremediation (*in situ*) Enhanced Bioremediation	Groundwater	BTEX; Volatiles-Nonhalogenated	1998	2001
Sparks Solvents/Fuel Site, Sparks, NV	271	Multi Phase Extraction	Groundwater; LNAPLs	BTEX; MTBE; Volatiles-Nonhalogenated; PCE; TCE; Volatiles-Halogenated	1995	2001
Tinkham's Garage Superfund Site, NH	281	Multi Phase Extraction	Groundwater; Soil	PCE; TCE; Volatiles-Halogenated	1994	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
U.S. Coast Guard Support Center, NC	287	Permeable Reactive Barrier	Groundwater; DNAPLs	TCE; Volatiles-Halogenated; Heavy Metals	1996	1998
U.S. Department of Energy Savannah River Site, A/M Area, SC	294	In-Well Air Stripping; Pump and Treat (Field Demonstration)	Groundwater; Soil; DNAPLs	PCE; TCE; Volatiles-Halogenated	1990	1995
Visalia Superfund Site, CA	309	Thermal Treatment (*in situ*) (Field Demonstration)	Groundwater	Semivolatiles-Halogenated; Semivolatiles-Nonhalogenated	1997	2000
Debris/Solid Media Treatment (28 Projects)						
Alabama Army Ammunition Plant, AL	4	Thermal Desorption (*ex situ*) (Field Demonstration)	Debris/Slag/ Solid	Explosives/Propellants	1995	1998
Argonne National Laboratory - East, IL	9	Physical Separation (Scabbling) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	Not Provided	2000
Argonne National Laboratory - East, IL	11	Physical Separation (Concrete Demolition) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	2000
Argonne National Laboratory, IL	10	Solidification/Stabilization (Phosphate Bonded Ceramics) (Field Demonstration)	Debris/Slag/ Solid; Groundwater	Heavy Metals	Not Provided	2000
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	38	Physical Separation (Centrifugal Shot Blast) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	1998
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	39	Physical Separation (Rotary Peening with Captive Shot) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	1998
Chicago Pile 5 (CP-5) Research Reactor, Argonne National Laboratory, IL	40	Physical Separation (Roto Peen Scaler with VAC-PAC^{R} System) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1996	1998

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Clemson University, SC	42	Solidification/Stabilization (Sintering) (Bench Scale)	Debris/Slag/ Solid	Heavy Metals	1995	2000
Envirocare of Utah, UT	67	Solidification/Stabilization (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1996	1998
Fernald Site, OH	71	Physical Separation (Soft Media Blasting) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1996	2000
Hanford Site, C Reactor, WA	102	Solidification/Stabilization (Polymer Coating) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	1998
Hanford Site, WA	97	Physical Separation(Concrete Grinder) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	2000
Hanford Site, WA	98	Physical Separation (Concrete Shaver) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1997	2000
Hanford Site, WA	99	Physical Separation (Concrete Spaller) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1998	2000
Hanford Site, WA	100	Solidification/Stabilization (Polyester Resins) (Field Demonstration)	Debris/Slag/ Solid; Groundwater	Radioactive Metals; Heavy Metals; Arsenic	Not Provided	2000
Hanford Site, WA	103	Physical Separation; Solvent Extraction (Ultrasonic Baths) (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1998	1998
Idaho National Engineering and Environmental Laboratory, ID	110	Solidification/Stabilization (Innovative Grouting and Retrieval) (Full scale and Field Demonstration)	Debris/Slag/ Solid; Soil	Radioactive Metals	1994	2000
Idaho National Engineering and Environmental Laboratory, ID	109	Solidification/Stabilization (DeHg^{SM} Process) (Field Demonstration)	Debris/Slag/ Solid	Heavy Metals	1998	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
Idaho National Engineering and Environmental Laboratory, ID	113	Physical Separation (Wall Scabbler) (Field Demonstration)	Debris/Slag/ Solid	Heavy Metals	2000	2001
Idaho National Engineering and Environmental Laboratory, ID	112	Vitrification (*ex situ*) (Graphite Furnace) (Field Demonstration)	Debris/Slag/ Solid; Organic Liquids; Soil	Heavy Metals; Radioactive Metals	1997	2000
Idaho National Engineering and Environmental Laboratory, Pit 2, ID	111	Solidification/Stabilization (Polysiloxane) (Field Demonstration)	Debris/Slag/ Solid; Groundwater	Heavy Metals	1997	2000
Lawrence Livermore National Laboratory, CA	132	Chemical Oxidation/Reduction (*ex situ*) (Field Demonstration)	Debris/Slag/ Solid; Groundwater	PCE; TCE; Volatiles-Halogenated PCBs; Semivolatiles-Halogenated; Explosives/Propellants	Not Provided	2000
Los Alamos National Laboratory, NM	139	Solidification/Stabilization (ADA Process) (Field Demonstration)	Debris/Slag/ Solid	Heavy Metals	1998	2000
Los Alamos National Laboratory, Technical Area 33, NM	140	Solidification/Stabilization (Field Demonstration)	Sludge	Heavy Metals; DCE; Volatiles-Halogenated; Radioactive Metals	1997	2000
Pacific Northwest National Laboratory, WA	210	Solidification/Stabilization (Sol Gel Process) (Bench Scale)	Debris/Slag/ Solid; Groundwater	Heavy Metals	Not Provided	2000
Portsmouth Gaseous Diffusion Plant, OH	224	Solidification/Stabilization (ATG Process) (Field Demonstration)	Organic Liquids	Heavy Metals; Radioactive Metals	1998	2000
Savannah River Site, SC	249	Acid Leaching (Field Demonstration)	Debris/Slag/ Solid	Radioactive Metals	1996	2000

EXHIBIT A-1. SUMMARY OF 361 REMEDIATION CASE STUDIES (continued)

Site Name, Location	Case Study ID	Technology *†	Media	Contaminants	Year Operation Began	Year Published
STAR Center, ID	274	Vitrification (*ex situ*) (Plasma Process) (Field Demonstration)	Debris/Slag/ Solid; Soil; Sludge	Heavy Metals; Radioactive Metals	1993	2000
Containment (7 Projects)						
Dover Air Force Base, Groundwater Remediation Field Laboratory National Test Site, Dover DE	58	Containment - Barrier Walls (Field Demonstration)	Groundwater	-	1996	2001
Lawrence Livermore National Laboratory (LLNL) Site 300 - Pit 6 Landfill OU, CA	131	Containment - Caps	Debris/Slag/ Solid	TCE; Volatiles-Halogenated; Radioactive Metals	1997	1998
Marine Corps Base Hawaii, HI	148	Containment - Caps (Field Demonstration)	Soil	-	1994	1998
Naval Shipyard, CA	191	Containment - Caps (Field Demonstration)	Soil	BTEX; Volatiles-Nonhalogenated	1997	1998
Oak Ridge National Laboratory, TN	200	Containment - Barrier Walls (Field Demonstration)	Soil; Sediment; Groundwater	Radioactive Metals	1996	2000
Sandia National Laboratory, Albuquerque, NM	247	Containment - Caps (Field Demonstration)	Soil	-	1995	2001
U.S. Department of Energy, SEG Facilities, TN	252	Containment - Barrier Walls (Field Demonstration)	Soil	-	1994	1997

* Full scale unless otherwise noted
† Technology focused on in case study listed first, followed by other technologies identified in the case study

Key:
DNAPLs = Dense Non-Aqueous Phase Liquids
SVOCs = Semi-Volatile Organic Compounds
GAC = Granular Activated Carbon
SVE = Soil Vapor Extraction
BTEX = Benzene, Toluene, Ethylbenzene, and Xylene
TPH = Total Petroleum Hydrocarbons
PAHs = Polycyclic Aromatic Hydrocarbons
PCBs = Polychlorinated Biphenyls
TCA = 1,1,1-Trichloroethane
TCE = Trichloroethene
PCE = Tetrachloroethene
DCE = Dichloroethene
TNT = 2,4,6-Trinitrotoluene
RDX = Hexahydro-1,3,5-trinitro-1,3,5 triazine
HMX = Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
MBOCA = 4,4-methylene bis(2-chloroaniline)
MIBK = Methyl isobutyl ketone
MTBE = Methyl tert butyl ether

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