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Remediation Case Studies:
Innovative Groundwater Treatment Technologies

Volume 11

Federal Remediation Technologies Roundtable
<www.frtr.gov>

Prepared by the

Member Agencies of the Federal Remediation Technologies Roundtable

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Federal Remediation Technologies Roundtable

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

Department of Energy
Department of Interior
National Aeronautics and Space Administration
Tennessee Valley Authority
Coast Guard

September 1998

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FOREWORD

This report is a collection of twelve case studies of innovative groundwater treatment technology projects prepared by federal agencies. The case studies, collected under the auspices of the Federal Remediation Technologies 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, 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 in a multi-volume set listed below. Remediation Case Studies, Volumes 1-6, and Abstracts, Volumes 1 and 2, were published previously, and contain 54 case studies. Remediation Case Studies, Volumes 7-13, and Abstracts, Volume 3, were published in September 1998. Volumes 7-13 cover a wide variety of technologies, including innovative groundwater treatment technologies (Volume 11). The 12 innovative groundwater treatment technology case studies in this report include completed full-scale remediations and large-scale field demonstrations. In the future, the set will grow as agencies prepare additional case studies.

1995 Series

Volume 1: Bioremediation, EPA-542-R-95-002; March 1995; PB95-182911

Volume 2: Groundwater Treatment, EPA-542-R-95-003; March 1995; PB95-182929

Volume 3: Soil Vapor Extraction, EPA-542-R-95-004; March 1995; PB95-182937

Volume 4: Thermal Desorption, Soil Washing, and In Situ Vitrification, EPA-542-R-95-005; March 1995; PB95-182945

1997 Series

Volume 5: Bioremediation and Vitrification, EPA-542-R-97-008; July 1997; PB97-177554

Volume 6: Soil Vapor Extraction and Other In Situ Technologies, EPA-542-R-97-009; July 1997; PB97-177562

1998 Series

Volume 7: Ex Situ Soil Treatment Technologies (Bioremediation, Solvent Extraction, Thermal Desorption), EPA-542-R-98-011; September 1998

Volume 8: In Situ Soil Treatment Technologies (Soil Vapor Extraction, Thermal Processes), EPA-542-R-98-012; September 1998

1998 Series (continued)

Volume 9:	Groundwater Pump and Treat (Chlorinated Solvents), EPA-542-R-98-013; September 1998
Volume 10:	Groundwater Pump and Treat (Nonchlorinated Contaminants), EPA-542-R-98-014; September 1998
Volume 11:	Innovative Groundwater Treatment Technologies, EPA-542-R-98-015; September 1998
Volume 12:	On-Site Incineration, EPA-542-R-98-016; September 1998
Volume 13:	Debris and Surface Cleaning Technologies, and Other Miscellaneous Technologies, EPA-542-R-98-017; September 1998

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

Accessing Case Studies

The case studies and case study abstracts are available on the Internet through the Federal Remediation Technologies Roundtable web site at: http://www.frtr.gov. 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, and primary and supplemental technology types. The search function provides users with basic information about the case studies, and allows them 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. Some of the case studies are also available on individual agency web sites, such as for the Department of Energy.

In addition, a limited number of hard copies are available free of charge by mail from NCEPI (allow 4-6 weeks for delivery), at the following address:

U.S. EPA/National Center for Environmental Publications and Information (NCEPI)
P.O. Box 42419
Cincinnati, OH 45242
Phone: (513) 489-8190 or
(800) 490-9198
Fax: (513) 489-8695

TABLE OF CONTENTS

Section **Page**

INTRODUCTION 1

INNOVATIVE GROUNDWATER TREATMENT TECHNOLOGIES CASE STUDIES 9

Enhanced Bioremediation of Contaminated Groundwater - Balfour Road Site, Brentwood, CA; Fourth Plain Service Station Site, Vancouver, WA; Steve's Standard and Golden Belt 66 Site, Great Bend, KS 11

Coagulation/Flocculation/Dissolved Air Flotation and Oleofiltration™ at the Coastal Systems Station, AOC 1, Panama City, Florida 33

Pump and Treat and Permeable Reactive Barrier to Treat Contaminated Groundwater at the Former Intersil, Inc. Site, Sunnyvale, California 55

Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the French Ltd. Superfund Site, Crosby, Texas 73

Pump and Treat and Air Sparging of Contaminated Groundwater at the Gold Coast Superfund Site, Miami, Florida 91

Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the Libby Groundwater Superfund Site, Libby, Montana 109

Permeable Reactive Barrier to Treat Contaminated Groundwater at the Moffett Federal Airfield, Mountain View, California 131

Dual Auger Rotary Steam Stripping at Pinellas Northeast Site, Largo, Florida 147

In Situ Anaerobic Bioremediation at Pinellas Northeast Site, Largo, Florida 183

PerVap™ Membrane Separation Groundwater Treatment at Pinellas Northeast Site, Largo, Florida 221

Pump and Treat, In Situ Bioremediation, and In Situ Air Sparging of Contaminated Groundwater at Site A, Long Island, New York 247

In Situ Permeable Reactive Barrier for Treatment of Contaminated Groundwater at the U.S. Coast Guard Support Center, Elizabeth City, North Carolina 265

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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 projects. Previously, the Roundtable published a six-volume series of case study reports. At this time, the Roundtable is publishing seven additional volumes of case study reports, primarily focused on 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). The case studies 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). (The October 1998 guide supersedes the original Guide to Documenting Cost and Performance for Remediation Projects, published in March 1995.)

The case studies 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 and setting, contaminants and media treated, technology, cost and performance, and points of contact for the technology application. The studies contain varying levels of detail, reflecting the differences in the availability of data and information. Because full-scale cleanup efforts are not conducted primarily for the purpose of technology evaluation, data on technology cost and performance may be limited.

The case studies in this volume describe twelve groundwater remediation applications that used innovative treatment technologies. Three of the applications used permeable reactive barriers; four used in situ bioremediation (some in conjunction with pump and treat); one used air sparging alone; one used a combination of in situ bioremediation, air sparging, and pump and treat; one used a combination air and stream stripping process; one used a membrane filtration process; and one used a chemical reaction and dissolved air flotation process. Seven of these applications were conducted at full scale, and the remaining five at a field demonstration scale. Contaminants treated included chlorinated solvents, petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), and metals. Some of these

applications are ongoing, and the case studies are interim reports about these applications.

Table 1 provides a summary including information on technology used, contaminants and media treated, and project duration for the 12 innovative groundwater treatment technology applications in this volume. This table also provides highlights about each application. Table 2 summarizes cost data, including information on 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 project cost. (The column showing the calculated unit costs for treatment provides a dollar value per unit of groundwater treated or contaminant removed.) Cost data are shown as reported in 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).

While a summary of project costs is useful, it may be difficult to compare costs for different projects because of unique site-specific factors. However, by including a recommended reporting format, the Roundtable is working to standardize the reporting of costs 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. Key factors that potentially affect project costs for incineration projects include economies of scale, concentration levels in contaminated media, required cleanup levels, completion schedules, matrix characteristics such as soil classification, clay content and/or particle size distribution, hydraulic conductivity, pH, depth and thickness of zone of interest, total organic carbon, oil and grease or total petroleum hydrocarbons, presence of NAPLs, and other site conditions.

Table 1. Summary of Remediation Case Studies: Innovative Groundwater Treatment Technologies

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	PAHs	Pesticides/Herbicides	Explosives	Metals			
Balfour Road Site, CA; Fourth Plain Service Station Site, WA; Steve's Standard and Golden Belt 66 Site, KS (Enhanced Bioremediation of Groundwater)		●					Groundwater (estimated 20,400 ft^2 for Fourth Plain)	Balfour Road: Status: Ongoing Report Covers: 12/95 - 10/97 Fourth Plain and Steve's Standard: Status: Ongoing Report Covers: 7/96 - 10/97	Evaluate the cost and performance of ORC[R] to remediate groundwater at three sites
Coastal Systems Station, AOC 1, FL (Chemical Reaction and Flocculation, and Dissolved Air Flotation)		●				●	Wastewater (126,400 gallons)	8/97 (Demonstration conducted for a total of 448 hours)	Demonstrate the effectiveness of CRF/DAF and Oleofiltration™ in treating TPH and metals in wastewater from a full-scale bioslurper system
Former Intersil, Inc. Site, CA (Pump and Treat with Air Stripping; Permeable Reactive Barrier)	●						Groundwater: P&T (38 million gallons) PRB (2 million gallons)	Status: PRB Ongoing Report Covers: P&T (11/87 - 2/95) PRB (2/95 - 11/97)	Used P&T for eight years; replaced this technology with PRB; PRB used for three years
French Ltd. Superfund Site, TX (Pump and Treat with Activated Sludge for Extracted Groundwater; In Situ Bioremediation)	●						Groundwater (306 million gallons, ex situ)	Status: Ongoing Report Covers: 1/92 - 12/95	Regulatory requirements for this site based on use of modeling results to show effects of natural attenuation at a site boundary 10 years after pump and treat completed

Table 1. Summary of Remediation Case Studies: Innovative Groundwater Treatment Technologies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	PAHs	Pesticides/Herbicides	Explosives	Metals			
Gold Coast Superfund Site, FL (Pump and Treat with Air Sparging)	●						Groundwater (80 million gallons)	7/90 - 3/94: pump and treat 11/94 - 2/95: air sparging	Met goals within four years of operation; included pump and treat and air sparging
Libby Groundwater Superfund Site, MT (Pump and Treat; In Situ Bioremediation)			●				Groundwater (15.1 million gallons)	Status: Ongoing Report Covers: 9/91 - 12/96	Combination of pump and treat and in situ bioremediation at site with LNAPL, DNAPL, and dissolved-phase contaminants
Moffett Federal Airfield, CA (Permeable Reactive Barrier)	●						Groundwater (0.284 million gallons)	Status: Ongoing Report Covers: 4/96 - 7/97	Use of PRB technology in a pilot study for treatment of chlorinated solvents; included extensive sampling conducted at locations within the wall
Pinellas Northeast Site, FL (In Situ Air and Steam Stripping -Dual Auger Rotary Steam Stripping)	●						Soil (2,000 yd^3) Groundwater	12/96 - 4/97	Demonstration of in situ air and steam stripping technology used to supplement an ongoing system of pump and treat with air stripping
Pinellas Northeast Site, FL (In Situ Anaerobic Bioremediation)	●						Groundwater (250,000 gallons)	2/7/97 - 6/30/97	Demonstration of in situ anaerobic bioremediation technology used to supplement an ongoing system of pump and treat with air stripping
Pinellas Northeast Site, FL (Membrane Filtration - PerVap)	●						Groundwater (6,200 gallons)	6/14/95 - 3/2/96	Demonstration of the PerVap™ technology for treating VOC-contaminated groundwater

Table 1. Summary of Remediation Case Studies: Innovative Groundwater Treatment Technologies (continued)

Site Name, State (Technology)	Principal Contaminants*						Media (Quantity Treated)	Project Duration	Highlights
	Chlorinated Solvents	BTEX and/or TPH	PAHs	Pesticides/Herbicides	Explosives	Metals			
Site A (actual name confidential), NY (Pump and Treat with Air Stripping; In Situ Bioremediation; Air Sparging; Soil Vapor Extraction)		◐					Groundwater (8.4 million gallons)	Status: Ongoing Report Covers: 7/95 - 10/96	System included groundwater extraction, air sparging, and SVE wells
U.S. Coast Guard Support Center, NC (Permeable Reactive Barrier)	●					●	Groundwater (2.6 million gallons)	Status: Ongoing Report Covers: 7/96 - 7/97	Use of PRB to treat groundwater contaminated with TCE and hexavalent chromium; extensive sampling conducted to evaluate PRB

* 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 ($)*	Quantity Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment**	Key Factors Potentially Affecting Technology Costs***
Balfour Road Site, CA; Fourth Plain Service Station Site, WA; Steve's Standard and Golden Belt 66 Site, KS (Enhanced Bioremediation of Groundwater)	Balfour Road: $33,500; Fourth Plain Service Station: $35,700 Steve's Standard and Golden Belt 66: $93,400	Not provided	Not provided	Not provided	Amount of ORC[R] applied, number of ORC[R] source points, and method used to apply ORC[R]
Coastal Systems Station, AOC 1, FL (Chemical Reaction and Flocculation, and Dissolved Air Flotation)	Monthly lease and operation costs: CRF/DAF: $7,580 Oleofiltration: $3,650	126,400 gallons	Not provided	Not provided	Operating costs for CRF/DAF are twice as high as for Oleofiltration primarily due to higher leasing costs; however, the CRF/DAF had a much higher removal percentage of contaminants
Former Intersil, Inc. Site, CA (Pump and Treat with Air Stripping; Permeable Reactive Barrier)	Total (P&T): $1,343,800 Total (PRB) $762,000	Total: 38 million gallons P&T: 36 million gallons PRB: 2 million gallons	Total: 140 lbs P&T: 124 lbs PRB: 16 lbs	P&T: $38/1,000 gals GW $10,900/lb of cont. PRB: $38/1,000 gals GW $49,400/lb of cont.	P&T replaced with PRB to minimize operating cost for treatment while increasing treatment effectiveness
French Ltd. Superfund Site, TX (Pump and Treat with Activated Sludge for Extracted Groundwater; In Situ Bioremediation)	Total: $33,689,000 C: $15,487,000 O: $18,202,000	306 million gallons	517,000 lbs	$110/1,000 gals GW $15/lb of cont.	Use of three technologies (P&T, in situ bioremediation, and sheet pile walls to contain DNAPL source)
Gold Coast Superfund Site, FL (Pump and Treat with Air Sparging)	Total: $694,325 C: $249,005 O: $445,320	80 million gallons	1,961 lbs	$9/1,000 gals GW $354/lb of cont.	Optimization of extractions wells to focus on problem areas; cleanup goals achieved within four years
Libby Groundwater Superfund Site, MT (Pump and Treat; In Situ Bioremediation)	Total: $5,628,600 C: $3,101,000 O: $2,618,600	15.1 million gallons	37,570 lbs	$374/1,000 gals GW $150/lb of cont.	Use of Protec pump for source area increased both capital and operating costs (pumps malfunctioned if run for extended periods of time)
Moffett Federal Airfield, CA (Permeable Reactive Barrier)	Total: $405,000 C: $373,000 O: $32,000	0.284 million gallons	Not provided	$1,400/1,000 gals GW	Increased performance monitoring conducted for technology certification and validation

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

Site Name, State (Technology)	Technology Cost ($)*	Quantity Treated	Quantity of Contaminant Removed	Calculated Cost for Treatment**	Key Factors Potentially Affecting Technology Costs***
Pinellas Northeast Site, FL (In Situ Air and Steam Stripping - Dual Auger Rotary Steam Stripping)	Total: $981,251 (for demonstration)	2,000 yd^3 of soil	1,200 lbs	Projected for full-scale O: $50-400/$yd^3$ $300-500/lb of cont.	Factors for full-scale include accurate design and operation of key sub-systems (drill tower, catox unit, acid gas scrubber) is crucial for cost effective operation of this technology
Pinellas Northeast Site, FL (In Situ Anaerobic Bioremediation)	Total: $397,074 (for demonstration)	0.25 million gallons	Not provided	Projected for full-scale O: $0.12/gal GW	Limiting factors for full-scale are the ability to deliver appropriate nutrients to all contaminated areas and the hydrogeologic characteristics of the site which affect nutrient transport
Pinellas Northeast Site, FL (Membrane Filtration - PerVap)	Total: $88,728 (for demonstration)	6,200 gallons	Not provided	Projected for full-scale $0.01-0.015/gal GW	Costs for full-scale will vary based on desired treatment volume and level; unit costs for pilot system should be comparable to those for full-scale operation
Site A (actual name confidential), NY (Pump and Treat with Air Stripping; In Situ Bioremediation; Air Sparging; Soil Vapor Extraction)	Total: $1,941,560 C: $1,503,133 O: $358,427	8.4 million gallons	5,315 lbs	$200/1,000 gals GW $365/lb of cont.	Use of skid-mounted modular equipment reduced construction costs
U.S. Coast Guard Support Center, NC (Permeable Reactive Barrier)	Total: $585,000 C: $500,000 O: $85,000	2.6 million gallons	Not provided	$225/1,000 gals GW	Use of a PRB was estimated to save nearly $4,000,000 in construction and long-term maintenance costs when compared with a typical pump and treat system

Technology Cost*
C = Capital costs
O = Operation and maintenance (O&M) costs

Calculated Cost for Treatment**
Calculated based on sum of capital and O&M costs, divided by quantity treated or removed. Calculated costs shown as "Not Calculated" if an estimate of costs or quantity treated or removed was not available. Unit costs calculated based on both quantity of media treated and quantity of contaminant removed, as appropriate.

*** For full-scale remediation projects, this identifies factors affecting actual technology costs. For demonstration-scale projects, this identifies generic factors which would affect costs for a future application using this technology.

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Innovative Groundwater Treatment Technologies

Case Studies

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Enhanced Bioremediation of Contaminated Groundwater - Balfour Road Site, Brentwood, CA; Fourth Plain Service Station Site, Vancouver, WA; Steve's Standard and Golden Belt 66 Site, Great Bend, KS

Enhanced Bioremediation of Contaminated Groundwater - Balfour Road Site, Brentwood, CA; Fourth Plain Service Station Site, Vancouver, WA; Steve's Standard and Golden Belt 66 Site, Great Bend, KS

Site Name: Balfour Road Site Fourth Plain Service Station Site Steve's Standard and Golden Belt 66 Site	**Contaminants:** Benzene, toluene, ethylbenzene, and xylenes (BTEX) and total petroleum hydrocarbons (TPH)	**Period of Operation:** Balfour Road: December 1995 to present (report covers the period through October 1997) Fourth Plain: July 1996 to present (report covers the period through October 1997) Steve's Standard: July 1996 to present (report covers the period through October 1997)
Location: Brentwood, CA Vancouver, WA Great Bend, KS		**Cleanup Type:** Full-scale (Balfour Road and Fourth Plain) Demonstration (Steve's Standard)
Vendor: Steve Koenigsberg Craig Sandefur Regenesis Bioremediation Products, Inc. 27130A Paseo Espada, Suite 1407 San Juan Capistrano, CA 92675 (714) 443-3136	**Technology:** Enhanced Bioremediation of Groundwater using ORC® - ORC® (oxygen release compound) is a proprietary formulation based on magnesium peroxide and is available from Regenesis - ORC® is applied to the groundwater using different methods and dosages (dosage based on several factors including the estimated mass of contaminant at the site and the specific properties of the aquifer) - Details of the application method and dosage for each site are included in the report	**Cleanup Authority:** State voluntary cleanup
Construction/Design: Thomas Morin (Fourth Plain) Environmental Partners Inc. 10940 NE 33rd Place, Suite 110 Bellevue, WA 98004 (206) 889-4747 Additional contacts in the report		**State Contacts:** Joel Weiss California Regional Water Quality Control Board Central Valley Region (916) 255-3077 (Balfour Road) Carol Fleshes Washington Department of Ecology (206) 649-7000 (Fourth Plain) Emily McGuire Kansas Department of Health and Environment (913) 296-7005 (Steve's Standard)
Waste Source: Various waste disposal practices, including leaks at service stations	**Type/Quantity of Media Treated:** Groundwater - estimated 20,400 square feet for Fourth Plain; estimates were not provided for Balfour Road or Steve's Standard	
Purpose/Significance of Application: Evaluate the cost and performance of ORC® to remediate groundwater at three petroleum-contaminated sites		

Enhanced Bioremediation of Contaminated Groundwater - Balfour Road Site, Brentwood, CA; Fourth Plain Service Station Site, Vancouver, WA; Steve's Standard and Golden Belt 66 Site, Great Bend, KS

Regulatory Requirements/Cleanup Goals:
- Balfour Road - federal MCLs for groundwater.
- Fourth Plain - benzene - 0.005 mg/L, total BTEX - 0.095 mg/L and TPH -1.0 mg/L.
- Steve's Standard - no cleanup goals; demonstration project.

Results:
- Balfour Road and Fourth Plain sites - the cleanup goals had not been met at either the Balfour Road or Fourth Plain sites as of October 1997. The geometric mean concentration and mass of benzene, total BTEX, and TPH had been reduced by approximately 50 percent.
- Steve's Standard - over the first seven months of operation, the concentration and mass of benzene, total BTEX, and TPH had been reduced; however, over the next nine months, concentrations appeared to stabilize or rise slightly; a continuing source was identified at the site.

Cost:
- Total cost - $41,600 for Bafour Road; $37,300 for Fourth Plain; $96,000 for Steve's Standard.
- Treatment cost - $33,500 for Bafour Road; $35,700 for Fourth Plain; $93,400 for Steve's Standard (two service stations located next to each other).

Description:
Contamination at each site resulted from leaks in underground petroleum storage tanks and supply pipelines at or near retail dispensing locations. Refined petroleum product was released to the subsurface soil and groundwater at each site for unknown periods of time, until being detected in the 1990's. The three sites were cleaned up under their respective state voluntary cleanup programs. Oversight was performed by the respective state agency without involvement of EPA. Enhanced bioremediation using ORC® was selected by the lead contractors for each of the sites because it was expected to reduce the mass of contaminants in the aquifer by more than 50 percent in only six months, thereby reducing risk to human health and the environment from exposure to contaminated groundwater, and because it required a smaller capital investment and lower operating expenses than alternative technologies such as pump and treat. Regenesis indicated that enhanced bioremediation using ORC® was not expected to treat the groundwater to the federal maximum contaminant levels (MCL), but that the treatment would reduce substantially the dissolved-phase mass of contaminants present in the aquifer, as well as reduce sources characterized as moderate smear zones.

Enhanced bioremediation was performed at the three sites, using application of ORC®. ORC® is a proprietary formulation based on magnesium peroxide and is available from Regenesis Bioremediation Products, Inc. According to Regenesis, the quantity of ORC® required for a site is based on several factors including the estimated mass of contaminant at the site (dissolved-phase concentration) and the specific properties of the aquifer such as porosity and thickness. Details on the specific applications of this technology at each of the three sites in included in the report. As of October 1997, the cleanup goals had not been met at either the Balfour Road or Fourth Plain sites; however the geometric mean concentration and mass of benzene, total BTEX, and TPH had been reduced by approximately 50 percent in the aquifers in only 6 months for roughly $50,000 per site. In addition, at the Steve's Standard site, the concentration and mass of benzene, total BTEX, and TPH had been reduced in portions of the aquifer. The report presents a detailed summary of the progress at each site and the plans for future activities at the sites.

SITE INFORMATION

This report summarizes data on the cost and performance of enhanced bioremediation using Oxygen Release Compound (ORC®) to treat groundwater contaminated with gasoline-range petroleum hydrocarbons at the following three sites:

- Balfour Road, Brentwood, California
- Fourth Plain Service Station, Vancouver, Washington
- Steve's Standard and Golden Belt 66, Great Bend, Kansas

Table 1 summarizes information about the sites, including location, operations, year contamination was detected, source of contamination, and regulatory agency that oversees the cleanup.

This report describes remedial activities involving the use of ORC at three sites at which groundwater is contaminated with gasoline-range petroleum hydrocarbons. It provides information about the cost and performance of ORC®, methods used to apply ORC® to groundwater, and lessons learned.

Table 1: Summary of Site Information [2, 3, 4]

Site	Location	Operations	Year Contamination Detected	Source of Contamination	Regulatory Agency
Balfour Road	Brentwood, California	Supply Pipeline	1990	Pipeline Leak	California Regional Water Quality Control Board
Fourth Plain	Vancouver, Washington	Retail Station	1993	Pinhole Leak below Product Dispenser	Washington Department of Ecology
Steve's Standard	Great Bend, Kansas	Retail Stations	1994	Leak in Piping and Underground Storage Tanks	Kansas Department of Health and the Environment

Background [2, 3, 4]

History: Contamination at each site resulted from leaks in underground petroleum storage tanks and supply pipelines at or near retail dispensing locations. Refined petroleum product was released to the subsurface soil and groundwater at each site for unknown periods of time, until being detected in the 1990's.

At Balfour Road, pipeline leaks were discovered in a gasoline supply pipeline in 1990. From 1990 to 1995, groundwater was extracted at the site through an excavation trench and treated. Once the majority of the free product was recovered, the trench system was no longer a cost effective solution. Enhanced bioremediation of the groundwater using ORC® was implemented in December 1995.

At Fourth Plain, a release of gasoline-range petroleum hydrocarbons beneath a product dispenser was discovered in May 1993. At that time, the source was repaired and contaminated soils were excavated. Groundwater monitoring began in 1993, and a feasibility study and technology evaluation were conducted in 1995. That study included a pilot test of soil vapor

SITE INFORMATION (CONTINUED)

extraction (SVE) conducted in March 1995. Groundwater pumping constant discharge and recovery tests also were conducted in March 1995. Enhanced bioremediation of the groundwater using ORC® was implemented in July 1996.

At Steve's Standard, leaks in piping and underground storage tanks were discovered in 1994. Steve's Standard is a combination of two sites, Steve's Standard and Golden Belt 66. The two sites are adjacent to one another; remediation of the contamination plume in the groundwater beneath the sites has been considered as a single project for this report (referred to as Steve's Standard for this report). At Steve's Standard, enhanced bioremediation of the groundwater using ORC® was implemented in July 1996.

Regulatory Context: The three sites were cleaned up under their respective state voluntary cleanup programs. Oversight was performed by the respective state agency (see Table 1), without involvement of EPA.

Information on cleanup goals for the three sites is discussed under the Treatment System Performance section of this report.

Remedy Selection: Enhanced bioremediation using ORC® was selected by the lead contractors for each of the sites on the basis of results of an evaluation that compared enhanced bioremediation using ORC®, air sparging and SVE (AS/SVE), and groundwater extraction (pump-and-treat). Enhanced bioremediation using ORC® was selected because it was expected to reduce the mass of contaminants in the aquifer by more than 50 percent in only six months, thereby reducing risk to human health and the environment from exposure to contaminated groundwater, and because it required a smaller capital investment and lower operating expenses than the two alternative technologies. Regenesis indicated that enhanced biodegradation using ORC® was not expected to treat the groundwater to the federal maximum contaminant levels (MCL), but that the treatment would reduce substantially the dissolved-phase mass of contaminants present in the aquifer, as well as reduce sources characterized as moderate smear zones. Direct injection of ORC® into the source or a line of wells on the perimeter of the plume are the primary methods used to achieve the stated goals.

Period of Operation:

Balfour Road:	December 1995 to present (report covers the period through October 1997)
Fourth Plain:	July 1996 to present (report covers the period through October 1997)
Steve's Standard:	July 1996 to present (report covers the period through October 1997)

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Treated: Groundwater

Contaminant Characterization [2, 3, 4]

Primary Contaminant Groups: Benzene, toluene, ethylbenzene, and xylenes (BTEX) and total petroleum hydrocarbons (TPH)

At the three sites, benzene, total BTEX, and TPH were detected at concentrations in groundwater ranging from 0.43 milligrams per liter (mg/L) to 5.1 mg/L, 13.2 to 14 mg/L, and 10 to 120 mg/L, respectively. Table 2 presents the maximum concentrations of benzene, total BTEX, and TPH detected in groundwater at Balfour Road, Fourth Plain, and Steve's Standard before application of ORC®.

MATRIX DESCRIPTION (CONTINUED)

Matrix Characteristics Affecting Cost or Performance [2, 3, 4]

Table 3 summarizes the matrix characteristics that affect the cost or performance of the technology and the values measured. At each site, contamination occurred in a shallow unconfined aquifer that consisted of a sandy and clayey mixture and ranged in thickness from 7 to 18 feet. As shown on Table 3, Fourth Plain had a relatively high groundwater velocity. According to Regenesis, the vendor of ORC®, higher groundwater velocity aids in dispersing oxygen from an application of ORC® more quickly over a wider area and in mixing the oxygen with contaminants.

Table 2: Maximum Initial Concentrations Detected Prior to Application of ORC® [2, 3, 4]

Contaminants	Site		
	Balfour Road	Fourth Plain	Steve's Standard
Benzene (mg/L)	0.43	1.0	5.1
Total BTEX (mg/L)	Not available	14.0	13.2
Total Petroleum Hydrocarbons (mg/L)	10	120	30

Table 3: Matrix Characteristics Affecting Cost or Performance [2, 3, 4]

Parameters	Site			Method of Measurement
	Balfour Road	Fourth Plain	Steve's Standard	
Thickness of Aquifer (ft)	18	12 - 15	7 - 10	Visual inspection of core samples
Conductivity (centimeters per second [cm/sec])	0.001*	0.08	0.02	Slug or constant discharge and recovery test
Groundwater velocity (ft/day)	0.00076**	1 - 10	0.025**	Calculation using Darcy's Law
Hydraulic Gradient (ft/ft)	0.0009	0.003 - 0.03	0.0015	Water level indicator and site survey

* estimated as 0.001cm/sec for silty clay
** calculated using estimate of porosity, 0.3

MATRIX DESCRIPTION (CONTINUED)

Table 3 (continued): Matrix Characteristics Affecting Cost or Performance [2, 3, 4]

Parameters	Site			Method of Measurement
	Balfour Road	Fourth Plain	Steve's Standards	
Depth to Groundwater (feet below ground surface [ft bgs])	15 - 22	13-21	7-9	Water level indicator
Soil Type or Classification	Aquifer is a heterogeneous combination of silty clays on top of clayey silts, with sand lenses and fingers (CL-ML 80-95%)	Aquifer primarily consists of sands and gravels, with silty and clayey zones (Sand/ gravel/silt 65/25/10)	Aquifer consists of loose, medium- to coarse-grain sand, overlain by silty clay soil	Visual inspection of core samples
pH	Not provided	6.2-7.4	6.8-7.2	-
Porosity	20-30% (estimated based on soil type)	20-30%	~25-30%	-
Seasonal water table fluctuation	Not provided	1-2 ft	~4 ft	Time series data from water level indicator

DESCRIPTION OF TREATMENT SYSTEM

Primary Treatment Technology

Enhanced bioremediation

Supplemental Treatment Technology

None

System Description and Operation [1, 2, 3, 4]

Enhanced bioremediation was performed at the three sites, using in situ bioremediation and application of ORC®. ORC® is a proprietary formulation based on magnesium peroxide and is available from Regenesis Bioremediation Products, Inc (Regenesis). The following information on ORC® was provided by Regenesis. When it comes in contact with groundwater, ORC® slowly releases oxygen to the groundwater and is converted to a magnesium hydroxide byproduct. Regenesis has indicated that, when hydrated, ORC® can release oxygen for up to a year or longer (often typically 6 months) depending on contaminant flux and that the rate of release is a function of the molecular matrix Regenesis produces during synthesis and is not achieved by a coating process.

When ORC® is used, the level of dissolved oxygen (DO) measured in the groundwater is raised above background levels, and the rate of natural bioremediation is increased. The level of DO varies according to several factors, including:

DESCRIPTION OF TREATMENT SYSTEM (CONTINUED)

- The dosage of ORC® applied to the groundwater.
- The amount of DO consumed during biological degradation of hydrocarbons.
- The amount of time that has elapsed since ORC® was applied to the groundwater.

According to Regenesis, the quantity of ORC® required for a site is based on several factors including the estimated mass of contaminant at the site (dissolved-phase concentration) and the specific, properties of the aquifer such as parasity and thickness. Regenesis indicates that a key factor in estimating the quantity of ORC® required is the stoichiometric quantity of oxygen required to degrade the contaminants. For example, fully degrading one pound of benzene to carbon dioxide and water would require 3 pounds of oxygen. Given that ORC® releases 10 percent of its mass as oxygen, 30 pounds of ORC® would be required to fully degrade one pound of benzene. Oxygen typically is released from ORC® over a four- to eight-month period, resulting in a sustained increase in the amount of dissolved oxygen available to promote aerobic biodegradation of groundwater contamination.

Application of ORC® [2, 3, 4]

A different method of applying ORC® to the groundwater was used at each site, as identified below:

- Balfour Road: wells containing filter socks
- Fourth Plain: borings containing slurry
- Steve's Standard: direct push injection

Descriptions of the systems used at the three sites to apply ORC® to the groundwater and to monitor the concentrations of contaminants and DO in the groundwater are presented below.

Balfour Road - At the Balfour Road site, filter socks containing ORC® and an inert carrier matrix (silica sand) were applied to the groundwater through a system of 10 wells in two barriers, one line of four and another of six wells installed downgradient of the source areas. The barrier of four wells was installed closer to the source than the second barrier. Both barriers were arranged in a line perpendicular to the direction of groundwater flow. Approximately 200 pounds of ORC® were applied to the groundwater at this site. The mass of contaminants in the aquifer was not available for this site, and therefore the amount of ORC applied at Balfour Road was estimated based on the concentrations of contaminants and properties of the aquifer. Monitoring wells (MW) were placed 42 feet upgradient and downgradient of each battery of wells. Monthly monitoring of DO, benzene, and TPH was conducted.

MW SB-43A was installed to monitor groundwater downgradient of the battery of ORC® wells nearest to the source of contamination, and MW SB-37A was installed to monitor groundwater downgradient from the battery of wells farther downstream from the source of contamination.

Fourth Plain - At the Fourth Plain site, a fence of 15 boreholes (borings) at 10-foot spacing was drilled near the upgradient edge of the anaerobic core of the contaminant plume. The borings were drilled to about 25 feet bgs and each was filled from about 10 ft bgs to 25 ft bgs with a slurry containing approximately 70 pounds of ORC®. The oxygen released by the ORC® was transported to the anaerobic core of the contaminant plume by the natural flow of groundwater at the site. The site initially was estimated to have approximately 33 pounds of dissolved-phase contaminant (BTEX) in the groundwater; on the basis of the 30 to 1 ratio for ORC® to dissolved-phase contaminant discussed earlier in this report, approximately 1,000 pounds of ORC® would be required to treat the groundwater at the site. The 15 borings drilled at the site contained a total of approximately 1,000 pounds of ORC® (70 lbs x 15 wells). MWs were located on site and

DESCRIPTION OF TREATMENT SYSTEM (CONTINUED)

approximately 90 to 120 feet downgradient of the site. The MWs were monitored monthly for DO, BTEX, TPH, and pH.

Steve's Standard - At this site, a total of 2,325 pounds of ORC® slurry was injected into the groundwater with a Geoprobe™ (direct-push technology). Slurry was injected at approximately 118 points at the site, at an injection pressure ranging from 50 to 100 pounds per square inch (psi), on a rectangular grid pattern. Similarly to Balfour Road, the mass of contaminants in the aquifer was not available for this site, and therefore the amount of ORC applied at Steve's Standard was estimated based on the dissolved-phase concentrations of contaminants and properties of the aquifer.

Approximately 50 MWs provided monitoring of the performance of the system at Steve's Standard. The site was monitored periodically fora variety of parameters, including BTEX, TPH, and DO. MWs were located throughout the site and were used to measure the concentrations of contaminants within source areas (for example, MW-10 at Steve's Standard and OB-06 at Golden Belt 66) and at locations downgradient of the source areas (for example, MW-8 and MW-15).

Operating Parameters Affecting Treatment Cost or Performance

Operating parameters that affect cost or performance include the number of points at which ORC® is introduced (ORC® source points), the screened intervals of source points, the spacing of the source points (if using socks and wells), the dosage of ORC®, and background and operating concentrations of DO. Table 4 presents the major operating parameters that affect cost and performance for the technology and the values measured for each of those parameters.

Table 4: Operating Parameters Affecting Cost or Performance [2, 3, 4]

Parameter	Value		
	Balfour Road	Fourth Plain	Steve's Standard
Method of Application	Wells filled with ORC® filter socks	Borings filled with slurry	Geoprobe™ injection of slurry
Number of Source Points	10 wells	15 borings	118 injection points
Screened Interval (ft below ground surface)	10 - 25 and 30 - 33	10 - 25	10 - 25*
Source Point Spacing (ft)	20	10	5 - 10
Dosage of ORC® (lbs/well)	20	70	20
Dosage of ORC® (total lbs applied)	200	1,000	2,325
Background Dissolved Oxygen Concentration (mg/L)	<1	1 - 4	0-2

* There is no screened interval for a Geoprobe™ direct-push technology; the value given represents the depth below the surface of the water table at which ORC® was injected at a pressure ranging from 50 to 100 pounds per square inch.

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals [2, 10, 12]

The three sites were remediated under their respective state voluntary cleanup programs. The following is a discussion on how the remediation objectives were established for each site.

The cleanup goals identified for the Balfour Road site were groundwater drinking-water standards; however, no specific numerical standards were provided by Santa Fe Pipeline Partners. Federal groundwater drinking standards at 40 Code of Federal Regulations (CFR) 141.61 include an MCL for benzene of 0.005 mg/L.

The cleanup goals for the Fourth Plain site identified by Environmental Partners, Inc. were:

- Benzene, 0.005 mg/L
- Total BTEX, 0.095 mg/L
- TPH, 1.0 mg/L

The Fourth Plain site was remediated under the state of Washington's Independent Remedial Action Program (IRAP) that allows site owners to manage site cleanups independently. Under the IRAP, managed by the Washington State Department of Ecology, the state does not provide oversight or direction to site owners on the appropriateness of their remedial approaches. Instead, under the program, the state provides a letter requiring "no further action" when a site owner provides to the state sufficient evidence that cleanup levels have been met and that the site no longer represents a threat to human health and the environment.

Because the aquifer at the site was a source of potable water, as defined by the state of Washington, and because a surface-water body was immediately down-gradient from the site, the cleanup level identified for benzene was the MTCA cleanup level of 0.005 mg/L. The cleanup level for TPH was established for aesthetic reasons; no risk-based cleanup level was identified for TPH.

No cleanup levels were established for the Steve's Standard site. Remediation of the Steve's Standard site was conducted as a pilot test by the Kansas Department of Health and the Environment (KDHE) to determine whether ORC® could be used as a cost-effective method of remediating groundwater contaminated with hydrocarbons. As such, it was intended to evaluate the effectiveness of ORC® rather than to achieve a specified cleanup goal for the groundwater. The application also was intended to identify design parameters needed to optimize an ORC® application while attracting only minimal attention in the neighboring community. It was funded partially by the State.

Treatment Performance Data

Performance data collected for these three sites are summarized in Tables 5 through 8. Table 5 identifies the number of MWs, locations of MWs, frequency of sampling, and method of analysis for each site. Tables 6, 7, and 8 summarize analytical data for benzene, total BTEX, TPH, and DO for selected MWs at each of the three sites. Figures 1 and 2 present graphically the data shown on Table 6 for Balfour Road.

None of the sites reported any exceptions to the quality assurance and quality control plans.

TREATMENT SYSTEM PERFORMANCE (CONTINUED)

Table 5: Performance Data Sampling [1, 2, 3]

Sampling Information	Balfour Road	Fourth Plain	Steve's Standard
Number of MWs	4 (on site)	10 (on site)	Approximately 50
Locations of MWs	One Well up- and one down-gradient of each of the two barriers of ORC® wells	Up- and downgradient of the ORC® barrier of borings	Throughout the application area and on the perimeter of the property
Frequency of Sampling	Monthly	Quarterly	Week, month, two-month (doubling period between sampling events)
Method of Analysis	YSI 55 (DO) 8015/8020 (organics)	Hach AccuVac (DO) Hydrocarbon Methods	Hach AccuVac (DO) Method 8260 (BTEX) OA-1 (TPH)

Table 6: Summary of Treatment Performance Data for the Balfour Road Site (mg/L) [2]

Date	Well SB-37A		Well SB-43A	
	Benzene	DO	Benzene	DO
December 1995*	NR	0.77	NR	NR
January 1996	0.43	1.75	0.080	1.29
February 1996	0.41	0.87	0.093	1.30
March 1996	0.25	3.40	0.0035	3.32
April 1996	0.11	1.19	0.0028	1.92
May 1996	0.19	1.69	0.0014	2.47

* = ORC® socks placed in wells
NR = Not reported

TREATMENT SYSTEM PERFORMANCE (CONTINUED)

Figure 1. Summary of Monitoring Data. SB-37A, Balfour Road [2]*

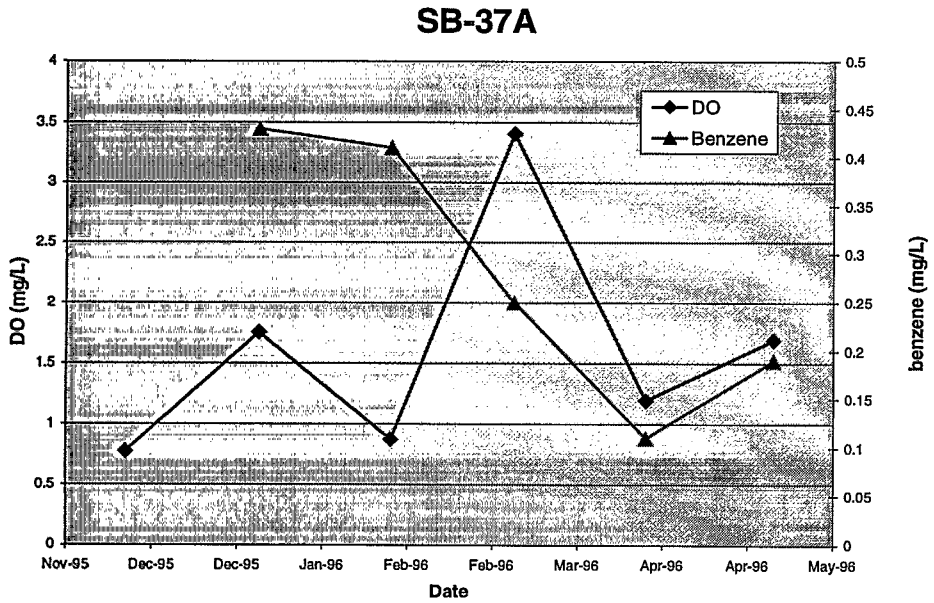
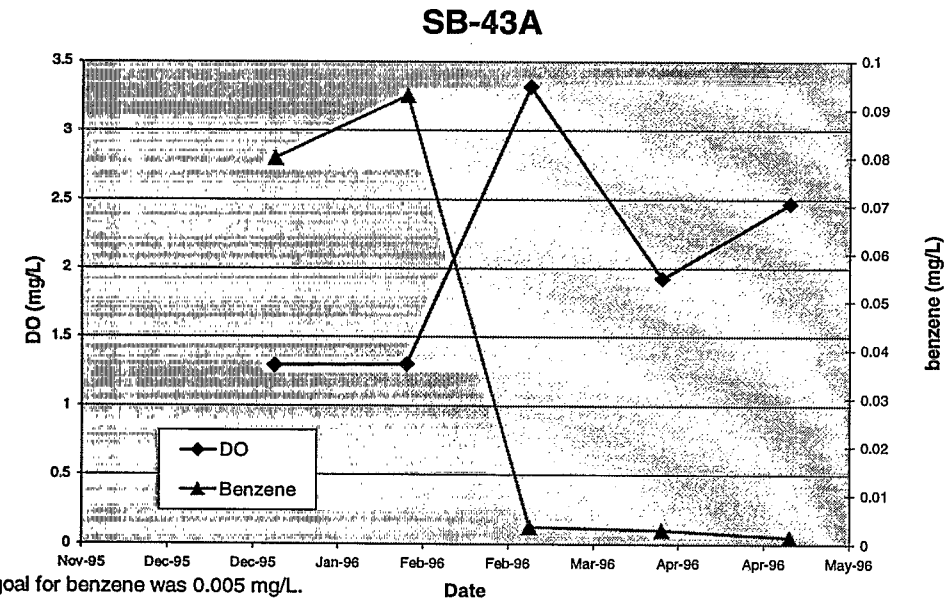


Figure 2. Summary of Monitoring Data. SB-43A, Balfour Road [2]*



* Cleanup goal for benzene was 0.005 mg/L.

TREATMENT SYSTEM PERFORMANCE (CONTINUED)

Table 7: Summary of Treatment Performance Measured using a Geometric Mean for Fourth Plain Site (mg/L) [17]*

Date	Benzene	Total BTEX	TPH/GRO
July 1996 **	0.053	0.976	11.10
October 1996	0.029	0.481	6.90
January 1997	0.032	0.850	6.16

* = Calculated based on data from 6 monitoring wells.

Table 8: Summary of Treatment Performance Measured using a Geometric Mean for Steve's Standard Site* (mg/L) [4, 20]

Date	Benzene	Total BTEX	TPH/GRO
July 1996**	0.18	0.66	4.1
November 1996	0.04	0.14	2.5
February 1997	0.03	0.06	2.6
August 1997	0.11	0.27	2.6
November 1997	0.11	0.30	2.5

* = Based on 17 monitoring wells
** = ORC® injected
NS = Not Sampled

Performance Data Assessment

This section presents a discussion of the data on concentrations of contaminants for each of the three sites. Where possible, the geometric mean of wells at each site was evaluated to provide an indication of the trend in contaminant concentrations at the site.

Balfour Road. Table 6 and Figures 1 and 2 show the results of monitoring from December 1995 to May 1996 for benzene and dissolved oxygen at two MWs at Balfour Road located downgradient of the barrier of the ORC® wells. Figures 1 and 2 show that, as of May 1996, concentrations of benzene were reduced by more than 50 percent in six months. In well MW SB-43A, closest to the source of contamination, concentrations of benzene were reduced from 0.080 mg/L to 0.0014 mg/L, which is below the cleanup goal of 0.005 mg/L. In the well, concentrations of DO varied from 1.29 to 3.32 mg/L. In well MW-SB-37A, farther from the source of contamination, concentrations of benzene were reduced 56 percent from 0.43 mg/L to 0.19 mg/L. In that well, concentrations of DO varied from 0.77 to 3.40 mg/L.

Fourth Plain. At the Fourth Plain site, concentrations of contaminants were reported in six MWs located throughout the plume (MW-4, 6, 7, 9, 11, 14). During baseline monitoring of the groundwater at the site (July 1996), wells in this area were shown to have the highest

TREATMENT SYSTEM PERFORMANCE (CONTINUED)

concentrations of benzene, total BTEX, and TPH-G, and the lowest concentrations of DO. Table 7 shows the geometric mean concentrations of benzene, total BTEX, and TPH-G measured in these wells in July 1996, October 1996, and January 1997, covering approximately 180 days after the application of ORC®. Over that 180-day period, the geometric mean concentrations of benzene, total BTEX, and TPH-G decreased by 45, 51, and 38 percent after 90 days, and 38, 12, and 44 percent after 180 days, respectively.

Background concentrations of DO at the Fourth Plain site ranged from 1 to 4 mg/L, as shown in Table 5. Before application of ORC®, the anoxic core of the plume extended over an area of approximately 1 acre, with a concentration of DO in that area of less than 0.3 mg/L. The anoxic core of the plume had the highest levels of BTEX and TPH; MW-7 was located within the anoxic core area. The concentrations of DO in the area increased to levels ranging from 2.6 to 4.9 mg/L during the first 90 days after application of ORC® and continued to rise to a maximum of 7.8 mg/L, reached 180 days after application of ORC®.

Steve's Standard. Table 8 summarizes the results for a geometric mean of 18 of the MWs at this site. The monitoring data cover approximately a 16-month period after the application of ORC®. A photo-ionization detector (PID) analysis conducted in early 1997 identified a continuing source of hydrocarbons in the subsurface at this site. [20] The PID data were used to develop a plot of hydrocarbon concentrations in the subsurface which indicated a continuing source near the OB-6 boring. Over the first seven months after application of ORC (July 1996 - February 1997), concentrations of benzene, BTEX, and TPH-G were reduced; over the next nine months, concentrations appeared to stabilize or rise slightly. During the first seven months, concentrations for benzene, total BTEX, and TPH-G were reduced 83, 91, and 36 percent, respectively, while overall from July 1996 - November 1997, concentrations were reduced 39, 55, and 39 percent, respectively.

The concentration of DO throughout the site ranged from 0 to 6 mg/L over the period from July 1996 to February 1997. By February 1997, the concentration of DO was measured as 0 mg/L for 80 percent of the MWs.

The vendor supporting the KDHE (Terranext) concluded the following about the effectiveness of ORC at the Steve's Standard site:

- the use of ORC stimulated aerobic biodegradation of petroleum constituents to almost non-detect levels in areas around the petroleum release source areas
- total BTEX levels in wells hydraulically downgradient of the source areas have continued to decrease
- total BTEX levels in source areas increased, thus indicating that the total mass of BTEX in these areas is greater than was estimated during the design of ORC injection

Estimate of Mass of Contaminants Degraded

In 1997, Regenesis commissioned Principia Mathematica, a groundwater modeling firm, to model two of the sites (Fourth Plain and Steve's Standard) to estimate the mass of contaminants degraded in the aquifers. As mentioned in the previous discussion of performance data, a photo ionization detector identified a continuing source below Steve's Standard. This complicates the interpretation of modeling results for Steve's Standard; therefore, only modeling results for Fourth Plain are presented below. Table 9 presents a summary of the modeling results, including assumptions applied in the modeling, and mass of contaminants degraded. Approximately 280 pounds of TPH were degraded in six months at this site.

Table 10 shows a comparison of the mass of ORC® dosage applied at Fourth Plain with the mass of BTEX degraded. Approximately 30 lbs of ORC® were applied for each pound of BTEX degraded.

TREATMENT SYSTEM PERFORMANCE (CONTINUED)

Table 9: Summary of Modeling Results for Estimating Mass of Contaminants Degraded [13]

Estimated Quantity	Fourth Plain
Area (ft^2) (see assumptions)	20,400
Mass of Benzene Degraded (lbs)	1.8
Mass of Total BTEX Degraded (lbs)	32.2
Mass of GRO-TPH Degraded (lbs)	281.5
Assumptions: • Area defined by 10 mg/L isopleth • Porosity = 0.3 and density of water = 28.3 kg/ft^3 • Affected thickness of aquifer = 10 feet	

Note: Calculations are based on a logarithmic Kriging analysis fitting a surface to the available data points and saving the fitted surface to a finite difference grid. Volumes used in the analysis are a function of the areal extent of the 10 mg/L concentration isopleths times a 10 -foot-thick contaminated zone with a porosity of 0.3. In addition, volumes presented here assume a low groundwater velocity over a short period, resulting in only one volume of throughput. (It is likely that, because groundwater velocity at Fourth Plain is higher than at Steve's Standard, the volume used in this analysis for Fourth Plain was underestimated.)

Table 10: Ratio of ORC® Dosage to Mass of BTEX Degraded [2, 3, 4, 13, 18]

Parameter	Fourth Plain
Mass of ORC® Dosage (lbs)	1,000
Estimated Mass of BTEX Before Application (lb)	33
Mass of Total BTEX Degraded (lbs)	32.2
Ratio of ORC® Dosage to Mass of BTEX Degraded	31.1

Recent Activities [10, 11, 12]

As of October 1997, the cleanup goals described above had not been met at either the Balfour Road or Fourth Plain sites; however the geometric mean concentration and mass of benzene, total BTEX, and TPH had been reduced by approximately 50 percent in the aquifers in only 6 months for roughly $50,000 per site. In addition, at the Steve's Standard site, the concentration and mass of benzene, total BTEX, and TPH had been reduced in portions of the aquifer. Recent activities at the three sites are discussed below.

Balfour Road SFPP divided the site into two areas, referred to as north of Balfour Road and south of Balfour Road, for requesting closure letters from the state. For the area north of Balfour Road, a single ORC® source well contained benzene at 0.15 mg/L. There has been no reapplication of ORC® since the original application (December 1995). The vendor of the treatment indicated that it is likely that there will be a second application of ORC® in the affected well and that the site will request from the state a letter for no further action at that time. According to the vendor, for the area south of Balfour Road, SFPP conducted further

TREATMENT SYSTEM PERFORMANCE (CONTINUED)

activities in the summer of 1997 to characterize the levels of contamination in the soil and groundwater at the site. The results of these activities revealed additional contamination in a utility trench located along the boundary of the area. The contamination had not been detected previously. SFPP had not yet identified an appropriate remedial action for the areas south of Balfour Road.

Fourth Plain As shown above, the concentrations of benzene, total BTEX, and TPH had not met the cleanup levels for the site after six months of treatment. Environmental Partners Inc. stated its belief that the application of an additional 200 pounds of ORC® per quarter for a period of 1.25 years (1,000 pounds of ORC® total) would help achieve the cleanup goal. The cost of the additional effort was estimated to be an additional $50,000. The references available do not provide information about whether the additional treatment was being performed.

Steve's Standard Jacobs Engineering Group indicated that the dissolved-phase plume was reduced in volume following application of ORC®, but that elevated concentrations of hydrocarbons remained at one location at the site. In September 1997, 1,500 pounds of ORC® were injected into the aquifer, at a cost of $25,000; samples of groundwater were collected from the location in November 1997 to evaluate the concentrations of hydrocarbons remaining after that latest application of ORC®. As shown in Table 9, concentrations had not changed much from August to November 1997.

COST OF THE TREATMENT SYSTEM

Procurement Process [2, 3, 4]

At each site, the site owner chose a prime contractor to be responsible for site management. That contractor entered into subcontracts with other firms, such as Regenesis, to help with design and construction of treatment systems for enhanced bioremediation, including the use of ORC®. No information is available that indicates whether the prime contractors or subcontractors were selected through a competitive bidding process.

Costs for the Treatment System [2, 3, 4]

Table 11 summarizes the actual costs of enhanced bioremediation, including use of ORC®, at the three sites. All cost data were solicited and collected from the contractor that performed the work. Total costs for the three sites varied by a factor of 2.5, with costs at Fourth Plain the lowest ($37,300), and those at Steve's Standard the highest ($96,187). Steve's Standard covered three times the area, including two service stations (As discussed earlier, Steve's Standard referred to in this report comprises both the Steve's Standard and Golden Belt 66 sites). The costs of individual elements of the projects are presented in Table 12.

The costs for installation of wells at Balfour Road were high, compared with those at the other two sites (where borings and direct push technology were used). According to SFPP, Balfour Road used a more expensive method of application of ORC® to facilitate use of air sparging as a contingency if application of ORC® did not meet goals of the project (the ORC® wells could be converted to sparging wells). The costs of site work and installation of wells at Fourth Plain are less than those for the other two sites because the site operator used some MWs that had been installed for site characterization in the ORC® application system.

COST OF THE TREATMENT SYSTEM (CONTINUED)

Vendor Input on Costs [19]

The primary costs of using ORC® are those for the installation of ORC® source points, the amount of ORC® applied, and the amount and type of monitoring required. Contaminant mass, hydrogeology of the aquifer, and groundwater flow rate are the most significant parameters that affect those costs because they determine the spacing of the source points, the number of source points required, and the amount of ORC® to be applied. Monitoring costs will depend on the regulatory requirements and are beyond the direct control of the vendor.

Table 11: Summary of Cost Data [2, 3, 4]

Cleanup Activity	Balfour Road	Fourth Plain	Steve's Standard**
Treatment Activities ($)			
Site Work and Well Installation	25,488	7,200	37,126
ORC®	6,520	9,900	23,599
Operations	1,500	18,600	6,046
Monitoring[a]	-	-	26,668
Treatment Subtotal	33,508	35,700	93,439
After Treatment Activities ($)			
Decontamination	4,900	500	2,748
Site Restoration	1,000	500	-
Demobilization and Disposal	2,200	600	-
After Treatment Subtotal	8,100	1,600	2,748
TOTAL COST	$41,608	$37,300	$96,182

[a] For Balfour Road and Fourth Plain, this cost was not provided separately from operating costs.
** Steve's Standard comprises two adjacent facilities.

SITE CONTACTS

Table 12 presents the contacts for each of the three sites.

Table 12: Site Contacts

Balfour Road	
Site Management/Design: Mark Sandon Santa Fe Pipeline Partners L.P. 1100 Towne & Country Road Orange, CA 92868 (714) 560-4867	**State Contact:** Joel Weiss California Regional Water Quality Control Board Central Valley Region (916) 255-3077
Construction: Levine-Fricke 2001 Douglas Boulevard Roseville, CA 95661 (916) 786-0320	**Design (Additional):** Craig Sandefur Regenesis Bioremediation Products, Inc. 27130A Paseo Espada, Suite 1407 San Juan Capistrano, CA 92675 (714) 443-3136
Fourth Plain	
Site Management: Joseph L. Glassman Environmental Insurance Management, Inc. 512 North Oakland Street Arlington, VA 22203	**State Contact:** Carol Fleshes Washington Department of Ecology NW Region, Mail Stop PV11 Olympia, WA 98504-8711 (206) 649-7000
Construction/Design: Thomas Morin Environmental Partners Inc. 10940 NE 33rd Place, Suite 110 Bellevue, WA 98004 (206) 889-4747	**Design (Additional):** Steve Koenigsberg Regenesis Bioremediation Products, Inc. 27130A Paseo Espada, Suite 1407 San Juan Capistrano, CA 92675 (714) 443-3136
Steve's Standard	
Site Management: Roger Lamb Jacobs Engineering Group Inc. 8208 Melrose Drive, Suite 210 Lenexa, KS 66214 (913) 492-9218	**State Contact:** Emily McGuire Kansas Department of Health and Environment Bureau of Environmental Remediation Forbes Field, Building 740 Topeka, KS 66620 (913) 296-7005
Construction: Roger Lamb Jacobs Engineering Group Inc. 8208 Melrose Drive, Suite 210 Lenexa, KS 66214 (913) 492-9218	**Design:** Craig Sandefur and David Peterson Regenesis Bioremediation Products, Inc. 27130A Paseo Espada, Suite 1407 San Juan Capistrano, CA 92675 (714) 443-3136

OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

- Actual costs for enhanced bioremediation using ORC® at the three sites ranged from $37,300 to $96,187, with costs at two of the three sites less than $50,000. The relatively high cost at Steve's Standard is attributed to the large area treated for two service stations. The costs included activities directly attributed to treatment, such as site work, installation of wells, application of ORC®, operations, and monitoring, and activities performed after treatment, such as decontamination, site restoration, and demobilization and disposal.

- The factors that most affected costs at the three sites included the amount of ORC® applied, (e.g., 200 lbs at Balfour Road; 1,000 lbs at Fourth Plain; 2,325 lbs at Steve's Standard) the number of ORC® source points, (e.g., 10 wells at Balfour Road; 15 borings at Fourth Plain; 118 injection points at Steve's Standard), and the type of equipment used to apply ORC® (for example, the wells used at Balfour Road were relatively more expensive than equipment used at the other two sites).

- The firms responsible for site management and construction compared the cost of remediating the sites by enhanced bioremediation using ORC® with the costs of other technologies such as an AS/SVE system. For example, at the Balfour Road site, the installation and startup costs alone for an AS/SVE system were estimated to cost $181,077 compared to $33,508 for a complete ORC application. At the Steve's Standard site, the site management firm estimated that installation and operation of an AS/SVE system would have cost $250,000, including $36,000 for operations. The firm indicated that pilot tests showed that AS/SVE would have been effective at the site, but that it would not have been practical to install such a system because of limited space available for equipment and the close proximity of residential housing. [12]

- At the Balfour Road site, use of ORC® was estimated by SFPP to have saved the site owner approximately $100,000 over the cost of AS/SVE. [2]

Performance Observations and Lessons Learned

- At the Balfour Road site, the overall cleanup goal was not met during the six-month operation period of the ORC® application. However, benzene concentrations in the well closest to the source of contamination were reduced by 98 percent to 0.0014 mg/L (below the cleanup goal of 0.005 mg/L). Benzene concentrations in a well farther from the source were reduced by 56 percent, but concentrationd remained above the cleanup goal.

- The six-month application of ORC® at the Fourth Plain site resulted in a 40 percent reduction in the mean benzene concentration, a 45 percent reduction in the mean TPH/GRO concentration, and a 13 percent reduction in the mean BTEX concentration. However, the final concentrations of all three parameters remained above the cleanup goals.

- The application at the Steve's Standard site was conducted by the state as a pilot test; there were no specific cleanup goals for the application. The geometric mean concentrations for benzene, total BTEX, and TPH-G were reduced by nearly 40 percent at this site during the first seven months of operation. However, there was a continuing source of contamination at this site, and this limited the effectiveness of the technology application.

OBSERVATIONS AND LESSONS LEARNED (CONTINUED)

- Modeling was used to estimate the mass of contaminant degraded in the aquifer at the Fourth Plain site. The total mass of total BTEX and TPH degraded was 32.2 and 282 lbs, respectively. This corresponds to a ratio of dose of ORC® to mass of total BTEX degraded of 31:1. The ratio identified for the Fourth Plain site is very close to the ratio of dose of ORC® to mass of total BTEX degraded of 31.1. The ratio identified for the Fourth Plain site is very close to the ratio of 30:1 estimated on the basis of soichiometric relationships.

- Remediation at all three sites was conducted in relatively shallow unconfined aquifers (less than 20 feet deep) contaminated with gasoline-range petroleum hydrocarbons. At Fourth Plain, the mass of contaminants in the aquifer was estimated to be 30 lbs before treatment with ORC®. The mass of contaminants in the aquifer before treatment was not provided for either the Balfour Road or the Steve's Standard site. For those sites, Regenesis determined the amount of ORC® to apply to the groundwater on the basis of concentrations of contaminants and hydrogeological data. The amount of ORC® applied to the aquifers at the three sites differed by a factor of 10, ranging from 200 lbs at Balfour Road to 2,325 lbs at Steve's Standard.

- The levels of DO measured in the aquifers at the three sites generally were higher after application of ORC® than before its application. The levels of DO typically ranged from 2 to 8 mg/L within six months after application of ORC®.

Other Observations and Lessons Learned

Regenesis has stated that it developed ORC® to reduce the mass of petroleum hydrocarbons in groundwater over a shorter period of time and for a lower cost than can be achieved by conventional technologies, and provided the following additional observations about the use of ORC®:

- Costs for ORC® are less than those for other technologies such as AS/SVE or pump-and-treat. ORC® requires less capital investment in equipment than the other technologies and can be deployed relatively quickly. Use of ORC® will substantially reduce the mass of contaminants in an aquifer, and will control levels of contamination in source areas, reducing risk to human health and the environment from exposure to contaminants in an aquifer and increasing levels of DO in an aquifer. ORC® typically will reduce concentrations of contaminants in an aquifer by at least 50 percent in six months, but is likely not the best remedy for a site that must be remediated to meet MCLs. In addition, ORC may be used to remediate relatively less-contaminated areas of an aquifer (polishing).

- Compared with other technologies, such as pump-and-treat or AS/SVE, ORC® is a passive technology, the implementation of which does not require an extensive design.

- ORC® may be used not only as a treatment barrier to reduce concentrations of contaminants in dissolved hydrocarbon plumes migrating off site but also as a source control technology when injected directly into a source.

- The effectiveness of ORC® over the long term remains unknown. Monitoring over two-year periods and multiple applications will be useful in obtaining the data needed to determine the technology's ability to achieve cleanup goals.

- Further research on the applicability of ORC® in more complex hydrogeological environments is necessary. The three sites presented in this report all had relatively shallow, unconfined aquifers.

- ORC® provides a quick response technology for elevating concentrations of DO and increasing aerobic degradation processes in groundwater over a wide area.

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Preparation Of The Analysis

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Coagulation/Flocculation/Dissolved Air Flotation and Oleofiltration™ at the Coastal Systems Station, AOC 1, Panama City, Florida

Coagulation/Flocculation/Dissolved Air Flotation and Oleofiltration™ at the Coastal Systems Station, AOC 1, Panama City, Florida

Site Name: Coastal Systems Station, AOC 1	**Contaminants:** Total Petroleum Hydrocarbon (TPH) - concentrations in the bioslurper process wastewater ranged from 5,000 to 21,000 mg/kg Metals - copper, lead, zinc	**Period of Operation:** August 1997 (Demonstration conducted for a total of 448 hours)
Location: Panama City, FL		**Cleanup Type:** Demonstration
Vendor: CRF/DAF: Great Lakes Environmental Inc 315 S. Stewart Ave Addison, IL 60101 Oleofiltration™: North American Technologies Group Inc 4719 Bellaire Blvd, Suite 301 Bellaire, TX 77401	**Technology:** CRF/DAF (Chemical reaction and flocculation and dissolved air flotation): - DAF system (Model DAF-5) was a skid-mounted unit containing a flotation chamber, including a skimmer, sump, and air dissolving tank - CRF system (Model CRF-15) included a two-stage chemical reaction tank, a polymer mix preparation tank, pumps, and mixers - Oleofiltration™ treatment system included a conventional oil/water separator, coalescing unit, and ceramic granule filtration system	**Cleanup Authority:** RCRA
Additional Contacts: Naval Facilities Engineering Service 1100 23rd Avenue Port Hueneme, CA 93043-4301		**Regulatory Point of Contact:** Information not provided
Waste Source: Fire-fighting training using ignitable hydrocarbons	**Type/Quantity of Media Treated:** Wastewater - 126,400 gallons	
Purpose/Significance of Application: Demonstrate the effectiveness of CRF/DAF and Oleofiltration™ in treating TPH and metals from wastewater from a full-scale bioslurper system		
Regulatory Requirements/Cleanup Goals: The objective of the demonstration was to determine the ability of the two water treatment systems to remove emulsified oil/grease from a bioslurper wastewater stream. A secondary objective was to determine if the CRF/DAF system could effectively remove metals.		

Coagulation/Flocculation/Dissolved Air Flotation and Oleofiltration™ at the Coastal Systems Station, AOC 1, Panama City, Florida (continued)

Results:
- The CRF/DAF system removed more than 98% of TPH from the wastewater stream containing an influent concentration of 5,000 mg/kg TPH as compared to the Oleofilter™ which removed between 56% and 90% TPH.
- The CRF/DAF system removed 98.9% of lead and zinc and more than 90% of copper from the wastewater stream whereas the Oleofilter™ removed 75% lead and 71% zinc. In addition, the percent removal of metals by the Oleofilter™ was reported to have varied significantly from sample to sample. Copper concentrations in the influent to the Oleofilter™ were below detection limits; therefore, a percent removal could not be calculated.

Cost:
- The results of the demonstration were used to estimate full-scale costs. Short-term (6-month) operating costs were calculated for both systems, assuming that the equipment was leased. The estimated cost per month to lease and operate each system was $7,580 for the CRF/DAF (for a six-month total of $45,500) and $3,650 for the Oleofilter™ (for a six-month total of $21,900)
- Excluding lease rates, the monthly operating costs for the CRF/DAF and Oleofilter™ systems are estimated to be $3,650 and $1,150, respectively.
- Based on these estimates, the CRF/DAF system costs about twice as much to lease and operate as the Oleofilter™ system.

Description:
The Coastal Systems Station is located in Panama City, Florida along the St. Andrews Bay. AOC 1 is a former fire-fighting training area used from 1955 to 1978, where waste oil and other ignitable such as diesel, gasoline, JP-5 jet fuel, and paint thinner were used during fire training exericse. An estimated 63,000 gallons of flammable hydrocarbons were in this area and light, nonaqueous-phase liquid (LNAPL) was identified during the RCRA Facility Investigation. The Navy selected bioslurping to remove LNAPL from the subsurface. During a pilot-scale test, it was determined that the wastewater generated from the system contained high levels of emulsified hydrocarbons as well as high concentrations of copper, lead, and zinc; high levels also were expected in the full-scale bioslurping system. To identify a cost-effective treatment technology for the full-scale bioslurping system wastewater, the Navy selected two technologies, CRF/DAF and Oleofiltration™, for demonstration. The concentrations in the bioslurper wastewater during the demonstration were TPH as high as 27,000 ppm, and copper, lead, and zinc as high as 228 ppm, 1,430 ppm, and 6,210 ppm, respectively.

The CRF system included a two-stage chemical reaction tank, a polymer mix preparation tank, pumps, and mixers. The skid-mounted DAF system included a flotation chamber, including a skimmer, sump, and air dissolving tank. The 10 gpm capacity Oleofiltration™ treatment system included a conventional oil/water separator, coalescing unit, and ceramic granule filtration system. For the CRF/DAF system, the influent water flow rate was 1.5 to 6.5 gpm. The retention time for the two-stage CRF unit was 37 to 160 minutes for Stage 1 and 22 to 94 minutes for Stage 2. The retention time for the DAF unit was 13 to 55 minutes. For the Oleofiltration™ treatment system, the influent flow rate ranged from 5 to 7.5 gpm with a retention time of 25 to 37 minutes.

Section 1.0: SITE INFORMATION

The Coastal Systems Station (CSS) Panama City is located along the St. Andrew Bay in Panama City, Florida. The site, Area of Concern (AOC) 1, currently is being managed under the Resource Conservation and Recovery Act (RCRA). The site is bound by parking to the west and south, by shipping and receiving facilities to the east, and by woodland and Solid Waste Management Unit (SWMU) 9 to the north. AOC 1 is a former fire-fighting training area that was operational from about 1955 to 1978. Primarily waste oil was used during fire-fighting training exercises; however, other materials that were reportedly ignited include diesel, gasoline, JP-5 jet fuel, and paint thinner. It is estimated that approximately 63,000 gallons of flammable hydrocarbons were released and ignited throughout the 23-year operation of this facility (ABB, 1995). AOC 1 was graded, paved, and used as an open storage area once it ceased to be used as a fire-fighting training area in 1978.

An initial assessment study (IAS) was performed by C. C. Johnson and Associates in 1985 to collect background information on chemicals used at the CSS and at specific sites where chemicals and wastes were known to have been used, stored, or disposed of. The IAS indicated the possibility of contamination at AOC 1. A confirmation study performed by Environmental Science and Engineering was begun in 1987 to confirm the results of the IAS. The results of the study recommended future, more detailed investigations at AOC 1 (ABB, 1996). In 1991, ABB Environmental Services initiated a RCRA Facility Investigation (RFI). The purpose of the RFI was to evaluate and characterize releases at the CSS. The presence of a light, nonaqueous-phase liquid (LNAPL) was identified at AOC 1. As a result of the findings of the RCRA investigation, ABB Environmental Services performed additional investigative work to determine the extent of the LNAPL contamination at AOC 1 and recommend an appropriate treatment technology. In 1994, 15 piezometers were installed to determine the extent of the LNAPL plume. The maximum apparent LNAPL thickness of 1.5 ft was measured immediately southeast of the center of the fire-fighting training area (ABB, 1996). The approximate extent of the plume as delineated by ABB in 1994 is shown in Figure 1.

ABB recommended a product recovery system consisting of two LNAPL collection trenches with a number of sumps containing product recovery pumps as an interim corrective measure at AOC 1. Because these types of recovery systems can operate for years without achieving cleanup goals, the Navy investigated other cost-effective treatment technologies. The Navy elected to implement bioslurping - an innovative treatment technology to remove LNAPL from the subsurface. Previous investigations (Battelle, 1997) have indicated that bioslurping recovers LNAPL about 10 times faster than conventional technologies such as skimming or dual-pump drawdown.

Battelle Memorial Institute performed a pilot-scale bioslurper test at AOC 1 during October 1996. Results indicated that bioslurping would be an appropriate remediation technology for implementation at AOC 1. However, the wastewater produced during the pilot test contained high levels of emulsified hydrocarbons and high concentrations of copper, lead, and zinc. Total petroleum hydrocarbon (TPH) concentrations in the wastewater ranged from 1,500 to 6,200 ppm. In addition, levels of copper, lead, and zinc as high as 69, 190, and 1,900 ppb, respectively, were observed. It was expected that water extracted during the full-scale bioslurper operation would exhibit similar characteristics. In an effort to select a cost-effective water treatment technology to treat the water generated by the full-scale bioslurper system, two technologies, coagulation/flocculation combined with dissolved air flotation and Oleofiltration™, were selected and demonstrated during startup of the full-scale bioslurper system. Information regarding the site and the evaluation of these technologies is presented in Table 1.

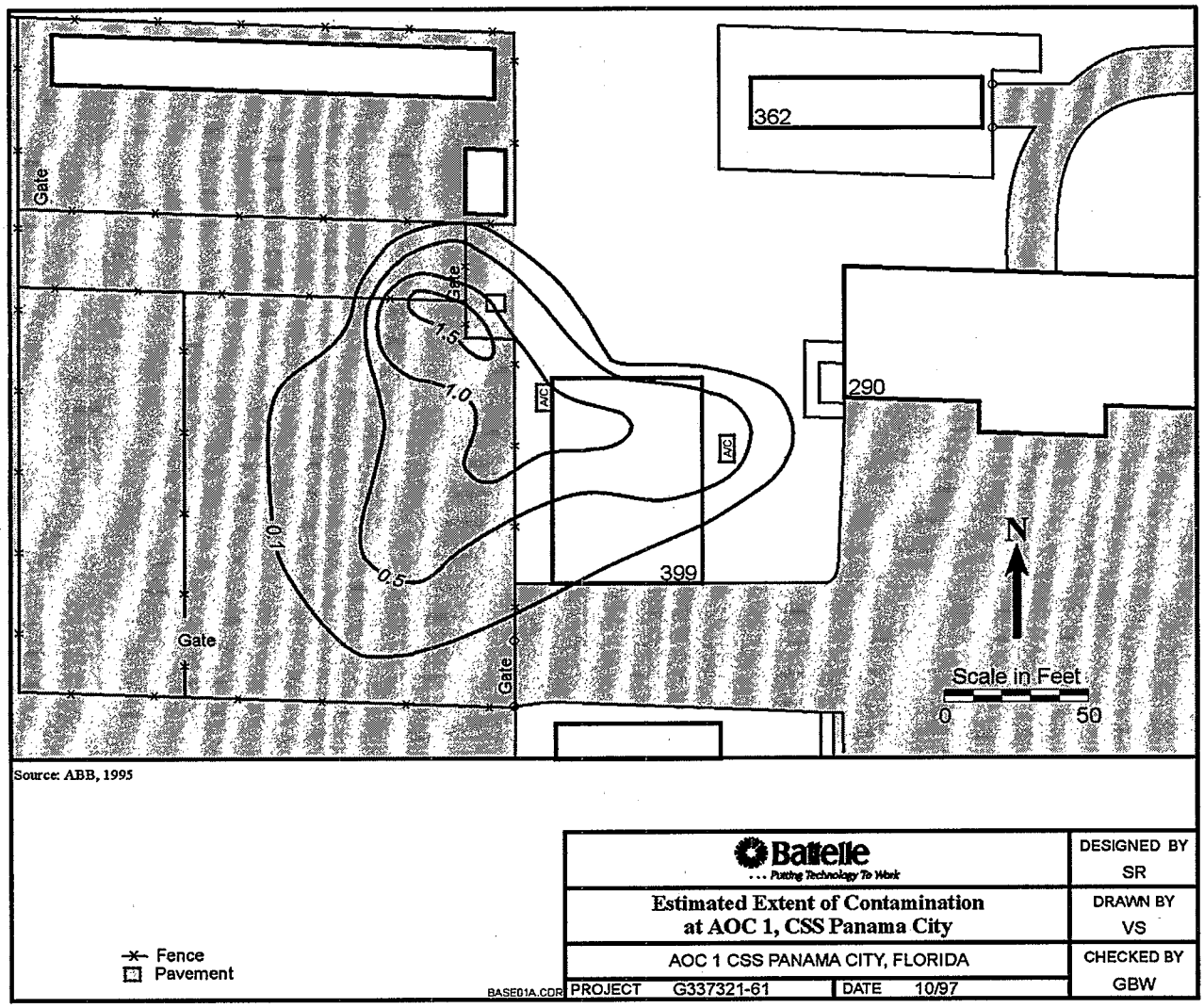


Figure 1. Extent of LNAPL Plume at Area of Concern 1

Table 1. Site and Technology Information

Site:	Area of Concern 1 at the Coastal Systems Station, Panama City, Florida
Activity that Generated Contamination:	Fire-fighting training
Standard Industrial Classification Code:	2869; Industrial organic chemicals not elsewhere classified
Site Characteristics ***Media treated:*** ***Contaminants Treated:***	 Wastewater generated by a full-scale bioslurper process Emulsified oil/grease and heavy metals including copper, lead, and zinc
Treatment Systems (Water):	• Coagulation/flocculation combined with dissolved air flotation; manufactured by Great Lakes Environmental Inc., 315 S. Stewart Avenue, Addison, Illinois 60101 • Oleofiltration™; manufactured by North American Technologies Group Inc, Suite 301, 4710 Bellaire Blvd, Bellaire, Texas 77401
Cleanup Type:	Implementation and evaluation of water treatment technologies to treat wastewater generated by a full-scale bioslurper process
Period of Evaluation:	448 hours of operation beginning August 1997
Total Volume of Water Treated During Demo:	126,400 gallons

Section 2.0: MATRIX DESCRIPTION

The matrix characteristics that affect the cost and/or performance of the water treatment system are presented in Table 2. The process water from the bioslurper system contained a high concentration of emulsified oil/grease. A concentration as high as 27,000 ppm was measured. During the demonstration, the water was milky yellow in appearance and had a strong hydrocarbon odor. Metal contaminants that were identified for removal during the demonstration include copper, lead, and zinc. Concentrations of copper, lead, and zinc as high as 228, 1,430, and 6,210 ppm, respectively, were measured in the bioslurper process water.

Table 2. Matrix Characteristics Affecting Treatment Cost and/or Performance

Parameter	Value(s)	Method of Measurement
TPH in Water (ppm)	5,000 to 27,000	EPA Mod. 8015
Copper in Water (ppm)	ND to 228	EPA 200.7/SW6010
Lead in Water (ppm)	62 to 1,430	EPA 239.2/SW7421
Zinc in Water (ppm)	697 to 6,210	EPA 200.7/SW6010
Total Suspended Solids (mg/L)	211 to 570	EPA 160.2
Influent Process Water pH	4.81 to 5.91	EPA 150.1

ND - below detection limit

Section 3.0: TREATMENT SYSTEM DESCRIPTION AND OPERATION

Two types of treatment systems were evaluated for treating the wastewater produced by the full-scale bioslurper process. One system consisted of a chemical reaction and flocculation (CRF) tank and a dissolved air flotation (DAF) system, manufactured by Great Lakes Environmental, Addison, Illinois. Bench-scale tests performed on water samples collected during bioslurper pilot testing indicated that the CRF/DAF could achieve a 99% reduction of TPH in the process water. The other water treatment technology that was tested was an Oleofiltration™ system. The Oleofiltration™ system is a hydrocarbon recovery technology utilizing amine-coated oleophilic granules to separate suspended and emulsified hydrocarbons from water, manufactured by North American Technologies, Inc., Belaire, Texas. Literature (EPA, 1995) has indicated that a 97% reduction in TPH is achievable using this technology.

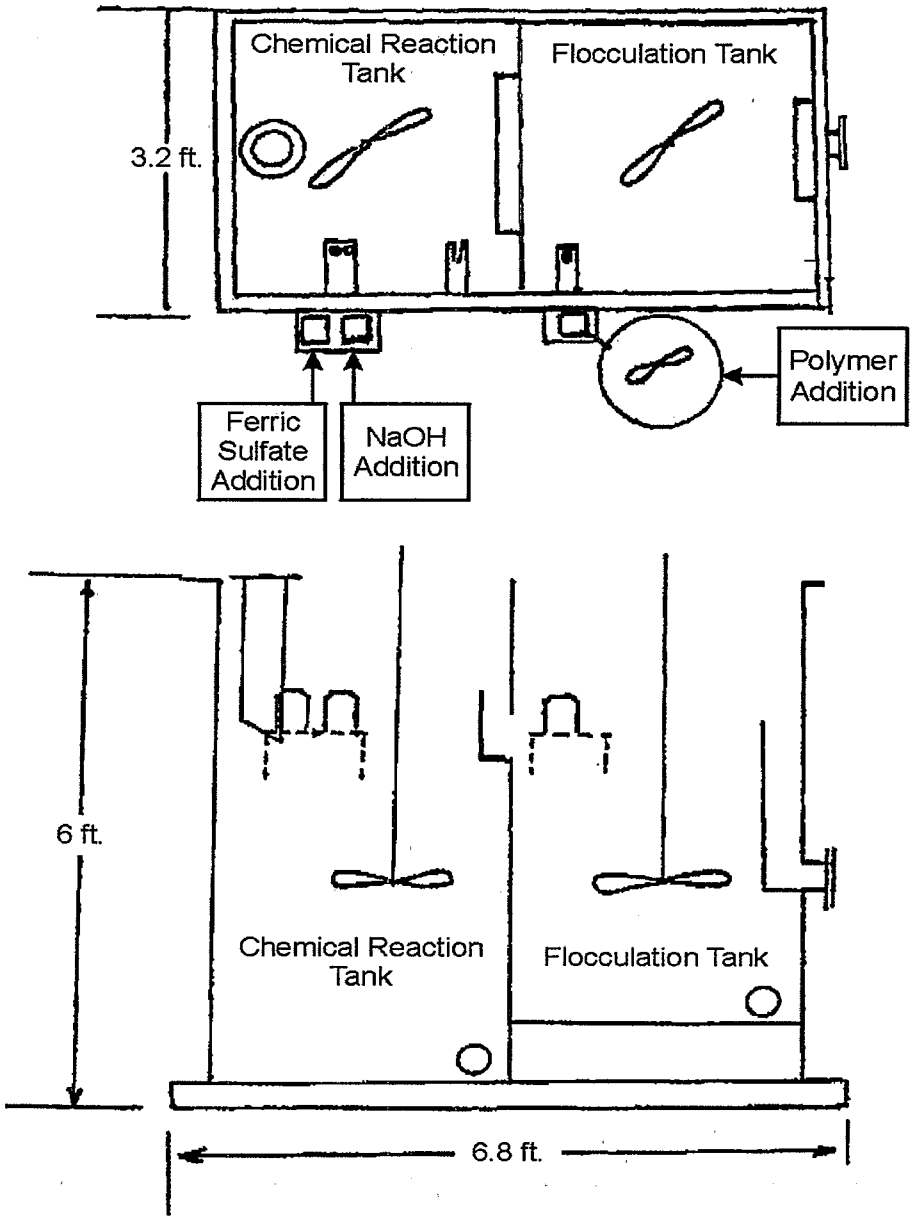
The objective of the demonstration was to evaluate the ability of the two water treatment systems to remove emulsified oil/grease from the bioslurper wastewater stream. A secondary objective was to determine if the CRF/DAF system could effectively remove metals, including copper, lead, and zinc, by increasing the pH of the process water.

3.1 Treatment System Description.

3.1.1 CRF/DAF Treatment System. The CRF system (Model CRF-15) consists of a two-stage chemical reaction tank, a polymer preparation mix tank, chemical metering pumps, constant and variable speed mixers, and associated instruments and controllers. A schematic illustration of the CRF system is shown in Figure 2. The aqueous effluent from the bioslurper process enters the two-stage mix tank. Coagulation is performed in the first stage by dosing and mixing a 50% ferric sulfate solution and a 50% sodium hydroxide solution into the process water. For optimum hydrocarbon removal the manufacturer recommends that the pH of the process water be maintained around 6. The water then enters the second stage where a flocculating polymer is mixed into the process water. Following the chemical addition, the stream gravity flows into the DAF system.

The DAF system (Model DAF-5) is shown in Figure 3. The unit is skid mounted. It contains a flotation chamber that includes a float skimmer and a float storage sump, an air dissolving tank, and appropriate controls and meters. An air compressor is required for operation. Microscopic bubbles are pumped into the water. The bubbles attach themselves to the flocs created in the CRF, giving them positive buoyancy that causes them to rise to the surface of the water. The skimmer skims the solids into a temporary storage compartment mounted inside the unit. If necessary, an auger can be installed to periodically pump out heavy solids that have settled at the bottom of the DAF unit. The resulting solids slurry is passed into a tank where it is allowed to settle. The separated liquid is recycled through the system. The sludge is transported off site by a waste disposal company and is recycled and blended for heat recovery.

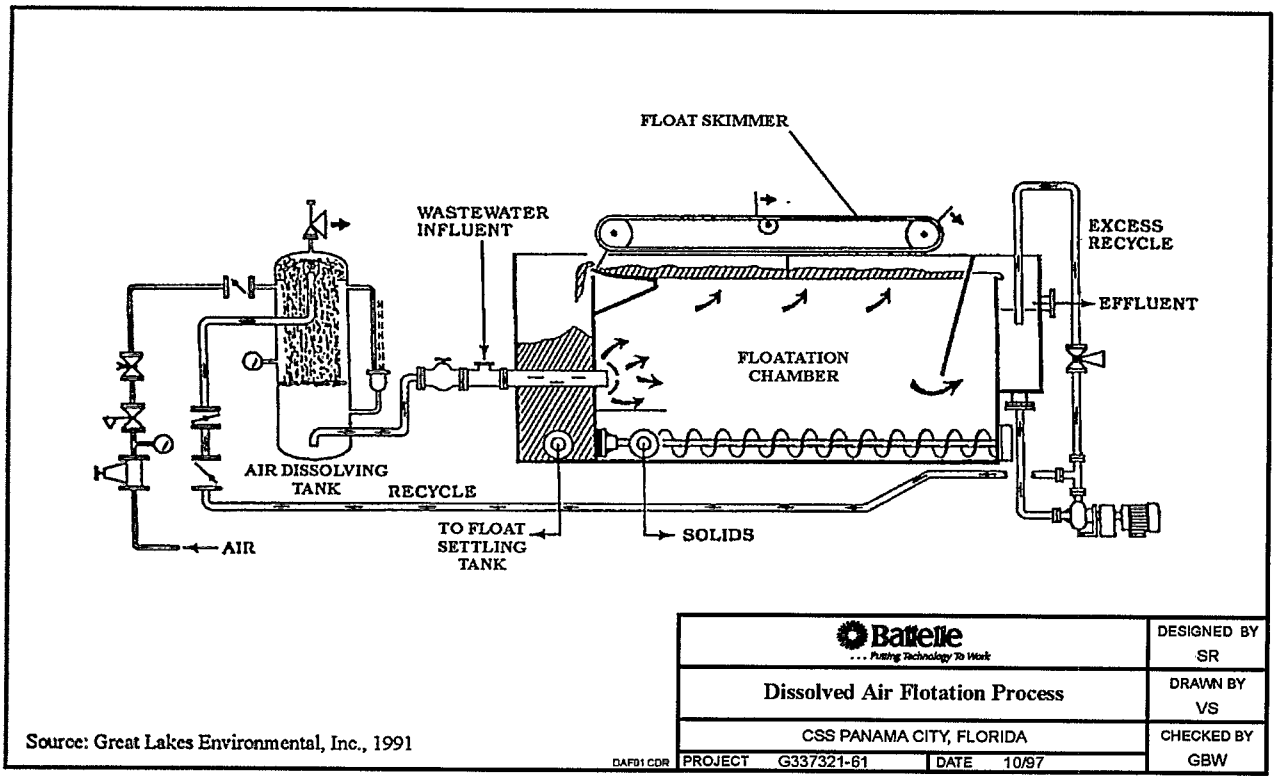
3.1.2 Oleofilter™ Treatment System. The Oleofilter™ combines a conventional oil/water separator, a coalescing unit, and a ceramic granule filtration system. Figure 4 illustrates the concept. Any free-phase oil present in the wastewater is removed by the oil/water separator. Water containing emulsified oil then flows downward inside the unit's outer shell and upward past a series of coalescing plates. Any remaining emulsified oil is removed as the water flows upward through the center of the unit through a bed of oleophilic amine-coated ceramic granules. Over time, the Oleofilter™ bed will become saturated with hydrocarbons. When saturation occurs, the filtering bed automatically regenerates itself by backflushing. The wastewater and oil produced during the backflushing process is recycled through the system. Hence, no waste products (other than reclaimed oil) are generated.



Source: Great Lakes Environmental, Inc., 1992

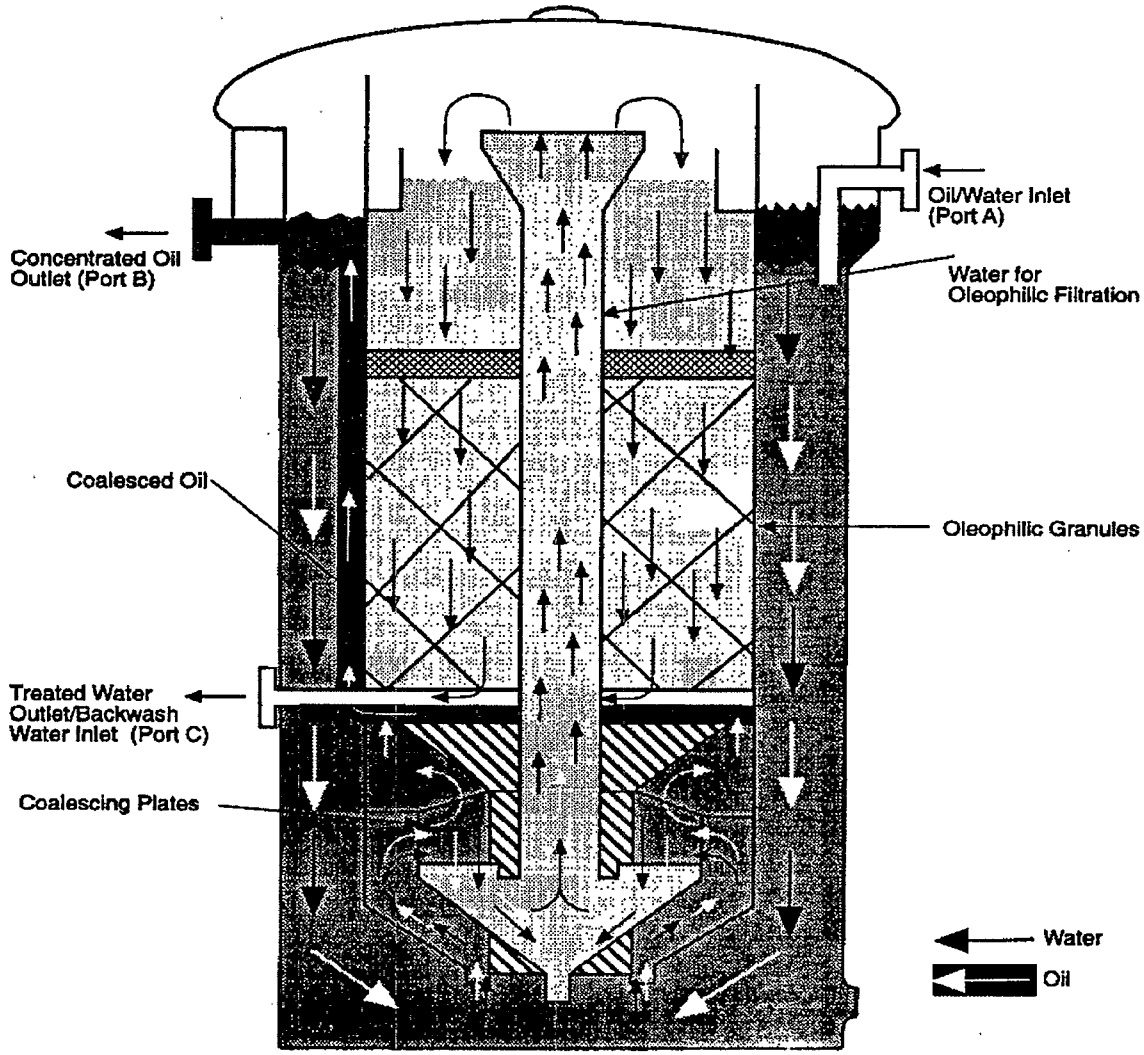
Battelle ... Putting Technology To Work		DESIGNED BY SR
Coagulation/Flocculation Equipment		DRAWN BY VS
CSS PANAMA CITY, FLORIDA		CHECKED BY GBW
COAG01.CDR PROJECT G337321-61	DATE 10/97	

Figure 2. Chemical Reaction and Flocculation System



Source: Great Lakes Environmental, Inc., 1991

Figure 3. Dissolved Air Flocculation System



Note: The backwash water outlet (Port D) is not shown in this view.

Source: Adapted from SFC 0.5x Operating Manual, 1992

Battelle ... Putting Technology To Work		DESIGNED BY SR
SFC 0.5 System Configuration		DRAWN BY VS
CSS PANAMA CITY, FLORIDA		CHECKED BY GBW
SFC01.CDR PROJECT G337321-61	DATE 10/97	

Figure 4. Oleofilter™ Treatment System

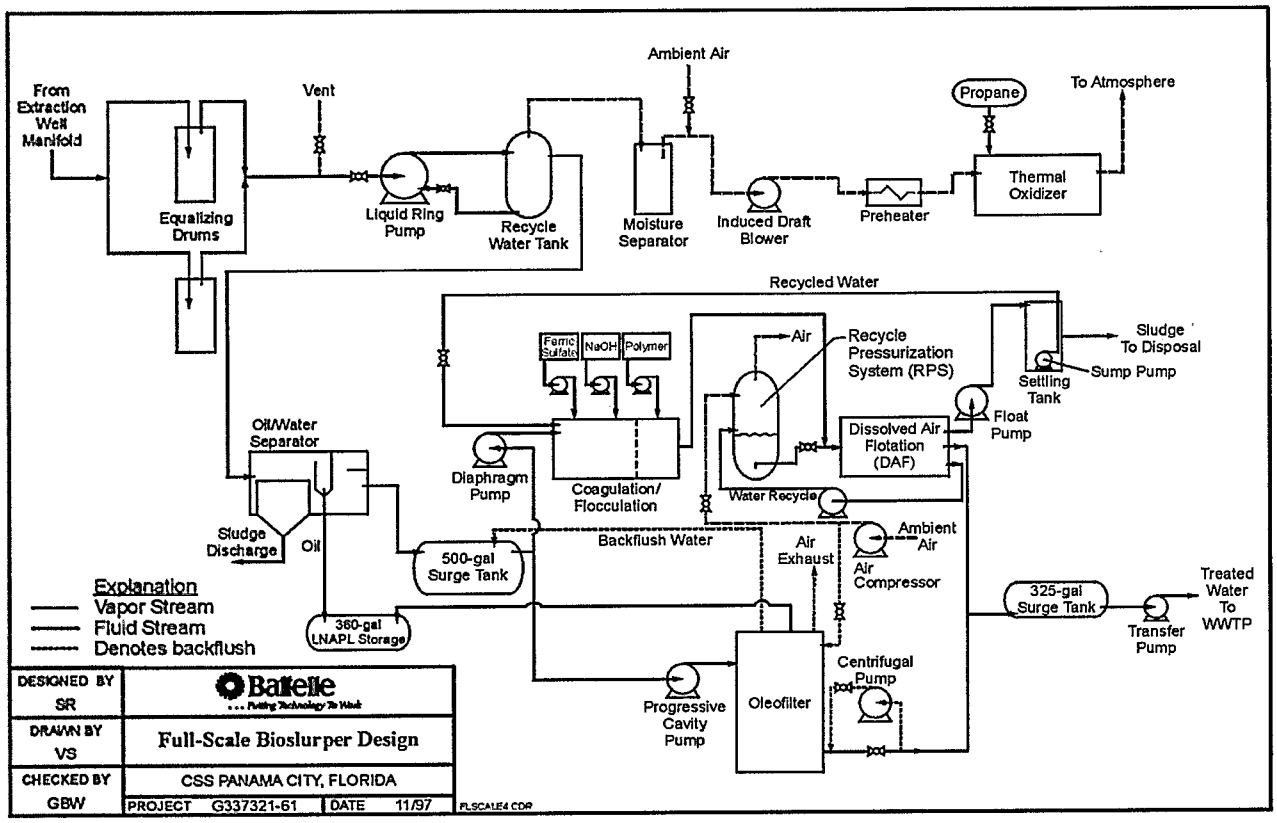


Figure 5. Full-Scale Bioslurper Process with Oleofilter™ and CRF/DAF in Series

3.2 Operation. The CRF/DAF and Oleofiltration™ treatment systems were operated in parallel. The process flow is illustrated in Figure 5. Both treatment systems require a compressed air supply for
proper operation. A weatherproof Ingersoll-Rand reciprocating air compressor (Model 2545E10P) was used to supply air to both processes. A pneumatic double-diaphragm pump was used to pump the wastewater from the bioslurper process to the 2-stage CRF tank. Electronic metering pumps were used to meter ferric sulfate and sodium hydroxide into the first stage of the tank and polymer into the second stage of the tank. The sodium hydroxide dosage was controlled using a GLI conventional pH combination electrode with a Model 672 pH controller with a set point range set between 8.7 and 9.2. This high pH range was selected to induce precipitation of metals in the first stage of the CRF. The rate of ferric sulfate and polymer addition was based on results of a bench-scale test performed on process water samples that had been collected during the pilot-scale bioslurper test. Results indicated that a dosage of 250 ppm ferric sulfate and 2 ppm polymer significantly reduced the concentration of emulsified oil/water in the process water. The chemically treated water gravity fed from the second stage of the CRF into the DAF through a schedule 80, 1.5-inch-diameter polyvinyl chloride (PVC) transfer pipe. This pipe was later replaced with a 2-inch-diameter clear polyethylene hose; fouling of the 1.5-inch-diameter pipe with flocculated material caused the CRF to overflow with water when the process flowrate was greater than 6 gpm.

The flocs were separated from the water by introducing microscopic air bubbles into the process stream inside the DAF. The air bubbles were introduced into a portion of treated water pumped from the DAF into the recycle repressurization tank using a 1.5-hp Grundfos™ centrifugal pump (Model CR2-50). A ¾-inch globe valve controlled the flowrate of aerated water bled into the influent process stream. An adjustable speed drag belt skimmer was used to skim the separated flocs floating on the surface of the treated water into the sludge reservoir located in the leftmost compartment of the DAF system. The sludge was pumped into a 2,550-gallon tank using a ½-inch-diameter ARO pneumatic double-diaphragm pump. The treated water gravity fed into the rightmost compartment of the DAF system. A 1-inch-diameter ARO pneumatic pump also was used to pump the water into a 325-gallon surge tank prior to discharging it into a sanitary sewer. The sludge that accumulated inside the 2,550-gallon tank was periodically dewatered. A ½-hp sump pump was used to pump water from the bottom of the sludge tank into the 500-gal surge tank that provided the process water to the water treatment processes. The operating parameters that affect the cost and/or performance for this technology are presented in Table 3. The range of values that were measured during the demonstration are shown in the second column.

A 10-gpm Oleofilter™ was tested. The Oleofilter™ was equipped with a 1-hp progressive cavity pump that pumped the process water from the 500-gallon surge tank into the top of the Oleofilter™. A 1-hp centrifugal pump was used to pump the treated water out of the Oleofilter™ into the 500-gallon surge tank. The influent and effluent pump flowrates were balanced using a bypass valve (1-inch-diameter globe valve) located on the inlet side of the progressive cavity pump. It was originally intended that the water treated by the Oleofilter™ be pumped into the 325-gallon treated water surge tank (Figure 5); however, visual observations indicated that a high concentration of oil/grease remained in the water after treatment by the Oleofilter™. Therefore, the water was recycled back into the 500-gallon surge tank. The LNAPL that was separated from the wastewater was gravity fed into the 360-gallon LNAPL storage tank. The operating parameters that affect the cost and/or performance for this technology are presented in
Table 3

Table 3. Water Treatment System Operating Parameters

Parameter	Value(s)	Method of Measurement
	CRF/DAF	
Influent Water Flowrate (gpm)	1.5 to 6.5	Rotameter
Retention Time (min) • CRF, Stage 1 • CRF, Stage 2 • DAF	 37 to 160 22 to 94 13 to 55	Calculation based on flowrate and process equipment dimensions
Ferric Sulfate Dosage, 50% Concentration (ml/min)	1.2 to 23	Graduated cylinder
Polymer Dosage (ml/min) pH of Treated Process Water	20 to 47 8.25 to 9.26	Graduated cylinder Calibrated pH meter; laboratory method EPA 150.1
Average Volume of Sludge Produced, Dewatered (gal/day)	20	Graduations on tank
Recycle Water Flowrate (gpm)	10 to 18	Magnetrol™ flow indicator
Recycle Pressurization Tank Pressure (psig)	40 to 65	Pressure gauge
	Oleofilter™	
Influent Water Flowrate (gpm)	5 to 7.5	Rotameter
Retention Time (min)	25 to 37	Calculation
Differential Pressure Across Oleofilter (psig)	1.5 to 4.5	Differential pressure gauge

The Oleofilter™ was equipped with an automatic backflush system to clean the packing media after it became saturated with hydrocarbons. It was set to activate when the pressure differential across the packing media exceeded 5 psig. The backflush process consisted of washing the packing by pumping treated water and compressed air through it. The wastewater produced during backflushing was pumped back into the 500-gallon surge tank and the small volume of air generated was vented to the atmosphere. The pressure differential remained below 5 psig during the demonstration; therefore, the backflush process never actuated automatically. However, a manual backflush was performed several times during the demonstration in an effort to troubleshoot and improve the efficiency of the unit.

3.3 Sampling and Analysis. Water samples were collected on a weekly basis; samples were collected from the bioslurper oil/water separator effluent, the DAF effluent, and the Oleofilter™ effluent. The Oleofilter™ was shut off for about 3 hours prior to collecting the DAF effluent sample so that the partially treated stream from the Oleofilter™ would not dilute the influent stream to the CRF/DAF, thereby biasing treatment results. Samples were analyzed for TPH as diesel (EPA Modified 8015), copper and zinc (EPA 200.7/SW6010), and lead (EPA 239.2/SW7421).

Section 4.0: TREATMENT SYSTEM PERFORMANCE

4.1 Cleanup Goals. The full-scale bioslurper system is being operated in a manner to ensure that oil/grease and heavy metals in the treated water effluent from the CSS Waste Water Treatment Plant (WWTP) will not exceed current levels. Water samples from the effluent of the full-scale bioslurper system are collected monthly and are analyzed for TPH, copper, lead, and zinc. In the event that the flowrate of water to the WWTP approaches the maximum operating capacity of the WWTP, the vacuum-enhanced recovery system either will be adjusted to reduce the water flowrate to the WWTP or will be shut down until the flowrate to the WWTP returns to its normal operating range. Water samples are collected periodically from the effluent discharged from the WWTP to ensure that the treated water is in compliance with permitting requirements. This water treatment technology demonstration was performed to determine the percent removal of TPH, copper, lead, and zinc and the quality of the effluent water that is economically achievable using the CRF/DAF and Oleofilter™ water treatment technologies to treat the water generated by the full-scale bioslurper process.

4.2 Treatment Performance. Water samples were collected from the influent and effluent of each water treatment process and were analyzed for TPH, lead, copper, zinc, and total suspended solids (TSS). The analytical results were used to assess the performance of each treatment system. Treatment performance results are presented in Table 4. The TPH concentrations were measured as both diesel and motor oil; however, only the TPH as diesel is reported since in most instances the TPH concentration as motor oil was below the laboratory detection limit. The CRF/DAF system removed greater than 98% of the TPH compared to the 56 to 90% that was removed by the Oleofilter™. The high concentrations of TPH in the influent process water likely reduced the separation efficiency of the packing media inside the Oleofilter™. Previous investigations (US EPA, 1995) have indicated that the operating efficiency of the Oleofilter™ decreases when the influent concentration of TPH is greater than 500 ppm. The TPH analytical results are consistent with visual observations made regarding the operation of the treatment system. The influent water to the processes was a milky yellow color, indicating a high TPH concentration. The effluent from the CRF/DAF process was clear and had very little if any hydrocarbon odor associated with it. However, the effluent from the Oleofilter™ was milky, but not as yellow as the influent water. It had a strong hydrocarbon odor associated with it.

The ability of the CRF/DAF system to remove heavy metals, including copper, lead, and zinc, was evaluated. The first two sets of samples collected from the CRF/DAF were analyzed for 13 metals including antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. Of these metals, copper, lead, and zinc are the primary contaminants of concern since concentrations of these metals in the treated water from the CSS WWTP approach maximum allowable discharge concentrations. Analytical results for the remaining metals were below laboratory detection limits for both influent and effluent water to the water treatment processes. The performance results for removal of copper, lead, and zinc are presented in Table 4. In some instances the concentrations of metals in the influent and/or effluent streams were below laboratory detection limits. Matrix interferences encountered during the laboratory analyses prevented some of the samples from being reported at lower detection limits. Therefore, in some cases, it was impossible to accurately assess the percent removal of a particular metal. The detection limit was used to calculate the percent removal and the results are expressed with a greater-than sign.

Table 4. Water Treatment System Performance Results

Constituent	Average Untreated Concentration (ppm)	Average Treated Concentration (ppm)	Range of Percent Removal (%)	Average Percent Removal (%)
		CRF/DAF		
TPH as Diesel	10,950	43.8	98.2 to 99.9	99.5
Lead	442	<56.3	>67.7 to 98.9	>88.0
Copper	<101	<55	>90.2	>90.2
Zinc	2,450	<136	>81.3 to 97.9	>91.3
TSS	308	<12.2	92.1 to >98.2	>95.2
		Oleofilter™		
TPH	10,950	4,687	55.6 to 90.3	72.6
Lead	442	55	12.5 to 75.3	50.8
Copper	<101	<100	NA	NA
Zinc	2,450	4,204	-827 to 73.3	0.322
TSS	308	237	-12.8 to 58.6	17.2

NA – Not applicable. Copper concentrations were below the detection limit both before and after treatment, therefore percent removal could not be calculated.

The effluent from the Oleofilter™ also was analyzed for copper, lead, and zinc. Although the Oleofilter™ was not expected to remove these metals from the process stream, samples were collected and analyzed for comparison with the CRF/DAF results. The results are presented in Table 4. The percent removal varies significantly from one sample to the next. The low pH (4.8 to 5.9) of the water may have been causing the metal cations to be absorbed by the unit and/or packing material. Eventually, these cations would have desorbed back into the process stream. This would account for the significant fluctuations observed in the data.

Water samples also were analyzed for TSS. The reduction of TSS after treatment by the CRF/DAF indicates a good separation of the coagulated/flocced material from the process water. If good separation and removal were not occurring, the concentration of TSS could potentially be much greater in the effluent than in the influent water samples.

4.3 Performance Data Assessment. This demonstration has indicated that the CRF/DAF system is effective at removing significant quantities of emulsified oils and metals from the process water. Good removal efficiency of metals was achievable by adding sodium hydroxide to increase the pH to about 9 in the CRF tank and removing the resulting precipitate as part of the oil saturated sludge that accumulates inside the DAF. The sludge was automatically pumped into a settling tank. It was periodically dewatered by turning on a sump pump located at the bottom of the tank. The resulting water was pumped back into the 500-gallon process water surge tank. An average of 20 gallons of dewatered sludge were accumulated each day of operation. A Toxicity Characteristic Leaching Procedure (TCLP) analysis was performed on the sludge to determine if it was hazardous. The results, presented in Appendix A, indicate that the sludge can be disposed of as a nonhazardous waste. In addition, the high oil/grease content in the sludge allows the sludge to be recycled and blended for heat recovery.

The Oleofilter™ did not perform as well as the CRF/DAF treatment system. The percent removal of hydrocarbons ranged between 56 and 90%. It is believed that removal would be greater when the concentration of emulsified hydrocarbons in the influent water to the unit is less. The Oleofilter™

is not designed to remove metals from the treatment stream. If this technology was used for the remainder of the full-scale remediation, a clarifier would need to be installed downstream of the Oleofilter ™ to remove metals to levels observed when using the CRF/DAF.

Operation and maintenance requirements for the CRF/DAF are significantly greater than for the Oleofilter™. The CRF/DAF system is equipped with 3 metering pumps, two mixers, a belt skimmer, a centrifugal pump, and two pneumatically operated diaphragm pumps. Each piece of equipment must be maintained and be functioning properly to meet the desired treatment goals. Ferric sulfate, sodium hydroxide, and polymer are automatically metered into the CRF tank. The operator must calculate and set the flowrates of the ferric sulfate and polymer metering pumps in order to treat the process water to the required treatment levels. The dosage of sodium hydroxide is controlled by a pH controller that uses a general-purpose electrode to measure pH. The pH controller held its calibration during the 4-week demonstration. It is recommended that the probe be rinsed once a week and that the controller be calibrated bimonthly. The ferric sulfate and sodium hydroxide solutions are supplied in 55-gallon drums. The operator must replace the drums periodically. One drum of ferric sulfate lasts approximately 1 month and a drum of sodium hydroxide lasts about 2 months. The polymer is shipped in a concentrated form. A 5-gallon bucket should last about 4 months, assuming water flowrates and contaminant loadings and polymer dosage rate remain consistent with what was observed during the demonstration. A solution of polymer must be made up every 72 hours. Approximately 1.3 cups of polymer is added to about 50 gallons of water.

During the 4-week demonstration, a number of operational difficulties with CRF/DAF were encountered. These problems, and the solutions to them, are presented in Table 5. The majority of the problems encountered were a result of integrating the CRF/DAF into the bioslurper process. In addition, the CRF and DAF units used were prototypes developed by Great Lakes Environmental, Inc. for use in relatively low flowrate applications.

Table 5. Problems and Resulting Solutions Encountered with the CRF/DAF System

Problem	Solution
Water does not flow fast enough from the CRF into the DAF at high process water flowrates, resulting in fouling of the CRF by sludge that accumulates in the unit	First raised CRF by 8 inches. Flowrate still not fast enough; therefore, replaced 1.5-inch PVC line with a 2-inch polypropylene hose.
Water effluent and sludge diaphragm pumps operate continuously.	Install timer to periodically turn on sludge pump. Install level switch inside DAF to turn on water effluent pump. An auxiliary control panel had to be installed to operate.
Vapor lock occurs in centrifugal recycle pump after extended periods of shut down	Uncouple effluent line from pump; allow air to bleed out.
Potential spill hazard from CRF and DAF if effluent pump shuts off.	Install high level switches in CRF and DAF to shut down diaphragm pump that supplies flow to the water treatment equipment.
Potential splashing of process water from high winds and rain; potential damage to mixers from rain.	Manufactured fabricated covers and supplied rain shields to protect tanks and mixers

Minimal maintenance is required for the Oleofilter™. The unit consists of two pumps, a fixed-bed containing ceramic packing, and a number of pneumatically operated solenoid valves. The manufacturer has indicated that 8% of the packing will need to be replaced annually. During the demonstration, corrosion in the housing of the centrifugal pump resulted in a leak. The system had to be shut down until the housing could be repaired. No other mechanical difficulties were encountered during the 4-week demonstration period.

Section 5.0: TREATMENT SYSTEM COST

The costs for treating the process water using the two water treatment technologies are standardized according to the format for the interagency work breakdown structure (WBS) (Member Agencies of the Federal Remediation Technologies Roundtable, 1995b). The interagency WBS specifies 9 before-treatment cost elements, 12 treatment cost elements, and 5 after-treatment cost elements. The cost breakdown for the CRF/DAF and Oleofiltration™ treatment systems are presented in Table 6. Travel costs have not been included in this estimate. The before-treatment costs include costs associated with procuring and installing the equipment. These costs were not broken down according to treatment process. However, it can be assumed that about half of the preparatory costs were associated with the procurement and mobilization of each water treatment process.

The treatment costs for each water treatment technology have been calculated. Treatment costs have been grouped into four categories consisting of setup, startup and evaluation, training, and operation. The costs for setup, startup and evaluation, and training were estimated based on actual costs associated with the project. The short-term operating costs (6 months of operation) were estimated based on data collected during demonstration of the equipment. These costs assume that the treatment equipment will be leased. The lease rate for the DAF is $4,500 per month and the monthly lease price for the Oleofilter™ is $2,500. If desired, the CRF/DAF system may be purchased for about $51,000 and the Oleofilter can be purchased for about $12,000.

Operating costs of the CRF/DAF are twice as great as those of the Oleofilter™. This is primarily a result of the greater rental cost associated with the CRF/DAF system. In addition, there is about twice as much labor associated with maintaining the CRF/DAF system than there is with maintaining the Oleofilter™. The additional labor results from having to supply and monitor the treatment chemical dosage rates. Another cost associated with operating the CRF/DAF system is the disposal cost for the sludge that the process generates (currently about $170/month).

The after-treatment costs include dismantling, demobilization, and reporting costs. The dismantling and demobilization costs presented in Table 6 are associated with the Oleofilter™. These estimates are based on actual labor hours and costs that were incurred while removing the Oleofilter™ from the system at the end of the demonstration. These costs do not include costs to remove subsurface plumbing that was installed from the bioslurper process to the Oleofilter™, since the plumbing was left in place at the site for possible future use during the remainder of full-scale bioslurper operation.

Table 6. CRF/DAF and Oleofiltration™ Cost Elements

Cost Element	Cost ($)
Before Treatment Costs	
Mobilization and Preparatory Work	$9,120
CRF/DAF Treatment Costs	
Setup • Rental of DAF • Installation materials • Labor	$18,900
Startup and Evaluation • Labor • Analytical • Materials • Waste disposal	$7,160
Training	$688
Operation (short-term operating costs; assumes 6 months of operation) • Labor to perform routine O&M activities • Equipment (rental of CRF/DAF) and materials • Bulk chemicals • Waste disposal • Analytical	$45,400
Oleofiltration™ Treatment Costs	
Setup • Rental of Oleofilter™ • Installation materials • Labor	$6,260
Startup and Evaluation • Labor • Analytical • Materials • Waste disposal	$7,160
Training	$132
Operation (short-term operating costs; assumes 6 months of operation) • Labor to perform routine O&M activities • Equipment and materials • Bulk chemicals • Waste disposal • Analytical	$21,900
After-Treatment Costs	
Dismantling Oleofilter™	$392
Demobilizing Oleofilter™	$3,577
Reporting	$8,040

Section 6.0: OBSERVATIONS AND LESSONS LEARNED

Performance observations and lessons learned:

- The CRF/DAF removed a greater percentage of TPH from the process water than did the Oleofilter™.
- The CRF/DAF system is capable of removing >99.9% TPH as diesel from an influent stream containing greater than 5,000 ppm TPH as diesel.
- The CRF/DAF system can precipitate and remove a significant concentration of copper, lead, and zinc. Greater than 90% removal of these metals was observed.
- Greater than 90% removal of TPH by the Oleofilter™ cannot be achieved at high influent water concentrations.

Cost observations and lessons learned:

- It costs twice as much to operate the CRF/DAF system than to operate the Oleofiltration™ system. It is estimated that it will cost about $7,580/month to lease and operate the CRF/DAF and about $3,650/month to lease and operate the Oleofiltration™ system.
- Excluding lease rates, the monthly operating costs for the CRF/DAF and Oleofilter™ are estimated to be $3,080 and $1,150, respectively.

General:

- Although the CRF/DAF system is more expensive to operate than the Oleofilter™, it has a much greater percent removal of TPH at high influent concentrations (5,000 to 27,000) ppm than does the Oleofilter™. In addition, it efficiently removes metals, including copper, lead, and zinc, from the process water. Therefore, it is believed that the CRF/DAF is the more appropriate technology for treating the bioslurper process water produced at AOC 1.
- The pH electrode in the CRF stage 2 tank should be rinsed once a week. The pH controller should be calibrated bimonthly.
- The CRF should be installed about 8 inches higher than the DAF, and a 2-inch-diameter or greater hose should be used to plumb the CRF effluent port to the DAF influent port. This allows the water to pass between the units at a greater flowrate.

Section 7.0: REFERENCES

ABB Environmental Services, Inc. 1995. *Performance Criteria Package, Free-Product Removal, Area of Concern 1, Coastal Systems Station Panama City, Panama City, Florida.* Prepared for the Naval Facilities Engineering Command, North Charleston, SC.

ABB Environmental Services, Inc. 1996. *Resource Conservation and Recovery Act, Facilities Investigation, Coastal Systems Station Panama City, Panama City, Florida.* Prepared for the Naval Facilities Engineering Command, North Charleston, SC.

Battelle. 1997. *Interim Measures Workplan for Full-Scale Bioslurper Implementation at Area of Concern 1. Coastal Systems Station, Panama City, Florida.* Prepared for the Naval Facilities Engineering Service Center, Port Hueneme, California.

Member Agencies of the Federal Remediation Technology Roundtable. 1995a. *Remediation Case Studies: Bioremediation.*

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U.S. Environmental Protection Agency. 1995. *InPlant Systems, Inc. SFC 0.5 Oleofiltration System, Innovative Technology Report.*

Pump and Treat and Permeable Reactive Barrier to Treat Contaminated Groundwater at the Former Intersil, Inc. Site, Sunnyvale, California

Pump and Treat and Permeable Reactive Barrier to Treat Contaminated Groundwater at the Former Intersil, Inc. Site, Sunnyvale, California

Site Name:
Former Intersil, Inc. Site

Location:
Sunnyvale, California

Contaminants:
Chlorinated solvents
- Maximum concentrations detected in 1986 were TCE (13,000 ug/L), cis-1,2-DCE (19,000 ug/L), Vinyl chloride (1,800 ug/L), and Freon-113 (16,000 ug/L)

Period of Operation:
Status: PRB Ongoing
Report covers:
- P&T: 11/87 - 2/95
- PRB: 2/95 - 11/97

Cleanup Type:
Full-scale cleanup (interim results)

Vendor:
Construction and Operations:
Scott Warner
Geomatrix Consultants, Inc.
100 Pine St., 10th floor
San Francisco, CA 94111
(415) 434-9400
P&T: Reidel Environmental Services/Delta Cooling Towers
PRB: EnviroMetal

Technology:
Pump and Treat and Permeable Reactive Barrier
- Groundwater was extracted using three wells and one trench well at an average total pumping rate of 8 gpm
- Extracted groundwater was treated with air stripping and discharged to an on-site storm sewer under a NPDES permit
- The permeable reactive barrier (PRB, treatment wall) is 100% granular iron, 4 ft thick, 40 ft wide, and approximately 13 ft deep; 2 slurry walls are used to route groundwater through the PRB

Cleanup Authority:
State cleanup
- Site cleanup requirements order: 10/15/86

Additional Contacts:
Deborah Hankins, Ph.D.
Intersil, Inc.
114 Sansome St., 14th floor
San Francisco, CA 94104
(415) 274-1904

State Point of Contact:
Habte Kifle
CA RWQCB
2101 Webster Street, #500
Oakland, CA 94612
(510) 286-0467

Waste Source:
Leakage from sub-grade neutralization system

Purpose/Significance of Application:
Used P&T for eight years, and replaced this technology with PRB; PRB used for three years.

Type/Quantity of Media Treated:
Groundwater
- 38 million gallons treated as of November 1996 (36 million by pump-and-treat and 2 million by PRB)
- Extraction wells are located in 1 aquifer, to a depth of 18 ft (depth to groundwater not provided)
- Transmissivity reported as 370 ft^2/day (hydraulic conductivity not provided)

Regulatory Requirements/Cleanup Goals:
- The cleanup goal for the site is to reduce contaminant concentrations throughout the aquifer to levels below the maximum contaminant levels (MCLs) set by the state of California and primary drinking water standards.
- Remedial goals were identified for vinyl chloride (0.5 ug/L), cis-1,2-DCE (6 ug/L), TCE (5 ug/L), and Freon-113 (1,200 ug/L).
- Effluent from the treatment system was required to meet the remedial goals prior to discharge.
- A secondary goal was identified to create an inward gradient to contain the plume.
- The primary goal for the PRB is to reduce contaminant levels in groundwater passing through the wall to the cleanup goals for the site.
- The secondary goal for the PRB is to contain the contaminant plume upgradient of the wall.

Pump and Treat and Permeable Reactive Barrier to Treat Contaminated Groundwater at the Former Intersil, Inc. Site, Sunnyvale, California (continued)

Results:
- The contaminant plume has been reduced in size at this site, however, contamination remains elevated at three hot spots.
- Average total contaminant concentrations have decreased from 1,609 ug/L in 1986 to 31 ug/L in 1997.
- By 2/95, the P&T system had removed 56 kg of contaminants from the groundwater; from 2/95 to 8/96, the PRB had removed 7 kg of contaminants from the groundwater.
- The contaminant plume has been contained.

Cost:
- Estimated costs for the P&T system from 1987 to 1995 were approximately $1,343,800 ($325,000 in capital and $1,018,800 in O&M), which correspond to $38 per 1,000 gallons of groundwater extracted and $10,900 per pound of contaminant removed.
- Estimated costs for the PRB system through 11/96 were approximately $762,000 ($5955,000 in capital and $167,000 in O&M), which correspond to $38 per 1,000 gallons of groundwater extracted and $49,400 per pound of contaminant removed.

Description:
Intersil operated at the site as a semi-conductor manufacturer from the early 1970s until 1983. The site is currently owned by Sobrato Development Company, and was released to another tenant in 1995. In 1972, Intersil installed a concrete, epoxy-lined, in-ground acid neutralization system at the facility to neutralize wastewater before discharge to a sanitary sewer. In 1982, the California Regional Water Quality Control Board (RWQCB) requested sampling of shallow groundwater and soil near the neutralization holding tank, and Intersil identified chlorinated solvents in the shallow groundwater and soil. Under a state program, a site cleanup requirements order was issued in October 1986.

A pump and treat (P&T) system was operated at this site from 1987 until 1995. The system consisted of three extraction and one trench wells. The wells were installed to a depth of 18 ft and had a design yield of 6 gpm. Extracted groundwater was treated with an air stripper designed to handle a maximum of 40 gpm.In 1993, Intersil examined alternative groundwater remediation technologies based on achievement of two goals. Intersil wanted to minimize the cost of treatment while increasing treatment effectiveness, given that the mass removal by the P&T system had asymptotically declined, and to return the site to leasable/sellable conditions. The selected alternative, approved by the RWQCB, was a PRB. The treatment technologies used at this site have removed contaminant mass and reduced concentrations in the aquifer; however, site cleanup goals have not yet been met.

SITE INFORMATION

Identifying Information:

Former Intersil, Inc. Site
Sunnyvale, California

CERCLIS #: Not Applicable (NA)

ROD Date: NA, not a CERCLA Site
Site Cleanup Requirements Order:
October 15, 1986

Treatment Application:

Type of Action: State cleanup

Period of operation:
Pump and treat (P&T) system: 11/87 - 2/95
Permeable Reactive Barrier: 2/95 - Ongoing
(Data on performance collected through November 1997)
(Cost data and data on mass removal collected through November 1996)

Quantity of material treated during application: 38 million gallons of groundwater
(36 million gallons through a P&T system)
(2 million gallons through treatment wall as of November 1996)

Background

Historical Activity that Generated Contamination at the Site: Semiconductor manufacturing

Corresponding SIC Code: 3674
(Semiconductors and Related Devices)

Waste Management Practice That Contributed to Contamination: Leakage from subgrade neutralization system

Location: Sunnyvale, California

Facility Operations: [2,3]

- Intersil operated at the site as a semi-conductor manufacturer from the early 1970s until 1983. In 1983, the facility shut down and was used to warehouse office equipment and surplus supplies. The site is currently owned by Sobrato Development Company. The site was released to another tenant in 1995.

- In 1972, Intersil installed a concrete, epoxy-lined, in-ground acid neutralization system at the facility to neutralize wastewater before discharge to a sanitary sewer.

- In 1982, the California Regional Water Quality Control Board (RWQCB) requested shallow groundwater and soil sampling near the neutralization holding tank. Investigations performed on behalf of Intersil identified halogenated volatile organic compounds (VOCs) as the main contaminant in the shallow groundwater beneath the site. In 1985, at the request of the RWQCB, further investigations were performed at the site. Intersil found halogenated VOC contamination in the soil beneath the site. Further soil and groundwater investigations performed in 1986 indicated a potential contaminant source was in the area of the neutralization holding tank. An unknown amount of contaminants was released to the soil and groundwater.

- In January 1987, Intersil inactivated the neutralization holding tank and removed it along with the associated contaminated soil. Further investigation of the soil and groundwater beneath the site was performed by Geomatrix on behalf of Intersil in 1987 and 1988, including the installation of an extraction well in the former tank area. Groundwater surveys were also performed by Western Microwave, Inc. (WM), at the property east of Intersil. These surveys identified VOC contamination at the WM facility. Groundwater extraction and treatment through an air stripper began at the Intersil site in November 1987 as an interim corrective action.

SITE INFORMATION (CONTINUED)

Background (Cont.)

- The extraction system was expanded in 1989 and again in 1991.
- An alternative remedy, a permeable reactive barrier (PRB), was installed and completed in February 1995 to replace the P&T system. PRBs are also referred to as *in situ* treatment walls for the purposes of this report.

Regulatory Context:

- Site activities are regulated by the RWQCB. Site activities during operation of the P&T system were conducted under provisions of two Waste Discharge Requirements (WDR) Orders for the site: Site Cleanup Requirements (SCR) Order dated October 15, 1986 for groundwater cleanup and a NPDES permit issued August 19, 1987. The initial NPDES Permit was replaced by General NPDES Permit No. 94-087 dated July 20, 1994.

Remedy Selection: Following seven years of a P&T application, a PRB, or *in situ* treatment wall, was selected as a final remedy for groundwater remediation because of its lower maintenance requirements, and because it allowed Intersil to transfer the lease [2].

Site Logistics/Contacts

Site Lead: PRP

Oversight: State

State Contact:
Habte Kifle*
RWQCB
2101 Webster Street, #500
Oakland, California 94612
510-286-0467

Scott Warner
Geomatrix
100 Pine St., 10th Fl.
San Francisco, CA 94111
415-434-9400

*Indicates primary contact

Treatment System Vendor:
Construction Prime: Geomatrix Consultants, Inc.
General Contractor: Inquip
Treatment Technology: EnviroMetal (Treatment Wall)
Treatment Technology (Pump and Treat)
Reidel Environmental Services/Delta Cooling Towers
Operations Contractor: Geomatrix Consultants, Inc.

PRP:
Deborah Hankins, Ph.D.
Intersil, Inc.
114 Sansome St., 14th Fl.
San Francisco, CA 94104
415-274-1904

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater

Contaminant Characterization [1, 2]

Primary Contaminant Groups: Halogenated volatile organic compounds (VOCs)

- The contaminants of concern at the site are trichlorethene (TCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), vinyl chloride (VC), and

MATRIX DESCRIPTION (CONTINUED)

Contaminant Characterization (Cont.)

Freon-113. The maximum concentrations initially detected at the site during the 1986 shallow groundwater survey were TCE at 13,000 µg/L, *cis*-1,2-DCE at 19,000 µg/L, VC at 1,800 µg/L, and Freon-113 at 16,000 µg/L. Contamination has only been detected in the upper aquifer (A-zone).

- The source of the contamination is the former in-ground neutralization system, located east of the on-site building. However, groundwater survey data from wells installed at adjacent facilities reveal that the adjacent property, WM, has released tetrachloroethene (PCE) and other chemicals to the soil and groundwater. Intersil is cross- and down-gradient of WM. Geomatrix, the PRP's contractor, found that the distribution of VOC contamination at the Intersil facility did not change significantly from 1986 to 1993. However, documents maintained at the RWQCB show that VOC concentrations increased at the WM facility from 1986 to 1993.

- Figure 1 depicts the concentration contours of TCE detected during the 1986 shallow groundwater survey by Geomatrix in the A-zone (upper aquifer) at the Intersil site. The plume hot spots are north and northwest of the suspected source.

- Based on the 1986 contour map shown in Figure 1, an average aquifer thickness of four feet, and a porosity of 0.30, the initial contaminant plume was estimated for this report to be approximately 2.4 acres in surface area with a volume of approximately 933,730 gallons. No additional information on the size of the initial plume was available in references.

Matrix Characteristics Affecting Treatment Costs or Performance

Hydrogeology: [1,2]

Two distinct hydrogeological units have been identified beneath this site.

Unit 1	A-zone	The A-zone unit is a semiconfined aquifer that ranges in thickness from eight feet to less than one foot, with a general thickness in the area of the site of two to four feet. It is composed of interfingering zones of silty fine-grained sand, fine- to medium-grained sand, and gravelly sand. The geometry of the aquifer is irregular, with a local presence of clay lenses. The A-zone unit is mostly confined by an upper silty-clay and clay layer ranging from nine to 12 feet thick in the area of the site and by a lower aquitard of clay and silty clay, which is approximately 65 feet thick in the vicinity of the site. The A-zone aquifer is generally not usable for consumption due to a high level of total dissolved solids. Groundwater flow is northerly.
Unit 2	B-zone	The B-zone has not been fully penetrated by soil borings, and no contamination has been detected in this zone. It is separated from the A-zone by the 65-foot thick aquitard of clay and silty clay. Based on characteristics of the aquitard, and an upward vertical hydraulic gradient contaminated groundwater from the A-zone is not expected to migrate to the B-zone.

Tables 1 and 2 present technical aquifer information and technical well data, respectively.

MATRIX DESCRIPTION (CONTINUED)

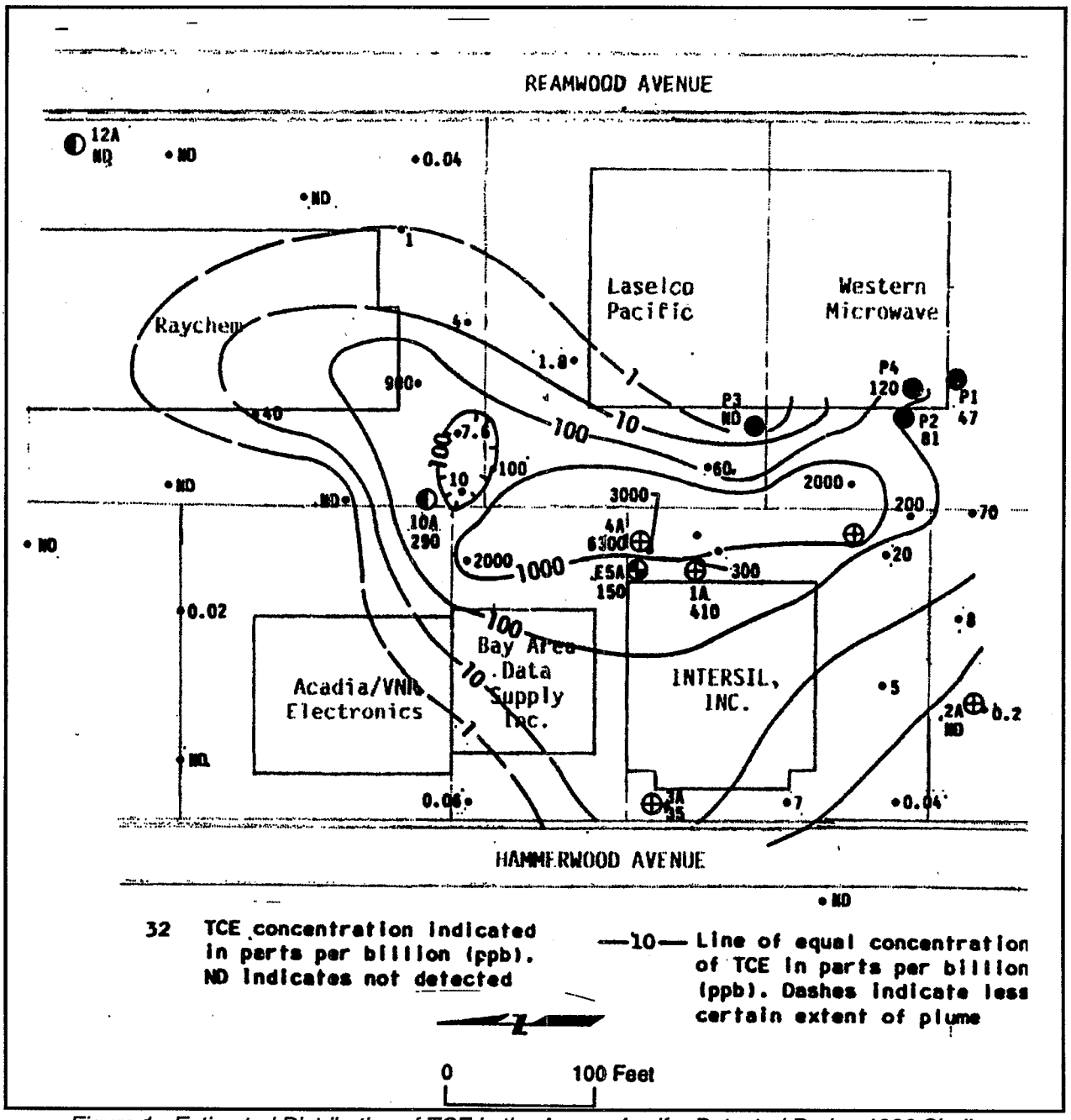

Figure 1. Estimated Distribution of TCE in the A-zone Aquifer Detected During 1986 Shallow Groundwater Survey (Best Copy Available) [1]. (The former neutralization system was located south of monitoring well 1A, along the eastern edge of the on-site building)

MATRIX DESCRIPTION (CONTINUED)

Matrix Characteristics Affecting Treatment Costs or Performance (Cont.)

Table 1. Technical Aquifer Information

Unit Name	Thickness (ft)	Transmissivity (ft^2/day)	Average Flow Rate (ft/day)	Flow Direction
A-zone	1-8 feet	370.0	0.8	Northwest to Northeast
B-zone	Not Characterized	Not Characterized	Not Characterized	Not Characterized

Source: [1]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Pump and treat with air stripping (1987 until 1995); Permeable Reactive Barrier (PRB) (1995 to present)

Supplemental Treatment Technology

Liquid-phase carbon adsorption (1987 until 1995, associated with the P&T system)

System Description and Operation [2,9,12,15,16]

Table 2. Technical Well Data

Well Name	Unit Name	Depth (ft)	Design Yield (gpm)
E7A	A-zone	18	6
E14A	A-zone	18	6
E15A	A-zone	18	6
E18A	A-zone	18	6

Source: [1,4-12,13]

System Description

- The original extraction system operated from 1987 until 1995. The system, initially one extraction trench well, was expanded to include three extraction wells; the system was then expanded to three extraction and one trench wells. The treatment system consisted of an air stripper. In addition, two carbon adsorption units were installed as backup if needed; however, these units were never used. Treated water was discharged to an on-site storm sewer under an NPDES permit. The stripper tower was three feet in diameter and designed to handle a maximum flow of 40 gpm. Treated water was discharged to a storm sewer.
- The PRB, or *in situ* treatment wall system, completed in 1995, consists of a granular iron treatment zone and hydraulic barrier system. The components are two slurry walls, permeability zones upgradient and downgradient of the treatment wall, and the treatment wall. Technical wall design data, including design transmissivity, are listed in Table 3. Figure 2 illustrates the plan view of the treatment wall system located at the northeast corner of the property, downgradient of the suspected on-site source area.

TREATMENT SYSTEM DESCRIPTION (CONT.)

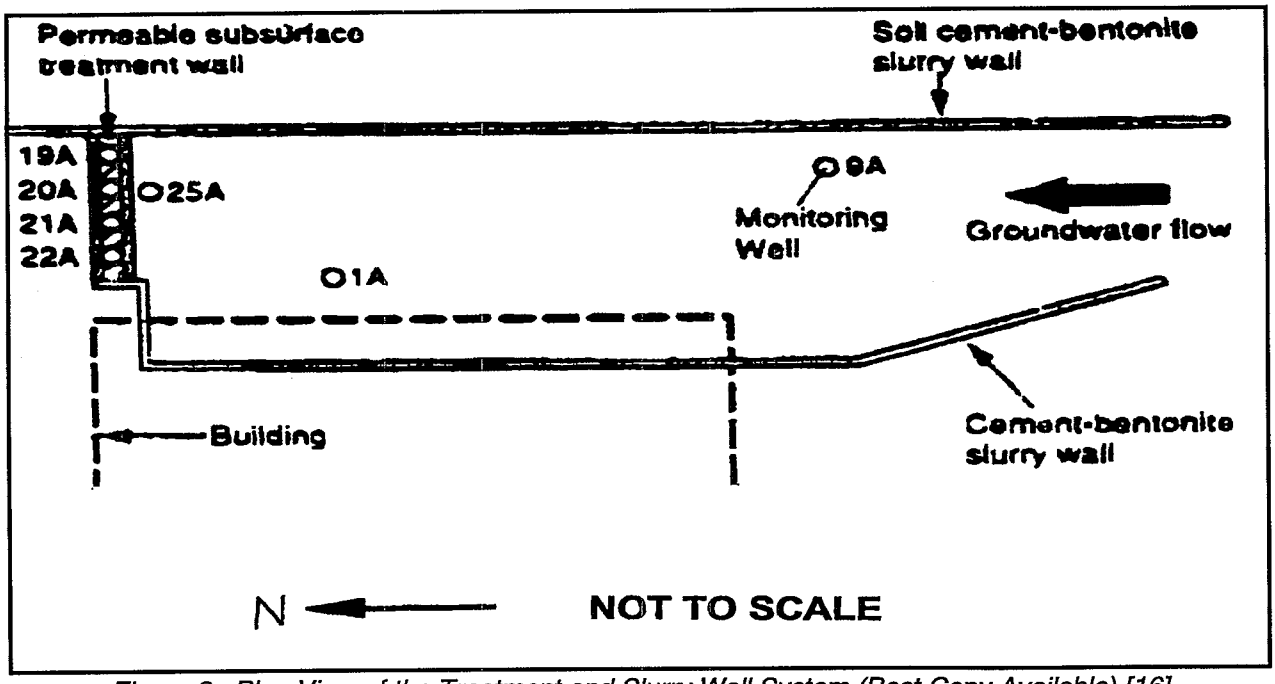

Figure 2. Plan View of the Treatment and Slurry Wall System (Best Copy Available) [16]

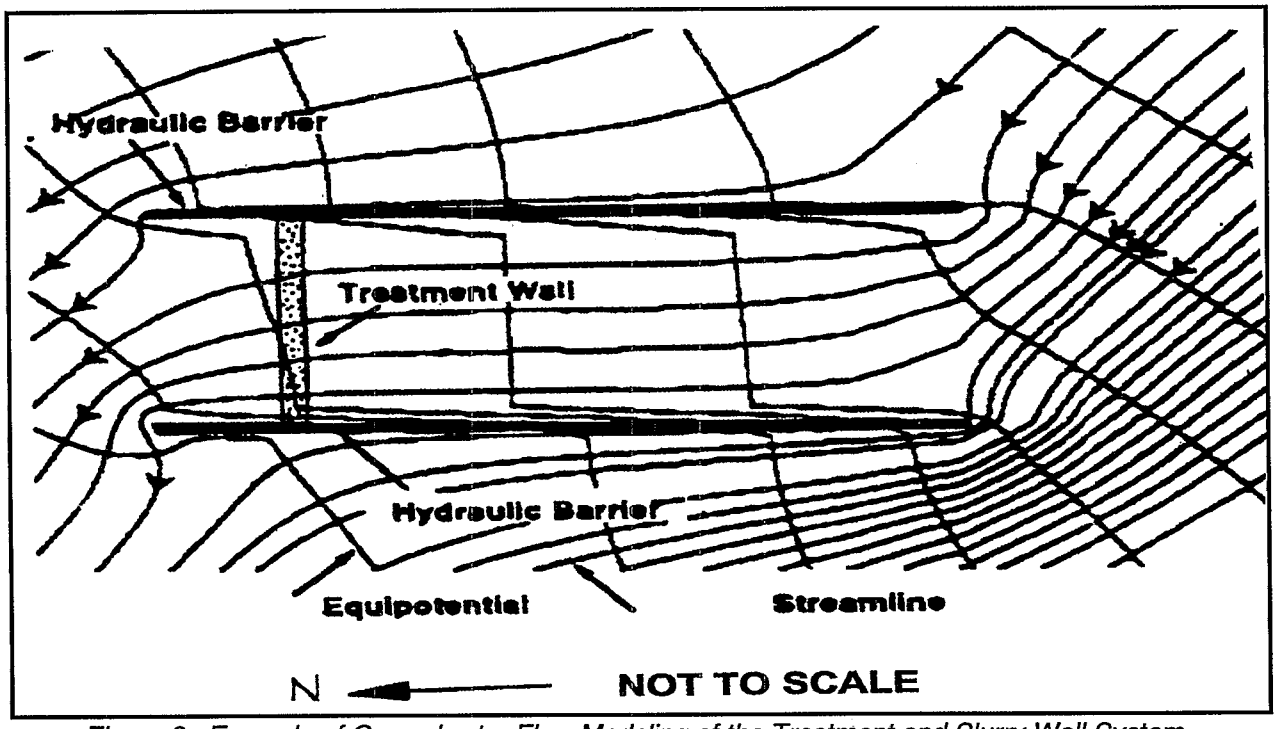

Figure 3. Example of Groundwater Flow Modeling of the Treatment and Slurry Wall System (Best Copy Available) [16]

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

Table 3. Technical Wall Data - Design Parameters

Unit	Flow-Through Thickness	Transmissivity[1] (ft^2/day)	Material	Vertical Thickness
Flow Control Zone	2 feet	10,000	Pea Gravel	13 feet
Treatment Wall	4 feet	1,400	Granular Iron	13 feet
Flow Control Zone	2 feet	10,000	Pea Gravel	13 feet

[1]Approximate values used for model development

Source: [4]

- The two slurry walls, 300 feet long on one side of the treatment wall and 235 feet long on the other side, route groundwater through the treatment wall. Groundwater flow through the treatment and slurry wall system was modeled by Geomatrix. Figure 3 illustrates how groundwater flows north-northwest through the funnel and through the treatment wall. Modeling also was performed for groundwater flow to the north and northeast.

- Two permeable zones are used upgradient and downgradient of the treatment zone to provide uniform velocity. The permeable zones, called flow control zones, are composed of high permeability pea gravel. The zones are two feet thick, and are the same height and width as the treatment wall.

- The treatment zone of the wall is composed of 100% granular iron which degrades the chlorinated VOCs into end products of chloride and ethylene through reductive dechlorination. The zone is 4 feet thick, approximately 40 feet wide, and approximately 13 feet high.

- During the P&T system operation, groundwater quality was monitored through a network of 17 wells: 13 monitoring wells and up to four extraction wells. Water table levels were monitored through the wells and three piezometers.

- During the operation of the current treatment wall, the groundwater quality has been monitored through a network of 13 wells. Six monitoring wells were installed within the treatment wall; one additional was installed just upgradient of the treatment wall to measure its performance. The other seven monitoring wells are the same monitoring wells used during the P&T system operation. Water table levels are monitored through a network of 14 piezometers in addition to the 13 monitoring wells.

System Operation

- Quantity of groundwater treated:

Year	Average Volume Pumped (gal/day)	Treatment System
1987-1992	25,000,000[1]	P&T
1993-1994	10,659,465[1]	P&T
1995-1997	2,361,776[2]	Treatment Wall

[1]Based on actual pumping rate through the treatment system
Calculated for this report, based on average groundwater velocity of 0.94 ft/day through treatment wall (in Final Design Report [4]) and dimensions of 40 feet wide and 13 feet high [6].

- The *in situ* treatment wall is operational 100% of the time. The P&T system was operational approximately 98% of the time.

- The extraction system was modified over the life of the P&T system from one trench well to three extraction wells and a trench well. Details on extraction well construction and use are specified in Table 5, Timeline.

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

- In 1993, Intersil examined alternative groundwater remediation technologies to evaluate cost-effective alternatives. One goal was to minimize the cost of treatment while increasing the treatment effectiveness, given that the mass removal by the P&T system had asymptotically declined. Another goal was to return the site to leasable/sellable conditions. According to Intersil, as long as the P&T system was operating at the site, the company would have to continue to lease the site to provide for power and space for the system.

- The selected alternative approved by the RWQCB was an *in situ* granular iron treatment wall system, followed by shutdown and removal of the P&T system. Construction of the iron treatment wall was completed and the P&T system was shut down in February 1995.

- Groundwater is routed to the treatment wall by the two slurry walls which are keyed into the confining clay layer. The treatment wall is keyed into the slurry walls on the eastern and western ends and into the confining lower layer at the bottom. Groundwater flow varies from the northwest to the north on site. The low permeability slurry walls help provide uniform flow direction and velocity through the wall. In addition, the flow control zones provide uniform velocity.

- Pilot-scale studies and canister studies were performed by EnviroMetal, Inc., the treatment wall vendor, and Geomatrix to determine the required residence time to fully degrade the halogenated VOCs. VC was determined to take the longest time to degrade, with a required residence time of approximately two days in the wall, to reduce site concentrations to cleanup standards. Therefore, the full-scale iron treatment wall was designed based on a 4-foot flow through thickness and a maximum velocity of 1.2 feet per day, to provide a groundwater residence time greater than the required two days.

- In August 1995, the eastern slurry wall was determined by Geomatrix to be leaking. The cause of the leak was believed by Geomatrix to be damage from construction by others at the eastern adjacent WM facility and from pumping at the WM P&T system. The slurry wall was repaired in December 1995 by injecting grout into the ground adjacent to the wall. Eleven piezometers were added to monitor the effect of the WM extraction system, resulting in the current total network of 14 piezometers. Monitoring data since December 1995 indicate the slurry wall has been functioning properly.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameters affecting cost or performance for the treatment wall and the P&T system are residence time and extraction rate, respectively. Table 4 presents the values measured for each.

Table 4. Performance Parameters

Parameter	Value
Actual Average Extraction Rate (P&T)	8 gpm
Average Flow Rate through Treatment Wall	2.5 gpm
Minimum Required Residence Time (Treatment Wall)	2 days
Approximate Residence Time	At least 3 days
Performance Standards for P&T NPDES Requirements (Effluent)	TCE: 5.0 µg/L *cis*-1,2-DCE: 5.0 µg/L VC: 0.5 µg/L Freon-113: 5.0 µg/L
Performance Standard for Treatment Wall California and EPA Maximum Contaminant Levels (MCL)	TCE: 5.0 µg/L *cis*-1,2-DCE: 6.0 µg/L VC: 0.5 µg/L Freon-113: 1,200 µg/L
Remedial Goal for P&T, in µg/L (aquifer)	California and EPA MCLs (same as Performance Standard for Treatment Wall)
Remedial Goal for Treatment wall, in µg/L	California and EPA MCLs (same as Performance Standard for Treatment Wall)

Source: [1,2]

Timeline

Table 5 presents a timeline for this remedial project.

Table 5. Project Timeline

Start Date	End Date	Activity
10/15/86	---	Site Cleanup Requirements (SCR) order issued
01/87	---	Inactive in-ground neutralization system and approximately 50 yd^3 of surrounding contaminated soil excavated under the direction of the RWQCB, first extraction well installed, monitoring of groundwater begun
11/87	---	Approximately 108 yd^3 of contaminated soil excavated from northeast corner of site, extraction of groundwater and treatment through air stripper begun as RWQCB approved interim measure
11/89	---	Groundwater extraction system expanded to three wells, and 11 monitoring wells installed
12/91	---	Fourth, temporary extraction well installed
02/92	12/92	Groundwater extracted through temporary extraction well
11/94	---	Installation of treatment wall initiated
02/95	---	Treatment wall installation completed, P&T system shut down
8/95	12/95	Low water levels observed near eastern slurry wall, 11 piezometer network installed and eastern slurry wall
1/96	---	Slurry wall repaired

Source: [1,2,6,15]

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

The cleanup goal for the site is to reduce concentrations of TCE, *cis*-1,2-DCE, VC, and Freon-113 to levels below the MCL set by the State of California and Primary Drinking Water Standards. The required cleanup levels are listed above in Table 4 and are applied throughout the aquifer, as measured in all on-site monitoring wells [1].

Treatment Performance Goals

- The primary goal of the treatment system was to reduce contaminant levels in the effluent to meet NPDES requirements, listed above in Table 4 [1].
- The secondary goal of the P&T system was to contain the contaminant plume by creating an inward hydraulic gradient [1].
- The primary goal of the treatment wall is to reduce contaminant levels in groundwater passing through the wall to the cleanup goals discussed in Table 4 [15].
- The secondary goal of the treatment wall is to contain the contaminant plume upgradient of the treatment wall system by using two slurry walls to route the plume through the treatment wall [15].

Performance Data Assessment [4-16]

For this report, total contaminant concentration includes the sum of the concentrations of TCE, cis-1,2-DCE, VC, and Freon-113. Performance is described in terms of the overall progress towards the cleanup goals, based on both the P&T and treatment wall systems, then in terms of each system.

Overall Progress

- The contaminant plume size has been reduced. However, contamination remains elevated at three hotspots: upgradient of the treatment wall (wells 1A and 25A), south of the treatment wall (well 9A), and northeast of the former Intersil property (well 10A).
- Figure 4 illustrates the temporal change in average total contaminant concentrations detected during monitoring. Average total contaminant concentrations have decreased from 1,609 µg/L in 1986 to 31 µg/L in 1997, a reduction of 98%.
- The average concentration of total contaminants in the aquifer after seven years and two months of P&T system operation was 312 µg/L. The average concentration of total contaminants downgradient of the wall after one year and eight months of treatment wall system operation was 39 µg/L. In addition, the contaminant plume has been contained.
- Figure 5 presents the removal of contaminants from the groundwater treated in the P&T system annually from 1987 until 1995 and through the treatment wall system from 1995 until August 1996. By February 1995, the P&T system had removed approximately 56 kg of total contaminant mass from the groundwater. From February 1995 until August 1996, the treatment wall system had removed 7 kg of total contaminant mass from the groundwater.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (Cont.)

P&T System

- Figure 5 shows the P&T system achieved a maximum rate of total contaminant removal of close to 0.05 kg/day when operations first began in December 1987. In December 1990, the P&T total contaminant removal rate was at its lowest (0.01 kg/day). Overall, the total contaminant removal rate during P&T operation declined exponentially from the initial P&T startup.

- During the P&T system operation, the contaminant concentrations in the effluent were below standards set by the NPDES permit in Table 4.

- During the P&T system operation, the extraction system was determined by site operators to have created an inward hydraulic gradient. In doing so, the P&T system assisted in containing the plume.

Treatment Wall

- During the treatment wall system operation, the concentrations of TCE and Freon-113 in monitoring wells downgradient of the treatment wall were all below cleanup goals during quarterly sampling events from March 1995 to November 1996. Levels of *cis*-1,2-DCE and VC have been detected at up to 26 µg/L and 2.1 µg/L, respectively (compared to cleanup goals of 6.0 µg/L and 0.5 µg/L, respectively) near the WM property line.

- A P&T remediation system was installed on the WM site in May 1995. The zone of capture for that system was determined not to have affected the treatment wall. Since the treatment wall was installed, contaminant levels in wells downgradient of the wall have not increased, indicating that the plume has been contained.

- During 1995, the eastern slurry wall of the treatment wall system leaked from being damaged, but subsequent repairs worked to seal the leak.

- According to the state contact, although some levels downgradient of the wall are above cleanup levels, natural attenuation is occurring, and contaminants are not migrating further.

Performance Data Completeness [3,4-14]

- Data for the P&T system were available for December 1987 until February 1995. Data for the treatment wall system were available for March 1995 until November 1997. Concentrations of contaminants in the groundwater have been monitored quarterly since January 1987. Previously, from February 1985 until January 1987, concentrations of contaminants in the influent and effluent were monitored weekly. These data are available from the site contact in the Self Monitoring and Technical Status Reports and the NPDES Self Monitoring Quarterly Reports. For the analyses in this report, annual data were used.

- Data from all monitoring wells within the original contaminant plume identified in Figure 1 were used to calculate the mean concentration for both P&T and treatment wall systems. This includes wells upgradient of the wall. When concentrations were below detection limits, half of the detection limit was used for evaluation purposes.

- The contaminant mass removal rate by the P&T system shown in Figure 5 was determined for this report using analytical results from the treatment plant influent and effluent, along with well extraction flow rate data. The contaminant mass removal rate by the

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Completeness (Cont.)

treatment wall system shown in Figure 5 was determined for this report using an estimated average linear velocity of 0.94 ft/day, dimensions of the wall, and the contaminant concentration gradient observed across the wall from February 1995 to November 1996.

- For Figure 4, a geometric mean was used for average groundwater concentrations detected in monitoring wells to show the trend across the entire plume. Annual data from 11 wells were used for the P&T system, and data from nine wells were used for the treatment wall system.

Performance Data Quality

The QA/QC program used throughout the remedial action met the EPA and the State of California requirements. All monitoring was performed using EPA-approved methods SW-846 Methods 601, 602, 624, 625, Hardness, and TDS. The vendor did not note any exceptions to the QA/QC protocols [4-13].

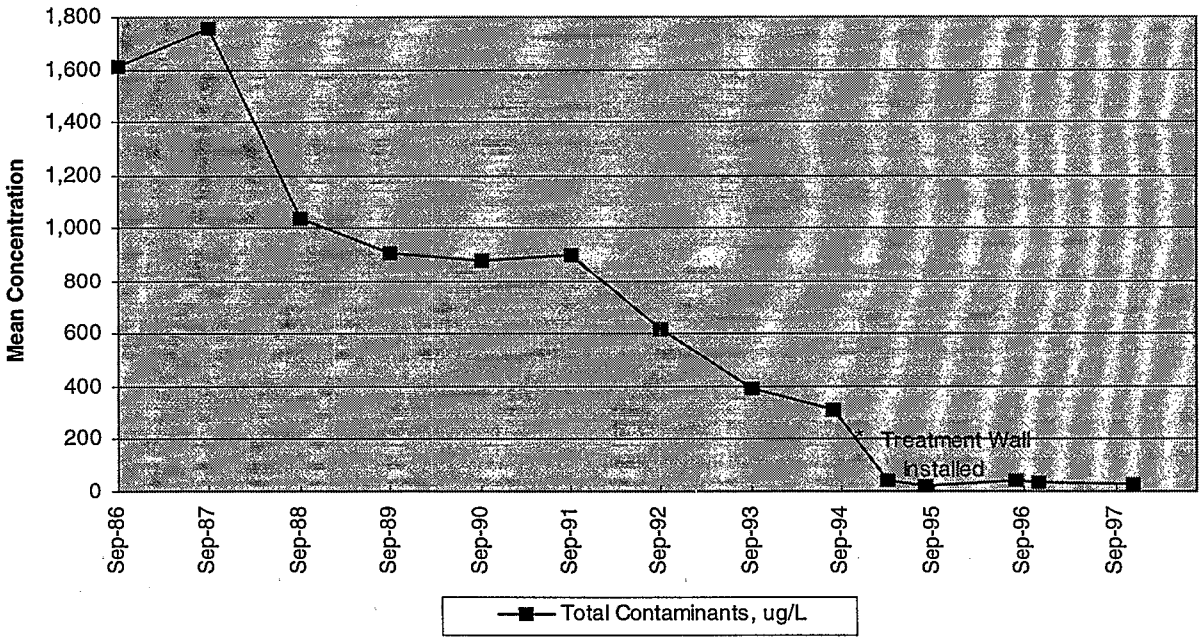

Figure 4. Total Contaminant Concentrations in the Groundwater(1987-1996) [4-13,16]

TREATMENT SYSTEM PERFORMANCE (CONT.)

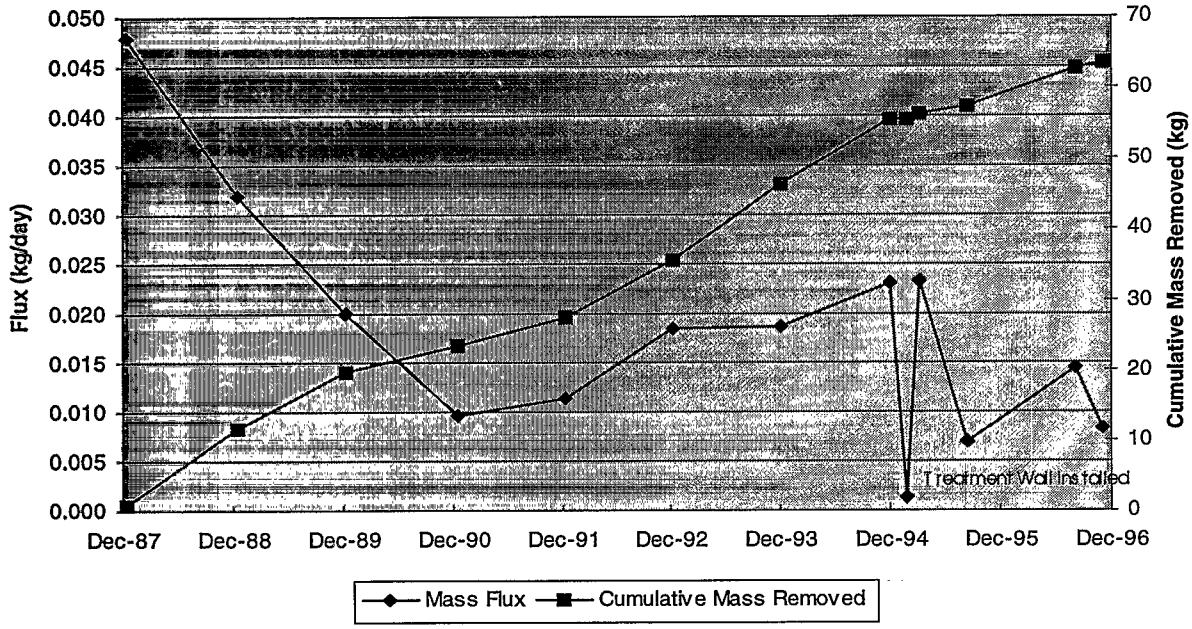

Figure 5. Total Contaminant Mass Flux and Mass Removed as a Function of Time (1987-1996) [4-13,16]

TREATMENT SYSTEM COST

Procurement Process

Intersil contracted with Geomatrix to construct and manage the on-site remediation systems. Intersil contracted with EnviroMetal, Inc. to contribute to design of the *in situ* treatment wall.

Cost Analysis

- All costs for investigation, design, construction and operation of the treatment system at this site were borne by Intersil.

Capital Costs (Estimated)

P&T Remedial Construction [1,3]	
1987 System Costs	
Extraction Well and Treatment System	$250,000
1990 System Costs	
Extraction Wells	$75,000
Total P&T Site Cost	**$325,000**
Treatment Wall Construction (1995) [2, 21]	
Slurry Walls	$178,000
Treatment Wall	$100,000
Transport/Disposal of Soil	$45,000
Treatment/Disposal of Water (dewatering)	$5,000
Site Restoration	$55,000
Demolition	$10,000
New Wells	$18,000
Permitting and Initial Sampling	$30,000
Bid and Scope Contingencies	$154,000
Total Cost Treatment Wall	**$595,000**

TREATMENT SYSTEM COST (CONT.)

Operating Costs (Estimated)

P&T System [1]	
Plant Operation & Maintenance Costs (1987-1995)	$525,600
Annual NPDES Monitoring Costs	$349,200
Annual Groundwater Monitoring Costs	$144,000
Cumulative P&T Operating Costs 12/87 - 2/95	**$1,018,800**

Treatment Wall System [2, 21]	
Cumulative Treatment Wall Operating Costs 2/95 - 11/96	**$167,000**

Other Costs (Estimated)

Construction Oversight (Treatment Wall)	$75,000
Engineering Design Costs	$100,000

Cost Data Quality

- The cost figures provided were based on estimates by Geomatrix, not actual vendor costs, which were not available for this site.
- The Geomatrix site contact reported that the cost estimate for the treatment wall system, including subsequent repairs, is within 10% of the actual costs incurred [17].

OBSERVATIONS AND LESSONS LEARNED

- Estimated costs for the P&T system at Intersil for the period from 1987 to 1995 were approximately $1,343,800 ($325,000 in capital construction costs and $1,018,800 in total operation and maintenance costs), corresponding to $10,900 per pound of total contaminants removed and $38 per 1,000 gallons of groundwater treated.
- Estimated costs for the treatment wall through November 1996 are approximately $762,000 ($595,000 in capital costs and $167,000 in total operation and maintenance costs) for the period from 1995 to 1996, corresponding to $38 per 1,000 gallons of groundwater treated and $108,900 per kg ($49,400/pound) of total contaminants removed.
- By using the passive, *in situ* treatment wall system, Intersil did not have to continue to lease the Sunnyvale property [17]. While this resulted in less cost to Intersil, information on specific cost savings was not provided.
- The P&T system removed 56 kg of contaminants from the groundwater over seven years; the treatment wall removed 7 kg over two years. However, cleanup goals have not yet been achieved.
- For the treatment wall to be effective, the entire contaminant plume upgradient of the wall must be routed through the wall. At the Intersil site, the plume was captured by the slurry walls and routed to the treatment wall [13,15]. For sites at which groundwater flow direction varies greatly, plume capture can be more difficult.
- If a subsurface source is present, the plume upgradient of the wall may persist, and cleanup goals may not be achieved. However, the overall goal to eliminate risk to human health and environment is immediately achieved downgradient of the wall. The advantage of the treatment wall over the P&T system is the ability to passively contain and treat the contaminated plume [20].
- The site hydrogeology enabled the treatment wall to be keyed into a bottom confining layer [15]. At sites where the contaminated aquifer is not fully confined on the bottom, vertical containment of the plume can be an issue [18].

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2. Draft Revised Final Remedial Action Plan, Volumes I and II, Geomatrix Consultants, Inc., January 1993.
3. Correspondence with Dr. Deborah Hankins, PhD, Intersil, April 30, 1997.
4. Self Monitoring and Technical Status Report Combined Annual Summary, Calendar Quarter October - December 1993, Geomatrix Consultants, Inc., January 31, 1994.
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21. Correspondence with Scott Warner, Geomatrix, June 30 and July 6, 1998.

Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Eastern Research Group, Inc. and Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.

Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the French Ltd. Superfund Site, Crosby, Texas

Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the French Ltd. Superfund Site, Crosby, Texas

<table>
<tr><td>Site Name:
French Ltd. Superfund Site</td><td rowspan="2">Contaminants:
Chlorinated solvents and Volatiles - nonhalogenated
- Contaminants of concern in the groundwater were benzene, toluene, chloroform, 1,2-DCA, and vinyl chloride
- Initial maximum concentrations were benzene (19,000 ug/L), 1,2-DCA (920,000 ug/L), and vinyl chloride (8,200 ug/L)</td><td>Period of Operation:
Status: Ongoing
Report covers: January 1992 through December 1995</td></tr>
<tr><td>Location:
Crosby, Texas</td><td>Cleanup Type:
Full-scale cleanup (interim results)</td></tr>
<tr><td>Vendor:
Prime Contractor:
Jon McLeod
CH2M Hill
(512) 346-2001
Treatment System Vendor:
Mike Day, President
Applied Hydrology Associates, Inc.
Denver, CO</td><td rowspan="2">Technology:
Pump and Treat with activated sludge for extracted groundwater; in situ bioremediation for contaminated groundwater
- Active remediation conducted from January 1992 through December 1995 consisted of extraction and above-ground treatment, enhanced aquifer flushing through pressure injection of clean water, and accelerated in situ bioremediation through the addition of oxygen, phosphorus, and nitrate.
- Source control was achieved by installation of cutoff (sheet-pile) walls around lagoon and DNAPL source areas.
- Since December 1995, active pumping was stopped and natural attenuation has been used to reduce remaining concentrations of contaminants. Limited pumping began in March 1998.</td><td>Cleanup Authority:
CERCLA Remedial
- ROD Date: 3/24/88</td></tr>
<tr><td>State Point of Contact:
Emmanuel Ndame
TNRCC
(512) 239-2444

PRP: Richard Sloan
ARCO Chemical Company
FLTG Project Coordinator
15010 FM 2100, Ste. 200
Crosby, TX 77532
(713) 328-3541</td><td>EPA Point of Contact:
Ernest Franke, RPM
U.S. EPA Region 6
1445 Ross Avenue
Dallas, TX 75202-2733
(214) 665-6739</td></tr>
<tr><td>Waste Source:
Unlined disposal pit (lagoon)</td><td colspan="2" rowspan="2">Type/Quantity of Media Treated:
Groundwater
- 306 million gallons of groundwater and surface treated as of December 1995
- Groundwater is found at 10-12 ft bgs
- Extraction wells are located in two aquifers
- Hydraulic conductivity ranges from 0.283 to 2.835 ft/day</td></tr>
<tr><td>Purpose/Significance of Application:
Regulatory requirements for this site based on use of modeling results to show effects of natural attenuation at the site boundary 10 years after pump and treat completed.</td></tr>
</table>

Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the French Ltd. Superfund Site, Crosby, Texas (continued)

Regulatory Requirements/Cleanup Goals:

- According to the 1988 ROD, "groundwater recovery and treatment will continue until modeling shows that a reduction in the concentration of volatile organics to a level which attains the 10^{-6} human health criteria at the site boundary can be achieved through natural attenuation in 10 years or less." In response, remedial goals were established for vinyl chloride (2 ug/L), benzene (5 ug/L), toluene (1,000 ug/L), 1,2-DCA (100 ug/L), and chloroform (100 ug/L).
- A primary goal of the remedial system was plume containment, accompanied by in situ bioremediation and source control using sheet-pile walls.

Results:

- A modeling study conducted in late 1995 demonstrated that natural attenuation would reduce groundwater contaminant concentrations below the remedial goals at the site boundary within 10 years after system shut-off. As a result, EPA allowed the groundwater recovery and treatment operations to be shut down in December 1995.
- Average concentrations of 1,2-DCA, vinyl chloride, and benzene had been reduced to approximately 1 ug/L in the twp aquifers at the site by October 1995. As of December 1995, the pump and treat system had removed 517,000 pounds of contaminants (measured as TOC) from the groundwater. No data were available to quantify the amount of contaminants destroyed through bioremediation.

Cost:

- Actual costs for pump and treat and in situ bioremediation were $33,689,000 ($15,487,000 in capital and $18,202,000 in O&M), which correspond to $110 per 1,000 gallons of groundwater extracted and $15 per pound of contaminant removed. The unit cost does not account for the amount of contaminants destroyed through bioremediation.

Description:

The French Limited site was used for sand mining in the 1960s and 1970s. During the period from 1966 through 1971, the site was permitted to accept industrial waste material for disposal in a seven-acre lagoon created from an open sand pit. About 80 million gallons of waste material was disposed of in the main waste lagoon. The facility's permit was revoked and the site was closed in 1973. The site was placed on the NPL in 1981, and a remedial investigation was performed at the site from 1983 to 1986 through a cooperative agreement. A ROD was signed in May 1987, and amended in March 1988.

Active remediation was conducted at the site from January 1992 through December 1995 by groundwater extraction and above-ground treatment, enhanced aquifer flushing through pressure injection of clean water, and accelerated in situ bioremediation through the addition of oxygen, phosphorus, and nitrate. Source control was achieved by installation of sheet-pile walls around lagoon and DNAPL source areas. As of December 1995, active pumping was stopped and natural attenuation has been used to reduce remaining concentrations of contaminants. Limited pumping began in March 1998.

SITE INFORMATION

Identifying Information:

French Limited Superfund Site
Crosby, TX

CERCLIS #: TXD980514814

ROD Date: March 24, 1988

Treatment Application:

Type of Action: Remedial

Period of operation: January 1992 through December 1995 (Performance data collected through December 1995)

Quantity of material treated during application: 281 million gallons of groundwater, and 25 million gallons of surface water.

Background [11, 22]

Historical Activity that Generated Contamination at the Site: Industrial waste disposal

Corresponding SIC Code: 4953E (Waste management-refuse systems; sand and gravel pit disposal)

Waste Management Practice That Contributed to Contamination: Unlined disposal pit (lagoon)

Location: Crosby, TX

Facility Operations:

- The French Limited site is a 22.5-acre tract of land located adjacent to Highway US-90 in eastern Harris County, Texas. The site is in the floodplain of the San Jacinto River and was used for sand mining in the 1960s and 1970s. During the period of 1966 through 1971, the site was permitted by the State of Texas to accept industrial waste material for disposal in a 7-acre lagoon created from an open sand pit. About 80 million gallons of waste material was disposed of in the main waste lagoon, creating 300,000 cubic yards of contaminated sludges and soils. The facility's permit was revoked and the site was closed in 1973.

- In 1981, a flood caused the dike surrounding the waste lagoon to breach and in 1982, EPA repaired the dike, and pumped most of the discharged sludges back into the lagoon.

- A remedial investigation was performed from 1983 to 1986 through a cooperative agreement. The French Limited Task Group (FLTG), a private company formed by potentially responsible parties (PRP), conducted a 1986 Field Investigation and prepared a Supplemental Remedial Investigation Report; using the results to select the site remedy.

- In April 1987, the responsible parties conducted a slurry-phase bioremediation pilot demonstration. Based on the results of the demonstration, EPA selected slurry-phase bioremediation as the preferred remedial technology for lagoon sludges and contaminated soils in the EPA Record of Decision (ROD), dated March 24, 1988.

- The 1988 ROD also specified extraction and treatment of contaminated groundwater with *in situ* bioremediation to enhance contaminant reductions. This report focuses on the groundwater remedial activities.

- In 1989, as a source control measure, the 7-acre lagoon was isolated and contained within a wall of double-interlock, steel sheet pile that surrounded the lagoon, and keyed into the second clay unit. The sheetpile wall is also called the floodwall.

- Beginning in January 1992, the contaminated sludges and soils within the lagoon were treated in place using slurry-phase bioremediation. Treatment of the soils and sludges was completed in December 1993. A Cost and Performance

SITE INFORMATION (CONT.)

Background (Cont.)

report (Reference #7) describes the slurry-phase bioremediation of lagoon sludges and soils.

- The site was placed on the National Priorities List (NPL) in 1981.

Regulatory Context [26]:

- A ROD was signed on May 1987 and amended on March 24, 1988.
- Site activities are conducted under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 §121, and the National Contingency Plan (NCP), 40 CFR 300. Post-closure monitoring of the upper and lower aquifers for a period of 30 years is required under the Resource Conservation and Recovery Act (RCRA) of 1976.

Remedy Selection [20]:
The contaminated groundwater was extracted and treated in an aboveground treatment system. *In situ* bioremediation was implemented for the groundwater plume to expedite the cleanup process. The ROD for this site allows for 10 years of natural attenuation to meet final remedial goals. Lagoon sludges were treated via slurry-phase bioremediation. Surface water (from the lagoon) was treated in an aboveground treatment system. Treated water was discharged to the San Jacinto River.

Site Logistics/Contacts

Site Lead: PRP

Oversight: EPA

Remedial Project Manager:
*Ernest Franke
EPA - Region 6
1445 Ross Avenue
Dallas, TX 75202-2733
214-665-6739

State Contact:
Emmanuel Ndame
Texas Natural Resources Conservation Commission (TNRCC)
512-239-2444

*Indicates primary site contact

PRP:
*Richard L. Sloan
ARCO Chemical Company
FLTG Project Coordinator
15010 FM 2100, Ste. 200
Crosby, TX 77532
713-328-3541

Prime Contractor:
CH2M Hill
Jon McLeod
512-346-2001

Treatment System Vendor:
Applied Hydrology Associates, Inc.
Mike Day, President
Denver, CO

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater

Contaminant Characterization [13]

Primary Contaminant Groups: Volatile organic compounds (VOCs)

- Major chemicals in the lagoon sludges included chlorinated and nonchlorinated VOCs and semivolatile organic compounds (SVOCs), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). Dense non-aqueous phase liquid (DNAPL), containing a significant component of VOCs, also migrated into the underlying subsoils. Leaching lagoon sludges and contaminated subsoils resulted in a dissolved groundwater plume of VOCs extending approximately 600 feet downgradient (south) of the site.

- Contaminants of concern in the groundwater were benzene, toluene, chloroform, 1,2-dichloroethane (1,2-DCA), and vinyl chloride. Benzene was the most prevalent organic compound. 1,2-DCA was the primary chlorinated solvent compound found in the DNAPL in the source areas. Initial maximum detected levels of selected contaminants were benzene (19,000 µg/L), vinyl chloride (8,200 µg/L), and 1,2-DCA (920,000 µg/L).

- Figures 1 and 2 show the extent of benzene and 1,2-DCA contamination, respectively, in the uppermost aquifer (S1) as of December 1991.

- The VOC plume at the site initially consisted of 91 million gallons of contaminated groundwater. In the S1 aquifer, the plume was 500 feet long (north-south) and 1,500 feet wide (east-west), or 750,000 square feet. In the INT unit, the plume was 950 feet long (north-south) and 1,800 feet wide (east-west), or 1.7 million square feet. The plume volume was determined for this report based on the areal extent of the plumes, a depth of 20 feet in the S1 aquifer, a depth of 15 feet in the INT aquifer, and a standard porosity of 30% [1].

- Slight mounding of the water table near the waste pit indicated slow seepage. Lateral contaminant migration within the shallow aquifer was estimated at approximately 80 feet per year.

- In January 1992, shortly after the startup of the pump and treat (P&T) system, DNAPL was detected at well S1-16 inside the floodwall and at well INT-11 just outside the floodwall. A preliminary study conducted by Applied Hydrology Associates, Inc. (AHA) in the spring of 1992 confirmed the presence of DNAPL in the INT-11 area outside the floodwall. A comprehensive DNAPL field study was conducted by AHA between March and July 1993. The subsequent field data report concluded that the INT-11 area was the only area where DNAPL was confirmed to exist outside the sheetpile floodwall. DNAPL extended up to 63 feet south of the floodwall and was a continuing source of contamination to the groundwater. Construction of a second sheetpile wall around the DNAPL source area was completed in August 1994.

MATRIX DESCRIPTION (CONT.)

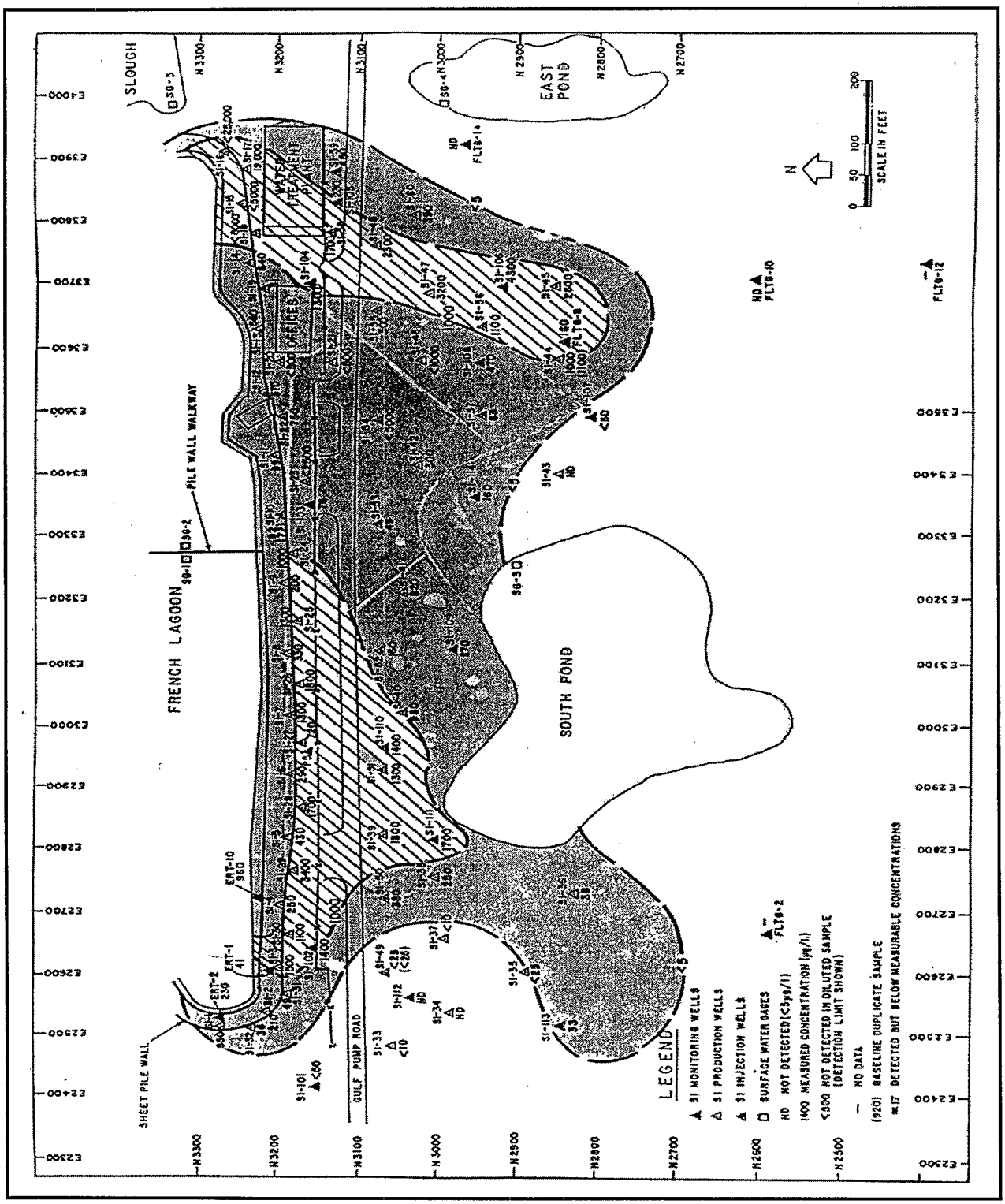

Figure 1. Initial Benzene Concentration Contour Map, S1 Unit (October - December 1991 baseline sampling) [24]

MATRIX DESCRIPTION (CONT.)

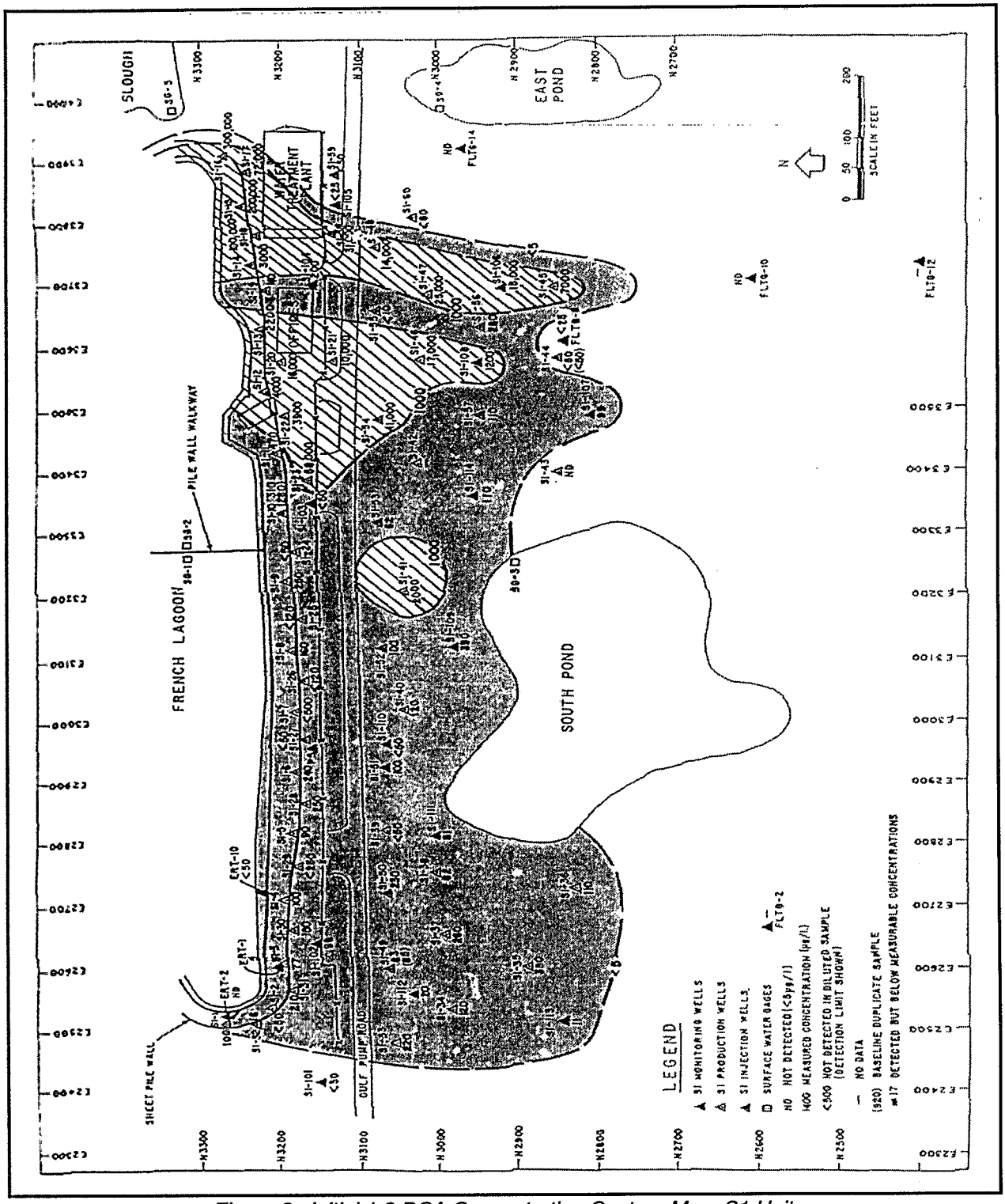

Figure 2. Initial 1,2-DCA Concentration Contour Map, S1 Unit (October - December 1991 baseline sampling) [24]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Costs or Performance

Hydrogeology [13]:

Five distinct hydrogeological units have been identified beneath this site. Groundwater is encountered approximately 10 to 12 feet below ground surface. Shallow alluvial deposits of Holocene age, consisting of sands, silts, and clays extend to a depth of 55 feet. These sediments were deposited in the San Jacinto River flood plain and have been subdivided into the following hydrogeologic units. Table 1 presents technical aquifer information.

Unit 1	S1	Clean medium to coarse sand with minor amounts of fine gravel. The unit is comprised of primarily fluvial channel deposits. The French lagoon was created by mining sand from this unit.
Unit 2	C1	Laterally discontinuous clay with minor thin silt and fine sand layers. Where present, it functions as an aquitard between the S1 and INT units.
Unit 3	INT	Interbedded fine sand and clayey silts. This unit represents overbank flood deposits and exhibits a fining-upward sequence with transitional contact with overlying clays.
Unit 4	C2 (Beaumont Formation)	Predominantly clay deposit with minor thin silt and fine sand layers. This unit functions as a major aquitard between the upper alluvial units and the underlying Chicot aquifer.
Unit 5	S2 (Chicot Aquifer)	A sequence of fluvial-deltaic sands, silts, and clays. This unit (along with the Evangeline aquifer beneath it), composes the primary water supply aquifer in this area. This unit is not contaminated.

Table 1. Technical Aquifer Information [13]

Unit Name	Depth Below Surface (ft)	Conductivity (ft/day)	Average Velocity (ft/day)	Flow Direction
S1	10-35	2.835	NA	S/SE
C1	0-4	---	---	---
INT	40-55	0.283	NA	S/SE
C2	70	---	---	---
S2	NA	NA	NA	NA

NA- Data not included in documentation.
Source: [13]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Pump and treat (P&T) with activated sludge for extracted groundwater. *In situ* bioremediation for contaminated groundwater.

Supplemental Treatment Technology

Carbon adsorption, metals precipitation, and neutralization

System Description and Operation

Table 2. Extraction and Injection Well Data

Well Name (Number of Wells)	Unit Name	Depth (ft)	Yield (gal/min)
Pumping wells (53)	S1	35	1.8
Pumping wells (56)	INT	55	0.6
Injection wells (17)	S1	35	2.3
Injection wells (42)	INT	55	0.7

Source: [1, 14]

System Description [19]

- Groundwater at the French Limited site was actively remediated from January 1992 through December 1995 via a combination of conventional pumping and above-ground treatment, enhanced aquifer flushing through pressure injection of clean water, and accelerated *in situ* bioremediation through the addition of dissolved oxygen, diammonium phosphate, and nitrate to injection water. The aboveground treatment unit operations included equalization, biological treatment, metals precipitation, clarification, filtration, neutralization and carbon adsorption (polishing).

- Source control was achieved by installing cutoff (sheet-pile) walls around the lagoon in 1989 and around the DNAPL source area in 1994. The sheet-pile wall around the lagoon is referred to as the floodwall and consists of 996 sheet-pile pairs. The total length of the floodwall is 2,090 feet. The top of the floodwall is 3 feet higher than the 100-year flood level. The bottom of the 65- to 75-foot-long sheet-piles is keyed into the clay stratum underlying the INT unit [27].

- A phased groundwater remediation strategy was developed for this site. The strategy involved installing unit operations in incremental steps to verify design assumptions for P&T enhanced by *in situ* bioremediation. The first phase of the groundwater strategy was aimed at hydraulic containment of all groundwater that exceeded cleanup criteria. The *in situ* bioremediation equipment was next installed to enhance contaminant reduction. The metals precipitation unit was added later when the activated sludge system failed to sufficiently remove metals. Effluent from the treatment system was discharged to the San Jacinto River under a state discharge permit, following treatment to the State of Texas standards.

- The *in situ* bioremediation sequence of flushing, nitrifying conditions, and finally aerobic conditions was designed to stimulate different types of microorganisms. This design created cometabolic biodegradation processes to biodegrade a wide variety of chlorinated and nonchlorinated constituents throughout the plume. First, clean water only (no added nitrate or oxygen) was injected for 30 days. Second, the nitrate and diammonium phosphate was mixed with clean water and injected for 90 days. Finally, the oxygen was mixed with clean water and injected for 44 months.

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

- Table 2 shows well-specific extraction rates. The goal of well placement was hydraulic containment. Most wells were located downgradient (outside) of the floodwall, to intercept the larger portion of the plume and contain the plume. The wells located inside the floodwall were used to contain DNAPLs within the floodwall area.

- The injection and extraction system consisted of 109 recovery wells and 59 injection wells; 53 recovery wells and 17 injection wells for the S1 unit and 56 recovery wells and 42 injection wells for the INT unit.

System Operation

- Quantity of groundwater pumped from aquifer by year:

Year	Total Volume Pumped (gal)	Unit Name
1992	42.8 million	S1
	13.2 million	INT
1993	68 million	S1
	13.6 million	INT
1994	54 million	S1
	26 million	INT
1995	24.5 million	S1
	23.4 million	INT

- The P&T system at this site was operational nearly 90% of the time. Major causes of groundwater extraction system downtime included problems with pneumatic pumps, flow meters clogging, air valves locking, surface leaks in injection wells, and low yields in several INT extraction wells [1].

- 1.5 million pounds of carbon was used in the water treatment plant from 1992 through 1995.

- The nitrate additive for *in situ* bioremediation was controlled so that the concentration of nitrate in the groundwater did not exceed the drinking water standard of 10 mg/L. The oxygen concentration in the injected water was maintained between 35 and 40 mg/L.

- Active pumping of groundwater at this site was stopped in December 1995. Natural attenuation has been allowed to reduce the remaining concentrations of contaminants where possible. In March 1998, the FLTG began adding liquid oxygen in areas where contaminants persisted along with a focused groundwater pumping program. This allowed the site operators to control and monitor the spread of increased dissolved oxygen (DO) levels and to enhance bioremediation.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Operating Parameters Affecting Treatment Cost or Performance [16]

Table 3 presents major operating parameters affecting performance.

Table 3: Performance Parameters

Parameter	Value	
Average Extraction Rate	189 gpm	
Performance Standards (effluent)	TNRCC discharge permit limits for the San Jacinto River	
	pH	6-9
	TSS	55 mg/L
	Benzene	150 µg/L
	Halogenated VOCs	500 µg/L
	Napthalene	300 µg/L
	Arsenic	150 µg/L
	Barium	1,000 µg/L
	Cadmium	50 µg/L
	Chromium	500 µg/L
	Copper	15 µg/L
	Lead	66 µg/L
	Manganese	300 µg/L
	Mercury	1 µg/L
	Nickel	148 µg/L
	Selenium	20 µg/L
	Silver	5 µg/L
	Zinc	162 µg/L
Remedial Goal for Target Compounds (aquifer)	Vinyl Chloride	2 µg/L
	Benzene	5 µg/L
	Toluene	1,000 µg/L
	1,2-DCA	100 µg/L
	Chloroform	100 µg/L

Source: [16]

Timeline

Table 4 presents a timeline for this remedial project.

Table 4: Project Timeline

Start Date	End Date	Activity
---	1973	Site closed to receiving wastes
1981		Site listed on NPL
1982	1987	EPA and PRP remedial investigations, feasibility studies, and pilot studies conducted
03/87	---	ROD signed
03/88	---	Amended ROD signed
04/90	12/90	Remedial system designed
1991		Construction completed
1989	---	First sheetpile floodwall installed around lagoon
01/92	---	Site remediation operations begun (operational and functional letter)
01/92	---	DNAPL detected in S1 and INT extraction wells
03/93	07/93	Comprehensive DNAPL field study conducted
08/94	---	Second sheetpile wall installed to contain DNAPL residue found outside original sheetpile floodwall
12/95	---	Active site remediation completed. 10-year timeframe to achieve ground water cleanup criteria through natural attenuation begun.

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards [20]

The 1988 ROD states: "Groundwater recovery and treatment will continue until modeling shows that a reduction in the concentration of volatile organics to a level which attains the 10^{-6} human health criteria (listed in Table 3) at the site boundary can be achieved through natural attenuation in 10 years or less."

Additional Information on Goals

The aquifer remediation compliance point is the point of first public exposure downgradient from the site (i.e., the first point where someone could install a potable water well in the shallow alluvial aquifer). The PRPs own the site and much of the surrounding property to limit the point of first public exposure. The compliance point is located along Gulf Pump Road toward the Riverdale subdivision.

Treatment Performance Goals [20]

- The primary goal of the remedial system was plume containment, accompanied by *in situ* bioremediation and source control via sheetpile walls.
- The secondary goal of the P&T system was to reduce effluent contaminant levels to meet TNRCC discharge permit requirements for discharge to the San Jacinto River. Table 3 lists effluent permit requirements.

Performance Data Assessment [10,13-18, 28]

- A natural attenuation modeling study conducted in late 1995 demonstrated that natural attenuation would reduce groundwater contaminant concentrations below the remedial goals at the site boundaries within 10 years after system shut-off. The October 1, 1995 data were used as starting conditions for the natural attenuation study. Visual MODFLOW and BioTrans were used for modeling purposes. As a result, EPA allowed the groundwater recovery and treatment operations to be shut down in December 1995.
- In May 1994, one well in a downgradient residential subdivision showed levels of vinyl chloride at 7 µg/L. Other wells sampled in the area showed no contaminants above detection limits. No contaminants have been detected in downgradient monitoring wells since May 1994, indicating successful plume contaminant at that time.
- Figure 3 illustrates how contaminant concentrations in the groundwater have changed in the S1 unit. Wells S1-108, S1-109, and S1-111 in the S1 unit (all located outside the floodwall) were used to illustrate the trend. These wells are evenly spaced along the downgradient side of the lagoon. A geometric mean of the data from all three wells was calculated and presented in the figure. The figure shows declining concentrations for benzene, 1,2-DCA, and vinyl chloride from 516 to 0.6 µg/L, 256 to 0.8 µg/L, and 129 to 1.2 µg/L, respectively.
- Figure 4 illustrates how contaminant concentrations in the groundwater have changed in the INT unit. Wells INT-102, INT-104, INT-108, INT-109, and INT-110 in the INT unit (all located outside the floodwall) were used to illustrate the trend. A geometric mean of the data was calculated and presented in Figure 4. The figure shows declining concentrations for benzene, 1,2-DCA, and vinyl chloride from 640 to 2 µg/L, 917 to 1 µg/L and 420 to 1 µg/L, respectively.

TREATMENT SYSTEM PERFORMANCE (CONT.)

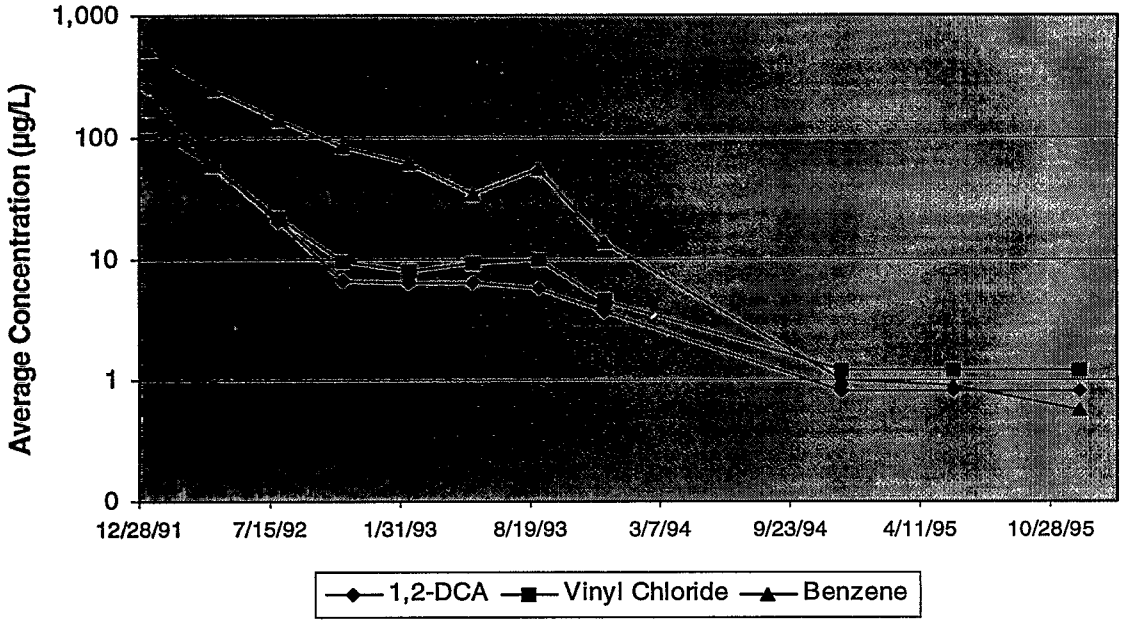

Figure 3. Average Groundwater Concentrations in S1 Unit (1992 - 1995) [5,28]

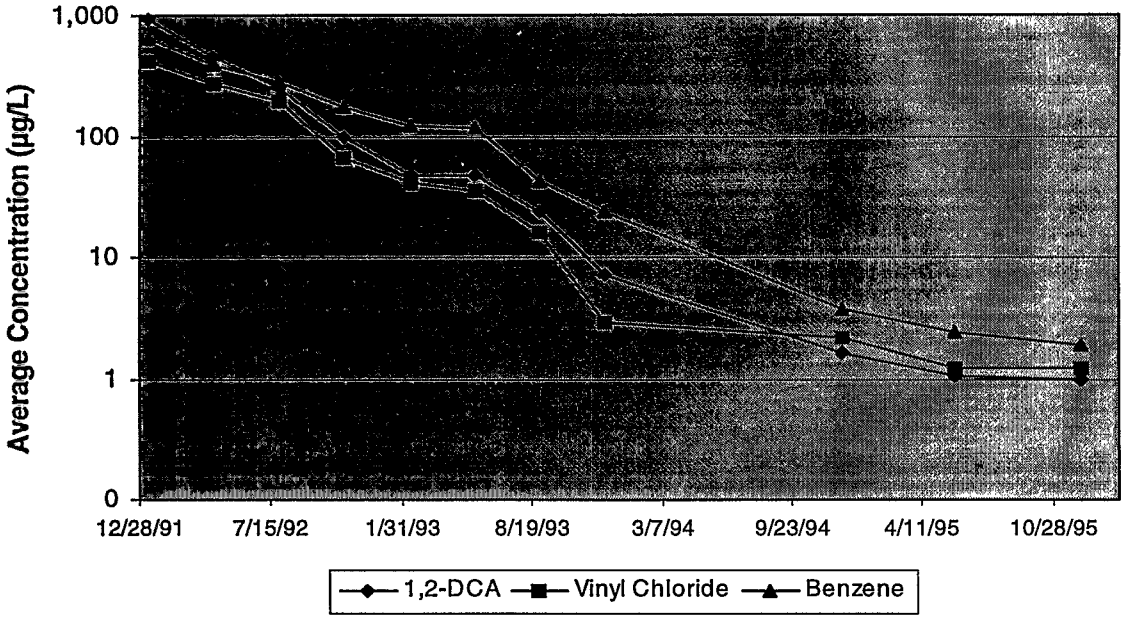

Figure 4. Average Groundwater Concentrations in INT Unit (1992 - 1995) [5,28]

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (Cont.)

- Figure 5 presents the mass flux and cumulative removal of contaminants through the treatment system from 1992 to 1995. Mass flux through the treatment system varied between 170 lbs/day and 735 lbs/day. From 1992 to December 1995, the P&T system removed 517,000 pounds of contaminant mass (measured as TOC) from the groundwater.
- The contaminant removal rate has not followed the expected asymptotic decline as seen in typical P&T applications. Likewise, the cumulative mass removal data have not reached a plateau as seen in typical P&T applications.
- No data were available to quantify the amount of contaminants destroyed through bioremediation.

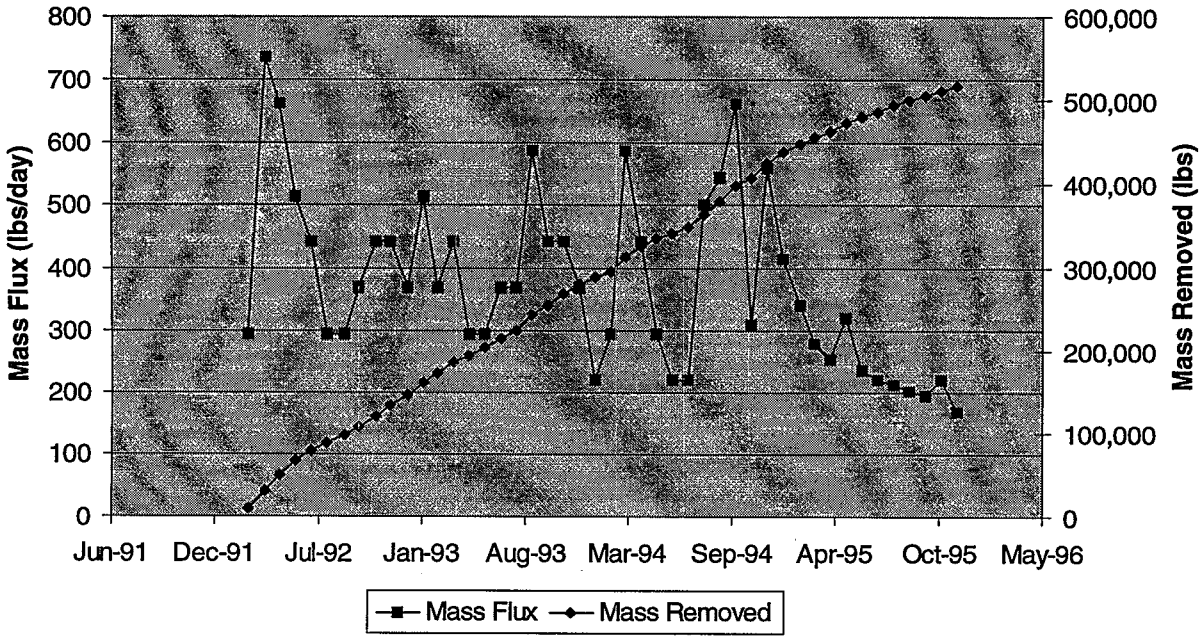

Figure 5. Mass Flux Rate and Cumulative Contaminant Removal (1992 - 1995) [15,16]

Performance Data Completeness

- Monthly data on treatment performance are available in annual groundwater monitoring reports.
- Monthly influent rates to the treatment plant and yearly average total organic carbon (TOC) data were provided by the site contact in a correspondence dated April 20, 1998 [12].
- Data on groundwater concentrations were reported in figures included in the Five Year Review as well as annual groundwater reports [5, 16-18].
- Contaminant mass removal data were provided in annual monitoring reports. Mass removal was calculated with TOC data. Actual TOC composition was not available.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Quality

The QA/QC program used throughout the remedial action met the EPA and the State of Texas requirements. All monitoring was performed using EPA-approved methods, and the site contact did not note any exceptions to the QA/QC protocols.

TREATMENT SYSTEM COST

Procurement Process

FLTG was responsible for the design, construction, and operation of the remedial action at the French Limited site. Oversight was provided by EPA Region 6 and TNRCC. The EPA oversight contractor was CH2M Hill. The design, construction, operation, and maintenance contractors were ENSR, Bechtel, ROG, AHA.

Cost Analysis

- All costs for investigation, design, construction, and operation of the treatment system at this site were borne by the 76 PRPs that comprise the FLTG. Costs for the two sheet-pile walls are included under capital costs because they are an integral part of containing the groundwater contaminant plume.

Capital Costs [25]

Site Preparation	
Sitework Construction	$300,000
Site Facility	$1,250,000
Installation of wells and piping	$3,000,000
Groundwater P&T Facility	$3,500,000
Nutrient Addition Facilities	$100,000
Sheet-pile Floodwall-Lagoon	
Construction	$4,000,000
Sheet-pile Wall-DNAPL	
Construction	$230,000
DNAPL Response	$507,000
Demobilization	$2,600,000
Total Capital Cost	**$15,487,000**

Operating Costs [25]

Operations and Maintenance	$11,000,000
Admin/Site Management	
Project Coordinator	$462,000
Project Manager	$287,500
Project Control	$1,088,000
Security	$364,500
FLTG Tech. Oversight	$5,000,000
Total Operating Costs (1992-1995)	**$18,202,000**

Other Costs [25]

Design	
Engineering Design	$700,000
Engineering Design Floodwall	$260,000
Engineering Design Sheetpile Wall	$15,000

Cost Data Quality

Cost data were provided by the site contact. No independent analysis has been performed to provide quality control of cost data.

OBSERVATIONS AND LESSONS LEARNED

- Actual costs for the P&T and *in situ* bioremediation were $33,689,000 ($15,487,000 in capital costs and $18,202,000 in operating and maintenance costs) corresponding to unit costs of $110 per 1,000 gallons treated and $15 per pound of contaminant removed.

- This site met requirements specified in the ROD that allowed it to shut down the groundwater treatment system within three years of operation. Computer models predict that groundwater concentrations will meet final cleanup criteria by December 2005. Land surrounding the site has been purchased by PRPs to provide a buffer zone until the groundwater concentrations have been reduced to below cleanup criteria.

- The treatment system performance data indicate that approximately 517,000 pounds of contaminants were removed from the groundwater over three years.

- Treatment costs at this site are relatively high. This may be due, in part, to the combined efforts of a P&T system, an *in situ* bioremediation system, and source control measures. Sheet pile walls were constructed around the lagoon and the DNAPL source area at a cost of $4,230,000.

- The ROD for this site included a provision to allow for 10 years of natural attenuation to meet final remedial goals. Groundwater flow and contaminant transport models were relied upon to predict compliance within 10 years after pumping ceased.

- This treatment application was part of a multifaceted cleanup program. The remedial program at this site included source control, *in situ* bioremediation, and P&T. The site contact reported that the combination of cleanup efforts resulted in successful remediation of the site within a reasonable time frame [3].

REFERENCES

1. Correspondence between Richard Sloan, FLTG Representative, and Lynn Gilbert, Dyncorp, Inc., September 1, 1994.

2. French Buy-Out Proposal, March 12, 1996.

3. Correspondence between Richard Sloan, FLTG Representative, and David Boram, ERG, June 25, 1997.

4. Site Remediation Report, FLTG, Inc. January 16, 1995.

5. Five Year Review, CH2M Hill, January 26, 1995.

6. EPA Fact Sheet, French Ltd., November 5, 1997.

7. Cost and Performance Report, Slurry-Phase Bioremediation at the French Limited Superfund Site, U.S. EPA, March 1995.

8. FLTG Memo, "Aquifer Remediation Review, December 10-11, 1992," January 18, 1993.

9. FLTG Memo, "Pulse Pumping Plan," October 8, 1993.

10. Natural Attenuation Modeling Report, Applied Hydrology Associates, December 1995.

11. Hydraulic Characterization of a Superfund Site: Remedial Investigation Through Remedial Action, O'Hayre A.P., April 1993, Proceedings of the Georgia Water Resources Conference, April 20-21, 1993.

12. Correspondence between Richard Sloan, FLTG Representative, and Charlie Carter, ERG, April 20, 1998.

13. Evaluation of Stratigraphic Controls on DNAPL Migration, Applied Hydrology Associates, September 1995.

14. Monthly Progress Report, FLTG, Inc., December 1994.

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15. Monthly Progress Report, FLTG, Inc., July 1994.

16. Annual Groundwater Monitoring Report, December 1994, FLTG, Inc., March 1995.

17. Annual Groundwater Monitoring Report, December 1993, FLTG, Inc., March 1994.

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19. "*In situ* Bioremediation of Groundwater and Subsoils at the French Limited Site, Texas," Biotreatment News.

20. "Remediation Facilities Design Report," ENSR Consulting and Engineering, June 1991.

21. *In situ* Bioremediation at the French Limited Site, Woodward R., IGT Symposium December 11-13, 1989.

22. "French Limited: A Successful Approach to Bioremediation," Biotreatment News, December 1992.

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24. Correspondence between Richard Sloan, FLTG Representative, and Charlie Carter, ERG, April 1, 1998.

25. Correspondence between Will Schorp, FLTG Representative and Charlie Carter, ERG, April 8, 1998.

26. U.S. Environmental Protection Agency, Record of Decision, March 24, 1988.

27. Evaluation of Subsurface Engineered Barriers at Waste Sites, U.S. EPA/OERR, September 30, 1998.

28. 1995 Annual Aquifer Sampling Report, FLTG, Inc., March 1996

Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Eastern Research Group, Inc. and Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.

Pump and Treat and Air Sparging of Contaminated Groundwater at the Gold Coast Superfund Site, Miami, Florida

Pump and Treat and Air Sparging of Contaminated Groundwater at the Gold Coast Superfund Site, Miami, Florida

<table>
<tr><td>Site Name:
Gold Coast Superfund Site</td><td rowspan="2">Contaminants:
Chlorinated solvents and volatiles - nonhalogenated (toluene)
- Maximum initial concentrations were methylene chloride (100 ug/L), 1,1-DCA (2,000 ug/L), trans-1,2-DCE (3,000 ug/L), TCE (48,000 ug/L), PCE (100,000 ug/L), and toluene (545 ug/L)</td><td>Period of Operation:
7/90 - 3/94: pump and treat
11/94 - 2/95: air sparging</td></tr>
<tr><td>Location:
Miami, Florida</td><td>Cleanup Type:
Full-scale cleanup</td></tr>
<tr><td>Vendors:
Construction: Simmons Consulting, Inc.
Treatment System Vendor: Lantec
Operations: Simmons Consulting, Inc., and The Balijet Corp./Edward E. Clark Engineers-Scientists, Inc.</td><td rowspan="2">Technology:
Pump and Treat and Air Sparging
- Groundwater was extracted using five wells, located on site, at an average total pumping rate of 44 gpm
- Extracted groundwater was treated with air stripping and reinjected into the aquifer through three injection wells
- Groundwater was sparged with a portable sparger and contaminants were allowed to volatilize</td><td>Cleanup Authority:
CERCLA Remedial
- ROD Date: 9/11/87</td></tr>
<tr><td>State Point of Contact:
Marvin Collins
Florida Department of Environmental Protection (FDEP)
Tallahassee, FL
(850) 488-0190</td><td>EPA Point of Contact:
Brad Jackson, RPM
U.S. EPA Region 4
3456 Courtland Street, N.E.
Atlanta, GA 30365
(404) 562-8975</td></tr>
<tr><td>Waste Source:
Direct discharge of solvent reclamation blowdown to soil; improper storage of waste</td><td colspan="2" rowspan="2">Type/Quantity of Media Treated:
Groundwater
- 80 million gallons treated as of February 1996
- DNAPL observed in groundwater on site
- Groundwater is found at 5 ft bgs
- Extraction wells are located in one aquifer and are influenced by a nearby surface water
- Hydraulic conductivity was reported as 1,000 ft/day</td></tr>
<tr><td>Purpose/Significance of Application:
Met goals within four years of operation; included pump and treat and air sparging</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
- The remedial goal was to reduce contaminant concentrations throughout the aquifer to levels below the maximum contaminant levels (MCLs) set by the FDEP, DERM, and primary drinking water standards.
- Remedial goals were identified for 1,1-DCA (5 ug/L), trans-1,2-DCE (70 ug/L), methylene chloride (5 ug/L), PCE (0.7 ug/L), TCE (3 ug/L), and toluene (340 ug/L).
- Effluent from the treatment system was required to meet the remedial goals prior to re-injection.
- A secondary goal was identified to create an inward gradient toward the site to contain the plume.</td></tr>
</table>

Pump and Treat and Air Sparging of Contaminated Groundwater at the Gold Coast Superfund Site, Miami, Florida (continued)

Results:

- Groundwater monitoring results indicate that contaminant concentrations have been reduced below treatment goals; from 1991 to 1994, 1,961 lbs of TCE and PCE were removed from the groundwater.
- Optimization efforts were used to focus cleanup on the problem areas at the site; excavation of soil suspected to contain DNAPLs and groundwater sparging were performed to complete cleanup of problem areas.
- Performance monitoring results indicate that effluent requirements have been met throughout the operation of the treatment system.
- No contaminants were detected in downgradient monitoring wells during remedial operations, indicating that the plume was contained throughout the remedial action.

Cost:

- Actual cost data were provided by the responsible parties for this application.
- Costs for pump and treat were $694,325 ($249,005 in capital and $445,320 in O&M), which correspond to $9 per 1,000 gallons of groundwater extracted and $354 per pound of contaminant removed.

Description:

Gold Coast Oil Corporation operated as a spent oil and solvent recovery facility from 1970 to 1982. Recovery operations at the 2-acre site included distillation of lacquer thinner and mineral spirits; blowdown from these operations was discharged directly onto the soil. In 1980, the FDEP detected soil and groundwater contamination in on-site soil (heavy metals and organics) and an off-site groundwater well (VOCs). The site was placed on the NPL in September 1983 and a ROD was signed in September 1987.

Five extraction wells were constructed in the Biscayne Aquifer at the site. Three wells were installed to a depth of 15 ft, with a design yield of 10 gpm; two wells were installed to a depth of 30 ft, with a design yield of 35 gpm. Extracted groundwater was treated using two air stripping towers in series, with each tower 36 ft high, 3 ft diameter, and packed to 26 ft with IMPAC, a material that enhances stripping of VOCs from water. Treated groundwater was re-injected into the aquifer through three injection wells.

Cleanup standards were met at this site within approximately four years of operation. Cleanup was achieved after excavation of soil suspected to contain DNAPLs and groundwater sparging were performed.

SITE INFORMATION

Identifying Information:

Gold Coast Superfund Site
Miami, Florida

CERCLIS #: FLD071307680

ROD Date: September 11, 1987

Treatment Application:

Type of Action: Remedial

Period of operation: 7/90 - 3/94
(Data collected through February 1996)

Quantity of material treated during application: 80 million gallons of groundwater

Background

Historical Activity that Generated Contamination at the Site: Spent oil and solvent reclamation

Corresponding SIC Code: 4953W
(Miscellaneous Waste Processing)

Waste Management Practice That Contributed to Contamination: Direct discharge of reclamation blowdown to the soil; improper storage of waste

Location: Miami, Florida

Facility Operations: [1,7]

- Gold Coast Oil Corporation operated as a spent oil and solvent recovery facility from 1970 to 1982. Recovery operations at the 2-acre site included distillation of lacquer thinner and mineral spirits. Blowdown from these operations was discharged directly onto the soil.
- In 1980, the FDEP detected soil and groundwater contamination from sampling on-site soil and an on-site well.
- In 1981, the FDEP, DERM, and the EPA conducted soil and groundwater investigations. Soils were found to be contaminated with heavy metals and organics; groundwater was found to be contaminated with VOCs.
- In 1982, facility operations ceased. The remaining hazardous liquid and solid waste was disposed off site by the owners.
- Visibly contaminated soil was excavated from the site in 1982 and disposed off site. After excavation, the remaining soils were tested. According to the Site Closeout Report, no contamination was detected in the remaining soils [8]. Had contamination been detected, the plan was to solidify and stabilize the soils [8].
- From 1982 until 1990, additional remedial investigations were performed. As part of these investigations, 15 monitoring wells were installed at the site.
- In September 1983, the site was placed on the National Priorities List (NPL).

Regulatory Context:

- EPA issued a ROD on September 11, 1987.
- Site activities were conducted under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA) §121, and the National Contingency Plan (NCP), 40 CFR 300.

Groundwater Remedy Selection: The selected groundwater treatment was extraction of the groundwater followed by treatment using an air stripper, with treated groundwater being re-injected into the upper Biscayne Aquifer.

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Lead: EPA

Remedial Project Manager:
Brad Jackson*
U.S. EPA Region 4
3456 Courtland Street, N.E.
Atlanta, Georgia 30365
(404) 562-8975

*Indicates primary contact

State Contact:
Marvin Collins
FDEP
Tallahassee, Florida
(850) 488-0190

Treatment System Vendors:
Construction: Simmons Consulting, Inc.
Treatment System Vendor: Lantec
Operations: Simmons Consulting, Inc. and The Baljet Corporation/Edward E. Clark Engineers-Scientists, Inc.

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater

Contaminant Characterization [1,6]

Primary Contaminant Groups: Volatile organic compounds

- The groundwater contaminants of concern at the site were VOCs. The maximum initial concentrations of the VOCs detected at the site were methylene chloride at 100 µg/L; 1,1-DCA at 2,000 µg/L; trans-1,2-DCE at 3,000 µg/L; TCE at 48,000 µg/L; PCE at 100,000 µg/L; and toluene at 545 µg/L.
- The initial areal extent of the contaminant plume was estimated to be 0.87 acres, based on the 1990 plume map prepared by Edward E. Clark Engineers (EEC). Based on a plume thickness of approximately 10 feet, a porosity of 30%, the initial plume volume was estimated for this report at 2,834,700 gallons.
- Figure 1 illustrates the contaminant contours observed prior to remediation and after one year of remediation in 1991. The contaminant plume as observed during sampling events from 1991 to 1993 is illustrated in Figures 2 and 3.
- The initial concentrations of TCE and PCE detected in the groundwater were greater than 1 and 60 percent of TCE and PCE solubilities, respectively, which indicates the likely presence of a dense nonaqueous phase liquid (DNAPL) [10].
- Figures 1, 2, and 3 show the extent of DNAPL presence from 1990 to 1993, based on data from sampling events. The estimated distribution of DNAPL is labeled the DNAPL residual zone. After remediation was completed in 1994, no evidence of residual DNAPL was found. The reduction in plume size and the elimination of residual DNAPL is further discussed in the Performance Data Assessment section of this report.

MATRIX DESCRIPTION (CONT.)

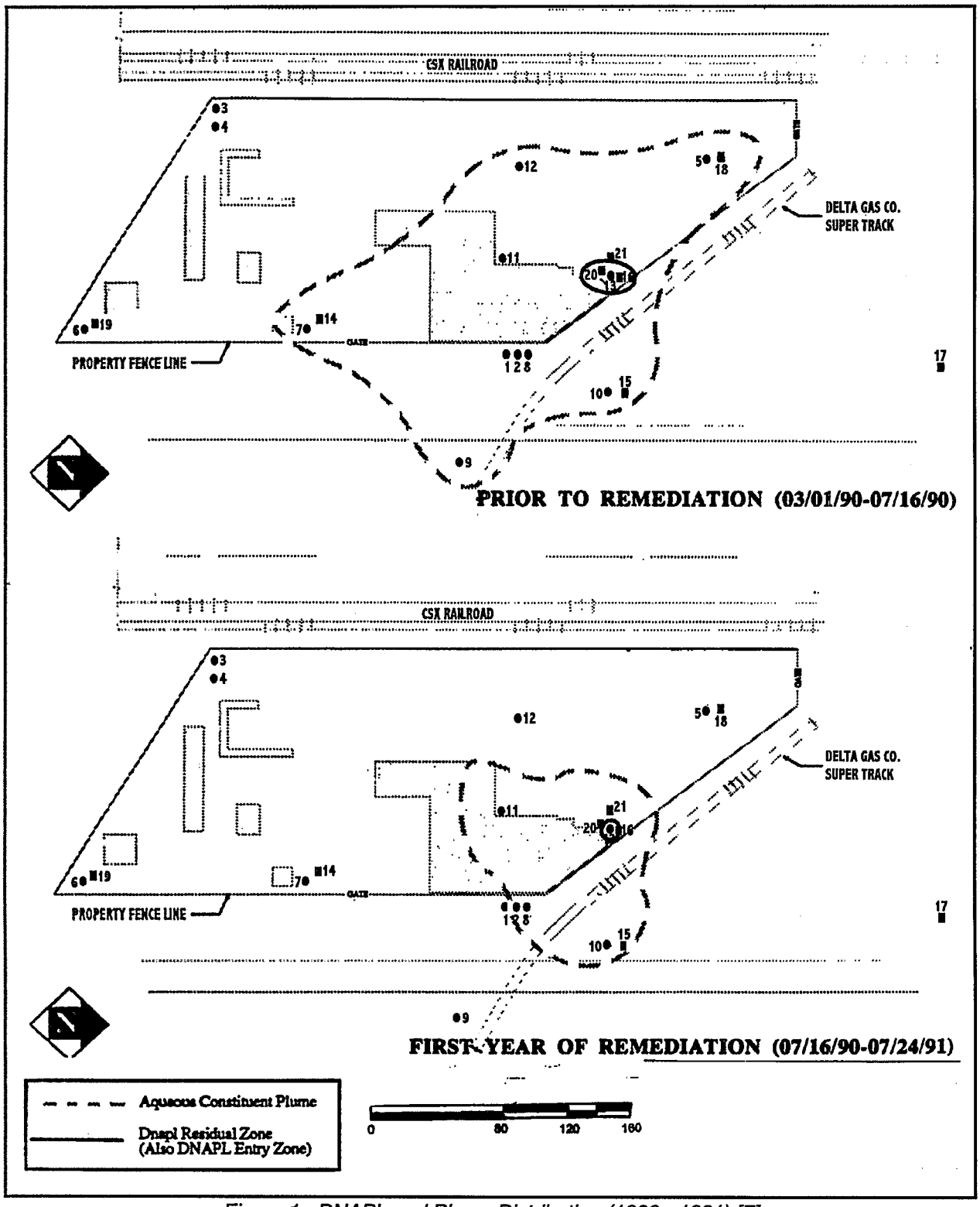


Figure 1. DNAPL and Plume Distribution (1990 - 1991) [7]

MATRIX DESCRIPTION (CONT.)

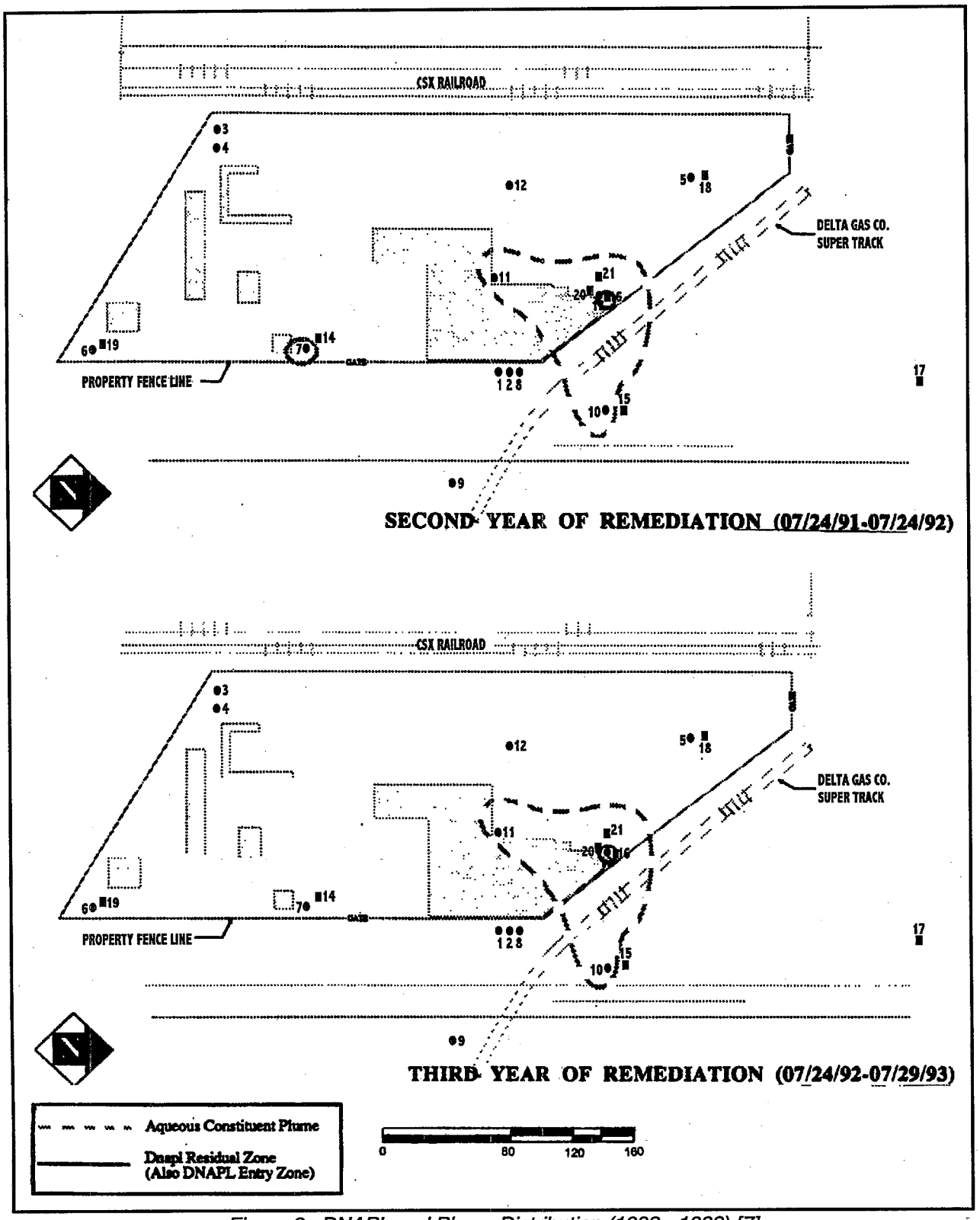


Figure 2. DNAPL and Plume Distribution (1992 - 1993) [7]

MATRIX DESCRIPTION (CONT.)

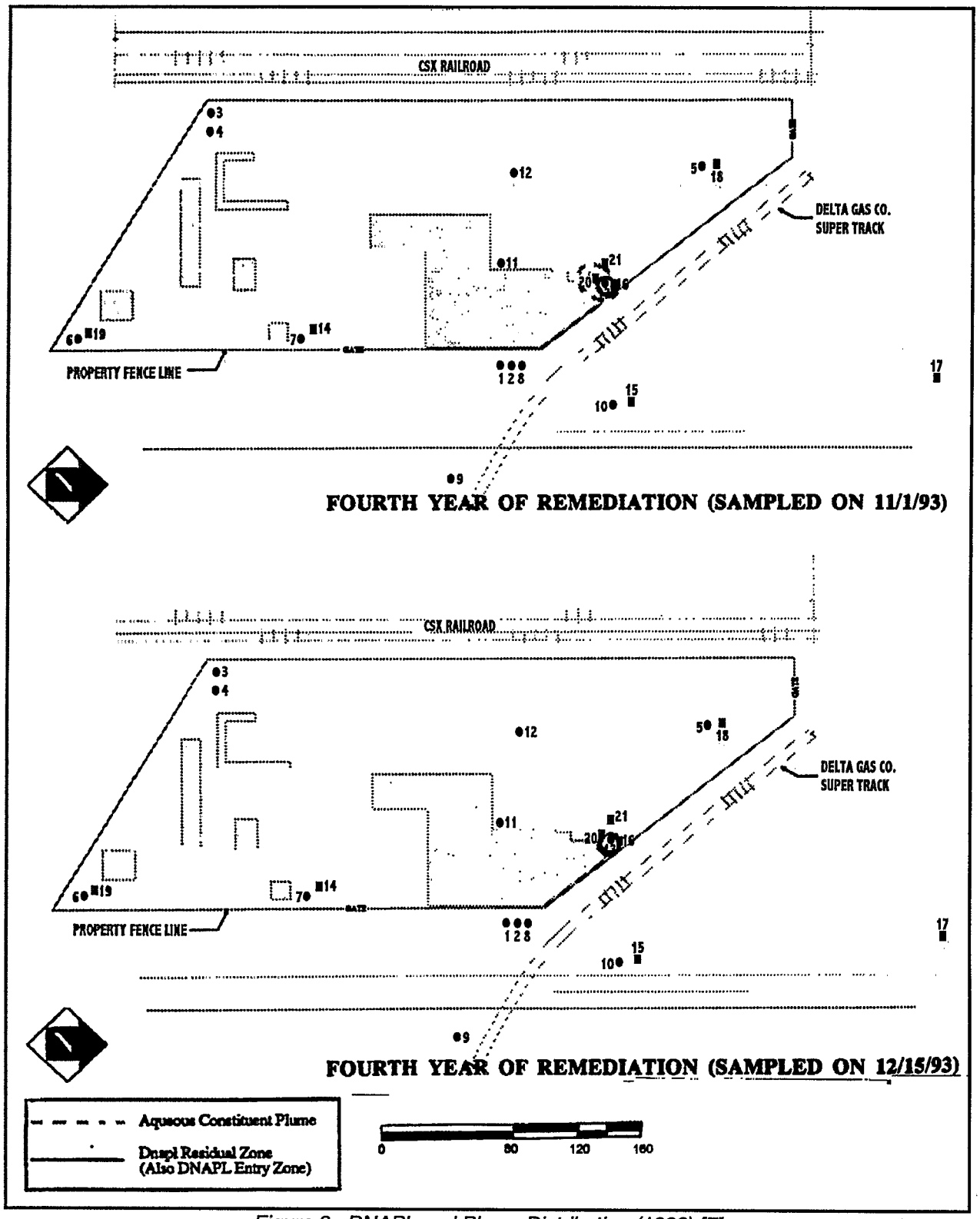


Figure 3. DNAPL and Plume Distribution (1993) [7]

Matrix Characteristics Affecting Treatment Costs or Performance

Hydrogeology [1, 2, 7]:

Two distinct hydrogeologic units have been identified beneath this site.

Unit 1	Biscayne Aquifer	The Biscayne Aquifer is the sole source of drinking water for the area. It lies approximately 5 feet below the ground surface [7]. The upper layers of the aquifer are composed of sand, shell, and unconsolidated limestone. Hard condensed limestone with layers of thick solution-riddled limestone are found in the lowest layers. The Miami Oolite and Fort Thompson formations, which consist of consolidated limestone divided by a layer of hard sand, form the base of the Biscayne Aquifer. At the site, the aquifer ranges in thickness from approximately 100 to 110 feet. Unit 1 is not hydraulically connected to the deep aquifer, Unit 2. Regionally, groundwater flow is to the east with a very low hydraulic gradient. However, groundwater flow is governed locally by the nearby Coral Gables and Tamiami Canals and will change direction depending on canal water levels [2].
Unit 2	Floridan Aquifer	The saline Floridan Aquifer is a deep aquifer separated from the Biscayne Aquifer by the Tamiami and Hawthorne Formations. The Tamiami and Hawthorne formations reach a depth of approximately 700 feet and consist of sand, silt, marl, and clay materials [2]. This aquifer has not been sampled at this site.

Tables 1 and 2 present technical aquifer information and well data, respectively.

Table 1. Technical Aquifer Information [6]

Unit Name	Thickness (ft)	Conductivity (ft/day)	Average Velocity (ft/day)	Flow Direction
Biscayne Aquifer	100 - 110	1,000[a]	2.0	East[b]
Floridan Aquifer	700	NA	NA	NA

[a] As measured by Howard Klein in *Biscayne Aquifer, Southeast Florida:* U.S. Geological Survey Water Resources Investigations Report 78-107.
[b] Groundwater flow direction is governed locally by the nearby Coral Gables and Tamiami Canals and will change direction depending on canal water levels.

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Pump and treat with air stripping

Supplemental Treatment Technology

None

System Description and Operation

Table 2. Technical Well Data [6]

Well Name	Unit Name	Depth (ft)	Design Yield (gpm)
MW-10	Biscayne Aquifer	15	10
MW-11	Biscayne Aquifer	15	10
MW-13	Biscayne Aquifer	15	10
MW-16	Biscayne Aquifer	30	35
MW-20	Biscayne Aquifer	30	35

System Description [2,3,7]

- The extraction system was a network of five extraction wells, with three wells at depths of 15 feet and two wells at depths of 30 feet. Figure 1 shows the site layout and well locations. Two of the three shallow wells, MW-11 and MW-13, were located in suspected DNAPL source zones along the western edge of the former on-site building. The two deeper wells were located in the same source zone as MW-13. The third shallow monitoring well was located along the eastern, downgradient edge of the plume. Well locations were selected to pump from the most contaminated areas and to contain the plume. The overall average pump rate, based on a 95% operation rate and a total of 80 million gallons extracted, was approximately 44 gpm.
- The treatment system consisted of two air stripping towers in series, two holding tanks, and associated pumps and valves. Each stripping tower was 36 feet high and 3 feet in diameter and packed to a height of 26 feet with IMPAC, a packing material that enhances stripping of VOCs from water.
- Groundwater was pumped through the stripping towers, into the holding tanks, and re-injected into the aquifer through three injection wells.

System Operation [6,7,8]

- Quantity of groundwater pumped from aquifer in gallons:

Year	Volume Pumped (gal)
July 1990-1991	29,736,200
1992	28,560,200
1993	20,297,890
March 1994	1,060,950

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

- From 1990 to 1994, the system was operational 95% of the time. The system was shut down for routine maintenance and during August 1992 as a result of power outages from Hurricane Andrew. The system was not damaged by the hurricane.

- Extraction wells MW-11 and MW-13 were pumped throughout system operation because they were located in suspected source zones. The other extraction wells were pumped sporadically and at lower rates.

- In July 1991, wells MW-11 and MW-13 were enlarged from 2-inch diameter to 4-inch diameter wellpoints to increase extraction rates.

- In February 1992, pumping began from MW-10.

- Because elevated levels of TCE and PCE persisted in MW-11 and MW-13, EPA and the site engineer decided to consider alternative efforts to capture further contamination. The maximum TCE and PCE levels detected during monthly sampling events persisted at levels up to 10 µg/L and 30 µg/L, respectively. (The cleanup goals were 3.0 µg/L for TCE and 0.7 µg/L for PCE.) Hydrogen peroxide was added to MW-11 and MW-13 from March through July 1993. However, the elevated contaminant levels persisted in MW-11 and MW-13, which indicated the likely presence of a subsurface source zone, or DNAPL [7].

- In August 1993, EPA and the site engineer tried another alternative. The extraction system was shut down to increase the amount of TCE and PCE desorbing from aquifer materials into the groundwater. Monitoring continued through the shutdown. The extraction system was restarted in November 1993. The mass flux into the treatment system did not increase, and it was determined the shut-down did not increase contaminant desorption. Maximum concentrations of TCE and PCE persisted at 6 µg/L and 24 µg/L.

- In March 1994, EPA decided to temporarily shut down the extraction system while monitoring continued. Through May 1994, contaminant concentrations had not increased and the groundwater treatment system was officially shut down by the EPA [7].

- In November 1994, soil in the areas of suspected DNAPL contamination was excavated around wells MW-11 and MW-13, as approved by EPA. The excavated soil tested below detection limits for PCE and TCE. The groundwater was sparged using a portable sparger and contaminants were allowed to volatilize in accordance with EPA correspondence. Subsequent testing of the groundwater in the excavations revealed that contaminant levels were below cleanup goals [7].

- Contaminant levels in monitoring wells sampled from February 1995 through April 1995 did not exceed detection limits.

- The wells were decommissioned in April 1995.

- The Close-Out Report was signed by the EPA on February 16, 1996, and the site was deleted from the NPL on August 21, 1996.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Operating Parameters Affecting Treatment Cost or Performance

Table 3 presents operating parameters affecting cost or performance for this technology.

Table 3. Performance Parameters

Parameter	Value
Average Pump Rate	44 gpm
Remedial Goal (aquifer)	same as performance standards
Performance Standard (effluent)	1,1-DCA 5.0 µg/L trans-1,2-DCE 70.0 µg/L Methylene Chloride 5.0 µg/L PCE 0.7 µg/L Toluene 340.0 µg/L TCE 3.0 µg/L

Note: Average system rate was 44 gallons per minute (gpm), based on a total of 80 million gallons pumped since operations began and a 95% operation rate.

Source: [1,2]

Timeline

Table 4 presents a timeline for this remedial project.

Table 4. Project Timeline

Start Date	End Date	Activity
09/11/87	---	ROD signed
04/89	---	683 tons of soil excavated
01/90	07/15/90	Construction of remedial system
07/90	---	Pump and treat system and quarterly monitoring begun
7/91	---	Wells 11 and 13 enlarged to 4-inch diameter wells to increase effectiveness
2/29/92	---	Pumping from MW-10 begun
10/92	---	Concrete base of MW-10 regrouted after hurricane damage
1/93	---	Contaminant levels persist and alternative efforts to increase contaminant capture considered
3/21/93	---	Hydrogen peroxide injected into wells MW-13 and MW-20
4/8/93	---	Hydrogen peroxide injected into wells MW-13 and MW-20
5/7/93	---	Hydrogen peroxide injected into wells MW-13 and MW-20
7/26/93	---	Hydrogen peroxide injected into wells MW-13 and MW-20
8/1/93	9/1/93	Groundwater extraction system operation ceased for 30-day period in attempt to increase desorption of TCE and PCE from aquifer to groundwater
91/93	11/1/93	Groundwater extraction system operation ceased for 60-day period in attempt to increase desorption of TCE and PCE from the aquifer to groundwater
3/15/94	---	Groundwater extraction system stopped operating to allow aquifer equilibration and pending stability sampling
11/94	2/95	Soil in suspected source areas excavated and backfilled with clean soil. Groundwater in open pits sparged
5/16/94	---	EPA authorizes final shutdown of pump and treat system
5/94	5/95	Aquifer stability sampling continued through quarterly monitoring
5/95	---	Wells abandoned and site officially shut down by EPA

Source: [2,4,6]

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

The remedial goal for the site was to reduce concentrations of 1,1-DCA, trans-1,2-DCE, methylene chloride, PCE, toluene, and TCE to levels below the maximum contaminant levels (MCLs) set by the DERM, FDEP, and Primary Drinking Water Standards. The required cleanup levels are listed above in Table 3 and are applied throughout the aquifer, as measured in all on-site monitoring wells [1].

Treatment Performance Goals

- Effluent discharged from the treatment system must meet the remedial goals listed in Table 3 for re-injection [1,2].
- As a secondary goal, the remedial system is designed to create an inward gradient toward the site to contain the plume [2].

Performance Data Assessment [4,5,7,8]

- Groundwater monitoring results indicate that contaminant concentrations have been reduced below treatment goals.
- Performance monitoring results indicate that effluent requirements have been met throughout the operation of the treatment system.
- No contaminants were detected in downgradient monitoring wells during the remedial operations. Based on this information, the plume was contained throughout the remedial action.
- After the first year of operation, the concentrations of all contaminants except for TCE and PCE were reduced to levels below cleanup goals. Elevated levels of TCE and PCE were detected primarily in wells MW-11 and MW-13, in the suspected DNAPL zones.
- During remedial system operations, the contaminant plume was reduced in size, as shown in Figures 1, 2, and 3. Also shown in the figures is the location of the residual DNAPL around wells MW-11 and MW-13. The estimated distribution of DNAPL residual decreased each year from 1990 until 1993. In 1994, sampling events did not indicate the presence of DNAPL.
- The performance measures for the Gold Coast system focused on TCE and PCE because they were the only contaminants remaining to be remediated after July 1991. Figure 4 illustrates PCE and TCE removal from 1991 to 1994.
- Figure 4 shows that from 1991 to 1994, 1,961 pounds of TCE and PCE were removed from the groundwater. The removal curve shows the typical flattening that indicates a reduction in removal efficiency beginning in the first year and continuing through the remaining system operation. In addition, Figure 4 shows that the mass flux rate declined from 3.4 lbs/day during the first year to 0.006 lbs/day in the final year.
- Figure 5 shows the average levels of TCE and PCE detected in groundwater from March 1990 until February 1995. Average contaminant concentrations in the groundwater declined from 176 µg/L of PCE to 8 µg/L of PCE and from 88 µg/L of TCE to 9 µg/L of TCE in the first year. Contaminant levels were elevated primarily in wells MW-11 and MW-13. By May 1991, the average PCE and TCE concentrations had leveled off, illustrating that the pump and treat system was not as effective in decreasing TCE and PCE concentrations.

TREATMENT SYSTEM PERFORMANCE (CONT.)

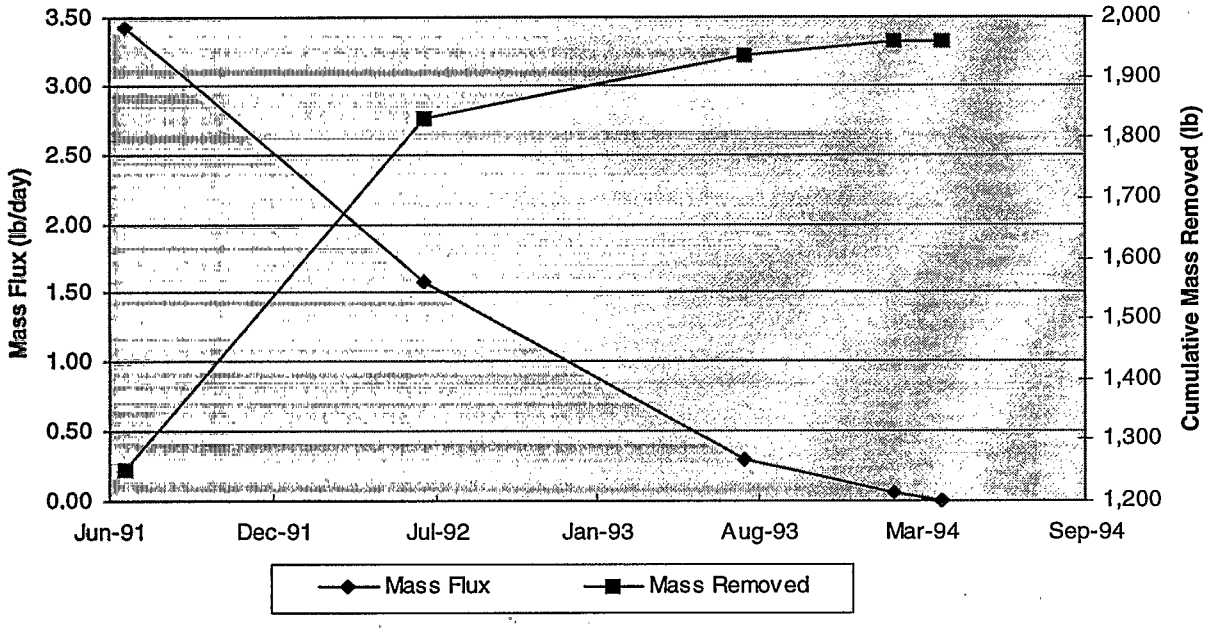


Figure 4. TCE and PCE Mass Flux Rate and Cumulative TCE and PCE Removal (July 1991 to March 1994) [4, 5]

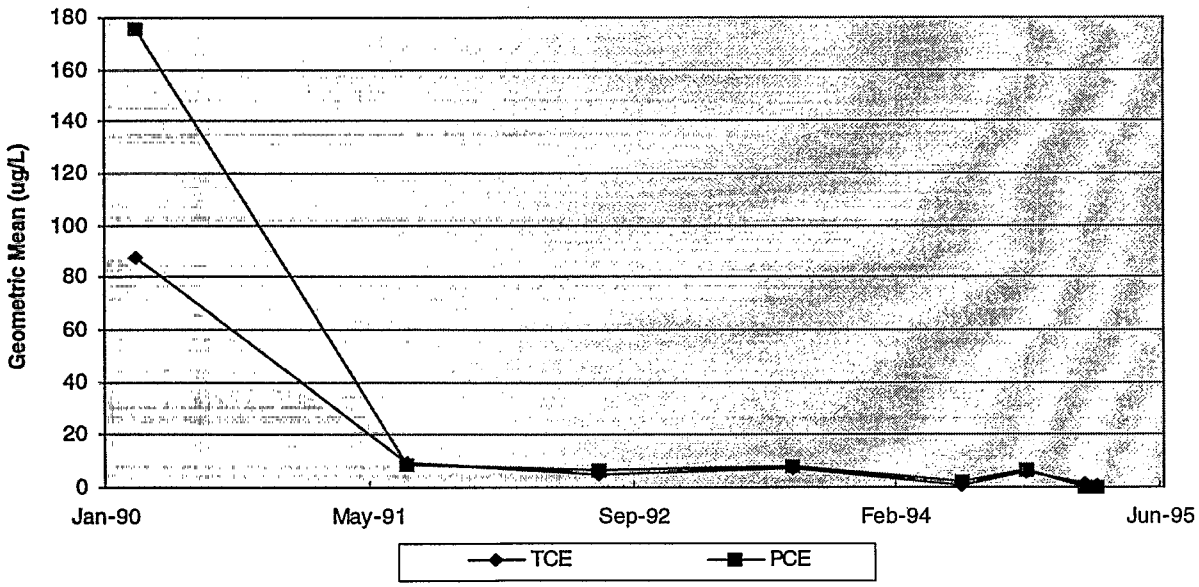


Figure 5. Average TCE and PCE Concentrations in the Groundwater [4, 5]

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (Cont.)

- Figure 6 illustrates the TCE and PCE levels detected in extraction well MW-11 from March 1990 until April 1995. Contaminant levels declined from 89 µg/L of PCE to 13 µg/L of PCE and from 34 µg/L of TCE to 19 µg/L of TCE in the first year of remediation, but levels of contamination above MCLs persisted through 1995.
- Figure 7 illustrates TCE and PCE levels detected in extraction well MW-13 from July 1991 until February 1995. Just as with MW-11, contaminant levels declined from 44,000 to 680 µg/L of PCE and from 1,700 µg/L to 210 µg/L of TCE in the first year of remediation, but levels of contamination above MCLs persisted through 1995. PCE levels fluctuated from below detection limits in June 1994 to 94.9 µg/L in October 1994.

Performance Data Completeness

- For the contaminant concentrations in Figures 5, 6, and 7, annual monitoring data were used. Monthly monitoring data are available from the site contact.
- A geometric mean of contaminant concentrations was used to represent the trend of contaminant concentrations across the site.
- Contaminant mass removal depicted in Figure 4 was determined using analytical results from extraction wells and well extraction flow rate data. Well data on an annual basis were used. The mass removal is, therefore, a best estimate based on available data. Contaminant concentrations in the influent and effluent to and from the treatment system were not available, because all information was archived.

Performance Data Quality

The QA/QC program used throughout the remedial action met the EPA and the FDEP requirements. All monitoring was performed using EPA-approved methods, and the vendor did not note any exceptions to the QA/QC protocols [4].

TREATMENT SYSTEM PERFORMANCE (CONT.)

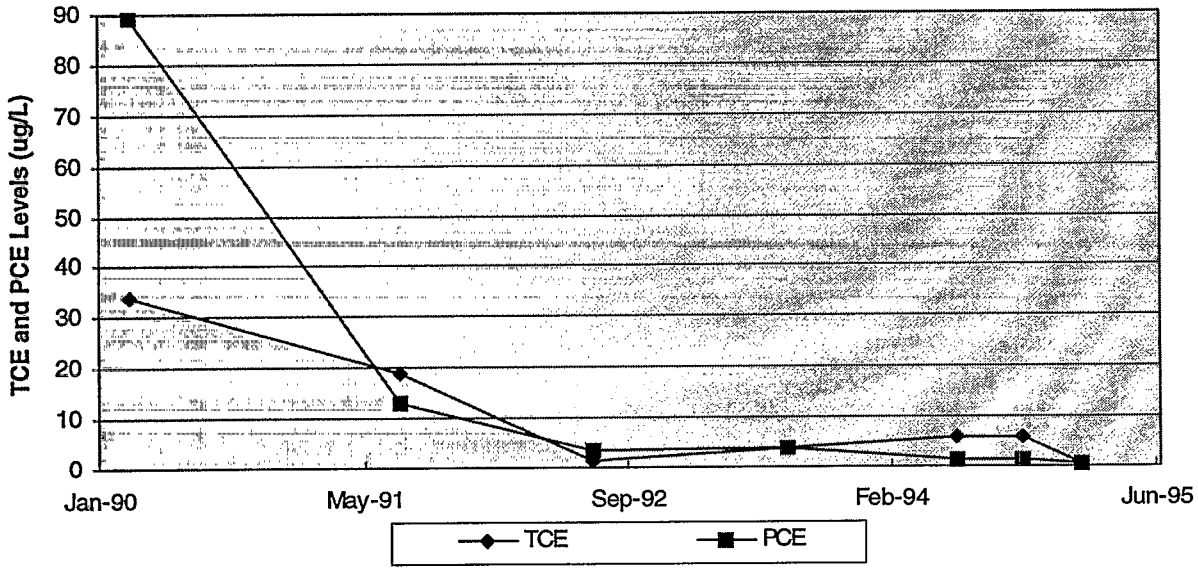
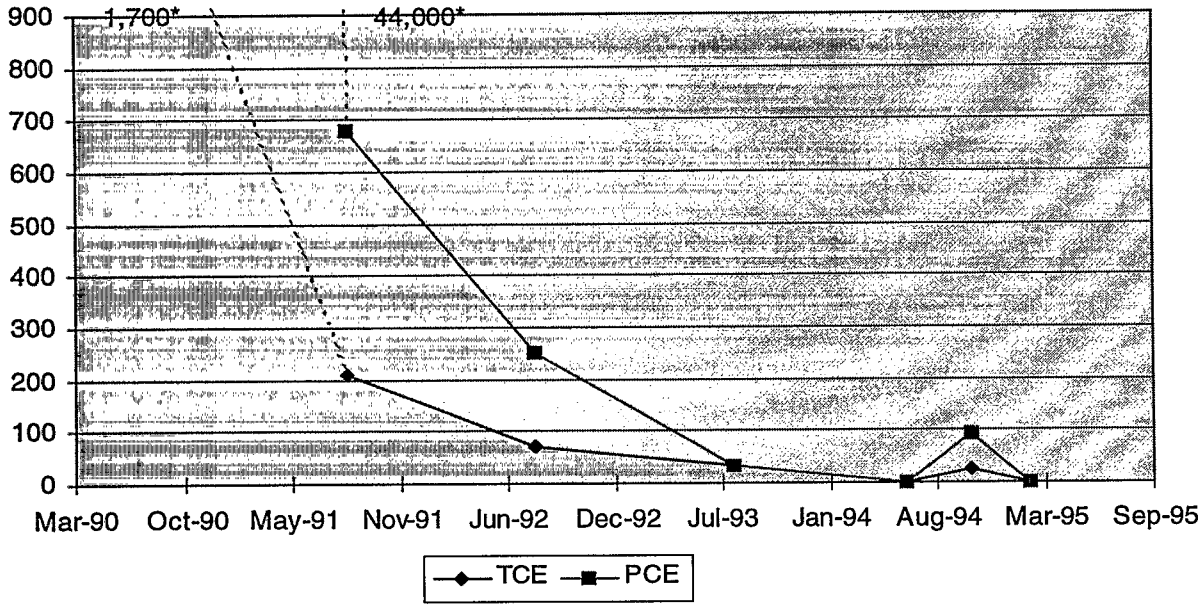


Figure 6. TCE and PCE Concentrations Detected in MW-11 [4, 5]



* Concentrations detected during March 1990

** MCLs not shown because of scale limitations

Figure 7. TCE and PCE Concentrations Detected in MW-13 [4, 5]

Treatment System Cost

Procurement Process

The group of responsible parties contracted with a private consulting firm to construct and operate the remedial system, under the oversight of EPA.

Cost Analysis

All costs for investigation, design, construction, and operation of the treatment system at this site were borne by the group of responsible parties.

Capital Costs [9]

Remedial Construction	
Startup	$14,700
Analytical Costs	$8,220
Tower and Packing	$77,110
Tower Installation	$6,350
Well Installation	$36,855
Construction Management	$105,770
Total Construction	**$249,005**

Operating Costs [9]

Operation and Maintenance	$196,050
Utilities	$19,820
Analyses	$36,950
Pump Replacement	$10,060
Periodic Maintenance	$182,440
Cumulative Operating Expenses	**$445,320**

Other Costs [9]

Remedial Design	$183,290

Cost Data Quality

Actual capital and operation and maintenance cost data are available from the responsible parties for this application.

Decommissioning costs were not available. No other costs were incurred that affected cost by greater than 10%.

Observations and Lessons Learned

- Actual costs for the pump-and-treat application at Gold Coast were approximately $694,325 ($249,005 in capital costs and $445,320 in annual operation and maintenance costs), not including design costs, which corresponds to $354 per pound of contaminants removed and $9 per 1,000 gallons of groundwater treated.
- The cleanup standards were met at this site within approximately four years [8]. Within the first year of operation, the contaminant levels at the site had been reduced below cleanup goals with the exception of TCE and PCE. Only two monitoring wells were found to have consistently elevated levels of TCE and PCE. Extraction was then focused in the area of the two wells [6]. This optimization of extraction well management allowed cleanup to focus on the problem areas.

OBSERVATIONS AND LESSONS LEARNED (CONT.)

- When pump-and-treat did not quickly reduce the concentrations of TCE and PCE in the groundwater, two alternative actions were evaluated - hydrogen peroxide injection and stopping extraction for three months to allow contaminants to desorb from aquifer materials. However, these actions did not reduce the levels of TCE and PCE, indicating they were not as effective as sparging in quickly removing persistent volatile organics from the groundwater given relatively simple hydrogeology [6].

- The pattern of persistent and fluctuating contaminant levels observed in MW-11 and MW-13 was indicative of a possible subsurface source area or DNAPL presence. Cleanup was not achieved until soil in the areas suspected to contain DNAPL was excavated and the groundwater sparged. Because the soil tested clean, it is likely that the source of the persistent elevated TCE and PCE levels was removed through sparging. The excavation likely helped volatilize contaminants from the groundwater to the open air.

- The porous limestone at the site allowed groundwater to be extracted without clogging the wells and enabled easier installation of wells. Deep wells installed in bedrock or harder subsurface environments could have increased cost [6].

REFERENCES

1. Record of Decision, U.S. EPA, September 11, 1987.
2. Remedial Design/Remedial Action Report, The Baljet Corporation, November 1990.
3. Well Installation Plan, EEC, May 1989.
4. Monthly Reports, through Clark Engineers-Scientists, November 1991 through May 1995.
5. Technical Impracticability Evaluation for Further Groundwater Restoration, The Baljet Corporation, February 24, 1994.
6. Five-Year Review, U.S. EPA, November 1994.
7. Site Close-out Report, Edward E. Clark Engineers-Scientists, Inc. January 18, 1995.
8. Gold Coast Close Out Report, U.S. EPA, February 1996.
9. Correspondence with Mr. Larry Kirsch and Mr. Al Simmons, previous site contacts.
10. Dense Nonaqueous Phase Liquids, Halin, Scott G. and J.W. Weaver. U.S. EPA, March 1991.
11. Groundwater Regions of the United States. Heath, Ralph. U.S. Geological Survey Water Supply Paper 2242, 1984.

Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Eastern Research Group and Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.

Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the Libby Groundwater Superfund Site, Libby, Montana

Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the Libby Groundwater Superfund Site, Libby, Montana

<table>
<tr>
<td>Site Name:
Libby Groundwater Superfund Site</td>
<td rowspan="2">Contaminants:
Semivolatiles - halogenated (PCP); and PAHs
- Maximum concentrations detected during 1986 RI/FS were PCP (3,200 ug/L), acenaphthene (100 ug/L), acenaphthylene (200 ug/L), benzo(a)anthracene(1 ug/L), and naphthalene (500 ug/L)</td>
<td>Period of Operation:
Status: Ongoing
Report covers: September 1991 through December 1996</td>
</tr>
<tr>
<td>Location:
Libby, Montana</td>
<td>Cleanup Type:
Full-scale cleanup (interim results)</td>
</tr>
<tr>
<td rowspan="2">Vendor:
Design: Woodward-Clyde Consultants
4582 South Ulster Street
Stanford Place 3, Suite 1000
Denver, CO 80237
Operations:
Ralph Heinert
Champion Intl. Corp.
Highway 2 South
P.O. Box 1590
Libby, MT 59923
(406) 293-6238</td>
<td rowspan="2">Technology:
Pump and Treat and In Situ Bioremediation
- Groundwater is extracted using 5 wells (3 of which are no longer in service), at an average total pumping rate of 16 gpm
- NAPLs are separated from the extracted groundwater, and the groundwater is then routed to 2 fixed-film bioreactors in series
- Nutrients (nitrogen and phosphorus) are added prior to bioreactors and oxygen is added within the bioreactors
- Treated water is reinjected through 2 gravity injection systems (9 wells total)</td>
<td>Cleanup Authority:
CERCLA Remedial
- ROD Date: 12/30/88</td>
</tr>
<tr>
<td>State Point of Contact:
Neil Marsh
Montana DEQ
Remediation Division
(406) 444-0487</td>
<td>EPA Point of Contact:
Jim Harris, RPM
U.S. EPA Region 8
301 S. Park Drive
P.O. Box 10096
Helena, MT 59626
(406) 441-1150 ext. 260</td>
</tr>
<tr>
<td>Waste Source:
Improper storage and disposal of wood preserving products</td>
<td colspan="2" rowspan="2">Type/Quantity of Media Treated:
Groundwater
- 15.1 million gallons treated as of December 1996
- DNAPL and LNAPL observed in several monitoring wells on site
- Groundwater is found at 10-20 ft bgs
- Extraction wells are located in 1 aquifer, which is influenced by a nearby surface water and production wells
- Hydraulic conductivity ranges from 100 to 1,000 ft/day</td>
</tr>
<tr>
<td>Purpose/Significance of Application:
Combination of pump and treat and in situ bioremediation at site with LNAPL, DNAPL, and dissolved-phase contaminants.</td>
</tr>
</table>

Pump and Treat and In Situ Bioremediation of Contaminated Groundwater at the Libby Groundwater Superfund Site, Libby, Montana (continued)

Regulatory Requirements/Cleanup Goals:

- Remedial goals, developed based on a risk assessment and updated MCLs, were established for non-carcinogenic PAHs: naphthalene (1,460 ug/L), acenaphthene (2,100 ug/L), fluorene (1,460 ug/L), anthracene (11,000 ug/L), pyrene (1,100 ug/L), and fluoranthene (1,460 ug/L); carcinogenic PAHs: benzo(a)anthracene (0.1 ug/L), chrysene (0.2 ug/L), benzo(b)fluoranthene (0.2 ug/L), benzo(a)pyrene (0.2 ug/L), dibenzo(a,h)anthracene (0.3 ug/L), and indeno(1,2,3-cd)pyrene (0.4 ug/L); arsenic (50 ug/L); benzene (5 ug/L); and PCP (1 ug/L).
- The goal of the source area extraction system is to remove oil-contaminated groundwater and NAPL from the area of the waste pit and remove as much NAPL as possible.
- The goal of the in situ bioremediation and pump and treat system is to reduce PAH and PCP concentrations in the upper aquifer to levels below remedial goals.

Results:

- As of December 1996, concentrations in many parts of the plume had declined to either remedial goals or detection limits. However, there are areas of groundwater contamination in which levels of PAHs and PCP remain near original levels.
- DO levels have been measured as an indication of the extent of influence on the intermediate injection system and as an indicator for PAH and PCP in the groundwater.
- The source area treatment system had removed 37,570 pounds of PAHs from the groundwater from 1992 to 1996.

Cost:

- Estimated costs for treatment through 1996 were $5,628,600 ($3,010,000 in capital and $2,618,600 in O&M), which correspond to $374 per 1,000 gallons of groundwater extracted and $150 per pound of contaminant removed. These costs do not account for the volume of groundwater treated or the mass removed through in situ bioremediation. No estimates have been made for these two items.

Description:

The Libby Montana site has been used as a lumber mill and wood-treating facility since 1946. From 1946 to 1969, the site used various compounds, including creosote and PCP, in their wood-treating operations. The mill was operated by the St. Regis Company until 1985 when it was purchased by Champion International. In 1979, homeowners detected a creosote odor in their well water. EPA monitoring in 1981 confirmed groundwater contamination from the Libby site. The site was placed on the NPL in September 1983 and a ROD was signed in December 1988.

The remedial strategy at this site was to address the source area by removing NAPL and to stimulate bioremediation in the down-gradient upper aquifer plume. The three components to the aquifer remedial system are a source area extraction system, intermediate injection system, and boundary injection system. As of December 1996, concentrations in many parts of the plume had declined to either remedial goals or detection limits. However, there are areas of groundwater contamination in which levels of PAHs and PCP remain near original levels. The site operators believe that no additional modifications could be made to improve the system's performance or to reduce the time required to remediate the intermediate injection area.

SITE INFORMATION

Identifying Information:

Libby Groundwater Site
Libby, Montana

CERCLIS #: MTD980502736

ROD Date: December 30, 1988

ESD Date: (1) September 4, 1993, (2) January 22, 1997

Treatment Application:

Type of Action: Remedial

Period of operation: September 1991 - Ongoing (Performance data collected through December 1996)

Quantity of material treated during application: As of December 31, 1996, 15.1 million gallons of groundwater were treated.

Background [1,2]

Historical Activity that Generated Contamination at the Site: Lumber Mill - Wood Preserving

Corresponding SIC Code: 2491 (Wood Preserving - Creosote & Pentachlorophenol)

Waste Management Practice That Contributed to Contamination: Improper storage and disposal of wood preserving products.

Location: Libby, Montana

Operations:

- The Libby, Montana site has been used as a lumber mill and wood-treating facility since 1946. From 1946 to 1969, the site used various compounds, including creosote and pentachlorophenol (PCP) in their wood-treating facility. The mill was operated by the St. Regis Company until 1985 when it was purchased by Champion International.
- The area around the facility includes residential areas and businesses. The site is bordered on the west by Flower Creek, on the east by Libby Creek, and on the north by the Kootenai River. The contaminated soil and source area is within the confines of the site. The groundwater contamination extends into the City of Libby, located less than 1,000 feet downgradient.
- In 1979, homeowners detected a creosote odor in their well water. EPA monitoring in 1981 confirmed groundwater contamination from the Libby site.
- The site was placed on the National Priorities List (NPL) on September 8, 1983.
- Source removal activities included the excavation of approximately 67,000 cubic yards of soil and debris. The rock and debris were physically separated from the soils, resulting in 45,000 cubic yards of contaminated soils, which were treated through land treatment.
- A Phase IV remedial investigation/feasibility study (RI/FS) report was prepared by Woodward-Clyde Consultants in July 1986. Field operations were conducted from May 1985 to February 1986. The September 1986 Record of Decision (ROD) provided an alternate water supply to residents whose wells were contaminated through a Buy Water Plan. In a second ROD in December 1988, final remedial actions for contaminated groundwater included pump and treat and *in situ* bioremediation.
- An Explanation of Significant Differences (ESD) was issued in 1997 to change the remedial goals to reflect new information on exposure levels for several contaminants of concern.

SITE INFORMATION (CONT.)

Background (Cont.)

Regulatory Context:

- In 1983, St. Regis and EPA signed an Administrative Order on Consent for the company to study contamination at the site. Champion International purchased the St. Regis Corporation in 1985 and has taken over its obligations to the Order. In 1989, EPA and Champion signed a Consent Decree in which the company agreed to pay the U.S. Government past and future oversight costs and to complete implementation of the remedial action. A construction completion approval was obtained in late 1993.
- A ROD for the Upper Aquifer operable unit was signed on December 30, 1988.
- Site activities are conducted under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA) §121, and the National Contingency Plan (NCP), 40 CFR 300.

Remedy Selection:
The remedy for contaminated groundwater includes *in situ* bioremediation and groundwater extraction and treatment via an oil water separator and an above-ground fixed-film bioreactor.

Site Logistics/Contacts

Site Lead: PRP

Oversight: EPA

Remedial Project Manager:
Jim Harris*
U.S. EPA - Region 8
301 S. Park Dr.
P.O. Box 10096
Helena, MT 59626
(406) 441-1150 ext. 260

State Contact:
Neil Marsh
Montana Department of Environmental Quality (MDEQ)
Remediation Division
(406) 444-0487

* Indicates primary contacts.

Treatment System Design:
Woodward-Clyde Consultants
4582 South Ulster Street
Stanford Place 3, Suite 1000
Denver, CO 80237

Facility Operations:
Ralph Heinert*
Champion International Corporation
Corporate Environmental
Highway 2 South
P.O. Box 1590
Libby, MT 59923
(406) 293-6238 phone
(406) 293-5415 fax

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater

Contaminant Characterization

Primary Contaminant Groups: Polycyclic aromatic hydrocarbon (PAH) compounds and pentachlorophenol (PCP).

The contaminants described here are limited to those found in the Upper Aquifer. Contamination has migrated to the Lower Aquifer but remedial actions are limited to the Upper Aquifer. Remediation of the Lower Aquifer was addressed in a 1993 ESD.

- The primary contaminants of concern include PAH compounds (both carcinogenic and noncarcinogenic) and PCP (Appendix A presents the levels of contaminants of concern detected in private groundwater wells in 1986).
- Maximum concentrations found during the 1986 RI/FS were: pentachlorophenol (3,200 µg/L), acenaphthene (100 µg/L), napthalene (500 µg/L), acenapthylene (200 µg/L), and benzo(a)anthracene (1 µg/L) [1].
- The areal extent of the contaminated groundwater plume was estimated in 1992 to be 1.2 miles long and cover approximately 232 acres [3]. The contaminant plume was estimated to contain as much as 2.2 million gallons of free product [4]. Figures 1 through 3 depict the areal extent of groundwater contamination from carcinogenic PAHs, noncarcinogenic PAHs and PCP, respectively, as measured in July 1992.
- Nonaqueous phase liquids (NAPLs), both dense and light, have been consistently observed in monitoring wells in the source area and downgradient of the intermediate injection system. In a 1997 report, site engineers stated that the NAPL in the upper aquifer appears to exist as free-phase product in small pools, trapped between strata or as a residual phase trapped in pore spaces [4].

Matrix Characteristics Affecting Treatment Costs or Performance

Hydrogeology:
Groundwater is present at this site in a highly transmissive aquifer, and is encountered at approximately 10 to 20 feet below land surface (bls). Groundwater flows through the alluvial valley formed by the Kootenai River. To identify different zones of contamination, the aquifer has been divided into two primary units. The upper aquifer, also referred to as the upper saturated unit, is formed of highly transmissive deposits of unconsolidated, interbedded gravel, sand, and clay. The upper aquifer extends to 60 to 70 feet bls and flows from the site north and northwest toward the City of Libby. The deposits are predominantly clean to silty gravel and sand with occasional interbedded layers approximately 2 to 10 feet thick containing clay and silt. From 70 to 110 feet bls, the deposits consist of silt and clay with interbedded layers of clean to silty gravel and sand. These deposits form a discontinuous aquitard, separating the upper aquifer from the lower. The lower aquifer is found at approximately 110 feet bls and extends to approximately 160 to 180 feet bls. The lower aquifer is composed of clean to silty gravel and sand layers, interbedded with clay and silt layers, extending to bedrock [2].

MATRIX DESCRIPTION (CONT.)

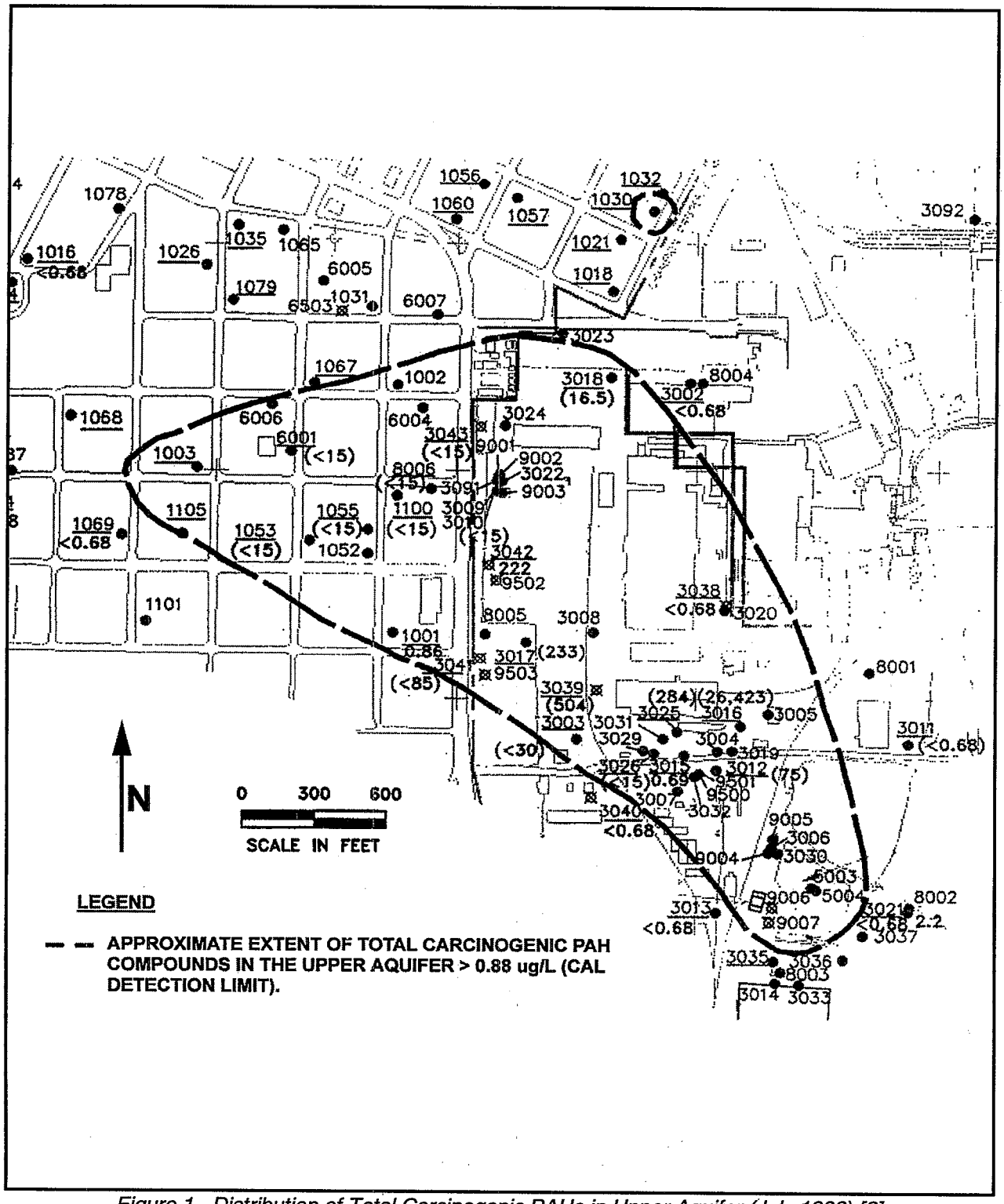


Figure 1. Distribution of Total Carcinogenic PAHs in Upper Aquifer (July 1992) [2]

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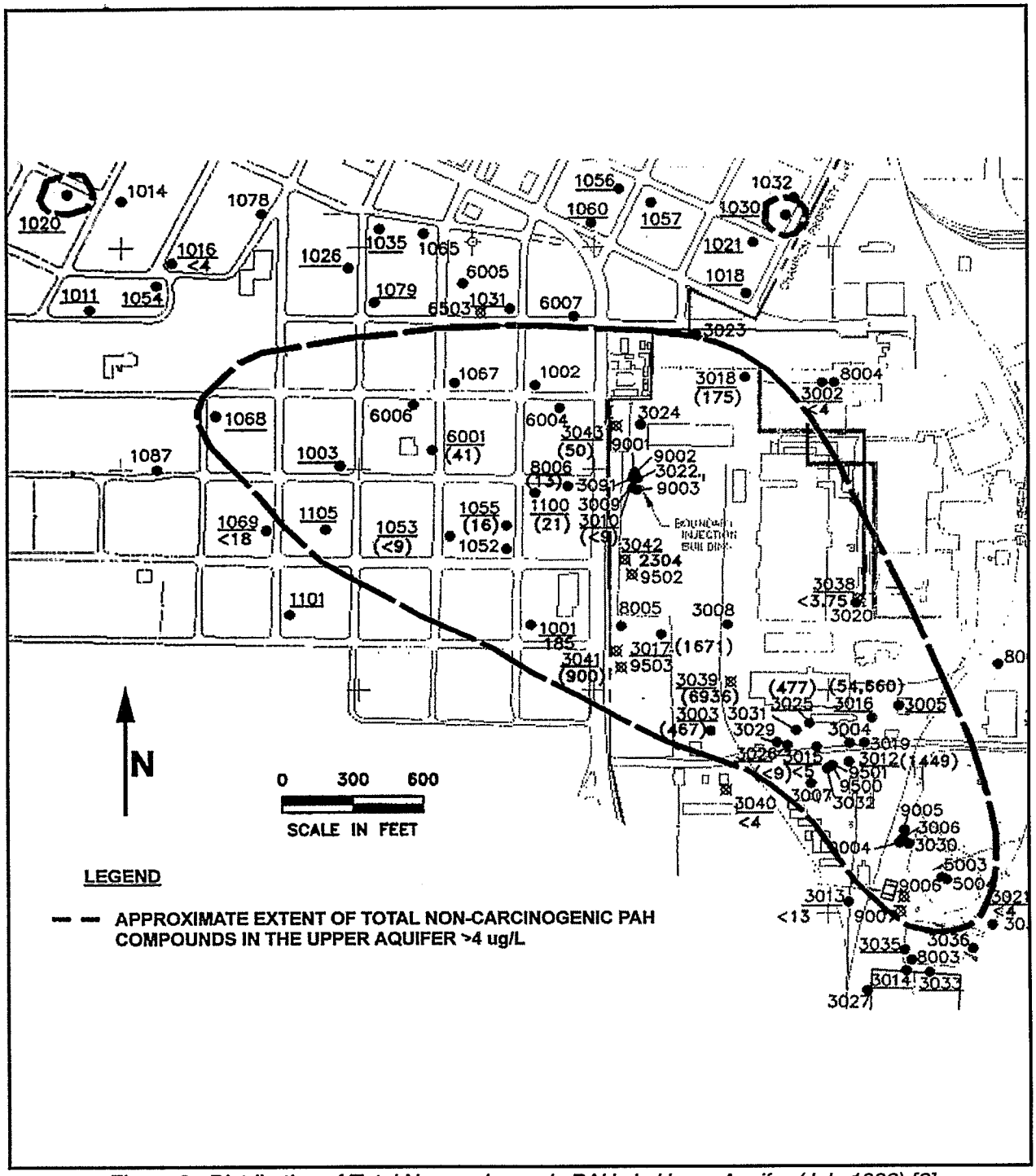

Figure 2. Distribution of Total Noncarcinogenic PAHs in Upper Aquifer (July 1992) [2]

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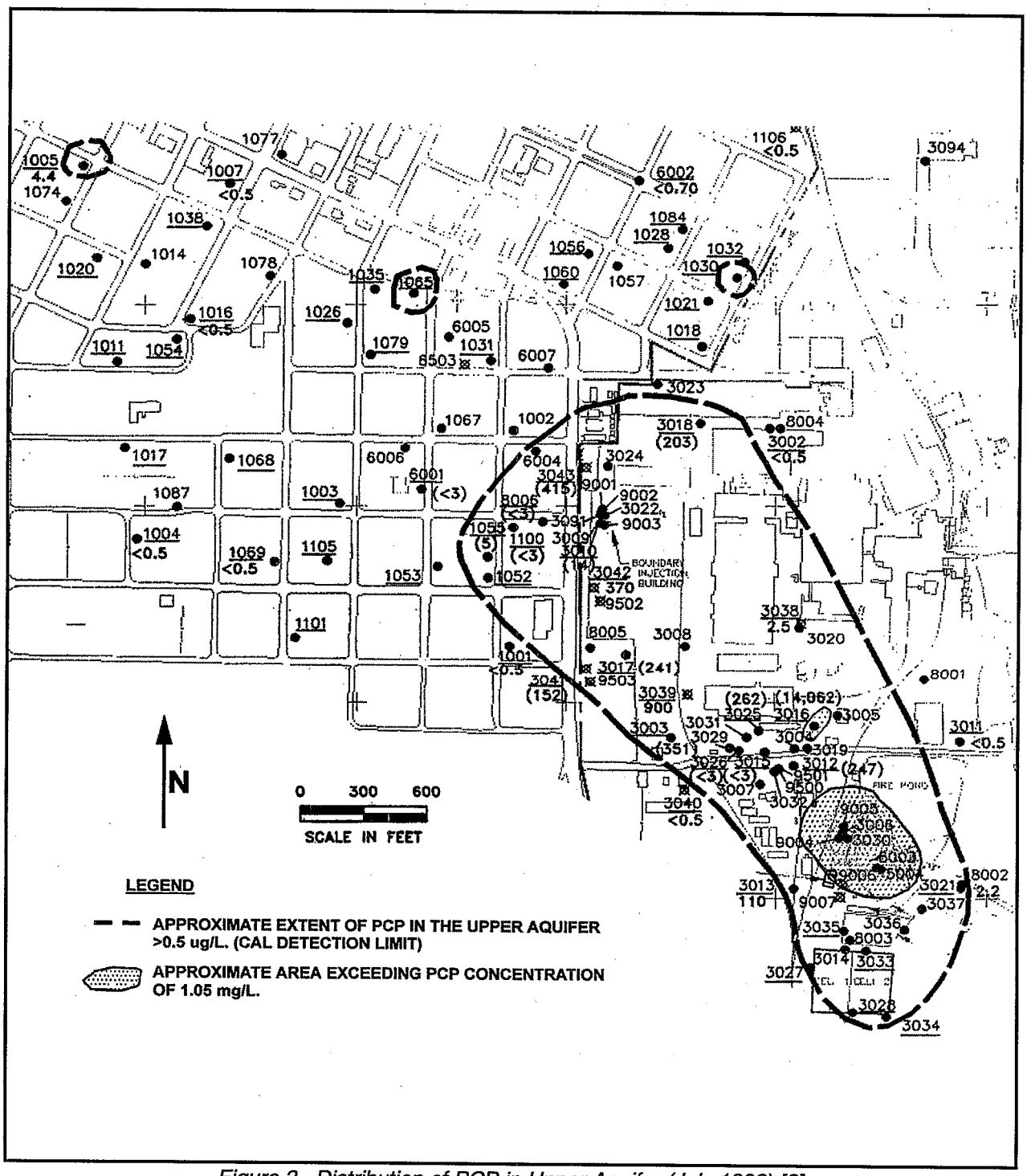


Figure 3. Distribution of PCP in Upper Aquifer (July 1992) [2]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Costs or Performance (Cont.)

Table 1 presents technical aquifer information.

Table 1. Technical Aquifer Information

Unit Name	Thickness (ft)	Conductivity (ft/day)	Average Velocity (ft/day)	Flow Direction
Upper Aquifer	15-70	100 - 1,000	**3-10**	North-Northwest
Lower Aquifer	160-180	100	**<3**	North-Northwest

Source: [5,6]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

In situ bioremediation and pump and treat (P&T) consisting of an oil/water separator followed by two fixed-film bioreactors in series

Supplemental Treatment Technology

None

System Description and Operation

Tables 2 and 3 provide technical information about the extraction and injection wells used at this site, respectively.

Table 2. Extraction Well Data

Well Name	Unit Name	Depth (ft)	Design Yield (gal/min)
9006	Deeper portion of Upper Aquifer	67-73	16
9008	Deeper portion of Upper Aquifer	76	6

Note: Average system extraction rate was 6.6 gpm (currently operating at 16 gpm).

Source: [5,6]

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

Table 3. Injection Well Data

Well Name	Unit Name	Depth (ft)	Design Injection Rate (gal/min)
Intermediate Injection System			
3004-1	Upper Aquifer	18-21	27
3004-2	Upper Aquifer	34-37	2
3007-1	Upper Aquifer	20-23	3
3007-3	Upper Aquifer	42-45	1
9500	Upper Aquifer	45-65	10
9501	Upper Aquifer	18-38	50
Boundary Injection System			
9001	Upper Aquifer	25-40	67
9502-1	Upper Aquifer	20-40	50
9502-2	Upper Aquifer	46-56	50
9503-1	Upper Aquifer	19-39	50
9503-2	Upper Aquifer	45-55	15

Source: [5,6]

System Description

- The remedial strategy at this site was to address the source area by removing NAPL and to stimulate bioremediation in the downgradient upper aquifer plume. An Applicable or Relevant and Appropriate Requirements (ARAR) waiver has been granted for the lower aquifer due to the technical impracticability of remediating NAPLs and the low likelihood that the lower aquifer poses a risk to human health and the environment [6].

- There are three components to the upper aquifer remedial system at the Libby site: source area extraction system, intermediate injection system, and boundary injection system shown in Figure 4. The components were constructed in phases beginning in late 1989 and were finished in early 1993 [4,5].

- The source area extraction and treatment system consists of extraction wells, an oil/water separator, nutrient addition, and two fixed-film bioreactors, operated in series. The system extracts heavily contaminated groundwater from the upper aquifer, separates the NAPL from the water in the oil/water separator, adds nutrients to the extracted groundwater, and then treats the dissolved-phase contamination in bioreactors. From the bioreactors, the effluent is discharged to infiltration trenches. The objective of the system is to remove NAPL from the upper aquifer to improve the performance of the naturally occurring *in situ* biodegradation downgradient of the source area [5].

TREATMENT SYSTEM DESCRIPTION (CONT.)

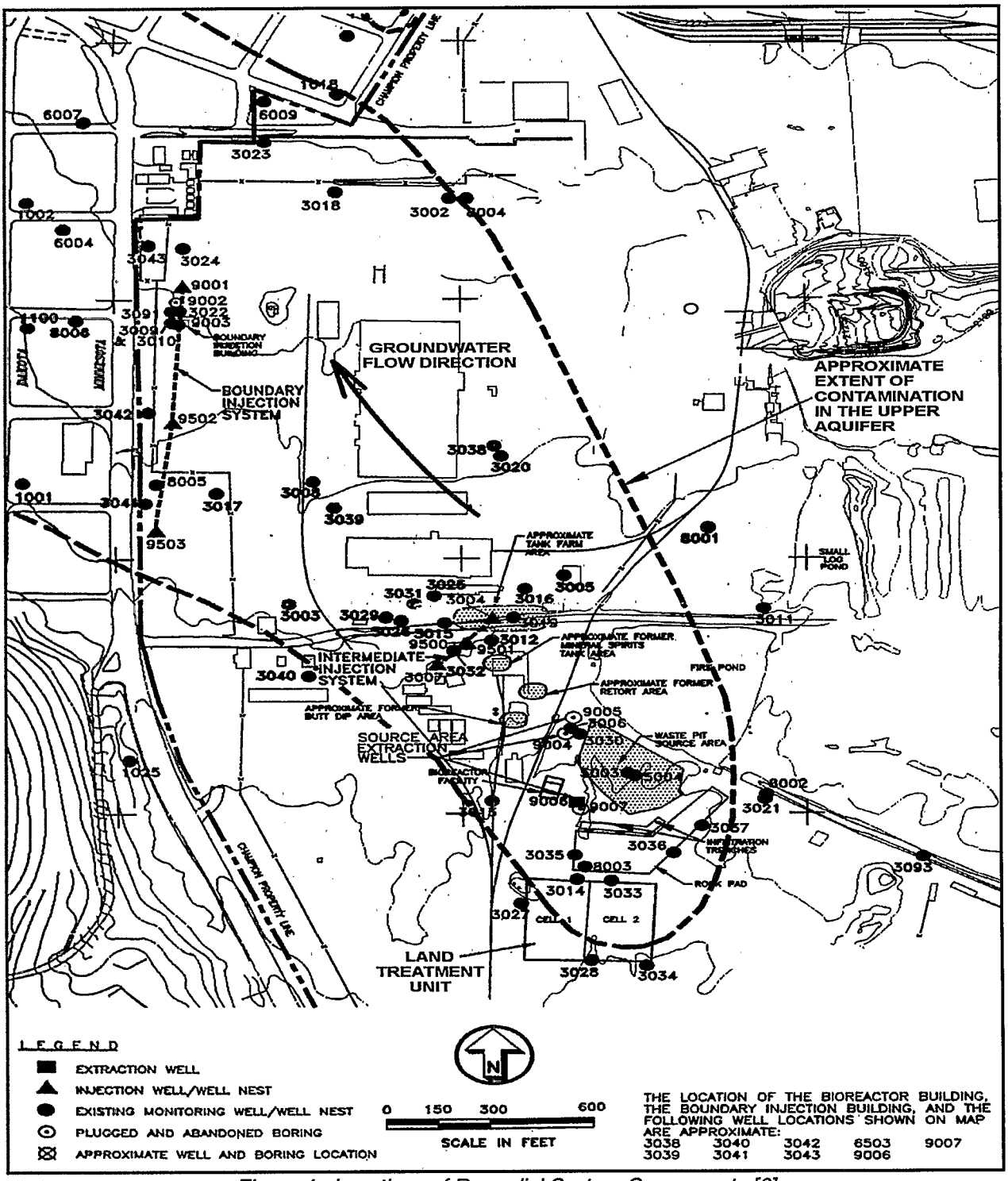


Figure 4. Locations of Remedial System Components [6]

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

- Five extraction wells were installed at different depths in the upper aquifer in the source area. Four of these wells were completed as two-well pairs, with one well of each pair screened in the shallow portion of the upper aquifer and the other well screened in the lower portion. This well design allows flexibility in selecting the best pumping scenario. As of 1998, only two wells remain in service, extracting approximately 16 gpm.

- The extracted groundwater flows to a 10,000-gallon oil/water separator where floating and sinking NAPLs are removed. The tank is eight feet in diameter and 26 feet long. From the separator, the process water flows to the bioreactors. Liquid nutrients are added to the process water before it enters the bioreactors. Oxygen is added through an aeration system within each bioreactor [5].

- The bioreactor units consist of two 10,000-gallon tanks filled with a polyethylene media. The process water from the oil/water separator is heated in the first bioreactor to 22° Celsius to stimulate biological activity. The polyethylene media is designed to provide surface area on which the biofilm forms. Contaminants are adsorbed onto the biofilm where they become a food source for the microbes. Byproducts of aerobic biodegradation are carbon dioxide, water, and additional biomass [5].

- The first reactor reduces the concentrations in the process water by 70 to 80 percent. The process water then flows to the second tank where most of the remaining contaminants are removed. The elevated level of oxygen in the bioreactors re-oxygenates the effluent before it is discharged to the infiltration trenches [5].

- The *in situ* bioremediation system consists of two gravity injection systems--the intermediate and boundary injection systems--through which oxygen and nutrients are added to the Upper Aquifer. The intermediate injection system consists of six wells, and the boundary injection system consists of three wells [4, 5].

- The source of water for injection is an on-site pond. Hydrogen peroxide was initially used to oxygenate the water and was added at a rate of 100 mg/L. However, when the boundary system was installed in early 1993, alternative oxygenation methods were investigated to lower costs of operations. As a result, a U-Tube oxygenator system and a bubbleless aeration system were installed. Based on its success, this method also replaced the hydrogen peroxide method used in the intermediate injection system [5].

- Nutrients (nitrogen and phosphorous) are added to the water for the intermediate injection system to maintain levels of 2.4 mg/L and 1 mg/L, respectively in the injection water [5]. During the design of the boundary system, it was found that sufficient levels of nutrients already were present in the groundwater, originating from natural sources or migrating from the intermediate system wells; therefore, the addition of nutrients was not necessary for this system.

- The monitoring plan at this site requires sampling of the extraction well system, the *in situ* system, and the monitoring wells for the intermediate and boundary systems. Water levels, concentrations of contaminants, and geochemical parameters, such as temperature, dissolved oxygen levels, and nutrients, are monitored. Twenty-three wells are sampled annually for PAHs and PCP. Twenty-one wells are monitored monthly for dissolved oxygen and water levels [5].

- There is an on-site laboratory that performs wet chemistry. Most PAH and PCP analyses are performed on site, but some contaminant analyses are performed by an off-site commercial laboratory for quality assurance purposes [5]. Dissolved oxygen (DO) analyses are performed in the field with direct reading instruments.

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

System Operation

- Quantity of groundwater pumped from aquifer from 1992 to 1996:

Year	Total Volume Pumped (gal)	Average Pump Rate (gal/min)
1992	4,355,000	8.4
1993	2,620,000	5.6
1994	1,100,000	2.2
1995	3,470,000	6.6
1996	3,520,000	7.5
Total	15,065,000	6.1

Source: [2, 6, 7, 8, 9]

- The source area extraction system has operated nearly continuously since operations began. There were some interruptions to system operations because of several failures of the Protec pump, such as drive-rod breakage and gear box failure. The percentage of time that the system has operated ranges from 89 to 100 [6].

- The intermediate and boundary injection systems have been in near-continuous operation from mid-1990 through December 1996 [2, 6, 7, 8, 9].

- The intermediate injection system operates at an average rate of 70 gpm, and nutrients are added to the injection water to maintain levels of approximately 2.4 mg/L nitrogen and 1 mg/L phosphorus. The level of DO is maintained at approximately 40 mg/L [2,6,7,8,9].

- The boundary injection system operates at an average rate of 232 gpm; no nutrients are added. Dissolved oxygen levels are maintained at approximately 51 mg/L [2,6,7,8,9].

- PAH removal occurs primarily in the first fixed film bioreactor; PCP removal occurs primarily in the second reactor [4].

- During 1992, a study was performed to optimize the temperature of the bioreactors to lower the cost of their operation. The results indicated that there was no difference in performance between 22° and 30° Celsius. The temperature in the bioreactors was lowered to 22° Celsius [6].

- During the summers of 1992 and 1993, efforts were made to expand the capacity of the source area treatment system. Two different fixed film bioreactors were tested and both were successful in expanding the treatment capacity. However, it was determined that it was more cost-effective to improve the efficiency of the system by improving the performance of the oil/water separator. Consequently, the tests on the growth bioreactors were stopped, and several studies were undertaken to improve the performance of the separator. [6]

- Studies to improve the performance of the oil/water separator included adding dissolved-air flotation and flocculation, and lengthening retention times. The studies showed that the performance of the separator improved when droplet size increased. A positive-displacement, progressive-cavity pump was installed, which increased NAPL droplet size by reducing the extent of shearing produced by the pump [6].

- A review of the monitoring data from the intermediate injection system wells in 1992 revealed a negative correlation between DO levels and concentrations of PCP and PAHs. On this basis, samples taken from intermediate system wells from 1993 onward were analyzed for DO, and not PCP and PAHs. If DO levels change significantly, samples will be analyzed for PCP and PAHs to directly measure the change in groundwater quality [6].

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

- In May 1993, the hydrogen peroxide injection system for the intermediate injection system was replaced with a bubbleless aeration system. The bubbleless aeration system was pilot-tested over the previous year to measure its cost and performance. The site engineer determined that a cost savings could be achieved, without a loss in performance [6].

- In 1996, three of the four original source area extraction wells were abandoned because they were no longer removing NAPL. In December 1996, a fifth well was installed to increase the removal of NAPL from the source area groundwater [6].

- During 1996, the facility operator tested a Protec pump in one extraction well to evaluate the pump's ability to reduce emulsification of NAPL, and improve the performance of the oil/water separator. The original pump operated at 3,450 rpm, a speed at which free product was being emulsified and resisted gravity separation. The Protec pump, operating at 350 rpm, significantly reduces emulsification in the well [7]. The Protec pump, however, has not been able to operate for extended periods of time without malfunctions.

- According to the RPM, a Phase II design report for the upper aquifer was submitted in April 1997 and a Technical Impracticability (TI) report is currently being prepared. At this time, no "additional groundwater treatment activities are anticipated" [11].

Operating Parameters Affecting Treatment Cost or Performance

The major operating parameter affecting cost or performance for this technology is the pumping rate. Table 4 presents the average pumping rate and other performance parameters.

Table 4. Performance Parameters

Parameter	Value	
Average Pump Rate	6.6 gpm	
Performance Standard (Effluent)	**Non-carcinogenic PAH Compounds**	
	Napthalene	1,460 µg/l
	Acenaphthene	2,100 µg/l
	Fluorene	1,460 µg/l
	Anthracene	11,000 µg/l
	Pyrene	1,100 µg/l
	Fluoranthene	1,460 µg/l
Performance Standard (Effluent)	**Carcinogenic PAH Compounds**	
	Benzo(a) anthracene	0.1 µg/l
	Chrysene	0.2 µg/l
	Benzo(b)fluoranthene	0.2 µg/l
	Benzo(a)pyrene	0.2 µg/l
	Dibenzo(a,h)anthracene	0.3 µg/l
	Indeno(1,2,3-cd)pyrene	0.4 µg/l
	Arsenic	50 µg/l
	Benzene	5 µg/l
	Pentachlorophenol	1 µg/l
Remedial Goals (Aquifer)	Same as above	

Source: [6]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Timeline

Table 5 presents a timeline for this remedial project.

Table 5. Project Timeline

Start Date	End Date	Activity
7/87	4/88	Pilot scale test for *in situ* bioremediation conducted
12/88	---	ROD signed
1/90	1/91	Demonstration program for *in situ* bioremediation conducted
1/90	8/91	Phase I Remedial Design conducted
1991	---	Remedial construction performed
2/91	---	Operations for source area extraction system begun
1996	---	Three wells abandoned; one new well installed; change in pump speed tested
1997	---	ESD signed; remedial goals revised

Source: [2, 4, 6]

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards [1]

- The remedial goals were revised in the 1997 ESD to reflect a recent risk assessment and updated MCLs. Table 4 presents the revised goals.

Additional Information on Goals [4]

- The cleanup goals for this site were originally established in the December 1988 ROD based on achieving a 10^{-5} risk level in the groundwater. At that time, the limit set for total noncarcinogenic PAHs was 400 ng/L, and 40 ng/L for total carcinogenic PAHs.

Treatment Performance Goals [6]

- The goal of the source area extraction system is to remove oil-contaminated groundwater and NAPL from the area of the waste pit and remove as much NAPL as possible.
- The goal of the *in situ* bioremediation and P&T system is to reduce PAH and PCP concentrations in the upper aquifer to levels below remedial goals.

Performance Data Assessment

Total PAHs include napthalene, acenapthylene, acenapthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo(g,h,i)perylene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene, indeno(1,2,3-cd)pyrene.

- As of December 1996, concentrations in many parts of the plume had declined to either remedial levels or detection limits. However, there are areas of groundwater contamination in which levels of PAHs and PCP remain near original levels.
- As discussed in System Operation, DO levels have been monitored to evaluate the extent of the influence of the intermediate injection system and as an indicator measure for PAH and PCP levels in the groundwater. Background levels for DO at this site range from 3.0 mg/L to 4.2 mg/L (DO levels in contaminated groundwater are typically less than 1 mg/L). Decreases in

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (Cont.)

DO levels indicate that increased contaminant concentrations are depleting available DO faster than it can be supplemented from the injection system.

- Figure 5 shows DO concentrations in three of the 18 wells that are used to monitor the progress of the intermediate injection system. These three wells are located within 600 feet of the injection system, which is the limit of the influence of the intermediate injection wells. In these and five other wells, PAH and PCP concentrations have declined to either remedial goals or below detection limits. The spikes and troughs seen in these graphs do not necessarily directly correspond with a decline or increase in PAH or PCP levels. According to the site engineers, an order of magnitude change in DO concentrations is required before a "significant" change in groundwater quality would be indicated [4, 6].

- In the remaining 11 wells used to monitor the performance of the intermediate injection system, PAH and PCP concentrations have shown little decline from original levels [4].

- Figure 6 shows trends in PCP, PAH, and DO levels in one of the wells used to monitor the progress of the boundary injection system. DO levels in this well and nine other boundary injection system monitoring wells have increased. In most wells, a corresponding decrease in PAH and PCP concentrations, such as that shown in Figure 6, has been observed. By September 1996, PCP and PAH concentrations were not detected in seven and eight of the 10 wells, respectively. However, because the remedial goals for PCP and carcinogenic PAHs are below the on-site laboratory detection limit, data from the on-site laboratory do not indicate whether remedial goals have been met in these wells [4].

- According to the Phase II Design Report, migration in the PAH and PCP plumes had ceased by the end of 1996. The site engineers believe that an equilibrium has been reached between the advection, dispersion, and degradation of PAHs and PCP in the aquifer and the rate of dissolution of those compounds in the source areas [4].

- The source area treatment system removed a total of 37,570 pounds of PAHs from the groundwater from 1992 to 1996. Of the two components of the treatment system, the oil/water separator removed a total of 23,200 pounds of PAHs, while the bioreactor degraded 14,370 pounds [4].

Performance Data Completeness [4]

- A total of 42 monitoring wells are sampled annually for PAHs and PCP.

- Bimonthly DO analyses are performed in each of the monitoring wells. Samples are taken from the influent and effluent of the treatment system on a weekly basis and analyzed for PAHs, PCP, and DO.

Performance Data Quality [4]

Analyses for PAHs and PCP are performed using modified EPA Methods 8100 and 8040, respectively. The on-site laboratory was used for the majority of analyses required for this site.

The QA/QC program used throughout the remedial action met the EPA and the State of Montana requirements. All monitoring is performed using EPA-approved methods, and the site contact did not note any exceptions to the QA/QC protocols.

TREATMENT SYSTEM PERFORMANCE (CONT.)

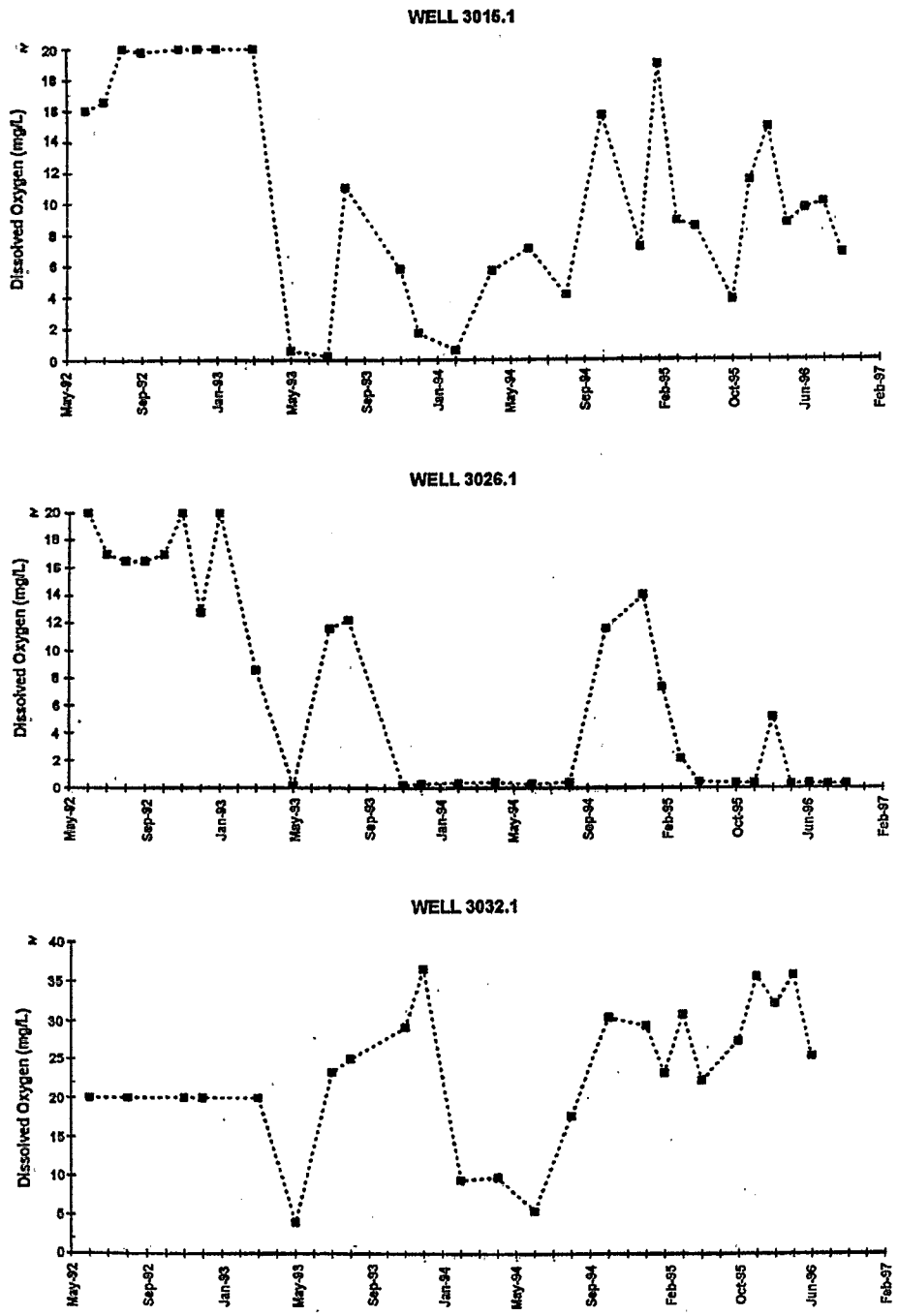
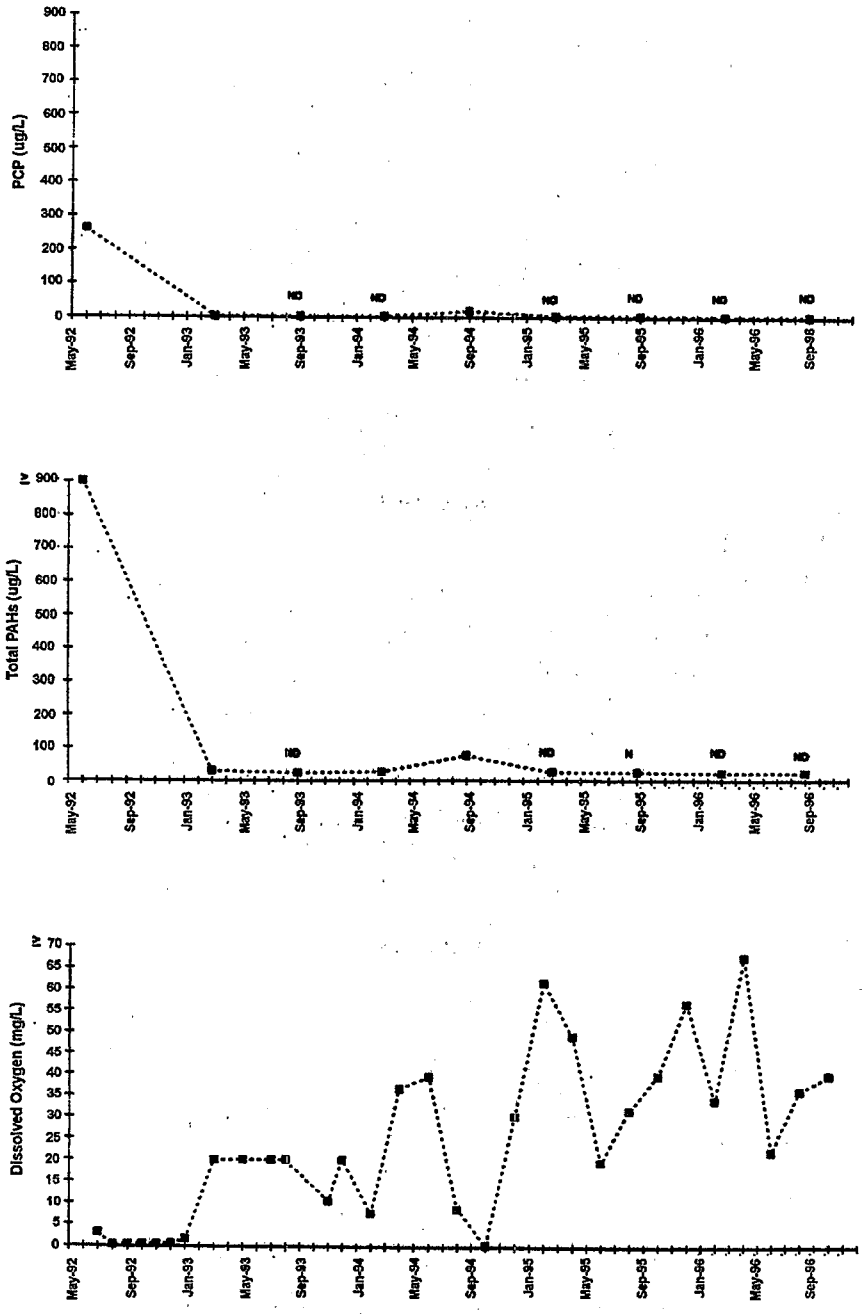


Figure 5. Dissolved Oxygen Concentrations in Three Intermediate Monitoring Wells [6]

TREATMENT SYSTEM PERFORMANCE (CONT.)



ND = NOT DETECTED

Figure 6. Graphs of PCP, Total PAH, and Dissolved Oxygen in One Boundary Monitoring Well 3042.2 [6]

TREATMENT SYSTEM COST

Procurement Process

Champion International Corporation, in cooperation with EPA Region 8, leads the remedial activities for the Libby Site. Woodward-Clyde Consultants provides design and oversight services for Champion. The remedial activities at the site are part of a performance evaluation of groundwater biological treatment processes (bioremediation) being conducted by the U.S. EPA National Risk Management Research Laboratory (Scott Huling) and Utah State University.

Cost Analysis [10]

- All costs for design, construction and operation of the treatment system at this site are borne by Champion International Corporation.

Capital Costs

Remedial Construction	
Engineering and Site Services	$1,050,000
Construction	$700,000
Sample Analysis/Data Management	$210,000
Drilling and Sampling	$140,000
Equipment/Supplies	$910,000
Total Remedial Construction	**$3,010,000**

Operating Costs

1989-92 Operations and Services	$980,000
1993 Operations	$437,000
1994 Operations	$363,400
1995 Operations	$418,200
1996 Operations	$420,000
Total Operations 1989 - 1996	**$2,618,600**
Average Annual Operating Expenses	**$327,300**

Other Costs

Remedial Design	$350,000

Cost Data Quality

Estimated capital and operating and maintenance cost data were available from Champion International. Limited information on the items included in the total project costs was provided. To date, including RI/FS and EPA oversight, over $14 million was spent in total for this site.

OBSERVATIONS AND LESSONS LEARNED

- Estimated costs incurred through 1996 were $5,628,600 ($3,010,000 in capital costs and $2,618,600 in operating and maintenance costs). This corresponds to $374 per 1,000 gallons treated and $150 per pound of contaminant removed. These costs do not account for the volume of groundwater treated or the mass removed through *in situ* bioremediation. No estimates have been made of the mass of PAHs and PCP that have been degraded through *in situ* bioremediation [10].
- The selection of the Protec pump for the source area extraction wells had an impact on the overall cost of the system. Each pump cost approximately $10,000, and two were purchased. The pumps cannot be run for extended periods of time without malfunctions, which has interrupted the operation of the source area treatment system. Prior to the use of Protec pumps, standard centrifugal pumps were used at this site. The use of standard centrifugal pumps with rotation speeds of 3450 rpm did not let the oil settle in the extraction wells because droplets were too small [4].

OBSERVATIONS AND LESSONS LEARNED (CONTINUED)

- The adoption of a U-Tube oxygenator system and a bubbleless aeration system for the two injection systems proved to be a cost-effective alteration to the systems [4].
- To avoid clogging with biological growth, two infiltration trenches were constructed and used alternately, allowing one to dry while the other was in use [4].
- According to the 1997 Phase II Design report, the NAPL pools in the upper aquifer will dissolve slowly. The time required to dissolve a NAPL pool depends on the contaminant. According to the Design Report, it would take 270 years to dissolve the PCP, 75 years for naphthalene, and 110,000 years for benzo(a)pyrene [4].
- The site operators believe that no additional modifications could be made to improve the systems performance and to reduce the time required to remediate the intermediate injection area. The individual systems are operating as expected [4].

REFERENCES

1. Superfund Record of Decision for Libby Groundwater Contamination Site, U.S. EPA, December 30, 1988.
2. 1992 Annual Operations Report For The Upper Aquifer, Woodward-Clyde Consultants, February 28, 1993.
3. Performance Evaluation of Bioremediation: *In situ* Bioremediation of the Upper Aquifer. Utah Water Research Laboratory, Utah State University, May 1997, unpublished.
4. Upper Aquifer Phase II Design Assessment Report Libby Superfund Site, Woodward-Clyde Consultants, April 1997.
5. Remedial Design Report Upper Aquifer Operable Unit Libby Groundwater Site Libby, Montana, Woodward-Clyde Consultants, August 1991.
6. 1996 Annual Operations Report For The Upper Aquifer, Woodward-Clyde Consultants, February 1997.
7. 1995 Annual Operations Report For The Upper Aquifer, Woodward-Clyde Consultants, February 1996.
8. 1993 Annual Operations Report For The Upper Aquifer, Woodward-Clyde Consultants, February 28, 1994.
9. 1994 Annual Operations Report For The Upper Aquifer, Woodward-Clyde Consultants, February 28, 1995.
10. Remedial Cost Report provided by Champion International Corporation, June 1997.
11. Comments on draft report from Jim Harris, EPA RPM, July 1, 1998.
12. Comments on draft report from Ralph Heinert, Champion International Corp., July 8, 1998.

Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Eastern Research Group, Inc. and Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.

Appendix A
Contaminants Detected in Private Groundwater Wells As Reported in the 1986 ROD

Contaminant of Concern	Maximum Concentration (µg/L)
Arsenic	5
Zinc	1,400
Copper	160
Chromium	10
Lead	30
Nickel	29
Pentachlorophenol (PCP)	3,200
Napthalene	500
Acenapthylene	200
Acenapthene	100
Fluorene	48
Phenanthrene	212
Anthracene	15
Fluoranthene	93
Pyrene	44
Chrysene	5
Benzo(a)anthracene	1
1-methyl napthalene	250
2-methyl napthalene	43
Benzene	20
Toluene	51
Carcinogenic PAHs	93

Permeable Reactive Barrier to Treat Contaminated Groundwater at the Moffett Federal Airfield, Mountain View, California

Permeable Reactive Barrier to Treat Contaminated Groundwater at the Moffett Federal Airfield, Mountain View, California

Site Name:
Moffett Federal Airfield

Location:
Mountain View, California

Contaminants:
Chlorinated solvents
- Maximum concentrations detected during 1991 investigations include TCE (20,000 ug/L) and PCE (500 ug/L)

Period of Operation:
Status: Ongoing
Report covers: 4/96 - 7/97

Cleanup Type:
Voluntary pilot-scale study

Vendor:
Tim Mower
Tetra Tech EM Inc.
1099 18th Street, Suite 1960
Denver, CO 80202
(303) 312-8874
Chuck Reeter
Naval Facilities Engineering Service Center
1100 23rd Ave., Code 411
Port Hueneme, CA 93043-4370
(805) 982-4991

Technology:
Permeable Reactive Barrier (PRB)
- The PRB is a funnel-and-gate iron treatment wall system consisting of 2 sheet pile walls, permeable zones up- and down-gradient of the wall, and the reactive zone
- The PRB is composed of 100% granular iron, is 6 ft thick, 10 ft wide, and 18 ft high beginning 5 ft below ground surface
- Average flow rate through the wall was estimated as 0.5 ft/day (alternate estimates also provided)

Cleanup Authority:
Not applicable

EPA Point of Contact:
Lynn Suer
EPA Region 9
75 Hawthorne Street
San Francisco, CA 94105
(415) 744-2396

Navy Point of Contact:
Stephen Chao (Navy Project Manager)
Bldg. 210
Department of the Navy
EFA-West
900 Commodore Drive
San Bruno, Ca 94066

Waste Source:
Leaking underground and aboveground storage tanks, waste sumps; on-site migration of contaminants from Silicon Valley plume

Purpose/Significance of Application:
Use of PRB technology in a pilot study for treatment of chlorinated solvents; included extensive sampling conducted at locations within the wall.

Type/Quantity of Media Treated:
Groundwater
- 0.284 million gallons treated as of July 1997
- DNAPL suspected in groundwater on site
- Groundwater is found at 5 ft bgs
- Extraction wells are located in 5 hydrogeologic units, which include upward hydraulic gradients
- Hydraulic conductivity ranges from 0.3 to 400 ft/day

Regulatory Requirements/Cleanup Goals:
- The objectives of the pilot project are to (1) demonstrate and validate the PRB technology in remediating groundwater contaminated with chlorinated hydrocarbons; (2) evaluate the long-term effectiveness of the barrier from a hydraulic stand point; and (3) develop cost and performance data.

Permeable Reactive Barrier to Treat Contaminated Groundwater at the Moffett Federal Airfield, Mountain View, California (continued)

Results:

- Data from sampling events in January, April, and July 1997 showed that chlorinated solvent concentrations were being reduced as the groundwater moves through the reactive zone. For example, TCE concentrations measured in upgradient wells during April 1997 were reduced to below the detection limit within the reactive zone. PCE and 1.2-DCE also were reduced to below the detection limit within the reactive zone.
- A tracer test performed in July 1997 showed that flow patterns within the wall are complex, with some lateral flow, and that flow velocities are lower than expected based on previous site characterization and modeling.

Cost:

- Actual costs for PRB use over one year at this site were $405,000 ($373,000 in capital and $32,000 in O&M), which correspond to $1,400 per 1,000 gallons of groundwater treated.

Description:

Moffett Federal Airfield is a former Navy facility providing support, training, operation, and maintenance associated with Navy aircraft. Aircraft engine repairs and aircraft maintenance have been performed on site for many years. Contaminant identification and cleanup activities have been underway at Moffett since 1987. Specific activities that contributed to the source at MFA included dry cleaning operations. The Navy and Department of Defense Environmental Security Technology Certification Program (ESTCP) are funding this PRB as a voluntary pilot study for treating a portion of a large plume that crosses the Moffett facility.

The PRB installed in 1986 is a funnel and gate iron treatment wall system. Components include two sheet pile walls, permeability zones up- and down-gradient of the wall, and the reactive zone. Analytical data showed that chlorinated solvent concentrations were being reduced as the groundwater moves through the reactive zone. A final technology evaluation report for this pilot study was planned to be completed by August 1998. Proposals are being presented to continue the sampling process annually or semi-annually.

SITE INFORMATION

Identifying Information:

Moffett Federal Airfield
Mountain View, California

CERCLIS #: Not applicable

ROD Date: Not applicable

Treatment Application:

Type of Action: Pilot Test

Period of operation: April 1996 - Ongoing (Performance data collected through July 1997)

Quantity of material treated during application: 284,000 gallons of groundwater

Background [2]

Historical Activity that Generated Contamination at the Site: Service and support for Navy aircraft

Corresponding SIC Code: 3728 (Aircraft parts and Auxiliary Equipment)

Waste Management Practice That Contributed to Contamination: Leaking underground and aboveground storage tanks, waste sumps; on-site migration of contaminants from Silicon Valley plume

Location: Mountain View, California

Facility Operations [1, 2]:

- Moffett Federal Airfield (MFA) is a former Navy facility providing support, training, operation, and maintenance associated with Navy aircraft. Aircraft engine repairs and aircraft maintenance have been performed on site for many years. Cleanup and contaminant identification activities have been underway at MFA since 1987.
- This report addresses a Permeable Reactive Barrier (PRB) pilot study that, if effective, will be scaled up to remediate a large portion of the shallow aquifer at MFA. Currently, the PRB intercepts and treats contaminated groundwater immediately downgradient of a single source area at MFA. This site is complicated by the presence of a large groundwater plume that crosses MFA from off-site sources. The Navy is working with the responsible parties for the off-site sources to remediate the groundwater contamination.
- Remedial investigations were started in August 1990 and completed in April 1991 by International Technology Corporation and Tetra Tech EM, Inc.
- Contaminants in the area of the PRB consist primarily of chlorinated solvents. Specific activities that contributed to the source at MFA included dry cleaning operations.
- The Navy and Department of Defense Environmental Security Technology Certification Program (ESTCP) is funding this PRB as a pilot study for treating a portion of the large plume that crosses MFA.
- Remedial performance monitoring is being conducted by Tetra Tech EM and the PRB performance evaluation is being conducted by Battelle Memorial Institute (Columbus operations).

Regulatory Context:
The PRB was constructed as part of a voluntary pilot-scale study to demonstrate the effectiveness of the PRB for treating a groundwater plume of chlorinated solvents.

Groundwater Remedy Selection:
An *in situ* PRB was selected for a pilot study at this site.

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Lead: U.S. Navy

Oversight: EPA

Treatment System Vendors:
Tim Mower*
Tetra Tech EM
1099 18th Street, Ste. 1960
Denver, CO 80202
303-312-8874

Chuck Reeter*
Naval Facilities Engineering Service Center
1100 23rd Ave., Code 411
Port Hueneme, CA 93043-4370
805-982-4991

*Indicates primary contacts

Remedial Project Manager:
Stephen Chao (Navy Project Manager)
Bldg. 210
Department of the Navy
EFA - West
900 Commodore Drive
San Bruno, CA 94066

EPA Contact:
Lynn Suer
EPA Region 9
75 Hawthorne Street
San Francisco, CA 94105
415-744-2396

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater

Contaminant Characterization [2, 3]

Primary Contaminant Groups: Halogenated volatile organic compounds (VOCs)

- Contaminants detected near the location of the treatment wall include perchloroethene (PCE), trichloroethene (TCE), *cis*- and *trans*-1,2-dichloroethene (1,2-DCE), 1,1-dichloroethene (1,1-DCE), and 1,1-dichloroethane (1,1-DCA). Historically, 1,2-DCE and TCE are the predominant groundwater contaminants in the vicinity of the PRB.
- Maximum contaminant concentrations detected during 1991 investigations include 20,000 µg/L of TCE and 500 µg/L of PCE. In June 1996, TCE levels of over 5,000 µg/L were measured upgradient of the wall location. This may indicate that the plume originates from a continuous source.
- Figure 1 is a contour map that depicts TCE concentrations detected in February/March 1995. The 2,000 µg/L TCE contour line is closest to the treatment wall location.
- Dense nonaqueous phase liquid (DNAPL) presence is likely because of elevated concentrations detected in groundwater samples and processes known to have occurred at the facility. The maximum concentration of TCE detected was near 2% of its solubility limit.
- In 1991, the TCE plume was estimated to be over 10,000 feet long and 5,000 feet wide. Contaminants have been detected to a depth of 70 feet. The volume of the contaminant plume was estimated to be 5.6 billion gallons in the remedial investigation (RI) report. The PRB at MFA is treating a small part of this plume located in a shallow aquifer immediately downgradient of a source area.

MATRIX DESCRIPTION (CONT.)

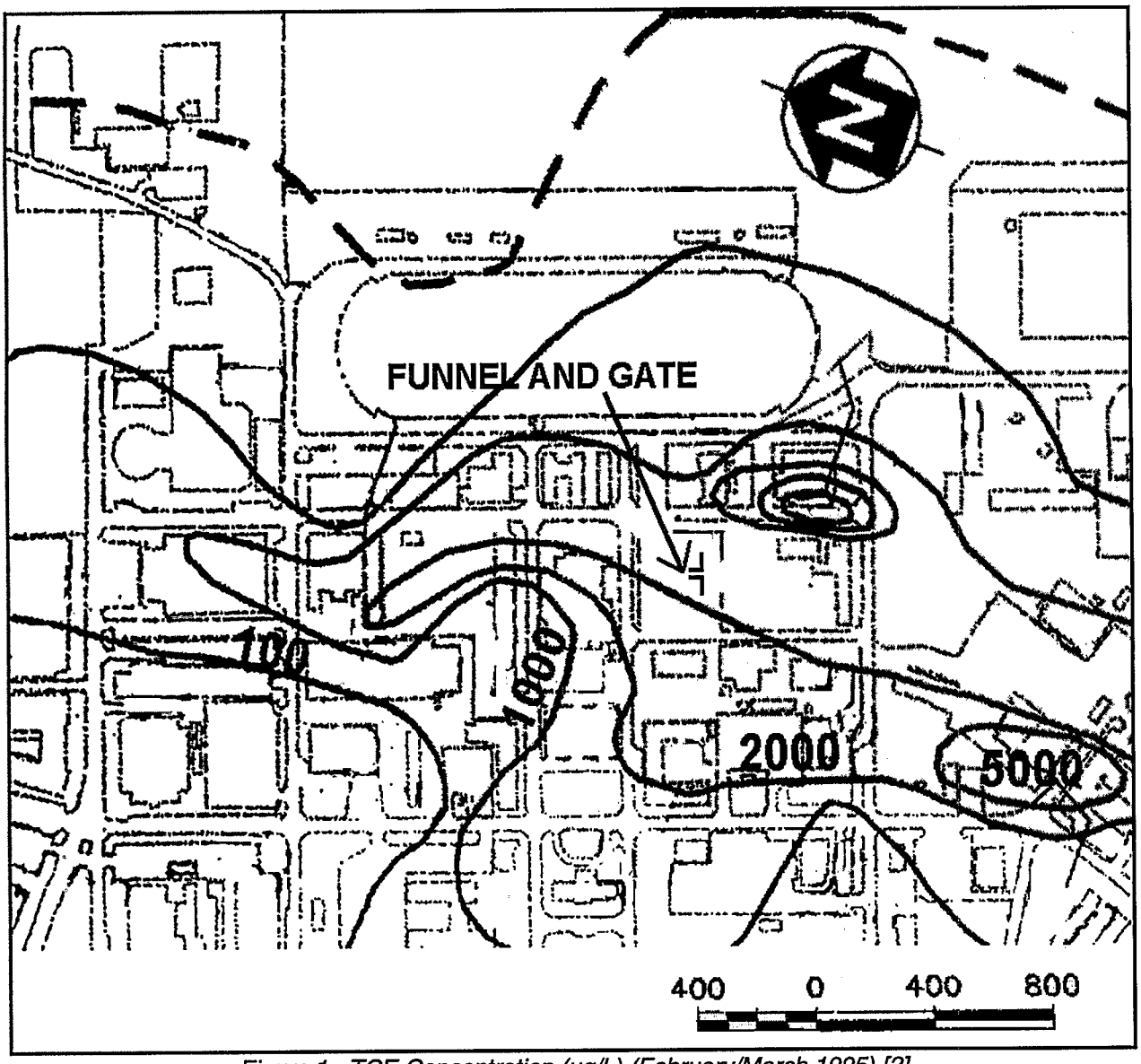


Figure 1. TCE Concentration (µg/L) (February/March 1995) [2]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Costs or Performance [2]

Hydrogeology:

Five distinct hydrogeologic units have been identified beneath this site. Groundwater is found approximately five feet below ground surface. MFA lies on a relatively flat depression, known as Santa Clara Valley, present between the San Andreas and Hayward Faults. Regionally, the Santa Clara Valley contains up to 1,500 feet of interbedded alluvial, fluvial, and estuarine deposits. These sediments consist of varying combinations of clay, silt, sand, and gravel. Subsurface sediments have been divided into the A, B, and C aquifers. Most contaminants at MFA are found within the A aquifer, which includes two permeable zones. The PRB is designed to treat only those contaminants in the A1 unit.

Unit A1	Surficial Sediments	Fine- to coarse-grained material. Uppermost permeable zone, highly contaminated. A discontinuous confining bed is present beneath this unit. Upward hydraulic gradients are present between units A1 and A2.
Unit A2	Surficial Sediments	Fine- to coarse-grained material. Highly contaminated and having a continuous 5- to 7-foot thick clay aquitard beneath. Upward hydraulic gradients are present between the A and B aquifers.
Unit B1	Fluvial Sediments	Thin sand and gravel beds in a fine-grained matrix. Not contaminated, highly conductive (similar to A aquifer).
Unit B2	Fluvial Sediments	Thin sand and gravel beds in a fine-grained matrix.
Unit C	Estuarine Sediments	Fine to medium clayey and silty sand.

Tables 1 and 2 include technical aquifer information and technical wall data, respectively.

Table 1. Technical Aquifer Information

Unit	Thickness (ft)	Conductivity (ft/day)	Average Velocity (ft/day)	Flow Direction
A1	25	1 - 400	0.005 - 2	North
A2	40	30 - 200	0.15 - 1	North
B1	45	0.3 - 50	0.0014 - 0.22	North
B2	15	0.4 - 40	0.0018 - 0.18	North
C	>100	Not available	Not available	Not available

Source: [2]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Permeable Reactive Barrier (PRB)

Supplemental Treatment Technology

None

System Description and Operation

Table 2. Treatment Wall Data

Unit	Flow-Through Thickness	Conductivity (ft/day)	Material	Vertical Thickness
Flow Control Zone	2 feet	>1,000	Pea gravel	18 feet
Continuous Treatment Wall	6 feet	1,000	100% Granular iron	18 feet
Flow Control Zone	2 feet	>1,000	Pea gravel	18 feet

Source: [2,4]

System Description [2, 3, 4, 7]

- The PRB is a passive, *in situ* treatment technology that makes use of natural groundwater flow to carry contaminants through the reaction zone.
- The PRB, installed in 1996, is a funnel and gate iron treatment wall system. The components include two sheet pile walls, permeability zones upgradient and downgradient of the wall, and the reactive zone. Table 2 provides technical wall data. Figures 2 and 3 illustrate the layout and dimensions of the PRB.
- Two sheet pile walls measuring 20 feet in length extend at a 90° angle from the wall (perpendicular to groundwater flow direction). These walls act as a funnel to force more of the contaminant plume through the PRB.
- The PRB is composed of 100% granular iron, has 6 feet of flow-through thickness, is 10 feet wide, and 18 feet high beginning 5 feet below ground surface. The flow control zones upgradient and downgradient of the wall are composed of pea gravel and have 2 feet of flow-through thickness.
- The PRB extends down through Unit A1, but is not keyed into the low conductivity unit comprised of clayey fine sand to silty clay that is found at a depth of approximately 23 to 25 feet below ground surface. This material is not classified as an aquitard; however, it is believed to inhibit contaminant transport to Unit A2. The iron filings begin at a depth of 5 feet below ground surface, which corresponds with the groundwater table. Native soil was backfilled above this depth. Two feet of concrete and bentonite were placed below the iron to prevent downward migration of contaminants.
- The PRB utilizes reactive zero-valent iron to dehalogenate the chlorinated compounds to chloride and ethylene.
- The actual residence time in the treatment zone for the dechlorination and reduction reactions has been estimated to be approximately 96 hours based on the highest concentration scenario. A minimal residence time of 48 hours is required to degrade contaminants to meet cleanup goals.

TREATMENT SYSTEM DESCRIPTION (CONT.)

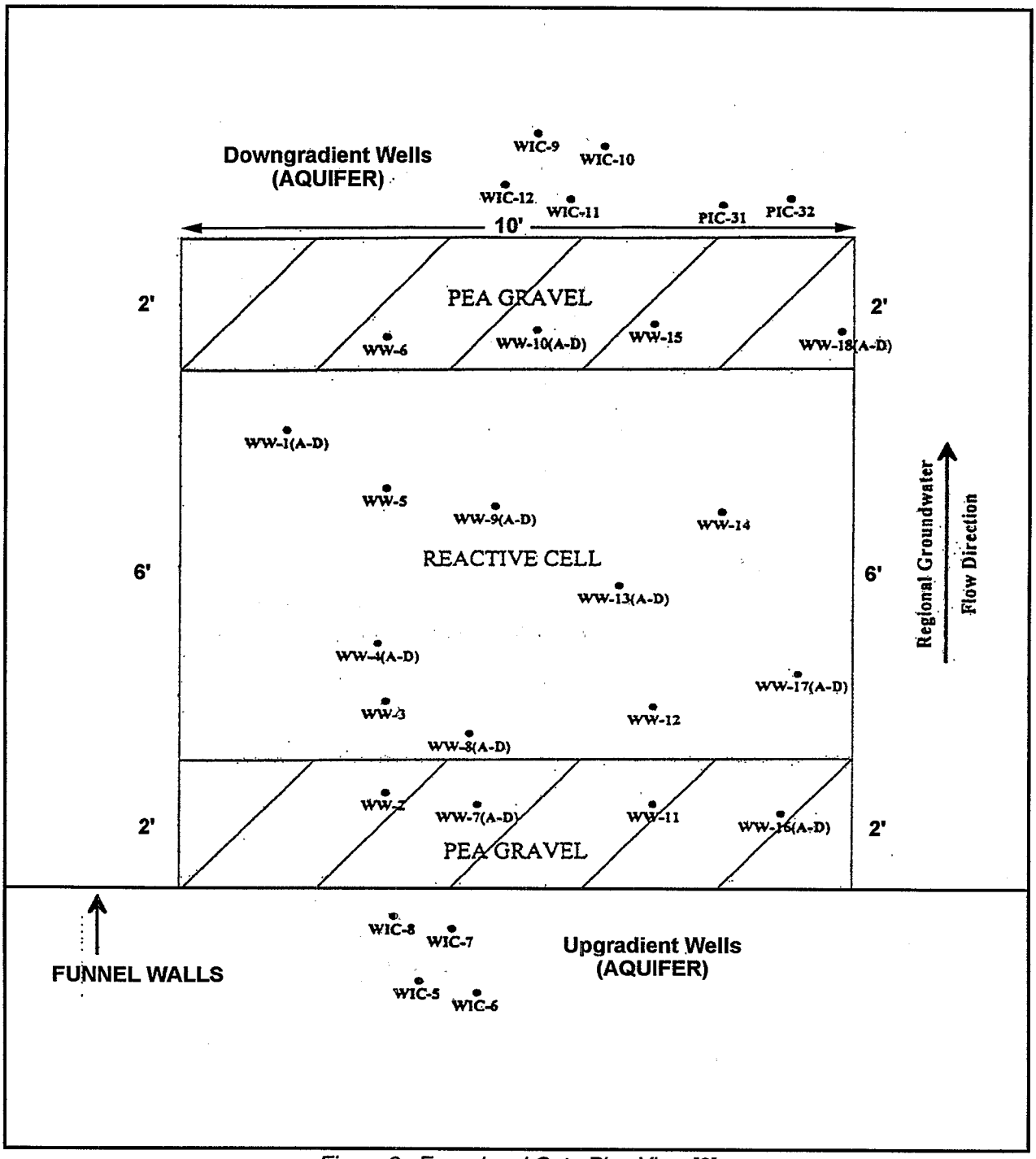


Figure 2. Funnel and Gate Plan View [3]

TREATMENT SYSTEM DESCRIPTION (CONT.)

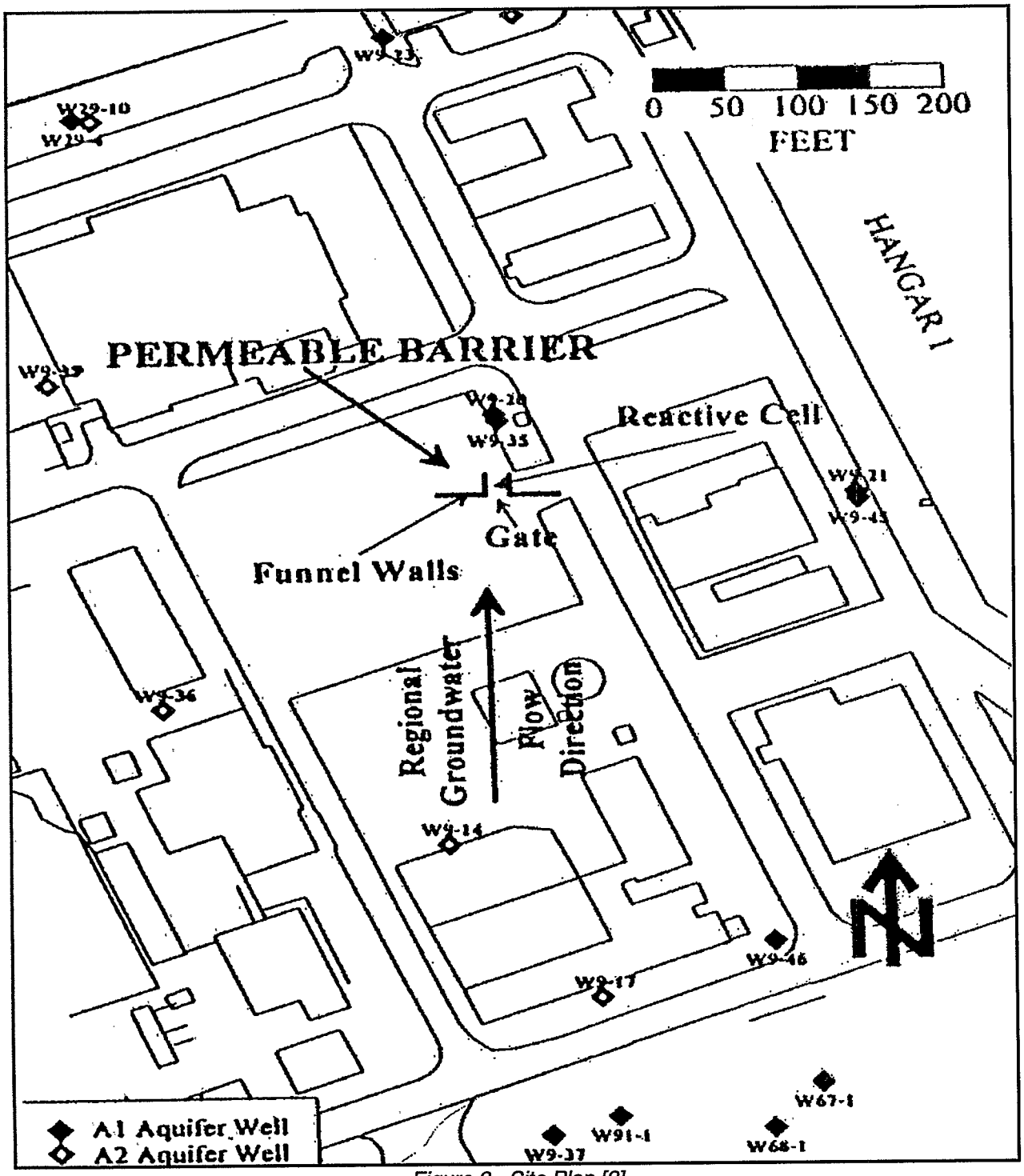


Figure 3. Site Plan [2]

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation Source (Cont.)

- Twenty-eight multi-level monitoring wells are located within the treatment zone. These wells are placed at 1 to 2 foot intervals to monitor contaminant concentration reduction through the wall. Four wells are located both upgradient and downgradient of the treatment zone to monitor influent and effluent concentrations.

System Operation [1, 2, 7-10]

- Quantity of groundwater treated:

Time Frame	Approximate Volume Treated
1996-1997	*284,000 gallons*

Based on average groundwater velocity of 0.5 ft/day, and dimensions of 10 feet wide and 18 feet deep [2].

- Since April 1996, the PRB has been 100% operational.
- There have been no maintenance requirements for the treatment wall to date. The reactive media may need to be replaced if the wall becomes clogged or ineffective. The monitoring plan requires monitoring of the wall for plugging and continued effectiveness. Sampling in December 1997 indicated no significant clogging.
- Monitoring wells and research sampling points are sampled quarterly, for piezometric head to evaluate groundwater velocity and flow direction through the treatment wall.

Operating Parameters Affecting Treatment Cost or Performance

Table 3 presents operating parameters affecting cost and performance for this technology.

Table 3: Performance Parameters

Parameter	Value
Average Flow Rate through Treatment Wall	0.5 ft/day [Estimate used for calculation purposes [9]]
Required Residence Time	48 hours

Source: [1]

TREATMENT SYSTEM DESCRIPTION (CONT.)

Timeline

Table 4 presents a timeline for this pilot-scale project.

Table 4: Project Timeline

Start Date	End Date	Activity
4/95	8/95	Lab tests and column studies performed
8/95	1/96	Treatment wall designed
1/96	---	Procurement process begun
4/96	5/96	3-week construction period
6/96	---	First sampling event conducted
9/96	---	Second sampling event conducted
1/97	---	Third sampling event conducted
4/97	---	Fourth sampling event conducted
7/97	---	Fifth sampling event conducted (in conjunction with tracer test)
10/97	---	Sixth sampling event conducted

Source: [1]

TREATMENT SYSTEM PERFORMANCE

Treatment Performance Goals [1]

The objectives of the pilot project are to: (1) demonstrate and validate the PRB technology in remediating groundwater contaminated with chlorinated hydrocarbons; (2) evaluate the long-term effectiveness of the barrier from a hydraulic standpoint; and (3) develop cost and performance data [7].

Performance Data Assessment [3, 6]

- Data from sampling events in January, April, and July 1997 showed that chlorinated VOC concentrations were being reduced as the groundwater moves through the reactive zone. For example, TCE concentrations measured in upgradient wells during April 1997 were reduced to below the detection limit within the reactive zone. PCE and 1,2-DCE were also reduced to below the detection limit within the reactive zone.

- Figure 4 shows that *cis*-1,2-DCE and TCE concentrations decrease as the groundwater flows through the PRB. An average of the January 1997 and April 1997 data at specific intervals through the wall was used to generate this figure. TCE concentrations in the upgradient wells are near 1,000 µg/L; at 4 feet into the PRB, TCE concentrations are approximately 1 µg/L. *Cis-1,2*-DCE concentrations begin near 200 µg/L upgradient and decrease to less than 10 µg/L by the 4-foot interval.

- Figure 5 presents mass flux data calculated for the January, April, and July sampling events. This figure indicates that mass removed by the PRB has increased from .007 lbs/day to .0086 lbs/day over the three sampling events. TCE and *cis*-1,2-DCE concentrations were used for this calculation as they account for most of the total contaminant mass entering the PRB.

TREATMENT SYSTEM PERFORMANCE (CONT.)

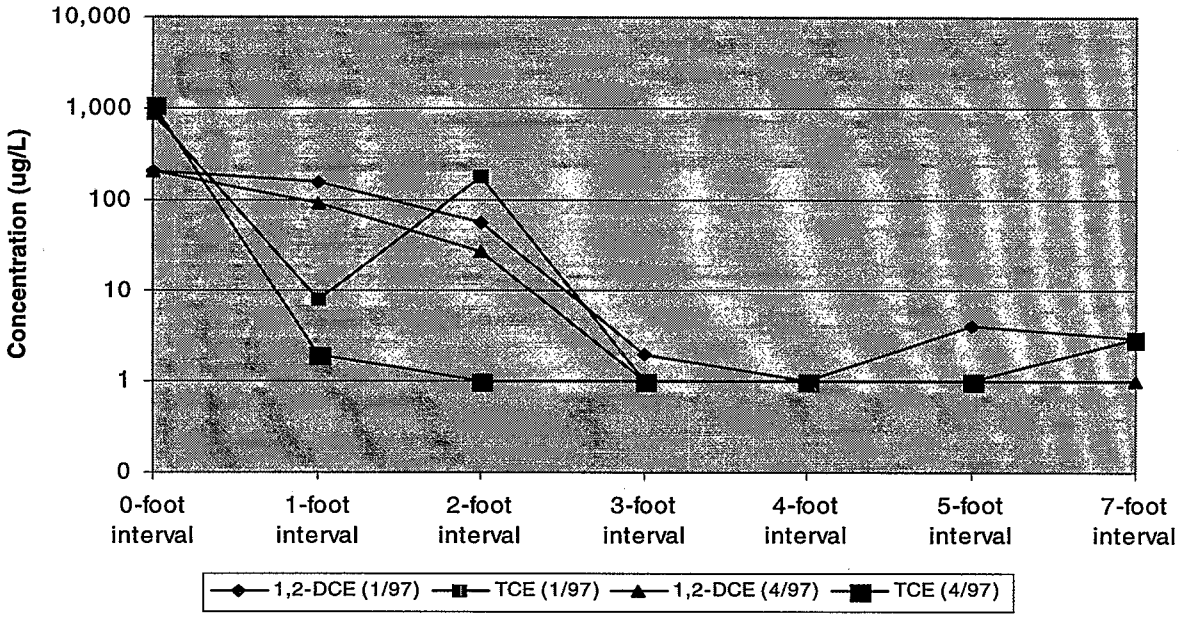


Figure 4. Concentration Reduction Through the PRB ***[3]***

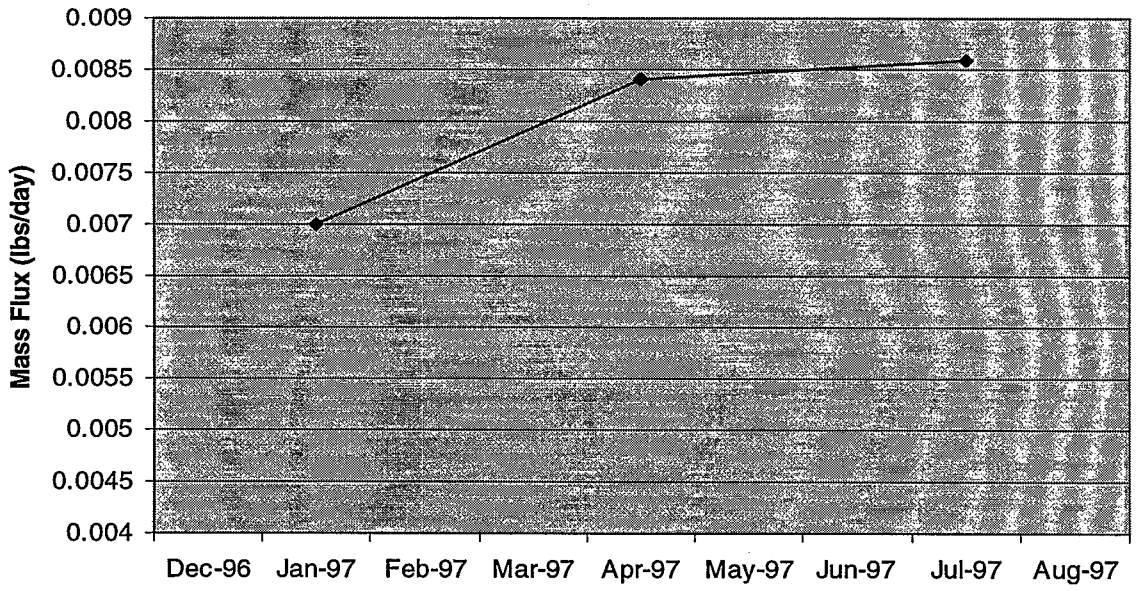


Figure 5. Mass Removal Through the PRB (January - July 1997) ***[3]***

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (Cont.)

- A tracer test was performed in July 1997 to assess performance of the PRB and to determine groundwater flow direction and velocity measurements within the treatment wall. The tracer test was performed using potassium bromide tracers. The results of the tracer test indicated that some lateral flow occurs within the wall and flow patterns appear to be rather complex (not always in straight lines). The flow patterns are attributed to the differential compaction of granular iron throughout the wall. Overall, flow velocities were lower than expected based on previous site characterization and modeling.
- Results from the tracer test indicate that flow velocity through the cell ranges from 0.05 to 0.45 ft/day. According to the contractor that performed the test (Battelle Columbus Operations), these flow velocities were much lower than were predicted by site characterization and modeling (about 3 ft/day), water level measurements (up to 5 ft/day), and downhole velocity measurement (1.1 to 6.1 ft/day) [6, 7].
- Cores of *in situ* iron were collected in December 1997 and analyzed for evidence of precipitates and corrosion materials that may reduce hydraulic and remedial effectiveness of the barrier. Microbial analysis of cored material also was conducted to assess presence of iron oxidizing or sulfate reducing bacteria [7].

Performance Data Completeness [1]

- Seventy-two monitoring wells are sampled quarterly. After one year of operation, the monitoring schedule may be adjusted if needed. The large number of wells are sampled for research purposes. According to Battelle, this number of wells exceeds the typical protocol necessary to demonstrate that the PRB is functioning properly and meeting treatment goals.
- Data from the January, April and July 1997 quarterly sampling events were available for this report. Additionally, a tracer test study was performed in July and also available for this report.
- In Figure 4, 2 µg/L is the detection limit. When data was reported as below detection limits, half the detection limit (1 µg/L) was used in the future.

Performance Data Quality

The QA/QC program used throughout the remedial action met the EPA and the State of California requirements. All monitoring was performed using EPA-approved methods, Method 353.1, Method N-601, SW-846 Method 8240, SW-846 Method 8020. Laboratory reports for the April 1997 sampling event indicated that detection limits were unacceptably high for the A1 aquifer zone wells and upgradient pea gravel wells due to excessive sampling dilution. The laboratory was asked to reanalyze samples. However, because the holding time had elapsed, the affected wells were resampled in July 1997.

The Navy is the lead for this site. MFA is responsible for on-site activities and oversight. EPA views the research activity as a means of remediating for a portion of the plume.

Cost Analysis

All costs for design, construction, and operation of the treatment system at this site are borne by the Navy and DoD.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Capital Costs

Remedial Construction	
System Installation	$323,000
Iron	$50,000
Total Remedial Construction	$373,000

Operating Costs

Monitoring/Analytical	$32,000[a]

[a]First annual monitoring and analytical contract

Cost Data Quality

Actual capital and operating and maintenance cost data are available from the Navy contact for this site.

OBSERVATIONS AND LESSONS LEARNED

- The cost for groundwater remediation at this site over one year was approximately $405,000 ($373,000 in capital costs and $32,000 in operating costs), corresponding to a unit cost of $1,400 per 1,000 gallons of groundwater treated.
- Based on sampling data from the January, April, and July sampling events, concentrations of PCE, TCE, and 1,2-DCE are being reduced as groundwater passes through the reactive zone.
- Data from monitoring points within the iron show that, by the fourth foot of iron, contaminant concentrations were reduced below detection limits.
- Mass flux was calculated from the quarterly data and an estimate of groundwater velocity from the tracer test conducted in July. Mass flux data have increased over the three sampling events indicating an increase in influent concentrations, while treatment goals continue to be met.
- ESTCP is sponsoring performance monitoring and cost data collection for technology certification and validation. Performance sampling is scheduled to continue on an annual basis for at least two more years. The final technology evaluation report is planned to be completed by August 1998. Proposals are being presented to continue the sampling process annually or semiannually.

REFERENCES

1. Draft Performance Monitoring Plan, Battelle Columbus Operations, Cleveland, Ohio, September 16, 1996.
2. Draft Operable Unit 4 Feasibility Study Report, PRC Environmental Management, Inc., Denver, Colorado, August 3, 1992.
3. April 1997 Monitoring Report for the Pilot Permeable Barrier at Moffett Federal Airfield, Battelle, September 1997.
4. Phone Conversations with Deidre O'Dwyer, June 21, 1997.
5. Phone Conversations with Tim Mower, Tetra Tech EM Inc., May 28, 1997.
6. Field Tracer Application to Evaluate the Hydraulic Performance of the Pilot-Scale Permeable Barrier at Moffett Federal Airfield, Battelle, October 1997.

REFERENCES (CONT.)

7. Permeable Reactive Wall Remediation of Chlorinated Hyrdocarbons in Groundwater at Moffett Federal Airfield, Mountain View, California, IBC Proceedings, January 1998.

8. Comments on draft report from Chuck Reeter, NFRSC, July 8, 1998.

9. Comments on draft report from Michael Gill, Region IX RPM, July 17, 1998.

10. Comments on draft report from Tim Mower, Tetra Tech EM Inc., July 17, 1998.

Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Eastern Research Group, Inc. and Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.

Dual Auger Rotary Steam Stripping at Pinellas Northeast Site, Largo, Florida

Dual Auger Rotary Steam Stripping at Pinellas Northeast Site, Largo, Florida

<table>
<tr><td>Site Name:
Pinellas STAR Center
Northeast Site</td><td rowspan="2">Contaminants:
- Chlorinated solvents and volatiles - nonhalogenated 1,1-dichloroethane, 1,1-DCE, benzene, ethylbenzene, 1,2-DCE, methylene, chloride, toluene, TCE, tetrachloroethene, vinyl chloride, total xylenes, and chloromethane
- Concentrations ranging from 500-5,000 ppm
- DNAPL suspected to occur as an immiscible phase</td><td>Period of Operation:
December 1996 through April 1997</td></tr>
<tr><td>Location:
Largo, Florida</td><td>Cleanup Type:
Demonstration (ITRD Technology Demonstration)</td></tr>
<tr><td>Vendor:
In-Situ Fixation, Inc. (ISF)
Chandler, Arizona</td><td rowspan="2">Technology:
In Situ Air and Steam Stripping
- ISF dual auger system consists of a Caterpillar 245D trackhoe modified to operate two, 35-ft long, hollow kelly bars with 5-ft diameter augers
- Air and/or steam injected through hollow kelly bars while augers drill into subsurface, to liberate VOCs
- Catalytic oxidation unit and acid-gas scrubber were used to treat the extracted VOCs
- 48 treatment holes drilled to a depth of approximately 32 feet
- Technology focused on treating saturated silty sands (below the water table) contaminated with high concentrations of VOCs (500-5,000 ppm)</td><td>Cleanup Authority:
RCRA</td></tr>
<tr><td>Additional Contacts:
David Ingle
DOE/GJO Environmental Restoration Program Manager
(813) 541-8943</td><td>Regulatory Point of Contact:
EPA Region 4 and State:
Florida Department of Environmental Protection</td></tr>
<tr><td>Waste Source:
Leakage of solvents from drum/container Storage</td><td colspan="2" rowspan="2">Type/Quantity of Media Treated:
Soil and Groundwater
- Water table present approximately 3-4 feet below ground surface
- Soils consist of saturated beach-type silty sands with permeabilities ranging between 10^{-3} to 10^{-5} cm/s
- Approximately 2,000 yd^3 of soil treated</td></tr>
<tr><td>Purpose/Significance of Application:
Demonstration of in situ air stripping technology used to supplement an ongoing system of pump and treat with air stripping</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
- The objective of this demonstration was to evaluate the performance of the ISF dual auger system in treating contaminated soil and groundwater.</td></tr>
</table>

Dual Auger Rotary Steam Stripping at Pinellas Northeast Site, Largo, Florida (continued)

Results:
- Demonstrated ability to remove large amounts of contaminants from soil and groundwater in a treatment column
- Removed an average of 77% of the VOCs in the groundwater and soil, and reduced the maximum contaminant concentrations by an average of 71%
- Treatment of over 2,000 yd^3 of soil and groundwater and the removal of approximately 1,200 pounds of VOCs

Cost:
Total cost of remediation project was $981,251, including:
- Preproject operation visit - $2,400
- Mobilization and preparatory work - $95,000
- Monitoring, sampling, testing, and analysis - $59,000
- Physical treatment - $773,651 (equipment, labor, supplies and materials, and fuel)
- Disposal - $200 (hydraulic oil)
- Demobilization - $51,000

Description:
The Pinellas STAR Center operated from 1956 to 1994, manufacturing neutron generators and other electronic and mechanical components for nuclear weapons under contract to the U.S. Department of Energy (DOE) and its predecessor agencies. The Northeast Site is associated with the location of a former waste solvent staging and storage area. In the late 1950s to the late 1960s an existing swampy area at the site was used to dispose drums of waste and construction debris.

A field demonstration using a dual auger rotary steam stripping technology was conducted at the site from December 1996 through April 1997. The demonstration was part of a program at the Pinellas STAR Center to evaluate several innovative remediation technologies that could enhance the cost or performance of the existing pump and treat system. In the demonstration, air and/or steam was injected through hollow kellys while the augers drill into the subsurface, liberating VOC contamination during the churning and mixing of the soil. This study identified operational issues, such as mechanical problems, catalyst overheating, and fugitive emissions that required system adjustments and operational changes. These issues slowed the progress of the remediation effort, but the system was overall very effective in liberating large quantities of VOCs from the site soil and groundwater. During the 3-month operating period, 48 auger holes were drilled to a depth of approximately 32 ft below land surface, resulting in treatment of approximately 2,000 yd^3 of the planned 10,000 yd^3 treatment volume. Overall, approximately 1,200 lbs of VOCs were removed from the soil and groundwater in the holes treated in this project.

The cost of this remediation project was $981,251, with most of the costs being equipment operating costs. The operational costs of the ISF system ranged from $50/$yd^3$ to $400/$yd^3$ of treated soil and groundwater, or about $300/lb to $500/lb of contaminant removed. The ISF system was able to meet many of the performance evaluation criteria; however, the off-gas treatment capacity of the catalytic oxidation unit along with initial operational problems slowed the system's expected treatment rates for the site.

1. SUMMARY

From December 1996 through April 1997, the DOE's Innovative Treatment Remediation Demonstration (ITRD) Program monitored the remediation performance of a dual auger rotary steam stripping technology deployed at the Pinellas STAR Center Northeast Site in Largo, Florida. The system allows in situ treatment of contaminated soil and ground water through the injection of air and/or steam into the subsurface. The objective of this remediation effort was to accelerate the cleanup of a portion of the site that consists of shallow, saturated soil and ground water contaminated with high concentrations (500-5000 ppm) of volatile organic compounds (VOCs). The rotary steam stripping system used during this remediation was developed and operated by In-Situ Fixation, Inc. (ISF), from Chandler, Arizona.

The ISF dual auger system consists of a Caterpillar 245D trackhoe that has been modified to operate two vertical, 35-ft long, hollow kelly bars with 5-ft diameter augers. Air and/or steam is injected through the hollow kellys while the augers drill into the subsurface, liberating VOC contamination during the churning and mixing of the soil. A large shroud covers the auger hole to capture the VOCs removed by this process for treatment. A catalytic oxidation unit and acid-gas scrubber were used to treat the extracted VOCs in this application at Pinellas.

The project provided adequate analytical and operational data to evaluate the performance of the dual auger rotary steam stripping technology. A Treatment Efficiency Characterization (TEC) Study was initially conducted to identify system operational capabilities and issues over the range of contaminant mixtures and concentrations in the planned treatment area. This study identified operational issues, such as mechanical problems, catalyst overheating, and fugitive emissions that required system adjustments and operational changes. These issues slowed the progress of the remediation effort, but the system was overall very effective in liberating large quantities of VOCs from the site soil and ground water. It was observed early in the project that a major limiting factor in the efficiency of the system in the areas of highest contaminant concentration was the off-gas treatment capacity of the catalytic oxidation unit.

During the 3-month operating period, 48 auger holes were drilled to a depth of approximately 32 ft below land surface, resulting in treatment of approximately 2,000 yd^3 of the planned 10,000 yd^3 treatment volume. Many of the treatment holes had to be treated more slowly than expected to prevent the catalyst in the catalytic oxidation unit from overheating from the large quantities of VOCs liberated by the augers. The treatment rates at this site varied from 1 to 5 holes/day or about 5 to 30 yd/hr, depending on the level of contamination encountered in each hole. Overall, approximately 1,200 lb of VOCs were removed from the soil and ground water in the holes treated in this project.

The cost of this remediation project was $981,251, with most of the costs being equipment operating costs. The on-line time of the ISF system, including the dual augers, off-gas treatment, and the acid gas scrubber components over the entire project averaged approximately 50%, while the on-line time of the system approached 75% after the initial operational problems and issues were addressed and corrected. Based on these on-line percentages, the operational costs of the ISF system at this site ranged from $50/yd^3 to $400/yd^3 of treated soil and ground water, or about $300/lb to $500/lb of contaminant removed.

Based on the results of this demonstration, the ISF dual auger rotary steam stripping system is an innovative technology capable of providing in situ treatment of VOC-contaminated soil and ground water. During the application of this technology at the Pinellas STAR Center, the ISF system was able to meet many of the performance evaluation criteria; however, the off-gas treatment capacity of the catalytic oxidation unit along with the initial operational problems slowed the system's expected treatment rates for the site. This prevented the system from achieving some of the performance objectives and treatment volumes initially expected in this remediation.

2. SITE INFORMATION

Identifying Information

Facility:	Pinellas STAR Center
OU/SWMU:	Northeast Site
Location:	Largo, Pinellas County, Florida
Regulatory Driver:	RCRA
Type of Action:	ITRD Remediation/Demonstration
Technology:	Dual auger rotary steam stripping
Period of operation:	12/96 to 4/30/97
Quantity of saturated soil treated:	2,048 yd^3

Site Background

The Pinellas STAR Center occupies approximately 100 acres in Pinellas County, Florida, which is situated along the west central coastline (Figure 1). The plant site is centrally located within the county; it is bordered on the north by a light industrial area, to the south and east by arterial roads, and to the west by railroad tracks. The topographic elevation of the Pinellas STAR Center site varies only slightly, ranging from 16 ft mean sea level (MSL) in the southeastern corner to 20 ft MSL in the western portion of the site. Pinellas County has a subtropical climate with abundant rainfall, particularly during the summer months.

The Northeast Site includes the East Pond and is located in the northeastern portion of the Pinellas STAR Center site. The Northeast Site is covered with introduced landscaping grass and contains no permanent buildings. The site contains approximately 6 acres and is generally flat, with slight elevation changes near the pond. Access to the Northeast Site is restricted and protected by fencing.

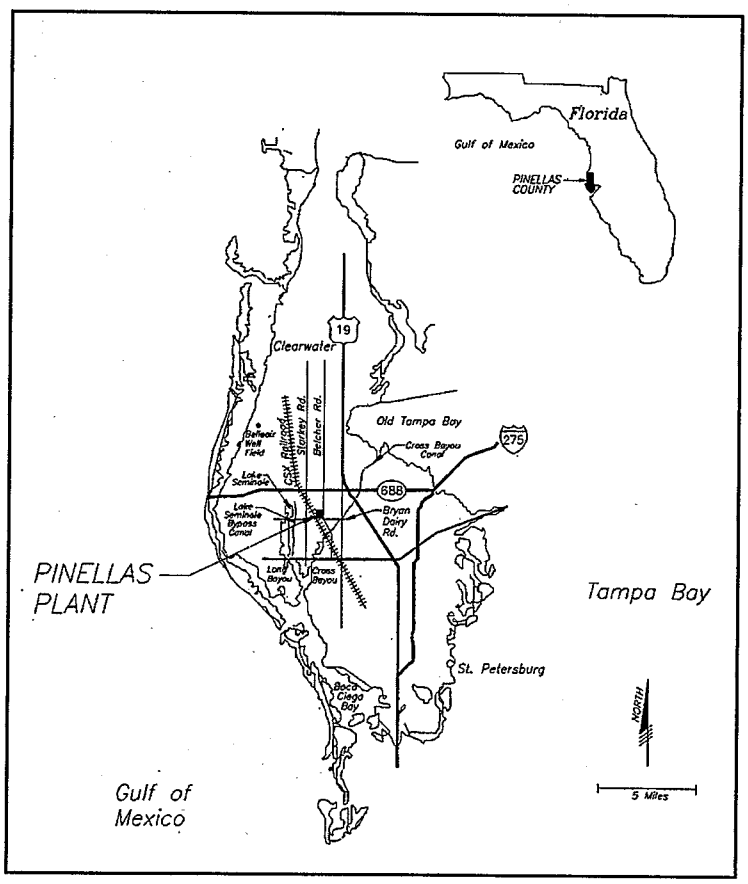


Figure 1. Pinellas STAR Center location.

Site History

The Pinellas STAR Center operated from 1956 to 1994, manufacturing neutron generators and other electronic and mechanical components for nuclear weapons under contract to the U.S. Department of Energy (DOE) and its predecessor agencies (SIC Code 9631A-Department of Energy Activities).

The Northeast Site is associated with the location of a former waste solvent staging and storage area. From the late 1950s to the late 1960s, before construction of the East Pond, an existing swampy area at the site was used to dispose drums of waste and construction debris. The East Pond was excavated in

1968 as a borrow pit. In 1986, an expansion of the East Pond was initiated to create additional storm water retention capacity. Excavation activities ceased when contamination was detected directly west of the East Pond.

The Northeast Site was identified as a Solid Waste Management Unit (SWMU) in a Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA) [1] conducted by EPA Region IV. Subsequently, a RCRA Facility Investigation (RFI) [2] was completed and approved in compliance with the facility's Hazardous and Solid Waste Amendments of 1984 (HSWA) permit.[3]

An Interim Corrective Measures (ICM) Study [4,5,6] was developed and submitted to EPA for approval. EPA issued final approval of the ICM in October 1991, and an interim ground water recovery system for the Northeast Site was installed and commenced operation in January 1992. The ICM system now consists of seven ground water recovery wells equipped with pneumatic recovery pumps that transfer ground water for temporary storage in a holding tank before being pumped to a ground water treatment system.

Release Characteristics

The Pinellas STAR Center's Northeast Site consists of a shallow ground water aquifer contaminated with a variety of VOCs, including chlorinated solvents such as trichloroethene (TCE), methylene chloride, dichloroethene (DCE), and vinyl chloride. The primary management practice that contributed to contamination was the storage of drums/containers. Because the site was used in the 1950s and 1960s for staging and burying construction debris and drums, some of which contained solvents, contamination at the Northeast Site is believed to be the result of leakage of solvents or resins from those drums. A recent debris removal activity at the site confirmed the presence of multiple buried drums, many of which were empty but contained solvent residue. The ongoing ICM system (pump and treat with air stripping) continues to recover contaminants from the site and has been successful in preventing off-site migration of VOCs.

Site Contacts

Site management is provided by the DOE Grand Junction Office (DOE/GJO). The DOE/GJO Environmental Restoration Program Manager is Mr. David Ingle [(813)-541-8943]. The Managing and Operating contractor for this project at the Pinellas STAR Center was Lockheed Martin Specialty Components, Inc. (LMSC). The technical contacts for the Rotary Steam Stripping Project are Mr. Barry Rice [(813) 545-6036], and Mr. Mike Hightower, the ITRD Program Technical Coordinator at Sandia National Laboratories [(505) 844-5499].

3. MATRIX AND CONTAMINANT DESCRIPTION

The types of media processed by the rotary stripping system during this application were soil and ground water (in situ). More specifically, this remediation technology focused on treating saturated silty sands (i.e., below the water table) contaminated with high concentrations of VOCs (500 to 5000 ppm).

Site Geology/Hydrology

Based on analyses of soil borings, details of well construction, and environmental studies at the Pinellas STAR Center, the thickness of the surficial deposit below the site ranges from 25 to 35 ft and is composed primarily of silty sand. Soils consist predominantly of saturated beach-type silty sands with permeabilities ranging between 10^{-3} to 10^{-5} cm/s. A few lenses of more silty materials exist, although no clay lenses occur in the soil being treated. The top of the Hawthorn Group (composed primarily of clay) at the Pinellas STAR Center is encountered at depths approximately 30 ft or greater below ground surface. The thickness of the Hawthorn Group ranges from 60 to 70 ft. The water table at the Pinellas STAR Center is generally 3 to 4 ft below the ground surface. Figure 2 shows the primary geologic units at the site.

The ground water system at the Pinellas STAR Center is composed of three primary units: (1) an upper unit, the surficial aquifer; (2) an intermediate confining unit, the undifferentiated portion of the Hawthorn Group; and (3) a lower unit, the Floridan aquifer. Undifferentiated sediments lie below the surficial aquifer and above the Floridan aquifer in Pinellas County. Because of the low permeability of these sediments in this region, these upper sediments are not considered part of the intermediate aquifer system and are generally considered to be a confining unit in the area of the Pinellas STAR Center.

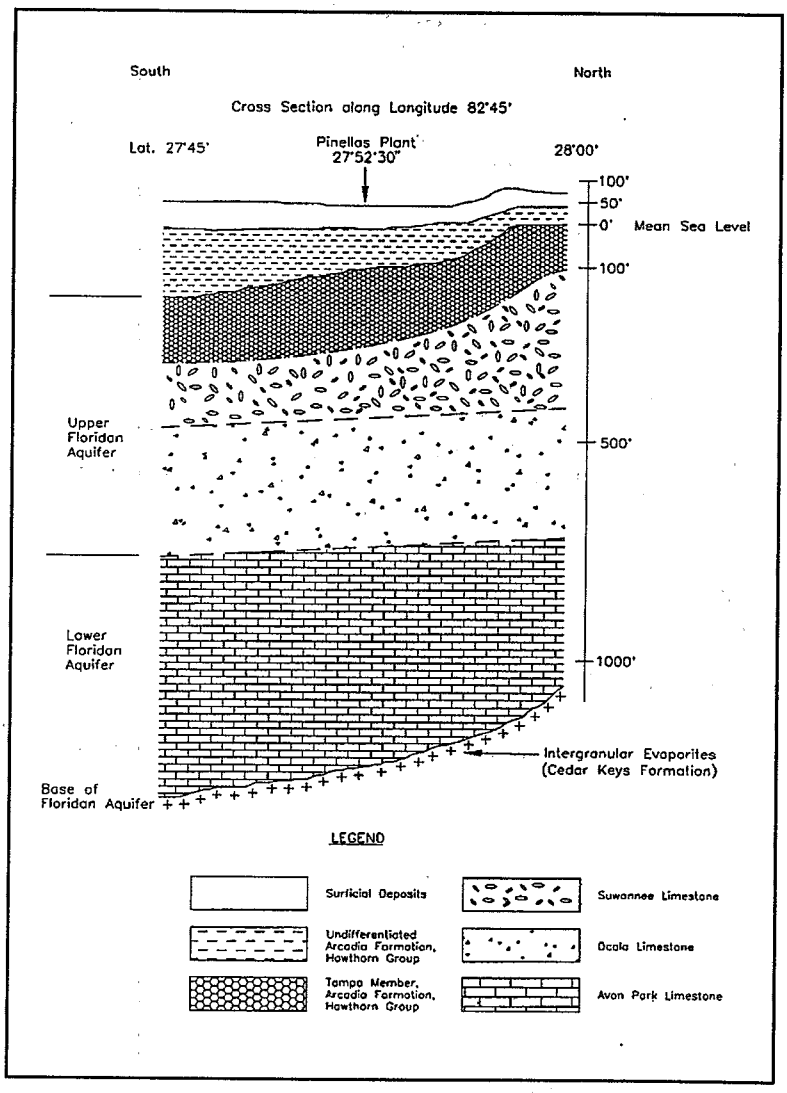


Figure 2. Geologic section at the Pinellas STAR Center.

Nature and Extent of Contamination

The primary contaminant group that this technology was designed to treat in this application was halogenated VOCs. Contamination at the Northeast Site is limited to ground water in the surficial aquifer. Contaminants of concern (COCs) detected in Northeast Site ground water include 1,1-dichloroethane, 1,1-DCE, benzene, ethylbenzene, 1,2-DCE (cis and trans isomers), methylene chloride, toluene, TCE, tetrachloroethene, methyl tert-butyl ether, vinyl chloride, total xylenes, and chloromethane. The

predominant contaminants detected at the site during performance of the demonstration were methylene chloride, 1,2-DCE, and TCE. Other VOCs detected in relatively high concentrations are toluene and vinyl chloride.

Figure 3 shows a contour map of historical total VOC concentrations in the southern groundwater plume at the Northeast Site as established by data collected prior to the rotary steam stripping project. Operation of the rotary steam stripping system was proposed in the areas of highest contaminant concentration (above 200-500 ppm). Table 1 summarizes the pretreatment concentrations of some of the COCs within the planned treatment area.

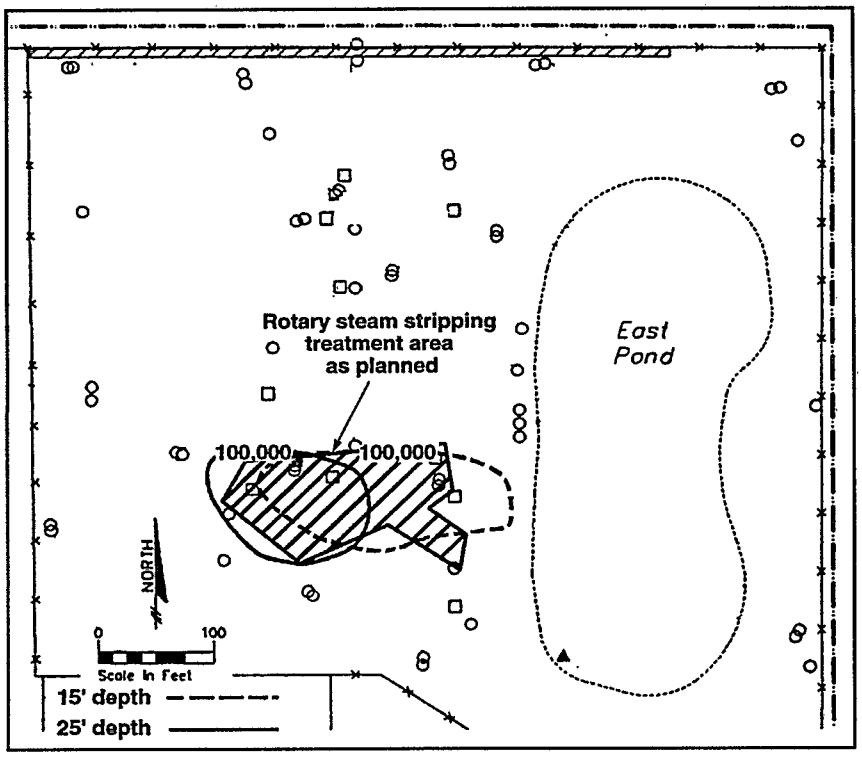


Figure 3. Total VOC concentrations in ground water (in μg/L) in the southern plume at the Northeast Site prior to the rotary steam stripping project.

Table 1. Pretreatment concentrations of COCs

	Ground water		Soil	
Contaminant	**Max. conc. (μg/L)**	**Avg. conc. (μg/L)**	**Max. conc. (μg/kg)***	**Avg. conc. (μg/kg)***
Methylene chloride	6,800,000	751,000	720,000	31,100
TCE	480,000	40,300	1,200,000	35,700
Toluene	150,000	18,600	660,000	20,600
cis-1,2-DCE	240,000	32,800	12,000	1,100
Vinyl chloride	75,000	10,000	1,700	90

* dry weight

Based on the pretreatment sampling and analyses and the volume of the treatment area, Table 2 summarizes the estimated mass of contaminants in the subsurface of the planned treatment area for the rotary steam stripping project. Sampling confirmed that the zone of highest contaminant concentrations generally lies in the western portion of the treatment area between 20 ft and 30 ft below the ground surface.

Table 2. Estimated contaminant mass in the planned treatment area

Methylene chloride	6,000 lb
TCE	1,900 lb
Toluene and other VOCs	1,100 lb
Total	9,000 lb

Matrix and Contaminant Characteristics Affecting Treatment Cost or Performance

The Northeast Site includes an ongoing pump-and-treat system of seven ground water recovery wells connected to an air stripper as an Interim Corrective Measure. Because of the high contaminant concentrations of the dense chlorinated solvents in the southern plume at the Northeast Site, the effectiveness of contaminant removal with a pump-and-treat system was a concern. Because of the high volatility of the contaminants of concern and the generally high permeability of the contaminated soils, in-situ stripping technologies were considered likely candidates to help accelerate remediation at the site. The potential benefit of the rotary steam stripping technology was its ability to quickly treat both the soil and ground water, aggressively reducing the source areas of high concentration to levels more consistent with the rest of the site and allowing the site to be more quickly and easily remediated. Table 3 summarizes some of the key matrix and contaminant characteristics at the site as they relate to the performance of an in situ rotary drilling/stripping technology.

The depth of contamination and soil classification were important matrix parameters in considering the application of this technology because shallow, loosely-consolidated, granular soils support faster penetration and enhance contaminant removal. Moisture content was an important matrix parameter because more energy can be required to achieve contaminant removal in saturated soils. Similarly, as TOC in soil increases, VOCs are more strongly adsorbed to soil, requiring more energy for volatilization. In terms of contaminant parameters, the volatility of the specific contaminants of interest is obviously a key characteristic for any type of stripping or heating technology. The heat of combustion of contaminants, including associated chemicals that are not the primary COCs, is important in the selection and design of the off-gas treatment components of the sytem (as discussed in Section 5).

Table 3. Key matrix and contaminant characteristics

Parameter	Value
Total depth of treatment	32 ft
Unsaturated thickness	3-5 ft
Saturated thickness	27 ft
Primary zone of contamination	20-30 ft
Soil classification	Silty sand
Clay content	Low; approx. 5%
Soil hydraulic conductivity	10^{-3} to 10^{-5}
Moisture content	Saturated
Total organic content	Low
Contaminant volatility	
Vapor pressure	
Methylene chloride	3790 mmHg@20°C
TCE	58 mmHg@20°C
Toluene	22 mmHg@20°C
Contaminant heat of combustion	
Methylene chloride	144 kcal/mol
TCE	226 kcal/mol
Toluene	934 kcal/mol
Presence of DNAPLs	Highly likely, as indicated by the very high VOC concentrations; believed to occur as an immiscible phase, rather than as a single discrete "pool."

4. TECHNOLOGY DESCRIPTION

The technology evaluated in this field demonstration was rotary steam stripping for the in situ removal of high concentrations of chlorinated organic solvents from soil and ground water. With this technology, a mobile rotary drilling or augering system is used to inject hot air or steam into VOC-contaminated soils to strip the contaminants from the soils and ground water. Several companies have developed mobile treatment technologies based on this process. As stated previously, In-Situ Fixation of Chandler, Arizona, developed and operated the rotary steam stripping equipment selected for this remediation effort.

Technology Description

The rotary steam stripping system is based on rotary drilling technology.[7,8] As shown in Figure 4, the system consists of a drill tower attached to a mobile platform. In most applications, the drill tower supports one or two drill blades or augers designed to inject hot air or steam into the subsurface soil as the drill blades or augers penetrate below the ground surface. The augers shear and mix the soil while the hot air or steam is being injected, causing stripping and thermal desorption of the organic contaminants from the soil particles and volatilization of the contaminants.[9] The air, steam, and contaminant vapors are carried to the surface by the injected air and steam and are collected by a shroud placed over the soil being treated. The shroud, which is operated under a slight vacuum, rests firmly on the ground so that the gases and vapors released during subsurface treatment are captured.

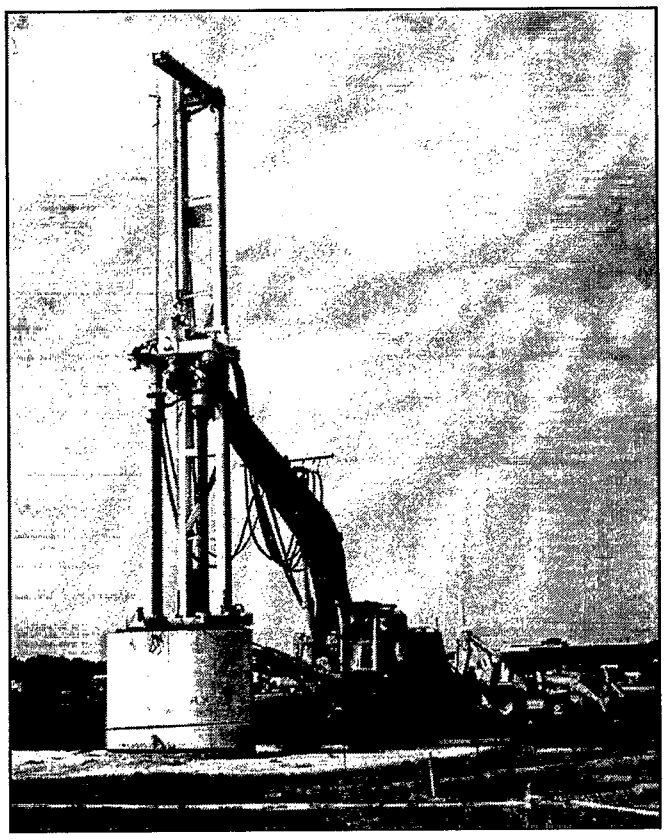


Figure 4. Photo of system.

The contaminant vapors collected in the shroud are sent to an above-ground processing unit for treatment. Depending on the type and concentration removed, contaminants can be treated in various ways: condensation, activated carbon adsorption, or thermal destruction. The treated air and steam can be reinjected for further soil treatment.

These systems can be used to treat both the vadose and saturated soils in a batch process. To fully treat an area, a grid of overlapping treatment zones is used. After one treatment zone is completed, the rotary drilling system is moved to the next zone for treatment. Depending on the contaminant types and concentrations, treatment rates of 4 to 20 yds/hr are possible with these systems. The number of passes made up and down through the soil column by the drilling system is varied as needed to reduce the contaminants to the desired treatment levels, thereby often obtaining contaminant removal efficiencies ranging from 85% to 99%.[10]

A patent on certain aspects of the steam stripping technology exists, and the patent holder has pursued what was interpreted to be patent infringements in the past. The exact details of this patent are not known by the ITRD Program. According to In-Situ Fixation, Inc., no patent infringements occurred during the Pinellas Project. Anyone wishing to place contracts for the use of this technology should be aware of the potential for patent-related issues.

Technology Advantages

The treatment of VOC-contaminated soils and ground water using this type of system offers the following advantages:

- treats the contaminated soils and ground water in situ without excavation while capturing air emissions;
- provides thorough mixing and homogenization of the treated soil, resulting in effective contact between the treatment agents and the contaminants;
- can operate in bedded soils of varying permeability, such as clays and sands;
- can operate in both vadose and saturated soils; and
- can be used to focus remediation at specific contaminated strata.

Technology Limitations

This technology has the following limitations:

- Contaminant removal rates can be limited by the size and operational capabilities of the required off-gas treatment system.
- Treatment is generally limited to contaminated soils less than 40 ft deep.
- Removal effectiveness and efficiency are dependent on the contaminant volatility and concentrations and soil types.
- The intended treatment area must be cleared of underground obstructions.

In-Situ Fixation System Description

The ISF treatment system uses a dual-auger steam injection system. An integral drill tower containing the dual augers and collection shroud are mounted on a Caterpillar trackhoe chassis. The dual augers (Figure 5) operate in a counter-rotating mode to provide balanced forces and stability of the drill tower. The dual 5-ft-diam augers overlap slightly, providing a treatment area of about 4.5 ft by 7.5 ft, or about 35 ft^2. The current fixed-tower design allows soil treatment to a depth of about 35 ft. By being mounted on the trackhoe chassis, the drill tower and augers can be moved easily from one treatment zone to another.

Figure 5. ISF dual auger bits and shroud.

For application at the Northeast Site, the dual auger system was connected to a steam plant and air compressor to provide both air and steam as the injection fluids for stripping the VOCs from the soil and ground water. The shroud used to collect the stripped VOCs was connected to a catalytic oxidation (CATOX) system (Figure 6) for destruction of the organic contaminants. The oxidation system was connected to an acid-gas scrubber (Figure 7) to neutralize air emissions.

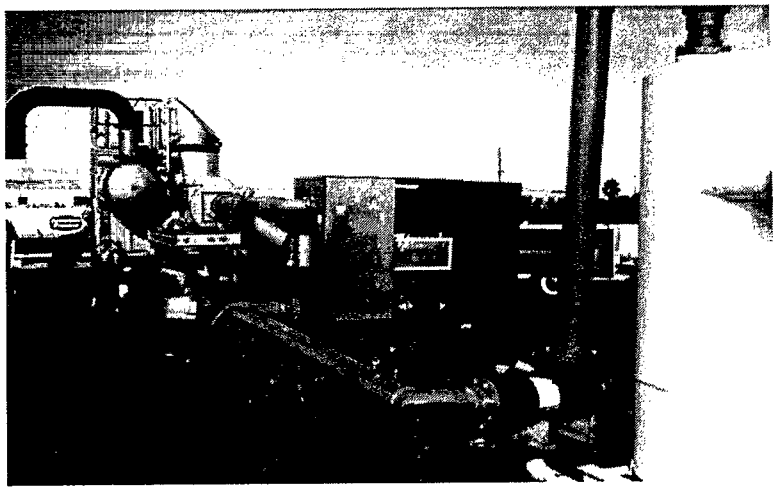


Figure 6. Off-gas treatment system prior to completed assembly, showing (from right to left) knock-out tank, vacuum extraction unit, and CATOX.

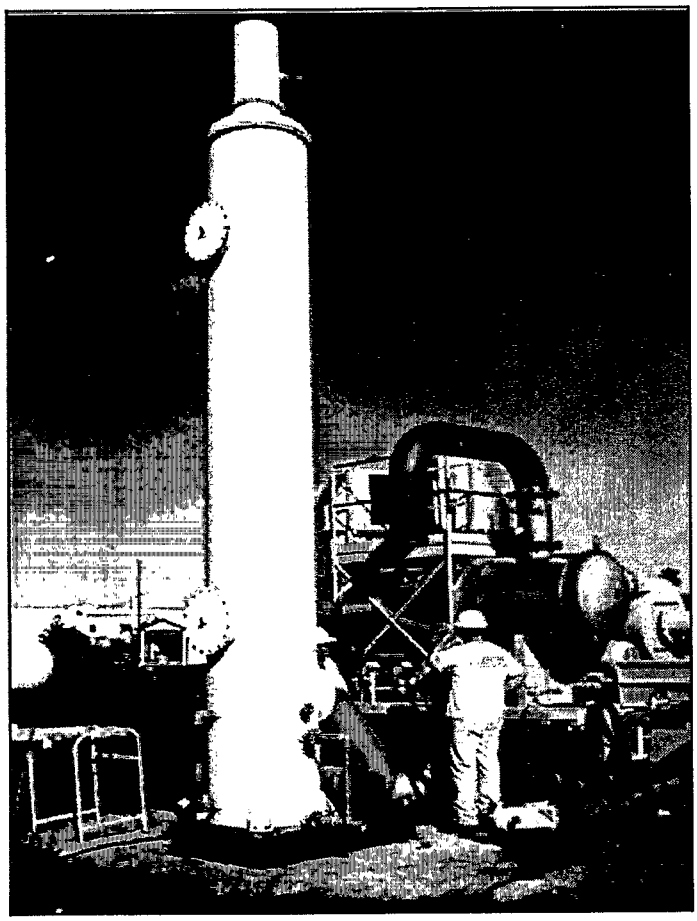


Figure 7. Acid-gas scrubber tower prior to assembly with quench unit and CATOX.

Treatment System Schematic and Operation

Figure 8 is a schematic of the ISF treatment system operated at the Pinellas STAR Center. The treatment system process flow was as follows:

- The rotary steam stripping system was moved to the area to be treated, and the shroud was lowered to the ground surface and placed under negative pressure.
- The rotating augers began penetration into the contaminated soil, continuously injecting either air and/or steam through the drilling kelly bars into the contaminated soil and ground water.
- Depending on the contaminant removal rates and the amount of contaminants removed, the augers made a series of passes up and down through the soil column.
- The contaminant vapors collected with the shroud were directed first to a water knock-out tank and then to a catalytic thermal oxidizer, where the VOCs were destroyed.
- The emissions from the catalytic oxidation system were passed through an acid-gas scrubber to remove hydrochloric acid (generated during the destruction of the chlorinated VOCs) before discharge into the atmosphere.

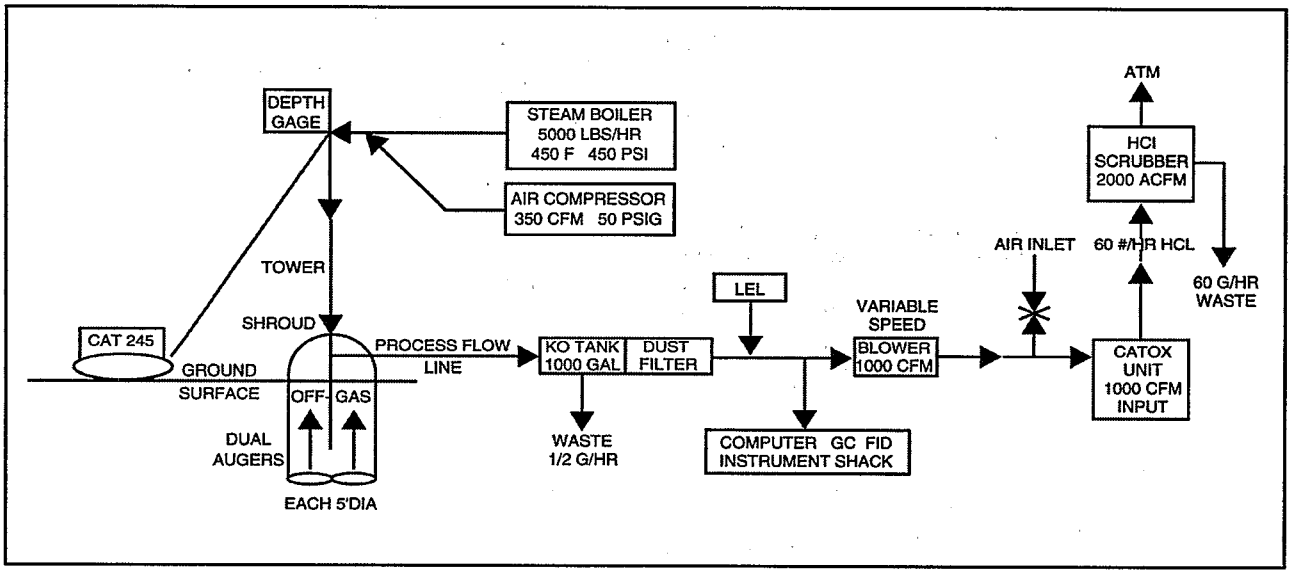


Figure 8. Process schematic.

Health and safety requirements for the operation of the system required continuous monitoring of the following: the areas around the shroud for leakage of contaminant vapors, the concentration of contaminants entering the catalytic thermal oxidation system, and the air emissions from the off-gas treatment system. Figure 9 is an aerial view of the entire treatment system in operation at the Pinellas STAR Center.

Key Design Criteria

In situ anaerobic bioremediation is being considered as a potential remediation technology for the Pinellas STAR Center's Northeast Site. The application of the rotary steam stripping technology at this site was initiated to reduce the areas of very high levels of chlorinated solvents to levels more consistent with the rest of the site and more compatible with bioremediation. This goal required the reduction of the identified contaminants in the areas of high concentration from levels of 500 to 5000 ppm to levels of 100 to 200 ppm.

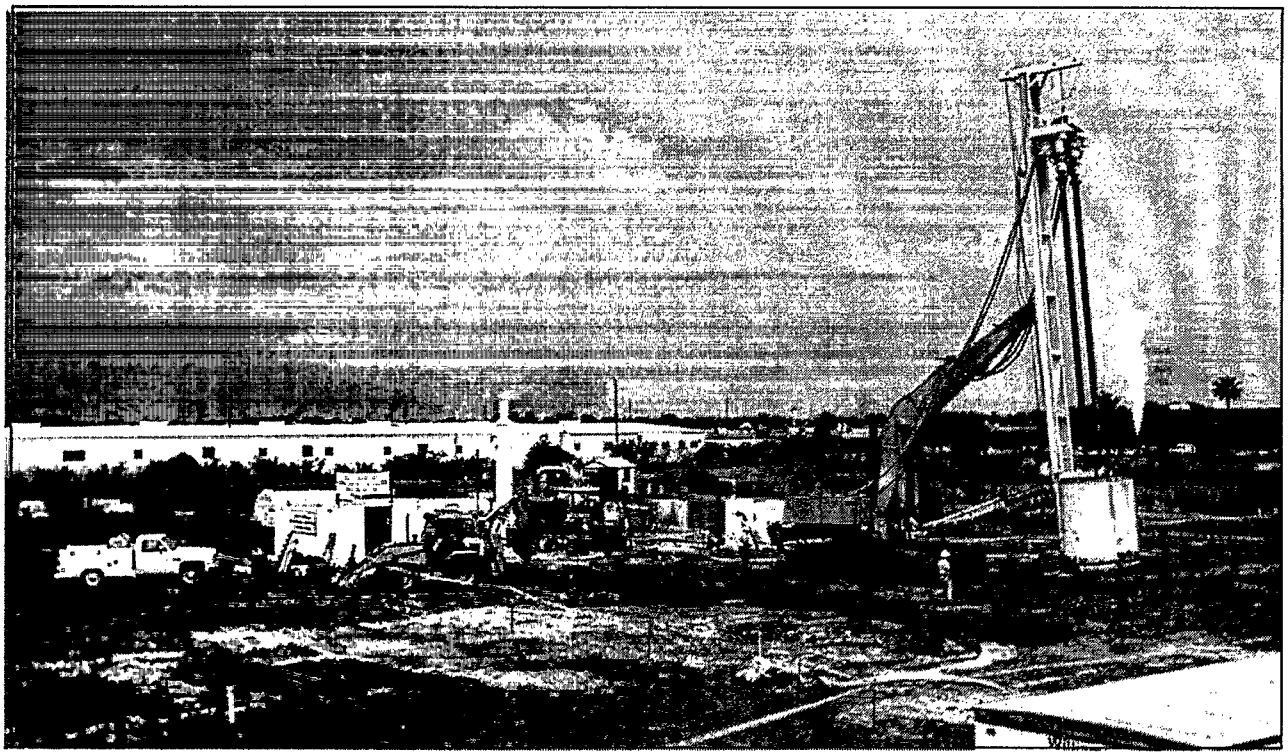


Figure 9. Aerial view of the dual auger rotary steam stripping and off-gas treatment system.

Based on the areal extent and depth of the contamination at Pinellas, it was expected that approximately 10,000 cubic yards of soil could require treatment to a depth of approximately 30 ft. Based on the Florida Department of Environmental Protection (FDEP) guidelines, the removal of these high concentrations of VOCs from this volume of material would require air emission treatment. Initial estimates suggested that the use of thermal treatment technologies would be more cost effective than other air emission control devices, such as activated carbon. Based on the volume of contaminants to be treated, the largest easily portable catalytic oxidation system was selected for use with the rotary steam system. Because the VOCs being treated at the Northeast Site are predominately chlorinated solvents, an acid-gas scrubber was also required to meet the FDEP's air discharge requirements.

ISF proposed a CATOX system design that would treat 60 lb/hr of methylene chloride, the major site contaminant. The scrubber capacity (60 lb/hr HCl) was sized slightly larger to account for the presence of TCE. It was anticipated that only in the most concentrated areas would the removal rate exceed 60 lb/hr. In these cases, process controls would be initiated to limit the VOC throughput to the off-gas destruction system. The critical factors that determined the selection of the 60 lb/hr capability of the off-gas treatment system were (1) the combined cost of the scrubber, catalyst and CATOX; (2) the pretreatment site characterization chemical data; and (3) the delivery schedule of the scrubber and CATOX.

Based on the site pretreatment chemical data, the presence of toluene was noted as significant in one area of the site. As indicated in Section 3, toluene has a much higher (approx. 7 times) heat of combustion than methylene chloride. If toluene occurred in even moderate amounts, its destruction would release enough heat to limit off-gas throughput by causing catalyst overheating. It was difficult to evaluate the extent of this potential problem prior to the remediation.

Operating Parameters

The operating parameters (Table 4) of the rotary steam stripping system can be adjusted depending on the effluent concentrations of the contaminants being treated, the capacity of the off-gas treatment system, air emission requirements, and the type of soil being treated. Because the levels of contaminants varied across the site to be treated, it was expected that different combinations of air/steam, injection pressures, penetration rates, etc., would be varied to cost effectively reduce the contaminant concentration levels across the site. For this application, two major areas of contaminated soil/ground water treatment were addressed—one area had VOC concentration levels in excess of 5000 ppm, and the other area had VOC concentration levels of about 500 ppm. Because of the flexibility of the treatment system, each area was treated differently to optimize the treatment performance.

At the Northeast Site, treatment operations were generally conducted 8 to 10 hrs/day, 5 days/week. ISF typically had five people involved in operations: a site supervisor, a health and safety officer [who doubled as a sampler and gas chromatograph (GC) operator], a trackhoe operator, a boiler operator, and a general laborer. Oversight by LMSC typically involved a project manager, and an individual from the LMSC Industrial Hygiene/Safety Department routinely visited the site during operations.

Operation of the rotary steam stripping system was controlled and adjusted based on the VOC levels coming out of the shroud, which were continuously monitored with an in-line flame ionization detector (FID). Treatment parameters (depth, FID, process temperature, air injection rate, steam injection rate, and process flow rate) were continuously monitored with a digital display, strip chart recorder, flowline meters, and pressure gauges located throughout the system. A remote FID and depth display was mounted in the CAT245 cab for the operator. The operator observed and used these data to adjust the penetration rates and treatment times in each of the treatment holes. This continuous monitoring during drilling reduced the chance of exceeding the catalyst temperature threshold in the CATOX system and assisted in directing treatment to the appropriate horizons in each hole.

Table 4. Typical operating parameters

Parameter	Value
System equipment base/mover	Caterpillar 245D trackhoe
Stripping system	Dual counter-rotating, 5 ft-diam augers
Support equipment	Backhoe, welder, off-gas treatment system, compressor, boiler, generator, parts trailer
Treatment area per hole	35 ft^2
Auger rotation rate	12 rpm
Auger penetration rate	1 ft/min avg
Air injection rate/pressure	200-300 scfm avg @ 125 psi
Steam injection capacity/ temperature	2,000-4,000 lbs/hr @ 450°F @ 550 psi
Vacuum on shroud	5-10 in. water
CATOX capacity/throughput	60 lb/hr (based on methylene chloride)
CATOX operating temperature	approx. 1000-1100°F

5. ROTARY STEAM STRIPPING SYSTEM PERFORMANCE

ISF treated an area within the Pinellas STAR Center Northeast Site from January through April 1997. The following sections of this report present a summary of the system's performance.

Remediation Objectives and Approach

The remediation was coordinated by LMSC, the DOE's site contractor for the Pinellas STAR Center, in cooperation with the ITRD Program. The primary objective of the rotary steam stripping project was to quickly remediate areas of high concentrations of contaminants within the designated treatment area of the Northeast Site. Through the remediation of these areas of high concentration, the Northeast Site would then have more moderate contaminant levels that could be more easily treated with a proposed in situ bioremediation effort.

The approach to the remediation focused on four supporting objectives:

1. optimize system operating parameters through an initial Treatment Efficiency Characterization (TEC) study,
2. evaluate overall system performance in treating VOC-contaminated soil and ground water,
3. evaluate system operation effects on the surrounding environment, and
4. quantify site-specific unit treatment costs.

Performance Evaluation Criteria

Performance criteria considered in the evaluation of the rotary steam stripping technology included the following:

- ability of the system to remove VOCs in the soil and ground water to a level of 100 to 200 ppm in an approximate 10,000-yd^3 treatment volume,
- recovery and treatment of volatilized contaminants to air emission levels specified in the FDEP's Notice of Authorization [10,11] to conduct the rotary steam stripping project,
- absence of fugitive hazardous emissions from the treatment system, and
- absence of migration of contaminants outside the treatment area.

The methods used to assess performance were:

1. To gain further insight into the rotary steam stripping technology and to establish efficient operating parameters to remediate the treatment area, a TEC was conducted immediately after system setup.
2. To verify VOC removal and determine final contaminant levels, pre- and post-treatment soil and ground water sampling and analyses were performed. The ITRD group established a sampling grid (Figure 10) to characterize the planned treatment area and its perimeter.
3. To verify the level of recovery and treatment of volatilized contaminants, air samples were collected daily during operations from the CATOX influent, the CATOX effluent, and the scrubber effluent.
4. To verify the absence of any fugitive emissions from around the treatment system, monitoring was performed with a hand-held FID vapor analyzer during operations.
5. To verify the absence of migration of contaminants outside the treatment area, soil and ground water sampling points were established around the treatment area perimeter, and monitoring wells around the perimeter were sampled before and after treatment operations.

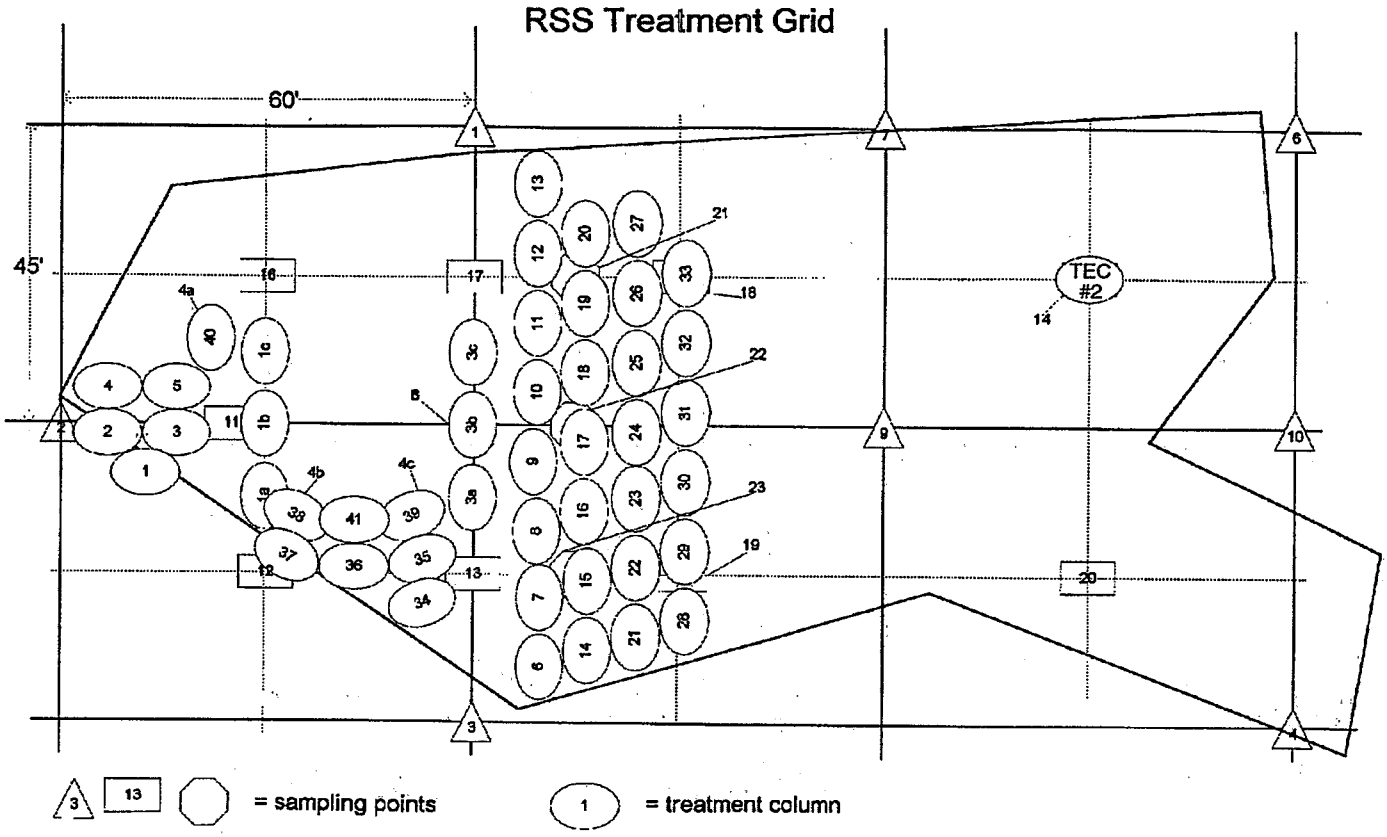


Figure 10. Sampling grid with overlay of treatment holes.

Operational Summary

Mobilization Phase

Equipment and materials were transported to the Pinellas STAR Center's Northeast Site from approximately September 25 through December 24, 1996. The original estimate for completion of transport of equipment was mid-November, with a completion of assembly by the end of November. Several issues resulted in the delay of completion of the mobilization phase until January 20, 1997. One significant issue was that an available CAT 245D trackhoe (this specific model was required to mate with the ISF dual auger system components) rental unit was not able to be located in the southeastern United States, necessitating the transport of one from Phoenix, Arizona.

After assembly, the drilling of two practice holes demonstrated that the dual-auger system was able to penetrate the soils at the Northeast Site without any significant resistance and that the air and steam injection through the soil and ground water, along with the resultant recovery of vapors, appeared to be functioning as expected. However, hydraulic problems (a broken fitting and incorrectly connected hydraulic lines) encountered on the first practice hole resulted in a one-week delay in beginning operations.

Treatment Efficiency Characterization Phase

A Treatment Efficiency Characterization (TEC) Study was conducted to identify system operational capabilities and issues over the range of contaminant mixtures and concentrations in the treatment area. The ITRD group chose three specific areas based on contaminant levels and characteristics. Figure 10 shows the locations of not only these areas, but also sampling points and later treatment holes. The 1A, B, and C holes were located in an area of very high VOC contamination in the ground water (up to 5,000,000 μg/L total VOCs). TEC No. 2 hole was located in an area of moderate VOC contamination in the ground water (approx. 250,000 μg/L total VOCs). The 3A, B, and C holes were located in an area with the highest levels of total VOCs in the soil (approx. 400,000 μg/kg total VOCs).

The TEC phase began on January 21 and continued through February 11. During the treatment of these areas, air only was injected into the 1A and 3A holes, air and steam was injected into the 1B and 3B holes, and air was injected in the first pass then steam for the remaining passes for the 1C and 3C holes. The results were monitored to develop optimal treatment settings for the rest of the treatment area. Sampling of soil and ground water was performed before and after treatment of the TEC locations, and an in-line FID was used during operations to collect continuous total VOC removal quantities. Several initial operational issues with the system were identified during the TEC and are listed in Table 5.

Table 5. Operational issues and delays during the TEC

Issue	Result and extent of delay
Field GC was not operating properly for approx. 2 weeks, necessitating the use of the LMSC Analytical Laboratory.	Delayed receipt of analytical results at least 1 day.
Destruction efficiency of the off-gas treatment system dropped below the permit-required 90% destruction.	Repaired CATOX unit and catalyst (2 days).
Because of efficiency problems of the off-gas treatment system, operations were limited to treating one hole and then ceasing operations until it was confirmed that the off-gas treatment system was effectively destroying the contaminant vapors in accordance with the air emissions permit requirements.	Resulted in the loss of approximately ½ to 1 day of operations after treating each hole.
Packing in the scrubber tower melted due to a loss of cooling water caused by a plant-wide water shutoff.	Removed and replaced with new packing (2 days).
Fugitive emissions were detected outside of the dual auger system shroud. Some of the fugitive emissions exceeded the Permissible Exposure Limits (PELs) in the breathing zone for the project.	Variable extent; this continued to occur throughout the project; however, the frequency of occurrence was decreased by limiting the air injection rate, creating an exclusion zone around the shroud and placing a large sheet of plastic around the shroud to limit fugitive emissions.
Automatic alarm shutdowns of the CATOX unit and the vacuum extraction unit occurred when the mass of VOCs being fed to the CATOX was large enough to raise the temperature of the catalyst beyond its operating limits.	Variable extent; this problem continued to occur throughout the project; however, it was limited by increasing the catalyst's operating temperature limits and implementing procedures to limit the mass of VOCs being fed to the CATOX.
During periods of recovery and treatment of large masses of VOCs, the acid-gas scrubber was incapable of controlling the pH of the air emissions.	Variable extent; further inspection revealed an undersized caustic-addition pump intake line. When the size of the intake line was increased, the scrubber was able to neutralize the air emissions at all times.

At the end of the TEC phase, the following operational characteristics of the rotary steam stripping system became apparent:

- The mass of VOCs (especially any VOC with a high heat of combustion) being fed to the CATOX had to be limited; otherwise, the catalyst could be overheated.
- Catalyst overheating protection shutdowns frequently occurred when air and steam were being injected.
- The dual-auger system was capable of removing more contaminants than the design capacity of the off-gas treatment system.
- Fugitive emissions were able to escape outside the shroud and could exceed PELs.
- Because of the FDEP's air emissions limitations, timely and accurate gas sample analysis was critical.
- Sampling of the TEC holes where only air injection was used (1A & 3A) showed mixed results, with negative removal (i.e., contaminant redistribution) of VOCs in the soil and groundwater at 20 ft below land surface (bls), and good removal of VOCs from the ground water at 30 ft bls.
- Sampling of the TEC holes where steam and air injection was used (1C, 2, 3B, 3C, & 4A-C) showed generally better results, with more limited occurrences of redistribution of VOCs in the soil and groundwater at 20 ft bls, and good removal of VOCs from the ground water at 30 ft bls.

Remediation Phase

As discussed in Section 3 and shown in Figure 3, the contaminants at the site in the area treated with the dual-auger system were mainly between 16 and 30 feet below the surface. Additionally, the highest levels of contamination occurred on the west end of the treatment area and decreased quickly to the east. Because of these relative levels of contamination, it was decided to begin treatment in the areas of highest contaminant concentration. From Figure 10, this included treatment holes 1-5. After beginning treatment of production hole No. 1 on February 12, the off-gas treatment system continued to experience problems with catalyst high temperature shut-downs. On February 18, the dual auger system sheared bolts that attach the kelly bars to the drive unit and was inoperable until February 25. Further problems with the off-gas treatment system resulted in only three holes being treated during this phase in February. (Two holes were treated in the TEC phase during February.)

March operations in the western portion of the treatment area continued to have problems with fugitive emissions and catalyst high-temperature shutdowns until March 4, when LMSC personnel decided that the rotary steam stripping system was not able to operate effectively at this elevated level of contamination, and no further knowledge of the technology's application at this site was being gained . On March 5, the system was moved to the central portion of the treatment area, where contamination levels were significantly lower. This included treatment holes 6-33. Holes 6-11 were quickly treated in two days. On March 7, the system was unable to back out of hole No. 11 due to a failed drive chain in the main gearbox. Repairs of the system lasted through March 18. Operations resumed on March 19, after which 26 holes were treated in 6 days, and progressively lower levels of contamination were being encountered as treatment progressed eastward.

On March 24, after finishing hole number 33, the system was moved back to the area of higher contaminant concentration because LMSC personnel felt that the knowledge and experience of system operations on-site had improved to a point where effective treatment could be accomplished in the higher concentration areas. The system remained in this area for the remainder of the remediation phase, treating holes 34-41. Because of the higher contaminant concentrations in this area, several passes were required in each hole, and operations were slowed to keep from overheating the catalyst. On March 27, clay buildup on the dual auger's cutting teeth was slowing penetration rates enough that the clay had to be removed, and it was discovered that the boiler had to be descaled. Operations once again resumed on March 31 and continued through April 2, at which time the funding for the time-and-materials phase of the subcontract was depleted, and the project was terminated.

System Performance and Treatment Results

Contaminant removal by the dual auger system from each of the treatment holes was monitored with an FID located on the dual auger shroud. This provided a continuous display of the amount of contaminants being removed by the system. It also allowed the operator to concentrate treatment in each borehole in the zone of highest contaminant concentration. The FID was calibrated with a GC throughout the remediation so that, along with the continuous monitoring of the air and steam flow rate through the shroud, the amount of contaminants removed from each treatment hole could be measured (Table 6). Based on this data, approximately 1200 lbs of contaminants were removed by the dual auger system. These results compare well with the results obtained from monitoring of the CATOX system and comparisons with pre- and post- treatment sampling of the soil and ground water.

Table 6. Examples of contaminant removal for several treatment holes based on calibrated FID data

Treatment hole no.	Air or steam	Time treated (hrs)	Contaminant removed (lbs)
1A	air	4	19
1B	air & steam	5	28
1C	air, then steam	3	17
3A	air	2	6
3B	air, then steam	3	7
3C	air & steam	3	10
2	air, then air & steam	6	92
5	air	3	50
6	air	3	3
7	air	1	2
8	air	1	2
9	air	1	2
10	air	1	4
11	air	1	1
37	air & steam	2.5	14
38	air & steam	5	42
39	air & steam	4	34
40	air & steam	4	47

Based on the historical VOC concentration data previously discussed and shown in Figure 3, several sets of soil and ground water samples were collected to assess system performance and system operational effects on the surrounding environment. As shown in Figure 10, about 20 different locations were selected on a defined grid pattern to collect soil and ground water samples inside and around the edges of the expected treatment zone. Soil and ground water samples were collected at these locations both before and after treatment. Because the existing historical data showed that most of the contamination in the treatment area was at depths between 15 and 30 feet deep, at the identified locations ground water samples were collected at depths of 15 and 25 feet, while soil samples were collected at depths of 10, 20, and 30 feet or depths of 15, 20, and 25 feet. All samples were collected using direct push sampling techniques and were analyzed using EPA Methods SW846 8240A for soils and 8260A for ground water.

As can be seen in Figure 10, several of the treatment holes were oriented to coincide with the identified monitoring locations. Additionally, many of the Treatment Efficiency Characterization treatment holes were sampled before and after treatment. At these locations, the soil was sampled continuously before treatment and the VOC distribution assessed using a PID detector. At the location of the highest PID reading, a soil sample was taken for analysis. After treatment, the soil was sampled at the same location for comparison. These are the maximum soil contamination values pre and post-treatment identified in Table 7. The results in Table 7 cover a wide range of soil and ground water contaminant concentration ranges and should be representative of the overall effectiveness of the rotary steam stripping system.

As can be seen from the results presented in Table 7, the overall removal efficiencies commonly vary from 69-95%. The percent removals were calculated from total contaminant estimates before and after treatment and from the GC-calibrated FID data collected during treatment. With a few exceptions, these results track with the general percent reduction in the levels in the maximum contaminant concentrations. The sampling data show that the contaminants of concern at the site, methylene chloride, TCE, DCE, vinyl chloride, and toluene are all removed equally well. None of the contaminants showed consistently lower removal rates than the other contaminants. In some cases, post-treatment sampling revealed higher VOC concentrations at some horizons than were detected pretreatment; this is believed to be caused by the liberation and vertical mixing of contaminants as the dual augers are rotated up and down the treatment hole. Still, the FID data indicated that, overall, many pounds of VOCs were removed from each hole.

Table 7. Pretreatment and post-treatment soil and ground water concentrations

Treatment hole/ monitoring point #	Pretreatment concentrations (ppm)		Post-treatment concentrations (ppm)		Percent reduction in observed maximum (%)	Percent removal based on FID data (%)	Air or steam	Treatment time
	Max. soil (μg/g)	Ground water (mg/L)	Max. soil (μg/g)	Ground water (mg/L)				
Hole 1A	<1	5170	120	1484	69	93	Air only	4 passes, 4 hrs
Hole 1C	1860	2480	106	724	81	55	Air, then steam	4 passes, 3 hrs
Hole 3A	20	1426	325	1019	7	95	Air only	2 passes, 2 hrs
Hole 3B	7	6952	11	1135	84	30	Air, then steam	3 passes, 3 hrs
Hole 3C	82	1860	29	341	81	95	Air and steam	4 passes, 3 hrs
Hole 4A	28	NA	143	NA	--	90	Air and steam	3 passes, 4 hrs
Hole 4B	900	NA	26	NA	97	95	Air and steam	Many passes, 5 hrs
Hole 4C	204	NA	158	NA	23	95	Air and steam	1.5 passes, 4 hrs
MP 14	19	251	<1	2	99	no data	Air and steam	2.6 passes,1 hr
MP 18	<1	1290	2	198	85	75	Air and steam	1 pass, 1 hr
MP 19	<1	1364	6	198	85	45	Air and steam	1 pass, 1 hr

NA = not analyzed

While the percent removal data is impressive, an important evaluation criterion is also the level to which the contaminant concentrations can be reduced. As shown in Table 7, even after several passes with the rotary steam stripping system, areas with the highest contaminant concentrations often still require additional treatment to reduce contaminant concentrations below 100 or 200 ppm, levels considered most compatible with a proposed in situ anaerobic bioremediation system. This, of course, would increase the total cost of a remediation effort using this technology.

Based on the results of the TEC study, a general understanding of the contaminant removal rates obtained by the dual-auger system and effectively handled by the off-gas treatment system was determined for various operating conditions and contaminant levels. Figure 11 shows the relationship at this site for the expected contaminant removal rates for various operating conditions. The amount of total VOC contaminants in each treatment hole was estimated based on the extensive soil and ground water sampling data generated for this remediation effort through the TEC study. As the dual-auger system made passes up and down through each treatment hole, the volume of VOCs removed was recorded continuously with a GC-calibrated FID. The results in this figure are based on the removal data from more than 100 separate treatment passes of the dual-auger system.

Based on the information presented in Figure 11, a few general observations can be made. First, higher air-flow rates provide higher contaminant-removal rates. In areas with low contaminant levels, the differences are less pronounced. The large contaminant-removal rates available with the dual auger system suggest that the selection of an appropriate off-gas treatment system is important, because it can become the rate-limiting factor in treating areas with high contaminant concentrations. In fact, this limitation occurred in the Northeast Site application in the area of high contaminant concentration where the catalytic oxidation system could not handle the amount of contaminants being produced by the dual auger system, forcing the operator to reduce the penetration rate and/or steam injection rate in order to limit the contaminant removal rate.

In addition, some areas contained TCE and toluene, compounds with much higher heats of combustion, in approximate concentrations of 350 ppm and 100 ppm, respectively. It was observed that during treatment in the areas with these compounds, the maximum temperature allowable for the catalyst (approx. 1,100° to 1,200°F) could be reached very quickly, resulting in an automatic over-temperature system shut-down. Further elevation of the catalyst temperature could result in irreversible physical damage to the catalyst. It is believed that the TCE and toluene quickly elevated the temperature of the catalyst when they were combusted. Slowing the auger penetration rate by 75% to 90% and decreasing or stopping steam injection helped to control the catalyst temperature. As discussed in Sect. 4, the design of the off-gas treatment system was based on the high concentration of methylene chloride in the western portion of the treatment area, and the potential impact of the high TCE and toluene concentrations on off-gas treatment was not fully understood.

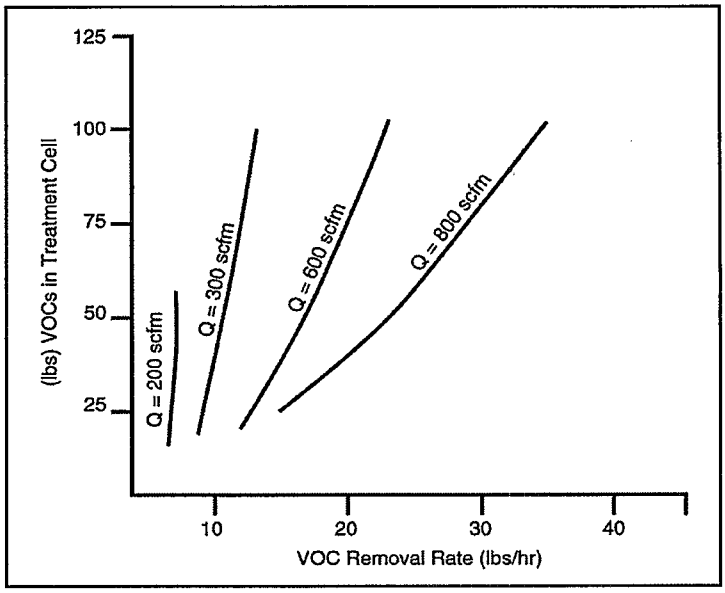


Figure 11. VOC removal rates compared to estimated original quantities of VOCs in treatment hole
(Q = extraction flow rate in standard cubic ft/min).

Another observation is that contaminant removal rates generally decrease as contaminant levels decrease, suggesting that a practical limit probably exists for the level to which the contaminant concentrations can be reduced cost effectively. For this remediation effort, the goal was to reduce the contaminant concentrations to levels approaching 100 to 200 ppm to be compatible with the rest of the site and a proposed in situ anaerobic bioremediation effort. In the areas of low contaminant concentration, contaminant levels were easily reduced from approximately 100 ppm to 1 to 10 ppm for both soil and ground water. Whether these levels could be attained cost effectively in areas of high contaminant concentration was not fully investigated at this site.

Part of the system performance evaluation included looking at the effects of the system operation on the surrounding environment. Major concerns were fugitive emissions and the possible migration of contaminants outside the treatment area. As previously discussed, fugitive emissions were detected above permissible exposure limits during some operations. These were minimized by limiting air injection rates, creating an exclusion zone around the shroud, and by placing plastic around the shroud. Post-treatment soil and ground water sampling around the perimeter of the treatment areas did not show any contaminant migration from the treatment areas into the adjacent untreated areas. During sampling of some post-treatment holes, it was discovered that it was difficult to obtain some water samples using direct push technology. This suggests that the permeability in the treated soils may have been reduced.

However, sufficient post treatment testing has not been conducted to determine if any long term reduction in the soil permeability has occured. This does suggest though that, if rotary steam stripping is to be used in conjunction with another technology, such as air sparging/soil vapor extraction, consideration should be given to determine whether rotary stripping operations would negatively affect the performance of a follow-on technology.

As discussed in the previous project chronology, system downtime affected the performance of the rotary steam stripping system. Figure 12 shows the operating time for the system, which averaged approximately 50% for the entire project. Figure 13 shows the downtime as a percent of available operating time per week, identified with the general cause of the downtime. The operating time for the system over the last half of the project increased continuously and averaged approximately 80% during the last three weeks of operation.

A summary of the performance of the rotary steam stripping system is provided in Table 8 relative to the performance measures of the remediation effort. After some initial operational problems, the system met many of the identified goals. However, problems with the capacity and operation of the off-gas treatment component did significantly reduce the treatment rate and overall system performance.

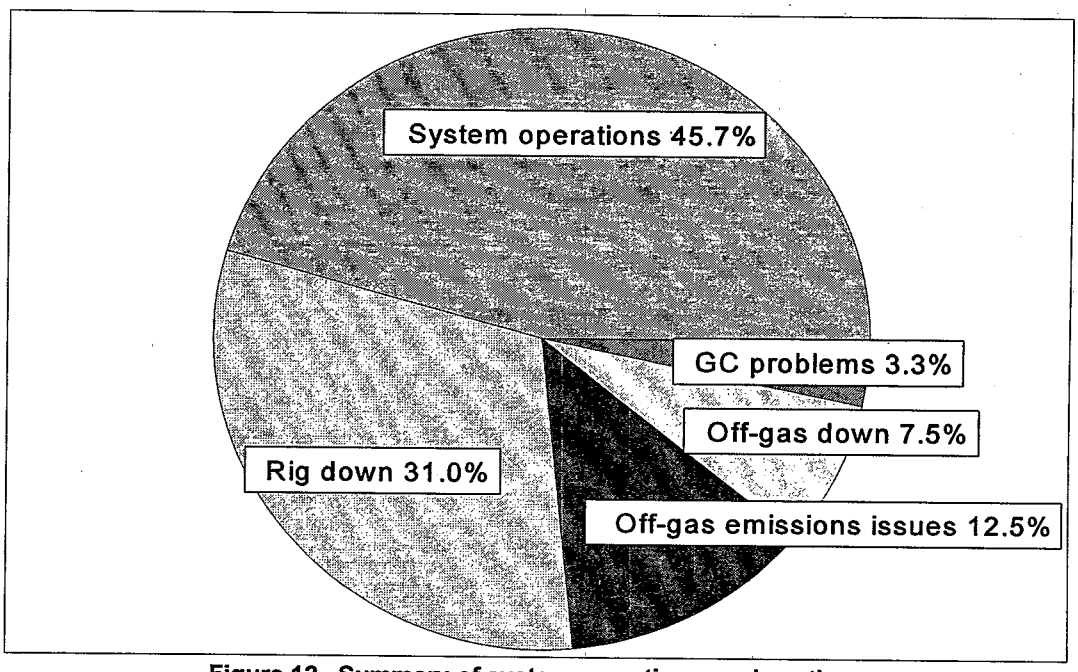


Figure 12. Summary of system operations vs downtime.

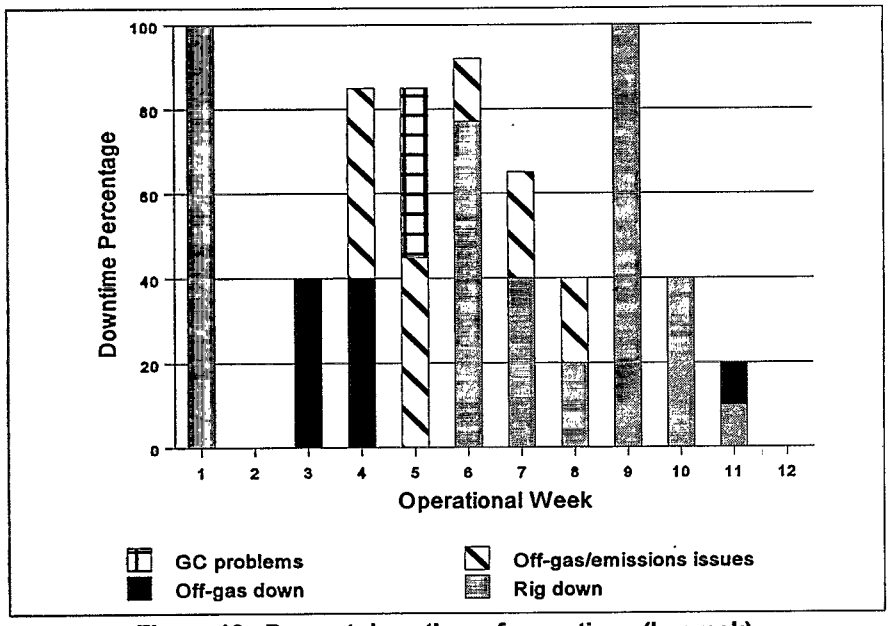


Figure 13. Percent downtime of operations (by week).

Table 8. Pinellas rotary stripping system performance summary

Performance Measure	Value/ Result
Quantity of soil/area treated • Planned • Actual	 10,000 yd^3 2,043 yd^3
Mass of contaminants • Estimate (pretreatment) in planned treatment area • Estimate (pretreatment) in actual treatment area • Estimated mass removed	 9,000 lbs 1,300-1,400 lbs 1,200 lbs
Remediation goals • Optimize parameters through a Treatment Efficiency Characterization • Removal of VOCs in the soil and ground water to approx. 100-200 ppm • Absence of fugitive emissions • Absence of contaminant migration	 • A TEC was performed, although multiple equipment problems limited the information obtained. • Some areas were reduced to below 100 ppm; however, time and funds available prevented reduction below 200 ppm in other areas. • Monitoring revealed fugitive emissions; these were reduced by limiting the drilling/injection rate and by covering the surrounding soil with plastic sheeting. • Sampling and analyses verified that contaminants did not migrate outside the treatment area.
Compliance Goals: Recovery and treatment of volatilized contaminants to FDEP's limits	Initial discharge from the off-gas treatment system exceeded the FDEP's limits; however, after repair, limits were not exceeded.
Residuals	Used hydraulic oil Scrubber, boiler, and knock-out tank effluent water
Quantity of material disposed	Approx. 100 gal. of used hydraulic oil Effluent water quantity unknown (approx. 5 gpm); routed to site wastewater system

6. ROTARY STEAM STRIPPING SYSTEM COST

The Rotary Steam Stripping project was subcontracted by LMSC to ISF with a fixed price for the mobilization and demobilization phases, and a time-and-materials reimbursement (with a not-to-exceed amount) for the treatment operations phase. The mobilization fixed amount was all-inclusive, including moving the equipment, personnel, supplies, materials, and any other necessary items to the job site prior to start. The demobilization fixed amount was all-inclusive, including moving the equipment, personnel, and any remaining items to ISF's next destination after completion of the project.

Under the subcontract, ISF agreed to the following financial terms:

Mobilization	$ 95,000.00
Demobilization	$ 51,000.00
Time and materials not to exceed	$773,651.08
Total subcontract established amount	$919,651.08

ISF was to perform all work according to the Scope of Work, dated April 17, 1996, and the subsequent clarifications. This not-to-exceed, time-and-materials type contract was based on crew-days on-site and did not specify the volume of soil and ground water to be treated.

Table 9 shows the breakdown of project costs in accordance with accepted Federal Remediation Technologies Roundtable [13] cost elements. Based on the nature of equipment used on such a project, equipment operating rates can be quite high and were the largest component of cost. In addition, standby rates were established for this project in case LMSC stopped the ISF operations and equipment was sitting idle. With this arrangement, full equipment operating costs were not incurred; instead, a minimal rate to cover the equipment rental rate was incurred.

Unit treatment costs are often calculated based on the volume of contaminants removed or the volume of soil treated. Either method must be used carefully because of the variation in treatment inherent at any site. For example, providing unit costs based on the volume of soil treated will vary based on the relative contamination level of the soils being treated, with soils having higher contaminant levels requiring longer treatment. On the other hand, providing unit costs based on the volume of contaminants removed will also vary based on the relative contaminant levels of the soil being treated. As discussed in Section 5, fewer pounds per hour of contaminant are removed in soils with lower contaminant levels. Therefore, in using either method, consideration should be given to both the contaminant level of the soil to be treated and the desired target treatment level.

Another complicating factor is that the rotary steam stripping system consists of several subsystems, each of which has a substantial impact on overall system performance and cost. In the application at the Pinellas STAR Center's Northeast Site, the off-gas treatment system was a major contribution to the unit treatment costs that may or may not be required or could be modified at a different site. Additionally, each of these systems has its own associated downtime that affects the overall system performance and cost.

Therefore, unit treatment costs as a function of the volume of soil treated, the initial contaminant levels in each treatment hole, and the required treatment levels were chosen as identifying factors. Based on the data provided in Table 9, general estimates of the costs per day for the dual auger and the off-gas treatment systems can be defined. Based on the results shown in Table 7 and Figure 11, the time required to reduce the various treatment hole contaminant levels to levels of approximately 200 to 300 ppm was used to calculate the unit removal and treatment costs.

Table 9. Pinellas Rotary Steam Stripping Project cost by interagency work breakdown structure (WBS)

Cost element (with interagency WBS Level 2 code[14])	Description		Costs ($)	Subtotals ($)
Preproject operations visit	Visit to similar project		$ 2,400	$ 2,400
Mobilization and preparatory work (331 01)	CAT 245D transport to Pinellas		$ 10,000	$ 95,000
	Dual auger transport to Pinellas		$ 15,000	
	Parts trailer transport to Pinellas		$ 11,000	
	Trucks and dual auger hood transport		$ 11,000	
	Steam processing equipment transport		$ 19,400	
	Personnel & equipment load out		$ 6,600	
	Personnel & equipment unload & assemble		$ 12,000	
	Operational precheck		$ 10,000	
Monitoring, sampling, testing, and analysis (331 02)	Pretreatment sampling and analysis		$ 23,000	$ 59,000
	Pre-TEC sampling and analysis		$ 9,000	
	Post-TEC sampling and analysis		$ 9,000	
	Post-treatment sampling and analysis		$ 18,000	
Physical treatment (331 13)	Equipment		$ 468,267	$ 773,651
	CAT 245D	$ 76,586		
	Dual auger system	$ 53,211		
	Backhoe	$ 11,643		
	Air compressor	$ 8,853		
	Generator	$ 14,889		
	Support equipment	$ 29,054		
	Boiler	$ 42,957		
	Gas chromatograph	$ 15,417		
	Off-gas treatment equip.	$ 215,657		
	Labor (incl. travel & per diem)		$ 259,097	
	Supplies & Materials		$ 25,250	
	Fuel		$ 21,037	
Disposal [other than commercial (331 18)]	Hydraulic oil		$ 200	$ 200
Demobilization (331 21)	CAT 245D		$ 5,000	$ 51,000
	Dual auger system		$ 7,000	
	Parts trailer		$ 6,000	
	Trucks and dual auger hood		$ 6,000	
	Steam processing equipment		$ 12,400	
	Personnel & equipment disassemble & load		$ 8,000	
	Personnel & equipment off-load		$ 6,600	
			TOTAL:	$ 981,251

As previously discussed, the operation of the rotary steam stripping treatment at Pinellas was affected by a number of operational issues and design limitations that caused great variations in the observed treatment rates. Contaminant mixtures and concentrations also affected the rate of treatment, particularly in the western portion of the treatment area. Because of these operational variations, the unit treatment costs for this project are more accurately represented by a range rather than a discrete value (Table 10).

Based on the time-and-materials contract used at this site, the operating costs of the rotary steam stripping system were approximately $13,000/day. In areas of low contaminant concentration, as many as 5 to 6 holes could be treated in one day, while in the areas of high contaminant concentration, often only one hole could be treated in one day. Based on this data, the operating costs of the system varied from approximately $50-$400/yd^3 of treated soil, depending on the contaminant levels.

Table 10. Range of observed unit treatment costs in the Pinellas rotary steam stripping project

Holes per day	Volume per day (yd^3)	Volume treated at this rate in 60 days (yd^3)	Operating Cost, based on $13,000 per crew-day ($/yd^3)	Mob./Demob. Cost, based on 60 day treatment period($2433/day) ($/yd^3)	**Total Cost ($/yd^3)**
1	40	2,400	$325	$62	**$387**
2	80	4,800	$163	$31	**$194**
3	120	7,200	$108	$21	**$129**
4	160	9,600	$81	$16	**$97**
5	200	12,000	$65	$12	**$77**
6	240	14,400	$54	$10	**$64**

The operating costs can also be viewed from the standpoint of costs per pound of contaminant treated. This method of assessing costs is often presented because it can more easily address the differences in contaminant levels in the treatment holes. Calculating operating costs based on this method, we determined that the unit operating costs for the system varied from $300-$500/lb of contaminant removed.

Key factors that affect overall treatment costs are the on-line time of the entire system, the level of contaminants in the treatment holes, and the target concentration levels one would like to achieve. These factors need to be considered and evaluated critically when trying to assess the expected treatment costs at other sites. Additionally, site-specific costs for mobilization/demobilization, technology performance monitoring, and environmental safety and health monitoring should be considered and included to determine the overall implementation cost of this technology at a specific site.

7. REGULATORY/INSTITUTIONAL ISSUES

In July 1993, DOE, EPA, FDEP, and LMSC entered into an agreement with the ITRD Program to evaluate innovative technologies to remediate ground water contamination at the Pinellas STAR Center Northeast Site effectively and expeditiously.

Under Section II.D.1 of the Pinellas STAR Center's HSWA Permit, interim measures may be conducted at SWMUs after EPA approval. Section II.D.3 requires the permittee to notify the EPA's Regional Administrator as soon as possible of any planned changes, reductions, or additions to the interim measures. The proposed rotary steam stripping project would temporarily interrupt the operation of the existing interim measures (pump and treat with air stripping); therefore, the Pinellas STAR Center ER's Program provided notice to the EPA and FDEP of a planned change (the implementation of ITRD field activities) to the approved interim measures and proposed implementation schedule for concurrence in August 1996. Authorization for implementation of the activities was received in August 1996.

In addition to the HSWA permit issues, FDEP required notification and authorization for air emissions from the rotary steam stripping project. In July 1996, DOE/PAO requested authorization to conduct the rotary steam stripping project. The PAO received authorization in August 1996 [9]. Two further amendments to the August authorization were received based on changes in equipment and the end date of the project [10]. The FDEP authorization specifically identified each component of the off-gas treatment system and required the use of that model or its equivalent during the project and a Professional Engineer's certification that the system will comply with FDEP's standards. Additional stipulations were as follows:

- The operating time of the air treatment system would not exceed 8 hrs/day and 90 operating days.
- The air treatment system would reduce VOC emissions by at least 90%.
- The maximum allowable air emissions from the air treatment system were as follows.

Pollutant	lbs/hr	lbs/day	Total project (lbs)
Methylene chloride	2.01	16.06	1447
Other VOCs	1.15	9.2	828

- Continuous monitoring of the inlet process stream would be performed with an FID organic vapor analyzer (HNU Model PI201 or equivalent), real-time analysis of the CATOX inlet, CATOX outlet, and scrubber outlet process stream by syringe sampling of the process stream and direct injection into an on-site FID/GC.
- Daily summary logs would be completed.
- If system operations or equipment indicated that the project was not operating according to the above requirements, the project would cease operation until the problems were corrected.

Local fire authorities required a permit for use of the propane tank that fueled the CATOX unit. Minimum distances to vegetation and ignition sources were conditional to issuance of the permit. Any future users of the steam stripping technology that involves fuel tanks should check with their local authorities for any necessary permitting.

Upon start-up of the rotary steam stripping operations, compliance with the FDEP air emissions authorization became a very significant part of the project. Initially, the field GC was not operational and necessitated the use of the LMSC Analytical Laboratory. This led to an approximate 1-day delay in receiving analytical results. When the CATOX efficiency was found to be below the FDEP's limits, DOE/PAO limited operations to treating one hole at a time and not proceeding to the next hole until analytical results confirmed that emissions were within the FDEP's limits. Confirmation of continual operations within FDEP's limits allowed the one-hole-at-a-time restriction to eventually be eliminated; however, duplicate sampling and analyses continued throughout the remainder of the project to ensure compliance.

8. SCHEDULE

Figure 14 shows the associated tasks and schedule for the demonstration and evaluation of the rotary steam stripping system at the Pinellas STAR Center.

ID	Task Name	Start	Finish
1	**Procurement Process**	**4/19/96**	**8/20/96**
11	**Planning & documents**	**8/23/96**	**1/3/97**
12	**Mobilization**	**12/2/96**	**1/10/97**
15	**Repair CAT 245D**	**1/13/97**	**1/17/97**
16	**TEC**	**1/20/97**	**2/11/97**
17	Treatment Ops	1/20/97	1/29/97
18	Repair Catox	1/30/97	1/31/97
19	Fugutive emissions	2/3/97	2/4/97
20	Repair Scrubber	2/5/97	2/6/97
21	Treatment Ops	2/7/97	2/10/97
22	A/W gas analysis	2/11/97	2/11/97
23	**Treatment Operations**	**2/12/97**	**4/2/97**
24	Treatment Ops	2/12/97	2/12/97
25	GC discrepancy	2/13/97	2/14/97
26	Treatment Ops	2/17/97	2/17/97
27	Repair augers	2/18/97	2/24/97
28	Treatment Ops	2/25/97	3/6/97
29	Repair drive table	3/7/97	3/18/97
30	Treatment Ops	3/19/97	3/26/97
31	Repair boiler/augers	3/27/97	3/28/97
32	Treatment Ops	3/31/97	4/2/97
33	**Demob. & Cleanup**	**4/3/97**	**4/11/97**
36	**Project Completion**	**4/14/97**	**4/30/97**
37	Project summary report	4/14/97	4/30/97
38	Final Invoice	4/30/97	4/30/97

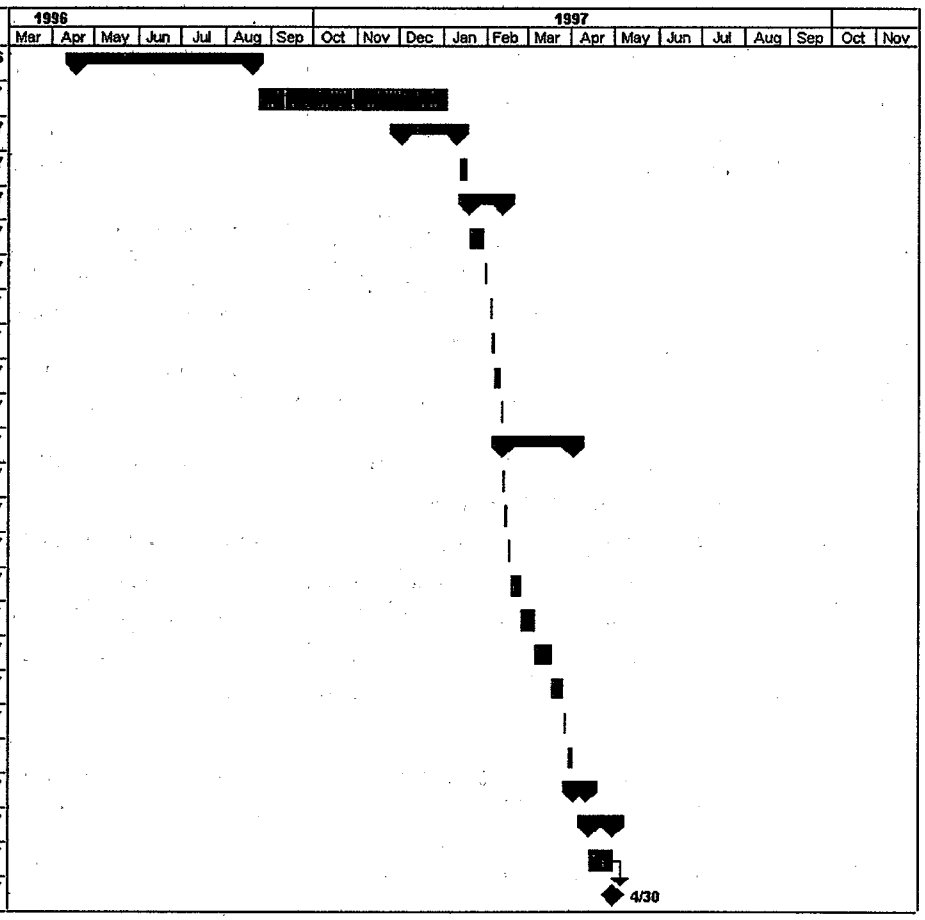


Figure 14. Project schedule.

9. OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

The rotary steam stripping system deployed at the Pinellas STAR Center's Northeast Site consisted of a dual-auger rotary drill tower for contaminant removal, a CATOX system for VOC vapor treatment, and an acid-gas scrubber for off-gas treatment. Although each subsystem consists of standard equipment, operating the entire system efficiently and reliably is demanding. Mechanical and operational problems are a given for this type of heavy equipment operation, and provisions should be made in the contracting to minimize costs during system downtime. VOC vapor and off-gas treatment can be significant portions of the overall treatment costs for this type of system. Accurate design and operation of these subsystems is crucial for the cost effective application of this technology at a site.

Other project cost observations include:

- The major cost items (74% of the entire project cost) were equipment and operating costs.
- The inability of the off-gas treatment system to process all of the contaminant vapors removed by the dual-auger system was a shortfall in the design process that severely affected the subsurface VOC removal rate and the cost per cubic yard of soil and ground water treated and the overall cost-effectiveness of the system.

Performance Observations and Lessons Learned

The ISF dual auger system deployed at the Pinellas STAR Center demonstrated the following performance characteristics.

- The ISF dual augers demonstrated the ability to remove large amounts of contaminants from the soil and ground water in a treatment column.
- For the columns that were sampled before and after treatment, the rotary steam stripping system removed an average of 77% of the VOCs in the ground water and soil, and reduced the maximum contaminant concentrations by an average of 71% (Table 7).
- The system did not consistently remove VOCs from the site's soil and ground water to a level of 200 ppm or less, especially in the areas of high initial concentrations.
- The only effects of the rotary steam stripping system on the surrounding environment was the escape of air outside the bore hole, which seemed to be limited to a radius approximately 6 ft from the shroud.
- The injection of only air appears to have produced a removal rate similar to that when air and steam are used; however, the ability of air by itself to quickly reduce contaminant levels of VOCs to very low final concentration is questionable, and the injection of only air appears to leave more contaminants deposited at shallower depths than when air and steam are injected.
- The higher the flow rate of air and/or steam, the better the removal of contaminants.

The project provided the following lessons learned on performance:

- Preproject discussions with regulatory agency personnel are essential. A cooperative relationship with the regulators, including full disclosure of all issues and problems that arise during a project, will minimize delays in obtaining authorizations and can facilitate the use of alternative emissions control methods and associated equipment.
- Any necessary permits, such as air emissions, should have long enough periods of performance to allow for potential delays in system mobilization and operation..

- The location, availability, and transport of all necessary equipment should be thoroughly evaluated for any impact on the project schedule.
- Evaluators of rotary steam stripping technologies should research the average downtime that a vendor experienced during past projects as a result of equipment failures and repairs.
- The impact of fugitive emissions on a project should be evaluated and planned for in case emissions are detected.
- Off-gas treatment systems should be evaluated for proper capabilities based on contaminant mass and combustion characteristics. The ability to increase treatment capability quickly, if needed, should be evaluated.
- Soil and ground water sampling after rotary steam stripping is performed can be delayed up to 2 to 3 weeks after treatment because of the inability of sampling vehicles to traverse the soft, loosened soil of each borehole.
- All site geology/hydrology characteristics may be changed following rotary steam stripping treatment, possibly affecting the ability to collect post-treatment samples (i.e., hydraulic conductivity, relatively firm soil, etc.).
- Patent issues, though not a factor in this application, should be thoroughly researched and evaluated and considered part of the bid review process for this technology.
- Utility supplies vital to project operations should have back-up supplies in the event of loss of that utility.
- Fuel storage regulations should be researched with local authorities; permits may need to be secured.

Summary

Based on the results of this demonstration, the ISF dual auger rotary steam stripping system is an innovative technology capable of providing in situ treatment of VOC-contaminated soil and ground water. During the demonstration of this technology at the Pinellas STAR Center, the ISF system was very effective in liberating large quantities of VOCs from the site soil and ground water. During the operating period, 48 treatment holes were drilled to a depth of approximately 32 feet, resulting in the treatment of over 2,000 yd^3 of soil and ground water and the removal of approximately 1,200 pounds of VOCs.

Initially, many operational problems were encountered with the system, especially with the off-gas treatment component because of high contaminant loading. As the project progressed, these problems were reduced through operational adjustments. The off-gas treatment capacity of the catalytic oxidation unit, initial operational problems, and mechanical breakdowns slowed the expected treatment rates for the system at the site. This prevented the system from meeting some of the performance objectives and treatment volumes initially expected in this remediation.

10. REFERENCES

1. *Installation Assessment, Pinellas Plant*, U.S. Department of Energy, Comprehensive Environmental Assessment and Response Program, Albuquerque Operations Office, Albuquerque, N.M., 1987.

2. *RCRA Facility Investigation Report, Pinellas Plant*, Vol. 1—Text, U.S. Department of Energy, Environmental Restoration Program, Albuquerque Operations Office, Albuquerque, N.M., 1991.

3. *RCRA Hazardous and Solid Waste Amendments Permit, U. S. Department of Energy Pinellas Plant, Largo, Florida.* EPA ID No. FL6-890-090-008, U.S. Environmental Protection Agency, February 9, 1990.

4. *Interim Corrective Measures Study, Northeast Site*, TPA2 6350.80.01, prepared by CH2M Hill for the U.S. Department of Energy and General Electric Company, Neutron Devices Department, Largo, Fla., May 1991.

5. *Corrective Measures Study Report, Northeast Site, Pinellas Plant, Largo, Florida*, U.S. Department of Energy, Environmental Restoration Program, Albuquerque Field Office, Albuquerque, N.M., 1993.

6. *Corrective Measures Implementation Plan*, Northeast Site, Pinellas Plant, Largo, Florida, U. S. Department of Energy, Environmental Restoration Program, Albuquerque Field Office, Albuquerque, N. M., March 1996.

7. *Toxic Treatments, In Situ Steam/Hot-Air Stripping Technology, Applications Analysis Report*, EPA/540/A5-90/008, Risk Reduction Engineering Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio, March 1991.

8. *Advanced Techniques for In Situ Remediation*, Milgard Environmental Corporation, Livonia, Mich., MEC-195, September 1993.

9. La Mori, P.N., "Using In-Situ Hot Air/Steam Stripping (HASS) of Hydrocarbons in Soils", HazMat International '94, Philadelphia, Pa., May 1994.

10. *Technology Profiles, Seventh Edition*, Superfund Innovative Technology Evaluation Program, EPA Office of Research and Development, Washington, D.C., November 1994, EPA/540/R-94/526.

11. *Interim Corrective Measures Study Addendum #2, Northeast Site*, U.S. Department of Energy and Lockheed Martin Specialty Components, Largo, Fla., August, 1996.

12. *Notice of Amended Revised Authorization to Conduct Rotary Steam Injection/Extraction Remediation Project*, Florida Department of Environmental Protection, Tampa, Fla., February, 1997.

13. *Guide to Documenting Cost and Performance for Remediation Projects*, Member Agencies of the Federal Remediation Technologies Roundtable, March 1995, EPA-542-B-95-002. (downloadable at http://clu-in.com/pubitech.htm)

14. *HTRW Remedial Action Work Breakdown Structure*, Hazardous, Toxic, Radioactive Waste Interagency Cost Engineering Group, February 1996. (downloadable at http://globe.lmi.org/lmi_hcas/wbs.htm)

11. VALIDATION

"This analysis accurately reflects the performance and costs of the remediation."

David S. Ingle 10-22-97

David S. Ingle, Pinellas Area Office
U.S. Department of Energy

Mike Hightower

Mike Hightower, Technical Coordinator
Innovative Treatment Remediation Demonstration Program
Sandia National Laboratories

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
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100 ALABAMA STREET, S.W.
ATLANTA, GEORGIA 30303-3104

4WD-FFB

OCT 16 1997

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

The United States Department of Energy
Pinellas Plant
Attn: Mr. David Ingle
P.O. Box 2900
Largo, FL 34649

SUBJ: Cost and Performance Reports for the:
1) Dual Auger Rotary Steam Stripping Technology, and
2) Pervap Membrane Separation Technology
Demonstrations at the Northeast Site
DOE Pinellas Plant, FL
EPA I.D. Number FL6 890 090 008

Dear Mr. Ingle:

The Environmental Protection Agency (EPA), Region 4, has completed our review of the above referenced documents. Both of these reports appear to accurately convey information gathered by the Innovative Treatment Remediation Demonstration (ITRD) Team for the two different technologies that were demonstrated on the small scale at the Northeast site.

The activities associated with the Northeast Site under the direction of the ITRD have been very important to the Agency because the successful demonstration of the various technologies would ultimately lead to a remedy selection for this solid waste management unit. Additionally, the information gained from these activities is valuable in determining the cost/benefit of using these innovative technologies at other sites. EPA remains committed to working with the Department of Energy (DOE) at the former Pinellas Plant to document the success of these technology demonstrations, for a final remedy selection at this site, and eventually facility restoration.

If you have any questions regarding the ITRD at the Northeast Site then please contact me at (404) 562-8550.

Sincerely,

Carl R. Froede Jr.

Carl R. Froede Jr., P.G.
DOE Remedial Section
Federal Facilities Branch
Waste Management Division

cc: Eric Nuzie, FDEP
Jim Crane, FDEP

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Department of Environmental Protection

Lawton Chiles
Governor

Twin Towers Building
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

Virginia B. Wetherell
Secretary

February 5, 1998

Mr. David Ingle
United States Department of Energy
7887 Brian Dairy Road
Suite 260
Largo, Florida 33777

Dear Mr. Ingle:

I have reviewed the *Cost and Performance Report, Dual Auger Rotary Steam Stripping, Pinellas Northeast Site, Largo, Florida*, dated December 1997, and find it acceptable. If you should have any questions please feel free to contact me.

If I can be of any further assistance please feel free to contact me at (850) 921 9983.

Sincerely,

John R. Armstrong P.G.
Remedial Project Manager

2/5/1998
Date

CC: Cheryl Walker-Smith, USEPA Atlanta
Satish Kastury, FDEP

JJC ESN for ESN

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In Situ Anaerobic Bioremediation at Pinellas Northeast Site, Largo, Florida

In Situ Anaerobic Bioremediation at Pinellas Northeast Site, Largo, Florida

<table>
<tr><td>Site Name:
Pinellas STAR Center
Northeast Site</td><td rowspan="2">Contaminants:
- Chlorinated solvents, including trichloroethene, methylene chloride, dichloroethene, and vinyl chloride
- Concentrations ranged from 10-400 mg/kg
- DNAPL suspected to occur in localized areas</td><td>Period of Operation:
February 7, 1997 to June 30, 1997</td></tr>
<tr><td>Location:
Largo, Florida</td><td>Cleanup Type:
Demonstration (ITRD Technology Demonstration)</td></tr>
<tr><td>Vendor/Consultant:
Lockheed Martin Specialty Components</td><td rowspan="2">Technology:
In Situ Anaerobic Bioremediation
- Three, 8-ft deep gravel-filled, surface infiltration trenches and two, 240-ft long horizontal wells with 30-ft screened intervals
- Groundwater extracted from upper horizontal well and recirculated via surface trenches and lower horizontal well at a rate of about 1.5 gpm
- Benzoate, lactate, and methanol added to recirculated water to serve as nutrients for dechlorinating bacteria
- 250,000 gallons of water circulated during pilot study over five month period</td><td>Cleanup Authority:
RCRA</td></tr>
<tr><td>Additional Contacts:
David Ingle, Site Management
DOE/GJO Environmental Restoration Program Manager
(813) 541-8943</td><td>Regulatory Point of Contact:
EPA Region 4 and State:
Florida Department of Environmental Protection</td></tr>
<tr><td>Waste Source:
Leakage of solvents or resins from drum/container storage</td><td colspan="2" rowspan="2">Type/Quantity of Media Treated:
Groundwater
- Water table present approximately 3-4 feet below ground surface
- Aquifer characterized as sandy
- Hydraulic conductivity of surficial aquifer in study is relatively heterogeneous; zones of reduced hydraulic conductivity occur at depths between 10 to 14 feet and 22 to 29 feet
- Approximately 250,000 gallons of water were treated</td></tr>
<tr><td>Purpose/Significance of Application:
Demonstration of in situ anaerobic bioremediation technology used to supplement an ongoing system of pump-and-treat with air stripping</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
- The objectives of this demonstration included evaluating the use of nutrient injection to enhance in situ anaerobic biological degradation of chlorinated VOCs in areas of moderate contaminant concentrations and obtaining operating and performance data on this technology.</td></tr>
<tr><td colspan="3">Results:
- Evaluated use of nutrient injection to enhance in situ anaerobic biological degradation of chlorinated VOCs in areas of moderate contaminant concentrations
- Obtained operating and performance data to optimize the design and operation of a full-scale system
- VOC concentrations reduced 60% - 91% within four to eight weeks after nutrient arrival
- Contaminant reduction probably result of groundwater mixing and contaminant redistribution
- Limiting factors for successful, cost effective implementation are ability to deliver appropriate nutrients to all contaminated areas and hydraulic travel times</td></tr>
</table>

In Situ Anaerobic Bioremediation at Pinellas Northeast Site, Largo, Florida (continued)

Cost:
Total cost of pilot remediation project was $397,074, including:
- Mobilization and preparatory work - $35,000
- Monitoring, sampling, testing, and analysis - $238,310
- Groundwater collection and control - $87,536
- Biological treatment - $23,748
- General requirements - $12,480

Description:
The Pinellas STAR Center operated from 1956 to 1994, manufacturing neutron generators and other electronic and mechanical components for nuclear weapons under contract to the U.S. Department of Energy and its predecessor agencies. The Northeast site is associated with the location of a former waste solvent staging and storage area. In the 1950s and 1960s, an existing swampy area at the site was used for staging and burial of construction debris and drums, some of which contained solvents. The site consists of a shallow groundwater aquifer contaminated with a variety of VOCs, including chlorinated solvents such as trichloroethene, methylene chloride, dichloroethene, and vinyl chloride.

From February 7, 1997 to June 30, 1997 a demonstration using in situ anaerobic bioremediation was conducted at the site. The demonstration was part of a program at the Pinellas STAR Center to evaluate several innovative remediation technologies that could enhance the cost or performance of an existing pump-and-treat system. The pilot system was located in an area of the site that had total chlorinated contaminant concentrations in groundwater generally ranging from 10-400 mg/kg, with one monitoring well having concentrations in excess of 2,900 mg/kg. The bioremediation pilot system consisted of three 8-ft deep gravel-filled, surface infiltration trenches and two 240-ft long horizontal wells with 30-ft screened intervals. The horizontal wells, directly underlying and parallel to the middle surface trench, were at 16- and 26-ft depths. The study area was about 45 feet by 45 feet and extended from the surface down to a thick, clay confining layer 30 feet below the surface. Groundwater was extracted from the upper horizontal well and recirculated via the surface trenches and the lower horizontal well while benzoate, lactate, and methanol were added to the recirculated water to serve as nutrients for the dechlorinating bacteria.

During this period, groundwater was extracted and recirculated at a rate of about 1.5 gpm. Approximately 250,000 gallons of water, based on soil porosity of about two pore volumes, were circulated during the pilot study. Tracer and nutrient monitoring data indicated that nutrients were delivered to 90% of the central treatment area during operations. Where nutrient breakthrough was observed, significant declines in total chlorinated VOC concentrations were generally observed.

The cost of the pilot system totaled approximately $400,000, with over half the costs associated with sampling and analyses. Most of the sampling and analyses were discretionary and were used to verify the system concept and design. This level of sampling would not be needed during a full-scale bioremediation project. System construction costs were about $90,000, while operating costs were about $30,000 or $0.12 per gallon of water treated. The extensive modeling, hydrogeologic, nutrient transport, and operating cost data developing during this pilot system operation suggest that the Northeast Site could be remediated using nutrient injection in approximately 2-3 years at a cost of about $4-6M.

1. SUMMARY

In early 1997, the Innovative Treatment Remediation Demonstration (ITRD) Prog ram conducted a pilot study at the Pinellas STAR Center's Northeast Site to treat chlorinated volatile organic compounds (VOC) using *in situ* anaerobic bioremediation. The Northeast Site is characterized by VOC contamination of a shallow, sandy, surficial aquifer. Monitoring data indicate that some biodegradation of these contaminants is already occurring at the site. The primary objectives of this pilot study were to 1) evaluate the use of nutrient injection to enhance *in situ* anaerobic biological degradation rates of chlorinated VOCs in areas of moderate contaminant concentrations and 2) obtain operating and performance data to optimize the design and operation of a full-scale system. During the short operational period of this pilot study, there was no emphasis on reducing any contaminants to a specific regulatory level.

The pilot system was located in an area of the site that had total chlorinated contaminant concentrations in ground water generally ranging from 10-400 ppm, with one monitoring well having concentrations in excess of 2900 ppm. The bioremediation pilot system consisted of three 8-ft deep, gravel-filled, surface infiltration trenches and two 240-ft long horizontal wells with 30-ft screened intervals. The horizontal wells, directly underlying and parallel to the middle surface trench, were at 16- and 26-ft depths. The study area was about 45 feet by 45 feet and extended from the surface down thirty feet to a thick, clay confining layer 30 feet below the surface. Ground water was extracted from the upper horizontal well and recirculated via the surface trenches and lower horizontal well while benzoate, lactate, and methanol were added to the recirculated water to serve as nutrients for the dechlorinating bacteria. The nutrient concentrations were selected based on an earlier laboratory treatment study conducted through the ITRD Program. To assess hydraulic flow characteristics and nutrient delivery, a bromide tracer was added to the water reinjected through the deep horizontal well and an iodide tracer was added to the water fed to the surface trenches. VOC, tracer, and nutrient concentrations were monitored bi-weekly at 16 well clusters (each with 4 vertically discrete sampling intervals) spaced throughout the treatment area. VOC concentrations of the extracted ground water were also continuously monitored.

The system operated from February 7, 1997 to June 30, 1997. During this period, ground water was extracted and recirculated at a rate of about 1.5 gpm. Approximately 250,000 gallons of water, based on soil porosity of about two pore volumes, were circulated during the pilot study. Tracer and nutrient monitoring data indicated that nutrient were delivered to 90% of the central treatment area during operations. Wells not showing breakthrough were generally in the areas of lower conductivity and perimeter wells. Where nutrient breakthrough was observed, significant declines in total chlorinated VOC concentrations (70-99%) were generally observed. These values correlated well with the results observed from the extraction. For those wells where nutrient arrival was not observed, generally in areas of lower permeability or perimeter wells, only modest contaminant reductions were recorded. Degradation rates of as high as 1-2 ppm per day were observed in the higher concentration areas, greater than 100 ppm, while in areas with lower concentrations, degradation rates of 0.05 to 0.10 ppm per day were observed. There was no evidence of significant degradation product build up in any monitoring well, and many wells with contaminant concentrations below 10 ppm showed contaminant reductions to regulatory allowable levels.

The cost of the pilot system totaled approximately $400,000 with over half the costs associated with sampling and analyses. Most of the sampling and analyses were discretionary and were used to verify the system concept and design. This level of sampling would not be needed during a full-scale bioremediation project. System construction costs were about $90,000 while operating costs were about $30,000 or $0.12 per gallon of water treated. The extensive modeling, hydrogeologic, nutrient transport, and operating cost data developed during this pilot operation suggest that the Northeast Site could be remediated using nutrient injection in approximately 2-3 years at a cost of about $4-6M. From the results of the pilot study, nutrient addition to stimulate existing *in situ* anaerobic biological degradation of chlorinated solvent contaminated soil and ground water appears to be a feasible and cost effective remediation approach at the Pinellas Northeast Site for areas of moderate contaminant levels.

2. SITE INFORMATION

Identifying Information

Facility:	Pinellas Science, Technology, and Research (STAR) Center, formerly the U. S. Department of Energy Pinellas Plant
Location:	Largo, Pinellas County, Florida
OU/SWMU:	Northeast Site
Regulatory Driver:	RCRA
Type of Action:	ITRD Technology Demonstration
Technology:	*In situ* anaerobic bioremediation
Period of operation:	February 1997 to July 1997
Treatment area:	45 ft x 45 ft x 30 ft (60750 ft^3)

Site Background

The Pinellas STAR Center occupies approximately 100 acres in Pinellas County, Florida, which is situated along the west central coastline of Florida (Figure 1). The plant site is centrally located within the county, and is bordered on the north by a light industrial area, to the south and east by arterial roads, and to the west by railroad tracks. The topographic elevation of the Pinellas STAR Center site varies only slightly, ranging from 16 feet MSL in the southeast corner to 20 feet MSL in the western portion of the site. Pinellas County has a subtropical climate with abundant rainfall, particularly during the summer months.

The Northeast Site includes the East Pond and is located in the northeast portion of the Pinellas STAR Center site. The Northeast Site is covered with introduced landscaping grass and contains no permanent buildings. The site contains approximately 6 acres and is generally flat, with slight elevation changes near the pond. Access to the Northeast Site is restricted and protected by fencing.

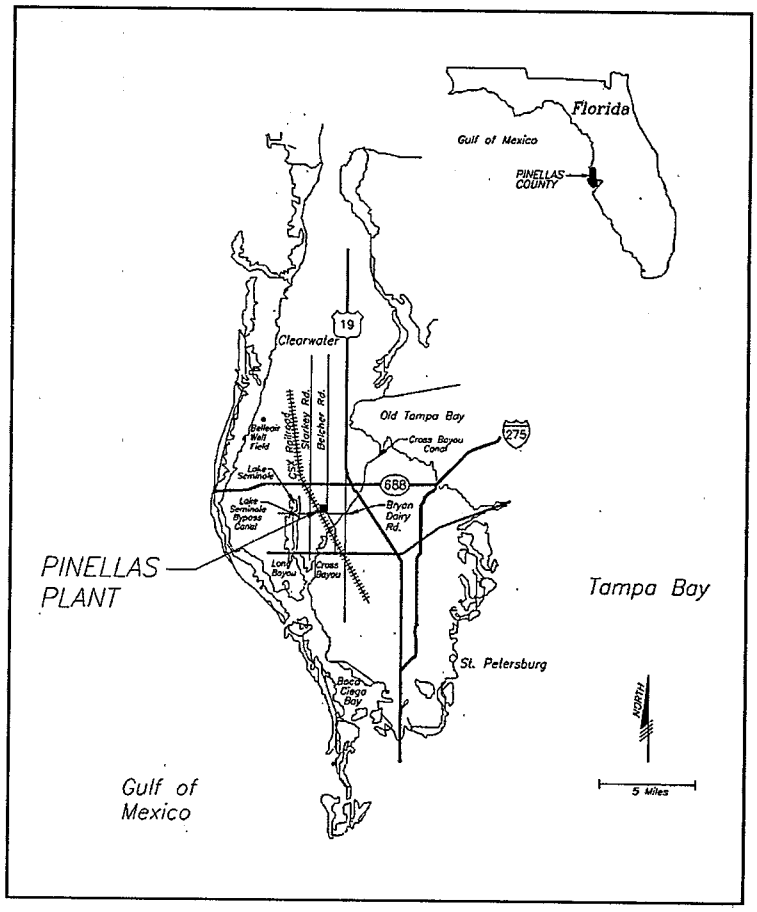


Figure 1. Pinellas STAR Center location.

Site History

The Pinellas Plant operated from 1956 to 1994, manufacturing neutron generators and other electronic and mechanical components for nuclear weapons under contract to the U.S. Department of Energy and its predecessor agencies (SIC Code 9631A-Department of Energy Activities).

The Northeast Site is associated with the location of a former waste solvent staging and storage area. From the late 1950s to the late 1960s, before construction of the East Pond, an existing swampy area at the site was used to dispose of drums of waste and construction debris. The East Pond was excavated in 1968 as a borrow pit. In 1986, an expansion of the East Pond was initiated to create additional storm water retention capacity. Excavation activities ceased when contamination was detected directly west of the East Pond.

The Northeast Site was identified as a Solid Waste Management Unit (SWMU) in a RCRA Facility Assessment (RFA)[1] conducted by EPA Region IV. Subsequently, a RCRA Facility Investigation (RFI)[2] was completed and approved in compliance with the facility's Hazardous and Solid Waste Amendments of 1984 (HSWA) permit.[3]

An Interim Corrective Measures (ICM) Study[4] was developed and submitted to EPA for approval. EPA issued final approval of the ICM in October 1991, and an interim ground water recovery system for the Northeast Site was installed and commenced operation in January 1992. A Corrective Measures Study Report was submitted to EPA in March 1993 and approved in November 1994[5]. A Corrective Measures Implementation Plan was submitted to EPA in March 1996 and approved in June 1996. The current system now consists of seven ground water recovery wells equipped with pneumatic recovery pumps that transfer ground water for temporary storage in a holding tank prior to being pumped to a ground water treatment system.

Release Characteristics

The primary management practice that contributed to contamination at this site was the storage of drums/containers. Because the site was used in the 1950s and 1960s for staging and burial of construction debris and drums, some of which contained solvents, contamination at the Northeast Site is believed to be the result of leakage of solvents or resins from those drums. The Pinellas Northeast Site consists of a shallow ground water aquifer contaminated with a variety of VOCs, including chlorinated solvents such as trichloroethylene, methylene chloride, dichloroethylene, and vinyl chloride. A recent debris removal activity at the site removed multiple buried drums, many of which were empty but contained solvent residue. The ongoing ICM system (pump and treat with air stripping) continues to recover contaminants from the site and has been successful in preventing off-site migration of VOCs.

Site Contacts

Site management is provided by the DOE Pinellas Area Office (DOE/GJO). The DOE/GJO Pinellas STAR Center Environmental Restoration Program Manager is David Ingle [(813)-541-8943]. The technical contact for the Pinellas Plant *in situ* anaerobic bioremediation project is Mike Hightower, the ITRD technical coordinator at Sandia National Laboratories [(505)-844-5499].

3. MATRIX AND CONTAMINANT DESCRIPTION

The anaerobic bioremediation system treated a matrix of soil and ground water to enhance the degradation of chlorinated organic compounds (*in situ*).

Site Geology/Hydrology

Based on analysis of soil borings, details of well construction, and environmental studies at the Pinellas STAR Center, the thickness of the surficial deposit below the site ranges from 25 to 35 feet and is primarily composed of silty sand. Figure 2 shows the primary geologic units at the site. The top of the Hawthorn Group (composed primarily of clay) is encountered at depths approximately 30 feet below ground surface. The thickness of the Hawthorn Group ranges from 60 to 70 feet. The water table at the Northeast Site is generally 3 to 4 feet below the ground surface. The ground water gradient and ground water flow velocity at the site are both very low.

The ground water system at the Pinellas Star Center is composed of three primary units: (1) an upper unit, the surficial aquifer; (2) an intermediate confining unit, the undifferentiated portion of the Hawthorn Group; and (3) a lower unit, the Floridan aquifer. Undifferentiated sediments lie below the surficial aquifer and above the Floridan aquifer in Pinellas County. Because of the low permeability of these sediments in this region, these upper sediments are not considered part of the intermediate aquifer system and are generally considered to be a confining unit in the area of the Pinellas STAR Center.

Measurements performed in the bioremediation study area, including down-hole flowmeter tests, have suggested that the surficial aquifer in the study area is relatively heterogeneous with regard to hydraulic conductivity. These heterogeneities appear in the vertical and horizontal direction. Specifically, zones of reduced (i.e., by a factor of 10 or greater) hydraulic conductivity occur at depths between 10 to 14 feet and 22 to 27 feet. The bulk of the contamination in the bioremediation study area has been detected within these low permeability layers.

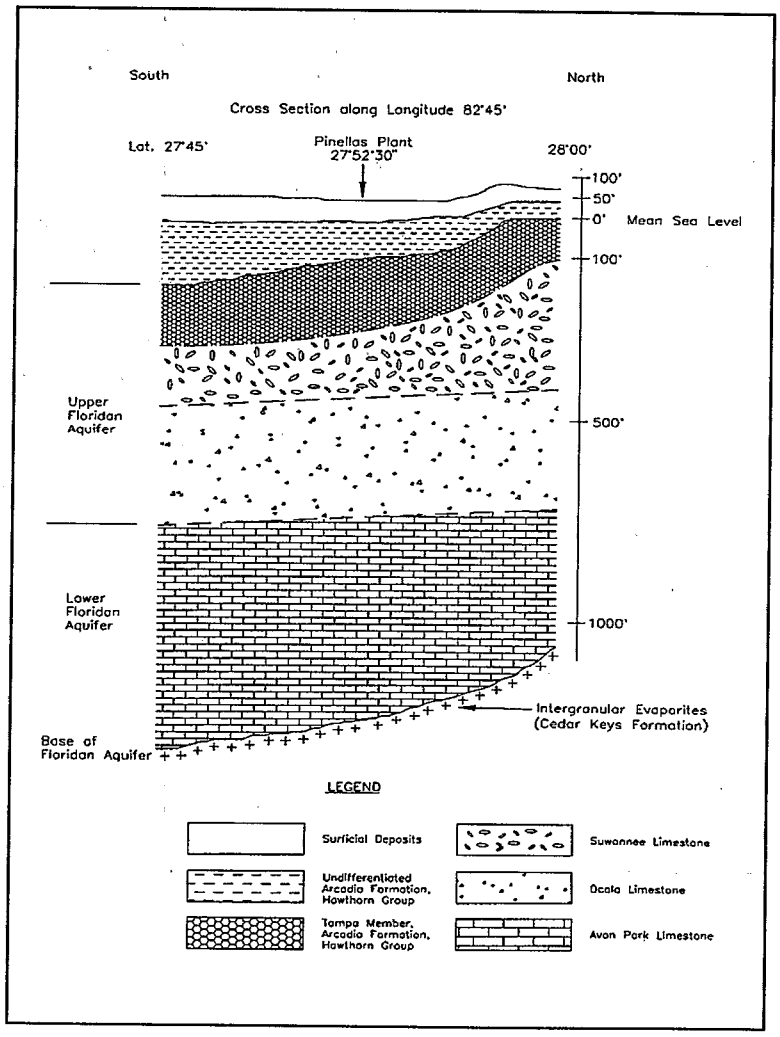


Figure 2. Geologic section at the Pinellas STAR Center.

Nature and Extent of Contamination

The primary contaminant group that the *in situ* bioremediation technology was designed to treat in this application was halogenated VOCs at the Northeast Site in the surficial aquifer. Contaminants of concern (COCs) detected in Northeast Site ground water include 1,1-dichloroethane, 1,1-dichloroethylene, benzene, ethylbenzene, 1,2-dichloroethylene (DCE) (cis and trans isomers), methylene chloride, toluene, trichloroethylene (TCE), tetrachloroethylene, methyl tert-butyl ether, vinyl chloride, xylenes, and chloromethane. The major contaminants of concern at this site, because of their concentrations and cleanup levels are methylene chloride, 1,2-DCE, TCE, toulene, and vinyl chloride. Figure 3 shows a contour map of VOC contamination in ground water at the Northeast Site and in the area selected for the bioremediation pilot-study. The concentrations prior to treatment and the solubilities of primary COCs within selected bioremediation treatment area are summarized in Table 1.

There is some evidence that non-aqueous phase liquid contamination may be present in localized areas at the Northeast Site. VOC concentrations for several COCs exceeded solubility limits in some of the ground water samples taken at the site, and the contaminant release scenario (leakage of solvents or resins from drums stored or buried at the site) is consistent with this type of contamination. While the exact extent and nature of this contaminant phase is unknown, these areas can be a continuing source of ground water contamination unless effectively addressed in a comprehensive site remediation system design.

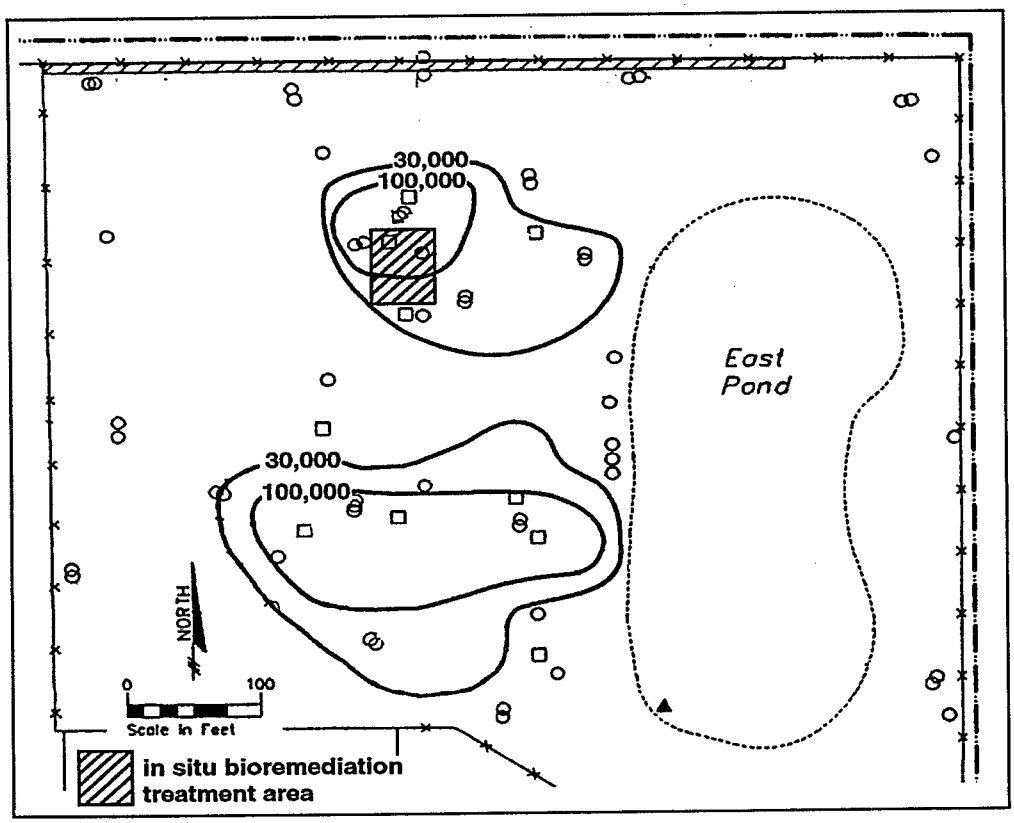


Figure 3. Total VOCs in ground water (in µg/L).

Table 1. Pretreatment concentrations of contaminants.

Contaminant	Ground water		Solubility limit
	Max. conc. (µg/L)	Avg. conc. (µg/L)	(µg/L)@20–25ºC
TCE	1,700,000	46,600	1,100,000
Toluene	2,200,000	45,600	515,000
cis-1,2-DCE	210,000	19,200	800,000
Methylene chloride	760,000	18,450	16,700,000
Vinyl chloride	130,000	9,500	1,10-1,100,000

Matrix Description and Characteristics

The surficial aquifer at this site consists predominantly of saturated beach-type silty sands (see Table 2). A few lenses of more silty materials exist, though no clay lenses occur in the soil being treated. For these soils, the hydraulic conductivities in the horizontal direction range from 10^{-3} to 10^{-5} cm/sec, while the vertical conductivities are approximately 10-100 times lower. The surficial aquifer is highly anaerobic as demonstrated by the dissolved oxygen and Eh values shown in Table 2.

Table 2. Matrix characteristics affecting treatment cost or performance.

Parameter	Value
Soil classification	Silty sand
Clay content	low; 5–10%
Moisture content	mostly saturated (see below)
Hydraulic conductivity $K_{horizontal}$ $K_{vertical}$	$7x10^{-5}$ to $2x10^{-3}$ cm/sec or 0.2–6.6 ft/day; $K_{vertical}$ is approx. 10-100 times less than $K_{horizontal}$, or 0.003 to 0.3 ft/day
Inorganic compounds: Potassium, soluble Nitrate/nitrite Phosphate as P	 2-10 mg/L 0,2-1.0 mg/L 0.1-0.5 mg/:
pH	5.5 to 7.2; mean 7.0
Total organic carbon	4–500 mg/kg; mean 50 mg/kg
Dissolved oxygen	0.1–0.8 mg/L; mean 0.1 mg/L
Eh	–175 to 30 mV; mean –50 mV
Maximum treatment depth: Saturated thickness treated:	approximately 30 ft 25-27 ft

4. TECHNOLOGY DESCRIPTION

This field demonstration evaluated *in situ* anaerobic bioremediation as a technology to treat chlorinated VOCs in soil and ground water. Bacteria metabolize soluble organic and inorganic compounds to provide energy for the growth and maintenance of bacterial cells. The complex organic molecules that bacteria consume are converted to new cells and various simpler compounds, such as carbon dioxide, that are released back into the environment. This process is referred to as biodegradation. Biodegradation has been used very cost effectively for more than a century in public and industrial wastewater treatment systems. Since bacteria occur naturally in both soil and ground water environments, bioremediation technologies attempt to stimulate the activity of these naturally occurring (or introduced bacteria) to degrade contaminants in a cost-effective manner. Bioremediation is being considered more often as the processes that control the biological degradation of contaminants in soil and ground water become better understood.

In Situ Anaerobic Bioremediation Technology Description

In order to produce new bacterial cells, bacteria require carbon, nitrogen, phosphorus, and energy sources, as well as a number of trace minerals. Electrons are released by the biochemical reactions that metabolize complex organic compounds for energy. Biological systems capture this biochemical energy through a series of electron transfer (redox) reactions. The bacteria that are most commonly used in bioremediation systems use organic compounds as their source of carbon and energy; these carbon compounds are referred to as electron donors. Bacterial respiration requires that some chemical compound is available to act as a terminal electron acceptor. Common electron acceptors used by bacteria include oxygen, nitrate, sulfate, Fe^{3+}, and carbon dioxide.

Recently, a class of anaerobic bacteria has been identified that uses halogenated organic compounds as their electron acceptors. The chlorinated VOCs present in the soil and ground water at the Northeast Site are among the halogenated organic compounds that can be used in this manner. Halogenated compounds have a high oxidation state; and when a halogen (e.g., chlorine) is chemically replaced by hydrogen, the oxidation state of the chemical is reduced. This process is referred to as reductive dehalogenation, and it forms the basis of the anaerobic process used by the *in situ* bacteria at the Northeast Site. Under anaerobic conditions, chlorinated compounds can be degraded via reductive dehalogenation reactions to successively lower chlorinated degradation products, and finally to compounds of significantly lower toxicity. This process is illustrated for TCE below.

$$\underset{\text{step 1}}{\textbf{TCE} \rightarrow} \underset{\text{step 2}}{\textbf{DCE} \rightarrow} \underset{\text{step 3}}{\textbf{VC} \rightarrow} \textbf{ethylene, ethane}$$

Biological activity is frequently limited by the availability of a single growth factor (e.g. electron acceptor, electron donor, nitrogen, etc.) and supplying the proper growth factor can often stimulate bacterial growth and biodegradation rates. For *in situ* remediation applications, nutrients or electron acceptors are often injected into the contaminated area to enhance the existing microbial degradation processes. Effectively delivering nutrients requires that factors such as site permeability and geochemistry be considered. Each class of contaminant varies in its susceptibility to biodegradation and factors such as aquifer oxidation-reduction potential, microbial ecology, and contaminant toxicity will affect the success of bioremediation at a site. The effective application of in situ bioremediation therefore depends upon careful consideration of the geologic and hydrologic properties at the site and on the type and concentration of contaminants to be treated. Bench scale treatability studies with aquifer soil and ground water samples are highly recommended prior to full-scale implementation of most bioremediation projects.

The application of *in situ* anaerobic bioremediation for the degradation of chlorinated solvents has received significant interest due to the excellent results obtained in laboratory and small pilot-scale applications using these processes. These studies have shown that the injection of simple nutrients can

significantly accelerate the natural degradation of compounds such as PCE, TCE, DCE, carbon tetrachloride, and methylene chloride in soil and ground water. Some companies hold patents on certain aspects of accelerated *in situ* anaerobic bioremediation for the treatment of chlorinated solvents. Sites interested in the use of this technology should be aware that patent related issues might need to be addressed

Evaluations of the monitoring data from the Northeast Site suggested that microbial dechlorination is occurring naturally. DCE and vinyl chloride (VC) are degradation products of TCE that were measured in high concentrations but were not contaminants originally disposed of at the site, which suggests that a population of dechlorinating microorganisms is relatively active at Pinellas. Based on these evaluations and the review of the site hydrologic conditions, it was expected that nutrient injection would be effective in accelerating the anaerobic microbial degradation of the major COCs at the Northeast Site.

Technology Advantages

The treatment of VOC-contaminated soils and ground water using nutrient injection to stimulate and accelerate *in situ* anaerobic bioremediation offers the following advantages:

- contaminants are treated *in situ* with little waste generation,
- contaminant degradation can be relatively fast,
- bioremediation is capable of reducing contaminants to very low levels,
- the process stimulates a microbial population that can continue to feed off the dissolved phase of a continuing source after nutrient injection ceases, and
- often provides a low overall remediation cost relative to other technologies.

Technology Limitations

The treatment of VOC-contaminated soils and ground water using nutrient injection to stimulate and accelerate *in situ* anaerobic bioremediation offers the following limitations:

- contaminant degradation enhancement is dependent on adequate nutrient delivery to all areas of contamination before the nutrients are directly metabolized, which often is primarily a function of site hydrogeology and the appropriate mixing of nutrients, contaminants, and active microbes,
- site conditions (e.g., soil and ground water chemistry, reductive processes, etc.) must be conducive to the stimulation of biological activity to be effective,
- bioremediation will not directly degrade contaminants occurring in an immiscible phase,
- high concentrations of contaminants often are toxic to microorganisms,
- bioremediation may be difficult to optimize at sites with multiple contaminants of concern,
- incomplete biodegradation of contaminants can lead to the generation of degradation products that are just as toxic or even more so than the parent contaminants, and
- regulatory concerns over chemical injections into aquifers.

Treatability Study

Through the ITRD Program, laboratory batch and column biotreatment studies were performed under anaerobic conditions using aquifer sediments and ground water from the Northeast Site. These studies were used to assess methods for stimulating and/or optimizing the existing anaerobic biological activity at the Northeast Site.[6] The laboratory studies generated information on contaminant degradation rates, the reductive dechlorination process, and byproduct formation for several different nutrient combinations and concentrations. The nutrient mixtures used included combinations of trace nutrients such as potassium and phosphorus, and other nutrients such as sodium benzoate, sodium lactate, methanol, and casamino acids. Nutrient concentrations generally ranged from 100-400 ppm.

The study showed that two nutrient combinations, both of which included methanol, were effective in reducing both TCE and methylene chloride and that degradation rates of as high as 1-2 ppm/per day were achievable for TCE. The results also showed that with these nutrient mixtures dehalogenation of TCE did not stop at any intermediate degradation products. In the case of toluene and trace contaminants, it was not determined from this laboratory study what conditions would optimize their utilization or degradation. Under the existing site conditions, toluene can degrade through fermentation, while simple electron acceptors are available to accelerate toluene treatment.

Based on the laboratory data, a preliminary full-scale bioremediation system cost and performance estimate was developed. From these engineering estimates, in situ anaerobic bioremediation appeared to be a very cost effective and rapid technique for treating ground water of low to moderate contaminant concentration (less than 200 ppm) at the Northeast Site. It was expected that areas of significantly higher contaminant concentration would probably need to be treated by a more aggressive treatment method.

Pinellas In-Situ Bioremediation System Description

Based on the laboratory treatability study results, and the engineering cost and performance estimates of in situ anaerobic bioremediation, a large pilot-scale remediation system was designed and constructed at the Northeast Site. The system was operated for approximately five months to assess the field performance of this technology and to identify the optimum operating parameters for a full-scale system. Historical data was used to select an area within the Pinellas Northeast Site that was understood to contain the entire suite of chlorinated compounds found at the site and with contaminant levels ranging from at least 100-200 ppm. If the initial concentrations were too high, there was a potential that the microbial population would be inactive. If the initial concentrations were too low, contaminant degradation could be difficult to monitor. Thus, an area expected to have mid-range contamination levels, as shown in Figure 3, was chosen for the *in situ* bioremediation pilot-study.

The hydraulic modeling, design, construction, and operation of the bioremediation pilot system and the associated monitoring well network are discussed in detail in this section. The operational concept developed for the pilot system was to create a closed-loop ground water recirculation system where ground water could be continually circulated through the treatment area while nutrients were added to the circulated water to accelerate in situ contaminant degradation. This was expected to minimize external ground water influence on performance assessment results, minimize nutrient loss and accelerate biodegradation, and eliminate the need for ground water treatment or disposal. A large number of clustered monitoring wells were also installed in the treatment area in order to assess contaminant degradation and system performance throughout all levels of the treatment area.

Figure 4 shows the general layout of the treatment area and perimeter and cluster monitoring wells . Four fully-screened monitoring wells were installed in the perimeter of the study area to perform flowmeter testing of the aquifer matrix. The flowmeter testing determined the relative hydraulic conductivities of the zones indicated in the cross section in Figure 5. The central area is approximately 45 ft x 45 ft.

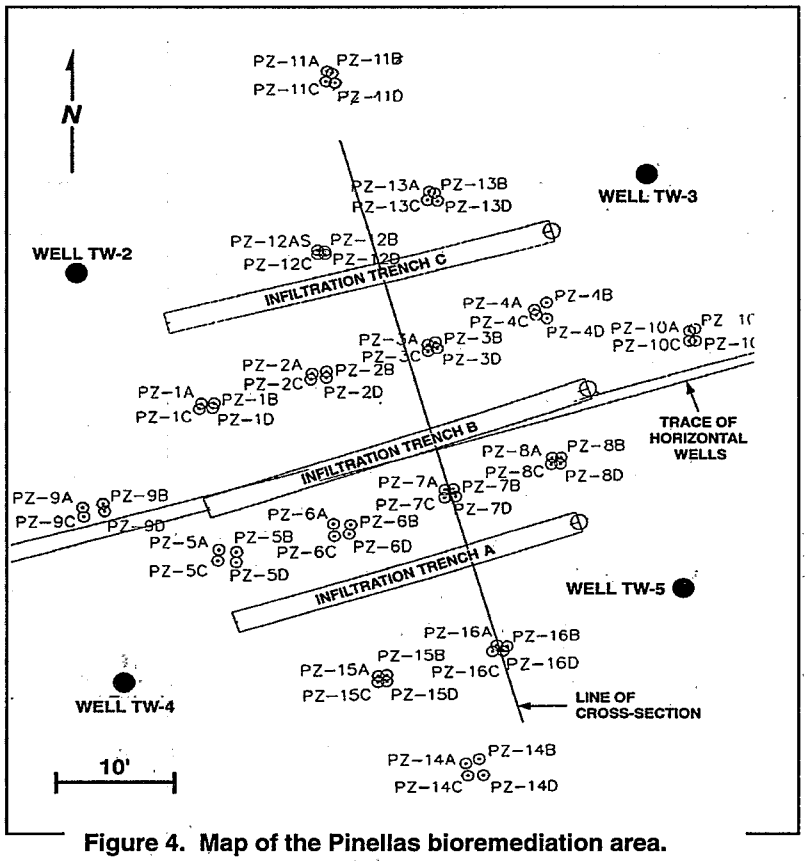


Figure 4. Map of the Pinellas bioremediation area.

The overall design, configuration, and location of the extraction and injection wells were developed based on a number of system performance assessments using MODFLO, a two-dimensional ground water flow model. The modeling looked at nutrient delivery and movement through the treatment area based on several possible vertical and horizontal system configurations and well locations and the site hydrogeologic data. This modeling effort suggested that ground water circulation using horizontal wells and trenches would provide better nutrient delivery across the horizontal layers of relatively low vertical hydraulic conductivity where contaminant concentrations were highest.

To achieve a vertical hydraulic gradient, a horizontal extraction well with a 30 foot screened section was installed through the center of the treatment area in a zone of higher conductivity 16 ft below ground surface (bgs). The ground water extracted from the horizontal well was then returned to the aquifer via one of the four infiltration points shown in Figure 5. The first three points were gravel-filled, surface trenches (A, B, & C) which were 30 ft long, 8 ft deep, and at least 2 ft wide. The fourth infiltration point (D) was a horizontal well similar to the extraction well but installed at 26 ft bgs. MODFLOW simulations indicated that this well and trench system would create a general flow pattern through the treatment area as shown in Figure 6, under nominal operating conditions. The system was designed to allow reversal of the extraction and infiltration points, providing flexibility in optimizing nutrient delivery to the different aquifer levels across the treatment area if needed.

The ground water monitoring system shown in Figure 6 included 16 clusters of 4 sampling points to create a three-dimensional monitoring network of the treatment area. These monitoring points were installed at discrete depths starting at the depth corresponding to the elevation of the bottom of the trenches. The "A" depth was 8-10 ft bgs, the "B" depth was 12-14 ft bgs, the "C" depth was 18-20 ft bgs, and the "D" depth was 22-24 ft bgs. The "B" and "D" depths were chosen to correspond with the layers of lower hydraulic conductivity within the study area, which contained the maximum contaminant concentration. This was an effort to monitor system performance in actual worst case conditions.

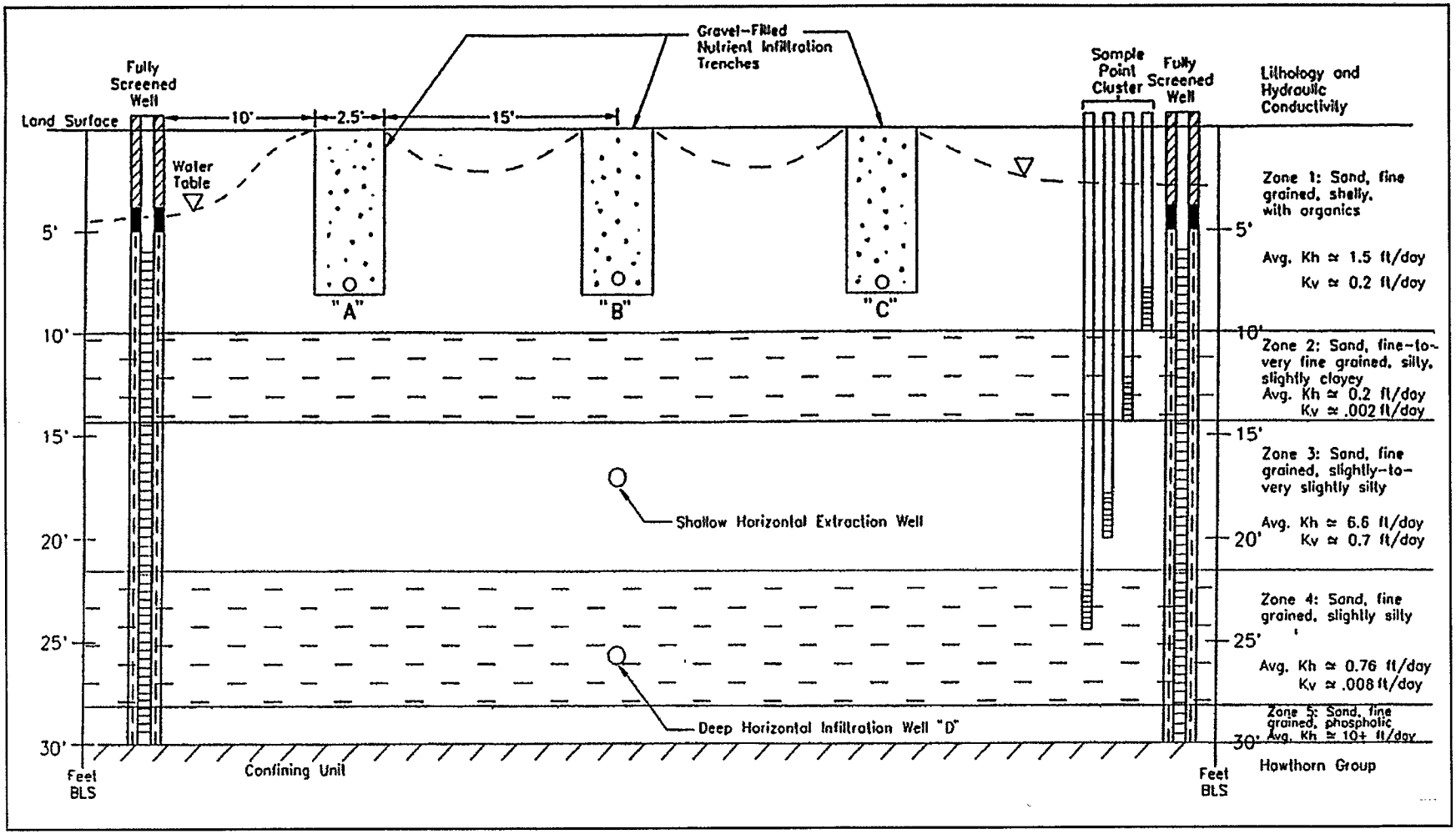
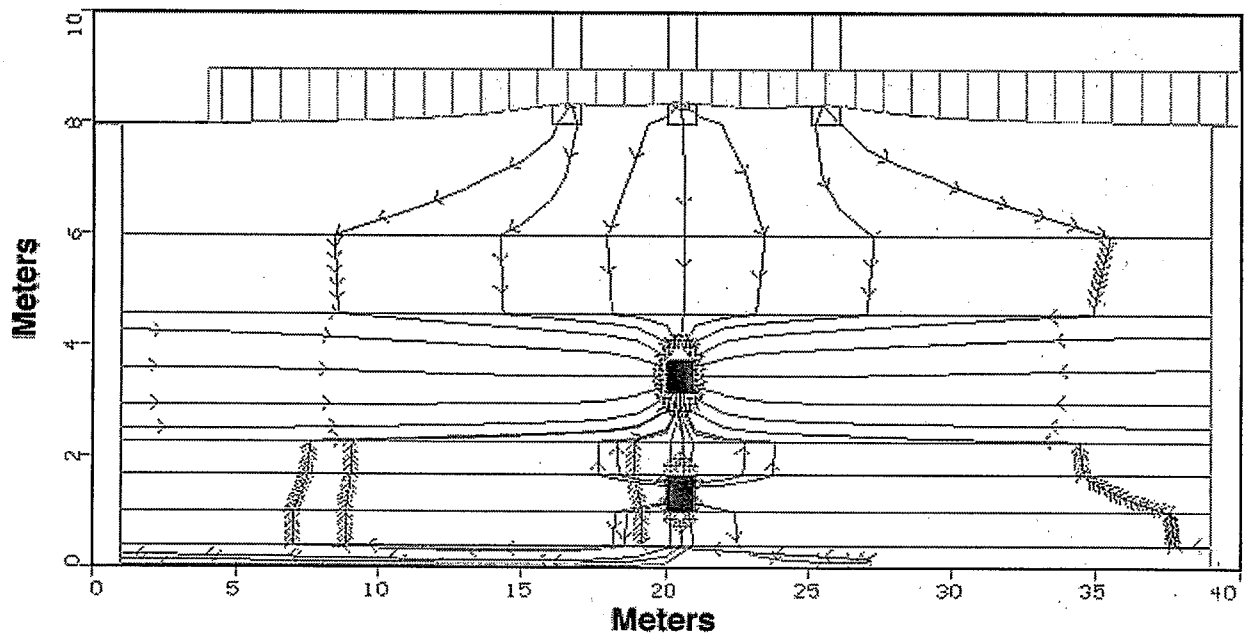


Figure 5. Cross section of treatment area looking west.



Tick marks are 10 days on tracks

Figure 6. MODFLO model of system ground water flow patterns and transit times.

Treatment System Schematic and Operation

Figure 7 is the process schematic for operation of the pilot anaerobic biotreatment system. In this system, the extracted ground water was pumped from the horizontal extraction well, monitored continuously for contaminant concentrations with an automatic field GC, had nutrients added in-line, and was then returned to the aquifer through the infiltration trenches and the horizontal infiltration well. The trenches had float switches installed just below ground surface that operated solenoid valves allowing ground water and nutrients to enter at a steady rate without overflow. When all three surface trenches were filled to their recharge capacity, a fourth solenoid valve would open to allow the nutrient rich ground water to enter the aquifer from the lower horizontal infiltration well in the treatment area.

Each infiltration point was separately metered for flow, and each infiltration point had a separate stock tank of nutrient solution so that the amount introduced into each point could be calibrated against the corresponding ground water flow. Total ground water flow through each infiltration point and the nutrient solution used from each stock tank were recorded daily. The use of individual stock tanks also provided the capability to conduct a multi-tracer study. The tracers were introduced into the nutrient solution tanks in a controlled, continuous release so that nutrient transport could be easily monitored. Because both upward and downward ground water movements were being studied, two different tracers were used. Bromide was selected for tracking the upward flow from the horizontal infiltration well and iodide was used for tracking the downward flow from the surface trenches.

An enclosed equipment control pad was located approximately 50 feet east of the system. All nutrient drums, nutrient pumps, flow meters, solenoid valves, and a filter were located at the control pad.

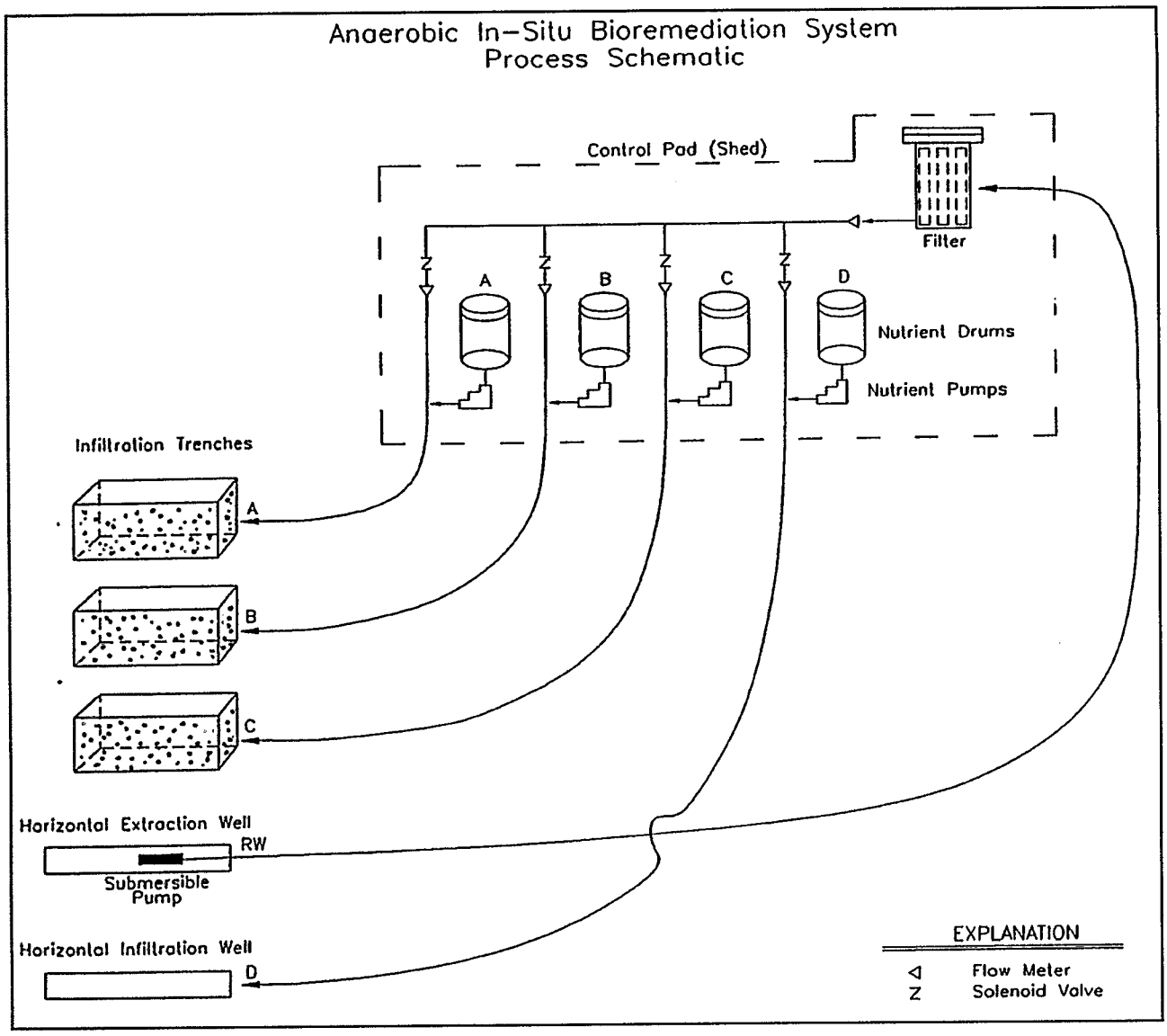


Figure 7. Bioremediation pilot system process schematic diagram.

Key Design Criteria

The *in situ* anaerobic bioremediation pilot system was designed for two main objectives:

- develop a nutrient delivery system capable of providing a mixture of nutrients to the subsurface within the heterogeneous aquifer, such that the nutrients will be delivered to all levels in the treatment area within an approximately 6-month operating period, and
- create a closed-loop ground water recirculation system that would minimize external influences and losses and requires no ground water disposal.

Operating Parameters

Operating parameters were adjusted slightly during the pilot test to help optimize operating conditions for the bioremediation system. The major operating parameters needed to assess the performance and cost of the bioremediation system were considered to be pumping rates, nutrient concentrations, tracer concentrations, and well redevelopment frequency. The general operating parameters for the system are summarized in Table 3.

Table 3. Operating parameters affecting treatment cost or performance.

Parameter	Value or Specification
Optimal pumping rate from horizontal extraction well	1.5 gpm
Optimal pumping rate to infiltration trenches A, B, and C	0.2 gpm each
Optimal pumping rate to horizontal infiltration well (D)	0.9 gpm
Concentration of methanol added to the ground water	60 ppm
Concentration of sodium benzoate added to the ground water	120 ppm
Concentration of sodium lactate added to the ground water	180 ppm
Concentration of iodide to trenches A, B, and C	250 ppm
Concentration of bromide to horizontal infiltration well (D)	250 ppm
Frequency of redevelopment of horizontal extraction well	average of once every 3 weeks
Frequency of redevelopment of horizontal infiltration well	once

The horizontal extraction well is located at a depth of 16 feet bgs in a zone of relatively high hydraulic conductivity. A pumping rate of 1.5 gpm was sustainable through this well. The horizontal infiltration well was at a depth of 26 feet bgs in a zone of somewhat lower hydraulic conductivity, however, it could accept a pumping rate of 0.9 gpm of the recirculated ground water under a pressure gradient of 5-10 psi above the ambient hydraulic head. The infiltration trenches are 8 feet deep and located in a zone of lower hydraulic conductivity. Each trench accepted only approximately 0.2 gpm of recirculated ground water.

Nutrient concentrations added to the ground water were based on the results of the original ITRD treatment study and follow-on discussions by the ITRD committee.[6] Methanol, benzoate, and sodium lactate, at concentrations of 60, 120, and 180 ppm, respectively, were added. This mixture of electron donors was used to provide nutrients that would be used at different rates by the bacteria in the aquifer to degrade the major COCs so that the reducing power could be delivered to all treatment levels. Methanol and benzoate additions were initiated on February 12, 1997 and discontinued on June 30, 1997. Lactate was added from February 27, 1997 to June 23, 1997. The tracer concentrations added were used to insure that the breakthrough of nutrient rich ground water could be detected at the monitoring point locations. Iodide, at a concentration of 250 ppm, was added to trenches A, B, and C. Bromide, at a concentration of 250 ppm, was added to the horizontal infiltration well (D). All tracer additions were initiated on March 7, 1997. Tracer additions to trenches A, B, C, and well D were discontinued on June 4, May 13, May 28, and April 25, respectively.

Due to subsurface conditions at the Northeast Site and possible fouling of well screens, redevelopment of the horizontal wells by hydraulic surging was needed to ensure efficient operation of the system. The horizontal extraction well was redeveloped on February 24, March 6, March 13, March 31, April 8, April 22, June 4, and June 16. The horizontal infiltration well was redeveloped only once on June 3, 1997.

5. *IN SITU* ANAEROBIC BIOREMEDIATION SYSTEM PERFORMANCE

The bioremediation pilot operations at the Northeast Site were conducted to assess the applicability of nutrient injection to accelerate the degradation of the chlorinated contaminants of concern and to identify optimal operating parameters. These data were used to determine the expected costs and performance of a full-scale system at the site.

Demonstration Objectives and Approach

The objectives of the pilot *in situ* anaerobic bioremediation project were as follows:

1. Convert chlorinated VOCs in the ground water at the Northeast Site to innocuous biodegradation products using *in situ* anaerobic biodegradation,
2. Determine the suitability and effectiveness of this technology on site soils and ground water, and estimate the time period needed to meet cleanup objectives,
3. Evaluate the horizontal extraction well and infiltration gallery design configuration for full-scale implementation and determine hydraulic parameters, such as flow rates, residence times, flowpaths, and treatment levels,
4. Determine optimal operating parameters and conditions for treatment and potential scale-up, such as nutrient concentrations, nutrient half-lives, and contaminant degradation rates,
5. Collect sufficient cost data to support cost estimates for a potential full-scale system; and
6. Conduct the pilot test in a location that is representative of site-wide conditions, is not impacted by neighboring treatment operations (rotary steam stripping) and does not detrimentally impact ongoing ground water recovery systems.

Performance Evaluation Criteria

The performance criteria considered in evaluating this *in situ* anaerobic bioremediation system included:

- nutrient transport and utilization in the remediation study area,
- contaminant degradation rates and the reduction in mass of the contaminants,
- fate of chlorinated solvent degradation compounds, and
- levels to which contaminants can be reduced.

The evaluation data were collected by a monitoring program that included: semimonthly sampling for VOCs, methane, ethane, and ethylene; weekly tracer sampling; semimonthly sampling of nutrients following tracer breakthrough; weekly measurements of water levels until ground water flow conditions stabilized; and maintenance of a daily log to record operational data.

Performance Summary

Table 4 summarizes the pretreatment (February 1997) and post-treatment (July 1997) contaminant concentrations at each of the 64 monitoring points within the bioremediation treatment area, as well as the period of time required for the nutrients to reach each monitoring point. The conceptual model of this microbially mediated, *in situ,* reductive dechlorination system requires that nutrients (primarily electron donors), contaminants, and adapted microorganisms reside or mix at the appropriate ratios and concentrations for significant contaminant reduction to occur.

Table 4. Pretreatment and post-treatment contaminant concentration at the Pinellas Plant in situ bioremediation treatment area.

Well #	Time to nutrient breakthrough in weeks	Toluene			Methylene Chloride			TCE			cis-1,2-DCE			Vinyl chloride			Total chlorinated VOCs		
		before	after	decline %	before	after	decline %	before	after	decline %	before	after	decline %	before	after	decline %	before	after	decline %
1A	10	47	58	-23	ND	<5.0	-	ND	<1.0	-	ND	<1.0	-	ND	<1.0	-	18	37	-104
1B	12	ND	13	-	ND	<5.0	-	ND	<1.0	-	220	<1.0	99	880	16	98	1,100	37	97
1C	-	ND	<1.0	-	ND	<5.0	-	ND	<1.0	-	ND	<1.0	-	22	54	-145	22	56	-156
1D	4	310	310	0	ND	<25	-	ND	<5.0	-	630	<5.0	99	640	<5.0	99	1,270	195	85
2A	11	1,600	130	92	ND	<10	-	ND	<2.0	-	ND	<2.0	-	83	<2.0	98	113	13	89
2B	10	100	700	-600	ND	<50	-	ND	<10	-	ND	<10	-	16	<10	38	27	15	44
2C	12	210	<10	96	ND	<50	-	ND	110	-	ND	450	-	12	990	-8150	12	1,550	-12817
2D	4	2,200	400	82	1,400	<50	96	420	<10	98	4,200	<10	99	3,500	<10	99	9,520	0	99
3A	14	190	1100	-479	ND	<250	-	ND	<50	-	31	<50	-	240	<50	80	291	0	99
3B	-	1,900	12000	-532	ND	<1200	-	ND	370	-	1,900	21000	-1005	11,000	14000	-27	12,900	35,370	-174
3C	14	9,800	7500	23	1,500	<1000	33	280	<200	29	6,600	1500	77	11,000	4100	63	19,380	5,600	71
3D	5	1,900	1500	21	3,800	<250	93	560	<50	91	1,900	<50	97	2,700	150	94	8,960	204	98
4A	10	3,600	3500	3	ND	<1200	-	ND	<250	-	260	<250	-	490	<250	50	750	0	99
4B	10	190,000	74000	61	25,000	<25000	-	210,000	20000	90	96,000	110000	-15	37,000	12000	68	368,000	142,000	61
4C	-	4,800	20000	-317	ND	<5000	-	ND	<1000	-	4,200	2500	40	12,000	6500	46	16,200	9,000	44
4D	7	7,800	16000	-105	ND	<2000	-	ND	<400	-	ND	4700	-	ND	3700	-	0	8,400	-
5A	10	470	62	87	ND	<25	-	ND	<5.0	-	ND	<5.0	-	ND	<5.0	-	0	9	-
5B	-	1,400	3000	-114	ND	<500	-	1,400	730	48	860	1700	-98	1,500	260	83	3,890	2,690	31
5C	10	130	590	-354	ND	<250	-	ND	<50	-	9	67	-644	58	57	2	117	124	-6
5D	5	1,500	1700	-13	3,300	<120	96	560	<25	96	1,600	140	91	1,800	68	96	7,260	208	97
6A	10	17	15	12	ND	<5.0	-	ND	<1.0	-	ND	<1.0	-	ND	14	-	0	18	-
6B	12	440	2500	-468	ND	<120	-	440	320	27	25	430	-1620	52	55	-6	517	805	-56
6C	12	530	1400	-164	680	<1000	-	230	<200	13	800	16000	-1900	840	14000	-1567	2,580	30,000	-1063
6D	4	2,800	980	65	ND	<120	-	ND	<25	-	4,600	48	99	3,400	31	99	8,000	79	99
7A	6	2,000	160	92	49	<10	80	ND	<2.0	-	14	4	71	67	50	25	152	69	55
7B	7	250	2100	-740	ND	<120	-	600	200	67	ND	1200	-	150	1400	-833	750	2,800	-273
7C	10	100	1300	-1200	ND	<100	-	ND	<20	-	31	250	-706	94	280	-198	125	530	-324
7D	4	1,600	1600	0	ND	<120	-	ND	<25	-	3,600	59	98	4,600	43	99	8,200	102	99
8A	6	2,300	4000	-74	810	<500	38	ND	1900	-	350	3400	-871	700	1300	-86	1,860	6,600	-255
8B	-	71,000	100000	-41	190,000	190000	0	160,000	240000	-50	210,000	170000	19	38,000	20000	47	598,000	620,000	-4
8C	8	150	840	-460	140	<100	29	ND	<20	-	120	59	51	320	63	80	580	122	79
8D	4	2,400	940	61	2,900	<100	97	370	<20	95	3,800	68	98	4,500	43	99	11,570	111	99

Table 4. Pretreatment and post-treatment contaminant concentration at the Pinellas Plant in situ bioremediation treatment area.

Well #	Time to nutrient breakthrough in weeks	Toluene			Methylene Chloride			TCE			cis-1,2-DCE			Vinyl chloride			Total chlorinated VOCs		
		before	after	decline %	before	after	decline %	before	after	decline %	before	after	decline %	before	after	decline %	before	after	decline %
9A	15	46	980	-2030	ND	<100	-	ND	<20	-	ND	<20	-	990	25	97	990	49	95
9B	12	ND	<2500	-	160,000	140000	13	31,000	<2500	92	80,000	21000	74	18,000	21000	-17	289,000	182,000	37
9C	-	ND	97	-	ND	<120	-	ND	96	-	ND	1200	-	ND	1200	-	0	2,496	-
9D	8	ND	<500	-	ND	<2500	-	ND	<500	-	56,000	21000	63	9,000	34000	-278	65,000	55,000	15
10A	10	9,900	2400	76	ND	<250	-	ND	<50	-	ND	77	-	ND	190	-	0	342	-
10B	10	2,200,000	110000	95	760,000	240000	68	1,700,000	74000	96	170,000	64000	62	130,000	25000	81	2,950,000	403,000	86
10C	14	1,000	1200	-20	ND	<250	-	ND	370	-	21,000	520	98	7,000	54	99	28,057	997	96
10D	6	19,000	850	96	2,400	<100	96	1,200	<20	98	21,000	100	99	21,000	160	99	45,600	260	99
11A	-	8	350	-4275	ND	<50	-	ND	<10	-	5	<10	-	21	<10	52	34	18	47
11B	-	71	4200	-5815	86	1600	-1760	380	130	66	170	680	-300	400	560	-40	1,036	3,026	-192
11C	-	ND	320	-	ND	<50	-	ND	16	-	ND	160	-	ND	240	-	0	416	-
11D	-	30	530	-1667	ND	<100	-	ND	22	-	390	960	-146	900	1400	-56	1,290	2,382	-85
12A	8	230	930	-304	ND	<120	-	ND	<25	-	ND	<25	-	19	<25	-	32	0	99
12B	-	56	250	-346	22	470	-2036	170	42	75	79	220	-178	310	170	45	602	917	-52
12C	-	ND	92	-	ND	<100	-	ND	<20	-	ND	260	-	ND	1100	-	0	1,360	-
12D	7	72	760	-956	7	<50	-	ND	<10	-	78	190	-144	180	290	-61	277	492	-78
13A	-	7,500	140	98	ND	<25	-	ND	<5.0	-	ND	<5.0	-	ND	<5.0	-	0	60	-
13B	-	68,000	47000	31	ND	<5000	-	ND	<1000	-	33,000	8100	75	36,000	24000	33	69,000	32,100	53
13C	-	ND	<50	-	ND	<250	-	ND	4000	-	ND	2800	-	ND	770	-	0	7,570	-
13D	6	47	1200	-2453	ND	<100	-	ND	<20	-	31	190	-513	100	300	-200	142	490	-245
14A	11	ND	<1000	-	ND	<5000	-	82,000	6000	93	65,000	56000	14	19,000	45000	-137	166,000	107,000	36
14B	-	ND	5800	-	ND	<25000	-	380,000	300000	21	ND	390000	-	95,000	56000	41	475,000	746,000	-57
14C	-	ND	19	-	ND	<50	-	ND	210	-	ND	280	-	ND	150	-	0	640	-
14D	6	ND	1600	-	ND	<1000	-	97,000	530	99	18,000	7800	57	ND	7200	-	115,000	15,530	86
15A	8	26	120	-362	ND	<25	-	440	70	84	110	230	-109	55	160	-191	605	473	22
15B	12	690	1800	-161	ND	<1000	-	2,000	14000	-600	570	12000	-2005	170	1600	-841	2,740	27,600	-907
15C	-	ND	76	-	ND	<25	-	ND	110	-	ND	270	-	ND	280	-	0	660	-
15D	5	1,300	1100	15	1,100	<100	91	1,600	43	97	2,500	410	84	4,500	440	90	9,700	893	91
16A	12	120,000	47000	61	ND	<5000	-	6,000	<1000	83	110,000	13000	88	27,000	35000	-30	143,000	48,000	66
16B	17	39,000	7900	80	ND	<1000	-	ND	6000	-	51,000	3300	94	50,000	4100	92	101,000	13,400	87
16C	-	140,000	48000	66	28,000	<5000	82	310,000	24000	92	240,000	88000	63	48,000	9500	80	626,000	121,500	81
16D	6	1,000	1700	-70	ND	<250	-	ND	<50	-	21,000	210	99	7,000	1400	80	28,000	1,610	94

Due to the nature of the subsurface hydrogeology, transport and mixing times for the added nutrients will vary across the site, and depending on system design and operation, nutrient delivery to some portions of the aquifer could require significant amounts of time. Therefore, good system performance often requires nutrients that will not be consumed immediately at an injection location and can be transported quickly and efficiently through the subsurface to all levels of the treatment areas.

System Hydraulics and Nutrient Fate and Transport

At the pumping rate of 1.5 gpm, approximately 250,000 gallons of water, or about two pore volumes, were recirculated through the pilot study treatment area over a five-month period. Tracers were used to identify nutrient breakthrough at each monitoring point for the first ten to twelve weeks of system operations. When over 50% of the monitoring points showed breakthrough, tracer additions were stopped and nutrient concentrations were monitored directly. Tracer and nutrient breakthrough were defined as a concentration greater than 10% of the injected concentrations. Tracer breakthrough was observed earliest (1-2 weeks) in several of the "D"-level wells in the central part of the treatment area. The "B" and "C" level wells showed much slower tracer and nutrient breakthrough and the perimeter wells (Wells 9, 10, 11, and 14) showed limited breakthrough during operations. Of the 48 central monitoring points, 43 wells (90%), experienced breakthrough during the first 16 weeks of operation. Of the wells showing breakthrough in the central treatment area, 77% did so in the first two to three months of system operation. Overall, Levels A, B, C, and D had 88%, 81%, 81%, and 100% respectively, of their monitoring points during the first 16 weeks of operation. These results suggest that though some of the recirculated water may have escaped from the treatment area in levels A and D, water was effectively circulated within the central treatment area of the pilot system.

The tracer and nutrient breakthrough observations were consistent with model predictions. Based on initial modeling with a flow rate of 2 gpm, it was expected that nutrient delivery to the "B" level could take three to four months. It was hoped that this flow rate could be achieved from the extraction well, though a flow of only 1.5 gpm was sustained. A higher flow rate might have improved nutrient delivery to the "B" level monitoring points. From field observations, it appears that the extraction well efficiency was reduced in part due to borehole skin effects caused by the drilling fluid used during installation. BioboreTM by Baroid was used by the drilling contractor and appears not to have degraded as well as expected. Additionally, the infiltration trenches accepted a smaller volume of water than was initially expected, which in turn limited nutrient delivery into the "A" and "B" level monitoring points.

Since enhanced bioremediation depends on adequate nutrient delivery, bioremediation at this site will be controlled by the rate at which nutrients can be delivered into the middle and identified lower permeability zones. This is one reason why the two horizontal well system was implemented, since it allows for reversing the injection and extraction wells and providing more flexibility in delivering nutrients to all levels in the aquifer. However, in order to minimize complications in evaluating the operational performance of the pilot system, reversing the operation of the two horizontal wells was not exercised during the pilot operations. Based on the results of this pilot study, it appears that a properly designed and operated system can deliver nutrients to all of the aquifer at this site within six to eight months.

Nutrient Fate Assessment

For this pilot study, a mixture of electron donors was selected based on the consideration that the relative degradation rates for the different compounds would allow for the delivery of the reducing power of the nutrients to be spread throughout the treatment system. Lactate was used because it is a readily available carbon source that should be quickly oxidized to acetate, which is expected to degrade much slower. Benzoate was expected to degrade slower than lactate but would also yield partial oxidation products such as acetate that again should take longer to degrade. Methanol was expected to degrade slower than lactate, but faster that benzoate, while also acting as an electron donor to accelerate biodegradation of methylene chloride.

During system operations, sodium benzoate was detected in 59 monitoring points. Of these, 5 had reported concentrations higher than the initial feed concentrations and were not included in the calculations. Using the remaining 54 data points, the average half-life of the nutrients in the aquifer were calculated to be about 110 days, with the calculated half-lives ranging from 12 to 949 days. The 110-day nutrient half-life should be considered a minimum in that dilution, dispersion, and retardation effects were not accounted for due to the difficulty in assessing their relative contributions to the observed concentration decreases.

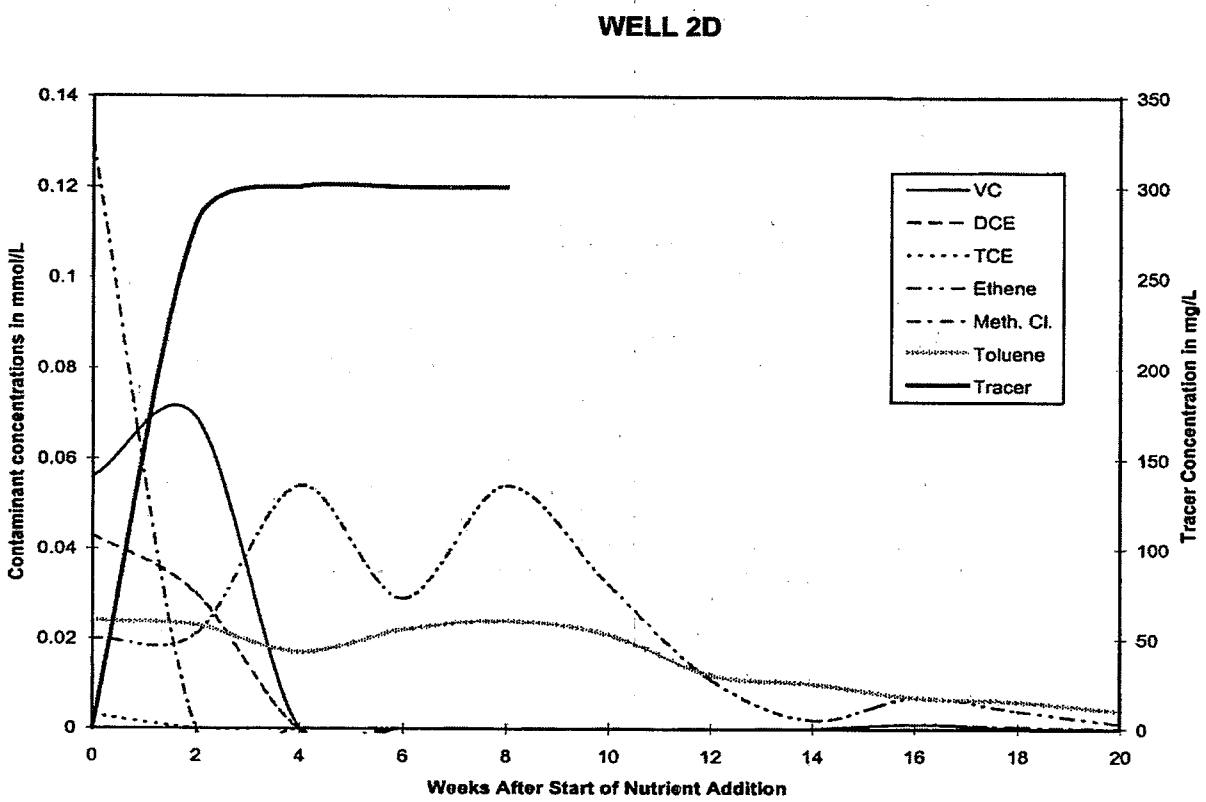
Similar calculations for lactate proved even more difficult due to the inability to resolve lactate/acetate contributions in the analytic methods used. It should be noted, however, that the observed concentrations at several locations in the pilot study area yielded lactate/acetate concentrations near or even above the initial lactate injection concentration of 180 mg/l. This suggests that lactate/acetate half lives in this system of a year or more are possible or that benzoate was being metabolized to acetate. The methanol concentrations varied widely across the treatment area. At some points, methanol concentrations in excess of ten times the added concentration were reported. This suggests that components in the ground water may have interfered with the laboratory analysis.

Together, these results suggest that the nutrients necessary to enhance bioremediation at this site were successfully delivered to areas reached by the injected water. The detection of significant concentrations of benzoate, methanol, and lactate/acetate throughout the treatment at the end of the pilot system operation suggests that the bioavailable reducing power from the injected nutrients were not a limiting factor for this pilot effort and should not be a limiting factor in the operation of a properly designed full-scale system. Based on the system operation, nutrient delivery can be expected to occur in all areas of the aquifer including the middle and lower permeability areas within the effective half-lives (four months to a year) determined for these nutrients.

Contaminant Degradation and Reduction Rates

Contaminant levels encountered at the different monitoring points within the treatment area generally ranged from 10 to 400 ppm total chlorinated VOCs, with one monitoring point location in Level "B" had a concentration of about 2900 ppm. The bioremediation system at this site was designed to develop a recirculation cell within the aquifer creating complex, three-dimensional, ground water and contaminant mixing, making the evaluation of system performance more complicated. Because of the mixing and recirculation of the ground water, temporal variations in contaminant levels in individual monitoring points could be expected. Therefore, it was important to look at contaminant reductions across the whole site, at various treatment levels, at individual wells, and in the extraction well to help assess system performance and define actual contaminant reductions due to biological treatment.

As shown in Table 4, in the wells where nutrient breakthrough, chlorinated VOC concentrations were commonly observed to fall by 60%–99% from their pretreatment levels in as little as four to eight weeks after nutrient arrival. In wells with at least six weeks of nutrient availability, TCE was reduced by 94%, DCE by 54%, vinyl chloride by 58%, methylene chloride by 60%, and toluene by 80%. In wells where nutrient breakthrough was not evident or of short duration, there was a reduction of only 10-15$ in total chlorinated VOCs and toluene. These results suggest that though contaminant reduction in part is probably the result of ground water mixing and contaminant redistribution, contaminant reduction is significantly greater in wells where nutrients are available. Likewise, because of the ground water recirculation, increases in contaminant levels in some wells should be expected. Contaminant increases were observed primarily in wells with lower (~1 ppm) concentrations. Many of the increases observed were for DCE or VCE, which is consistent with the reductive dechlorination process. Significantly fewer concentration increases were observed for TCE and methylene chloride in the wells with long term nutrient availability.



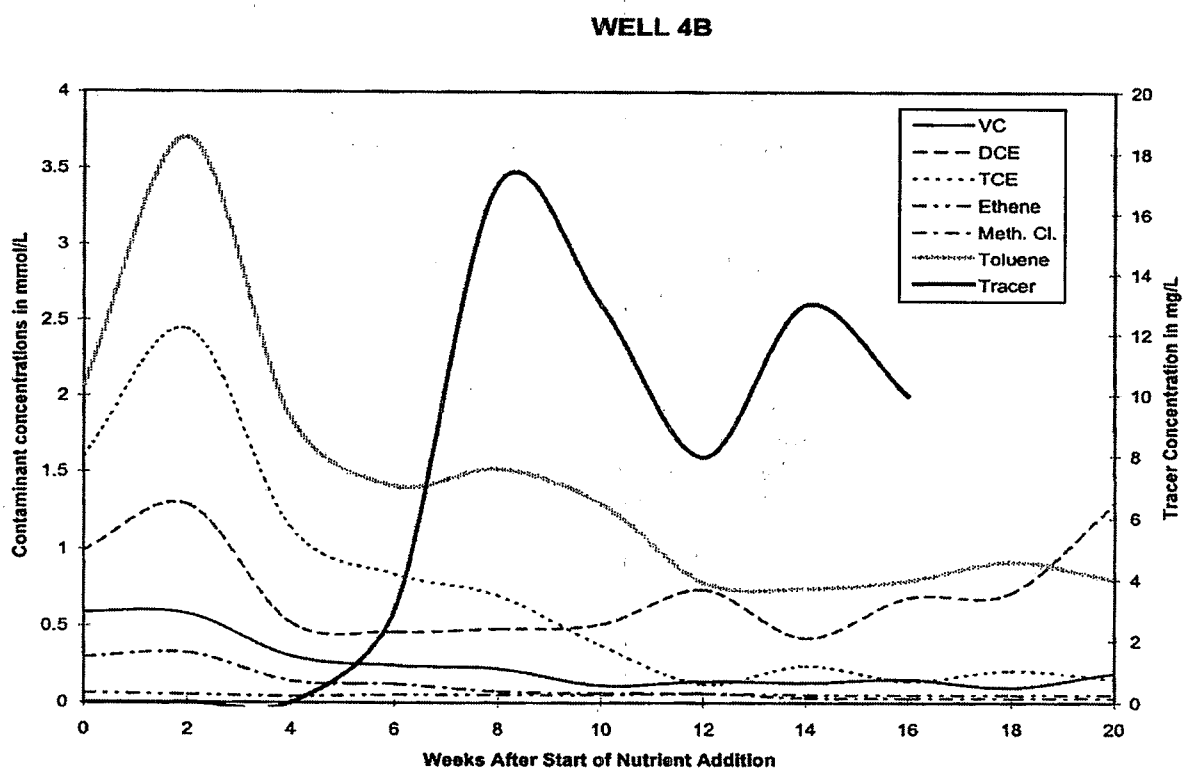


Figure 8. Contaminant monitoring data for well points 2D and 4B.

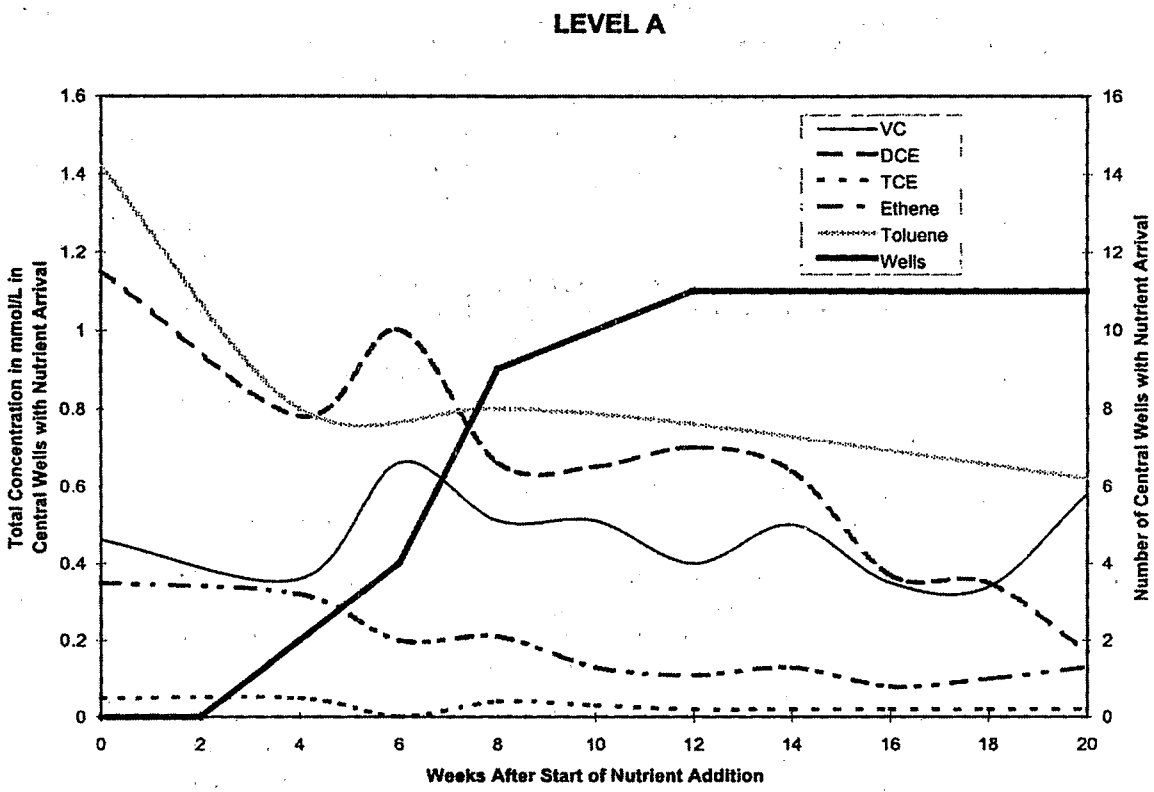
Figure 8 shows two wells, Well 2D and Well 4B, that are located in the central treatment area and provide a range of the observed monitoring well data. Well 2D is a low concentration well with very little TCE that is near the horizontal recirculation well. Nutrient arrival occurred shortly after nutrient addition as shown by the tracer concentration data measured. Well 4B has a much higher concentration of TCE and is in the lower permeability zone where nutrient breakthrough took much longer, approximately two months, and the level of nutrients delivered to this area was probably lower, as evidenced by the much lower tracer concentrations. The results for Well 2D are representative of many of the "D" level wells, showing a reduction of the chlorinated contaminants to regulatory levels in several weeks. Both DCE and vinyl chloride were reduced at a rate of 0.10-0.20 ppm per day. Since toluene was not specifically targeted for biological degradation, toluene was monitored to assess contaminant reductions attributable to mixing and redistribution. Over this period, toluene levels changed slightly while ethylene increased substantially, suggesting that anaerobic reductive dechlorination was the major mechanism for contaminant reduction. The results for Well 4B are typical of many "B" level wells, showing a much longer period for nutrient delivery and contaminant reduction than Well 2D. This is in part due to the much higher contaminant concentrations. The reductions in contaminant levels, including toluene, is similar until late in the operations where TCE continues to decrease and DCE begins to increase. The initial TCE reduction rate observed after nutrient arrival is over 2 ppm per day and as the TCE concentration approaches 0.2 mmol/L (25ppm), the degradation rate slows to 0.10-0.20 ppm per day observed in Well 2D.

In evaluating the monitoring data from all wells showing early to mid-period nutrient arrival, contaminant reduction rates of 1-2 ppm per day were observed for the high (above 200 ppm) contaminant levels to approximately 0.05-0.20 ppm per day for wells with contaminant levels of less than 20 ppm. These rates suggest that areas with moderate TCE contamination would require one to two months after nutrient arrival to reduce TCE to levels of 5-10 ppm and another one to two months to reduce the TCE to regulatory levels. The further reduction of the DCE and vinyl chloride produced to ethylene could take similar periods of time. This suggests that as much as a year may be necessary for areas of high contaminant concentration to be reduced to regulatory levels for all contaminants following nutrient availability.

Figures 9 and 10 show contaminant reduction trends by level for toluene, TCE, DCE, and vinyl chloride and the production of ethylene for the wells in the central treatment area that received nutrients. Since the monitoring points in each level do not receive nutrients at the same time, a classic step-wise dechlorination sequence was not expected. Each level was analyzed separately in an effort to identify trends in contaminant distribution and biological degradation. Similar to the results of Figure 8, contaminant reduction at each level begins as the wells receive nutrients. Level D, where most of the wells have nutrient arrival very early during system operation, is the only level where measurable ethylene production occurred. Level A, where nutrient arrival was longer, reductions in DCE and corresponding increases in vinyl chloride are observed. In Levels B and C, which have much higher contaminant concentrations and much shorter periods of nutrient availability, show much slower overall contaminant reductions. The contaminant reduction results in Levels B and C are overshadowed by the data from several monitoring points with high contaminant concentrations that had nutrient breakthrough in only the last four to five weeks of system operation. Contaminant reduction in the wells in these two levels with longer nutrient availability show more pronounced contaminant reductions as shown in
Table 4.

Contaminant Reduction Levels

Thought the pilot system was not designed nor operated to meet any specific cleanup criteria during the short operational period, final contaminant levels for many monitoring points were measured below 50-100 ppb, while several of the lower concentration wells had contaminant concentrations reduced to below 5 ppb. The data also show that monitoring points with individual contaminant concentrations above 5-10 ppm were not reduced to allowable levels during the pilot operations. This data, along with the degradation rate results discussed above, suggests that though contaminant degradation is rapid once nutrients are available, the operational period of a bioremediation system could be controlled by degradation rates at the lower contaminant levels.



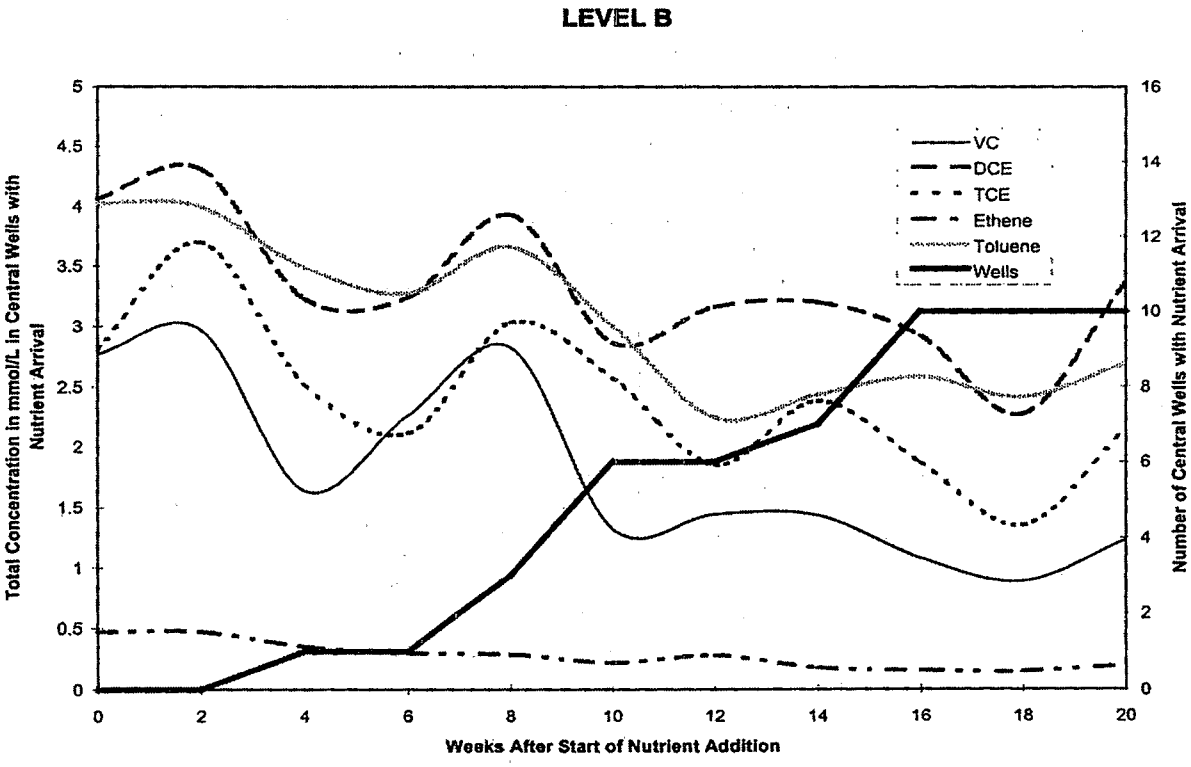
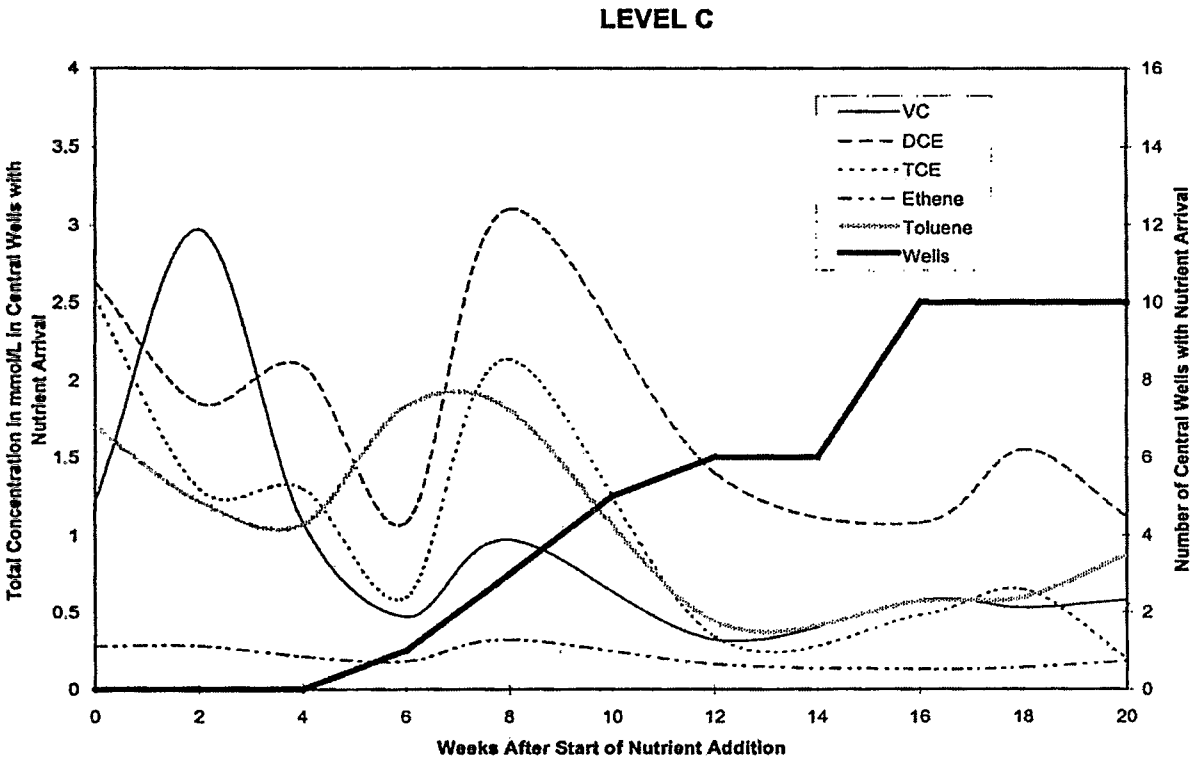


Figure 9. Contaminant monitoring data for Level A and B Wells.



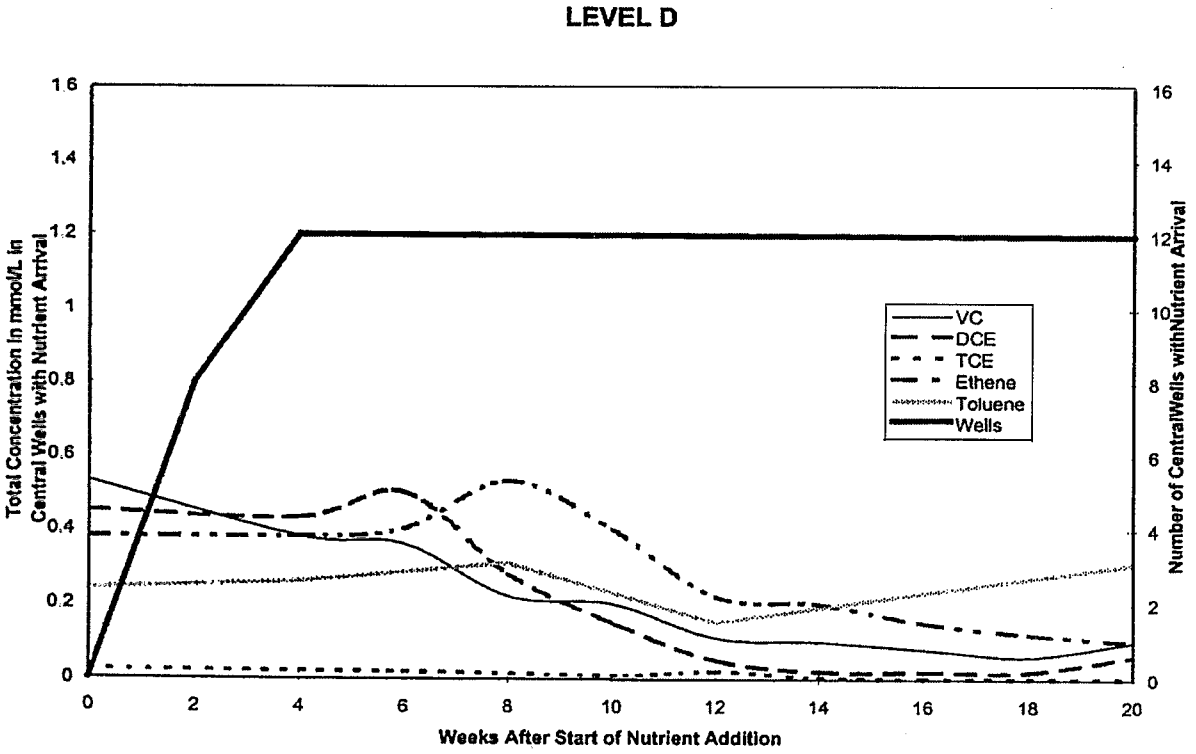


Figure 10. Contaminant monitoring data for Level C and D Wells.

Extraction Well Monitoring Data

In addition to the 64 monitoring point, the extracted ground water was monitored every two hours using an in-line, automated, gas chromatograph (GC). The system was continuously calibrated using a prepared standard. The data were compared with GC data from grab samples collected from the well. Both sets of data and were shown to be within the accuracy limits of the two instruments. The average daily data, shown in Figure 11, provide additional evidence of the biodegradation occurring in the subsurface and the overall rates of contaminant reduction. In general, the extracted ground water trends and the data from the monitoring points in the interior of the treatment zone correlate well. Contaminant reduction in the ground water began to occur rapidly in mid-April, which is the time when approximately half of the monitoring wells that would experience nutrient arrival had done so. Contaminant reduction continued throughout system operations, but was much slower as additional wells experienced nutrient arrival. The sharp increases in the contaminant concentrations and the data gaps shown for the GC generally correspond to redevelopment of the extraction well, which occurred as discussed previously on February 24, March 13, March 31, April 8, April 22, June 4, and June 16. This automated monitoring system worked well during the pilot operations and appears to be a simple method that can be used to guide operations and define sampling events of a full-scale bioremediation system.

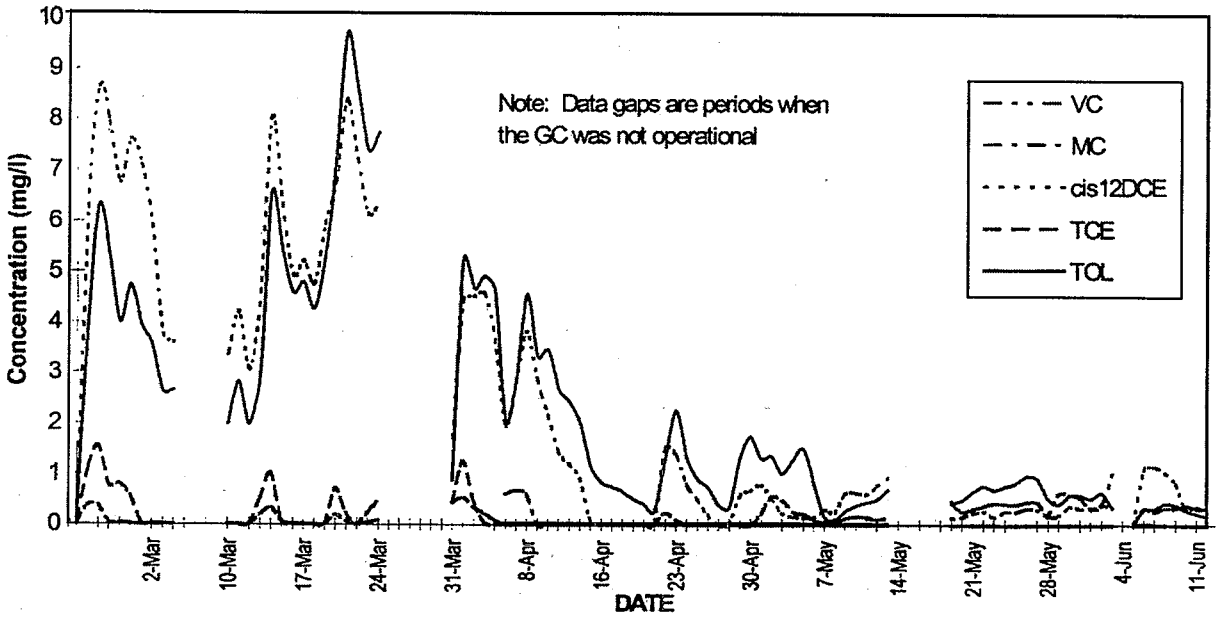


Figure 11. Continuous monitoring data of the extracted ground water.

Reduction of Other Contaminants

Table 4 and Figures 8-11 support the observation that across the site, enhanced bioremediation occurred as a result of system operations. As discussed, the pilot operations were designed to optimize conditions for the reduction of the chlorinated contaminants and were not optimized to reduce toluene. Though toluene concentrations decreased over much of the site, residual toluene levels will have to be addressed in a full-scale system design. This may require the addition of a different nutrient mix at some point during operations, though oxygen injection is often used to quickly, and effectively reduce toluene concentrations to regulatory levels.

A summary of the performance of the *in situ* anaerobic bioremediation pilot system is provided in Table 5, relative to the performance measures and objectives. Overall, the system met most of the identified system performance objectives.

Table 5. Bioremediation system performance summary.

Performance Evaluation Criteria	Values/ Results
Treatment volume:	Approximately 45 ft x 45 ft x 30 ft, 60750 ft^3
Ground water treated:	Approximately 250,000 gallons, about 2 pore volumes
Extraction/reinjection rate:	Approximately 1.5 gpm
System nutrient transport effectiveness:	Nutrients were effectively distributed to approximately 90% of the central monitoring points in 23 weeks,
Level A - 8-10 feet deep	Nutrients delivered to 88% of the monitoring points
Level B - 12-14 feet deep	Nutrients delivered to 81% of the monitoring points
Level C - 18-20 feet deep	Nutrients delivered to 81% of the monitoring points
Level D - 22-24 feet deep	Nutrients delivered to 100% of the monitoring points
Nutrient effectiveness:	Significant reductions in all contaminants occurred within 4-8 weeks after nutrient arrival at a well point
Nutrient viability	Average nutrient half-life of 110 days, up to > 1year
Contaminant degradation rates:	
>100 ppm concentration levels	1-2 ppm per day
1-10 ppm concentration levels	0.05-0.10 ppm per day
Reduction values for contaminants of concern:	
Toluene	50-70% within 4-8 weeks of nutrient arrival
TCE, DCE, vinyl chloride, methylene chloride	90–95% within 4-8 weeks of nutrient arrival
Chlorinated solvent by-product production	General decline in all contaminants with some temporary increases in degradation products, followed by reduction of the degradation products themselves by biological degradation.
Waste Generated	None, all extracted ground water was recirculated
Achievable contaminant reduction levels:	Many contaminants were reduced to the 50-100 ppb level, the detecton limit for most analyses. Some monitoring points with concentrations less than 10 ppm were reduced to <5 ppb.

6. *IN SITU* ANAEROBIC BIOREMEDIATION SYSTEM COST

The Pinellas *in situ* anaerobic bioremediation project was constructed and operated by Lockheed Martin Specialty Components (LMSC) under their cost-plus-fee management and operations (M&O) contract with DOE. Several organizations, including the EPA National Risk Management Laboratory, Sandia, FDEP, and several industry participants, played an important role in the design, operation, and monitoring of the remediation system. These services were often in an advisory or consulting role, though some direct support was provided to the project. For example, FDEP provided three-dimensional graphical data of sampling results on the Internet for use by the ITRD participants. Where appropriate, direct support costs are included in Table 6, which shows project costs in accordance with the interagency work breakdown structure adopted by the Federal Remediation Technologies Roundtable.

Table 6. Bioremediation Project cost by interagency work breakdown structure.

Cost element (with interagency WBS Level 2 code)	Description	Costs ($)	Subtotals ($)
Mobilization and preparatory work(331 01)	Four, fully-screened vertical wells at corners of treatment area	$ 10,000	$ 35,000
	Flow model calibration and analysis	$ 15,000	
	Flow meter testing	$ 10,000	
Monitoring ,sampling, testing, and analysis (331 02)	Monitoring point network	$ 15,663	$ 238,310
	Pre- and post-treatment coring	$ 20,000	
	Laboratory - VOCs (biweekly)	$ 48,728	
	Laboratory – methane, ethane, ethylene (biweekly)	$ 81,900	
	Laboratory - tracers (biweekly)	$ 9,492	
	Iodide tracer	$ 2,568	
	Laboratory - nutrients (weekly)	$ 8,860	
	Bromide tracer	$ 869	
	Labor	$ 40,230	
Ground water collection and control (331 06)	Horizontal well installation (2-240 feet long w/30 feet screens)	$ 41,235	$ 87,563
	Pumps and controls	$ 9,256	
	Trenches	$ 7,925	
	Plumbing, utilities, pad, shed, etc.	$ 29,120	
Biological Treatment (331 11)	Operations labor	$ 19,440	$ 23,748
	Methanol ~60 kg	$ 174	
	Sodium benzoate ~120 kg	$ 376	
	Sodium lactate (2 drums) ~170 kg	$ 3,483	
	Bromide	$ 869	
	Utilities: Electricity	$ 275	
General requirements (331 22)	Project management and engineering	$ 12,480	$ 12,480
		TOTAL	$ 397,074

As discussed earlier, the goal of the operation of this *in situ* anaerobic bioremediation pilot system was to assess the ability of nutrient injection to accelerate the reduction of contaminants at the Northeast Site and to identify optimum operating conditions for the design and operation of a full-scale system. Since the pilot system was not operated to meet any specific cleanup criteria and the treatment area selected had nominal contaminant levels higher than much of the Northeast Site, it would be inappropriate and possibly misleading to specify a direct treatment costs for a full-scale system implementation. However, general observations and estimates of biological treatment capital and operating costs can be made.

As can be seen from Table 6, almost two-thirds of the overall costs of the pilot operation were related to the extensive monitoring conducted. This level of monitoring was used in an effort to better understand the operation of the pilot system and to track the biodegradation occurring at different levels in the aquifer. As extensive a monitoring system and the associated costs would not be required in a full-scale system. The monitoring costs data provided though does show how systems like the continuous monitoring field GC can be used to provide significant bioremediation data at a low cost. Typical fully automated continuous monitoring systems like the one used at Pinellas are available for less than $50K.

From an operational viewpoint, the pilot system pumped approximately 250,000 gallons of water, this allowed for treatment of approximately two pore volumes of contaminated ground water in the central treatment area. The direct biological treatment costs for water treatment during the pilot operations were therefore approximately $0.10-0.12 per gallon of water treated. Since additional treatment would be required to reduce contaminants to regulatory levels in some areas, these costs are only approximate. Actual costs will vary based on the contaminant levels and the hydrogeology encountered across the site, though much of the site has significantly lower contaminant levels than the pilot study area.

The system construction, operations labor, and chemical costs are often proportional to the scale of a project and can be more easily used to quantify potential full-scale system operating and construction costs. Initial estimates of the construction and operating costs of an *in situ* anaerobic bioremediation system were developed by the ITRD Program based on site hydrogeologic data and the results of the biodegradation treatment study.[7] The initial estimates were developed by two, environmental consulting firms familiar with implementing bioremediation systems. They estimated that a vertical well based treatment system would take approximately a year to construct, require about a year to deliver nutrients to all areas of the site, and about six months to a year for contaminant degradation, for a three to four year total remediation period. The nutrient costs were estimated to be about $750K, with system operational costs of $600K per year. Capital costs for a ground water extraction and recirculation system were estimated at $2M, for an estimated total site remediation cost of $3.5-4.5M. These cost estimates assumed application of a bioremediation system in the areas of low to moderate concentration (less than 200 ppm), while the higher contaminant levels would be treated with another more aggressive technology.

The performance of the pilot system generally substantiated many of the initial performance and unit cost assumptions and related overall cost estimates. Based on the pilot data, it appears that it would take about 6-8 months to get nutrients to all levels of the aquifer and another 8-12 months for contaminant degradation and reduction in all levels to regulatory limits, or about two years for system operations. Based on nutrient costs and the levels used for the pilot and two year operational period, nutrient costs for treatment of the three to four-acre Northeast Site would be about $750K to $1M, depending on the savings of buying nutrients in bulk quantities. Scaling of the construction costs of the horizontal pilot-system for application to the entire Northeast Site suggest a full-scale cost of approximately $3-4M. These results suggest that a full-scale bioremediation system based on a horizontal extraction and recirculation design would cost $4.5-5.5M to construct and operate for a two to three-year period. The required operational period and associated costs for some portions of the system might be reduced since much of the Northeast Site has nominal contaminant levels of 10-30 ppm, rather than the higher contaminant levels observed in the selected pilot-system treatment area.

7. REGULATORY/INSTITUTIONAL ISSUES

In July 1993, DOE, EPA, FDEP, and LMSC entered into an agreement with the ITRD Program to evaluate innovative technologies to remediate ground water contamination at the Pinellas STAR Center Northeast Site effectively and expeditiously.

Under Section II.D.1 of the Department of Energy's HSWA Permit, interim measures may be conducted at SWMUs after EPA approval. Section II.D.3 requires the permittee to notify the EPA Regional Administrator, as soon as possible, of any planned changes, reductions, or additions to the interim measures. The proposed *in situ* anaerobic bioremediation project would temporarily interrupt the operation of the existing interim measures (pump and treat with air stripping); therefore, the DOE provided notice to the EPA and FDEP of a planned change (the implementation of ITRD field activities) to the approved interim measures and proposed implementation schedule for concurrence in August 1996. Authorization for implementation of the activities was received in August 1996.

Initially, both industry and regulatory participants of the ITRD committee were concerned that underground injection control (UIC) requirements may prevent the recirculation of ground water. Through assistance from the FDEP, discussions were held with the State of Florida, who has UIC delegation, about this issue. Because of the system design (i.e., *in situ* recirculation) the state determined that no UIC permit was required.

8. SCHEDULE

Figure 12 shows the tasks and schedule associated with the *in situ* anaerobic bioremediation project at the Pinellas STAR Center.

ID	Task Name	Start	Finish
1	Workplan completed	8/1/96	8/1/96
2	System construction	8/1/96	11/8/96
3	Install horizontal wells	8/19/96	8/22/96
4	Install infiltration trenches	9/3/96	9/17/96
5	Install monitoring network	9/26/96	10/1/96
6	System checkout & hydraulic tests	10/1/96	12/20/96
7	System operation	2/10/97	6/27/97
8	Recirculate ground water	2/10/97	6/27/97
9	Add methanol & benzoate	2/12/97	6/27/97
10	Add lactate	2/27/97	6/23/97
11	Conduct tracer study	3/7/97	6/4/97
12	Add iodide to trenches	3/7/97	6/4/97
13	Add bromide to lower horiz well	3/7/97	4/25/97
14	Groundwater sampling	11/7/96	7/9/97
15	Pretreatment VOC sampling	11/7/96	11/8/96
16	Operational VOC sampling	2/17/97	7/8/97
17	Methane, Ethane, Ethene sampl	3/4/97	7/9/97
18	Tracer sampling	3/7/97	7/7/97
19	Nutrient sampling	5/8/97	7/9/97

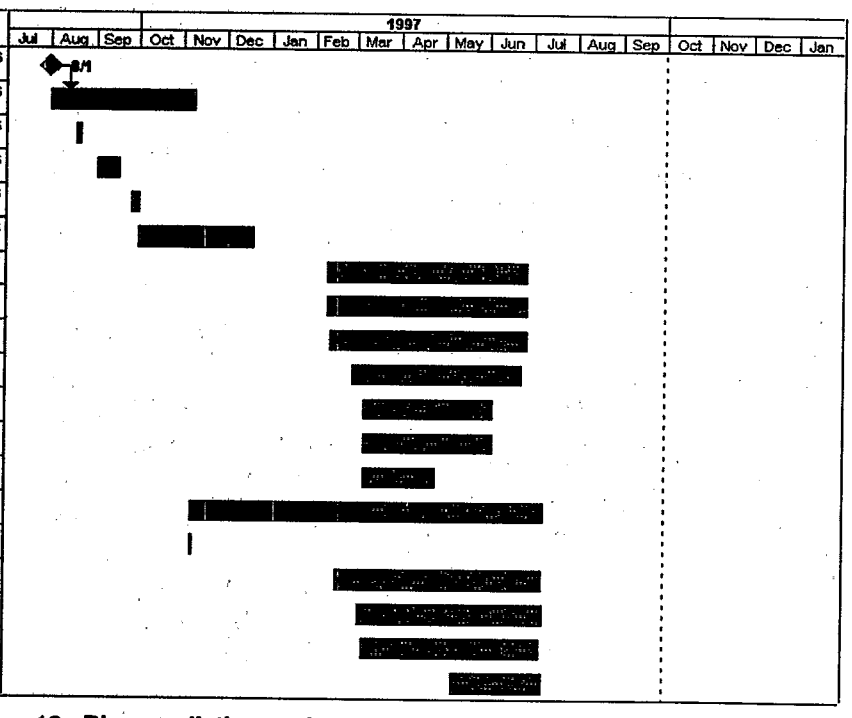


Figure 12. Bioremediation project schedule.

9. OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

Based on the construction and operating treatment cost data from the pilot system operation, it appears that *in situ* anaerobic bioremediation is a cost-effective method for reducing chlorinated VOCs in subsurface environments, given favorable geochemical, microbal, and hydraulic/hydrologic characteristics, such as at the Pinellas Northeast Site.

Performance Observations and Lessons Learned

Laboratory batch and column studies, using site soil and ground water, if used correctly can help identify whether a population of anaerobic microorganisms exists capable of remediating the contaminants of concern at a site and which nutrients can enhance degradation of those contaminants.

Good nutrient distribution is critical to effectively enhancing contaminant degradation in a treatment area. Therefore, a thorough and detailed understanding of the site hydrology is necessary to design an effective nutrient delivery system. Flow meter field testing and numerical modeling should be used to help identify the best nutrient delivery system for a site.

The recirculation system of infiltration trenches and two horizontal wells developed for this site proved effective in the pilot operations. Because of the recirculation design, no waste water was generated. Improvements, such as deeper surface trenches and the flexibility of switching extraction and injection roles of the horizontal wells, could accelerate nutrient delivery to the middle and lower permeability layers and overall remediation of the site. Effective redevelopment of long horizontal wells can sometimes be difficult and should be considered in the overall design and operation of a full-scale system.

At monitoring points were nutrient breakthrough was observed for at least four to eight weeks, significant declines in total chlorinated VOC concentrations (70-95%) were generally observed. These values correlate well with the results from the extraction well. For those wells where nutrient arrival was not observed, generally in the areas of lower permeability or in perimeter wells, only modest contaminant reductions were recorded. Though the nutrient mixture and concentrations were not specifically optimized during pilot operations, degradation rates as high as 1-2 ppm per day were observed in higher concentration areas (>100 ppm), while in areas with lower concentrations degradation rates ranging from 0.05 to 0.10 ppm per day were observed. It is possible that the nutrient mixture might be adjusted to further accelerate contaminant reduction. There was little evidence of significant degradation product buildup at monitoring wells after nutrient arrival.

Contaminant degradation observed in the pilot study at concentrations higher than 200 ppm suggests that anaerobic bioremediation is more robust and has a broader operational capability than previously identified.

Summary

The extensive modeling and hydrogeologic, nutrient transport, and operating cost data developed during the pilot system operation suggest that nutrient addition to stimulate *in situ* anaerobic biological degradation of chlorinated solvent contaminated soil and ground water is a feasible, cost-effective, remediation approach at the Pinellas Northeast Site for areas of moderate contamination. The limiting factors for successful, cost-effective implementation are the ability to deliver appropriate nutrients to all contaminated areas and hydraulic travel times.

10. REFERENCES

1. *Installation Assessment, Pinellas Plant*, U.S. Department of Energy, Comprehensive Environmental Assessment and Response Program, Albuquerque Operations Office, Albuquerque, N.M., 1987.

2. *RCRA Facility Investigation Report, Pinellas Plant*, U.S. Department of Energy, Environmental Restoration Program, Albuquerque Operations Office, Albuquerque, N. M., 1991.

3. *RCRA Hazardous and Solid Waste Amendments Permit, U. S. Department of Energy Pinellas Plant, Largo, Florida.* EPA ID No. FL6-890-090-008, U.S. Environmental Protection Agency, February 9, 1990.

4. *Interim Corrective Measures Study, Northeast Site*, TPA2 6350.80.01, prepared by CH2M Hill for the U.S. Department of Energy and General Electric Company, Neutron Devices Department, Largo, FL, May 1991.

5. *Corrective Measures Study Report, Northeast Site, Pinellas Plant, Largo, Florida*, U.S. Department of Energy, Environmental Restoration Program, Albuquerque Field Office, Albuquerque, N.M., 1993.

6. Flanagan, W.P., et al. "Anaerobic Microbial Transformation of Trichloroethylene and Methylene Chloride in Pinellas Soil and Ground Water," General Electric Corporate Research and Development Center, Schenectady, NY, May 1995.

7. Pinellas Northeast Site Project, Innovative Technology Review, letter to David Ingle, U. S. Department of Energy, from Mike Hightower, Sandia National Laboratories, February 8, 1995.

11. VALIDATION

Signatories:

"This analysis accurately reflects the performance and costs of the remediation."

David S. Ingle, ER Program Manager
U.S. Department of Energy
Grand Junction Office

Mike Hightower, Technical Coordinator
Innovative Treatment Remediation Demonstration Program
Sandia National Laboratories

Guy Sewell, Research Microbiologist
National Risk Management Research Laboratory
U.S. Environmental Protection Agency

Department of Environmental Protection

Lawton Chiles
Governor

Twin Towers Building
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

Virginia B. Wetherell
Secretary

April 14, 1998

Mr. David Ingle
c/o MACTEC-ERS
7887 Brian Dairy Road
Suite 200
Largo, Florida 33777

Dear Mr. Ingle:

I have reviewed the "Cost and Performance Report, In Situ Anaerobic Bioremediation, Pinellas Plant Northeast Site" final draft dated March 16, 1998. I concur with the purpose of the report. Unless the EPA or other parties desire modifications, we recommend that the report proceed to "final" designation.

If I can be of any further assistance with this matter, please do not hesitate to contact me at 904/921-9983.

Sincerely,

John R. Armstrong P.G.
Remedial Project Manager

April 14, 1998
Date

CC: Cheryl Walker-Smith, USEPA Atlanta
Satish Kastury, FDEP

JJC JJC ESN ESN

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CERTIFIED MAIL
RETURN RECEIPT REQUESTED

The United States Department of Energy
Pinellas Plant
ATTN: Mr. David Ingle
P.O. Box 2900
Largo, FL 34649

SUBJ: Revised Cost and Performance Report: In Situ Anaerobic Bioremediation
Pinellas Northeast Site, Largo, Florida
Final Draft - March 16, 1998
DOE Pinellas Plant, FL
EPA I.D. Number FL6 890 090 008

Dear Mr. Ingle:

The Environmental Protection Agency (EPA), Region 4, has completed our review of the revised Cost and Performance Report for the in situ anaerobic Bioremediation project conducted at the Northeast Site (Solid Waste Management Unit PIN 15). This work was conducted under the Innovative Treatment Remediation Demonstration (ITRD) agreement between EPA Region 4, the Florida Department of Environmental Protection (FDEP), the U.S. Department of Energy, Clean Sites, Inc., the EPA Technology Innovation Office, and Sandia National Laboratories. This team's mission was to identify and demonstrate various innovative technologies applicable to this and other contaminated waste sites around the country. This is the third innovative technology demonstration conducted at the Northeast Site.

This project utilized the experience and expertise of personnel from the EPA National Risk Management Research Laboratory (NRMRL) and Lockheed-Martin in the design, construction, implementation, and sampling efforts. The FDEP participants played a key role in system design, permitting issues, and computer support. The facilitator of the ITRD effort, Mr. Mike Hightower, deserves special credit for unifying and focusing the efforts of this team, and in the overall success of this ITRD project.

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The EPA approves of the changes made in this revised document and looks forward to the possibility of other ITRD projects occurring across Region 4.

Any and all concerns raised by the FDEP for this revised document must be addressed as required under their authority.

Sincerely,

Carl R. Froede Jr.

Carl R. Froede Jr., P.G.
DOE Remedial Section
Federal Facilities Branch
Waste Management Division

cc: J. Crane, FDEP
E. Nuzie, FDEP
J. Armstrong, FDEP

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PerVap™ Membrane Separation Groundwater Treatment at Pinellas Northeast Site, Largo, Florida

PerVap™ Membrane Separation Groundwater Treatment at Pinellas Northeast Site, Largo, Florida

Site Name: Pinellas Northeast Site	**Contaminants:** Volatile Organic Compounds: Trichloroethene (TCE) Methlyene Chloride 1,2-Dichloroethene	**Period of Operation:** 6/14/95 - 3/2/96
Location: Largo, Florida		**Cleanup Type:** Demonstration (ITRD Technology Demonstration)
Vendor: Membrane Technology and Research, Inc. (MTR) and the Advanced Technology Group of Hoechst Celanese Corp	**Technology:** Membrane Filtration: - Membrane separation (pervaporation) using the PerVap™ technology. - organic permeable, hydrophobic membrane used to remove organic contaminants from water - MTR PerVap pilot system was skid-mounted; capacity of 1-2 gallons/minute on a batch basis	**Cleanup Authority:** RCRA
Additional Contacts: DOE Environmental Restoration Program Manager: David Ingle (813) 541-8943 Lockheed Martin Specialty Components Barry Rice (813) 545-6036		**Regulatory Point of Contact:** EPA Region 4 and State: Florida Department of Environmental Protection
Waste Source: Disposal of drums of waste and construction debris	**Type/Quantity of Media Treated:** Groundwater - 125 batches or 6,200 gallons	
Purpose/Significance of Application: Demonstration of the PerVap™ technology for treating VOC-contaminated groundwater at the Northeast Site		

Regulatory Requirements/Cleanup Goals:
- The objectives of the demonstration were to achieve greater than 99% removal of VOCs, eliminate the need for pretreatment of groundwater, and to produce no air emissions. For effluent to the POTW, there was a discharge limit of 850 ug/L total toxic organics.
- No air permitting or air permit modifications were required for this demonstration because the demonstration was performed at an existing SWMU.

Results:
- Removal efficiency was highly variable (ranging from 90% when membranes were not clogged to zero when membranes were clogged). The goal of 99% removal was not maintained during the demonstration.
- The clogging was attributed to oxidation of aqueous iron. Because of persistent clogging problems with the membranes, groundwater pretreatment was required. Several pretreatment alternatives were tried; however, the effectiveness and applicability of each was determined to be site-specific.
- The discharge limits were not achieved and water was treated using the existing groundwater treatment system.
- No air emissions were detected; however, a very strong odor was noted during operation.

PerVap Membrane Separation Groundwater Treatment at Pinellas Northeast Site, Largo, Florida (continued)

Cost:

- Total cost for pilot system - $88,728, including pre-demonstration consultation, mobilization and demobilization, monitoring, sampling and analysis, treatment, and disposal. The total cost includes $29,000 in costs for MTR who agreed to provide the pilot system and engineering services to Lockheed Martin on a fixed-price basis ($5,000 for the first month and $3,000/month for eight months)
- Cost per unit of groundwater treated during the pilot test - $0.01-0.015/gallon
- Projected cost for full-scale - capital cost of $250,000 and operating cost of $0.01/gallon.

Description:

The Pinellas Northeast site, located at the DOE Pinellas Plant in Largo, Florida, includes the East Pond and was identified as a Solid Waste Management Unit in a RCRA Facility Assessment conducted by EPA Region 4. The East Pond was excavated in 1968 and used as a borrow pit. The area was used to store construction debris and waste, including solvents, in drums and containers. In 1986 shallow groundwater at the site was determined to be contaminated with a variety of VOCs . The predominant contaminants at the site were TCE, methylene chloride, and 1,2-dichloroethene, detected at levels as high as 360,000 ppb, 1,200,000 ppb, and 58,000 ppb, respectively. Vinyl chloride and toluene were also detected at relatively high concentrations.

The groundwater pump and treat system at the site includes seven recovery wells connected to an air stripper. Effluent is discharged to a POTW. Because the aquifer is anaerobic and contains high levels of dissolved solids and iron, the extracted groundwater must be pretreated prior to the air stripper. The purpose of the demonstration was to determine if the pervaporation system would be able to treat the groundwater directly without pretreatment and would be able to concentrate contaminants in a condensate that could be recycled, thereby reducing waste disposal costs as well as air emissions.

The MTR PerVap™ pilot system was a self-contained, field transportable pervaporation system that had been adapted for use in removing organics from aqueous liquid streams. Contaminated groundwater, pumped into a surge tank, was passed through a cloth filter into the 50 gallon process feed tank. The pervaporation cycle, begun when the feed tank was full, consisted of pumping a 50-gallon batch of water across a heater (to raise the temperature to 50° C), through two membranes modules in series, then back to the feed tank. A vacuum was applied across the membrane modules creating a pressure gradient to facilitate the transfer of VOCs across the membranes. The resultant vapor stream or permeate (about 1,500 ml/batch) was then cooled to condense the liquid which was then sent to a chilled permeate storage container. The treated water was discharged to a POTW. The capacity of the pilot system was 1-2 gal/min and a typical pervaporation cycle was 1-2 hours. The residuals produced by the system were filters and permeate, which were disposed of as hazardous waste, and used membranes, which were returned to MTR.

Optimal operating parameters could not be established during the demonstration. Because of membrane clogging problems caused by precipitants from the groundwater, the removal efficiencies were highly variable during the demonstration. Several groundwater pretreatment methods were evaluated an attempt to alleviate the clogging, including nitrogen blanketing, adding a chelator, adding a dispersant, and changing the pH of the water. The use of a nitrogen blanketing and the dispersant produced the best results, but were not compatible with the existing groundwater treatment system. Therefore, while cost effective pretreatment was available, the applicability is subject to site- specific constraints. In addition, the POTW discharge limit was not achieved and the water was treated using the existing groundwater treatment system.

1. SUMMARY

From July 1995 through March 1996, the Innovative Treatment Remediation Demonstration (ITRD) Program conducted a pilot demonstration of a membrane separation (also known as pervaporation) technology for the treatment of volatile organic compound (VOC)-contaminated ground water at the U.S. Department of Energy's (DOE) Pinellas Plant in Largo, Florida. This technology has often been used for separation of organic contaminants from air and industrial process water streams. These systems have been proposed for the treatment of VOC contaminated groundwater. The pilot system used during this demonstration was developed by Membrane Technology Research, Inc. of Menlo Park, California. The purpose of this evaluation report is to document the demonstration activities, present demonstration data, and provide evaluation results on the cost and performance of the MTR pilot-scale pervaporation system. The system was evaluated for analytical and operational performance relative to defined performance goals needed for full-scale implementation of this technology at the Pinellas Plant.

The membrane separation or pervaporation process uses an organic permeable but hydrophobic membrane to remove organic contaminants from the water to be treated. Bench-scale testing has suggested that removal efficiencies of 99% could be obtained. If the system could operate without fouling the membrane from the high iron and dissolved solids in the ground water at this site, the system would significantly reduce water pretreatment costs over the proposed baseline air stripper. Additionally, because the separated organics are condensed and concentrated in the process, they can be recycled, significantly reducing air emissions and waste disposal over the baseline air stripper.

The demonstration provided adequate analytical and operations data with which to evaluate the performance of the MTR PerVap™ Pilot System. Initial operational tests indicated that organic contaminant (TCE, DCE, and methylene chloride) removal efficiencies of 90–99% could be accomplished with the membrane system. Batch mode operation allowed groundwater at contamination levels as high as 1000 ppm to be reduced to 2–3 ppm in as little as 1-2 hours of treatment. The major problems associated with continuous batch operation of the system was fouling of the membranes by precipitated iron. Attempts to reduce this fouling through the modification of system operation and chemical additives met with some success. During continuous batch operation, contaminants generally could not be reduced below the 4-5 ppm total contaminant concentration. Concentration of the contaminants in an organic condensate was demonstrated. A limited analysis of field operational costs for the PerVap™ system shows that use of the system may provide cost-effective ground water treatment and direct operating costs of $.01/gal for treated ground water can be obtained.

Application of the system to ground water treatment seems feasible as long as compatibility with the chemistry of the ground water to be treated is fully considered before application. Because of the high levels of iron and dissolved solids in the ground water, this system was unable to meet the performance goals required for full-scale implementation at the Pinellas Plant.

2. SITE INFORMATION

Identifying Information

Facility:	DOE Pinellas Plant
OUS/WMU:	Northeast Site
Location:	Largo, Pinellas County, Florida
Regulatory Driver:	RCRA
Type of Action:	ITRD Technology Demonstration
Technology:	Groundwater pump-and-treat with membrane separation
Period of operation:	June 14, 1995 - March 12, 1996
Quantity of groundwater treated:	125 batches or 6,200 gallons

Site Background

The DOE Pinellas Plant occupies approximately 100 acres in Pinellas County, Florida, which is situated along the west central coastline of Florida (Figure 1). The plant site is centrally located within the county; it is bordered on the north by a light industrial area, to the south and east by arterial roads, and to the west by railroad tracks. The topographic elevation of the Pinellas Plant site varies only slightly, ranging from 16 feet MSL in the southeast corner to 20 feet MSL in the western portion of the site. Pinellas County has a subtropical climate with abundant rainfall, particularly during the summer months.

The Northeast Site includes the East Pond and is located in the northeast portion of the Pinellas Plant site (Figure 2). The Northeast Site is covered with introduced landscaping grass and contains no permanent buildings. The site contains approximately six acres and is generally flat, with slight elevation changes near the pond. Access to the Northeast Site is restricted and protected by fencing.

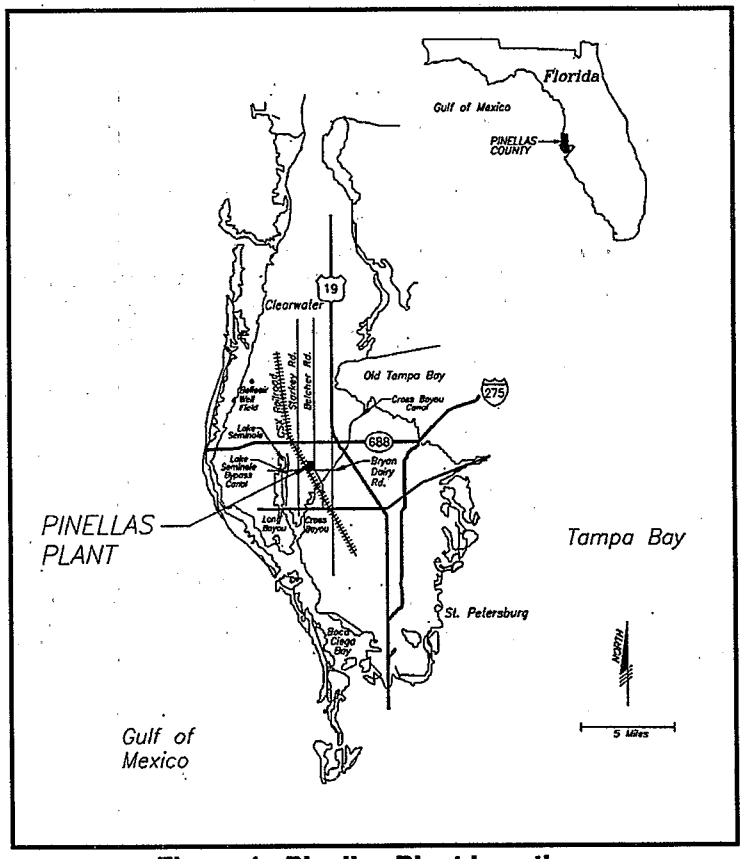


Figure 1. Pinellas Plant Location.

Site History

The DOE Pinellas Plant operated from 1956 to 1994 manufacturing neutron generators and other electronic and mechanical components fro nuclear weapons (SIC Code 9631A-Department of Energy Activities).

The Northeast Site is associated with the location of a former waste solvent staging and storage area. From the late 1950s to the late 1960s, before construction of the East Pond, an existing swampy area at the site was used to dispose of drums of waste and construction debris. The East Pond was excavated

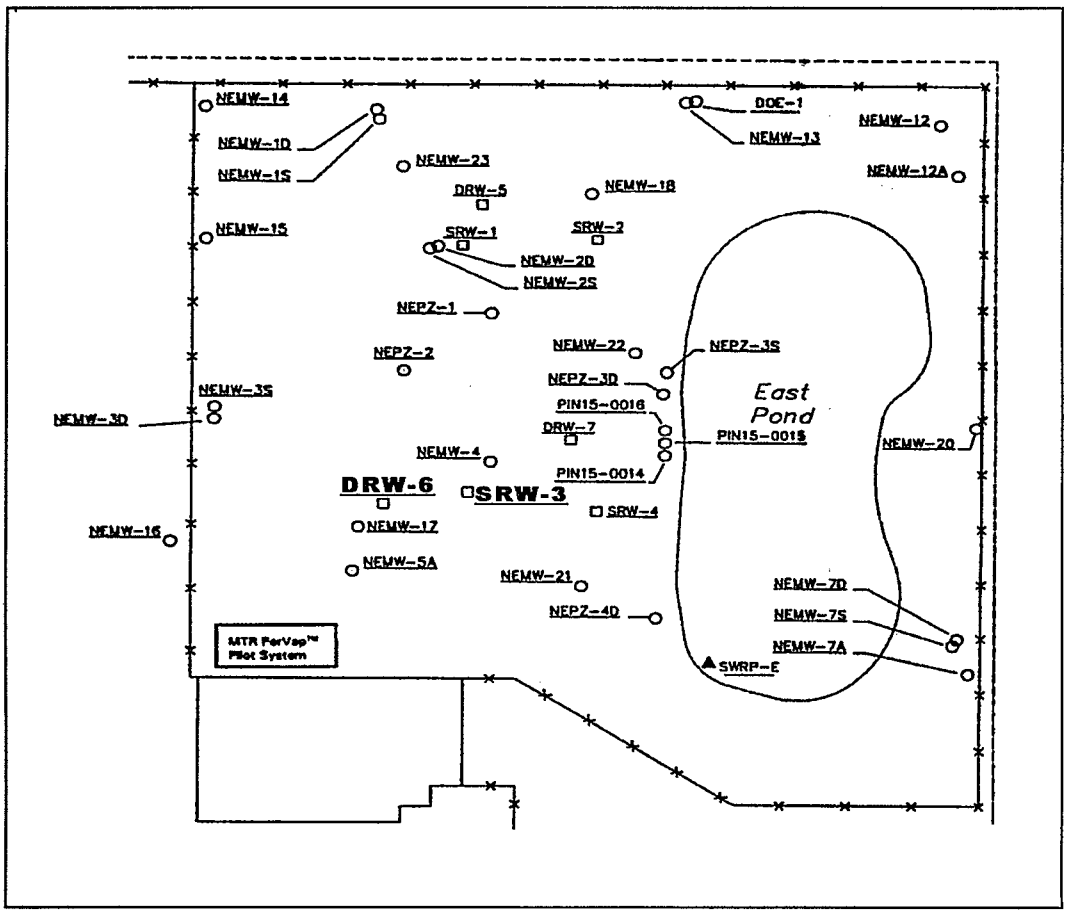


Figure 2. Pinellas Plant Northeast Site.

in 1968 as a borrow pit. In 1986, an expansion of the East Pond was initiated to create additional stormwater retention capacity. Excavation activities ceased when contamination was detected directly west of the East Pond.

The Northeast Site was identified as a Solid Waste Management Unit (SWMU) in a RCRA Facility Assessment (RFA)[1] conducted by the EPA Region IV. Subsequently, a RCRA Facility Investigation (RFI)[2] was completed and approved in compliance with the facility's Hazardous and Solid Waste Amendments of 1984 (HSWA) Permit.[3]

An Interim Corrective Measures (ICM) Study [4] was developed and submitted to EPA for approval. EPA issued final approval of the ICMS in October 1991, and an interim groundwater recovery system for the Northeast Site was installed and commenced operation in January 1992. The ICM system now consists of seven groundwater recovery wells equipped with pneumatic recovery pumps that transfer ground water for temporary storage in a holding tank prior to being pumped to a groundwater treatment system. Final disposition of the treated ground water is disposal in the Publicly Owned Treatment Works (POTW). The POTW discharge limit is 850 micrograms per liter (µg/l) total toxic organics (TTO).[5]

Release Characteristics

The Pinellas Northeast Site consists of a shallow groundwater aquifer contaminated with a variety of VOCs, including chlorinated solvents such as trichloroethene, methylene chloride, dichloroethene, and vinyl chloride. Because the site was used in the 1950s and 1960s for staging and burial of construction

debris and drums, some of which contained solvents, contamination at the Northeast Site is believe to be the result of leakage of solvents or resins from these drums. A recent debris removal activity at the site confirmed the presence of multiple buried drums, many of which were empty, but had solvent residue. The ongoing ICM system (pump and treat with air stripping) continues to recover contaminants from the site and has been successful in preventing offsite migration of VOCs.

Site Contacts

Site management is provided by the DOE Pinellas Area Office (DOE/PAO). The DOE/PAO Environmental Restoration Program Manager is David Ingle [(813)-541-8943]. The Managing and Operating contractor for the Pinellas Plant is Lockheed Martin Specialty Components, Inc. (LMSC). The LMSC technical contact for the Pinellas Plant pervaporation pilot study is Barry Rice [(813)-545-6036].

3. MATRIX AND CONTAMINANT DESCRIPTION

The primary environmental contamination pathway at the Northeast Site is ground water. The CMS[6] at the site determined that the soil was not a credible exposure pathway. The type of matrix processed by the remediation system during this application was groundwater (ex situ).

Site Geology/Hydrology

Based on analysis of soil borings, details of well construction, and environmental studies at the Pinellas Plant, the thickness of the surficial deposit below the site ranges from 25 to 35 feet and is primarily composed of silty sand. The top of the Hawthorn Group (composed primarily of clay) at the Pinellas Plant is encountered at depths approximately 30 feet or greater below ground surface. The thickness of the Hawthorn Group ranges from 60 to 70 feet. The water table at the Pinellas Plant is generally 3 to 4 feet below the ground surface. Figure 3 shows the primary geologic units at the site.

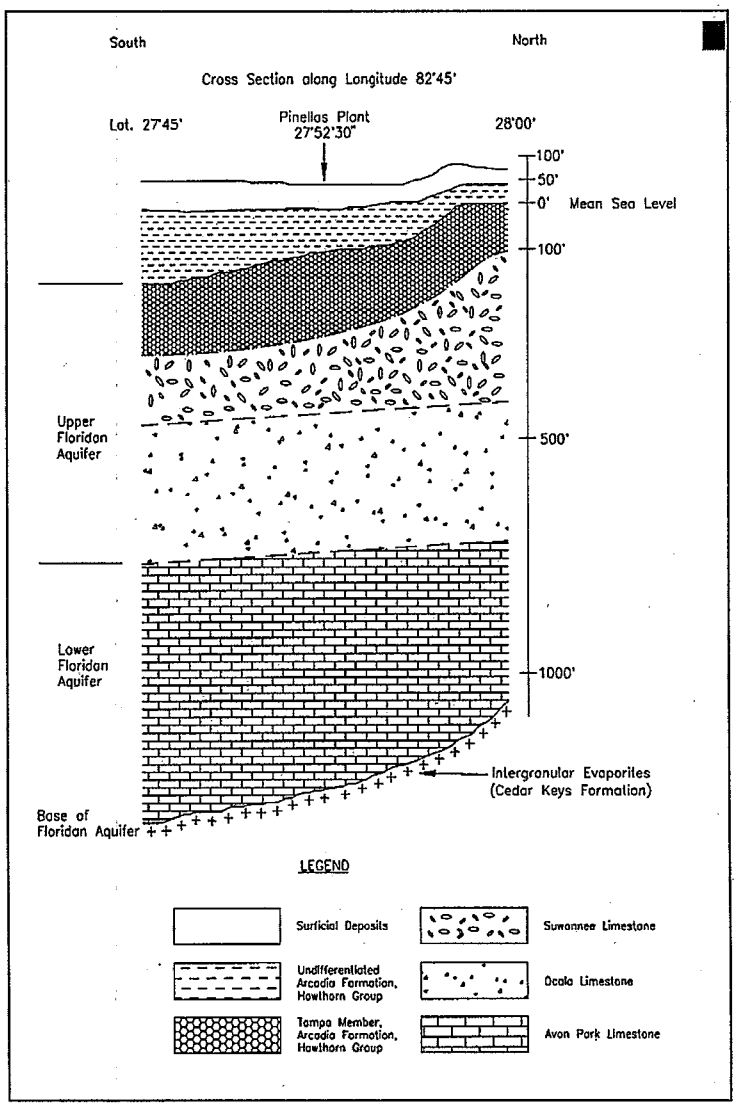


Figure 3. Geologic Section at the Pinellas Plant.

The groundwater system at the Pinellas Plant is composed of three primary units: (1) an upper unit, the surficial aquifer, (2) an intermediate confining unit, the undifferentiated portion of the Hawthorn Group, and (3) a lower unit, the Floridan aquifer. Undifferentiated sediments lie below the surficial aquifer and above the Floridan aquifer in Pinellas County. Because of the low permeability of these sediments in this region, these upper sediments are not considered part of the intermediate aquifer system and are generally considered to be a confining unit in the area of the Pinellas Plant.

Nature and Extent of Contamination

The primary contaminant group that this technology was designed to treat in this application was halogenated volatile organic compounds. Contamination at the Northeast Site is limited to groundwater in the surficial aquifer. Contaminants of concern detected in Northeast Site groundwater include 1,1-dichloroethane, 1,1-dichloroethene, benzene, ethylbenzene, 1,2-dichloroethene (cis and trans isomers), methylene chloride, toluene, trichloroethene, tetrachloroethene, methyl tert-butyl ether, vinyl chloride, total xylenes, and chloromethane. The predominant contaminants detected at the site during performance of the demonstration were methylene chloride, 1,2-dichloroethene, and trichloroethene. Other VOCs which are detected in relatively high concentrations are toluene and vinyl chloride.

At various times, limited VOC contamination has been detected at most of the surficial aquifer monitoring wells within the fenced portion of the site. However, the bulk of the contaminant mass is located in the central portion of the site, especially in the vicinity of recovery wells SRW-3 and DRW-6 which were used to provide water for the pilot study. Table 1 summarizes the concentrations of important parameters detected in these two wells.

Table 1. Typical Pervaporation Influent Contaminants
(concentrations in µg/l)

Analyte	SRW-3	DRW-6
Total 1,2-Dichloroethene	26,000	58,000
Trichloroethene	13,000	360,000
Methylene Chloride	82,000	1,200,000
Vinyl Chloride	9,700	5,000
Toluene	16,000	140,000
Iron	20,800	19,300
Manganese	52.2	101

Matrix Characteristics Affecting Treatment Cost or Performance

The site includes seven operating ground water recovery wells that are connected to an air stripper for water treatment before discharge to a public owned treatment works (POTW). The ground water at this site has naturally high dissolved solids and high iron content. Because the aquifer is anaerobic, the pumped ground water at this site requires pretreatment before air treatment in the air stripper. The potential benefit of the pervaporation system would be its ability to treat the ground water directly without costly pretreatment and to concentrate the contaminants in a condensate that could be recycled, reducing waste-disposal costs and significantly reducing air emissions. Surficial aquifer ground water iron concentrations at the site during the demonstration performance period ranged from 5,000 µg/L to 50,000 µg/L.

4. PERVAPORATION TECHNOLOGY DESCRIPTION

The technology evaluated in this field demonstration is membrane separation of multicomponent liquid streams or pervaporation. In the pervaporation process (Figure 4), a multicomponent liquid stream is passed across a membrane that preferentially permeates one or more of the components. The process can be applied to the dehydration of organic liquids, removal of dissolved organic compounds from water, and to the separation of mixed organic compounds.

Technology Description

Figure 4 shows the basic pervaporation process is shown schematically. As the feed liquid flows across a membrane surface, the preferentially permeated organic components pass through the membrane as a vapor. Transport through the membrane is induced by maintaining a vapor pressure on the permeate side of the membrane that is lower than the vapor pressure of the feed liquid. The pressure difference is achieved by vacuum pump. The permeate vapor is condensed and then removed as a concentrated permeate fraction. The treated liquid exits on the feed side of the membrane. The residue, depleted of the permeating component, exits on the feed side of the membrane.

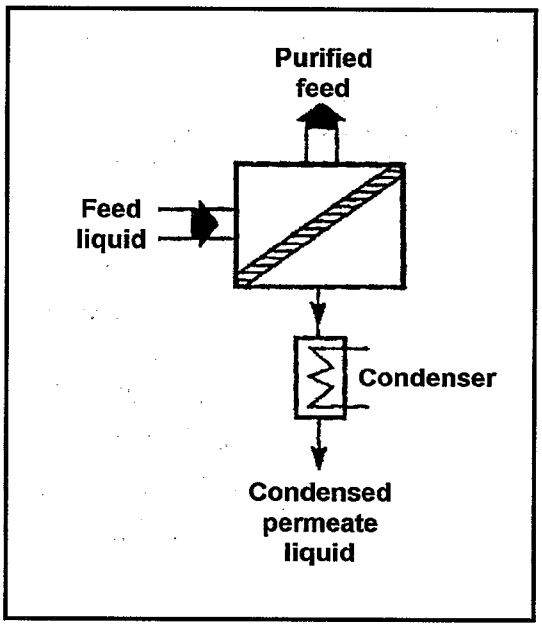


Figure 4. Basic pervaporation process.

Pervaporation is especially effective for handling aqueous streams containing VOCs in the concentration range of 100 ppm to 50000 ppm. Membranes are available to remove a broad range of VOCs from highly hydrophobic (toluene and TCE) to hydrophilic (ethyl acetate and acetone) organics. The technology has application to industries that generate VOC-containing process or waste water streams including chemical, petrochemical, pharmaceutical, pulp and paper, and food processing operations.

The technology also has application to the treatment of contaminated surface or ground waters, as demonstrated in this application. As the ground water flows across the membrane surface, the preferentially permeated organics pass through the membrane as a vapor. Transport through the membrane is induced by maintaining a vacuum on the permeate side of the membrane. The concentrated permeate or condensate containing the recovered organics can then be recycled. The purified ground water can then be discharged or recycled. The overall system separation effectiveness depends on the volatility of the organic contaminants, their relative permeabilities, and the organic concentration of the ground water. The system can provide removal efficiencies for many common organic contaminants of 90-99% for concentration ranges of 100-1000 ppm.

The effectiveness of the pervaporation technology for separation of organics from water is dependent on the design of the multilayer composite membranes. The membranes consist of a tough, open, microporous polymer layer that provides strength and an ultrathin, dense polymer coating that is responsible for the separation properties. This selective layer is very thin, typically 0.1 to 5 µm. Some components of a fluid in contact with the membrane surface permeate the membrane faster than others, the difference in permeation rate depending on the relative solubility and mobility of the component in the membrane material. This difference enables separation of the feed components. Membranes can be made of different selective polymers to meet specific separation needs. The membranes are packaged in spiral wound modules as shown in Figure 5. During treatment, the feed fluid enters the module and flows between the membrane leaves. The fraction of the feed that permeates the membrane spirals inward to a central collection pipe. The rest of the feed flows across the membrane surface and exits as the residue. To meet the capacity and separation requirements of specific applications, membrane

modules may be connected in a serial or parallel arrangement. The residue flow can also be recycled through the membrane modules until the desired level of organic removal is attained.

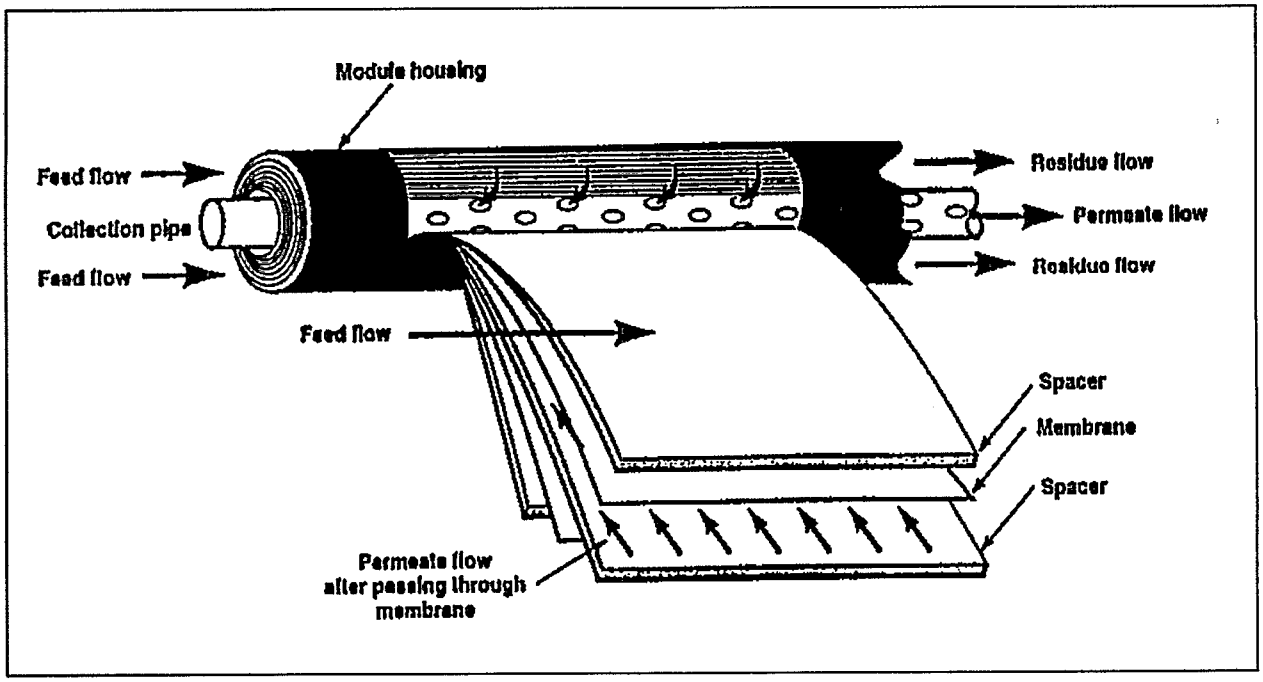


Figure 5. Typical spiral-wound membrane module.

PerVap™ Pilot System Description

Membrane Technology and Research, Inc. (MTR) and the Advanced Technology Group of Hoechst Celanese Corporation, who provides the membrane material, have formed an alliance to market the PerVap™ organic/water separation technology. MTR has developed a PerVap™ Pilot system that was used for this demonstration. The MTR PerVap™ pilot system is a self-contained, field-transportable pervaporation system which has been adapted for use in removing organics from aqueous liquid streams. Table 2 identifies the overall system capabilities. Figure 6 is a process flow diagram of the pilot system. Figure 7 is a photograph of the system in use at the Pinellas Plant..

Table 2. PerVap™ Pilot System Specification

Parameter	Developer's specification
Capacity	1–2 gal/min.
Operation mode	Batch
Batch size	50 gal
Operation	Continuous batches
Power requirement	480 V, 60Hz. 100 amp, 3-phase
Support equipment	Permeate collection system
Controller	Siemens

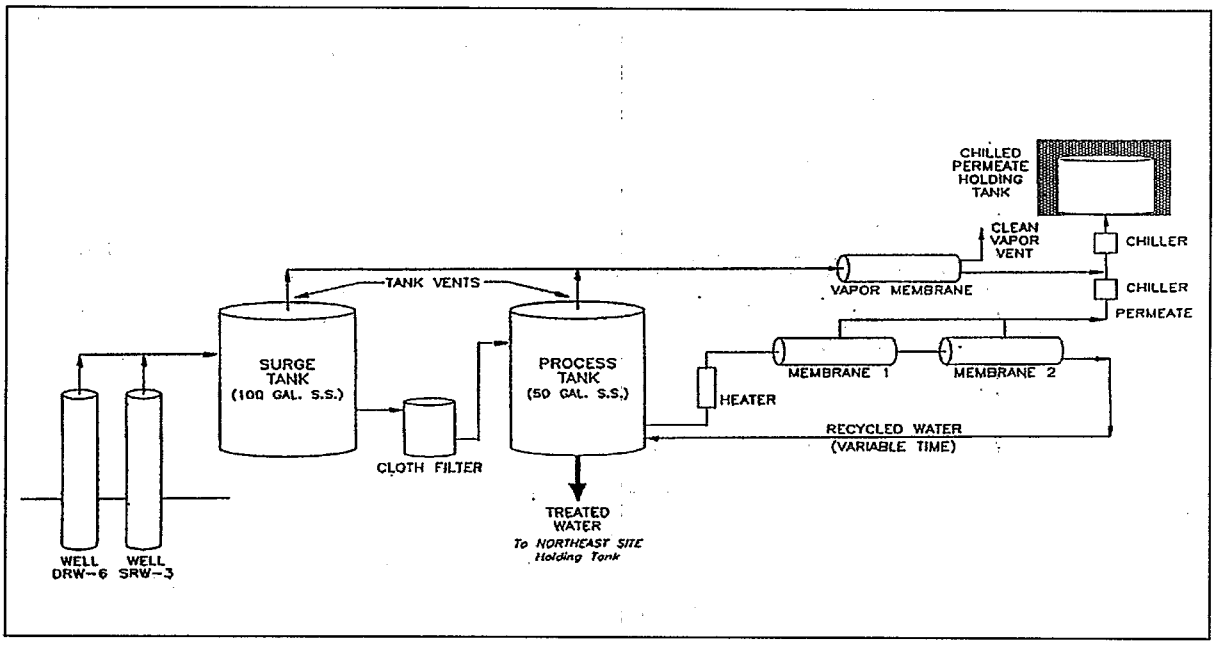


Figure 6. PerVap™ pilot system process flow diagram.

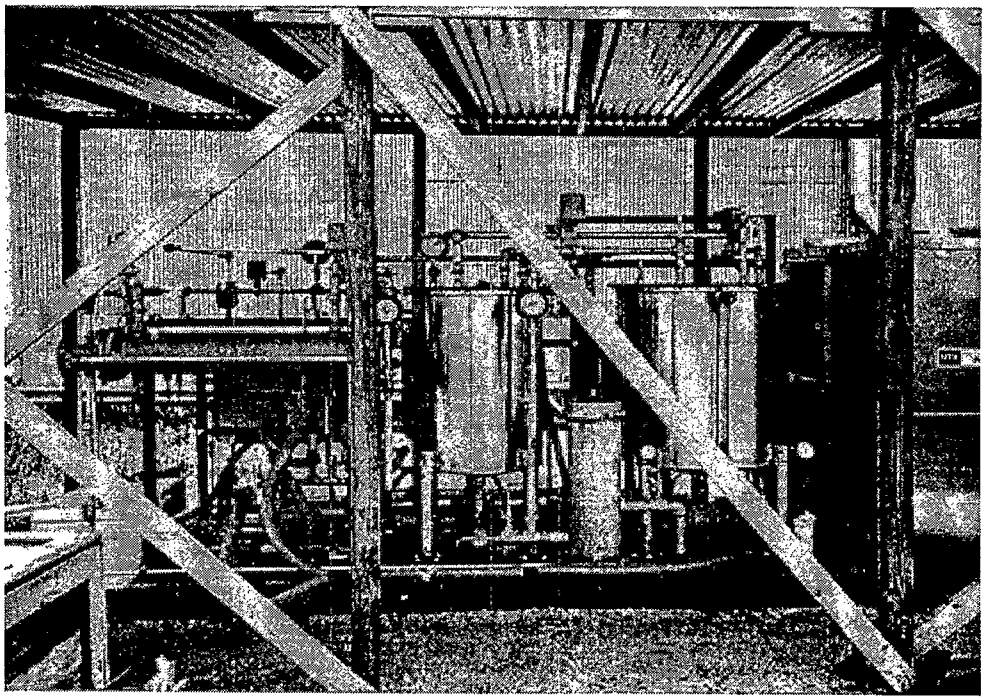


Figure 7. PerVap™ pilot system as used at the Pinellas Plant.

Technology Advantages

Treatment of VOC contaminated wastewater is practiced for several reasons: to recover valuable organic compounds, to minimize disposal costs of hazardous wastes, and to meet regulatory requirements. The advantages of the technology include:

- pervaporation is a low-temperature, non-destructive technology;
- VOCs are recovered in a concentrated liquid form, allowing recycling;
- no secondary wastes or air emissions requiring disposal or permitting;
- no expendable chemicals needed, and
- modular design allows easy modification to meet treatment requirements of streams with high or low VOC concentrations and flow rates.

Technology Limitations

The technology has the following limitations:

- potential membrane fouling from particulates or precipitation of dissolved solids (if the membranes foul, organic removal efficiency and cost effectiveness are reduced significantly);
- potential need pretreat for some ground water,
- diminished removal efficiencies at low organic concentration levels,
- high cost of membrane modules, and
- high initial capital costs.

Treatment System Schematic and Operation

Figure 6 is a schematic of the MTR Pervap™ pilot system.

Pilot system operation was controlled by a Siemens program logic controller that operated the pumps and solenoid-operated valves to process groundwater through the system in 50-gallon batches. The treatment system process flow was as follows:

- Groundwater was pumped to the 100-gal stainless steel surge tank.
- The groundwater was then transferred through a filter to the 55-gal stainless steel feed tank.
- When the feed tank was full, the pervaporation cycle started.
- The pervaporation cycle involved pumping a 50-gallon batch across the heater (elevating the water temperature to 50 degrees C) across the surface of each membrane module, and back into the feed tank.
- The pervaporation cycle timer controlled how long this process continued (typically 1 to 2 hrs). When the timer ended the pervaporation cycle, the treated groundwater was discharged through the effluent line.
- During the pervaporation cycle, a vacuum pump applied a pressure gradient across the membrane modules to assist in the transfer of VOCs across the membranes. The resultant vapor stream, called permeate, was then cooled to a concentrated liquid through a series of condensers and discharged to a chilled permeate storage container.
- All pilot system vents were routed through an MTR vapor separation membrane that functioned similar to the pervaporation modules by removing any VOC vapors from the air and releasing only treated air to the atmosphere.

Health and Safety requirements for the pilot system were limited to safety glasses during routine operations. The tanks emitted an objectional odor during pilot system operations; however, monitoring of the breathing zone around the pilot system with a photoionization detector did not detect any VOCs.

In continuous operating mode, system operation was automated. In this mode, personnel attendance was not required, though system operation was checked daily.

Key Design Criteria

- The MTR Pervap™ Pilot System was supplied as a complete skid-mounted system. It required only an electrical source, a groundwater supply, and a permeate collection container to become operational. As supplied, it was capable of treating the equivalent of 1 gal/min of ground water in a continuous batch mode.
- The pilot system was constructed for use in a hazardous atmosphere. All metal components in the system were corrosion resistant (mainly stainless steel) and the electrical system was contained in explosion-proof housings. MTR chose this construction for universal application; not specifically for the Pinellas Plant.
- The only residuals produced by the pilot system were permeate, spent filters, and used membranes. The filters and permeate were disposed of as hazardous waste. The used membranes were returned to MTR.

Operating Parameters

System throughput and temperatures are adjustable, depending on the desired effluent concentration and contaminants being treated. For this application the following operating conditions were used:

- Average total VOC influent concentration was 1000 parts per million (ppm).
- Nominal system throughput is approximately 1 gpm (50 gal treated for 60 minutes).
- Nominal flow rate through the membrane modules was 13 to 15 gpm.
- System operating temperature used at Pinellas was 50 degrees C.
- The chiller temperature used at Pinellas was 5 degrees C.
- Permeate discharge for the Pinellas ground water was approximately 1,500 mL/batch. (30 L/day assuming continuous 24-hr operation, relatively constant influent VOC concentration, and 1-hr pervaporation cycle.)
- Electrical consumption was approximately 200 kWh/day.

5. REMEDIATION SYSTEM PERFORMANCE

To evaluate the performance and cost effectiveness of the pervaporation process, the MTR PerVap™ pilot-scale field system was operated at the site from July 1995 through February 1996. The following sections of this report present the details of the technology demonstration as they relate to cost and performance results of the PerVap™ pilot system for the treatment of VOC-contaminated ground water at the Pinellas Northeast Site.

Demonstration Objectives and Approach

The primary objectives of this demonstration were as follows:

1. to evaluate overall system performance in treating VOC contaminated ground water;
2. to evaluate environmental factors on system performance; and,
3. to determine expected full-scale ground water treatment costs.

The demonstration was coordinated by LMSC, the DOE site contractor for the Pinellas Plant, in cooperation with the ITRD Program and was designed to evaluate the overall cost and performance of the PerVap™ system. The PerVap™ Pilot System was connected to two ground water recovery wells, each producing 1 to 2 gpm of contaminated ground water. The two wells provided ground water contaminated with approximately 1000 ppm and 100 ppm volatile organics respectively. These wells represented the nominal range of ground water contamination levels at the Pinellas Northeast Site. The PerVap™ system was operated in batch mode with approximately 125 50-gal batches.

Performance Evaluation Criteria

Performance criteria considered in the approach for evaluating membrane separation technology included the following:

1. removal of VOCs from groundwater without the need for pretreatment;
2. removal of VOCs to concentrations low enough to permit discharge to the POTW (a permit requirement);
3. system operation without air emissions in excess of accepted standards; and
4. removal of ground water contaminants as a recyclable product.

The pilot system's performance was evaluated against the original anticipated pervaporation technology benefits:

1. greater than 99% removal of contaminants from the groundwater.
2. no pretreatment of groundwater required.
3. no air emissions were observed in excess of accepted standards.
4. contaminants recovered as a recyclable product.

The approach used to operate the pilot system was based on the goal of evaluating the system for application at the Pinellas Plant Northeast Site. The following three types of evaluations were conducted.

- The first was an initial check of efficiency to verify performance of the membranes. This check included verification of proper system operations, membrane performance, and determination of the appropriate automatic operation cycle

- The second evaluation was a mechanical evaluation that focused on the actual design and construction of the pilot system. Previous experience with treatment systems at the Pinellas Plant

has shown that precipitation will occur in an aerobic environment and will eventually result in fouling or flow restriction in a treatment system. Based on this experience, the pilot system was evaluated to determine capability of sustained performance without reduction from clogging or precipitation of dissolved metals from the groundwater.

- The third evaluation focused on the pilot system's ability to remove VOCs during continuous (24 hrs/day) operation. MTR supplied new membrane modules for the performance evaluation.

Performance Summary

Before operating the pervaporation treatment system in a continuous batch mode, LMSC and MTR performed a series of evaluations, included a filter evaluation and re-evaluation, a backwash evaluation, and an efficiency evaluation. Filter and backwash evaluations concentrated on varying the mesh size of the cloth filter between the surge tank and the feed/process tank. Flow pressure was measured both before and after the cloth filter. Initially, a 1-µm mesh was used. Very early in the evaluation, a pressure differential across the filter and a reddish brown sediment were recognized in the water, fouling the filter MTR suggested that the aeration involved in the filtration process was oxidizing the dissolved iron in the process ground water, resulting in precipitate or increased suspended solids. Because 80% of suspended particles in the Pinellas ground water are in the 10- to 15-µm range, the 1-µm mesh filter was replaced with a 10-µm mesh filter in order to improve the system flow. The initial efficiency evaluation of process water across the membranes consisted of a 20-hour batch test with sampling every 10 min. The greatest VOC reductions occurred in the first 60 min. Typical results are shown in Figures 8 and 9.

Subsequent performance evaluations designed to mimic full-scale operations were then conducted on a more or less continuous batch mode. The system operated in automatic mode for 1-hour pervaporation cycles. These evaluations included the addition of a hydrocyclone filter in front of the 10-µm cloth filter, and a cartridge filter was inserted between the heater and the first membrane. Initial VOC removal efficiency was very good, but it decreased with time.

A significant degree of membrane clogging occurred, likely the result of the oxidation of aqueous iron. The system shut down after 13 batches because of pressure buildup. The premembrane filter was replaced with coarser (20 to 100 µm) filters and the system was restarted. Over pressure shutdowns occurred again after 56 batches, then after 2 batches. Various acid washes and backflushes failed to solve the problems. The system was then operated with just the premembrane filter, but it rapidly shut down again because of pressure buildup.

Removal efficiencies during this phase were initially at a 90%+ level until the filters and membranes became clogged. Efficiency decreased to nearly zero as clogging of the membranes reduced the flow rate to as low as 5 gpm. During the tests, aqueous iron concentrations were measured. As much as 3 to 18 mg/L of iron were being removed from the ground water during each batch treatment. It became obvious that the system operation was oxidizing the iron in the ground water and causing the membranes to foul.

Several ground water pretreatment alternatives were identified and evaluated to eliminate the iron fouling problem. These included:

- replacing the air in the headspace of the surge and process tanks with nitrogen, thereby decreasing the oxidation of the water while it is in the tanks;
- adding muriatic acid to lower the pH of the process ground water to 3.5 to reduce precipitation;
- adding tetrapotassium pyrophosphate as a precipitate inhibitor;
- adding citric acid as a chelator to keep the iron in solution; and
- adding Nalco 8356-D as a dispersant to prevent precipitate deposition.

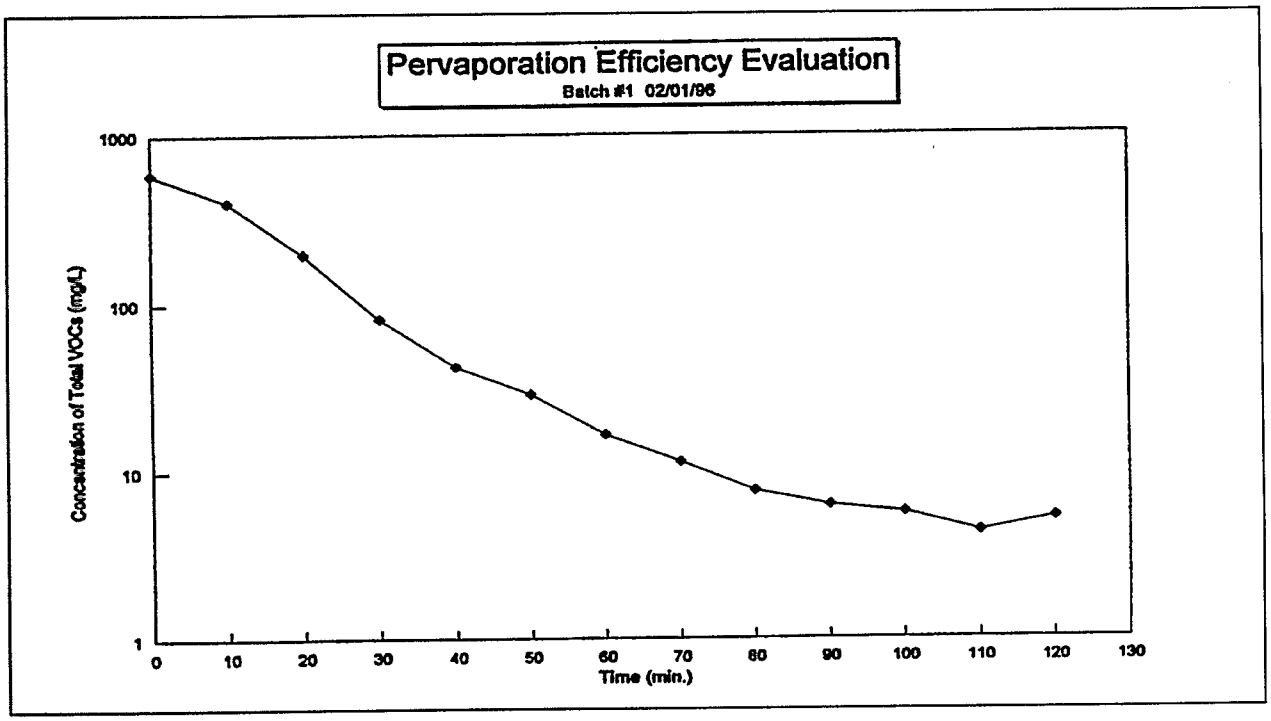


Figure 8. VOC Removal Batch #1.

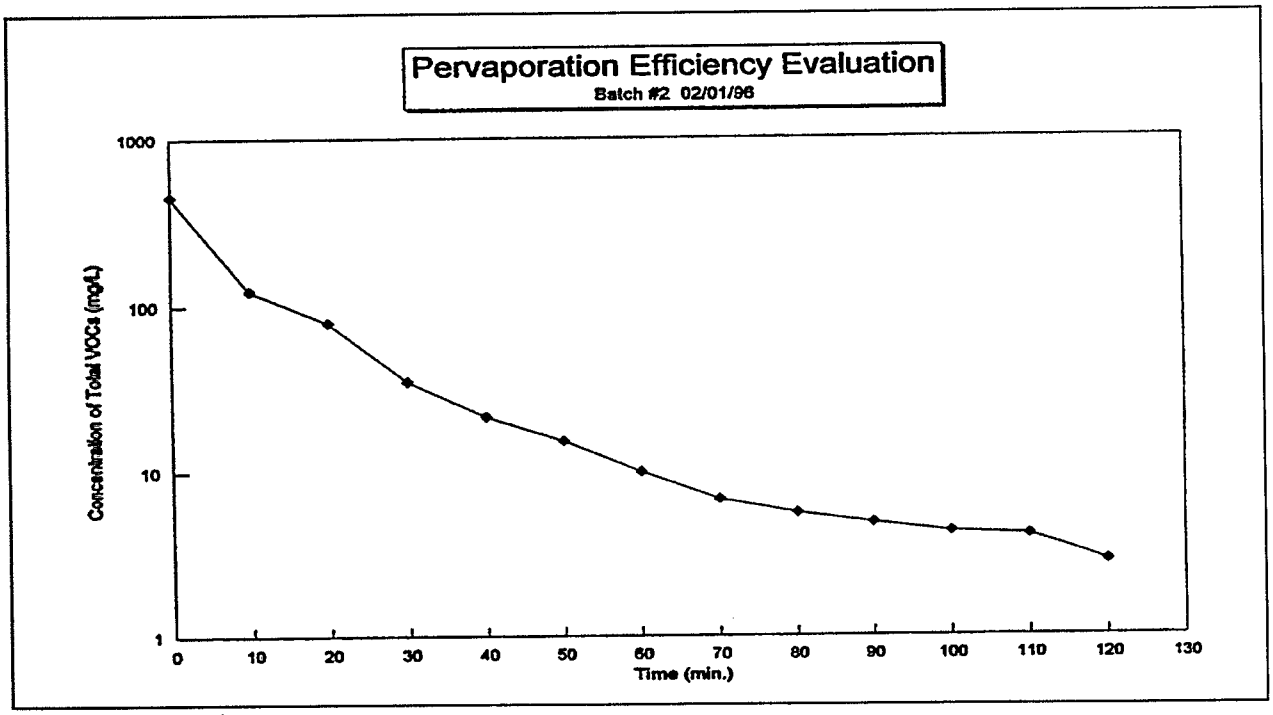


Figure 9. VOC Removal Batch #2.

Several batch operations were conducted to evaluate the alternatives, attempting to maintain high VOC removal rates but reduce the amount of iron being removed. In preliminary tests, nitrogen blanketing resulted in 83% removal of VOCs and 50% less removal of iron. Blanketing plus pH adjustment yielded similar results, but significant quantities of acid were required because of the buffering capacity of the Pinellas ground water. With precipitation inhibition, the results were 78% VOC removal and 88% less iron precipitation.

Efficiency evaluation testing using nitrogen blanketing and Nalco dispersant had the best results, with over 90% VOC removal and over 90% less iron precipitation. Unfortunately, the application of this dispersant and chelator at Pinellas was not compatible with existing ground water treatment systems at the plant. Therefore, it was decided to use nitrogen blanketing to see how well fouling could be reduced in continuous operations.

A mechanical evaluation was conducted to evaluate system performance for fouling/plugging of filters and membranes during continual, 24-hr/day operation, using nitrogen blanketing of the surge and feed tanks, 10-um filters between the tanks and before the first membrane, 70 degree C operating temperature, and a 2-hr pervaporation cycle time. After operating continously for 6.5 days and processing a total of 60 batches, the system continued to have filter fouling problems and showed less efficient overall VOC removal.

Table 3 summarizes design and operational performance data resulting from continuous system operation. The results show that pervaporation can remove VOCs from ground water at high efficiencies andconcentrate the contaminants in a permeate. However, the membranes are susceptible to fouling in certain geochemical conditions. Cost effective methods exist to reduce the fouling problems, but their applicability is subject to site specific requirements and constraints. The chemistry of the ground water to be treated must be fully evaluated before application of this technology can be considered at a site.

Table 3. Pervaporation pilot system performance summary

Performance goals	Values/results
Theoretical Pilot System Benefits • Greater than 99% removal of volatile organic compounds (VOCs from the ground water • No pretreatment of ground water • No air emissions	• Removal efficiencywas highly variable and did not maintain > 99% efficiency. • The POTW discharge limit was never achieved. (All effluent from the pilot system was treated by the existing ground water treatment system.). • Pretreatment of ground water was necessary because of membrane clogging from ground water percipitants. • No detectable air emissions occurred, although a very strong odor prevailed during operations. • Optimal operating parameters could not be established because of the highly variable removal efficiencies.
Compliance levels • Publicly Owned Treatment Works (POTW) discharge limit 850 ug/L total toxic organics (TTO)	• Influent concentrations ranged from approximately 500 to 1,000 mg/L total VOCs. • Effluent concentrations ranged from approximately 1 to 750 mg/L. During optimal conditions, the effluent concentrations were approximately 1 to 10mg/L. (Refer to Figs. 8 and 9 for typical VOC removal data.).
Quantity of ground water treated	• Approximately 125 batches or 6,250 gal.
Residuals	• Spent filters, clogged membranes, VOC permeate.
Quantity of material disposed	• Two 55-gal drums of spent filters, two 55-gal drums of permeate.

6. REMEDIATION SYSTEM COSTS

The pilot system supplied by MTR for evaluation at the Pinellas Plant was subcontracted by LMSC on a monthly fixed price basis. Under this subcontract, MTR agreed to supply the pilot system and engineering services at the following rates:

Cost for first month:	$ 5,000
Monthly cost thereafter:	$ 3,000/month for 8 months
Total cost:	$29,000

MTR provided the following engineering services, (1) during the first month, an engineer at the site to provide start-up assistance and training on the pilot system for 5 days, and (2) during the rest of the evaluation period, an engineer at the site 2 days per month to monitor the equipment and provide technical support.

The costs for the demonstration of the PerVap™ pilot system are shown in Table 4. The costs provided are based on accepted Federal Remediation Technologies Roundtable cost elements.

Table 4. Pinellas pervaporation system cost by interagency work breakdown structure

Cost element (with Interagency WBS Level 2 code)	Description	Costs ($)	Subtotals ($)
Pre-demo consultation	MTR visit & system inspection	1,500	1,500
Mobilization and preparatory work (33 01)	Shipping to Pinellas	1,500	22,478
	Site preparation (utilities, materials, etc.)	12,260	
	System installation and startup	8,718	
Monitoring, sampling, testing, and analysis (33 02)[a]	Sampling and analysis	30,000	30,000
Physical treatment (33 13)	Daily operations (50 days)	3,250	32,250
	Membranes	unknown	
	Subcontract costs	29,000	
Disposal (other than commercial) (33 18)	Spent filters	1,000	1,000
Demobilization (33 21)	Return shipment	1,500	1,500
Total cost			88,728

[a]Monitoring and sample analysis costs for this evaluation were very extensive. This cost is highly variable and depend on the number and frequency of contaminants analyzed.

The most important cost information in this evaluation are the expected capital and operating costs for a full-scale implementation. These costs will vary depending on the desired treatment volume and level. MTR submitted the cost of a full-scale as part of the pilot system evaluation. The specifications for this system are as follows:

- design feed flow: 20 gpm
- design organics concentration in: 400 ppm total VOCs of which 250 ppm is methylene chloride
- design organics concentration out: <850 µg/L TTO, and
- capital costs: $250,000 ±20%, operating costs: $.01/gal.

The maximum site discharge to the POTW is 850 µg/L TTO. This price does not include a 2,000 gal surge tank, a 1,000-gal feed tank, local site setup, or utility connection costs; they would be supplied locally.

During the evaluation of the pilot system the unit operating costs for the ground water treated varied between $.01-$.015/gal during continuous operations. These values suggest that during full scale operations the projected operating costs suggested by MTR will indeed be attainable, provided fouling of the membranes is controlled.

7. REGULATORY/INSTITUTIONAL ISSUES

In July 1993, the DOE, EPA, the Florida Department of Environmental Protection (FDEP), and LMSC entered into an agreement with the ITRD Program to evaluate innovative technologies to remediate ground water contamination at the Pinellas Plant Northeast Site effectively and expeditiously.

Because the membrane separation demonstration was performed at an existing SWMU, no additional permitting or regulatory requirements were applicable. Ground water monitoring reports for the Northeast Site are submitted quarterly to FDEP and EPA Region IV. For each quarterly report submitted during the performance period of the demonstration, a description of the membrane separation demonstration activities was provided thus agencies were made aware of the progress of the demonstration.

Effluent from the membrane separation demonstration was expected to meet the requirements of the Pinellas Plant's Industrial Wastewater Discharge Permit. According to this permit, the limit for TTO is 0.850 mg/l for disposal in the Pinellas County Sewer System (PCSS). (Because it was not initially known if the effluent from the membrane separation demonstration would exceeded this limit, the effluent was disposed with ground water that is normally treated in the plant's ground water treatment system.

No air permitting or air permit modifications were necessary to support this demonstration. Cleanup criteria for groundwater at the Northeast Site are the FDEP maximum contaminant levels and are listed in Table 6.

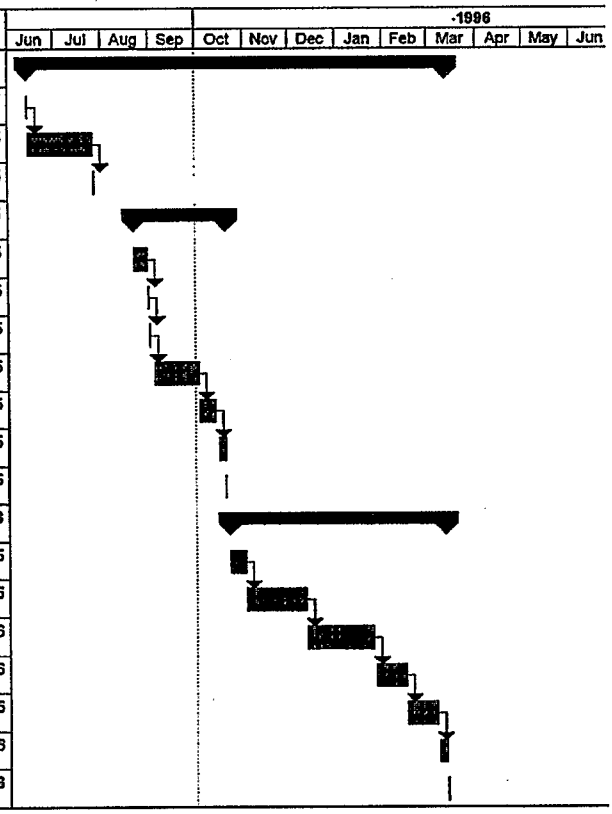
No air permitting or air permit modifications were necessary to support this demonstration.

8. SCHEDULE

The demonstration an devaluation of the pervaporation pilot system at the Pinellas Plant, the associated tasks, and schedule for each task are provided below.

Pinellas Plant Pervaporation Pilot Study

ID	Task Name	Start	Finish
1	Pervaporation Pilot Study	6/14/95	3/12/96
2	System arrival	6/14/95	6/14/95
3	System setup & initial operation	6/15/95	7/26/95
4	Initial Efficiency Evaluation	7/27/95	7/27/95
5	Mechanical Evaluation	8/22/95	10/20/95
6	Filter Evaluation	8/22/95	8/30/95
7	Front End Plumbing Mod.s	8/31/95	8/31/95
8	Filter Re-evaluation	9/1/95	9/1/95
9	Plumbing Modifications	9/4/95	10/2/95
10	Backwash Evaluation	10/3/95	10/13/95
11	Back End Plumbing Mod.s	10/16/95	10/20/95
12	Membrane Changeout	10/20/95	10/20/95
13	Performance Evaluation	10/23/95	3/11/96
14	Auto-mode Operation	10/23/95	11/1/95
15	Progress Evaluation by ITRD	11/2/95	12/11/95
16	Pretreatment Evaluation	12/12/95	1/24/96
17	Auto-mode Operation	1/26/96	2/14/96
18	Nitrogen Blanketing addition	2/15/96	3/5/96
19	Auto-mode Operation	3/7/96	3/11/96
20	System Shut-off & Decon.	3/12/96	3/12/96



9. OBSERVATIONS AND LESSONS LEARNED

Cost Observations and Lessons Learned

The major cost item for the pilot system was sampling and analysis, particularly the laboratory analytical cost, which was reflective of (1) the need to have an accelerated analysis time (3–5 days) to stay abreast of system efficiency, and (2) the number of analytes monitored (EPA 8240A suite). If problems with clogging and efficiency had not occurred, it might have been possible to relax the accelerated analysis time. In addition, less contaminants of concern would have lowered analytical costs.

A limited analysis of direct operating costs for this technology shows that the system can provide cost-effective ground water treatment provided the chemistry of the water is compatible with the system.

Performance Observations and Lessons Learned

The demonstration provided adequate analytical and operations data with which to evaluate the applicability of the MTR PerVap™ Pilot System for remediation of VOC contaminated ground water. Initial operational tests indicated that organic removal efficiencies of 90–99% could be achieved with the pilot system. Batch mode operation allowed 50 gal of ground water at contamination levels as high as 1,000 ppm total VOCs to be reduced to 2 to 3 ppm total VOCs in as little as two hours of treatment.

However, major problems developed during continuous batch operation of the system at the Pinellas Northeast Site because of fouling of the membranes by precipitated iron. Attempts to reduce this fouling through the modification of system operation and some chemical additives met with limited success at the Northeast Site. During continuous batch operation, contaminant concentrations could generally be reduced below 4 to 5 ppm total VOCs.

Summary

Base on the results of the demonstration, the MTR PerVap™ system is an innovative technology capable of providing ex-situ treatment of VOC-contaminated ground water, assuming there is no compatibility problems between the system and the ground water. At the Pinellas Plant, the PerVap™ system was incompatible with the ground water and the results were a major impact on system operations and performance. Because of these impacts, the PerVap™ system failed to meet the theoretical benefits and objectives of the technology demonstration for the Pinellas Plant.

10. REFERENCES

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6. *Corrective Measures Study Report, Northeast Site, Pinellas Plant, Largo, Florida,* U. S. Department of Energy, Environmental Restoration Program, Albuquerque Field Office, Albuquerque, N. M. 1993.

"This analysis accurately reflects the performance and costs of the remediation."

David S. Ingle 10-22-97

David S. Ingle, Pinellas Area Office
U.S. Department of Energy

Mike Hightower

Mike Hightower, Technical Coordinator
Innovative Treatment Remediation Demonstration Program
Sandia National Laboratories

Department of Environmental Protection

Lawton Chiles
Governor

Twin Towers Building
2600 Blair Stone Road
Tallahassee, Florida 32399-2400

Virginia B. Wetherell
Secretary

June 2, 1997

Mr. David S. Ingle
Albuquerque Operations Office
Pinellass Area Office
Post Office Box 2900
Largo, Florida 34649

Dear Mr. Ingle:

Jim Crane, John Armstrong and I have reviewed the "Cost and Performance Report, Innovative Treatment Remediation Demonstration, PerVap Membrane Separation Ground Water Treatment, Pinellas Plant Northeast Site" final draft dated April 15, 1997. We concur with the purpose of the report. Unless the EPA or other parties desire modifications, we recommend that the report proceed to "final" designation.

If I can be of any further assistance with this matter, please do not hesitate to contact me at 904/921-9999.

Sincerely,

Eric S. Nuzie
Federal Facilities Coordinator

ESN/sr

cc: Jim Crane, FDEP Technical Review Section
John Armstrong, FDEP Technical Review Section
Bill Kutash, FDEP Southwest District
Carl Froede, US EPA Region 4

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The United States Department of Energy
Pinellas Plant
Attn: Mr. David Ingle
P.O. Box 2900
Largo, FL 34649

SUBJ: Cost and Performance Reports for the:
1) Dual Auger Rotary Steam Stripping Technology, and
2) Pervap Membrane Separation Technology
Demonstrations at the Northeast Site
DOE Pinellas Plant, FL
EPA I.D. Number FL6 890 090 008

Dear Mr. Ingle:

The Environmental Protection Agency (EPA), Region 4, has completed our review of the above referenced documents. Both of these reports appear to accurately convey information gathered by the Innovative Treatment Remediation Demonstration (ITRD) Team for the two different technologies that were demonstrated on the small scale at the Northeast site.

The activities associated with the Northeast Site under the direction of the ITRD have been very important to the Agency because the successful demonstration of the various technologies would ultimately lead to a remedy selection for this solid waste management unit. Additionally, the information gained from these activities is valuable in determining the cost/benefit of using these innovative technologies at other sites. EPA remains committed to working with the Department of Energy (DOE) at the former Pinellas Plant to document the success of these technology demonstrations, for a final remedy selection at this site, and eventually facility restoration.

If you have any questions regarding the ITRD at the Northeast Site then please contact me at (404) 562-8550.

Sincerely,

Carl R. Froede Jr.

Carl R. Froede Jr., P.G.
DOE Remedial Section
Federal Facilities Branch
Waste Management Division

cc: Eric Nuzie, FDEP
Jim Crane, FDEP

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Pump and Treat, In Situ Bioremediation, and In Situ Air Sparging of Contaminated Groundwater at Site A, Long Island, New York

Pump and Treat, In Situ Bioremediation, and In Situ Air Sparging of Contaminated Groundwater at Site A, Long Island, New York

Site Name: Site A (actual name confidential)	**Contaminants:** Volatiles - nonhalogenated (BTEX) - Maximum initial concentrations were benzene (430 ug/L), toluene (350,000 ug/L), ethylbenzene (5,600 ug/L), and xylenes (45,000 ug/L)	**Period of Operation:** Status: Ongoing Report covers: 7/95 - 10/96
Location: Long Island, New York		**Cleanup Type:** Full-scale cleanup (interim results)
Vendor: Treatment System Vendor: RETEC Associates Site Management: RETEC Associates (1993-1997) Land Tech Remedial, Inc. (1997-present)	**Technology:** Pump and Treat; In Situ Bioremediation; Air Sparging, Soil Vapor Extraction - Groundwater was extracted using 5 wells, located on site, at an average total pumping rate of 18 gpm - Extracted groundwater was treated with air stripping and gravity separation - Nutrients were added to the treated water to adjust nitrogen and phosphorus levels, and then the water is reinjected into the aquifer through a reinjection trench located upgradient of the plume - Air was injected through 44 sparging wells at points approximately 10 ft below the water table, in a pulsed system operation, and effluent vapors are collected with 20 SVE wells (16 vertical and 4 horizontal)	**Cleanup Authority:** CERCLA Remedial - ROD Date: 6/24/91
State Point of Contact: Carl Hoffman New York State DEC Bureau of Hazardous Site Control 50 Wolf Road Albany, NY 13323-7010		**EPA Point of Contact:** Maria Jon, RPM U.S. EPA Region 2 290 Broadway, 19th Floor New York, NY 10007-1866 (212) 637-3967
Site Contact: Stephen Hoelsher Phillips Petroleum 13 DI Phillips Bldg Bartlesville, OK 74004 (918) 661-3769		
Waste Source: Leaking drums and spills of petroleum and solvent materials	**Type/Quantity of Media Treated:** Groundwater - 8.4 million gallons treated as of October 1996 - LNAPL observed in several monitoring wells on site - Groundwater is found at 15-18 ft bgs - Extraction wells are located in 1 aquifer, which is influenced by a nearby surface water - Hydraulic conductivity reported as 53.5 ft/day	
Purpose/Significance of Application: Relatively high unit cost; system included groundwater extraction, air sparging, and SVE wells.		

Pump and Treat, In Situ Bioremediation, and In Situ Air Sparging of Contaminated Groundwater at Site A, Long Island, New York (continued)

Regulatory Requirements/Cleanup Goals:

- Remediate the groundwater to meet maximum contaminant levels (MCLs) established by the NYSDEC, which are the primary drinking water standards.
- Cleanup goals were established for benzene (0.0007 mg/L), toluene (0.005 mg/L), ethylbenzene (0.005 mg/L), and xylene (0.005 mg/L).
- A primary goal of the extraction system is to contain the contaminant plume and prevent it from discharging to the harbor; the goal is for both horizontal and vertical containment.
- A primary performance goal for in situ bioremediation is to maintain specified levels for pH, nitrogen, phosphorus, and DO.

Results:

- Maximum BTEX levels have declined from 153 to 27 mg/L; however, cleanup goals have not been met. Monitoring data from 1997 indicate that elevated BTEX levels persist in wells along the western portion of the site.
- Plume containment appears to have been achieved, and performance standards were generally met for nitrogen, phosphorus, and DO; there were several exceptions where nitrogen, phosphorus, and DO were outside the specified ranges.
- From July 1995 to July 1996, the system removed approximately 5,314 pounds of BTEX from the groundwater (air sparging removed approximately 85% of the BTEX and P&T the remaining 15%).

Cost:

- Actual costs for the treatment system were approximately $1,941,560 ($1,503,133 in capital and $358,427 in O&M), which correspond to $200 per 1,000 gallons of groundwater extracted and $365 per pound of contaminant removed.

Description:

Site A operated as a petroleum bulking facility from 1939 until 1980, and it operated as a petroleum bulking and chemical mixing facility from 1980 to 1984. In 1984, in response to a toluene spill, EPA and the NYSDEC investigated the site, and discovered contamination by organics and metals in the soil, and organics in the groundwater, surface water, and air. The site was placed on the NPL in June 1986 and a ROD was signed in June 1991.

The groundwater extraction system consists of five wells installed in the areas of highest contamination within the plume, all screened at depths of approximately 10 ft below the water table. One well was placed in an area where free-phase BTEX product was observed in the western portion of the site. Extracted groundwater is treated with air stripping. After stripping, water is treated through pH adjustment and addition of nutrients, and then re-injected into the aquifer. In addition, oxygen is injected into the aquifer through 44 air sparging points. Effluent vapors from the sparging points are collected by 20 SVE wells.

Groundwater cleanup goals for this site have not been met after two years and three months of operation. However, the remedy has contained the plume, reduced average BTEX concentrations, and recovered free-phase product.

SITE INFORMATION

Identifying Information:

Site A, Recycling Facility
Long Island, New York
(Site name is confidential)

CERCLIS #: Confidential

ROD Date: June 24, 1991

Treatment Application:

Type of Action: Remedial

Period of operation: 07/95 - Ongoing
(Mass removal data collected through October 1996)
(Monitoring data collected through October 1997)

Quantity of material treated during application: 10,130,200 gallons through October 1997

Background

Historical Activity that Generated Contamination at the Site: Petroleum bulk storage, chemical bulk storage, chemical mixing, and chemical waste storage

Corresponding SIC Codes: 4226 (petroleum and chemical bulk stations) and 5169 (chemicals and allied products)

Waste Management Practice That Contributed to Contamination: Leaking drums and spills of petroleum and solvent materials

Location: Long Island, NY

Facility Operations: [1,5,7]

- Site A operated as a petroleum bulking facility from 1939 until 1980, and it operated as a petroleum bulking and chemical mixing facility from 1980 to 1984. In 1984, operations ceased when the tenant was evicted by the landlord. The site is adjacent to a harbor.
- In 1984, in response to a toluene spill, the EPA and the New York State Department of Environmental Conservation (NYSDEC) investigated the site. They discovered organics and metals in the soil and organics contamination in the groundwater, surface water, and air. An unknown volume of petroleum products, solvents, and other hazardous waste was released to the soil, groundwater, and surface water via spills and leaks.
- The current site owner was required to remove 255 of 410 on-site drums containing hazardous waste. In 1986, the state removed an additional 700,000 gallons of hazardous waste-containing sludges and drums, including sludge containing polychlorinated biphenyl (PCB) from a tank.
- In June 1986, the site was placed on the National Priorities List (NPL).
- Remedial investigations were performed from 1987 until 1992. Visibly contaminated soils and drums were removed. The investigation found benzene, toluene, ethylbenzene, and xylenes (BTEX). Other contaminants were detected but at concentrations below action levels. The remaining BTEX contamination in the soil and groundwater was left to be addressed through full-scale remediation. Community meetings were held during this time to hear public concern.
- During remedial construction activities in 1995, underground storage tanks were discovered. The tanks contained more sources of BTEX. The tanks were removed, and the contaminant plume was redefined to include this additional area.

Regulatory Context:

- On June 24, 1991, the Record of Decision (ROD) for the site was signed.

SITE INFORMATION (CONT.)

Background (Cont.)

- In 1992, a Consent Decree was entered into which named potentially responsible parties (PRPs). The decree established that remedial operations would be funded by the PRPs for the first six years of operation or until $1.75 million over and above the sums in a PRP trustfund had been spent, at which point the NYSDEC would assume the costs.
- Site activities are conducted under provisions of the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), §121, and the National Contingency Plan (NCP), 40 CFR 300.

Remedy Selection: Extraction and treatment of the groundwater, reinjection of nutrient-enriched, treated groundwater to promote *in situ* bioremediation, *in situ* air sparging, and thermal oxidation of effluent vapors was selected for groundwater remediation based on treatability study results. Soil vapor extraction was selected as the soil remediation remedy, to be used in conjunction with the groundwater remediation system.

Site Logistics/Contacts

Site Lead: State

Oversight: EPA

Remedial Project Manager:
Maria Jon
U.S. EPA Region 2
290 Broadway
New York, NY 10007-1866
(212) 637-3967

State Contact:
Carl Hoffman*
New York State Department of Environmental Conservation
Bureau of Hazardous Site Control
50 Wolf Road
Albany, New York 13323-7010

*Indicates primary contacts

Treatment System Vendor:
RETEC Associates

Site Management:
Land Tech Remedial, Inc. (1997-Present)
RETEC Associates, Inc. (1993-1997)

Site Contact:
Stephen Hoelsher*
Phillips Petroleum
13 DI Phillips Bldg
Bartlesville, OK 74004
(918) 661-3769

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater and Vadose Zone Vapors

MATRIX DESCRIPTION (CONT.)

Contaminant Characterization [1,4,5,6]

Primary Contaminant Groups: Volatile organic contaminants

- The groundwater contaminants of concern at the site are benzene, toluene, ethylbenzene, and xylene (BTEX). Other chlorinated volatile organic compounds (CVOCs) and semi-volatile organic compounds (SVOCs) were detected in the groundwater, but at concentrations below action levels.
- The maximum initial concentrations detected in the groundwater were benzene (0.43 mg/L), toluene (350 mg/L), ethylbenzene (5.6 mg/L), and xylene (45 mg/L).
- RETEC, the former site engineers, confirmed the presence of a light nonaqueous phase liquid (LNAPL) when BTEX product was observed in wells on site.
- Figure 1 illustrates the site layout and distribution of contaminant concentrations detected during a 1993 sampling event. A plume map was not available for this site.
- As illustrated in Figure 1, the most elevated BTEX groundwater contamination was primarily detected in the central and western portions of the site. The maximum total BTEX concentration was 299 mg/L detected in 1993 along the western portion of the site. The maximum total BTEX concentration detected in the central portion of the site was 12 mg/L.

Matrix Characteristics Affecting Treatment Costs or Performance [1,5,6]

Hydrogeology:

Three hydrogeologic units have been identified beneath this site.

Level A	Level A is composed of sandy soil and varies in thickness from two feet to 28 feet. It is hydraulically connected to the underlying level, Level B.
Level B	Level B is composed of sand and gravel, with lenses of silt and clay. It varies from 0 to 33 feet of thickness and is hydraulically connected to the underlying level, Level C.
Level C	Level C is composed of sand and varies in thickness from 22 to 55 feet.

The groundwater at the site flows generally to the west, discharging to the harbor. The groundwater flow is tidally influenced in the upper few feet of Level A. Underneath the three units is a clay layer at least five feet in thickness; it is not known if this layer is continuous throughout the site.

At this time contamination has been detected only in the upper 10 feet of groundwater, in Level A. Site engineers have concluded that BTEX contamination has been hydraulically contained in the upper 10 feet of aquifer.

The topography at the site is varied. The elevation of the southwest portion of the site is approximately five feet above mean sea level. The northeast portion of the site, the upper site area, is a hill which reaches a peak elevation of approximately ten feet above mean sea level. A 15-foot berm encloses the top of the hill. Rainfall recharge to the bermed area was determined to cause local mounding of the water table. The water table in the hill area is encountered at depths of 15 to 18 feet below ground surface. In the southwestern portion of the site, the lower site area, the water table is encountered at depths of approximately 8 to 10 feet below ground surface. The water table level in the lower area of the site is tidally influenced. Water levels in the lower site area have risen and flooded soil vapor extraction wells.

MATRIX DESCRIPTION (CONT.)

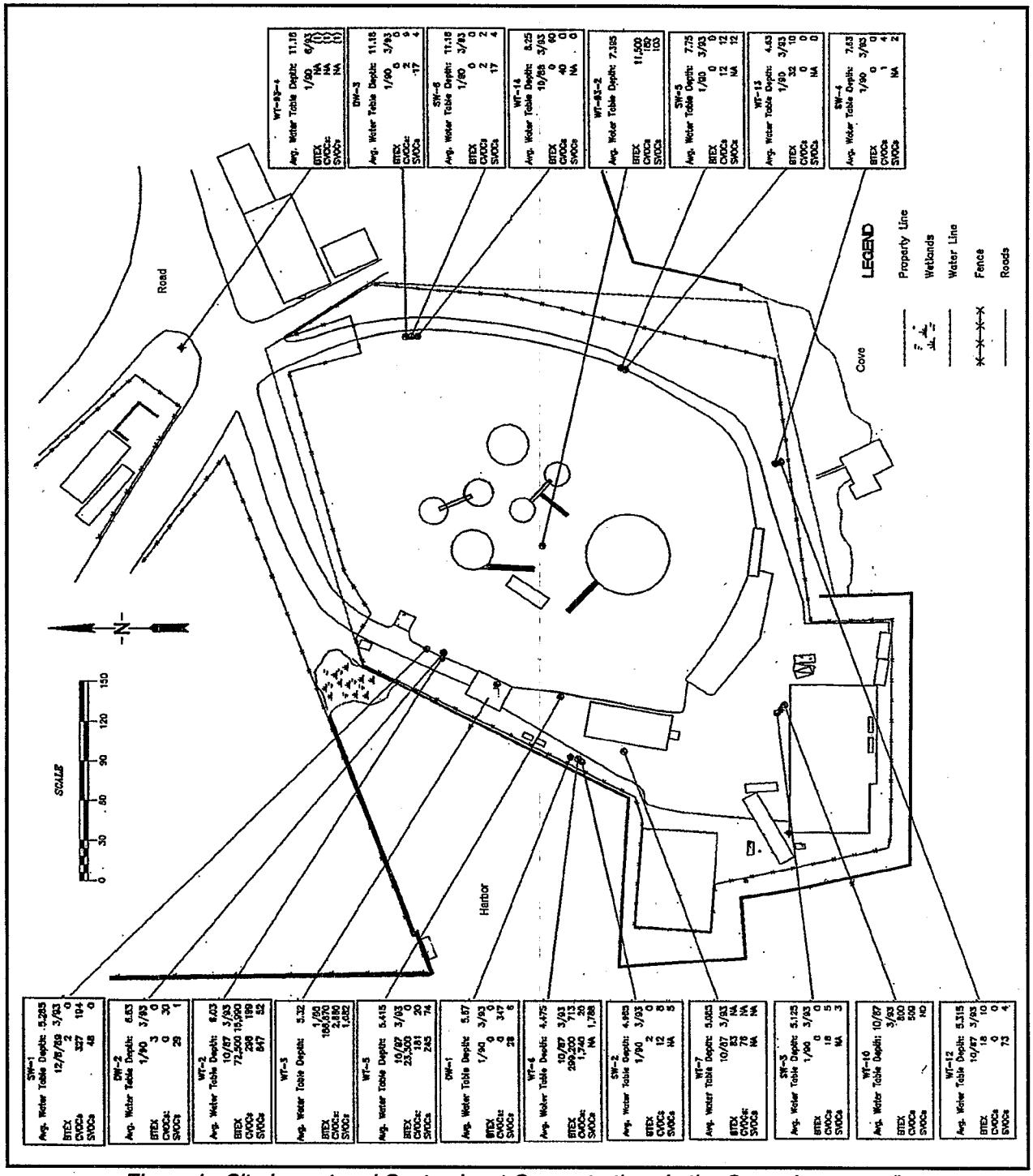

Figure 1. Site Layout and Contaminant Concentrations in the Groundwater, µg/L (1993, Best Copy Available) [5]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Costs or Performance (Cont.)

Tables 1 and 2 present technical aquifer information and well data, respectively.

Table 1. Technical Aquifer Information

Unit Name	Thickness (ft)	Conductivity (ft/day)	Average Velocity (ft/day)	Horizontal Flow Direction
Level A	2-28	53.5	1.80	West[a]
Level B	0-33	53.5	1.80	West
Level C	22-55	53.5	1.80	West

[a] Groundwater flow is tidally influenced in Level A but generally flows to the west and discharges into the harbor.

Source: [5,6]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

Pump and treat (P&T) with air stripping, *in situ* bioremediation, *in situ* air sparging, and soil vapor extraction (SVE).

Supplemental Treatment Technology

Nutrient addition and pH adjustment of liquid-phase effluent prior to reinjection and thermal oxidation of all system effluent vapor streams.

System Description and Operation [2,3,6,8]

Table 2. Extraction Well Data

Well Name	Unit Name	Screen Depth Below Water Table (ft)	Design Yield (gal/min)
GWX-0	Level A	10	1-3
GWX-1	Level A	10	1-3
GWX-2	Level A	10	6-8
GWX-3	Level A	10	1-3
GWX-4	Level A	10	1-3

Source: [5,6]

System Description

- The groundwater extraction system consists of five wells installed in the plume, all screened at depths of approximately ten feet below the water table. Table 2 presents extraction well data. Wells were placed in the areas of highest contamination. Groundwater is continuously withdrawn from the shallow aquifer, Level A, and treated through an air stripper. From 1995 to 1996, RETEC calculated that the system operated at an overall average extraction rate of 18 gpm, based on the actual volume of water treated.
- Well GWX-2 was placed in an area where free-phase BTEX product was observed in the western portion of the site. The extraction rate from GWX-2 was designed to be 6-8 gpm, greater than the 1-3 gpm design extraction rate for the other four wells. The elevated extraction rate in well GWX-2 promoted recovery of free-phase BTEX as well as recovery of the more highly contaminated part of the plume.

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

- The treatment system consists of a feed holding tank, a low profile air stripper, gravity separation tanks, effluent storage tanks, and a sand filter.
- The feed holding tank regulates groundwater flow to the air stripper from the extraction wells. The extracted water is fed to the air stripper at a constant rate of 18 gpm through a pipe located at the bottom of the tank.
- The air stripper is a stacked, stainless steel tray tower, consisting of four trays stacked 77 inches high. Each tray is 44 inches wide and 32 inches deep. Countercurrent flows of air and water are sent through the air stripper.
- Effluent from the air stripper passes through gravity separation/effluent storage tanks. Metals (at levels below concern) and particulate matter are gravity separated and filtered into a sludge. The sludge is pumped out for eventual off-site disposal. The remaining water is then treated for reinjection.
- The water is treated to promote *in situ* bioremediation when reinjected. The pH of the water is adjusted in the effluent storage tank. Treated water is then pumped through a sand filter, and nutrients are added to adjust the nitrogen and phosphorous levels.
- The treated water is reinjected into the aquifer through a reinjection trench located upgradient of the plume.
- Enhanced *in situ* bioremediation is achieved by adding nutrients at the reinjection point and supplying oxygen through air sparging points. BTEX compounds are biodegraded to end products of carbon dioxide and water by heterotrophic organisms (refer to later discussion under Performance Data Assessment, regarding heterotrophs)
- Pilot tests determined that optimal conditions for BTEX degrading organisms include a pH between 6.0 and 8.0 and nitrogen and phosphorus levels between 1 and 5 mg/L each. Target dissolved oxygen levels are between 2 and 8 mg/L.
- The SVE and air sparging systems are composed of air sparging and SVE wells. Air is injected through 44 sparging wells at points approximately 10 feet below the water table. The sparging system is pulsed at a system interval time of one day on two days off and at a period time of two hours on and one hour off.
- The effluent vapors from the sparging points are collected by 20 SVE wells. The SVE wells, 14 vertical and six horizontal, were placed in the vadose zone, a few feet above the water table. In the upper site area, the 16 vertical vapor extraction wells were placed at an average a depth of 12 feet. In the lower site area, the six horizontal vapor extraction wells were placed approximately six to eight feet deep. Horizontal wells were used in the lower site area because the groundwater is shallow.
- The SVE wells in the lower site area occasionally become flooded because groundwater levels are tidally influenced. These SVE wells are equipped with water level detectors which automatically shut off the wells to protect the system from taking in water. When water levels rise, only the affected wells are shutdown while the remainder of the SVE system continues to operate.
- The lower area of the site is paved to seal out atmospheric vapors from the SVE system and to further extend the radius of influence of the horizontal vapor extraction lines.
- The effluent vapors from the SVE system and from the air stripping tower pass through a thermal oxidation unit to destroy the VOCs before discharge to the atmosphere.
- Groundwater quality is monitored quarterly through a combination of five extraction wells, two air sparging wells, and three shallow monitoring wells. The air sparging/SVE system performance is

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation (Cont.)

monitored quarterly by analyzing soil vapor in 20 vapor extraction wells and five vapor monitoring points. The vapor-phase loading to the thermal oxidation unit and the effluent to the thermal oxidation unit is monitored on a monthly basis.

System Operation

- Quantity of groundwater pumped from the aquifer in gallons:

Year	Volume Pumped (gal)
July 1995 - July 1996	1,550,000
August 1996 - July 1997	6,730,000
August 1997 - October 1997	305,000

- Since September 1995, the P&T system has operated approximately 75% of the time. Problems during startup, primarily iron clogging in the injection wells, caused the low operation rate. Iron levels decreased after the first month of operation, and well clogging is no longer a problem. Currently, the treatment system is shut down on a weekly basis to clean the extraction wells and backflush the sand filter.

- The *in situ* air sparging and SVE system has been operational approximately 90% of the time.

- Nutrients, in the form of ammonium chloride, monopotassium phosphate, and dipotassium phosphate, are dissolved in batches and added to the effluent tank approximately every two weeks.

- The original air sparging and SVE system was expanded in September 1995 to address the underground storage tank contamination detected during demolition activities. Five air sparging wells and two SVE wells were added in the lower site area; two additional air sparging wells were added in July 1996. The air sparging and SVE system described under System Description reflects this expansion.

- LNAPL was visually observed in the air stripper influent holding tank in 1995 and 1996. Groundwater to be treated is fed from the bottom of the tank to avoid treating the LNAPL through the stripper. The free product was vacuumed into a wastewater truck for off-site disposal. The amount of free product recovered was not monitored, but the RETEC site contact estimated that approximately 40 gallons of free product were recovered in 1995 and 1996. No product was observed in 1997.

Parameters Affecting Treatment Cost or Performance

The major operating parameters affecting cost or performance for the technologies used at this site are listed in Table 3.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Parameters Affecting Treatment Cost or Performance (Cont.)

Table 3: Performance Parameters

Parameter	Value
Average P&T Extraction Rate	18 gpm (design)
Soil Vapor Extraction Vacuum Rate	660 scfm (design)
System Sparge Rate	330 scfm (design)
Performance Standards for *In Situ Bioremediation*	6.0 < pH < 8.0 1 mg/L < Nitrogen < 5 mg/L 1 mg/L < Phosphorus < 5 mg/L 2 mg/L < Dissolved Oxygen < 8 mg/L
Performance Standards for P&T Reinjection (Primary Drinking Water Standards)	benzene 0.0007 mg/L toluene 0.005 mg/L ethylbenzene 0.005 mg/L xylene 0.005 mg/L
Remedial Goals (aquifer)	NYSDEC Primary Drinking Water Standards (see above)

Source: [2, 3]

Timeline

Table 4 presents a timeline for this remedial project.

Table 4: Project Timeline

Start Date	End Date	Activity
6/10/86	---	Site listed on NPL
1987	1991	Remedial Investigation and Feasibility Study performed
06/91	---	Record of Decision signed
06/92	---	Consent Judgment entered into
09/92	---	Pre-Remedial & Remedial Design Activities begin
03/94	---	Remedial Design Approved by New York State Department of Environmental Conservation
05/94	---	Site structures decommissioned and demolished
08/94	07/95	Remedial system constructed
---	07/95	System begins operation and quarterly monitoring begins
09/95	---	Extraction system is expanded
7/96	---	Additional air sparging wells added

Source: [1, 2]

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards

The groundwater cleanup goal for this site is to remediate the groundwater to meet the Maximum Contaminant Levels (MCL) established by the NYSDEC, which are the Primary Drinking Water Standards. The cleanup goals are listed in Table 3 and are applied throughout the aquifer, as measured in all on-site monitoring wells [1].

Treatment Performance Goals [1,2]

- The primary performance goal of the extraction system is to contain the contaminant plume and prevent it from discharging to the harbor. The goal is both horizontal and vertical containment.
- The primary performance goal of the treatment system is to reduce BTEX concentrations to the performance standards listed in Table 3.
- The primary performance goal regarding *in situ* bioremediation is to maintain a pH level between 6.0 and 8.0, nitrogen and phosphorous levels between 1 and 5 mg/L, and dissolved oxygen levels between 2 and 8 mg/L.
- The primary performance goals of the air sparging system are to sparge at the minimum rate needed to achieve BTEX removal and to maintain a dissolved oxygen level between 2 and 8 mg/L to promote *in situ* bioremediation.

Performance Data Assessment [3,4,6,8]

Total BTEX includes benzene, toluene, ethylbenzene, and total xylenes.

- Maximum BTEX levels have declined from 153 mg/L to 27 mg/L, a reduction of 82 percent. However, cleanup goals have not been met at this site [3]. Monitoring data in 1997 indicate elevated BTEX levels persist in wells along the western portion of the site.
- Figure 2 illustrates that, overall, average BTEX levels have been reduced from 0.160 to 0.026 mg/L. Average concentrations of individual constituents were reduced to 0.0008 mg/L (benzene), 0.002 mg/L (toluene), 0.001 mg/L (ethylbenzene), and 0.01 mg/L (xylene). However, the October 1997 sampling event revealed maximum benzene levels of 0.008 mg/L, maximum toluene levels of 14.0 mg/L, maximum ethylbenzene levels of 0.018 mg/L, and maximum xylenes levels of 13.4 mg/L, all above cleanup goals.
- Containment of the plume appears to have been achieved based on quarterly groundwater monitoring results.
- For the enhanced *in situ* bioremediation, performance standards for nitrogen were met from July 1995 to July 1997. During that time, average monthly nitrogen levels were between 2 and 5 mg/L. However, from July 1996 to October 1996, nitrogen levels were above the 5 mg/L performance standard.
- For the enhanced *in situ* bioremediation, performance standards for phosphorous were met from June to October 1997. During this time, average phosphorus levels were at 1 mg/L. However, from July 1995 through May 1996, average phosphorus levels were below the 1 mg/L performance standard.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment (Cont.)

- For the enhanced *in situ* bioremediation, performance standards for dissolved oxygen were met from July 1995 through March 1996 and from August 1996 through October 1997. During this time, average dissolved oxygen levels were between 2.0 and 8.0 mg/L. However, from April 1996 through July 1996, dissolved oxygen levels were below the 2.0 mg/L performance standard.

- Between July 1995 and July 1996, approximately 8,845,200 gallons of groundwater passed through the air stripper. Based on computer model results which accounted for location of air sparging points and groundwater flow, RETEC approximated that the air-sparging/SVE system treats approximately 686,000 gallons per year. Based on those values, the total volume of groundwater treated through both the P&T and air sparging systems between July 1995 to October 1996 was 9,703,500 gallons.

- Figure 3 presents the removal of BTEX by the P&T and air sparging treatment systems from July 1995 to October 1996. From July 1995 to July 1996, the P&T system and the air sparging system have removed approximately 5,314 pounds of BTEX from the groundwater. The contaminant mass removed by the SVE system is not included in this estimate because this report addresses the groundwater remedy, not the soil remedy.

- In addition to the contaminant removal illustrated in Figure 3, the *in situ* bioremediation is believed to provide continuous treatment of a portion of the plume. The mass of contamination degraded through bioremediation is not measured directly. However, the site operators measure the number of heterotrophs in the groundwater. Monitoring data has shown that the population of heterotrophs has been sustained.

- The mass of free product recovered by the extraction system is not included in Figure 3.

- According to measurements performed by RETEC (see next section), the air sparging system removed approximately 85% of the 5,314 pounds of BTEX. The P&T system removed 15% of the BTEX.

- The BTEX removal rate reached a peak of approximately 20.1 lbs/day after six months of operation. The cumulative removal rate has varied between 20.1 lb/day and 7.6 lb/day during the life of the system.

- LNAPL has not been observed in any wells since the April 1996 sampling event. The small BTEX plume in the area of well GWX-2 is believed to have been recovered. However, GWX-2 will continue to be pumped at a higher rate compared to the other wells to extract the more concentrated portion of the plume.

- Effluent BTEX levels are not measured prior to reinjection.

Performance Data Completeness [3,4]

- Data are available for BTEX concentrations in the groundwater in some wells during quarterly sampling events from July 1995 to October 1997. Data were obtained for the October 1996 quarterly sampling event but were not included in the analysis, as explained below in Performance Data Quality. The air stripper influent and effluent have not been monitored for contaminant levels. Data on vapor from sparging and SVE are available in some SVE wells during quarterly sampling events from July 1995 to October 1996. Vapor contaminant loading to the thermal destruction unit has been measured on a monthly basis. Quarterly monitoring data are available in Quarterly Monitoring Reports. Weekly monitoring data are summarized in the monthly reports, and actual weekly readings are available from the site engineer.

TREATMENT SYSTEM PERFORMANCE (CONT.)

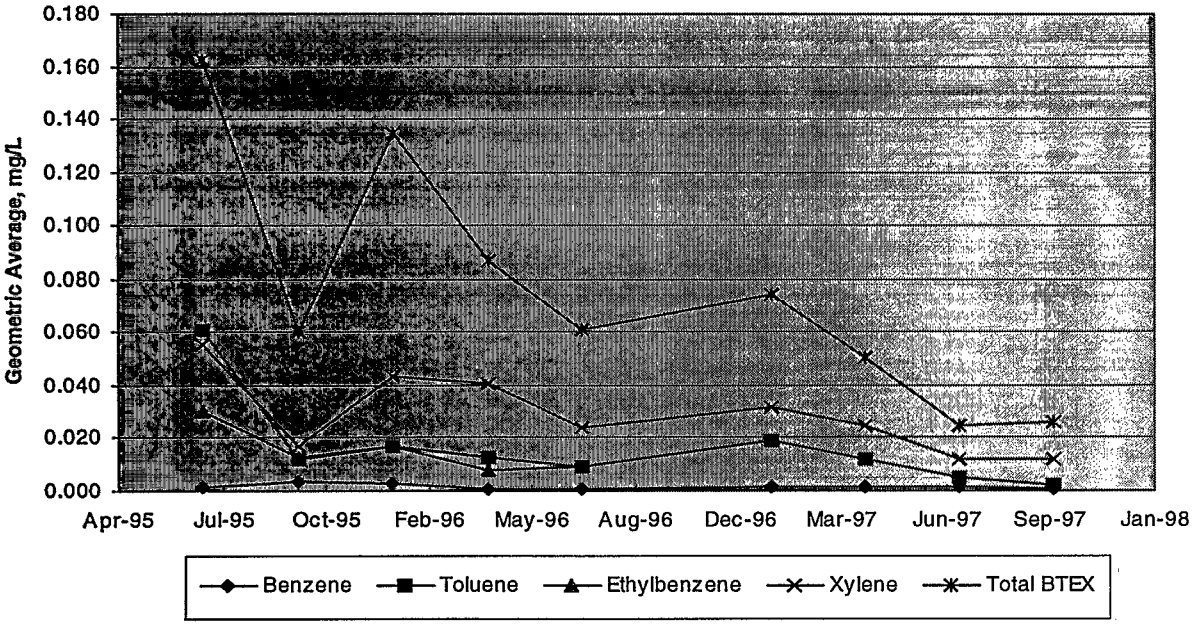

Figure 2. Average BTEX Concentrations (from July 1995 to July 1996) [3,6]*

**Data from October 1996 were not included - see Performance Data Quality*

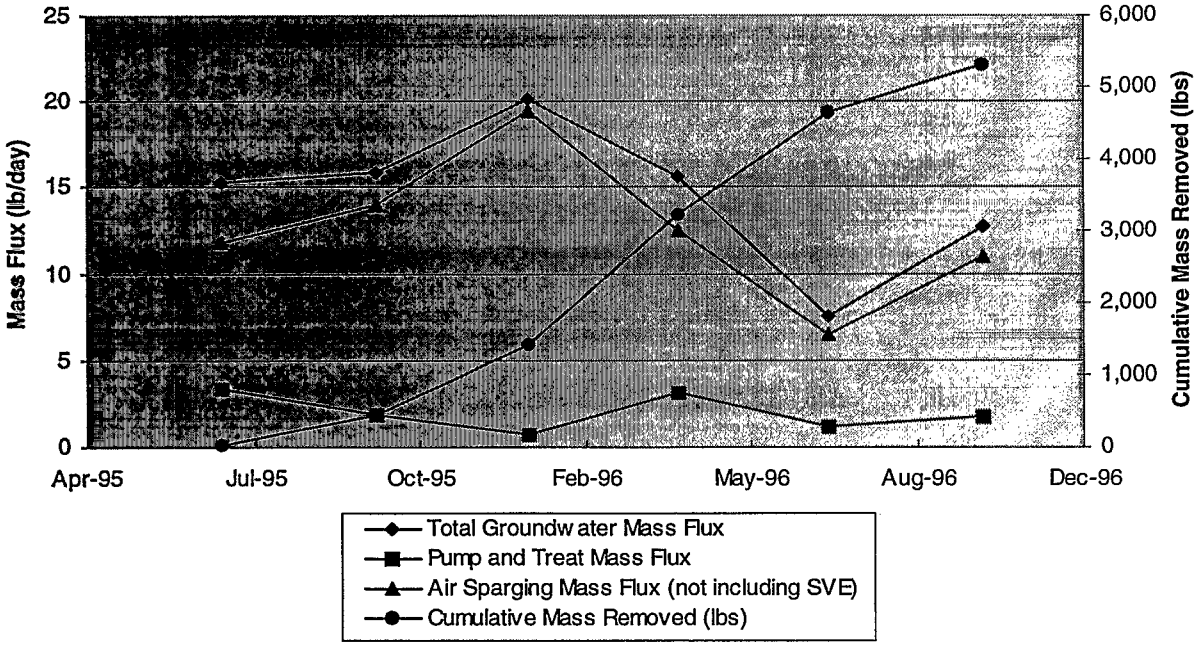

Figure 3. Mass Flux Rate and Cumulative Contaminant Removal (July 1995 to October 1996) [3]

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Completeness (Cont.)

- Total BTEX mass removal was determined by RETEC using analytical results from influent to and effluent from the thermal destruction unit. RETEC calculated the BTEX mass removed by the SVE system and the air sparging system based on charcoal tube data sampled on a quarterly basis. RETEC determined the mass removed by the P&T system as the difference between the total BTEX removal and the BTEX removal by the SVE system and the air sparging system. RETEC calculated that the mass removed by the air sparging system alone was based on an observed 7:3 ratio between mass removed by SVE to mass removed by air sparging.
- The BTEX mass removed by the P&T system did not include the free product mass that is separated prior to treatment. The amount of free product recovered was not monitored.
- A geometric mean was used for average groundwater concentrations detected in five extraction wells, two air sparging wells, and three shallow monitoring wells located within the original plume area. A geometric mean was used to show the trend across the entire plume. When concentrations below detection limits were encountered, half of the detection limit was used.

Performance Data Quality

- The sampling event performed in October 1996 did not meet QA/QC requirements in that BTEX concentrations were detected in both trip and field blanks. Therefore, data from this sampling event were not included in the analyses performed in this report [3].
- The QA/QC program used throughout the remedial action met the EPA and the State of New York requirements. All monitoring was performed using EPA-approved SW-846 Methods 601, 602, 624, 625, 353.2, 365.2. The only vendor-noted exception to the QA/QC protocols occurred during the October 1996 sampling event described above [3].

TREATMENT SYSTEM COST

Procurement Process

The group of responsible parties contracted with RETEC to design and construct the remediation system, under the oversight of the NYSDEC. After six years of system operation or after $1.75 million over and above the sums in a trust fund have been spent, the NYSDEC will take over system operation and will assume the remaining costs.

Cost Analysis

The responsible parties assumed all costs for design and construction and operation of the treatment system at this site.

TREATMENT SYSTEM COST (CONT.)

Capital Costs [6,7]

Remedial Construction	
Well construction (extraction, monitoring, sparge, SVE)	$1,007,915
Treatment system (air stripper, holding, tanks, chemical mixing tanks)	$97,944
Building	$100,960
Fence/Security	$17,392
Construction Management	$122,579
Total Remedial Construction	**$1,583,133**

Operating Costs [6,7]

Utilities	$59,782
Operations & Maintenance	$90,903
Monitoring	$30,658
Consumable (Chemicals and Nutrients)	$27,291
Disposals (sludge, free product)	$9,663
Project Management and Reporting	$121,209
Miscellaneous	$18,921
Total Operating Cost (July 1995 - October 1996)	**$358,427**

Other Costs [6,7]

Remedial Design	
Remedy	$539,320
Expansion	$32,586
Excavation and disposal of tanks	$179,035
Demolition of buildings	$57,308
EPA and NYSDEC Oversight	$20,000

Cost Data Quality

Actual capital and operations and maintenance cost data are available from the responsible party contact and the treatment vendor for this application. The cost of SVE wells (source control) could not be separated from the groundwater system costs.

OBSERVATIONS AND LESSONS LEARNED

- Actual costs for the P&T, *in situ* bioremediation, and *in situ* air sparging and soil vapor extraction treatment application at Site A were approximately $1,941,560 ($1,583,133 in capital and $358,427 in operations and maintenance), which corresponds to $365 per pound of contaminants removed and $200 per 1,000 gallons of groundwater treated.
- The site remediation system has been in operation for two years and three months. No substantial changes to the cost of the remedial system at this site were incurred during implementation. The system expansion constructed in September 1995 is included in the presented costs and had no impact on schedule [7].
- According to the site contact, the use of skid-mounted modular equipment reduced construction costs. Additionally, the responsible parties have indicated the competitive bidding process used resulted in lower costs [7].
- The groundwater cleanup goals for this site have not been met after two years and three months of operation. However, the selected remedy has worked to contain the plume, reduce average BTEX concentrations, and to recover LNAPL.
- RETEC observed the air sparging portion of the system has accounted for 85% of BTEX removal from the groundwater, while the P&T system accounted for 15% of BTEX removal in the groundwater.

Observations and Lessons Learned (Cont.)

- The success of the remedial systems is, in part, due to the simple aquifer material under the site. The uniform sandy soil at the site allowed sufficient sparging and SVE rates, as well as simplified zones of influence for extraction wells.
- The heterotroph population has been maintained at the level necessary to achieve bioremediation [8].
- Nitrogen levels met the performance goals of 1 to 5 mg/L from July 1995 through June 1996 but were above 5 mg/L from July 1996 to October 1997. The site operator encountered levels above 5 mg/L in 1997, and the amount of ammonium chloride added was reduced [3].
- Phosphorous levels did not meet performance goals and were detected below the optimal range of 1 to 5 mg/L from June 1996 to October 1996. In 1997, the phosphorous levels increased to optimal levels.
- The performance of the treatment system and the area of influence of the enhanced *in situ* bioremediation system could not be determined because it is not monitored.

References

1. Record of Decision, U.S. Environmental Protection Agency, Site B. June 24 1991.
2. Remedial Action Report, RETEC. February 1996.
3. *In situ* Monitoring for the Integrated Subsurface Remediation System, RETEC. February 1997.
4. Monthly Operations Report, RETEC. December 1996.
5. Preremedial Design Investigation Report, RETEC. July 1993.
6. Correspondence with Mr. Steve McInerny, RETEC, April 1997 and May 1997.
7. Correspondence with Mr. Steve Hoelsher, Phillips Petroleum, September 23, 1997.
8. Correspondence with Mr. Chris Poole, Land Tech, June and July 1998.

Analysis Preparation

This case study was prepared for the U.S. Environmental Protection Agency's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Eastern Research Group, Inc. and Tetra Tech EM Inc. under EPA Contract No. 68-W4-0004.

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In Situ Permeable Reactive Barrier for Treatment of Contaminated Groundwater at the U.S. Coast Guard Support Center, Elizabeth City, North Carolina

In Situ Permeable Reactive Barrier for Treatment of Contaminated Groundwater at the U.S. Coast Guard Support Center, Elizabeth City, North Carolina

<table>
<tr><td>Site Name:
U.S. Coast Guard Support Center</td><td rowspan="2">Contaminants:
Chlorinated solvents and heavy metals
- Maximum concentrations detected during initial investigations included TCE (>4,320 ug/L) and hexavalent chromium (Cr^{+6} (>3,430 ug/L))</td><td>Period of Operation:
Status: Ongoing
Report covers: 7/96 - 7/97</td></tr>
<tr><td>Location:
Elizabeth City, North Carolina</td><td>Cleanup Type:
Full-scale cleanup (interim results)</td></tr>
<tr><td>Vendor:
Design: University of Waterloo
Contractor: Parsons Engineering Science, Inc.
Licensing: Environmental Technologies, Inc.
Installation: Horizontal Technologies, Inc.</td><td rowspan="2">Technology:
Permeable Reactive Barrier (PRB)
- The PRB (treatment wall) is 100% granular iron, 2 ft wide, 152 ft long, begins 4-8 ft below ground surface (bgs) and extends to 24 ft bgs
- The PRB consists of 450 tons of granular zero-valent iron</td><td>Cleanup Authority:
RCRA Corrective Action - part of an Interim Corrective Measure</td></tr>
<tr><td>USCG Project Manager:
Jim Vardy, P.E.
U.S. Coast Guard
CEU Cleveland Env. Engr.
Building 19
Elizabeth City, NC 27909
(919) 335-6847

U.S. EPA Contact:
Robert Puls
U.S. EPA, Robert S. Kerr Environmental Research Center
Nat. Risk Mgmt. Research Lab.
P.O. Box 1198
Ada, OK 74821
(580) 436-8543</td><td>State Point of Contact:
Surabhi Shah
North Carolina DENR
Hazardous Waste Section
401 Oberlin Rd., Ste. 150
Raleigh, NC 27605</td></tr>
<tr><td>Waste Source:
Spills and leaks to the subsurface through floor drains and holes in building floor</td><td colspan="2" rowspan="2">Type/Quantity of Media Treated:
Groundwater
- 2.6 million gallons (estimated) treated
- DNAPL suspected in groundwater at the site
- Groundwater is found at 6 ft bgs
- The PRB is located in 1 aquifer at the site; this aquifer is influenced by a nearby surface water
- Hydraulic conductivity ranges from 11.3 to 25.5 ft/day</td></tr>
<tr><td>Purpose/Significance of Application:
Use of PRB to treat groundwater contaminated with TCE and hexavalent chromium; extensive sampling conducted to evaluate PRB.</td></tr>
</table>

Permeable Reactive Barrier for Treatment of Contaminated Groundwater at the U.S. Coast Guard Support Center, Elizabeth City, North Carolina (continued)

Regulatory Requirements/Cleanup Goals:
- Cleanup goals for this site are primary drinking water standards, with the following specific cleanup goals for the aquifer down-gradient of the wall: TCE (5 ug/L) and Cr^{+6} (0.1 ug/L).
- A secondary goal of the PRB is to contain the contaminated part of the plume up-gradient of the reactive zone.

Results:
- Cr^{+6} concentrations were below the cleanup goal in all down-gradient monitoring wells in November 1996 and September 1997 sampling events. However, TCE concentrations were above the cleanup goal in four of the six down-gradient wells in September 1997.
- A pilot study performed in 1994 and 1995 was successful at demonstrating the effectiveness of the PRB technology at this site; these results lead to the selection of PRB as the remedy for this RCRA corrective action.
- The data indicate that the TCE plume may not be contained; however, the reason for the elevated TCE concentrations in some down-gradient wells has not been confirmed.

Cost:
- Estimated costs for PRB were $585,000 ($500,000 in capital and $85,000 in O&M), which correspond to $225 per 1,000 gallons of groundwater treated.
- According to the USCG site contact, by using a PRB, the USCG will save nearly $4,000,000 in construction and long-term maintenance costs, when comparing PRB with a typical pump and treat system.

Description:
The Support Center, Elizabeth City (SCEC), is a USCG facility providing support, training, operation, and maintenance associated with USCG aircraft. The facility included an electroplating shop which operated for more than 30 years, ceasing operation in 1984. In December 1988, a release was discovered during demolition of a former plating shop. Soil excavated beneath the floor of the former plating shop was found to contain high levels of chromium. Subsequent investigations indicated that the groundwater had been impacted by chromium and chlorinated solvents. Multiple sources were suspected of having contributed to the groundwater contamination. A full-scale PRB was constructed as part of an Interim Corrective Measures (ICM) associated with a voluntary RCRA Facility Investigation (RFI), with the electroplating shop identified in the facility's RCRA Part B permit as a Solid Waste Management Unit (SWMU).

The PRB used at this site consists of 450 tons of granular zero-valent iron keyed into an underlying low conductivity layer at a depth of approximately 22 ft bgs. The required residence time in the treatment zone has been estimated as 21 hours, based on a highest concentration scenario. The average velocity through the wall was reported as 0.2 to 0.4 ft/day. Analytical data from the first year of full-scale operation show that the cleanup goal for Cr^{+6} has been met, but not the goal for TCE. Several possible reasons are provided for the elevated TCE levels.

SITE INFORMATION

Identifying Information:

U.S. Coast Guard Support Center
Elizabeth City, North Carolina

CERCLIS #: Not applicable

ROD Date: Not applicable

Treatment Application:

Type of Action: Corrective Action

Period of operation: 7/1/96 - Ongoing (Data collected through September 1997).

Quantity of groundwater treated during application: 2.6 million gallons (estimated)

Background

Historical Activity that Generated Contamination at the Site: Electroplating Operations

Corresponding SIC Code: 3471 (Electroplating of metals)

Waste Management Practice That Contributed to Contamination: Spills and leaks to the subsurface through floor drains and holes in building floor

Location: Elizabeth City, North Carolina

Facility Operations: [1, 2, 5]

- The Support Center, Elizabeth City (SCEC) is a U.S. Coast Guard (USCG) facility providing support, training, operation and maintenance associated with USCG aircraft.
- The groundwater plume is adjacent to a former electroplating shop which operated for more than 30 years. Operation ceased in 1984.
- In December 1988, a release was discovered during demolition of the former plating shop. Soil excavated beneath the floor of the former plating shop was found to contain chromium at concentrations up to 14,500 mg/kg.
- The majority of the contaminated soil at the site was believed to have been excavated during the 1988 activities. Subsequent investigations indicated that the groundwater had been impacted by chromium.
- Additional investigations by the USCG indicated the presence of chlorinated compounds in the groundwater. Multiple sources were suspected of having contributed to the groundwater contamination.
- A pilot study was initiated at the site in 1994 to demonstrate the effectiveness of the permeable reactive barrier (PRB) (iron treatment wall) at this site. Two different types of iron were poured into 16 cm inside-diameter hollow stem augers. A total of 21 iron cylinders were installed from 3 to 8 meters below ground surface. The cylinders were installed in three rows. Groundwater samples were taken downgradient of the iron cylinders to test for reduced groundwater concentrations.
- A full-scale PRB was installed in June 1996. The iron wall was constructed using a trencher which excavated the soil and back-filled with iron in one pass. The wall was installed in seven hours.

Regulatory Context:

- The full-scale PRB was constructed as part of an Interim Corrective Measures (ICM) associated with a voluntary RCRA Facility Investigation (RFI). The electroplating shop is identified in the facility's RCRA Part B permit as Solid Waste Management Unit (SWMU) No. 9. Corrective actions at the site are regulated under 40 CFR Subpart F.

Remedy Selection:

- An *in situ* PRB was selected as the remedy for this site.

SITE INFORMATION (CONT.)

Site Logistics/Contacts

Site Lead: USCG-Lead

Oversight: State

USCG Project Manager:
Jim Vardy, P.E.*
U.S. Coast Guard
CEU Cleveland Environmental Engineer
Bldg. 19
Elizabeth City, NC 27909
919-335-6847

Remedial Project Manager:
Surabhi Shah
North Carolina Department of Environment and Natural Resources (DENR)
Hazardous Waste Section
401 Oberlin Rd., Ste. 150
Raleigh, NC 27605

*Indicates Primary Contact

Treatment System Vendor:
Design
University of Waterloo, Waterloo, Canada
Contractor Support
Parsons Engineering Science, Inc. Cary, NC
Licensing
Environmental Technologies, Inc. Ontario, Canada
Installation
Horizontal Technologies, Inc.

Additional Contact:
Robert Puls
USEPA
Robert S. Kerr Environmental Research Center
Subsurface Protection and Remediation Division
National Risk Management Research Laboratory
P.O. Box 1198
Ada, OK 74821
580-436-8543

MATRIX DESCRIPTION

Matrix Identification

Type of Matrix Processed Through the Treatment System: Groundwater

Contaminant Characterization [1, 5]

Primary Contaminant Groups: Halogenated volatile organic compounds (VOC) and metals

- Contaminants of concern at the site are trichloroethene (TCE) and hexavalent chromium (Cr^{+6}).
- Maximum concentrations detected during initial investigations included TCE (>4,320 µg/L) and Cr^{+6} (>3,430 µg/L).
- Figure 1 is a contour map which depicts total chromium concentrations detected during a July/August 1994 sampling event. At least two overlapping plumes were identified at the site. A plume consisting of Cr^{+6} and minor amounts of halogenated VOCs began near the north end of the former electroplating shop and migrated north with the general groundwater flow direction. A second plume of primarily halogenated VOCs emanated from unknown sources. Most of these sources were suspected to be associated with old sewer drain lines. This plume also migrated north and overlaped the first plume. The plume discharged to the Pasquotank River.
- According to the site contact, the presence of dense non-aqueous phase liquid (DNAPL) at this site is likely based on elevated concentrations detected in groundwater samples and processes known to have occurred in the electroplating shop.
- The contaminant plume was estimated to be up to 5-6 feet thick and cover a 34,000 square foot area. The volume of contaminated groundwater was estimated to be 1.3 million gallons.

MATRIX DESCRIPTION (CONT.)

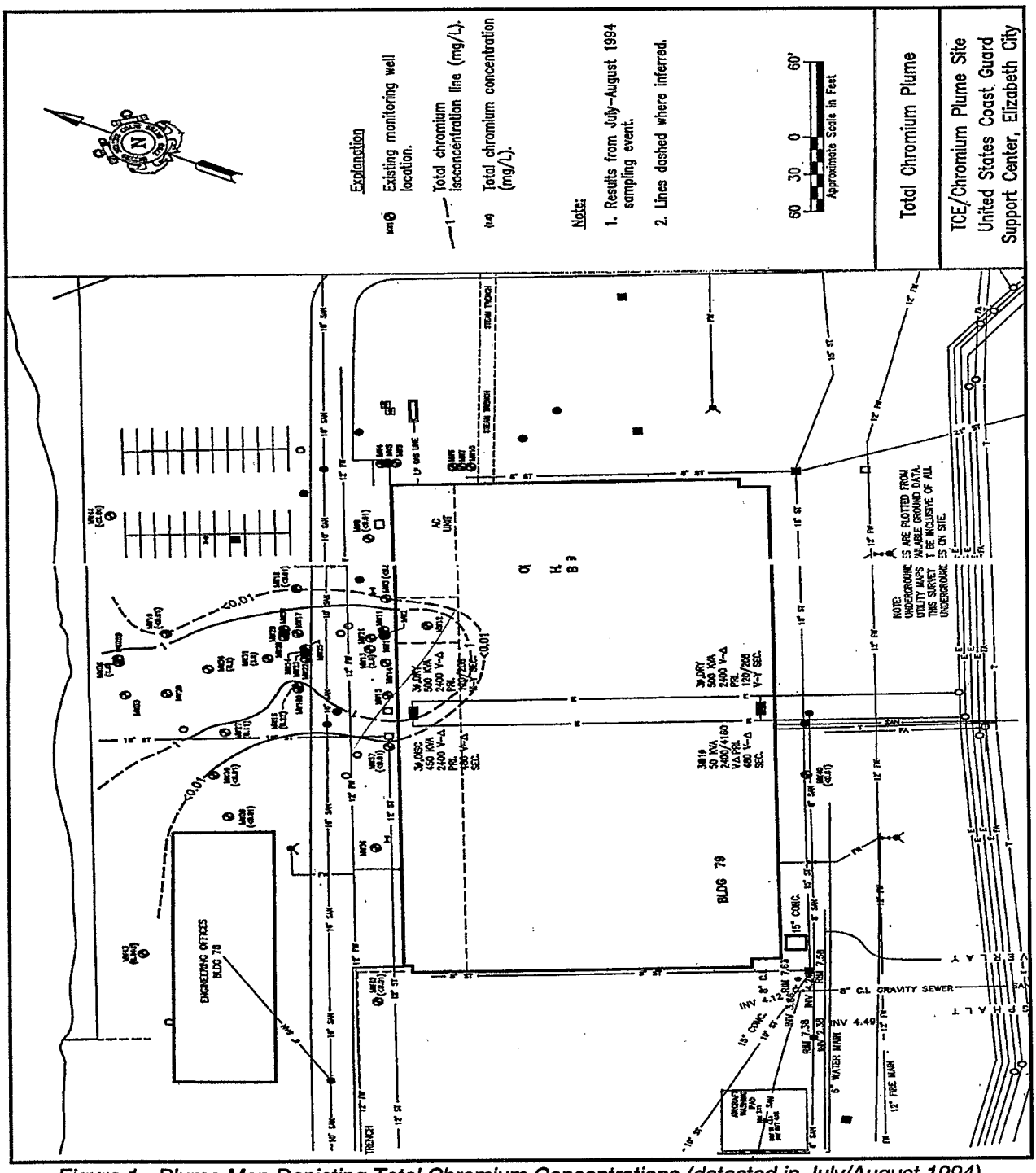

Figure 1. Plume Map Depicting Total Chromium Concentrations (detected in July/August 1994) Modified From [2]

MATRIX DESCRIPTION (CONT.)

Matrix Characteristics Affecting Treatment Costs or Performance

Hydrogeology: [1, 2]

Four distinct hydrogeological units have been identified beneath this site. Groundwater begins approximately six feet below ground surface and a highly conductive zone is located between 16-20 feet below ground surface. This conductive layer coincides with the highest aqueous concentrations of chromate and chlorinated organic compounds found on site. Groundwater flows in a north direction toward the Pasquotank River. A low conductivity layer of clayey fine sand to silty clay is located at a depth of approximately 22 feet. This layer acts as an aquitard to the contaminants located immediately above. This information was used when designing the treatment wall depth to end in a low conductivity layer to prevent contaminants from flowing under the treatment zone.

Unit 1	Surficial Sediments	Brown to yellow-brown sandy to silty clay. This is a non water-bearing unit.
Unit 2	Surficial Sediments	Medium to fine sand or silty to clayey sand, with interbedded sandy clays ranging from stiff to loose and brown to tan. This is the upper water-bearing unit at the site.
Unit 3	Surficial Sediments	Dense gray to green clay or silty clay. This unit acts as a major aquitard between the upper aquifer and the Yorktown Formation.
Unit 4	Yorktown Formation	Fine to medium clayey and silty sand. This unit is a major water-bearing formation. Groundwater in this unit has not been impacted by site contamination.

Tables 1 and 2 present technical aquifer information and well data, respectively.

Table 1. Technical Aquifer Information

Unit	Thickness (ft)	Conductivity (ft/day)	Average Velocity (ft/day)	Flow Direction
1	6-8	NA	NA	NA
2	50-60	11.3 - 25.5	0.3 - 0.6	North
3	25	Not characterized	Not characterized	Not characterized
4	>100	Not characterized	Not characterized	Not characterized

Source: [1, 5]

TREATMENT SYSTEM DESCRIPTION

Primary Treatment Technology

PRB

Supplemental Treatment Technology

None

TREATMENT SYSTEM DESCRIPTION (CONT.)

System Description and Operation [1, 2, 5]

Table 2. Technical Wall Data

Unit	Flow-Through Thickness	Conductivity (ft/day)	Material	Vertical Thickness
Continuous Treatment Wall	2 feet	1,000	Granular Iron	18 feet

Source: [1, 5]

System Description

- The PRB is a passive, *in situ* treatment technology which makes use of natural groundwater velocity and transport mechanisms to carry contaminants through the reaction zone.
- The full-scale PRB consists of 450 tons of granular zero-valent iron. The reactive zero-valent iron to dechlorinate TCE to chloride and ethylene, and reduce hexavalent chromium to trivalent chromium. Trivalent chromium forms an insoluble hydroxide compound and precipitates. The physical dimensions of the wall are 152 feet long by 2 feet wide. The reactive media begins 4 to 8 feet below ground surface and extends to 24 feet below ground surface.
- The PRB is keyed into an underlying low conductivity layer within Unit 2, which is comprised of clayey fine sand to silty clay and is found at a depth of approximately 22 feet. This material is not classified as an aquitard; however, chromium and TCE contamination is primarily found in a highly conductive zone directly above this unit at a depth of 16 to 20 feet.
- The required residence time in the treatment zone for the dechlorination and reduction reactions has been estimated to be approximately 21 hours based on the highest concentration scenario.
- Ten compliance monitoring wells are used to monitor the treatment wall performance. Six wells (MW46, MW47, MW49, MW50, MW52, MW35D) are located downgradient of the treatment wall. Well MW48 is located within the treatment wall. Three wells (MW38, MW48, MW13) are located upgradient of the treatment wall. Monitoring well MW52 was added between June 1997 and September 1997 to further monitor contaminant concentrations downgradient of the wall. Fifteen additional multi-level sampling points (135 total sampling points) have also been installed upgradient and downgradient of the treatment wall for research purposes.

System Operation

- Quantity of groundwater treated (gal):

	Approximate Volume Treated
1996-1997	2.6 million gallons

Based on average groundwater velocity of 0.4 ft/day and dimensions of 152 feet wide and 16 feet flow-through thickness [2].

- Since July 1996, the PRB has been 100% operational.
- Compliance monitoring wells and research sampling points are monitored for piezometric head to evaluate groundwater velocity and flow direction through the PRB.

Operating Parameters Affecting Treatment Cost or Performance

A major operating parameter affecting cost and performance for this technology is the groundwater flow rate through the treatment wall. The average flow rate through the wall and the required remedial goals are included in Table 3. In addition, a minimal residence time is required to treat the contaminants to the cleanup goal levels. For this application, the residence time is 21 hours.

TREATMENT SYSTEM DESCRIPTION (CONT.)

Operating Parameters Affecting Treatment Cost or Performance (Cont.)

Table 3: Performance Parameters

Parameter	Value
Average Velocity through Treatment Wall	0.2 - 0.4 ft/day
Remedial Goal (Aquifer downgradient of the wall)	TCE (5 µg/L) Cr^{+6} (0.1 mg/L)

Source: [1, 5]

Timeline

A timeline for this remedial project is shown in Table 4.

Table 4: Project Timeline

Start Date	End Date	Activity
9/90	6/95	Remedial system designed
9/94	on-going	Pilot study initiated
6/96	---	Construction of full-scale PRB completed (1 day)
6/96	---	Full-scale PRB begins operation
11/96	---	Date for initial quarterly monitoring round
11/97	---	Quarterly monitoring conducted

Source: [1]

TREATMENT SYSTEM PERFORMANCE

Cleanup Goals/Standards [1, 5]

- Cleanup goals for this site are Primary Drinking Water Standards. Specific concentrations for target compounds are included in Table 3. These goals are applied in monitoring wells downgradient of the treatment wall.

Treatment Performance Goals [1, 5]

- The primary goal of the PRB is to reduce contaminant concentrations in the groundwater downgradient of the reactive zone to cleanup goals.
- The secondary goal of the PRB is to contain the contaminated part of the plume upgradient of the reactive zone.

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Assessment [2,7,8,9]

- As shown in Figures 2 and 3, Cr^{+6} concentrations were below the cleanup goal of 0.1 mg/L in all six downgradient monitoring wells in both the November 1996 and September 1997 sampling events. Cr^{+6} concentrations were reported below the quantification limit (BQL) of 0.0041 mg/L in all cases.

- As shown in Figures 4 and 5, TCE concentrations remain above the cleanup goal of 5 µg/L in four of the six downgradient wells (MW46, MW49, MW50, MW52) as of September 1997. In addition, these figures show that the concentrations had increased in two of these four wells (MW49, from 2.8 to 5.5 µg/L and MW50, from 41 to 548 µg/L; both of these wells are located adjacent to the wall) over the period of November 1996 to September 1997. The other two downgradient wells (MW35D and MW47) remained below the cleanup goal of 5 µg/L during this time.

- The TCE concentration in MW50 has fluctuated from the November 1996 (baseline) concentration of 41 µg/L to 3.4 µg/L for the first quarter (of operation), 156 µg/L for the second quarter (of operation), and 548 µg/L during the September 1997 sampling event. This fluctuation may be attributed to large amounts of rainfall that washed into the open trench during construction. The heavy infiltration rate may have pushed the organic plume down or residual contamination in the soils downgradient of the wall may be leaching TCE into the aquifer [10].

- Monitoring wells MW13, MW18, MW38, MW47, MW48, MW49, MW50, MW35D, MW46 and MW52 are monitored quarterly for compliance purposes. TCE results from MW15, MW48, MW50 and MW46 are shown in Figure 6, and Cr^{+6} results from the same wells are shown in Figure 7.

- Figure 6 shows that TCE concentrations have decreased in MW48 and MW46 to approximately 100 µg/L (MW48) and 10 µg/L (MW46), respectively. TCE concentrations remained relatively constant at approximately 20 µg/L in MW13, and increased in MW50 to about 800 µg/L. Because well MW52 was installed between the June 1997 and September 1997 sampling event, only one data point is available. TCE concentrations were measured at about 500 µg/L for MW52 in September 1997. Well MW52 is screened at the same interval as well MW50, and is located adjacent to the river similar to well MW46.

- Figure 3 shows that Cr^{+6} concentrations in MW48, within the treatment wall, remained relatively constant at approximately 1.0 mg/L. Cr^{+6} concentrations in MW13, upgradient of the wall, were higher than the cleanup goal of 0.1 mg/L, at approximately 3 mg/L.

- The pilot study performed in 1994 and 1995 was successful at demonstrating the effectiveness of the iron treatment wall technology at this site. The results from the pilot study led to the selection of a full-scale reactive wall as the remedy for this RCRA corrective action.

- With respect to the secondary treatment performance goal of plume contaminant upgradient of the reactive zone, the data indicate that the TCE plume may not be contained. An explanation for the TCE concentrations found in MW50 and MW52 has not been confirmed.

Performance Data Completeness

- Ten compliance monitoring wells are sampled quarterly.

- Analyses were performed by the EPA NRMRL Laboratory and the University of Waterloo.

TREATMENT SYSTEM PERFORMANCE (CONT.)

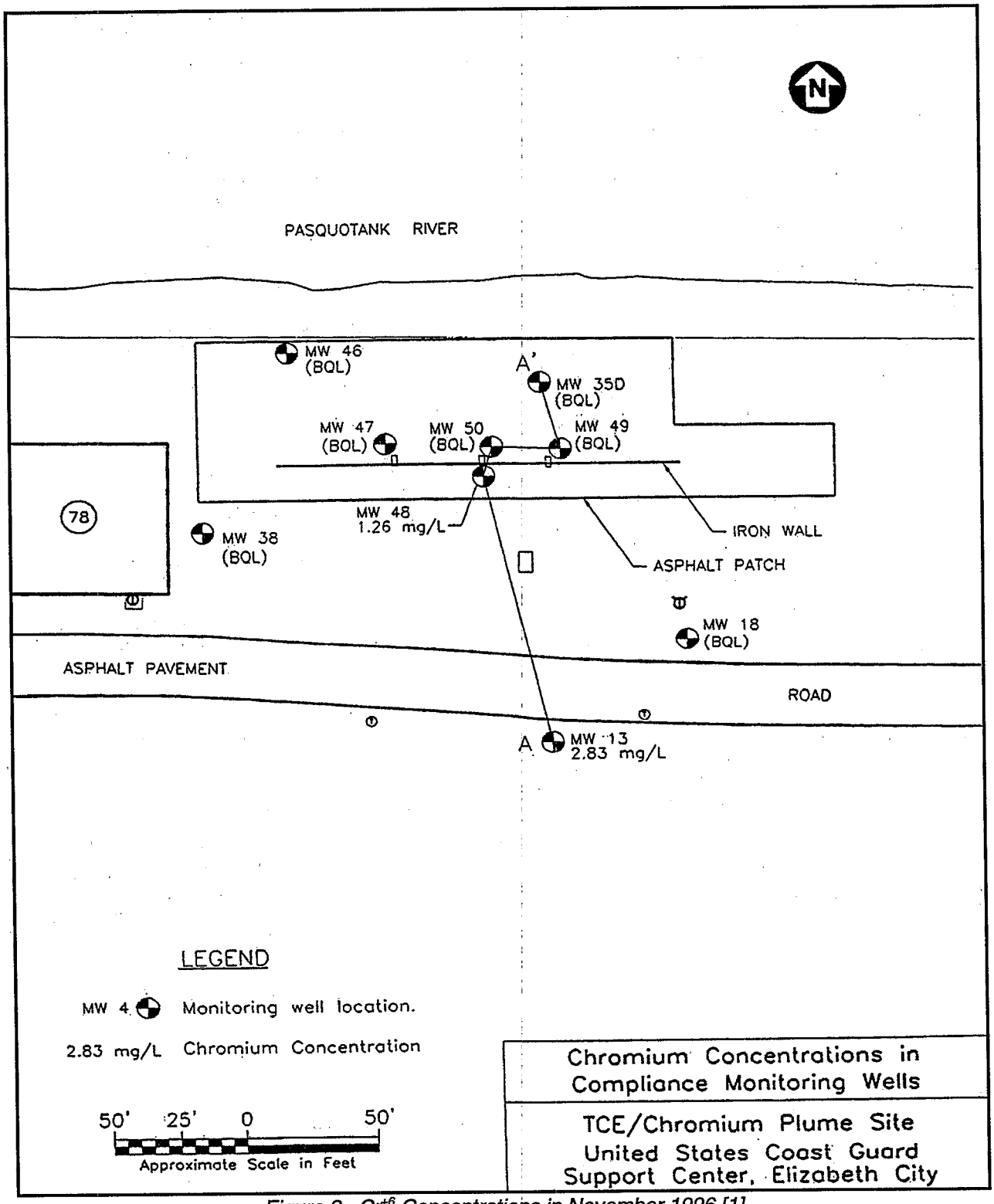

Figure 2. Cr^{+6} Concentrations in November 1996 [1]

TREATMENT SYSTEM PERFORMANCE (CONT.)

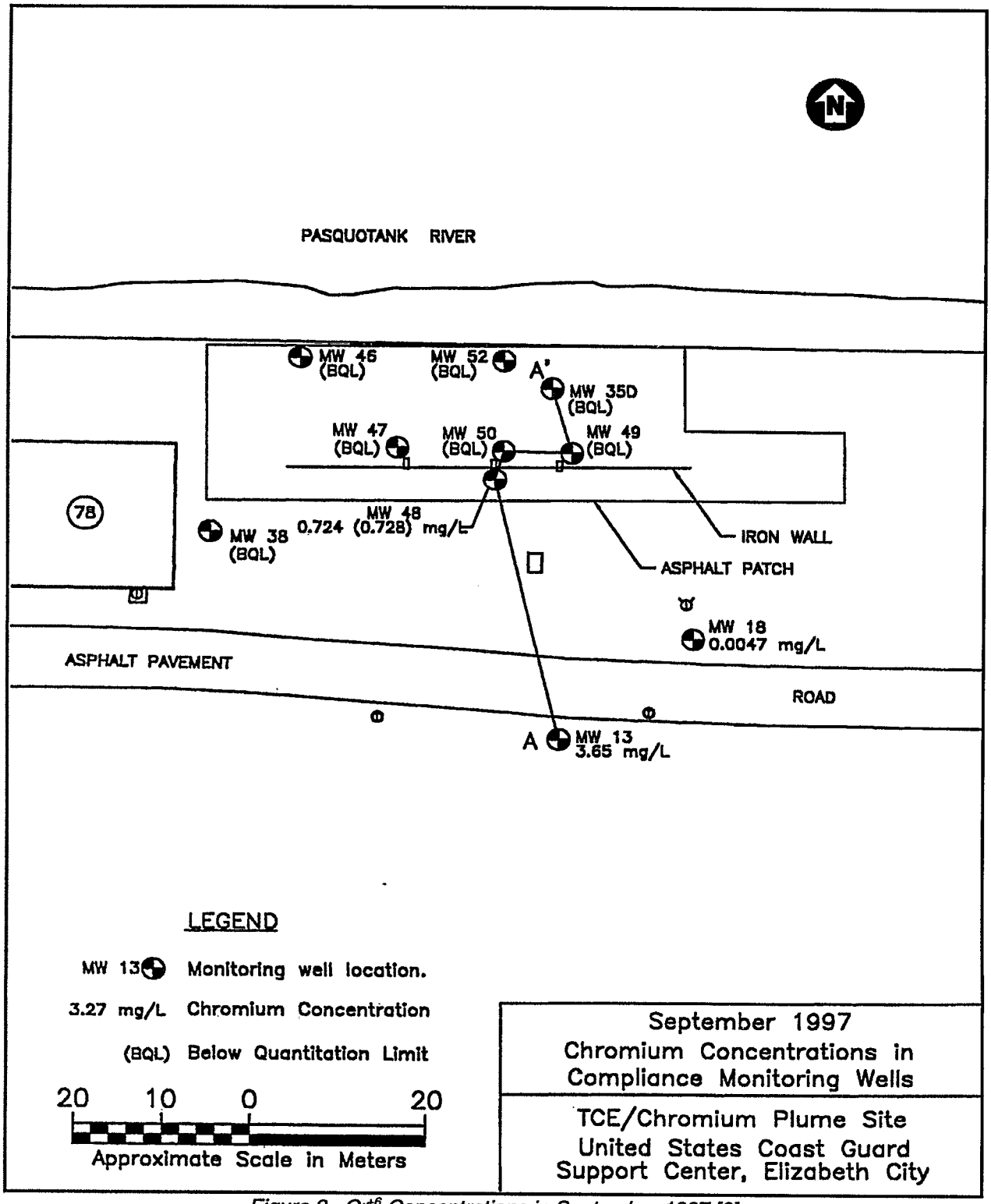

Figure 3. Cr^{+6} Concentrations in September 1997 [9]

TREATMENT SYSTEM PERFORMANCE (CONT.)

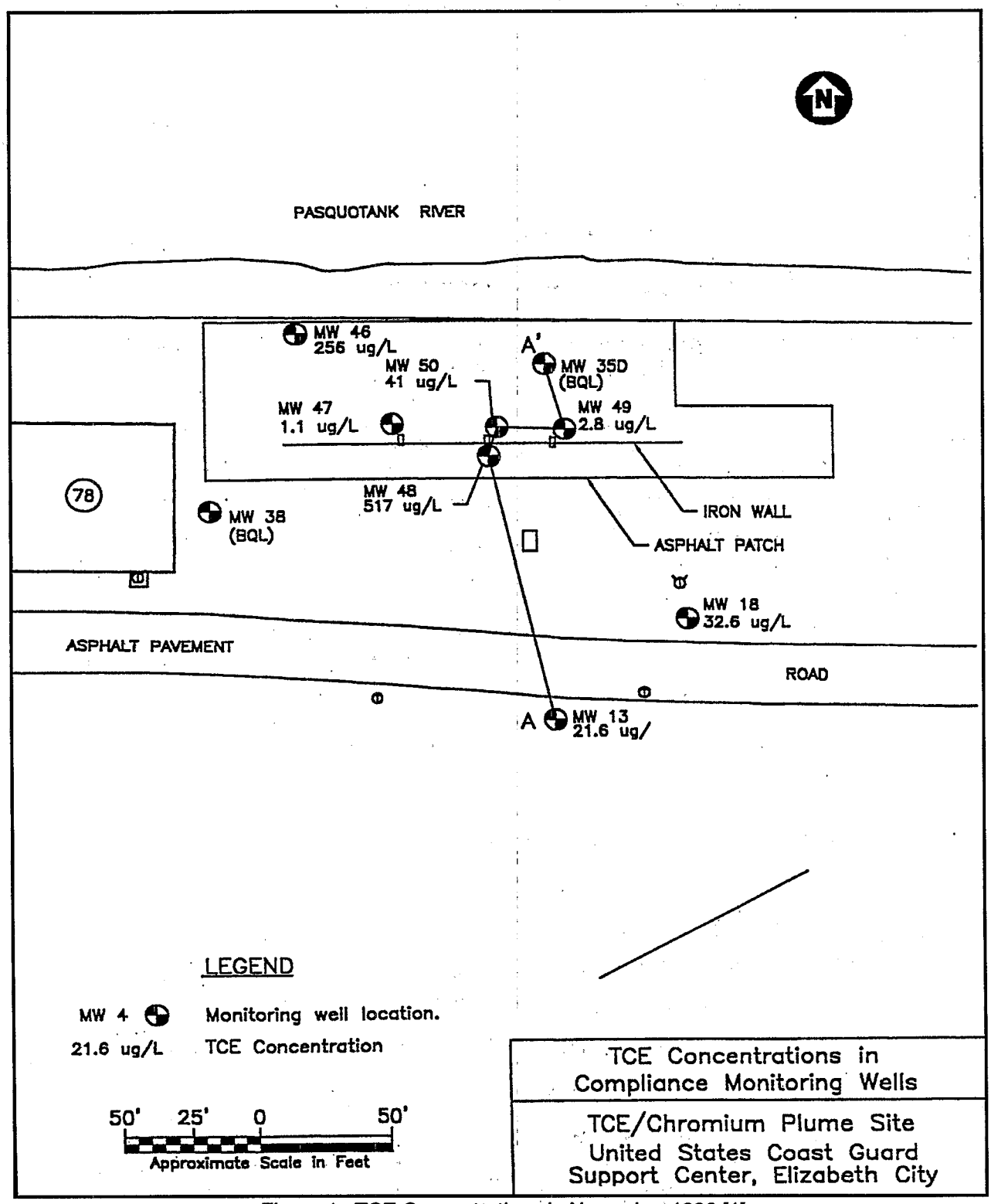

Figure 4. TCE Concentrations in November 1996 [1]

TREATMENT SYSTEM PERFORMANCE (CONT.)

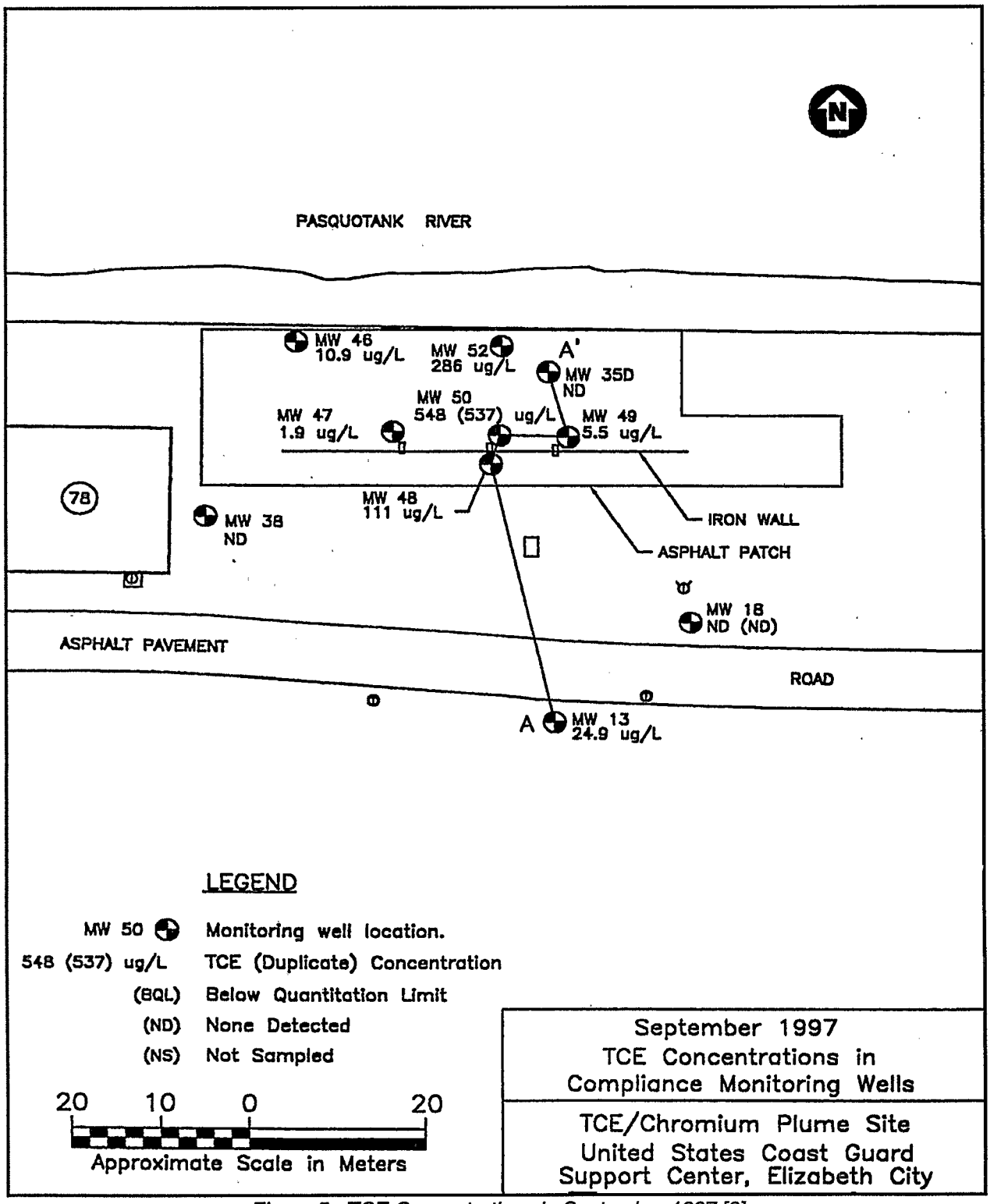

Figure 5. TCE Concentrations in September 1997 [9]

TREATMENT SYSTEM PERFORMANCE (CONT.)

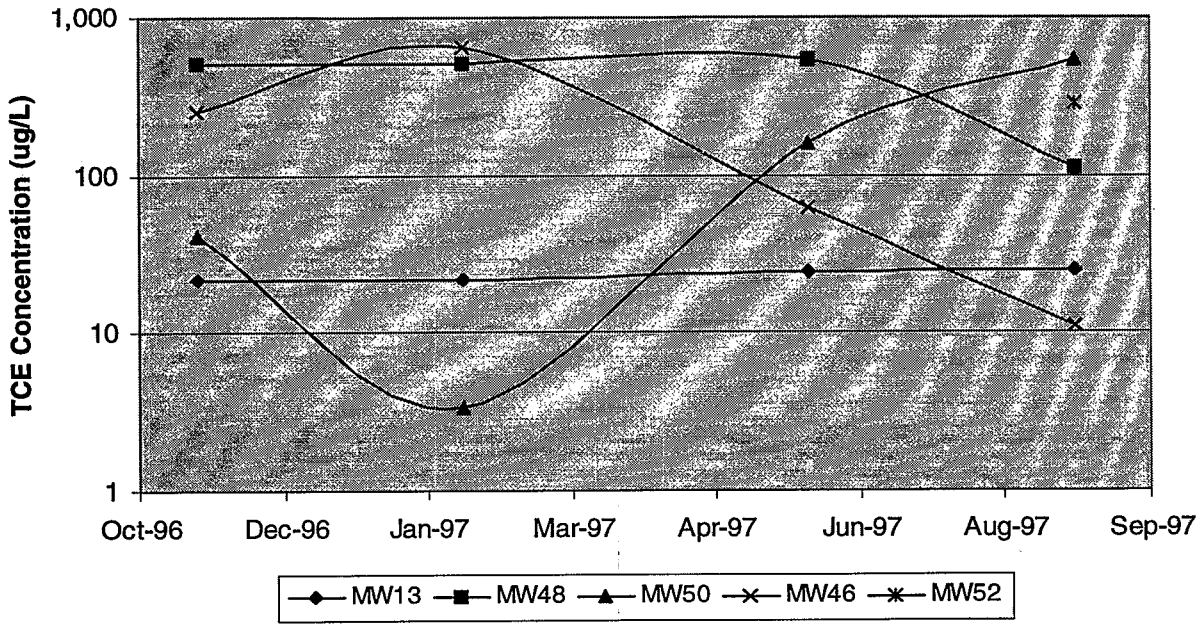

Figure 6. TCE Concentrations in Five Compliance Wells (1996 - 1997) [1,7,8,9]

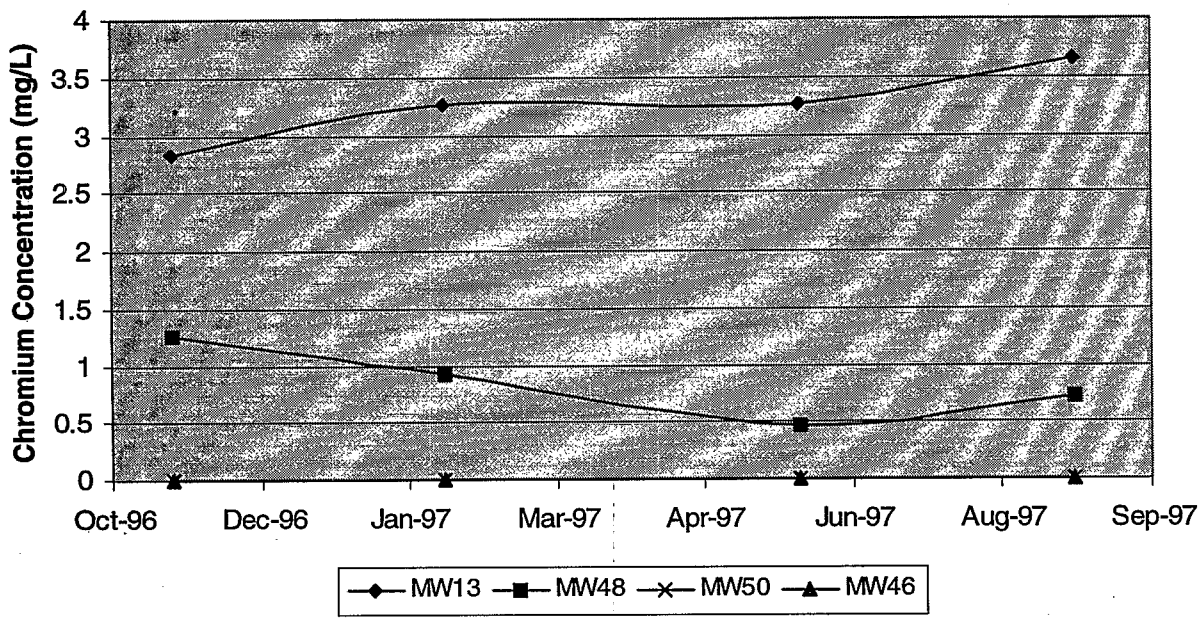

Figure 7. Cr^{+6} Concentrations in Four Compliance Wells (1996 - 1997) [1,7,8,9]

TREATMENT SYSTEM PERFORMANCE (CONT.)

Performance Data Quality

The QA/QC program used throughout the remedial action met the EPA and the State of North Carolina requirements. All monitoring was performed using EPA-approved methods, RSKSOP-102, RSKSOP-146, RSKSOP-147, RSKSOP-175, RSKSOP-179, RSKSOP-181, RSKSOP-183, RSKSOP-184, Method 353.1, Method N-601, SW-846 Method 8240, SW-846 Method 8020 and the vendor did not note any exceptions to the QA/QC protocols.

TREATMENT SYSTEM COST

Procurement Process

The USCG CEU-Cleveland is the lead for this site. SCEC is responsible for on-site activities and oversight. The State of North Carolina is responsible for RCRA activities within the state.

Cost Analysis

All costs for design, construction and operation of the treatment system at this site are borne by the USCG.

Capital Costs* [6]

	(Cost in 1996 dollars)
Remedial Construction	
System Installation	$200,000
Site Preparation	$100,000
Iron	$200,000
Total Remedial Construction	**$500,000**

*Estimated

Operating Costs [6]

Monitoring/Analytical	$40,000[1]
Report Preparation	$45,000[2]
Total	**$85,000**

[1]First annual monitoring and analytical contract.
[2]Baseline Report.

Other Costs [6]

Pilot Program	$150,000
Remedial Design	$60,000
State Oversight	$30,000

Cost Data Quality

Actual capital and operations and maintenance cost data provided by the USCG contact for this site. Some cost figures provided were estimated based on public sector industry standards.

OBSERVATIONS AND LESSONS LEARNED

- The cost for groundwater remediation at this site over one year was approximately $585,000 consisting of $500,000 in capital costs, and $85,000 in operating costs, corresponding to a unit cost of $225 per 1,000 gallons of groundwater treated.
- According to the USCG site contact, by using a treatment wall to remediate groundwater contamination, the USCG will save nearly $4 million in construction and long-term maintenance costs. This savings is based on a comparison with a typical pump and treat system with the following costs: $500,000 for installation, $200,000/year for monitoring and maintenance, and $500,000 for equipment replacement over a twenty-year operating life [6]. As this shows, construction and installation costs are similar in magnitude

OBSERVATIONS AND LESSONS LEARNED (CONT.)

for this technology when compared with a typical pump and treat application. However, operating costs are much less for the treatment wall technology.

- The results of sampling in November 1996 (after four months of operation) showed that Cr^{+6} had been reduced to below the cleanup goal of 1.0 mg/L in all downgradient compliance wells. Data from the September 1997 sampling event showed that Cr^{+6} levels remained below the quantification limit of 0.0041 mg/L.

- As of September 1997, TCE concentrations had been reduced to below the cleanup goal of 5 µg/L in two of the six downgradient compliance wells. While TCE concentrations were reported below the cleanup goal in three of these wells in November 1996, TCE concentration in well MW49 increased from 2.8 µg/L to 5.5 µg/L between sampling events. In addition, concentrations in well MW50 increased from 41 µg/L to 548 µg/L between November 1996 and September 1997. Possible reasons for the increase included ongoing leaching from residual contamination in the soil and infiltration caused by heavy rainfall.

- Because of the limited data available at the time of this report, mass flux and cumulative contaminant mass removal could not be calculated.

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Analysis Preparation

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