
Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

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FOREWORD

Abstract

EPA's Office of Superfund Remediation and Technology Innovation provided a grant through the National Network for Environmental Management Studies to research treatment technologies that have been employed at Superfund sites affected by DNAPL. This report was prepared by an undergraduate student from Wellesley College during the summer of 2010. The report is available on the Internet at www.cluin.org/studentpapers/.

The objective of this report is to provide an overview of remedial accomplishments at 12 current or former NPL sites affected by DNAPL and/or associated dissolved, vapor, or sorbed phase contamination. This report summarizes relevant information about these sites, including site sizes, contaminants, technologies, concentration level reductions, and current remedial status. A discussion of DNAPL characteristics, fate, and transport, as well as a summary of DNAPL remediation technologies, is also included. Case studies of individual sites are provided in Appendix A.

Acknowledgment

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TABLE OF CONTENTS

1.0	INTRODUCTION	1
1.1	Purpose	1
1.2	Scope	1
2.0	DENSE NONAQUEOUS PHASE LIQUID IN THE SUBSURFACE	2
2.1	Characteristics.....	2
2.2	Fate And Transport.....	3
3.0	DNAPL REMEDIATION TECHNOLOGIES	4
4.0	DNAPL CLEANUP AT TWELVE NPL SITES: SUMMARY AND ACCOMPLISHMENTS	5
4.1	General Information.....	6
4.2	Site Sizes	9
4.3	Aquifer Contamination	10
4.4	Dnapl Presence	10
4.5	Contaminants Of Concern	11
4.6	Treatment Technologies.....	13
4.7	Remedy Assessment.....	14
4.8	Conclusion.....	17
	APPENDIX A: CASE STUDIES	18
	SECTION I: CHLORINATED VOLATILE ORGANIC COMPOUNDS.....	18
1.	Caldwell Trucking Company.....	19
2.	Eastland Woolen Mill.....	22
3.	Fort Lewis Logistics Center	27
4.	Gold Coast Oil Company, Inc.....	31
5.	Memphis Defense Depot: Dunn Field	36
6.	Pemaco.....	41
7.	Stamina Mills, Inc.....	47
8.	Western Processing	52
	Section II: POLYNUCLEAR AROMATIC HYDROCARBONS.....	56
9.	Central Wood Preserving Company.....	57
10.	Koppers Co., Inc (Charleston Plant).....	59
11.	Southern California Edison, Visalia Pole Yard	63
12.	Southern Maryland Wood Treating	66
	APPENDIX B: SUSPECTED DNAPL THRESHOLDS BASED ON SOLUBILITY RELATIVE TO ONE PERCENT OF AQUEOUS SOLUBILITY.....	70
	REFERENCES.....	1

LIST OF EXHIBITS

Exhibit 1: Uses and Characteristics of Common DNAPLs 2
Exhibit 2: DNAPL Remediation Technologies 4
Exhibit 3: Site Types and Locations 6
Exhibit 4: Summary of 12 Sites 8
Exhibit 5: 12 Sites Listed by Acreage 9
Exhibit 6: Aquifer Contamination at 12 Sites 9
Exhibit 7: Presence of DNAPLs at 12 Sites 10
Exhibit 8: Specific Contaminants Treated at 12 Sites 11
Exhibit 9: Technologies Implemented at 12 Sites, Listed by Frequency of Use 12
Exhibit 10: Performance Assessment of Treatment Technologies of Interest at 12 Sites 15

LIST OF TABLES

Table 1.1 EISB Field Test - Caldwell Trucking: Results Over 30-Month Monitoring Period 21
Table 2.1 Initial COC Concentrations in Soil at EWM 22
Table 2.2 Cleanup Levels at EWM 23
Table 2.3 Percent Reductions in Soil and Groundwater COCs After ISCO Treatments 24
Table 3.1 MCLs for COCs at Logistics Center 28
Table 3.2 ERH at EGDY: NAPL Area Size and Time of Operation 29
Table 3.3 GW TCE Concentration Reductions Within ERH Treatment Areas at EGDY 29
Table 4.1 Contaminants of Concern at Gold Coast Oil Superfund Site 33
Table 5.1 Maximum Concentrations and Remedial Goals at Dunn Field 37
Table 6.1 Maximum Concentrations and RAOs for COCs at Pemaco Site 41
Table 7.1 ROD-Specified Soil Cleanup Standards for Stamina Mills Site 48
Table 7.2 TCE Concentration Reductions in Groundwater at Stamina Mills Site 49
Table 8.1 . “Trans” Plume Concentration Reductions at WPS 54
Table 9.1 COC Concentration Levels in Soil at CWP 58
Table 10.1 Koppers Site Soil and Sediment Excavation Levels 60
Table 10.2 NAPL Recovery Efficiencies at Koppers NPL Site 61
Table 11.1 Pounds of Hydrocarbons Removed by Visalia Steam Remediation Project 64
Table 11.2 Performance Results of Remedial Action at VPY Site 65
Table 12.1 ROD Cleanup Standards for COCs at SMWT Site 67

LIST OF FIGURES

Figure 2.1 Phase II/III ISCO Treatment Area at Eastland Woolen Mill 26
Figure 4.1 DNAPL and Plume Distribution at GCO, Pre-Treatment and After 1 Year of P&T .. 34
Figure 4.2 DNAPL and Plume Distribution at GCO, Post-Sparging 35
Figure 5.1 Figure 5.1 Total CVOC Concentrations at Dunn Field, Oct. 2006 (Pre-ISTD) 40
Figure 6.1 ERH Vicinity TCE Range Map – B Zone Wells (Groundwater), 8/3/2010 45
Figure 6.2 TCE Concentrations in Soil Before and After ERH, 8/21/08 46
Figure 7.1 TCE Plume at Stamina Mills Site – November 1992 (Pre-Treatment) 50
Figure 7.2 TCE Plume at Stamina Mills Site – June 2004 51
Figure 8.1 Western Processing Site Map 55
Figure 10.1 Solidified/Stabilized Section of Ashley River Cap 62
Figure 12.1 Before and After Photos of SMWT 68
Figure 12.2 SMWT Site Map 69

ACRONYMS AND ABBREVIATIONS

AST	aboveground storage tank
B[a]P	benzo[<i>a</i>]pyrene
bgs	below ground surface
BNA	Base-neutral and acid extractable compounds
BTEX	benzene, toluene, ethylbenzene, and xylenes
CCA	chromium/copper/arsenic
CCl ₄	carbon tetrachloride
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	contaminant of concern
cP	centipoise
CVOC	chlorinated volatile organic compound
CWP	Central Wood Preserving
DANC	Decontaminating Agent Non-Corrosive
DCA	dichloroethane
DCE	dichloroethene
DDMT	Defense Depot Memphis Tennessee
DHE	Dehalococcoides ethenogenes
DLA	Defense Logistics Agency
DNAPL	dense nonaqueous phase liquid
DPE	dual-phase extraction
DPVOC	daughter product volatile organic compound
DTSC	Department of Toxic Substances Control
DUS	Dynamic Underground Stripping
EBSR	East Branch of the Sebasticook River
EGDY	East Gate Disposal Yard
EISB	enhanced in-situ bioremediation
EPA	Environmental Protection Agency
eqv	toxicity equivalence
ERH	electrical resistance heating
ERP	Environmental Restoration Program
ESD	Explanation of Significant Differences
EWM	Eastland Woolen Mills
FFA	Federal Facilities Agreement
FRTR	Federal Remediation Technologies Roundtable
FS	Feasibility Study
FTA	Former Treatment Area
FTO	flameless thermal oxidation
GAC	granular activated carbon
GCO	Gold Coast Oil
GW	groundwater
GWTS	Groundwater Treatment System
HVDPE	High-Vacuum Dual-Phase Extraction
HPO	hydrous pyrolysis oxidation
ISB	in-situ bioremediation

ISCO	in-situ chemical oxidation
ISTD	in-situ thermal desorption
L.A.C&S	L.A. Clarke and Sons, Inc
MCL	Maximum Contaminant Level
mg	milligram
MNR	Monitored Natural Recovery
MPE	multi-phase extraction
NPL	National Priorities List
NTCRA	non-time critical removal action
OCDD	octachlorodibenzo-P-dioxin
OIA	Old Impoundment Area
PAH	polycyclic aromatic hydrocarbon
PAR	Performance Assessment Report
PCA	perchloroethane
PCE	perchloroethene (tetrachloroethene)
pg	picogram
PRB	permeable reactive barrier
P&T	pump and treat
RAO	Remedial Action Objective
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
ROD	Record of Decision
RPM	remedial project manager
RWQCB	Regional Water Quality Control Board
SCE	Southern California Edison
SLA	Sea Level Aquifer
SMS	Stamina Mills Site
S/S	solidification/stabilization
SVOC	semi-volatile organic compound
SRCPP	Solvent Refined Coal Pilot Plant
TCA	trichloroethane
TCDD	tetrachlorodibenzo-p-dioxin
TCE	trichloroethene
TCH	thermal conductive heating
TIFSD	Technology Innovation and Field Services Division
TPE	two-phase extraction
TN&A	TN & Associates
µg	microgram
USEPA	United States Environmental Protection Agency
UST	underground storage tank
UV Ox	Ultraviolet Oxidation
VC	vinyl chloride
VOC	volatile organic compound
VPY	Visalia Pole Yard
VSRP	Visalia Steam Remediation Project

VTS	Vapor Treatment System
WPS	Western Processing Site
WTP	water treatment plant
ZVI	zero-valent iron

1.0 INTRODUCTION

1.1 Purpose

The purpose of this report is to provide an overview of accomplishments at National Priorities List (NPL) sites that have employed conventional or innovative remediation technologies to address dense nonaqueous phase liquid (DNAPL) and/or associated dissolved, vapor, or sorbed phase contamination. It is particularly difficult to achieve regulatory goals at these kinds of sites because DNAPL is only sparingly soluble in water, which allows it to sustain aqueous or vapor phase plumes for decades or centuries, and it is denser than water, which facilitates its mobility to greater depths in the subsurface through non-resistive layers and bedrock fractures. Reverse diffusion, a process in which contaminants that have sorbed to solid subsurface matrixes diffuse back into groundwater or soil gas under certain conditions, poses additional challenges for site remediation. This report looks at 12 NPL sites that have addressed these challenges in a variety of ways, and summarizes their remedial performance to date.

This report highlights any remedial achievements these sites have made, such as meeting maximum contaminant levels (MCLs) or approved alternative concentration levels, removing significant quantities of contaminant mass from the subsurface, reducing the size and/or concentration of dissolved phase plumes, preventing migration of contamination, meeting other remedial action objectives (RAOs), employing unique or innovative technologies, or attaining deletion from the NPL.

1.2 Scope

This report provides a brief discussion of DNAPL characteristics and subsurface behavior, as well as a summary of several different DNAPL treatment technologies. Most of this report examines the use of these technologies at 12 hazardous waste sites currently or formerly on the NPL. This report discusses the implementation of several types of remedial technologies in a variety of hydrogeologic settings. The nature, volume and extent of contamination also vary significantly among the 12 sites. Sites affected by chlorinated volatile organic compounds (CVOCs) are the primary focus of this report because CVOCs are the most common source of DNAPL contamination at NPL sites (EPA 2004). However, sites affected by polynuclear aromatic hydrocarbons (PAHs) are also included, as PAHs are common DNAPL constituents as well.

2.0 DENSE NONAQUEOUS PHASE LIQUID IN THE SUBSURFACE

2.1 Characteristics

Dense nonaqueous phase liquids (DNAPLs) are a class of recalcitrant compounds that exist as a separate liquid phase in the presence of water, are generally denser than water, and are only sparingly soluble in water. Because of these characteristics, DNAPLs pose remediation challenges at many hazardous waste sites. DNAPLs can travel through fractured bedrock and unconsolidated sediment and migrate to significant depths below the water table. Because MCLs for common DNAPL chemicals are so low, such as 5 µg/L (ppb) for tetrachloroethylene (also known as perchloroethylene, or PCE), even slightly soluble compounds present at low concentrations can cause groundwater concentrations to exceed MCLs.

DNAPL is found at many industrial and commercial facilities, particularly those that use halogenated solvents, wood preservatives, coal tar derivatives, or certain pesticides. DNAPL may be single or multicomponent in chemical makeup. Most industrial waste and spent solvents that are discharged as DNAPL contain multiple compounds. DNAPL may consist of a mixture of multiple CVOCs or PAHs, in addition to other organic and inorganic chemicals that are miscible with the DNAPL (ITRC, 2003). Because the various compounds that may make up a particular DNAPL have different physical and chemical properties and are present in different percentages, they will consequently differ in the rate at which they dissolve in water, volatilize in unsaturated media, and sorb to solids.

Exhibit 1: Uses and Characteristics of Common DNAPLs

Class	Contaminants	Industrial Use	Density (kg/m ³)	Rate of Migration in Subsurface
			Viscosity (cP)	
Chlorinated Solvents	PCE, TCE, <i>cis</i> -1,2-DCE, 1,1,1-TCA, 1,2-DCA, chloroform, methylene chloride, CCl ₄ , chlorobenzene	Dry cleaning fluid, metal degreasers, pharmaceutical production, pesticide formulation, chemical intermediates	High (1,000 - 1,600)	Fast
			Low (0.57 - 1.0)	
Coal Tar	Hydrocarbons: BTEX compounds, PAHs such as naphthalene, benzo[a]pyrene, and phenanthrene	By-product of manufactured gas operations and blast furnace coke production	Low (1,010 - 1,100)	Slow
			High (20 to 100)	
Creosote	Coal tar distillates: PAHs and phenolic compounds	Wood preservative, component of roofing and road tars	Low (1,010 - 1,130)	Slow
			High (20 to 50)	
PCBs	Group of 209 congeners with multiple chlorine atoms attached to a biphenyl, such as Aroclor	Capacitors, transformer coolant, printing inks, paints, pesticides (Aroclor)	High (1,100 - 1,500)	Intermediate
			High (10 - 50)	

Based in part on Environment Agency 2003

Notes:

PCE = Tetrachloroethene
 TCE = Trichloroethene
 DCE = Dichloroethene
 TCA = Trichloroethane

DCA = Dichloroethane
 BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes
 PAH = Polynuclear Aromatic Hydrocarbon
 cP = centipoise

2.2 Fate and Transport

Both the hydrogeology of a particular site and the characteristics of the DNAPL itself affect the liquid's migration through the subsurface. Characterizing DNAPL distribution within a source zone can be challenging. Factors such as media permeability, heterogeneity, and matrix porosity, as well as DNAPL density, viscosity, and interfacial tension are varied and unique to every contaminated site. As a discharged DNAPL enters the subsurface, it typically flows downward as it moves through the vadose zone. When it encounters the saturated zone, capillary forces allow the liquid to form extensive horizontal layers connected by narrow vertical pathways as it follows the path of greatest permeability and least resistance (NRC 2005). DNAPL may exist in the soil or aquifer matrix in the form of entrapped, residual globules and ganglia, or as a potentially mobile, free-phase pool resting on top of a resistive layer such as clay or bedrock. The United States Environmental Protection Agency (USEPA) includes both residual and pooled DNAPL in its definition of source material (USEPA, 1991).

As shown in Exhibit 1, DNAPLs vary in density and viscosity depending on chemical make up, and this in turn affects their subsurface migration timescale. Chlorinated solvents released as DNAPL have a relatively high density and low viscosity, which facilitates speedier travel through soil and aquifer matrixes. In contrast, coal tar is quite viscous and tends to be less dense than chlorinated solvents. These properties help to explain why coal tar that leaked into the subsurface at a former manufactured gas plant may still be migrating as a DNAPL at the site 50 or 100 years later (Environment Agency 2003). Note that other factors, such as capillary effects and matrix porosity, influence DNAPL migration rates as well.

Over time, DNAPL source zones give rise to plumes of dissolved aqueous phase contaminants in the groundwater and/or gas phase contamination in unsaturated media, putting nearby humans and the environment at risk. Because DNAPL compounds are only sparingly soluble and thus have low dissolution rates, a source area can sustain a groundwater plume for decades or even centuries (see Appendix B for a solubility chart). Furthermore, in low-permeability or "stagnant" zones, dissolved aqueous phase contaminants can accumulate via diffusion, and sorb to solid materials in the aquifer or soil matrix. When contaminant concentrations in a plume are reduced during remediation or natural attenuation, sorbed contaminant mass may desorb into the groundwater again in order to obtain equilibrium. This process, known as reverse diffusion, contributes to plume persistence and can prevent MCLs from being reached in groundwater despite complete DNAPL depletion or source zone containment (Sale et al., 2005).

Because DNAPL constituents may diffuse into dissolved aqueous, gas, or sorbed phases, cleanup at sites affected by DNAPL entails more than just remediation of pooled product in a source zone. In order to meet regulatory criteria or other remedial objectives, it is equally important to assess and address groundwater plumes, volatile organic compounds (VOCs) in soil gas, and potential back diffusion of sorbed phase contaminants from solid matrixes.

3.0 DNAPL REMEDIATION TECHNOLOGIES

Because the nature and extent of DNAPL contamination at any individual waste site depends on unique factors such as hydrogeologic conditions and contaminant make-up, remedies must also be site-specific. Often it is favorable to employ a “treatment train” (USEPA, 2010) of different technologies used concurrently or sequentially in order to maximize remediation efforts at minimal cost. For example, thermal technology may effectively target a highly contaminated DNAPL source zone, but it would be difficult and costly to install an electrode system large enough to target a chlorinated solvent plume that extends for several thousand feet. Similarly, enhanced bioremediation may be less expensive than thermal technology, but bioremediation alone is unlikely to achieve remediation goals within a reasonable time period in a DNAPL source zone with high concentration levels and extremely large quantities of mass. Therefore, it may be advantageous to treat the source zone using a thermal technology to remove significant quantities of contaminant mass, while concurrently or subsequently implementing more passive, less costly remedies such as bioremediation to enhance in situ degradation of contaminants.

Exhibit 2 provides a brief overview of the most common remediation technologies employed at hazardous waste sites contaminated with DNAPL. Technologies are grouped into three categories: containment, physical removal, and chemical/biological treatment. DNAPL treatment technologies are discussed in more detail in the DNAPL section of USEPA’s CLU-IN website (www.clu-in.org/dnapl).

Exhibit 2: DNAPL Remediation Technologies

CONTAINMENT	
Physical Containment	Install impermeable barriers such as slurry wall (soil/bentonite or cement/bentonite), sheet pile, grout curtain, or cap around source zone
Hydraulic Containment	Intercept contaminant groundwater plume using extraction wells so that contaminants cannot migrate outside of the containment area (sometimes injection wells also are used to hydraulically isolate source zone)*
Permeable Reactive Barrier (PRB)	Intercept plume with continuous trench or funnel-and-gate barrier that treats groundwater with a reactive medium such as zero-valent iron (ZVI) as it passes through the barrier.
Solidification/Stabilization (S/S)	Solidify/stabilize soil and/or sludge with binding reagents such as cement, kiln dust, or lime/fly ash to prevent or reduce contaminant leaching
PHYSICAL REMOVAL	
Source Area Excavation	Excavate contaminated material by utilizing front loader (soil), backhoe (soil, sludge), pumping (sludge), or dredging (sediment)
Pump and Treat (P&T)	Remove groundwater via extraction well, then treat ex-situ at treatment plant
Multiphase Extraction (MPE)	Vacuum-extract air, water, and possibly NAPL via dual-phase extraction (DPE) or two-phase extraction (TPE) system. Lowers water table around the well, which may facilitate remediation of contaminants.
Surfactant/Cosolvent Flushing	Flush contaminated soil via injection or infiltration of detergents such as sodium dihexyl sulfosuccinate (surfactant) and/or alcohol such as isopropanol (cosolvent) to mobilize contaminants for extraction, collection, and treatment/disposal. Anionic or nonionic surfactants are most commonly used, as opposed to cationic.
Air Sparging*/Soil Vapor Extraction (SVE)	Utilize air injection wells to strip and volatilize contaminants below water table, then apply vacuum to capture VOCs/SVOCs from vadose zone and bring them to surface for treatment by adsorption to activated carbon or by thermal oxidation.
Electrical Resistance Heating (ERH)	Apply electricity to triangle (3-phase) hexagonal (6-phase) electrode arrangement in subsurface to heat soil and produce steam. Allow steam stripping/volatilization to occur, then remove contaminants with SVE.
In-Situ Thermal Desorption (ISTD)**	Also known as Thermal Conductive Heating (TCH). Use thermal blankets (shallow contamination) or thermal wells (contamination deeper than 1 m) to vaporize organic contaminants or destroy in-situ via oxidation or pyrolysis.
Steam Injection and Extraction	Steam injection techniques such as Dynamic Underground Stripping (DUS) flush/flood the treatment zone with steam to mobilize contaminants. DUS coupled with Hydrous Pyrolysis Oxidation (DUS/HPO) mixes oxygen with the steam to encourage in-situ chemical oxidation. Recovery wells capture contaminants, vapor, water and NAPL, which are then treated ex-situ.

*While primarily a physical removal technology, air sparging can also stimulate biodegradation of contaminants in the vadose and saturated zone

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

because it increases the amount of oxygen in the subsurface
 **Ex-situ thermal desorption processes can also be used to treat excavated waste

CHEMICAL/BIOLOGICAL TREATMENT	
In-Situ Chemical Oxidation (ISCO)	Induce redox reactions in contaminated source materials or dissolved-phase contaminants by applying oxidants such as potassium/sodium permanganate, hydrogen peroxide, Fenton's Reagent (H ₂ O ₂ + iron catalyst), sodium persulfate, or ozone.
In-Situ Chemical Reduction	Induce reductive dehalogenation of chlorinated organics by injecting zero-valent iron (ZVI) powder into contaminant zone, or mixing ZVI and clay in source zone to stagnate flow during reaction, or inject emulsified ZVI to target DNAPL, or utilize bimetallic nanoscale particle technology (ZVI + palladium catalyst).
Enhanced In-Situ Bioremediation (EISB)	While intrinsic bioremediation relies on natural degradation mechanisms, enhanced bioremediation uses biostimulation (add oxygen, organic substrates, or nutrients) and/or bioaugmentation (add necessary microorganisms such as <i>Dehalococcoides ethenogenes</i>) of the subsurface microbial environment to facilitate aerobic oxidation or anaerobic reductive dechlorination of contaminants.

Based in part on USEPA 2010, NRC 2005

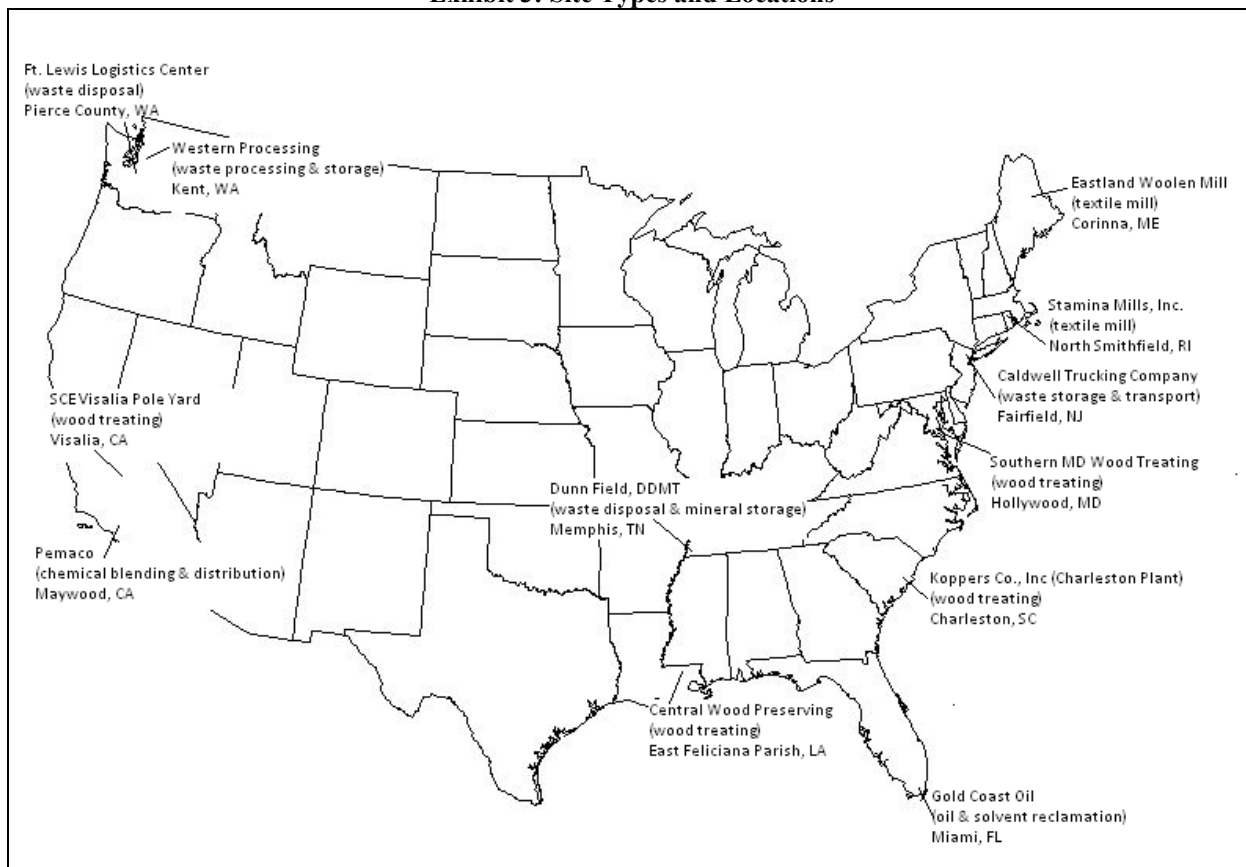
4.0 DNAPL CLEANUP AT 12 NPL SITES: SUMMARY AND ACCOMPLISHMENTS

The 12 DNAPL case studies included in this report were selected from USEPA's National Priorities List. Eight sites are currently on the final NPL and four sites have been delisted. These sites were selected based on the following criteria:

- Current or former NPL site
- DNAPL observed or suspected on-site
- Significant remedial accomplishments have been made, such as plume size/concentration reduction, plume containment, contaminant mass removal, unique or innovative technologies, NPL deletion, or meeting MCLs or other remediation goals.
- Adequate documentation of cleanup progress available

The selected sites are located in 10 states throughout the United States, as shown on the map in Exhibit 3. All 12 sites were placed on the final NPL in either the 1980s or 1990s. The majority of the sites in this report were primarily contaminated with CVOCs. Sites primarily affected by PAHs are also included. USEPA, State, and/or Potentially Responsible Parties (PRPs) are the leads at 10 sites, and two sites are federal facilities managed by the Department of Defense (DOD).

Exhibit 3: Site Types and Locations



4.1 GENERAL INFORMATION

Exhibit 4 provides general information about each of the 12 sites, such as remedial timelines, primary contaminants of concern (COCs), and any site highlights. The “Past Land Use” column is placed next to the “COC Category” column to show correlation between particular industries and associated waste products. For example, all four PAH sites are former wood treating facilities. These four facilities used the wood preservative creosote, which is primarily made up of PAH compounds. Land use at the VOC sites is more varied. Four sites were used for waste processing and/or disposal, two sites were textile mills, one site was an oil and solvent reclamation facility, and one site was a chemical blending and distribution center. While a number of these sites had COCs that do not fall under the category of PAH or VOC, such as pentachlorophenol (PCP) or heavy metals, this report focuses on VOCs and PAHs because these types of compounds are the primary constituents of DNAPL observed or suspected at the 12 sites.

Exhibit 4 also provides a list of the main remedial technologies implemented at each site. Bolded technologies were either highly effective, innovative, or uniquely implemented, and thus are particularly emphasized in this report. For example, while in situ solidification/stabilization (S/S) is a fairly common remedial technique, the Koppers (Charleston) site is one of the only sites in the US that has used this remediation method to stabilize contaminated sediments in a riverbed.

Sites were placed on the final NPL anywhere from 1983 to 1999. 10 sites have achieved construction completion. Of these 10 sites, the time between attaining final NPL status and construction

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

completion ranged from five to 17 years, with an average of ten years. Remediation is complete at five sites. Of these five sites, all except Dunn Field have been delisted from the NPL.

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

Exhibit 4: Summary of 12 Sites

Site Name, Location	Past Land Use	Type of COC	Remedy	Date Placed on Final NPL	Construction Complete	Deleted from NPL	Remediation Status	Site Highlights
Caldwell Trucking, NJ	Waste storage, transport	VOCs	EISB, P&T, SVE, S/S, PRB, excavation	1983	2004	2009	Ongoing	An EISB pilot study conducted in a DNAPL source zone.
Central Wood, LA	Wood treating	PAHs	Excavation, ex situ LTDD	1999	2010	-	Complete	Delisted from NPL
Dunn Field (OU), TN	Waste disposal, mineral storage	VOCs	ITSD, SVE, HVDPE, Air Sparging, P&T, Excavation	1992	2006	-	Complete	ITSD applied to eight source zones, all targets met
Eastland Woolen Mill, ME	Textile Mill	VOCs	ISCO, P&T, Excavation	1999	1992	1996	Ongoing	ISCO was used to treat residual DNAPL
Gold Coast, FL	Oil and solvent reclamation	VOCs	Air Sparging, P&T	1983	2003	-	Complete	Air sparging removed residual DNAPL, site delisted from NPL
Koppers (Charleston), SC	Wood treating	PAHs	In Situ S/S, excavation, DPE, soil and river caps, MNR, EISB	1994	-	-	Ongoing	Used in situ S/S to treat contaminated sediments in a riverbed
EGDY, Logistics Center, WA*	Waste disposal	VOCs	ERH, P&T	1989	2007	-	Ongoing	TCE concentrations fell from 100 ppm to below 100 ppb after ERH treatment
Pemaco, CA	Chemical blending, distribution	VOCs	ERH, P&T, HVDPE/SVE	1993	2001	2005	Ongoing	MCLs have been reached in some areas of TCE source zone after ERH treatment
S.M. Wood Treating, MD	Wood treating	PAHs	P&T, Sheet pile wall, excavation, ex situ LTDD	1986	2000	-	Complete	Delisted from NPL
Stamina Mills, RI	Textile Mill	VOCs	P&T, SVE, MPE, excavation	1983	2001	2009	Ongoing	MCLs have been achieved offsite, where TCE plume previously contaminated residential area
Visalia Pole Yard, CA	Wood treating	PAHs	Steam Remediation, EISB, P&T, slurry wall	1989	1991	-	Complete	Visalia Steam Remediation Project attained all standards. Site delisted from NPL.
Western Processing, WA	Waste processing and storage	VOCs	MNA & slurry wall, P&T, excavation, soil cap	1983	-	-	Ongoing	A VOC plume is degrading under MNA now that a slurry wall has cut off the source

Note: References contained in case studies

*EGDY (East Gate Disposal Yard) is the source zone at Logistics Center

4.2 SITE SIZES

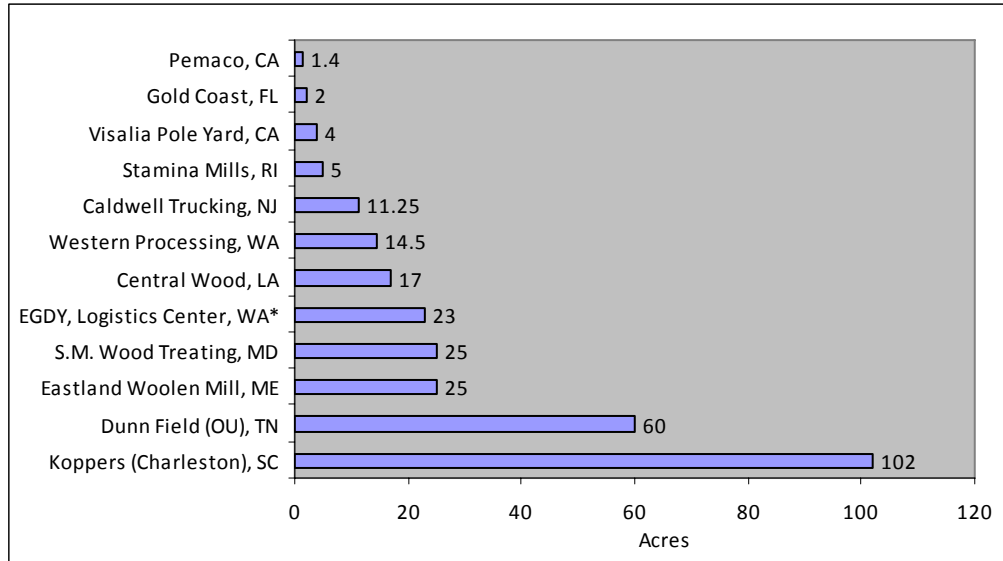
Site sizes range from one acre to 102 acres, with an average of 24 acres and a median of 16 acres.

Note that Exhibit 5 refers only to the 23-acre East Gate Disposal Yard (EGDY) at the Logistics

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

Center. While not specified here, the entire Logistics Center is 650 acres and therefore is actually the largest of the 12 sites. 60-acre Dunn Field is an operable unit of the Memphis Defense Depot site.

Exhibit 5: 12 Sites Listed by Acreage



Note: References contained in case studies
*EGDY (East Gate Disposal Yard) is source zone at Logistics Center

4.3 AQUIFER CONTAMINATION

Contamination affected groundwater at all sites except for Central Wood, where creosote contamination was mainly surficial. At five sites, contaminants have migrated into multiple aquifers. Current drinking water sources have been impacted at five sites, and one future potential drinking water source has been impacted. At one VOC site, Dunn Field, contamination may have entered the drinking water aquifer that underlies the contaminated aquifer, but long-term monitoring data indicates that this migration is occurring at very low levels, if at all. Contamination at all other VOC sites has affected drinking water sources, with the exception of Western Processing. Drinking water was not affected at any of the four wood treating facilities.

Exhibit 6: Aquifer Contamination at 12 Sites

Site Name and Location	Groundwater Affected	Multiple Aquifers Affected	Drinking Water Affected
VOC Sites			
Caldwell Trucking, NJ	×	×	×
Dunn Field (OU), TN	×	×	Possibly, at very low levels
Eastland Woolen Mill, ME	×		×
Gold Coast, FL	×		×
EGDY, Logistics Center, WA*	×	×	×
Pemaco, CA	×		× (future potential)
Stamina Mills, RI	×		×

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

Western Processing, WA	×		
<i>PAH Sites</i>			
Central Wood, LA			
Koppers (Charleston), SC	×	×	
S.M. Wood Treating, MD	×		
Visalia Pole Yard, CA	×	×	

Note: References contained in case studies

*EGDY (East Gate Disposal Yard) is source zone at Logistics Center

4.4 DNAPL PRESENCE

At all 12 sites, DNAPL was either observed during excavation and/or extraction, or it was suspected to be present based on subsurface sampling. Creosote, which is released as a DNAPL, was observed at all four wood treating PAH sites. Note that at one of these sites, Central Wood, creosote contamination was mainly surficial and therefore did not act as DNAPL because it did not migrate into the groundwater. DNAPL was also observed at three VOC sites, including both textile mills and Gold Coast. At all eight VOC sites, contaminant concentrations in the groundwater were detected at greater than one percent of their aqueous solubility, indicating presence of a DNAPL (Cohen and Mercer 1993). For example, TCE was present at Pemaco at a maximum of 22,000 µg/L, which is significantly higher than its aqueous solubility of 11,000 µg/L. Note that while DNAPL presence was suspected at Pemaco based on TCE concentrations, the actual amount of mass removed during thermal treatment was relatively low. This low recovery rate indicated that DNAPL was not present in the treatment area at the time of treatment (TN&A 2009).

Exhibit 7: Presence of DNAPLs at 12 Sites

Site Name and Location	DNAPL	
	Observed	Indicated by Concentration
<i>VOC Sites</i>		
Caldwell Trucking, NJ		×
Dunn Field (OU), TN		×
Eastland Woolen Mill, ME	×	×
Gold Coast, FL	×	×
EGDY, Logistics Center, WA*		×
Pemaco, CA		×
Stamina Mills, RI	×	×
Western Processing, WA		×
<i>PAH Sites</i>		
Central Wood, LA	×	
Koppers (Charleston), SC	×	
S.M. Wood Treating, MD	×	
Visalia Pole Yard, CA	×	

Notes: References contained in case studies

DNAPL is suspected to be present when the concentration of a chemical in groundwater is greater than 1 percent of its pure-phase solubility (see Appendix B, or Cohen and Mercer 1993)

*EGDY (East Gate Disposal Yard) is source zone at Logistics Center

4.5 CONTAMINANTS OF CONCERN

All 12 sites contained multiple COCs. The hydrogeologic conditions unique to each site influenced the fate and transport of these contaminants in the subsurface. Of the eight VOC sites, PCE was a COC at five sites, and TCE was a COC at seven sites. The only VOC site that was not affected by PCE or TCE is Eastland Woolen Mill, a textile mill that was primarily contaminated with chlorobenzene compounds. Various daughter products VOCs (DPVOCs), such as the carcinogen vinyl chloride, were also present at all eight sites. In Exhibit 8, daughter products that posed significant remedial challenges at a particular site are listed by name, while the term DPVOC is used to refer more generally to the various compounds that more highly chlorinated contaminants may degrade to over time. Other COCs found at one or more of the 12 sites were heavy metals such as arsenic, as well as PAHs and polychlorinated biphenyls (PCBs). Both soil and groundwater were highly contaminated with COCs at all eight VOC sites, and surface water contamination was problematic at four sites. Sediment was contaminated at both textile mills.

The primary COCs at the four PAH sites were wood treating chemicals. Creosote, a wood treating chemical that consists of various PAH compounds such as the carcinogenic PAH (CPAH) benzo(a)pyrene (B(a)P), extensively contaminated the land at all four sites. PCP, another wood preservative, was detected at three sites. At Visalia Pole Yard, wood was treated with a solution of PCP dissolved in a diesel oil carrier fluid. As a result, Visalia Pole Yard was also contaminated with diesel oil, which exists as a light NAPL (LNAPL). Additionally, dioxin, which can be present as a trace constituent in industrial grade PCP, was a COC at two sites. Two sites used the wood preservative chromated copper arsenate (CCA), which contains a mixture of chromium, copper, and arsenic formulated as oxides or salts. Contamination affected the soil at all four sites and the groundwater at three sites. Two sites had contaminated surface water, and three had contaminated sediment.

Exhibit 8: Specific Contaminants Treated at 12 Sites

Site Name and Location	Contaminants of Concern	Media			
		Soil	Groundwater	Surface Water	Sediment
<i>VOC Sites</i>					
Caldwell Trucking, NJ	PCE, TCE, 1,1,1-TCA, DPVOCs, PAHs, PCBs, metals	x	x	x	
Dunn Field (OU), TN	PCE, TCE, 1,1,2,2-PCA, DPVOCs, metals	x	x		
Eastland Woolen Mill, ME	Chlorobenzene (mono, di, tri, tetra)	x	x	x	x
Gold Coast, FL	PCE, TCE, DPVOCs, lead	x	x		
EGDY, Logistics Center, WA*	PCE, TCE, <i>cis</i> -DCE	x	x		
Pemaco, CA	PCE, TCE, DPVOCs	x	x		
Stamina Mills, RI	PCE, TCE, DPVOCs, PAHs, metals, dieldrin	x	x	x	x
Western Processing, WA	TCE, <i>cis</i> -1,2-DCE, DPVOCs, PCBs, metals	x	x	x	
<i>PAH Sites</i>					
Central Wood, LA	B(a)P and other CPAHs (creosote compounds), CCA	x			x
Koppers (Charleston), SC	CPAHs (creosote compounds), PCP, traces of dioxin, CCA, lead	x	x	x	x
S.M. Wood Treating, MD	B(a)P and other CPAHs (creosote compounds),	x	x	x	x

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

	PCP, VOCs				
Visalia Pole Yard, CA	B(a)P and other CPAHs (creosote compounds), diesel, PCP, dioxin	×	×		

Notes: References contained in case studies

DPVOC = Daughter Product Volatile Organic Compound, CPAH = Carcinogenic Polynuclear Aromatic Hydrocarbon.

*EGDY (East Gate Disposal Yard) is source zone at Logistics Center

4.6 TREATMENT TECHNOLOGIES

A wide variety of treatment technologies were employed at the 12 sites. Technologies generally fell under the category of containment, physical removal, thermal, or chemical/biological. The most common remedial technology was groundwater pump-and-treat (P&T), implemented at 11 sites, four of which used a multiphase extraction system (MPE). MPE is a type of groundwater extraction system that uses high powered vacuums to extract groundwater, soil vapor, and sometimes free product. MPE lowers the water table around extraction wells, effectively dewatering areas of the subsurface. One site did not have a P&T system because groundwater contamination was not an issue. Excavation of contaminated soil and/or sediment was the second most common remedial action, performed at eight sites. The containment method most frequently implemented among the 12 sites was a vertical engineered barrier. Electrical Resistance Heating was the most common in situ thermal technology, used at two sites. Of the six instances where chemical/biological technologies were employed, enhanced in situ bioremediation was applied most frequently, used at three sites.

Exhibit 9: Technologies Implemented at 12 Sites, Listed by Frequency of Use

Technology	Number of Sites
<i>Containment</i>	
Vertical Engineered Barrier	3
Solidification/Stabilization	2
Hydraulic Containment	1
Permeable Reactive Barrier	1
<i>Physical Removal</i>	
Groundwater Pump and Treat	11
Multiphase Extraction	4
Source Area Excavation	8
Soil Vapor Extraction	4
Air Sparging	2
<i>Thermal</i>	
Electrical Resistance Heating	2
Ex-situ LTTD	2
In Situ Thermal Desorption	1
Steam Remediation	1
<i>Chemical/Biological</i>	
Enhanced In Situ Bioremediation	3
In Situ Chemical Oxidation	1
Monitored Natural Attenuation (groundwater)	1

Monitored Natural Recovery (sediment)	1
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4.7 REMEDY ASSESSMENT

Progress has been made in addressing DNAPL and/or dissolved phase plumes, sorbed contaminants, or soil gas contamination at each of the 12 sites. Several sites have met some or all Record of Decision (ROD) remediation goals, and others are expected to meet objectives in the near future based on current monitoring data. Exhibit 10 assesses performance of select remedies at each of the 12 sites. While a comprehensive list of all technologies employed at each site can be found in Exhibit 4, Exhibit 10 reviews only the technologies that are of greatest interest and relevance to this report because they directly addressed DNAPL source zones or dissolved phase plumes and because they were either highly effective, innovative, and/or uniquely applied.

Pre and post-treatment contaminant concentrations are compared with ROD remediation goals for the target area, and mass removal and plume size reduction are also noted. Average and maximum concentrations pre- and post-treatment are provided as a means of assessing technology performance. Note that these four categories of concentrations were not consistently documented; at most sites, one or more of these concentrations was not readily available.

At the eight VOC sites, reported average initial individual CVOC concentrations in groundwater ranged from 88 µg/L to 16,656 µg/L. The highest reported maximum initial groundwater concentration, at 850,000 µg/L, was detected at Stamina Mills. Post-treatment concentrations ranged from non-detectable to 20,000 µg/L. Technologies reduced concentrations to the remediation goals for the treatment zone at three sites. The remaining five sites exhibit significant concentration reductions: One site has achieved onsite containment of a TCE plume and has achieved MCLs offsite, another has reached MCLs for all COCs in some monitoring wells where initial TCE concentrations were as high as 22,000 µg/L, maximum TCE concentrations have fallen from 100,000 µg/L to 500 µg/L at a third site, and a fourth achieved 96% reduction in trichlorobenzene (TCB) concentrations in an ISCO treatment area. The technology assessed at the fifth site, Caldwell Trucking, was a field test in which TCE and PCE concentrations were reduced by 93% and 95%, respectively. Overall, contaminant concentrations (particularly of degradation products) remain elevated at this site.

Percent reductions in individual CVOC concentrations ranged from 93 percent to 100 percent. Five VOC sites extracted contaminant mass from the subsurface during remedial action. Two sites destroyed mass in situ via chemical/biological means. One site, Western Processing, involved installation of a slurry wall coupled with Monitored Natural Attenuation. Plume size was considerably reduced at all four of VOC sites that reported plume size information.

At the four PAH sites, initial soil/sediment concentrations of B(a)P_{eqv} ranged from 0.059 mg/kg to 56,200 mg/kg. Post-treatment concentrations ranged from less than 0.1 mg/kg to less than 275 mg/kg. After implementation of the technologies listed in Exhibit 10, all PAH sites met ROD remediation goals in the treatment zone. Of the three sites that had groundwater plumes, one has reported plume size reduction; another has reported decreasing concentrations within the plume. Current plume information was not available for the third site.

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

Steam remediation at Visalia removed 1,330,000 lbs of contaminant mass, making it the site with the largest amount of mass removed. The most significant mass removals at the VOC sites occurred at the EGDY (Logistics Center) and Dunn Field (Memphis Defense Depot), which both removed over 12,500 lbs of contaminant mass. Thermal technologies were applied at both sites; electrical resistance heating (ERH) was used at EGDY, and in-situ thermal desorption (ISTD) was used at Dunn Field.

Overall, seven out of 12 sites have met remediation goals in target treatment areas. Percent reductions ranged from 93 to 100 percent.

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

Exhibit 10: Performance Assessment of Treatment Technologies of Interest at 12 Sites

Site Name, Location	Technology	Media	COC(s)	Initial Concentration	Post-Treatment Concentration	Percent Reduction	ROD Standard	Standard Met?	Contaminant Mass Removed	Plume Size Reduction
<i>VOC Sites</i>										
Caldwell Trucking, NJ	EISB (field test)	Groundwater	PCE	NR	131 (avg)	95%	5 (MCL)	N	N/A	N
			TCE	700,000	790 (avg)	93%	5 (MCL)	N		
Dunn Field, TN	ISTD	Soil	PCE	21.1 (max)	< 0.18	99.99%	0.18	Y	>12,500	Y
			TCE	671 (max)	< 0.182		0.182	Y		
			1,1,2,2-PCA	2850 (max)	<0.011		0.011	Y		
Eastland Woolen Mill, ME	ISCO	Soil	1,2,4-TCB	6,000,000 (max)	NR	96%	5	N	N/A	NR
Gold Coast, FL	P&T, Air Sparging	Groundwater	PCE	176 (avg) 100,000 (max)	ND	100%*	5 (MCL)	Y	1961	Y
		Groundwater	TCE	88 (avg) 48,000 (max)	ND	100%*	5 (MCL)	Y		
EGDY, Logistics Center, WA ¹	ERH	Groundwater	TCE	> 1,000 (avg) 100,000 (max)	69 (avg); 500 (max)	Approx. 95*	5 (MCL)	N	12,787	NR
Pemaco, CA	ERH	Groundwater	TCE	16,656 (avg) 22,000 (max)	Monitoring in progress, but MCLs reached in some monitoring wells	99%	5 (MCL)	N	40.5	NR
Stamina Mills, RI	P&T, SVE, MPE, excavation	Groundwater	TCE	850,000 (max)	Offsite <5 µg/L; Onsite 140 - 20,000 µg/L	NR	5 (MCL)	Offsite Y, Onsite N	3430 ²	Y
Western Processing, WA	MNA, slurry wall	Groundwater	cis-1,2-DCE	> 2000	ND	100%	70 (MCL)	Y	N/A	Y
<i>PAH Sites</i>										
Central Wood, LA	Excavation, LTTD	Soil	B(a)Peqv	0.059 - 56,200	0.08 - 210	NR	Risk-based criteria	Y	N/A	N/A
Koppers (Charleston), SC	Excavation, S/S	Soil, Sediment	B(a)Peqv	500 (max)	S < 20; SubS < 275	NR	S 20; SubS 275	Y	N/A	NR ³
S.M. Wood Treating, MD	Sheet pile, LTTD	Soil	B(a)Peqv	Tens to thousands	S < 0.1; SubS < 1	NR	S 0.1; SubS 1	Y	N/A	NR
		Sediment			< 3.2 (low MW); < 9.6 (high MW)	NR	3.2 (low MW); 9.6 (high MW)	Y		
Visalia Pole Yard, CA	Steam Remediation	Soil	B(a)P	42 (max)	< 0.39	NR	0.39	Y	1,330,000	Y
		Groundwater		5 (max)	< 0.2	NR	0.2	Y		

Notes: References contained in case studies

All soil and sediment concentrations in mg/kg. All groundwater concentrations in µg/L. All mass removal amounts in lbs. eqv = equivalent. NR = Not Reported. ND = Non-detectable. MW = molecular weight PAHs. S = surface. SubS = Subsurface

¹ EGDY (East Gate Disposal Yard) is source zone at Logistics Center

² As of 2004

³ Plume size not reported at Koppers, but plume concentrations are decreasing.

4.8 CONCLUSION

In 2003 a USEPA-sponsored DNAPL expert panel stated that, “As far as the Panel is aware, there is no documented, peer-reviewed case study of DNAPL source-zone depletion beneath the water table where U.S. drinking water standards or MCLs have been achieved and sustained throughout the affected subsurface volume, regardless of the in-situ technology applied” (USEPA 2003). Five years later, the Visalia Steam Remediation Project at the Visalia Pole Yard Superfund site attained all soil and groundwater remediation goals, becoming one of the best examples to date of a site with massive quantities of DNAPL in the saturated zone that has achieved and sustained drinking water standards following a source-mass depletion remedy. Even before the 2003 panel, groundwater sparging at the Gold Coast Oil Superfund Site reduced TCE and PCE concentration levels to non-detect in a DNAPL source zone, albeit a small area of localized contamination, and the site was delisted from the NPL in 1996. While these sites differed significantly in the nature and extent of contamination, DNAPL was present in the groundwater at both. This report found reliable sources of information that documented complete aquifer restoration to drinking water standards at these sites.

In addition to asking the obvious question, “Have MCLs been reached?”, perhaps another, better question to ask is, “Where have MCLs been reached?” At Stamina Mills, pump-and-treat technology with MPE/SVE has drawn back a TCE plume that had migrated offsite into a residential neighborhood and affected 50 residences. While further remedial activities are underway to address elevated concentrations onsite, MCLs have been achieved offsite, significantly reducing risks to nearby residents and the environment. At some sites, the nature and extent of contamination in some geologic settings may be such that it is impracticable to achieve MCLs sitewide, but there are still benefits to reducing the plume by partial source treatment or removal. A groundwater plume can still pose significant risks even if it is not being used as drinking water, due to the possibility of vapor intrusion, surface water exposure due to groundwater/surface water interfaces, migration of plume to drinking wells currently in use, noncompliance with institutional controls, ecosystem damage, unethical burdening of future generations, and unforeseen consequences. Because of these and other risks, DNAPL must be remediated to the maximum extent practicable.

It is also important to look at remedial progress at DNAPL sites even if contaminant concentrations still exceed MCLs or other RAOs, as some DNAPL sites appear to be fast approaching ROD remediation goals. For example, thermal treatments at Pemaco Superfund Site and Dunn Field (OU) have both reduced contaminant concentrations in the target area by an estimated 99 percent or more, and both are currently experiencing significant reductions in the sizes and concentrations of associated groundwater plumes. Based on current monitoring data, it appears likely that drinking water standards will be achieved in the future at these sites.

Another important question to ask when considering DNAPL remediation is, “How have MCLs been reached?” Based on the 12 case studies in this report, DNAPL source depletion is more effective than P&T in the long term, and reduces risks associated with containment. While the majority of DNAPL sites on the NPL, including some sites in this report, have not yet achieved drinking water standards site-wide, this statistic should not be used as a reason to shift attention away from source depletion and resort to containment or simply exposure prevention. Even if source depletion does not result in achieving MCLs in all affected areas, there are many other benefits associated with source removal/destruction. For example, once ERH addressed the most severely contaminated source areas

at the East Gate Disposal Yard, the nature and extent of contamination in other areas could be accurately evaluated, which is crucial to any successful remediation. Other benefits of source depletion include reductions in plume size, concentration, and longevity; reductions in mass flux from the source area; elimination of potentially mobile NAPL; shortened operation time period for P&T; and lowered net remedy cost. All of these factors are vital to USEPA's mission to protect human health and the environment.

In order to make more informed assessments of site remediation projects, more comprehensive documentation is needed on what effects source-mass depletion have had on groundwater quality in the source zone and the downgradient plume, as well as potential or actual vapor intrusion. Additionally, more research is needed to seek out and publicize other DNAPL sites that have achieved or are approaching drinking water standards or other remediation goals.

Based on the case studies in this report, DNAPL not only can be cleaned up but should be cleaned up to the best of our ability. This can be done in a cost-effective way; in fact, some of the most successful sites in this report saved money by applying aggressive source treatments in the beginning, reducing operations and maintenance costs over time.

APPENDIX A: CASE STUDIES

SECTION I: CHLORINATED VOLATILE ORGANIC COMPOUNDS

1. Caldwell Trucking Company

Fairfield Township, Essex County, New Jersey

Site Highlights

A full-scale field study at the Caldwell Trucking Company Superfund site demonstrated the use of enhanced in-situ bioremediation in a DNAPL source zone. After *Dehalococcoides ethenogenes* were injected into a chlorinated solvent source zone, contaminant concentration levels in some monitoring wells fell by over 93 percent and ethene concentrations increased in the area. The field test demonstrated that EISB is capable of fully dechlorinating compounds in this source zone.

Site History

The Caldwell Trucking site is an 11.25 acre facility that hauled and stored sewage from the early 1950s through 1988. Initially, the company disposed of both industrial waste and residential/commercial septic waste in unlined lagoons on site. In 1973 the company began using underground storage tanks to hold waste before off-site disposal until they abandoned waste storage in the early 1980s and became solely a transport facility. In 1988, the Caldwell Trucking Company ended all operations and went out of business.

The facility was placed on the final NPL on September 8, 1983. Over 300 private drinking wells have been closed since 1981 due to an extensive VOC groundwater plume emanating from this site. The OU-1 ROD, signed in 1986, focused on excavating contaminated soil, air stripping a municipal water supply well, and providing affected residents with an alternate water supply. An ESD removed the air-stripping portion of this remedy because the Town of Fairfield decided not to use the well. Another ESD modified the soil remedy, addressing disposal of certain waste materials and requiring stabilization of lead contaminated soils. In 1995, a ROD amendment required that excavation and off-site disposal of soils with VOC concentrations greater than 100 mg/kg, and in situ solidification/stabilization (S/S) of remaining soil contamination. Additionally, a soil vapor extraction (SVE) system was installed to address odors and soil gas emissions during S/S.

The OU-2 ROD, signed in 1989, called for P&T to intercept the groundwater plume. It also called for a technical impracticability waiver for groundwater. USEPA was unable to install groundwater recovery wells in fifteen locations due to access conflicts with local property owners, so an ESD called for well installation in the most highly contaminated areas of the lower water table aquifer and the upper bedrock aquifer (USEPA 2007). The OU-1 remedial action has been completed, and OU-2 action is currently underway.

Extent of Contamination

The primary source of soil, sludge, and groundwater contamination at the Caldwell site is industrial waste that was discharged into unlined lagoons during the 1950s, 60s, and early 70s. A CVOC groundwater plume extends 4,000 feet downgradient of the lagoons in the direction of the Passaic River, a recreational area and a local drinking water source (USEPA 2007).

The primary COCs found in the groundwater at the Caldwell site and nearby surface waters, including the Passaic River, are chlorinated VOCs (CVOCs) such as PCE, TCE, and daughter products. Residual DNAPL is suspected to be present in the fractured basalt bedrock aquifer beneath the glacial sand and gravel aquifer. TCE was detected in this source zone at levels up to 700 mg/L in 2005, which is about 60% of TCE solubility (see appendix B for solubility chart). In the soil, COCs consisted of metals, VOCs, SVOCs (PAHs), PCBs, and metals, largely from underground storage tanks (NRC 2005).

Remedial Action

Remedial action to date includes removal of underground storage tanks, soil and waste material excavation, S/S of metal-contaminated soils, soil vapor extraction (SVE) of VOCs, an iron reactive wall with a supplemental seep remediation system, enhanced in situ bioremediation (EISB), and hydraulic containment via P&T.

The SVE system operated from June 1996 to March 1997, until it was shut down due to odor complaints (NRC 2005). Next, 40,000 cubic yards (cy) of contaminated soils were stabilized from March through September of 1997. Additionally, an iron reactive wall was installed to intercept contaminated groundwater as it flows towards a surface water seep. As groundwater passes through the wall, contaminants should undergo abiotic degradation, forming harmless daughter products. However, the iron reactive wall did not sufficiently reduce contaminant concentrations to target levels, so the PRP installed a supplemental treatment system in 2002. Currently the iron wall is bypassed and an air stripper removes contaminants to meet permit requirements.

The PRP also conducted a full-scale field test of an enhanced biological treatment system from January 2001 to July 2002. The purpose of the test was to determine whether enhanced bioremediation was a viable tool that could be used to address residual DNAPL in the basalt bedrock, which is the source area giving rise to the VOC plume. The test goals were to accelerate the dissolution and treatment of source material and reduce the overall lifetime and impact of the source, rather than achieve specific concentration reductions (NRC 2005).

Groundwater conditions at Caldwell Trucking appear to be conducive to TCE biodegradation, which was already naturally occurring at low levels prior to the field test. A substrate feed including lactate, methanol, and ethanol, as well as a microbial supplement including *Dehalococcoides ethenogenes*, were injected into six nutrient injection wells screened in glacial deposits and bedrock. Seven monitoring wells were also installed.

A vapor intrusion study conducted by the PRPs was approved by USEPA in January 2007. The Work Plan included approximately 120 additional properties. In accordance with this Work Plan, the PRPs began sampling residential and commercial properties downgradient of the Caldwell Trucking Site in April 2007. Mitigation systems have been installed in many residences and there may be up to 25 systems required (USEPA 2010c).

Results

The SVE system removed significant quantities of contaminant mass from the subsurface. During the one year period in which it operated, the system recovered over 25,000 lbs of VOCs from the soil (USEPA 2005).

The EISB field test induced bacterial reductive dechlorination of contaminants in the residual DNAPL source zone during its 18-month test through July 2002.

- During a 30-month monitoring period, net reductions in PCE and TCE concentrations averaged 95% and 93% across the treatment zone, respectively (NRC 2005).
- Two out of seven monitoring wells in the EISB treatment area contained no PCE after the 30-month monitoring period, and one well had no detectable TCE. Breakdown products such as DCE and vinyl chloride remained at elevated concentrations in several wells (NRC 2005).
 - MW-B23: This overburden monitoring well exhibited disappearance of PCE and TCE coupled with ethene production. Concentrations of *cis*-DCE remained elevated, and vinyl chloride increased from December 2000 to December 2002. From December 2002 to September 2003, concentrations of both *cis*-DCE and vinyl chloride decreased to less than 20 u-moles/liter.
 - MW-C22: This is the bedrock well that had the highest TCE and PCE concentrations prior to EISB treatment. Post-treatment samples detected mixture of *cis*-1,2-DCE, vinyl chloride, and ethene.
- “Significant solvent reductions occurred in both injection wells and monitoring wells accompanied by large increases in ethene concentrations, indicating that a continuous treatment zone was present across the test area” (NRC 2005).

Table 1.1 EISB Field Test - Caldwell Trucking: Results Over 30-Month Monitoring Period

Location	Compound	Initial Concentration (µg/L)	Concentration Reduction (µg/L)	Average Net Reduction in Concentration	Degradation product production (µg/L)
Entire Treatment Zone	TCE	700,000	790	93%	Average observed ethene concentration was 723
	PCE	NR	131	94%	
Well C-22 (highest initial concentrations)	TCE	680,000	1,700	99.8%	Cis-DCE went from ND to 36,000 (then declined to 27,000), VC sustained at 2,000, ethene sustained at 30 – 40
	PCE	27,000	260	99.0%	

Sources: Finn et al. 2003, NRC 2005

The PRPs wanted to amend the P&T remedy, set forth in the 1989 ROD as amended by the 1993 ESD, and replace it with EISB. USEPA has not approved such an amendment, stating that while EISB does appear to be reducing VOC levels in the source zone, daughter products remain at elevated concentrations, indicating that P&T is necessary to hydraulically contain the groundwater plume (USEPA 2007). A P&T system was completed in December 2008. Monitoring data to date indicates that it is functioning as intended and that the most highly contaminated portion of the plume is contained (USEPA 2010c).

The PRPs have amended the EISB system and continue to perform voluntary bioaugmentation of the source zone. The 2007 Five Year Review indicated that groundwater contamination concentration levels are steadily decreasing, but remain above MCLs. Remedial activities continue and optimization studies are underway (USEPA 2007).

2. Eastland Woolen Mill

Corinna, Maine

Site Highlights

After performing initial removal actions, USEPA employed an innovative treatment technology, in situ chemical oxidation, at the Eastland Woolen Mill Superfund site (EWM) to address residual DNAPL remaining in the subsurface of this former textile mill. ISCO treatments reduced concentrations of chlorinated benzene compounds in the soil and groundwater, and appear to have reduced residual DNAPL mass. USEPA is currently considering applying ISCO to other DNAPL areas at the site.

Site History

The 25-acre EWM site was largely covered by a 250,000 square foot textile mill before the mill was demolished in 2000. From 1912 until 1996, EWM produced finished wool and blended woven fabric, which were dyed with the dye-aids Carolid MXS and Carolid EWS. These dye aids contained biphenyl and chlorinated benzene compounds. Until the Town of Corinna Wastewater Treatment Plant was constructed in 1969, the mill discharged all liquid wastes into the East Branch of the Sebasticook River (ESBR) watershed. After 1969, EWM began to discharge liquid waste to the plant, but eight years passed before all streams were redirected. Several storage tanks, above and below ground, contained fuel oil and other hazardous materials.

Groundwater contamination from EWM was first detected in 1983 by a restaurant in Corinna, where people noticed that the drinking water tasted and smelled unusual. Granular activated carbon filters were placed on affected drinking supplies, and Eastern Woolen conducted further investigations into the potential impact of the chlorinated benzene contamination on the local town. The PRP removed underground storage tanks and began pumping groundwater. Upon excavating a gravel riverbed in order to install a water supply line to serve affected residences, workers observed a DNAPL in the till beneath the riverbed. Further investigations determined that chlorinated benzenes were present at high concentrations in groundwater over 1,000 feet downstream from the mill. EWM was listed on the final NPL on July 22, 1999 (USEPA 2002a).

Extent of Contamination

The primary COCs at EWM are chlorobenzenes (mono, di, tri, and tetra). These chemicals not only contaminate the overburden soil and bedrock beneath the building facilities, but also the river sediment and underlying soil up to 1,000 feet downgradient from the site. Additionally, DNAPL was detected in the soil beneath the building and the river. DNAPL has migrated through the entire soil profile, leaving residual trails. It has accumulated along the bedrock in some areas, where it has migrated horizontally and entered fractured bedrock (USEPA 2002a). No DNAPL samples have been collected and analyzed, but data indicates that the DNAPL is mostly composed of 1,2,4-trichlorobenzene (Nobis 2009). The ESBR groundwater exceeds federal and state drinking water standards, and contamination has impacted several water supply wells. Initial COC groundwater concentrations were not available, but maximum soil concentrations are provided in Table 2.1.

Table 2.1 Initial COC Concentrations in Soil at EWM

Compound	Maximum Soil Concentration (mg/kg)
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Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

1,2,4-Trichlorobenzene	6,000,000
1,2-Dichlorobenzene	2,000,000
1,3-Dichlorobenzene	37,000
1,4-Dichlorobenzene	1,000,000
Chlorobenzene	530,000

Source: USEPA 2002a

Remedial Action

After the State removed hazardous materials from the site, USEPA excavated and treated 75,000 cy of soil beneath the building and along the EBSR as part of a non-time critical removal action (NTCRA) in 1999. Table 2.2 provides soil cleanup goals. Several NTCRA activities occurred through 2004, including relocation of the new EBSR riverbed, restoration of the former Mill Pond, and repair of Corundel Dam.

The remaining components of the remedy were divided into two operable units. OU-1 includes groundwater and remaining NAPL, and OU-2 includes sediments and floodplain contamination downstream from the mill. After a successful pilot test, contractors Nobis and XDD conducted full-scale ISCO applications to the Phase II soil and Phase III shallow bedrock treatment zones of Area 1 (see Figure 2.1). The chosen oxidant, iron-catalyzed sodium persulfate (ICP), was injected several times between 2005 and 2007.

ISCO Performance Assessment at EWM

- 2005, Phase II injection: Dissolved COC levels in GW reduced by an estimated 63%
- 2006, combined Phase II/III injection: residual contaminant mass in soil reduced by estimated 73%; dissolved contaminant mass in GW reduced by 27%
 - Results indicate residual DNAPL is sustaining contamination in soil, bedrock area, and GW
 - 2007, Phase II and III: Additional injection to address residual DNAPL
- 2007, combined Phase II/III injection: 14,572 gallons sodium persulfate into Phase II area, 7,283 gallons into Phase III. 40% reduction in target compound dissolved mass.
- Total mass reduction: 68% for residual COCs, 70% for dissolved COCs, 63% for residual TVOCs.

Source: Nobis 2009

Table 2.2 Cleanup Levels at EWM

Compound	Soil NTCRA Cleanup Level, µg/kg	Groundwater MCL (µg/L)
1,2,4-Trichlorobenzene	5,000	600
1,2-Dichlorobenzene	17,000	600
1,3-Dichlorobenzene	41,000	-
1,4-Dichlorobenzene	2,000	75
Chlorobenzene	1,000	100
Benzene	30	5

Source: Nobis 2009, USEPA 2002a

Results

NTCRA activities eliminated all soil contamination above the water table and most of the soil contamination below the water, including the majority of the DNAPL (USEPA 2002a). ISCO has reduced the overall level of remaining contamination. ISCO reduced total soil COCs by 84

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

percent, and reduced total groundwater COCs by 76 percent. In addition, residual COCs have been reduced by 68 percent, and dissolved COCs have been reduced by 63 percent.

Table 2.3 Percent Reductions in Soil and Groundwater COCs After ISCO Treatments

Soil COC	% Reduction in Average Concentration 2004 Pre-ISCO to 2009 Post-ISCO	% Reduction in Maximum Concentration 2004 Pre-ISCO to 2009 Post-ISCO
1,2,4-Trichlorobenzene	87%	96%
Chlorobenzene	77%	86%
1,2-Dichlorobenzene	67%	79%
1,3-Dichlorobenzene	67%	80%
1,4-Dichlorobenzene	66%	77%
Total COCs	84%	93%
Groundwater COC	% Reduction in Average Concentration 2004 Pre-ISCO to 2009 Post-ISCO	% Reduction in Maximum Concentration 2004 Pre-ISCO to 2009 Post-ISCO
Chlorobenzene	83%	79%
1,2-Dichlorobenzene	76%	65%
1,4-Dichlorobenzene	75%	67%
1,3-Dichlorobenzene	71%	59%
1,2,4-Trichlorobenzene	67%	38%
Total COCs	76%	65%

Table from Nobis 2009

The highest relative concentration reduction during initial ISCO injections in 2004 and 2005 was in 1,2,4-trichlorobenzene (TCB), the primary compound that makes up the DNAPL. During 2009 post-ISCO groundwater sampling, TCB was detected in 22 out of 22 samples at concentrations ranging from 2 µg/L to 7,500 µg/L, with an average of 1,671 µg/L. Eight samples were below 70 µg/L, which is the IGCL for TCB. This indicates that ISCO reduced the amount of residual DNAPL mass in the source zone (Nobis 2009). Further remediation is needed to address remaining pooled or residual DNAPL in Area 1.

Oxidant treatment efficiencies decreased with each ISCO application, from 22 pounds of oxidant consumed per pound of COCs destroyed (2006 Phase II Injection #1) to 33 pounds of oxidant consumed per pound of COCs destroyed by the final injection. This decrease was expected because the initial injections reacted with the most accessible DNAPL, while subsequent injections treated less accessible sorbed VOC mass (Nobis 2009). In addition, compound-specific concentrations vary considerably as free-phase compounds partition into sorbed and dissolved phases. DNAPL composition evolved as the more soluble compounds diffused from the liquid's surface, leaving behind lower solubility COCs such as 1,2,4-trichlorobenzene.

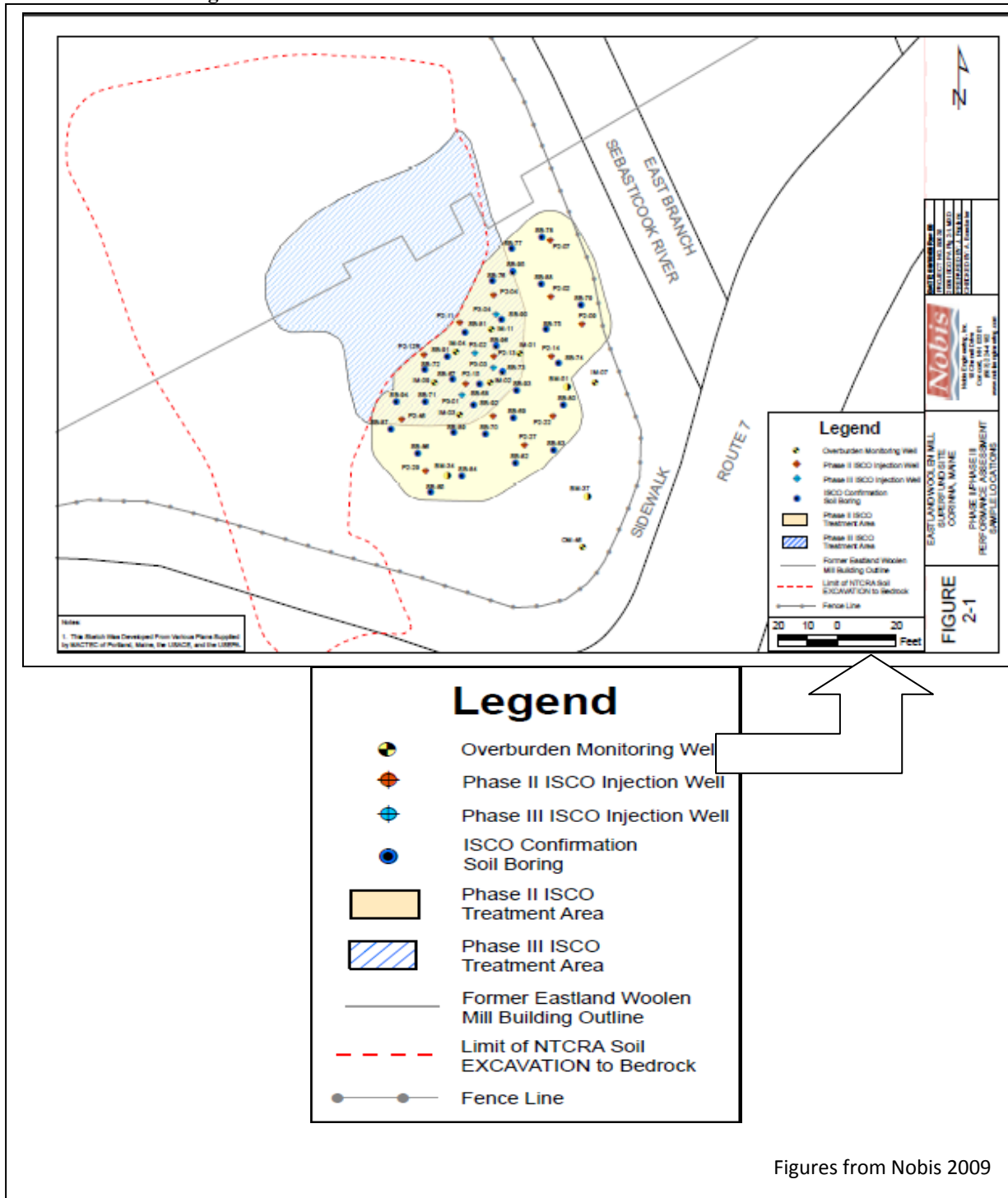
Initially, dissolved phase VOC concentration levels increased as the iron-catalyzed persulfate worked to transfer DNAPL and residual contaminant mass into the dissolved phase. Once enough mass transfer had occurred, the oxidant could react directly with dissolved phase VOCs,

rather than being consumed when reacting with desorbed mass. As ICP free radicals attacked the dissolved phase VOCs, the reaction generated daughter-product VOCs (DPVOCs).

While the concentrations and mass of these intermediate compounds have decreased overall, chloromethane (also called methyl chloride) and other intermediate compounds remain above applicable standards. The 2009 Performance Assessment Report (PAR) determined that ICP reactions and natural bioattenuation are effectively reducing DPVOC concentrations, but polishing treatments such as enhanced bioremediation may also be employed to further address DPVOCs (Nobis 2009).

In 2008, USEPA determined that the remedial action at EWM is operational and functional, and the site has entered the 10-year long-term remedial action period. A pilot study was conducted in 2007 to determine the effectiveness of ISCO on deep bedrock contamination, and results are currently being evaluated (Nobis 2009).

Figure 2.1 Phase II/III ISCO Treatment Area at Eastland Woolen Mill



Figures from Nobis 2009

3. Fort Lewis Logistics Center

Pierce County, Washington

Site Highlights

Fort Lewis received the fiscal year 2005 Secretary of Defense Environmental Award for Environmental Restoration for utilizing innovative thermal technology to address chlorinated solvent source zones at the Logistics Center. After a large-scale, complex treatment of three NAPL source zones using Electrical Resistance Heating (ERH), average TCE concentrations in the treatment zone fell from a historic maximum of 100 ppm to below 100 ppb. The Logistics Center case provides several lessons for other chlorinated solvent sites considering thermal remediation technology.

Site History

The 87,000-acre Fort Lewis Army facility, established in 1917, is the United States Army's fourth most populous military installation. Aircraft and vehicle maintenance, weapons repair and refurbishing, and caustic paint stripping waste/battery acid neutralizing operations are the main industrial activities that have taken place at Fort Lewis. The 1990 Federal Facilities Act (FFA) identified 16 CERCLA sites at Fort Lewis. The Army, represented by the Fort Lewis Environmental Restoration Program (ERP), is the lead agency for these sites. No Further Action is the selected remedy for seven sites, remedy selection is in process for one site, and selected remedies are currently being implemented at eight sites. Five of these eight sites are non-NPL CERCLA sites. The remaining three sites are the Logistics Center NPL site and its two operable units, Landfill 4 and the Solvent Refined Coal Pilot Plant (SRCPP). These were listed as three separate units in the 1990 FFA.

The 650-acre Logistics Center NPL site is the largest and most impacted site. The three major remedial projects at this site are occurring at the East Gate Disposal Yard (EGDY) next to the Logistics Center, SRCPP, and Landfill 4. The main focus of this case study is the EGDY/Logistics Center.

Logistics Center: This site has three main contamination units: the source area and two aquifers. The EGDY, also known as Landfill 2, is the 23-acre source area immediately southeast of the Logistics Center. The Logistics Center disposed of its cleaning and degreasing waste at EGDY from 1946 and 1960. This landfill has given rise to a large TCE plume that is affecting the unconfined Vashon Aquifer and has spread to the Sea Level Aquifer (SLA). The aquifers beneath the Logistics Center are drinking water sources.

SRCPP: The 25-acre SRCPP area was used by the Department of Energy from 1974 to 1981 to develop a solvent extraction technology capable of deriving petroleum-like products from coal.

Landfill 4: Solid waste disposal occurred in this 52-acre area from 1951 to 1967.

The Vashon Aquifer contamination was discovered in 1985. The Logistics Center was placed on the final NPL, with Landfill 4 and SRCPP as operable units, on November 21, 1989.

Extent of Contamination

Logistics Center: While petroleum, oils, lubricants, PCE, TCE and its degradation products *cis*-1,2-dichloroethene (DCE) and vinyl chloride (VC) were all detected at EDGY, TCE is the primary contaminant of concern. TCE is present in multiple locations over the 23 acre source area, often as a NAPL. The most highly contaminated areas have been designated as NAPL Areas 1, 2, and 3.

The TCE plume extends down the Vashon Aquifer from the source area for approximately two miles. About halfway down this plume, TCE also enters the SLA via a hydrogeologic preferential pathway, from which it extends in the SLA for approximately 2.5 miles. The level of TCE in both aquifers exceeds the ROD goal of 5 µg/L, which is the drinking water standard for TCE. TCE has been historically detected in the groundwater beneath the Logistics Center at a maximum concentration of 100,000 µg/L (USEPA 2007a).

SRCPP: Coal production and research activities resulted in soils contaminated with polycyclic aromatic hydrocarbons (PAHs).

Landfill 4: Chlorinated organic compounds such as TCE and VC leached into the soils and Vashon Aquifer groundwater.

Remedial Action

Logistics Center: The remedial action objectives stated in the 1990 ROD are to restore groundwater at the Logistics Center to MCLs, and to prevent contamination above MCLs from spreading beyond the site boundaries. During the remedial investigation (RI), the Army connected private drinking wells affected by contamination to other clean water sources. Between 1992 and 1995, one P&T system at EGDY and two systems downgradient from the landfill were constructed to contain the Vashon Aquifer plume, and they began operating in 1995. The EGDY P&T system was updated in 2005, adding four more wells to the original four extraction wells. Investigations to evaluate contamination in the SLA also began in 1992, but construction of an SLA P&T system did not begin until 2007. The Army performed a significant removal action at EGDY in 2000, digging up and removing over 1,000 buried waste drums. In situ thermal treatment of the source area occurred between 2003 and 2007. P&T is ongoing (USEPA 2010a).

Table 3.1 MCLs for COCs at Logistics Center

Groundwater	
TCE	5 ppb
<i>cis</i> -DCE	70 ppb
PCE	5 ppb
Surface Water	
TCE	80 ppb

Source: USEPA 2007a

ERH was the thermal technology chosen to treat NAPL Areas 1, 2, and 3 at EGDY over a four year period. During each ERH application, an array of electrodes spaced about 6 meters apart heated the subsurface. The increasing temperature enhanced contaminant extraction by volatilizing chemicals, and decreased fluid viscosity to allow for extraction of liquids (NAPL). In

addition, some contaminants may be oxidized/degraded in-situ during thermal treatment. NAPL Area 1 was the first treatment zone to undergo ERH, followed by Areas 2 and 3. Table 3.2 provides information about the target zone sizes and remedy operation timescales. Recovered liquid and vapor from the subsurface at EGDY was separated by phase and treated with thermal oxidation (Truex et al. 2009).

Table 3.2 ERH at EGDY: NAPL Area Size and Time of Operation

Parameter	NAPL Area 1	NAPL Area 2	NAPL Area 3
Treatment Surface Area (m ²)	2,400	2,080	1,700
Maximum Depth (m bgs)	10	16	9
Treatment Volume (m ³)	23,600	14,000	15,400
Energy On Date	12/17/2003	2/14/2005	10/11/2006
Energy Off Date	8/4/2004	8/5/2005	1/26/2007
Treatment Duration (days)	231	172	107

Table from Truex et al. 2009

SRCPP: 80,000 cy of PAH-contaminated soils were excavated and treated with low-temperature thermal desorption. Desorbed gases were incinerated.

Landfill 4: From 1996 to 2000, soils and shallow groundwater were treated with an air sparging/SVE system.

Results

<p>Electrical Resistance Heating at EGDY: Post-Treatment Results in Treatment Zones (NAPL Areas 1, 2, and 3)</p> <ul style="list-style-type: none"> • 12,787 lbs of VOCs (TCE and DCE) extracted • Groundwater TCE concentrations reduced from 100 ppm to less than 100 ppb • Soil TCE concentrations decreased by over 96% • Contaminant mass flux from EGDY reduced by 60% to 90% <p align="right">Source: Truex et al. 2009</p>

ERH at EGDY has effectively targeted NAPL source zones. Performance results are shown in the boxed text. According to a 2009 assessment of ERH at EGDY, “ERH treatment appeared to be robust in removing mass from the targeted zone with a minimal rebound of contamination observed” (Truex et al. 2009). The thermal remediation project at the Logistics Center was successful and can be used as a model for future thermal operations.

While other contaminated areas of EGDY not treated with ERH continue to be problematic, the most severely contaminated source areas have been addressed and no longer obscure attempts to evaluate the nature and extent of contamination in these other areas (Truex et al. 2009). Planning for future remedial action is currently in motion, and meanwhile the P&T system is an effective means of hydraulic containment of the source area.

Table 3.3 Groundwater TCE Concentration Reductions Within ERH Treatment Areas at EGDY

Remediation Goal	Pre-ERH Concentration		Post-ERH Concentration	
	Maximum	Average	Maximum	Average
5 ppb	100,000 ppb	> 1,000 ppb	500 ppb (2007)*	69 ppb (2009)

Source: Truex et al. 2009

The 2009 Assessment attributes the success of ERH at EGDY to the ERP's use of a "flexible, adaptive approach using multiple types of information to oversee the process and make decisions. Rigid requirements or use of a single performance metric would have been difficult to use to effectively manage the process" (Truex et al. 2009). Due to source removal (drum removal and in-situ thermal treatment), the timescale over which the P&T system at EGDY must be operated has been reduced from centuries to decades (USEPA 2007a). The average cost for treatment, project oversight, and electricity of the three treatment zones was \$143/cy in 2009 (Truex et al. 2009).

Landfill 2 is currently considered an industrial cleanup area, but future land use may be commercial or industrial. The future land use downgradient from Landfill 2 that overlies the Vashon and SLA TCE plumes will be primarily industrial with some residential, medical (equivalent to commercial), and open space (USEPA 2007a).

SRCPP: Cleanup was completed in 1997. Groundwater and surface water monitoring occurred until 1999. Land use controls are still in effect because some PAH levels exceeded the ROD goal in the Vashon Aquifer in 1996. There are no complete exposure pathways or potential current drinking water receptors. Administration buildings (equivalent to commercial) constitute current and anticipated future land use. Underlying groundwater currently meets drinking water standards (USEPA 2010a).

Landfill 4: Groundwater monitoring is ongoing because TCE and vinyl chloride levels are above ROD goals in some monitoring wells. However, human risk of exposure to contamination from this site is low. There are no complete exposure pathways and only one potential current drinking water receptor, which is 1200 feet upgradient of Landfill 4. Land use controls are in place. Current and anticipated future land use is restricted training (USEPA 2007a).

4. Gold Coast Oil Company, Inc.

Miami, Dade County, Florida

Site Highlights

The Gold Coast Oil Superfund site (GCO) is a case in which a chlorinated solvent plume in the Biscayne Aquifer was essentially eliminated in four years using P&T and air sparging in the DNAPL source zone. All cleanup goals, including meeting MCLs for all six VOCs detected in the groundwater, were achieved within four years, and the site has been delisted from the NPL.

Site History

Owned by CSX Transportation Corporation, the two-acre GCO property was leased to Gold Coast Oil in 1970. Gold Coast Oil and Solvent Extraction Inc. used the property to operate a mineral spirits and lacquer thinner distillation factory. The companies disposed of all spent oil and solvent waste on site, either by direct discharge to the soil or improper tank storage.

After Dade County Department of Environmental Resource Management and the Florida Department of Environmental Protection reported detections of soil and groundwater contamination at GCO to USEPA, the three organizations investigated the site and discovered that the soil was heavily contaminated with heavy metals and organics, and groundwater contained VOCs at levels that exceeded drinking water standards. 2,500 corroded drums full of distillation/paint sludge and contaminated soils were found leaking into the subsurface, in addition to large hazardous waste storage tanks and a tank truck. In 1982, CSX Transportation evicted Gold Coast Oil due to regulatory violations, and agreed to properly dispose of remaining hazardous liquids and solids off site.

At GCO, the water table is 5 feet below ground surface (bgs), and is part of the Biscayne Aquifer that supplies drinking water to Dade County. The extensive groundwater contamination posed a significant risk to humans and the environment, and USEPA placed the site on the NPL in September 1983. USEPA is the lead agency for all CERCLA activities at GCO (USACE 2001).

Extent of Contamination

The contaminants of concern at GCO were VOCs, including the chlorinated solvents TCE and PCE. Table 4.1 provides a full list of contaminants of concern found at the site, including initial concentrations, MCLs, ROD remediation goals, and post-treatment reductions. DNAPL was present in the groundwater, indicated by the presence of TCE and PCE at greater than 1 and 60 percent of their aqueous solubilities, respectively (see Appendix B), as well as visual observations on site. A TCE/PCE plume developed in the DNAPL source area with an initial areal extent estimated at 0.87 acres and initial volume estimated at 2,834,700 gallons (see Figure 4.1) (USEPA 1998a).

Remedial Action

Primary remedial actions included P&T and air sparging. After the ROD was issued in 1987, immediate removal actions took place such as drum and tank disposal and building demolition. Soil remediation including excavation of 683 tons of contaminated soils and hardened waste

sludges occurred from 1989 to 1990. The contaminant plume had not reached any private or municipal wells, so well reconnections were not necessary.

A P&T system operated from July 1990 to March 1994, treating extracted groundwater with an air stripper before discharging it into the Biscayne Aquifer. The groundwater recovery, treatment, and discharge system operated 21 wells and two air strippers. The porous limestone at GCO, a common geologic formation in Southern Florida, facilitated groundwater extraction (USEPA 1998a). Within one year of operation, the groundwater extraction system treated over 25 million gallons of water and reduced all COC concentration levels to below ROD goals with the exception of TCE and PCE. The remaining contamination was confined to two monitoring wells in the suspected DNAPL zone, MW-11 and MW-13.

Subsequent remedial action focused on the chlorinated solvent groundwater plume near MW-11 and MW-13, the source of which was most likely residual DNAPL trapped in the aquifer matrix (USEPA 1998a). Two unsuccessful attempts were made to address the PCE/TCE plume surrounding these wells. First, hydrogen peroxide was applied to the contaminated groundwater from March through July 1993. Second, the P&T system was shut down from August to November 1993 to encourage TCE/PCE desorption from the aquifer matrix into the groundwater. However, no significant desorption increase occurred and dissolved TCE/PCE lingered in groundwater in this area due to low hydraulic gradient that essentially prevented groundwater movement without pumping (USEPA 1998a).

Neither of these actions achieved significant reductions in contaminant concentration levels; maximum concentrations remained at 6 µg/L for TCE and 24 µg/L for PCE (USEPA 1998a). The area of recalcitrant PCE/TCE was confined to a 200 square foot area and extended to 30 feet bgs. Monitoring data during a temporary system shutdown indicated that P&T was no longer reducing concentrations, and USEPA officially shut the system down in May 1994.

In November 1994, soil near MW-11 and MW-13 suspected to contain DNAPL was excavated. Surprisingly, no PCE or TCE was detected in the excavated soil. Finally, the groundwater in the excavated area was sparged using a portable air sparger. Because TCE/PCE concentrations dropped after sparging, falling below ROD goals, it appears that the DNAPL was in the groundwater (USEPA 1998a).

Results

The soil remediation efforts that were completed in March 1990 sufficiently addressed heavy metal contamination. The P&T system contained and reduced the size of the groundwater plume throughout its operation from 1990 to 1994, and reduced levels of all COCs except PCE and TCE to below ROD standards within one year of operation (USEPA 1998a). P&T system did significantly reduce TCE and PCE concentrations during the first year of operation (see Table 4.1), but concentrations leveled off after that, indicating that the system was no longer as effective in reducing these concentrations.

1991 – 1994 P&T System Performance Data

- 1,961 pounds of TCE and PCE removed from groundwater
- Mass flux rate declined from 3.4 lbs/day (1991) to 0.006 lbs/day (1994)

Source: EPA 1998a

Air sparging proved to be an effective means of reducing the concentrations of PCE and TCE in the DNAPL source zone to

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

below MCLs. USEPA’s Cost and Performance Report concluded that, “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” (USEPA 1998a). The cleanup activities at GCO reduced all COC concentrations to below detection limits within four years, meeting all cleanup standards.

Table 4.1 Contaminants of Concern at Gold Coast Oil Superfund Site: Goals, Maximums, and Reductions (µg/L)

COC	2001 Federal MCL Value	1997 ROD Standard	Maximum Initial Concentrations	1991 Concentration (After 1 year of P&T)	October 1996 Concentration (1 year after P&T shutdown)
1,1-DCA	None*	5	2000	below MCL	BDL
<i>trans</i> -1,2-DCE	100	70	3000	below MCL	BDL
methylene chloride	5	5	100	below MCL	BDL
toluene	1000	340	545	below MCL	BDL
PCE	5	0.7	100,000 (avg 176)	8	BDL
TCE	5	3	48,000 (avg 88)	9	BDL

*MCL for 1,1-DCA is 5 µg/L

The ROD standards are at or below Federal MCLs.

BDL = Below Detection Limit (PCE detection limit = 0.5; for all other compounds, detection limit = 1.0)

Sources: USEPA 1998a, USACE 2001

According to the Cost and Performance Report from 1998, “Actual costs for the pump-and-treat application at Gold Coast were approximately \$694,325 [capital costs and 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” (USEPA 1998a). Region 4 deleted the GCO site from the NPL on October 9, 1996. All monitoring wells were abandoned in 1997.

Figure 4.1 DNAPL and Plume Distribution at GCO, Pre-Treatment and After 1 Year of P&T

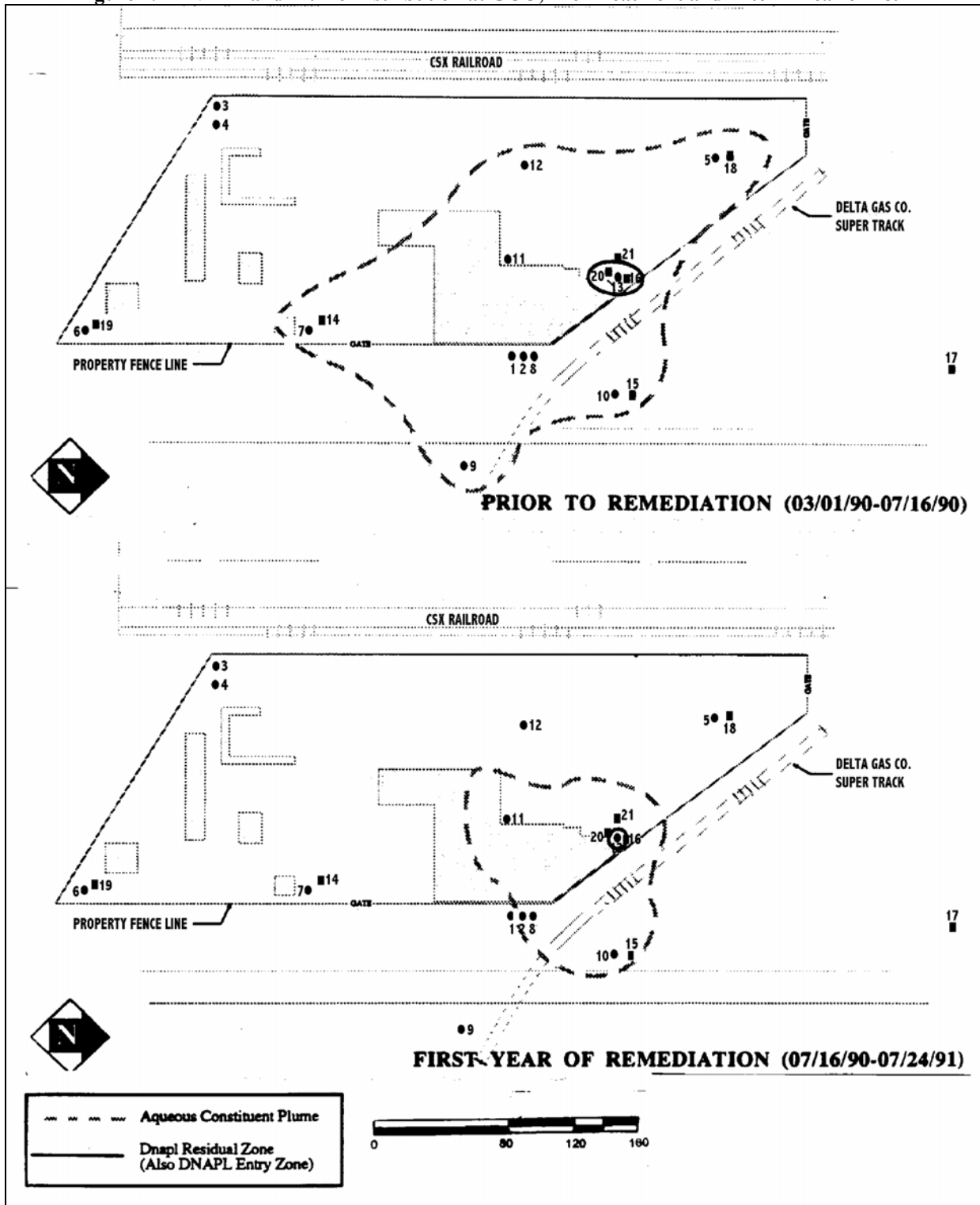


Figure from USACE 2001

Figure 4.2 DNAPL and Plume Distribution at GCO, Post-Sparging

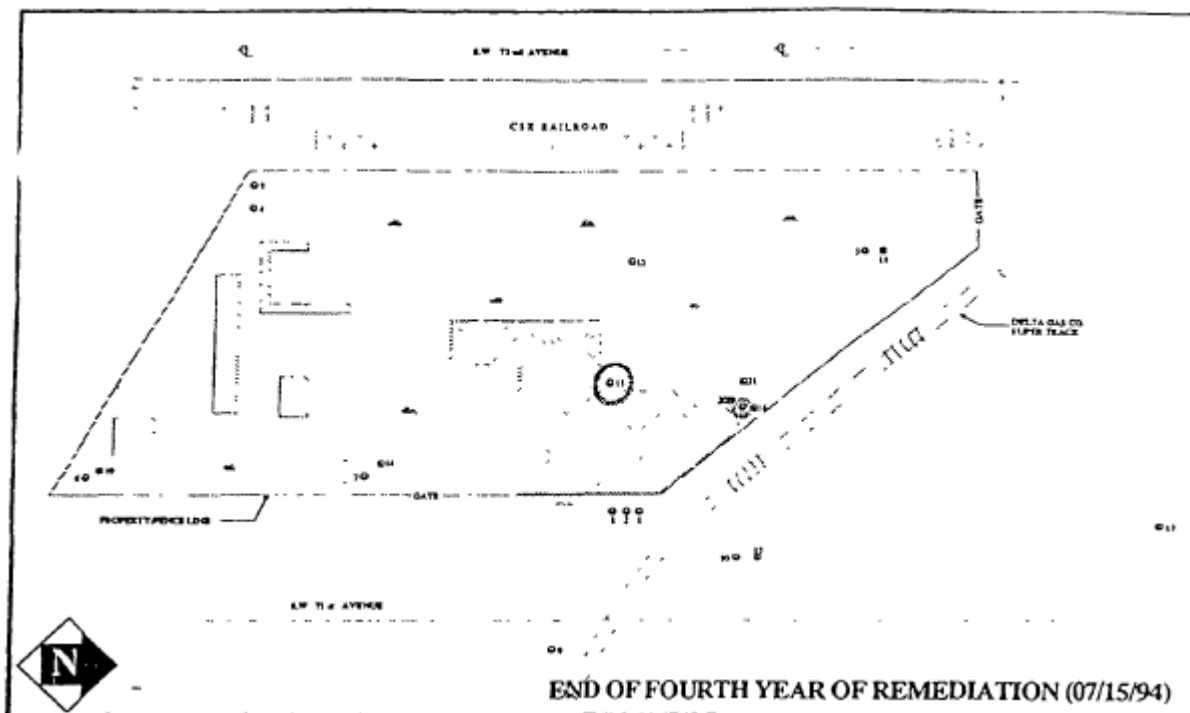


Figure from USACE 2001

5. Memphis Defense Depot: Dunn Field (OU)

Memphis, Shelby County, Tennessee

Site Highlights

After in situ thermal desorption (ITSD) of eight chlorinated solvent source zones at Dunn Field, a 60-acre paved and grassed area that the Memphis Defense Depot (DDMT) used for mineral storage and waste disposal for almost sixty years, all eight treatment areas met the stringent target criteria. Successful source remediation has led to significant reductions in the size and concentration of the associated groundwater plume. The Defense Distribution Center won the 2009 Secretary of Defense Environmental Restoration Award for its outstanding cleanup efforts and success at DDMT, and the Defense Logistics Agency (DLA) calls the thermal treatment at Dunn Field a “key component” of the overall success at the DDMT site (DLA 2009).

Site History

Dunn Field is one of four operable units at the 642-acre Memphis Defense Depot (DDMT). Dunn Field refers to the 60 acres of land adjacent to the 578-acre Main Installation, which contains the other three operable units. DDMT is currently surrounded by a mixed industrial/commercial/residential area of Memphis. The DDMT land was used for cotton farming until 1940 when the U.S. Army purchased it and opened a military supply distribution center on the property. The center was primarily used by the DLA from 1963 until 1997 when the facility closed under the Base Realignment and Closure process.

Dunn Field was formerly used for mineral storage and waste disposal. Numerous hazardous substances used at DDMT were stored at Dunn Field, including petroleum products, paint thinners, methyl bromide, pesticides, and chlorinated solvents. When the Army disposed of leaking mustard bombs at Dunn Field in 1946, it used Decontaminating Agent Non-Corrosive (DANC) solutions that contained 1,1,2,2-tetrachloroethane (PCA) and similar mixtures that contained PCE to decontaminate materials before destruction and burial. These compounds, along with several other CVOCs, highly contaminated the soil and groundwater at Dunn Field.

Environmental assessments of DDMT began in the 1980s, and it was placed on the final NPL on October 14, 1992. The DLA is the lead agency at DDMT, with oversight provided by USEPA and the Tennessee Department of Environmental Conservation (e²M 2007).

Extent of Contamination

COCs found at Dunn Field include PCE, TCE, 1,2-DCE, 1,1-DCE, 1,1,2,2-PCA, CCl₄, and heavy metals. TCE and PCA in the groundwater were both present at more than one percent of their aqueous solubility and contaminants were typically present in the soil at over 1000 mg/kg, indicating the presence of DNAPL. Three major CVOC plumes developed in the shallow groundwater under Dunn Field (northern, southern, and central plumes). All three plumes mix to some extent, and all extend beyond site boundaries (see Figure 5.1)

The youngest geologic unit at the site consists of loess deposits, which extend from the surface to about 20 to 30 feet bgs. While this unit lies above the water table, precipitation events cause contaminants in the loess to leach downward through the fluvial deposits in the vadose zone and

ultimately enter the uppermost, fluvial aquifer. A confining clay layer—with some openings northwest of Dunn Field—separates the fluvial aquifer from the discontinuous interbedded sand and clay layers that make up the intermediate aquifer. The contaminated groundwater at Dunn Field flows offsite to the west/northwest towards a known opening in the clay layer, where CVOCs can enter the intermediate aquifer. Another confining clay layer separates the intermediate aquifer from the underlying Memphis Aquifer. It is possible that contaminants are entering the Memphis Aquifer through suspected openings in the clay layer west and northwest of Dunn Field, however, long term monitoring data indicates that this is occurring at very low concentrations, if at all (Ballard 2010).

While the fluvial aquifer is not a current source of drinking water, the Memphis Aquifer is the primary drinking water source for the City of Memphis. One of the remedial action objectives in the April 1994 Dunn Field ROD is to restore the fluvial aquifer groundwater to drinking water quality, in order to ensure protectiveness of the deeper Memphis aquifer. The target groundwater contaminant concentration levels are within MCLs, but because multiple CVOCs were detected at Dunn Field, the targets vary slightly across the unit due to the possibility of exceeding cumulative toxicity limits even if individual MCLs are reached (e²M 2007). Table 5.1 provides target VOC levels for groundwater and loess soil. Target soil levels were also established for the fluvial sand and gravels underlying the loess, and can be found in the references listed below the table.

Remedial Action

Table 5.1 Maximum Concentrations and Remedial Goals at Dunn Field

<i>Compound</i>	<i>Soil (Loess) Maximum (mg/kg)</i>	<i>Soil (Loess) Goal (mg/kg)</i>	<i>Groundwater Maximum (µg/L)</i>	<i>Groundwater Goal (µg/L)</i>
PCE	21.1	0.18	2403	2.5
TCE	671	0.182	51,003	5
<i>cis</i> 1,2-DCE	199	0.755	5203 (total)*	35
<i>trans</i> -1,2-DCE		1.52		50
1,1-DCE		0.024	160	7
1,1,2,2-PCA	2850	0.011		2.2
1,1,2-TCA		0.062		1.9
CCl ₄	6.8	0.215		12
Chloroform	96.2	0.917		3

Note: Fluvial soil remedial goals have also been established for this site, and can be found in e2M 2007.

Sources: e2M 2007, Heron et al. 2009

A groundwater extraction system operated as part of the Interim Remedial Action at Dunn Field in 1998. Remedial actions performed as part of the final remedy are shown in the boxed text below.

Ongoing/Completed Remedial Actions at Dunn Field

- 2001 -- Excavation of soil and bomb casings completed
- 1998 – 2009: Interim Remedial Action GW extraction system, then barrier well system operated (discontinued due to ISTD success)
- Disposal Areas: 2004 – 2006 Excavation of disposal sites
- Source Areas: 2007 - 2009
 - **In situ thermal desorption** – 27 May to 4 Dec. 2008 (shallow subsurface loess)
 - SVE in fluvial deposits (ongoing)
 - Planned ZVI injections no longer necessary after successful thermal soil remediation
 - Excavation of one small area
 - Land use controls
- Offsite groundwater: air sparging/SVE* (ongoing)

*Note: A ROD Amendment changed part of the treatment for the offsite plume from a permeable reactive barrier to air sparging/SVE.

The in situ thermal desorption (ITSD) technology simultaneously treated eight CVOC source zones at Dunn Field. 367 heaters and 68 vapor extraction wells were used to volatilize and extract VOCs from eight source areas in the loess (silt) deposits. Source areas were up to 1200 feet apart. Almost 50,000 cy of subsurface material was treated in 177 days (Heron et al. 2009).

Results

Excavation of the disposal sites was completed in 2006, and associated RAOs were met. Monitoring data indicates that while the Interim Remedial Action groundwater extraction system recovered over 300 pounds of VOCs by 2003, the system was not adequately containing the plume in the fluvial aquifer, and contaminants were spreading beyond the western perimeter of Dunn Field (e²M 2007). For this reason, expansion of the extraction system was not selected as the final remedy. The barrier well system continued to operate through 2009, but has since been completely shut down and decommissioned.

ISTD proved to be extremely successful in targeting eight CVOC source areas at Dunn Field.

- Over 12,500 pounds of contaminants were removed from the soil (an estimated 9,000 to 14,000 pounds were originally present), and more contaminants were likely degraded in situ by hydrolysis
- A shotcrete vapor cover facilitated contaminant capture by acting as a vapor seal, preventing precipitation infiltration, and thermally insulating the upper few meters of soil
- Based on 47 soil samples collected after thermal treatment, all eight areas met the remedial targets for soil shown in Table 5.1.
- Areas where CVOC concentrations were typically above 1000 mg/kg dropped to less than 0.01 mg/kg
- CVOC concentration reductions on the order of 99.99% (Heron et al. 2009)
- Additional groundwater treatment was no longer required after thermal soil remediation was complete

This project was not only completed ahead of schedule, but was also much more cost-effective than simply expanding/continuing the P&T system. The total cost of the ITSD project was \$3.9 million, at \$79 per cubic yard. ZVI injections at \$2,200,000 with \$600,000 for associated

groundwater monitoring were avoided, and all extraction wells were shut down as of January 2009, saving \$140,000 annually. Cost savings due to ITSD success totaled \$2.5 million dollars (Baker et al. 2009).

The Interim Completion Report of Dunn Field Remedial Action was submitted in September 2009. Offsite groundwater continues to be treated by SVE and air sparging. SVE in the source zone fluvial deposits is ongoing. These systems will continue to operate until individual CVOC concentrations in groundwater fall below 50 µg/L in the source areas, and below MCLs off-site. The source zone fluvial SVE operations are expected to meet RAOs by 2010 (HDR|e2M 2009).

Figure 5.1 Total CVOC Concentrations at Dunn Field, Oct. 2006 (Pre-ISTD)

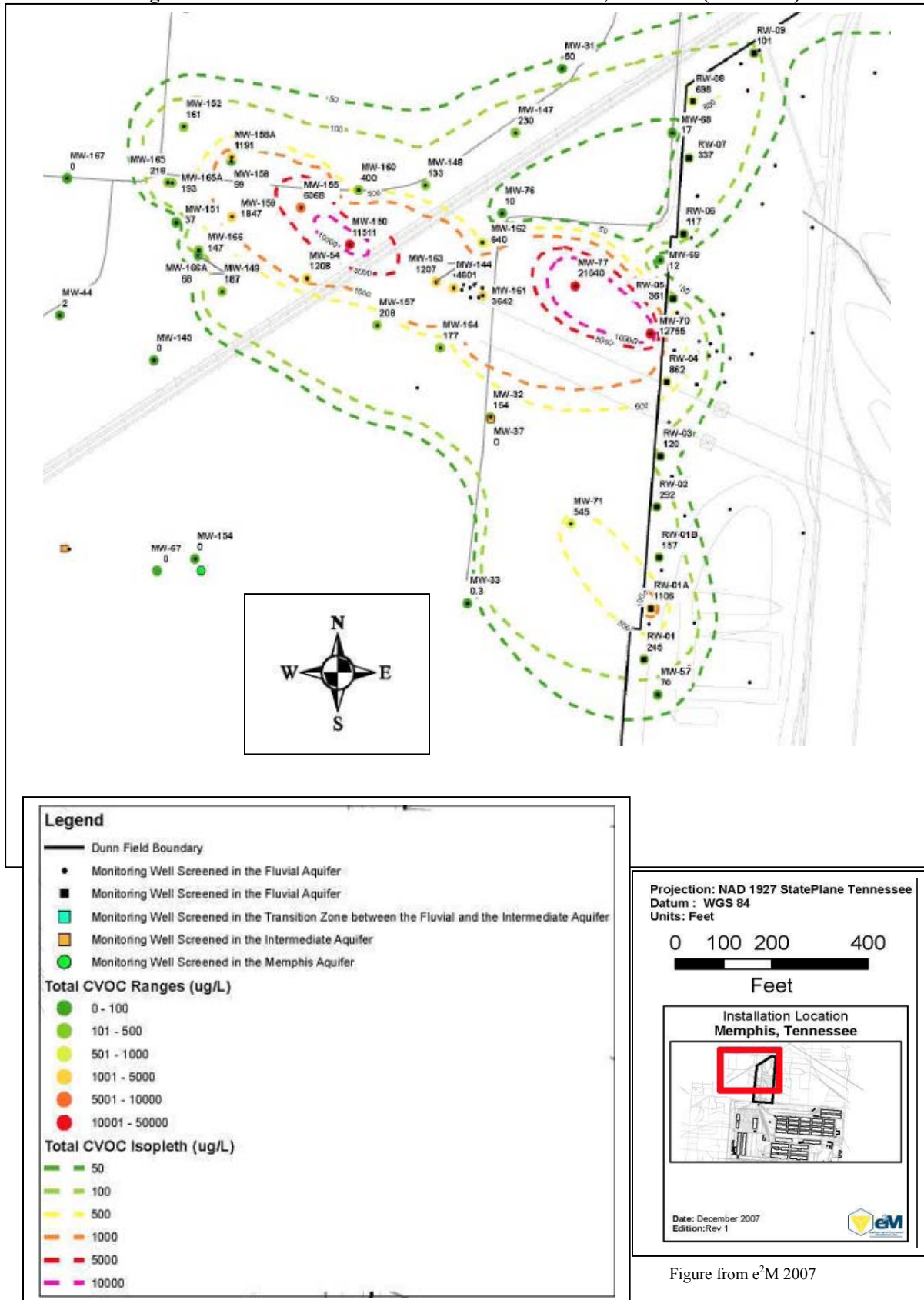


Figure from e²M 2007

6. Pemaco

Maywood, California

Site Highlights

At the Pemaco Superfund site, Electrical Resistance Heating technology was used to address a CVOC source zone. Initial concentrations of TCE in the source zone were as high as 22,000 µg/L. After six months of thermal treatment, TCE concentrations fell below MCLs in several monitoring wells and other wells exhibit significant concentration reductions.

Site History

A chemical blending and distributing facility operated on the 1.4 acre Pemaco site from the 1940s until June 1991, when the owner abandoned the site. Chlorinated and aromatic solvents, oils, flammable liquids, and specialty chemicals were used at this facility, stored in drums, aboveground storage tanks and underground storage tanks. In 1993, a fire destroyed the main warehouse on the property, but many drums and storage tanks remained intact. The USEPA conducted an emergency assessment and stabilization of the area after the fire, and called for further investigations into the extent of contamination at the site. Following these investigations, USEPA placed Pemaco on the final NPL on January 19, 1999. In December 2002, the City of Maywood acquired the site property and several other adjacent properties, so that they could be incorporated into the Maywood Riverfront Park along the Los Angeles River.

Extent of Contamination

Table 6.1 Maximum Concentrations and Remedial Action Objectives for COCs at Pemaco Site (ppb)

<i>Matrix/Zone</i>	<i>Compound</i>	<i>Maximum Concentration</i>	<i>RAO</i>
Soil/Upper Vadose	TCE	3,300	60
	PCE	2,000	-
Soil/Lower Vadose	TCE	2,100	-
Groundwater/Perched	TCE	680	5
	PCE	1,100	5
	1,1-DCE	2,000	6
	Vinyl Chloride	240	0.5
Groundwater/Exposition	TCE	22,000	5
	<i>cis</i> -1,2-DCE	14,000	6
	Vinyl Chloride	780	0.5

Source: USEPA 2005b

Both the soil and groundwater at Pemaco are contaminated, and groundwater contamination has migrated offsite beneath nearby industrial and residential properties. Plumes in the perched groundwater and the Exposition Aquifer are discussed below, and maximum concentrations of COCs are shown in Table 6.1.

1. In the surface and near-surface soil, COCs included SVOCs (PAHs) and metals.
2. In the perched groundwater, VOC plumes have developed containing primarily TCE, PCE and vinyl chloride. The presence of vinyl chloride is most likely due to TCE/PCE degradation. Multiple “hot spots” exist within the plumes where VOC concentrations exceed 10,000 µg/L. Contaminated groundwater extends 250 feet south and 200 feet

southwest of the site boundaries. In the perched groundwater, halogenated and non-halogenated contaminant plumes originating from other former industrial properties adjacent to Pemaco are mixing with the plumes originating at Pemaco (TN&A 2004).

3. In the upper zones of the Exposition Aquifer ('A' and 'B' zones), a contaminant source is giving rise to a contaminant plume consisting of TCE and its daughter products. DNAPL presence was suspected due to the presence of TCE at greater than 1% of its aqueous solubility; however, the relatively small amount of mass that was recovered from the source area during ERH treatment indicated that DNAPL was not present at the time of treatment. At its historic maximum, the plume extended laterally over an area measuring 1,300 ft by 750 ft, and its thickness ranged from 1.5 to 10 ft. TCE was present at a maximum concentration of 22,000 µg/L (TN&A 2004). Within the >10,000 µg/L contour of the plume, the average TCE concentration was approximately 16,700 µg/L (USEPA 2005b).

Remedial Action

Remedial Timeline at Pemaco

- 1991 - 1999: Emergency removal activities by EPA, including excavation and removal of USTs, ASTs, and drums, as well as building demolition.
- 1998 to 1999: SVE system removed 90,000 pounds of hydrocarbons and solvents from vadose zone soils. The system was shut off due to concerns about dioxin byproduct generation.
- 2005: Construction of final remedy begins after ROD is issued in January 2005. City of Maywood begins construction of Maywood Riverfront Park
- April 2007: Groundwater treatment system begins to operate
- May 2007: Vapor recovery and treatment system begins to operate. Maywood Riverfront Park completed.
- September 2007 – April 2008: ERH applied to source area
- June 2008: Vapor treatment system permanently switches from FTO to GAC due to substantial VOC concentration reductions

EPA 2010b, EPA 2005b

The ROD called for groundwater restoration to potential beneficial use as a drinking water source within a Remedial Action period of five years. In order to meet RAOs within five years, thermal technology was selected to address the highly contaminated soil and groundwater in the source zone. The 2005 ROD divides the Pemaco site into three subsurface zones in which to execute the final remedy. Each zone is described below, followed by a summary of the selected remedy for that zone.

1. The "surface and near surface soil remediation zone" extends from 0 to 3 feet bgs, and the selected remedy for this zone is soil cover and revegetation.
2. The "upper vadose zone soil and perched groundwater" extends from 3 to 35 feet bgs, and the selected remedy for this zone is High-Vacuum Dual-Phase Extraction (HVDPE). The HVDPE system removes liquid and gas phase contamination to address contaminated soil and the perched groundwater plume. Extracted soil vapor was treated with Flameless Thermal Oxidation (FTO) until VOC concentrations decreased sufficiently to allow vapor treatment via Granular Activated Carbon (GAC). Extracted groundwater is treated onsite using a GAC/UV Ox unit.

3. The “Lower vadose zone soil and Exposition Zone groundwater” extends from 35 to 100 feet bgs. This is considered the source area of the site; the most highly contaminated soil is found here, as well as the dissolved phase Exposition Zone groundwater plume. The selected remedy for this zone is Electrical Resistance Heating (ERH) with vapor extraction, vacuum-enhanced groundwater extraction, and groundwater P&T, followed by monitored natural attenuation (MNA). The ROD stated that ERH would be applied within the 10,000 ppb TCE groundwater contour, with electrodes installed as deep as 100 feet bgs. The design report amended the contour, expanding the heating area to include a 4,000 ppb contour. The ERH treatment area was approximately 14,000 ft². 30,000 cy of material was treated in the Exposition A and B zones, from 30 to 95 feet bgs. A FTO unit was used to treat vapor, while groundwater was treated with GAC/Uv OX (USEPA 2010b).

Pemaco achieved construction completion in September 2007. The ERH system was applied to the source area for approximately six months in conjunction with the vapor and groundwater extraction and treatment system.

Results

The initial TCE mass estimate in the ERH target zone ranged from 96 to 106 lbs. Pre-ERH groundwater pumping removed 70 percent of the dissolved TCE mass in this area. The remaining 30 percent was extracted during ERH, amounting to approximately 31.5 lbs of TCE in the vapor phase and 9 lbs of TCE in groundwater (TN&A 2009).

The small amount of mass removal indicates that no DNAPL was present in the source area at the time of treatment. Despite a relatively small amount of recovered contaminant mass, groundwater and soil TCE concentrations in the ERH area decreased by over 99% post-treatment (TN&A 2009).

The ERH treatment is considered to be a success. Since USEPA turned off the ERH system in April 2008, contaminant concentrations in the source area, dissolved phase plumes, and vapor have been declining steadily (USEPA 2010b). COC concentrations are now below remedial goals in several monitoring locations.

For example, in Exposition Zone B and the area immediately surrounding the treatment zone, July 2010 monitoring data shows that TCE groundwater concentrations are below MCLs in eleven out of eighteen monitoring wells shown in the “ERH Vicinity TCE Range Map B Zone Wells” document, shown in Figure 6.1 (TN&A 2010).

- Of the eleven wells that meet MCLs, the range of current TCE concentrations is 0.5 to 5 µg/L. Pre-ERH concentrations in these wells ranged from 100 to 4,600 µg/L.
- Of the seven wells that do not meet MCLs, the range of current TCE concentrations is 5.2 to 190 µg/L. Only three wells are above 25 µg/L. Pre-ERH concentrations in these wells ranged from 170 to 2,900 µg/L.

Additionally, almost all post-ERH soil samples taken from the treatment area in November 2008 exhibited TCE concentrations significantly below the ROD remediation goal of 60 µg/kg, as

shown in Figure 6.2 (TN&A 2008). Almost all concentrations are below 10 µg/kg. Pre-ERH concentrations in these wells were typically on the scale of hundreds or thousands of µg/kg.

Significant reductions in VOC levels have been achieved in other contaminated areas of the site as well, due to groundwater pumping and dual-phase extraction. A total of 14,584 lbs of VOCs have been removed site-wide, including a substantial amount of hexane and other light-end hydrocarbons. Groundwater pumping and monitoring are ongoing at Pemaco.

Figure 6.1 ERH Vicinity TCE Range Map – B Zone Wells (Groundwater), 8/3/2010

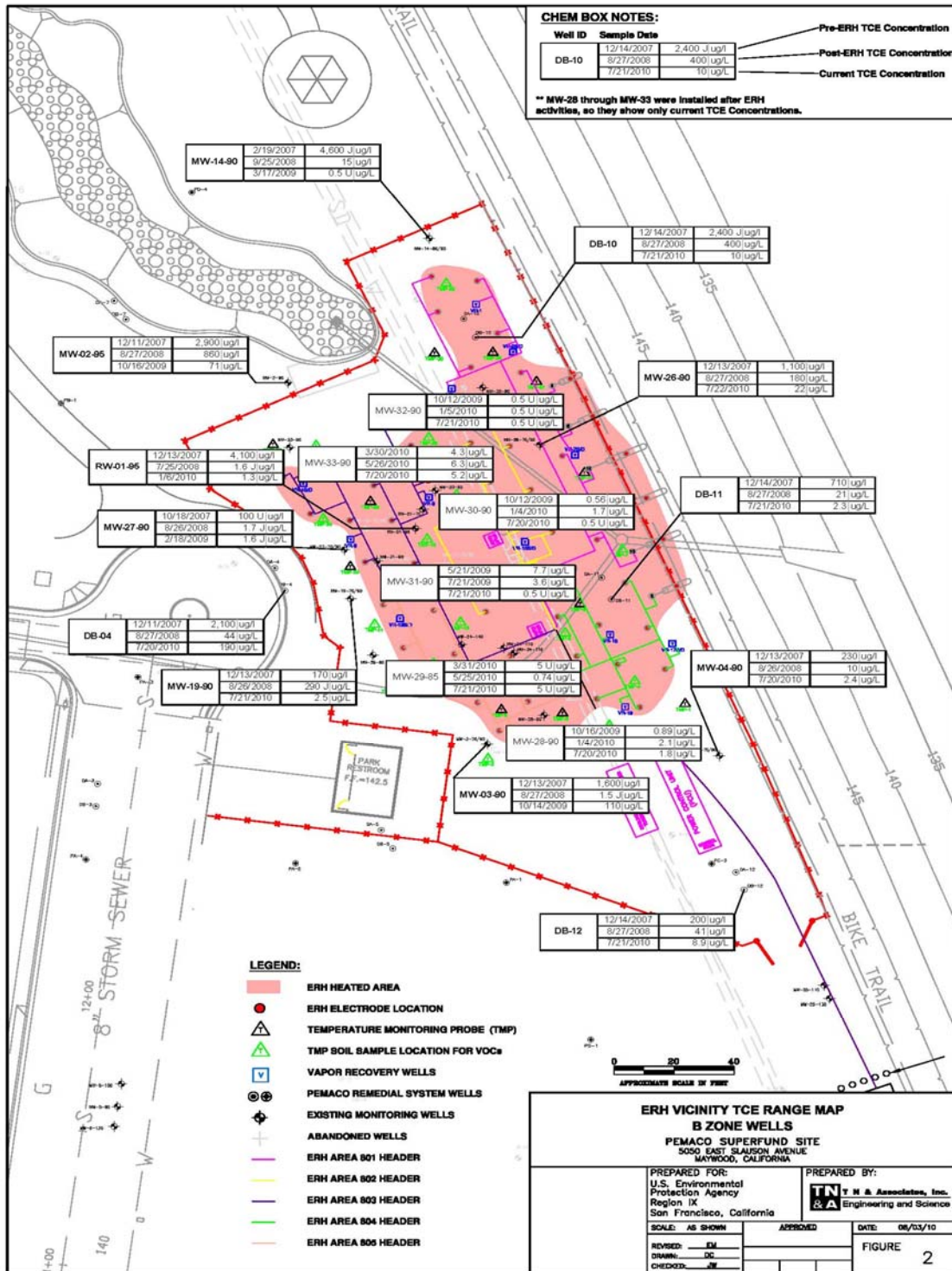


Figure from TN&A 2010

7. Stamina Mills, Inc.

North Smithfield, Providence County, Rhode Island

Site Highlights

TCE spills at the Stamina Mills Site (SMS) posed a health hazard to nearby residences that relied on the underlying aquifer as their sole source of drinking water. Over 50 residences had to be connected to an alternate drinking source due to the massive groundwater plume that reached offsite residential wells to the northwest of the site. The plume is now contained on site, and as of 2010, the offsite groundwater underlying these residences meets MCLs (USEPA 2010d). Achieving MCLs offsite is a significant accomplishment as it has greatly reduced human health risks in the nearby residential area.

Site History

SMS is a former textile mill that covers five acres of land in Rhode Island. The Branch River, along with several industrial and commercial buildings, forms the southern border of the property, making the site a wetland according to the State. The north and east boundaries of the site are lined with residential properties. Forestdale Manufacturing Company opened the mill in 1824 to process cotton. Operations ceased temporarily during the Depression, and Forestdale sold the mill to Stamina Mills in the 1940s.

In 1969, a new solvent scouring system was installed that used TCE to remove dirt and oil from textiles. A significant TCE spill occurred in 1969, contaminating the onsite drinking well at unacceptable levels within just a few months. The mill was closed in 1975, and two years later a fire burned the facility to the ground. Because the site remained vacant after the fire, the Town of North Smithfield installed a sewer across the site in 1978. Elevated TCE concentrations in groundwater was first detected offsite in 1979 in wells 800 feet north of Stamina Mills (USEPA 2005a).

Despite the fact that the TCE-contaminated aquifer was the sole drinking water source for the local community at that time, the State of Rhode Island and the Town of North Smithfield had only reconnected eight of the 50 residences impacted by the spill to an alternate water supply by 1984, reportedly due to prohibitive costs. USEPA placed the site on the NPL on September 8, 1983, and connected all remaining residences to the public water supply. A ROD was signed in 1990. Two ESDs have been issued to this ROD, one in 2000 and another in 2007. The first Five Year Review was completed in 2005.

Extent of Contamination

The primary COC at SMS is TCE, however, several other toxic compounds have been detected onsite such as other VOCs, SVOCs, inorganics, and dieldrin. Several areas of SMS are affected by TCE, including the TCE tank/spill area, a septic system, the onsite landfill (which slopes towards the Branch River), and the two raceways beneath the mill buildings that empty into the Branch River. A fractured bedrock aquifer stores groundwater at SMS starting at 10 to 20 feet bgs. Pumping the Forestdale Water Association Well and other individual bedrock supply wells resulted in a reversal of the regional hydraulic gradient, causing contaminated groundwater to

flow towards residential wells to the north of the site. When these wells were shut down in the early 1980s, contaminant concentrations in the north residential areas decreased (USEPA 2005a).

Soil TCE concentrations in the TCE tank/spill area were historically as high as 430,000 µg/kg. Both shallow and bedrock groundwater in this area are also affected by TCE contamination; bedrock groundwater TCE concentrations were detected at a maximum of 850,000 µg/L. DNAPL was detected in water-bearing fractures approximately 25 feet bgs, as indicated by samples taken from wells MW-10 and SMW. A large TCE plume in the bedrock aquifer extended offsite into the residential neighborhood to the northwest of the site. Figure 8.1 shows the extent of this plume in 1992. TCE and 1,2-DCE also contaminated surface water adjacent and downstream of the spill area, as well as downstream sediment (USEPA 2005a).

Remedial Action

The ROD called for restoration of groundwater in the aquifer underlying SMS to federal and state drinking water standards. In addition, soil cleanup standards were established, shown in Table 7.1. Remedial activities are shown below.

- Completed or Ongoing Remedial Actions at Stamina Mills Site**
- 1992: Building investigation and demolition
 - 1998 – 1999: **Landfill restoration** to meet ROD soil standards. An ESD changed the landfill remedy from a cap to excavation and offsite disposal of approximately 24,400 tons of contaminated material.
 - 1998 – 2004: **Soil Vapor Extraction and Multi-phase Extraction Systems** operated seasonally to treat contaminated overburden in spill area
 - May 2000: **Groundwater Extraction and MPE-Groundwater Systems** begin operating to recover DNAPL (using recovery wells SMW and MW-10) and draw back dissolved phase plume (using B-3).
 - Onsite treatment building contains Groundwater and Soil Treatment Systems (GWTS and VTS). GWTS uses an ultraviolet light/hydrogen peroxide system to treat groundwater before discharge to sewage treatment plant. VTS treats off-gas with granular activated carbon (GAC) units before discharge to atmosphere.
 - Institutional controls are currently in place.
 - Grading of the site.
 - Long-term environmental monitoring.

Table 7.1 ROD-Specified Soil Cleanup Standards for Stamina Mills Site

Compound	Standard (µg/kg)
TCE	195
PCE	66
1,1-DCE	17
1,2DCE	151

Source: USEPA 2005a

Results

The SVE/MPE system removed approximately 1,250 lbs of TCE during the first two seasons of operation, and approximately 1,600 lbs by 2004. Data indicates that all readily available mass has been removed from overburden soil (USEPA 2005a).

The GWE/MPE-GW system extracted a total of approximately 1,830 lbs of contaminants from 1998 through 2004. The GWTS processed over 20 million gallons of groundwater by 2005.

Initially, groundwater monitoring of VOCs occurred at four onsite and four offsite wells, referred to as Round I wells. Once cleanup standards were met in the Round I offsite wells, Round II wells were added to the monitoring program (see Figure 7.2). TCE concentrations in all four Round I offsite wells have decreased since 1998, and three of these wells fell below the MCL (5 µg/L) by 2005. Currently, all offsite wells meet MCLs (USEPA 2010d). TCE concentrations in onsite wells still exceed MCLs and fluctuate significantly over time, but they do exhibit “subtle decreasing trends over the long term” (USEPA 2005a). Table 7.2 provides specific TCE levels.

Table 7.2 TCE Concentration Reductions in Groundwater at Stamina Mills Site, up to 2005 (µg/L)

Note: As of 2010, MCLs have been reached offsite

<i>Historic Maximum</i>		<i>ROD standard (MCL)</i>
850,000		5
<i>Offsite Wells: Samples from Sep-00 to Jun-04</i>		
A-175, I-12, MW-17		I-37
ND (<6.0) - 4.0		4.7 - 35 (from 190 in Dec-93)
<i>Onsite Wells: Range from 2000 - 2004</i>		
B-3	MW-10	SMW
1,000 - 3000	<2,000 - >20,000	140 - 3,400

Source: USEPA 2005a

The size of the TCE plume has been significantly reduced since 1992, as shown in Figures 7.1 and 7.2. This size reduction is a considerable achievement not only because it marks a large step towards reaching ROD remediation goals, but also because it has reduced risks to the nearby residential area.

More recent information on remedial actions and progress at SMS can be found in the 2010 Five Year Review, which was not issued when this report was written.

Figure 7.1 TCE Plume at Stamina Mills Site – November 1992 (Pre-Treatment)

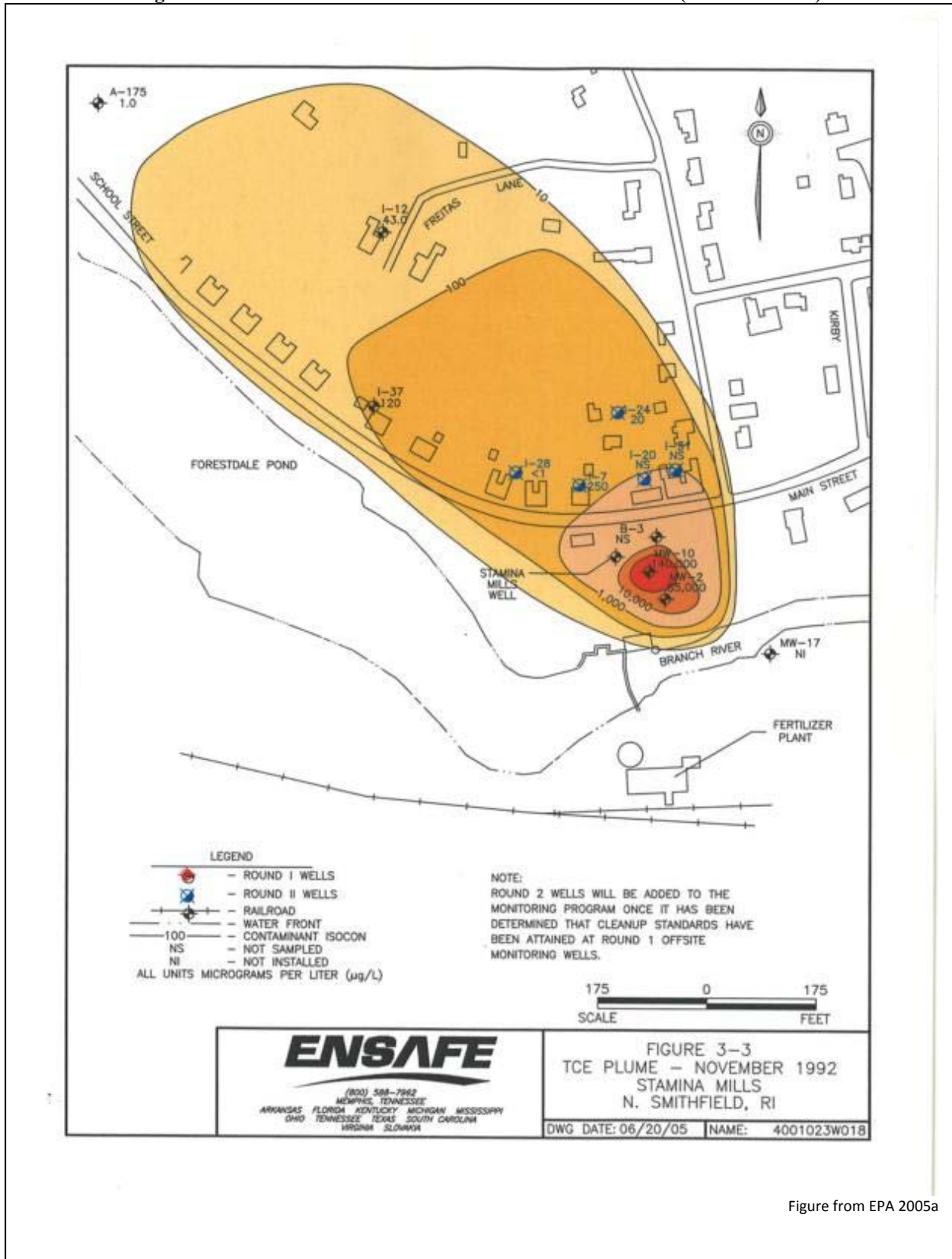


Figure from EPA 2005a

Figure 7.2 TCE Plume at Stamina Mills Site – June 2004

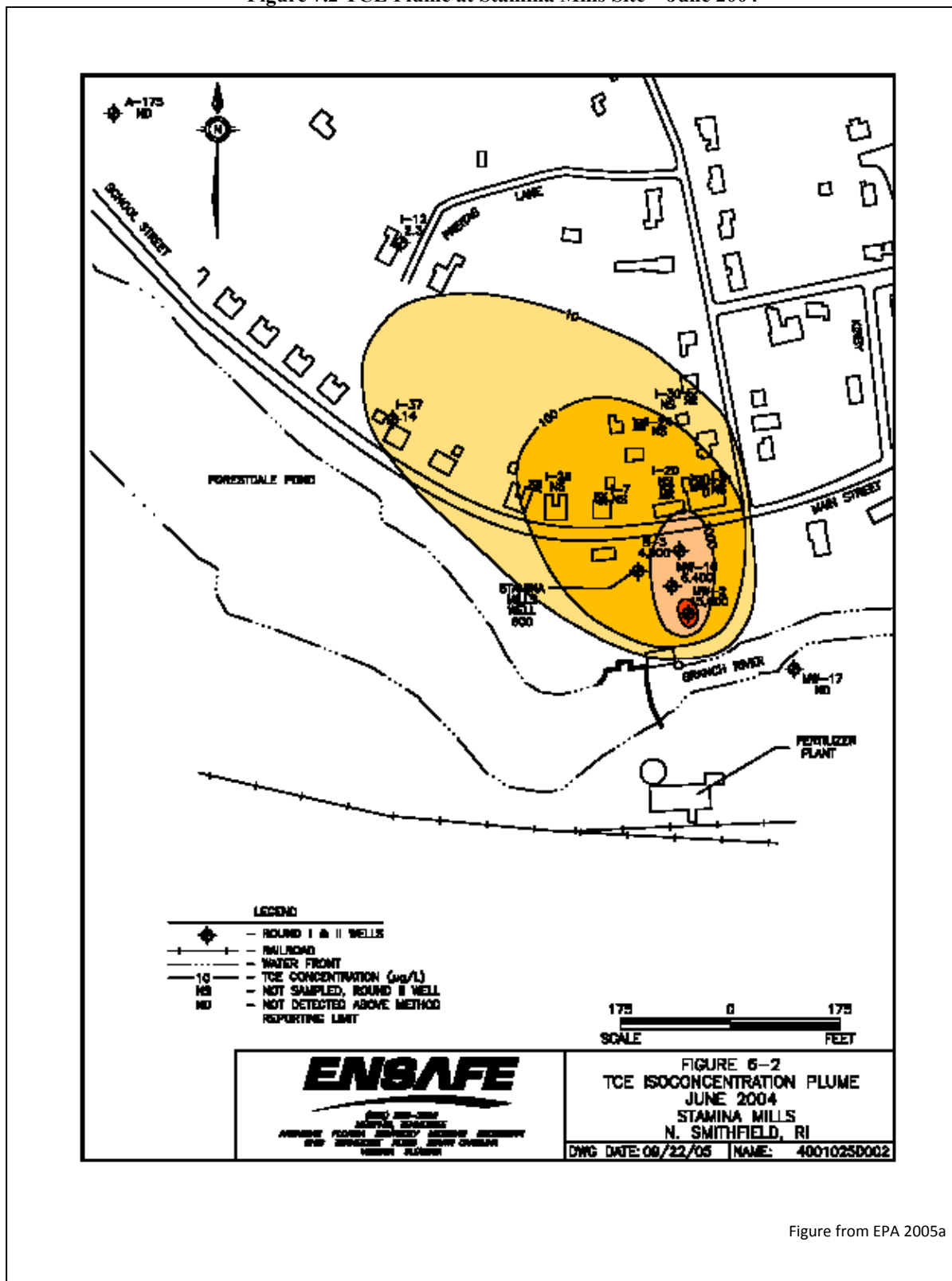


Figure from EPA 2005a

8. Western Processing

Kent, King County, Washington

Site Highlights

A *cis*-1,2-dichloroethene plume is currently biodegrading to well below MCLs at the Western Processing Superfund site (WPS) under a Monitored Natural Attenuation program coupled with a slurry wall that cut off the source of the plume. As *cis*-1,2-DCE (a daughter product of TCE) degrades to ethene, it produces an intermediate, carcinogenic compound called chloroethene (also called vinyl chloride). For this reason, MNA remedies backfire if the natural groundwater conditions are unable to completely dechlorinate intermediate compounds to the end compound, ethene. Now that the contaminant source has been isolated at WPS, MNA appears to be completely degrading contaminants in the groundwater plume, with no detections of intermediate compounds in the plume area since 2006.

Site History

The Western Processing Superfund Site (WPS) formerly operated as a waste processing facility from 1961 to 1983. In addition to reprocessing animal by-products and brewer's yeast, Western Processing performed industrial waste storage, reclamation, and burial services for over 300 businesses. The 14.5-acre WPS is surrounded by light industry, and Mill Creek forms the western boundary of the site.

Contamination concerns about WPS arose among local agencies in the 1970s, and USEPA began site investigations in 1982. A federal court order in April 1983 required Western Processing Company to cease all operations, after which USEPA performed immediate removal actions because the company claimed it was unable to do so. The Agency placed the site on the final NPL in September 1983. A 1984 ROD called for removal action (referred to as Phase I), followed by a 1985 ROD that called for remedial action (Phase II). The PRP, Western Processing, is the site lead, and USEPA and Washington State Department of Ecology (WDOE) are providing joint oversight.

Extent of Contamination

Due to improper waste storage/disposal and spills at WPS, site soils, shallow groundwater, and Mill Creek became heavily contaminated with over 90 of USEPA's priority pollutants. The primary categories of contaminants at this site are VOCs, SVOCs, and heavy metals. Organic COCs at this site include TCE, *cis*- and *trans*-1,2-DCE, dichloromethane (also called methylene chloride), toluene, and chloroethene. DCE concentrations detected in groundwater are greater than six percent of the compound's aqueous solubility (refer to appendix B), indicating that DNAPL is likely present in the subsurface (USEPA 1998). The water table begins at 5 to 20 feet bgs, and over 95 percent of all contamination at the site is located in the uppermost 15 feet of soil. Table 9.1 shows historical VOC concentrations at WPS.

Groundwater contamination onsite primarily affected the shallow groundwater (top of water table to 30 - 40 feet bgs) in the uppermost hydrogeologic zone (Zone A) out of the four delineated at this site. The volume of the shallow, onsite plume, consisting of a wide variety of contaminants, was estimated at 500 million gallons in 1987 (USEPA 1998). However,

contamination also reached the second hydrogeologic zone (Zone B), which extends to 80 feet bgs. In 1986 an offsite plume, consisting of what was thought to be *trans*-1,2-DCE, was discovered. This plume, referred to as the “trans” plume, had migrated underneath Mill Creek and extended just west of it. The primary compound in the plume was later determined to be *cis*-1,2-DCE, however, it is still referred to in site documents as the “trans” plume. No drinking water sources have been affected by this site.

Remedial Action

The site has been divided into four sectors, as shown in Figure 9.1. Sector 3 refers to the “trans” plume. Surface cleanup was completed in 1984 as part of the Phase I removal action. In 1988, two P&T systems began to operate, and a 40-foot-deep slurry wall was constructed around the site. On and off-site P&T systems operated to maintain an inward flow of groundwater around site boundaries and an upward flow within the slurry wall/source area. A shallow groundwater extraction/infiltration system and a “trans” plume extraction system were also constructed in 1988.

After eight years of aggressive efforts to restore the groundwater to acceptable levels via P&T and surface water infiltration, USEPA issued an ESD in December 1995 that changed the remedy to containment. The remedial objectives were changed for the following reasons:

- The chlorinated solvent plume had a continual source—DNAPL
- High operations and maintenance costs for the P&T system
- Monitoring showed that the plume was naturally attenuating outside the slurry wall

Since this ESD, the following remedial activities have occurred:

- 1996: New, more automated extraction systems installed to contain on-site and off-site plumes. Sector 2 and 3 equipment updated.
- 1997: Hot spot remediation via excavation/treatment/backfilling
- 1997: Isolation wall constructed around Sector 4 because it has relatively low contamination; this reduced necessary amount of groundwater pumping
- 1999: A RCRA cap was placed over the containment area (Sector 1) to reduce infiltration so as to reduce necessary amount of pumping
- 1999: Evaluation of geochemical indicators show that proper conditions for natural degradation of “trans” plume exist
- In 2000, extraction wells in Sector 3 were turned off and MNA for the “trans” plume officially began.

Results

Since 1990, the surface water in Mill Creek has consistently met performance standards (Federal Ambient Water Quality Criteria), indicating that the shallow groundwater is sufficiently clean. Creek remediation was completed in 1994. The ROD remediation goal of maintaining an inward groundwater flow from Zone B to Zone A within the slurry wall also has been met.

Significant achievements have been made in the “trans” plume area since the MNA program began in 2000. The offsite VOC plume currently extends in a northwest direction from the southwest portion of the site. Both the size of this plume and its VOC concentrations continue to steadily decrease. The plume is biodegrading to well below MCLs (USEPA 2008a).

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

Table 8.1 . “Trans” Plume Concentration Reductions at WPS (µg/L)

	1988	1995	1992	2002	2003	2005	2006	2007	2008	<i>MCL</i>
TCE			ND	ND	ND	ND	ND	ND	ND	5
<i>cis</i> -1,2-DCE	> 2000	< 100			ND	ND	ND	ND	ND	70
Chloroethene				150*		< 16**	< 16**	ND	ND	2

*detected in six wells **detected in one well

Note: A blank cell indicates that information was not readily available. The plume primarily contained *cis*-1,2-DCE when it was initially discovered in 1988.

Sources: USEPA 1998, USEPA 2008a

Geochemical indicators such as redox potential, dissolved iron, VOCs, methane, ethane, and ethene continue to be monitored to ensure that proper geochemical reducing conditions exist in Sector 3. Specific data on current levels of ethene in the plume area, which should increase if contaminants are completely degrading and the plume has not shifted away from the monitoring area, was not provided in the latest 5YR. However, USEPA stated that, “geochemical sampling continues to support that conditions in the trans plume area are conducive to the natural breakdown of vinyl chloride [chloroethene]; sampling results appear to verify that this breakdown is occurring as expected” (USEPA 2008a).

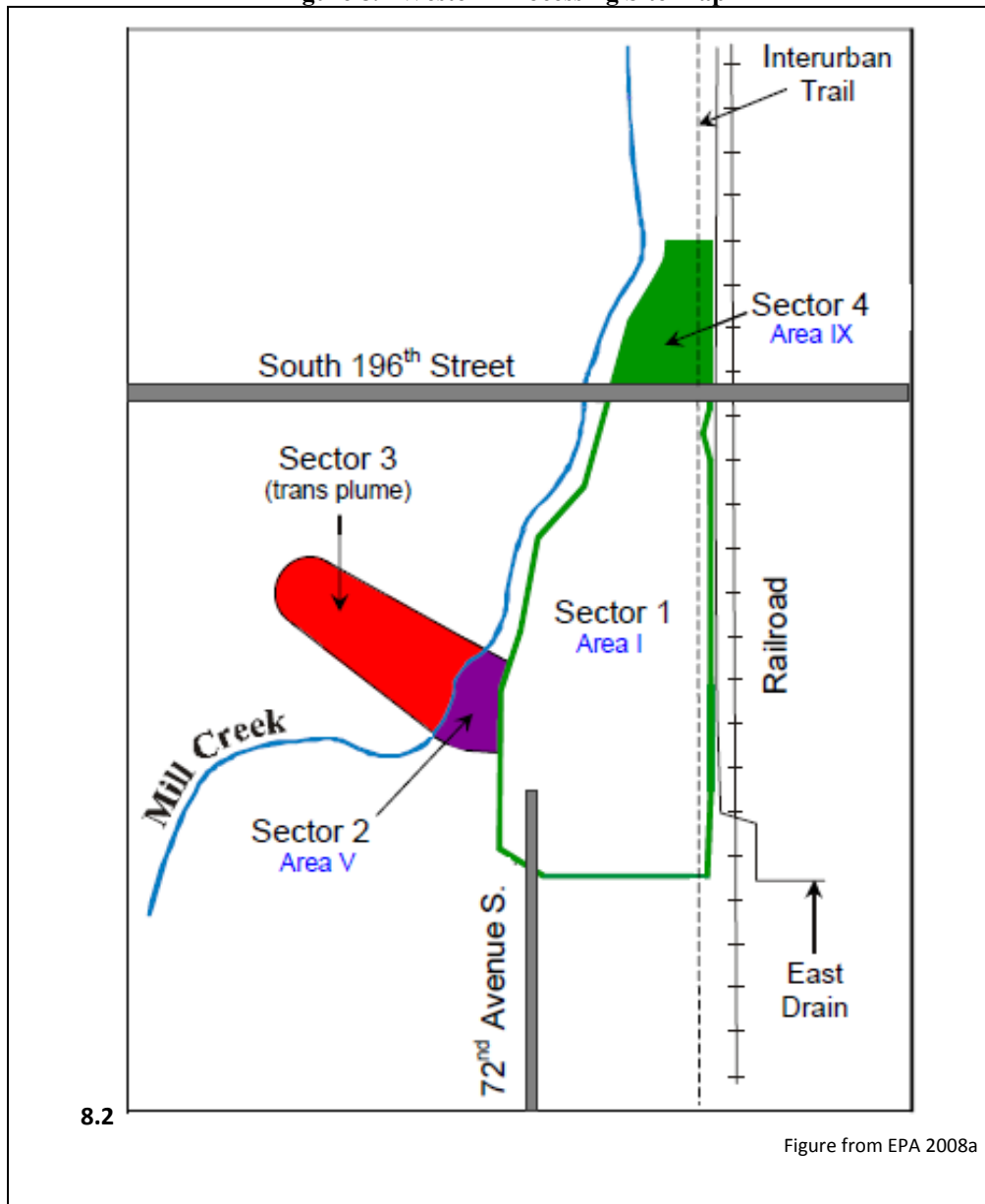
Indications of “Trans” Plume Breakdown

- TCE has not been detected since 1992
- 1,2-DCE has not been detected since 2002
- Chloroethene (vinyl chloride) has not been detected since 2006

Source: EPA 2008a

WPS is currently in the long-term operations and maintenance phase. The slurry wall has cut off the chlorinated solvent plumes and has isolated the contaminant mass. The P&T and MNA program has reduced the groundwater concentration outside the slurry wall to non-detectable levels. The new containment strategy adopted in 1995 has made it possible for the P&T system to operate at a much lower rate, while still containing onsite contamination. As a result, annual operating costs have fallen from \$5 million to approximately \$600,000. USEPA has determined that the entire site is currently Protective for People (USEPA 2008a).

Figure 8.1 Western Processing Site Map



Section II: POLYNUCLEAR AROMATIC HYDROCARBONS

9. Central Wood Preserving Company

East Feliciana Parish, Louisiana

Site Highlights

The Central Wood Preserving site (CWP) is a large site at which soil contaminated with creosote and arsenic was excavated and treated onsite with ex situ thermal desorption. The contamination did not migrate deep enough to significantly impact the groundwater, which allowed for a relatively quick cleanup. CWP achieved deletion from the NPL within eight years of the ROD issue date.

Site History

CWP is a former wood treating facility that operated over a span of 40 years. Central Creosoting Company, Inc. purchased this 17 acre site in the 1950s. As their name implies, Central Creosoting Co., Inc. used creosote to pressure-treat various wood products prior to export. Creosote use continued until January 1973 when the company was sold and became Central Wood Preserving Company, Inc. The new owners switched to a wood preservative called Womanack, which is a solution of copper oxide, chromic acid, and chromated copper arsenate. East Feliciana Parish is the current owner, as CWP abandoned the site.

The first cleanup action at CWP was initiated in April 1995. The site was placed on the NPL on May 10, 1999.

Extent of Contamination

While this site was primarily contaminated with arsenic, this case study focuses on creosote contamination, as creosote compounds primarily made up the small amount of DNAPL detected in an on-site monitoring well. It should be noted that while DNAPL was suspected to be present in the groundwater, further investigation revealed that the creosote contamination was mainly surficial and relatively contained.

On-site contamination was mainly due to spilled wood treating chemicals, especially in the main process area on the north side of the property. The COCs at CWP were polynuclear aromatic hydrocarbons (PAHs) from the creosote, as well as arsenic, copper and chromium.

Benzo(a)anthracene was the PAH most frequently detected at levels exceeding state screening standards, and thus was chosen to indicate total PAH contamination. While arsenic was found at a maximum depth of 5 feet bgs, creosote was found as deep as 23 feet bgs, with total PAH concentrations ranging from 0.059 ppm to 56,200 ppm. 0.2 feet of a DNAPL was detected in a shallow site monitoring well in November 2001.

The shallow groundwater zone that begins at 10 feet bgs is not laterally continuous and does not hold significant volumes of water. Furthermore, the ROD states that, "The groundwater encountered at 55 to 65 feet bgs demonstrates capacities that are borderline at best for meeting LDEQ's 2B classification for potentially potable groundwater, and groundwater is not used from within this or any other zone in the vicinity of the site." The creosote and arsenic contamination at CWP was mainly surficial, and USEPA does not believe that groundwater will be affected at this site because most of the creosote-contaminated soil was removed (USEPA 2001).

Remedial Action

As part of a time-critical removal action in 1995, hazardous waste sources such as tanks, pressure vessels, and highly contaminated soils were removed. All waste below 5 feet bgs remained in the subsurface, with institutional controls in place.

From November 2003 through September 2004, 9,142 tons of creosote-contaminated soil and sediment were treated onsite with Low Temperature Thermal Desorption (LTTD). The remaining ash from the thermal treatment, in addition to 19,764 cy of arsenic-only material, was disposed of off-site. Investigations after Hurricanes Katrina and Rita revealed lingering contamination in one area of the site, which resulted in excavation of an additional 980 cy of soil (USEPA 2009b).

Results

After soil excavation was completed, all arsenic samples fell well below the remediation goal of 20 mg/kg. Benzo(a)anthracene samples from 11 out of 19 sampling locations fell below target levels. The eight locations at which sample concentrations remained above target levels were all found in a limited area along a drainage pathway on the north property. Any DNAPL was most likely removed during excavation.

Table 9.1 COC Concentration Levels in Soil at CWP (mg/kg)

Contaminant	Arsenic	Benzo(a)anthracene
Remedial Goal	20	not provided*
Pre-remedy concentration levels	20 - 6,913	0.059 - 56,200
Post-remedy concentration levels	3.2 - 6.3	0.08 – 210**, average 29

*No federal or State of Louisiana regulatory cleanup standards had been promulgated for soil; therefore, risk based criteria were identified for this media.

**While eight of the 19 locations sampled showed exceedances for contaminants of potential concern (as identified in the RI), these exceedances were found in a limited area along a drainage pathway on the north property, north of State Highway 959.

Source: USEPA 2009b

After excavation areas were backfilled with 15,846 cy of clean clay, organic-rich topsoil was distributed over the property. 14 acres of the site were seeded with rye grass and Bermuda. Superior Loblolly pine seedlings and Cherrybark Oak trees were planted in 175 locations covering 12 acres. The southeast corner of the South Property remains treeless to allow space for a baseball field.

CWP was deleted from the NPL on September 18, 2009.

10. Koppers Co., Inc (Charleston Plant)

Charleston, Charleston County, South Carolina

Site Highlights

A multi-media remedy is currently being implemented to remediate the portion of the Ashley River watershed affected by wood treating chemicals from the Koppers Co., Inc. (Charleston Plant) Superfund site. According to the PRP, the groundwater/NAPL recovery system at the Charleston Plant is “among the top three most efficient systems out of approximately 20 that they operate in the United States” (USEPA 2008). Additionally, the Kopper site is unique because it is one of only a few hazardous waste sites in the United States where in-situ solidification/stabilization has been used to treat contaminated sediments in a riverbed (USEPA 2003).

Site History

The Koppers site covers approximately 102 acres of land that is currently used by several parties for industrial, commercial, and residential purposes. When the EPA issued the 1995 ROD, 150,000 people lived within a four-mile radius of this Superfund site. The Ashley River borders the western portion of the site.

Koppers Co., Inc. previously owned 45 acres of this land, where the company operated a wood-treating facility from 1940 to 1978. In 1978, Braswell Shipyards began using the northwest corner of the site to run a ship maintenance business. Ashpoo Phosphate Works operated a phosphate and fertilizer factory on a 57 acre parcel of the site from the early 1900s until 1978. Koppers Co. is now called Beazer East, Inc., but the corporation itself remains unchanged. Beazer is the PRP for the site, but has sold most of the site property to Ashley LLC for redevelopment (USEPA 1995).

The site was placed on the final NPL on December 1, 1994. An Interim Remedial Action ROD was signed in 1995, and a final ROD was issued in April 1998. Two ESDs to the 1998 ROD have been issued to alter the selected remedy.

Extent of Contamination

Wood preservatives used by Koppers Co. to treat raw lumber and utility poles are the main contaminants at this site. The company primarily used creosote to treat wood, but PCP and CCA also were used. PAHs, which are creosote compounds, have been detected in the Ashley River sediments at a maximum concentration of 500 mg/kg. DNAPL stringers have been discovered at up to 17 feet below the sediment interface (USEPA 2003).

Both LNAPL and DNAPL exist on site. One definite NAPL source area is the subsurface of the Former Treatment Area (FTA), from which dissolved phase constituents have migrated to two drainage ditches and the headwaters of the North Tidal Marsh. Another NAPL source area is the old impoundment area (OIA). NAPL has migrated to a depth of 30 feet bgs at the OIA, where it could potentially enter the Ashley River or barge canal. The Northwest Corner of the site is a third NAPL source area (USEPA 1995). Three acres of PAH and DNAPL-contaminated river

sediments found along 1500 feet of the Ashley River shoreline are considered an Area of Potential Ecological Concern (USEPA 2003).

Remedial Action

Remedial Actions February 1999 – March 2003	
• Soil	<ul style="list-style-type: none"> ○ 22,000 tons excavated, disposed of off-site ○ Protective engineered soil cover placed over 40 acres
• Surface water drainage ditches	<ul style="list-style-type: none"> ○ 3,600 linear feet reconstructed to block contaminant migration pathways
• Ashley River	<ul style="list-style-type: none"> ○ Geotextile/12 inch sand cover and cement-stabilized cap placed over three acres of river
• Barge Canal (3.2 acres)	<ul style="list-style-type: none"> ○ Monitored Natural Recovery (MNR)
• North Tidal Marsh	<ul style="list-style-type: none"> ○ 1,500 tons of sediment excavated ○ 1,300 linear feet of tidal creek restored
• South Tidal Marsh	<ul style="list-style-type: none"> ○ 2,500 tons sediment excavated ○ 2 acre area restored
• Northwest AND South Tidal Marsh	<ul style="list-style-type: none"> ○ In-situ bioremediation
• NAPL/Groundwater	<ul style="list-style-type: none"> ○ Northwest corner of site: In-situ Solidification/stabilization of 17,000 square foot area, extending one foot vertically into clay confining unit, to immobilize residual NAPL <ul style="list-style-type: none"> ▪ “Innovative” construction techniques were implemented during this project: Cement-based grout was injected and mixed using a tubular injector and a special amphibious marsh excavator that facilitated grout injection at required depths and allowed solidified sediment to serve as a platform on which equipment could reach untreated sediment (EPA 2003). ○ FTA and OIA: Installation of dual-phase extraction (DPE) wells for active groundwater and NAPL recovery. ○ A monitoring program was established for the NAPL recovery systems and the S/S remedy.

A variety of remedial actions have taken place at the Koppers site in order to address the environmental complexities of this contaminated watershed. The Interim Action ROD focused on preventing off-site migration of NAPL and eliminating potential exposure to NAPL constituents. The Final ROD selected several remedies to address a broad range of contaminated media. Remedies have been applied to site soil and drainage ditch sediments, North Tidal Marsh sediments, Northwest and South Tidal Marsh sediments, Barge Canal sediments, Ashley River sediments, and NAPL/groundwater.

Table 10.1 Koppers Site Soil and Sediment Excavation Levels

COC	Surface Soil Excavation Limits (mg/kg)	Subsurface Soil Excavation Limits (mg/kg)
Arsenic	135	1,550
B(a)P Toxicity Equivalent	20	275
Dioxin TEQ	0.0015	0.02
PCP	235	4,300

Source: USEPA 2008

The Koppers site achieved construction completion status in September 2003 when the Preliminary Close-Out Report was issued. The NAPL/groundwater recovery remedy, which was initially implemented as a small-scale pilot test, began to operate full-scale in the FTA and OIA in October 2003.

Results

Remedial Progress	
<ul style="list-style-type: none"> • Ashley River Subaqueous Cap <ul style="list-style-type: none"> ○ More permanent solutions that would enhance or replace the cap are under consideration. • Barge Canal MNR <ul style="list-style-type: none"> ○ PAH concentrations in surface sediments have decreased significantly over time. The PAH sample event mean has been reduced from 138.4 mg/kg in 1993 to 2.7 mg/kg in 2007 (5.2 mg/kg was the max), decreasing by nearly 2 orders of magnitude. ○ 0.80 acres of marsh grass has been added since 2000. ○ PAH levels are now within the reported background range of 4 to 28 mg/kg, and marsh vegetation is continuing to flourish (EPA 2008). • Northwest AND South Tidal Marsh ISB <ul style="list-style-type: none"> ○ An in-situ bioremediation pilot study indicated that this technique would not significantly biodegrade PAHs in the northwest and south tidal marshes, therefore this remedy was not implemented on a larger scale (EPA 2008). • S/S in northwest corner of site <ul style="list-style-type: none"> ○ The S/S remedy appears to be meeting the ROD performance standards shown in Table 10.1. NAPL has not been detected in any of the monitoring wells adjacent to the S/S area, and dissolved PAH levels have decreased over time since the implementation of the S/S remedy (EPA 2008). • NAPL/Groundwater Recovery System <ul style="list-style-type: none"> ○ FTA and OIA: Significant quantities of NAPL have been recovered from the shallow and intermediate saturated zones of the FTA and OIA using the DPE system. The FTA uses eleven shallow and four intermediate wells, while the OIA uses three shallow and one intermediate well. Giant Cement Company in Harleyville, SC, is using the recovered NAPL as an energy recovery fuel for their rotary cement kilns (EPA 2008). <ul style="list-style-type: none"> ▪ The extraction wells have recovered approximately 8,100 gallons of NAPL from the FTA and 6,200 gallons from the OIA. The NAPL recovery efficiencies are meeting system targets in both areas (see Table 5.2) (EPA 2008). PAH groundwater plumes appear to be stable based on over ten years of monitoring data. ▪ Additional remedial activities may be necessary to address the increase in PAH concentrations at one monitoring well near the barge canal due to shallow extraction activities in the OIA. 	

Progress has been made in multiple areas of the Koppers site, and remedial actions are ongoing. NAPL has been recovered in the FTA and OIA, and the PAH plumes from the source areas have been stable for over a decade. The S/S remedy is meeting performance standards, and PAH concentrations in sediments have significantly decreased in the Barge Canal.

**Table 10.2 NAPL Recovery Efficiencies at Koppers NPL Site:
Percentage of Total NAPL Recovered/Groundwater Collected**

Location	Range (%)	System Target	Target met?
FTA	0.0 - 0.46	0.1 - 1.0	YES
OIA	0.0 - 2.19	0.1 - 1.0	YES

Source: USEPA 2008

A majority of the Koppers site was purchased by Ashley LLC in 2003 and is now part of the 218-acre Magnolia redevelopment project. Residential and commercial units, as well as hotels and civic space, will be constructed under the Magnolia Project, which began construction in 2008.

According to the second five year review, the 2008 net worth of the remedy implemented at the Koppers site was an estimated \$20.4 million. The remedy is currently adequately protective of human health and the environment, and investigations to determine future remedial actions are underway (USEPA 2008).

Figure 10.1 Solidified/Stabilized Section of Ashley River Cap



Solidified/Stabilized Section of Ashley River Cap

Figure from USEPA 2008

11. Southern California Edison, Visalia Pole Yard

Visalia, California

Site Highlights

Successful cleanup of the Visalia Site was originally considered nearly impossible due to the nature and extent of contamination. Under a traditional pump and treat system combined with enhanced in-situ bioremediation, Southern California Edison (SCE) estimated that it would take 120 years of remedial action to meet USEPA's cleanup requirements (Walter 1998). However, steam remediation technology applied at the site significantly sped up the cleanup process and cost less than the Record of Decision (ROD) estimate. All remediation standards have been attained, and the site was deleted from the NPL in 2009.

Site History

Visalia Pole Yard (VPY) is a 4-acre Superfund site that operated as a utility pole treatment facility from 1925 to 1980. Creosote was the wood preservative used from 1925 until 1968, when SCE switched to a solution of 5 % PCP dissolved in diesel oil because PCP-treated poles looked “cleaner” than poles treated with creosote (USEPA 2009a). These preservatives, which both contain several highly toxic organic compounds, entered the subsurface primarily via leaky pipes connecting underground storage tanks with treatment tanks, as well as cracks and failures in the tanks themselves (USEPA 1994).

Groundwater contamination was first detected in 1966 in an onsite well. California placed VPY on the State Superfund List in 1985, and the site was added to the NPL on March 31, 1989. The State of California Department of Toxic Substances Control (DTSC) is the lead agency for CERCLA activities at the site. USEPA signed a ROD approving the State's Remedial Action Plan (RAP) on June 10, 1994. The site achieved construction completion in 2001, remedial action was completed in 2008, and the site was deleted from the NPL on September 25, 2009.

Extent of Contamination

Wood treating chemicals were found in both the vadose and saturated zone of the Visalia site to a maximum depth of 145 feet bgs, contaminating the shallow, intermediate, and deep aquifer. The COCs at VPY included creosote compounds such as benzo[*a*]pyrene (B[*a*]P), as well as PCP and its associated impurities, including 1 to 3 percent dioxin formulation byproduct. Pools of LNAPL consisting of diesel oil with PCP were present on site, as well as DNAPL pools of creosote and other wood treating chemicals. DNAPL migrated to a depth of 100 feet bgs, spreading laterally along the upper boundary of the intermediate aquitard. Maximum concentration levels for COCs in soil and groundwater at VPY are shown in Table 11.2.

Remedial Action

Immediate remedial actions, including installation of a P&T system and construction of a slurry wall, began in 1976 after the California Regional Water Quality Control Board, Central Valley Region issued a Cleanup and Abatement Order requiring SCE to “discontinue discharge of chemicals related to pole treatment operations”, “extract and treat contaminated groundwater”, and “contain contamination on site” (USEPA 1994). SCE closed the VPY site in June 1980. The company demolished all pole treatment facilities and removed 2300 cy of contaminated soil,

properly disposing of the debris and soil off site. SCE also constructed an on-site water treatment plant following state approval in September 1986. These interim response actions addressed the principal threats at the site. The 1994 RAP/ROD aimed to address remaining threats at VPY with in-situ bioremediation, property access restrictions and deed restrictions (USEPA 1994).

SCE evaluated steam injection coupled with liquid and vapor recovery, an alternative treatment technology developed by Lawrence Livermore National Laboratory with University of California, Berkeley, in 1995. The evaluation revealed that this technology would achieve cleanup goals sooner than in-situ bioremediation, so the DTSC approved a full-scale pilot project and construction of the Visalia Steam Remediation Project began soon after (Cal-DTSC 2005).

The Visalia Steam Remediation Project (VSRP) operated from May 1997 to June 2000. Over this 36-month period, 660 million pounds of steam were injected into the hydrocarbon plume target area in the saturated zone. This pilot study used Dynamic Underground Stripping (DUS), a steam injection technique that mobilizes contaminants, coupled with Hydrous Pyrolysis Oxidation (HPO), which mixes oxygen with the steam to encourage in-situ oxidation. The VSRP proceeded in two phases. The first phase operated wells screened between 80 and 100 feet bgs to target the intermediate aquifer, while the second phase targeted the deep aquifer via wells screened between 125 and 145 feet bgs. To inject steam into the subsurface, four 50,000 lb/hr steam boilers connected to eleven injection wells operated around the plume periphery. Vapor and liquid was then vacuum-extracted through four extraction wells. After phase separation and liquid cooling, both vapor and liquid were treated. In addition, an electrical resistance tomography (ERT) and thermocouple-based thermal monitoring array surrounded the steam injection/vacuum extraction system. When the COC removal rate slowed significantly in June 2000, the VSRP was terminated (USEPA 2009).

Next, enhanced in-situ bioremediation (EISB) technology was implemented to augment the physical processes initiated by DUS and to encourage natural biological degradation of COCs. This technology coupled vadose zone bioventing and saturated zone biosparging with the ongoing pump and treat (P&T) operation.

The groundwater P&T program continued to operate as part of the remedy until March 2004 when the treatment system was shut down so groundwater monitoring could begin (Cal-DTSC 2005).

Results

Before the VSRP began, the water treatment plant was removing approximately 7 pounds (lbs) of contaminant mass per week at a cost of 1 million dollars per year (Eaker 2010). Phase 1 of the steam remediation project removed 890,000 lbs, followed by removal of an additional 440,000 lbs during Phase 2 (Eaker 2010). In the 36 months during which the project operated, a total of approximately 1,330,000 lbs of creosote compounds were removed, either by mobilization and extraction or by in-situ oxidation. Table 11.1 provides the amount of contaminants removed.

Table 11.1 Pounds of Hydrocarbons Removed by Visalia Steam Remediation Project

Steam Injected	Vapor Phase, Removed by Extraction	Free Phase, Removed by Extraction	Aqueous Phase, Removed by Extraction	Remediated in-situ by HPO
660,000,000 lbs	239,400 lbs	678,000 lbs	199,500 lbs	212,200 lbs

Dense Nonaqueous Phase Liquid Cleanup: Accomplishments at Twelve NPL Sites

Source: Eaker 2010

Sampling data collected from 2004 to 2007 showed that concentration levels of B[a]P, PCP, and TCDD_{eqv} in both soil and groundwater had been reduced to RAP/ROD standards, with the exception of four locations where TCDD_{eqv} was found in exceedance of standards in 2004. These locations were addressed by soil excavation in 2006 (see Table 11.2).

As of 2008 all remediation standards have been attained at the VPY site. The total cost of the remedy was approximately 34% less than the ROD estimate (USEPA 2009a). On September 25, 2009, VPY was delisted from the NPL. The VSRP system and the water treatment plant were both demolished, and the owner is currently negotiating a property sale (Eaker, 2010).

Table 11.2 Performance Results of Remedial Action at VPY Site: COC Concentration Level Reductions

Media	Contaminant of Concern	1992 RI Maximum Concentration	RAP/ROD Standards*	Results of Remedial Action Confirmation Sampling
Soil	PCP	4,100 mg/kg	17 mg/kg	All standards attained**
	B[a]P	42 mg/kg	390 µg/kg	
	TCDD _{eqv}	2.3 mg/kg	1 µg/kg	
GW	PCP	610 µg/L	1 µg/L	All standards attained
	B[a]P	5 µg/L	0.2 µg/L	
	TCDD _{eqv}	11 µg/L	30 pg/L	

TCDD_{eqv} = Tetrachlorodibenzo-p-dioxin toxicity equivalence

*Soil standards are for surface soils (0-10 ft bgs)

**Tetrachlorodibenzo-p-dioxin (TCDD) was detected slightly above cleanup standards at four locations in November 2004 (see 2005 five year review). The contaminated surface soil was removed in July 2006, and subsequent sampling verified that TCDD levels were below ROD standards. In all other locations, all cleanup standards were attained.

Sources: USEPA 2009a, Cal-DTSC 2005

12. Southern Maryland Wood Treating

Hollywood, Maryland

Site Highlights

Soil, groundwater, surface water, and sediment at the Southern Maryland Wood Treating Superfund site (SMWT) were all highly contaminated with LNAPL, DNAPL, dissolved-phase PAHs, and several other hazardous compounds prior to CERCLA activities. Today, all ROD cleanup standards have been met, the site has been restored as a functioning wetland, and no restrictions on use or exposure are necessary. This site has been delisted from the NPL.

Site History

SMWT, which covers 25 acres, operated as a pressure-treatment facility for wood preservation from 1965 to 1978. The owner, L.A. Clarke and Sons, Inc. (L.A.C&S), also leased a portion of the property to Ridge Marine Sales for retail purposes. Creosote and PCP were used during wood preservation operations. When L.A.C&S applied for a new onsite well in the early 1970s, the health officials who inspected the potential well location discovered contamination and alerted the State of Maryland. After the state asked the company to clean up the site, L.A.C&S filed for bankruptcy and closed SMWT in 1978. In 1982, L.A.C&S, identified as the potentially responsible party (PRP), began cleanup in accordance with an agreement with the State.

Unfortunately, the cleanup activities performed by the PRP were unsuccessful and actually spread contamination to several other, previously clean areas of the site. For example, the PRP spray irrigated liquids from contaminated lagoons onto the adjacent, uncontaminated woods. In addition, after mixing excavated sludge with composted sewage sludge, woodchips, topsoil, and grass seed, they spread the toxic material over previously clean land located on the southeast of the property (USEPA 1988).

The site was listed on the final NPL on June 10, 1986. The initial 1988 ROD called for containment of the most highly contaminated area of the site (known as Phase One). This was followed by a 1995 ROD that focused on remediating materials within the containment area and also addressed contamination outside the containment area (known as Phase Two). The containment area and the land that became contaminated during the PRP's initial cleanup efforts are both shown in Figure 4.1.

Extent of Contamination

Base-neutral and acid extractable compounds (BNAs), which include PAHs and various phenolic compounds, were found in the subsurface of SMWT, as were VOCs and PCP. Carcinogenic PAHs are the COCs that pose the greatest risk at this site (USEPA 1995a). Both LNAPL and DNAPL were found in the subsurface beneath unlined lagoons used for liquid waste disposal. DNAPL has also migrated from this area, accumulating on top of the

Concentrations of COCs in Soil and Groundwater within Contained Area at SMWT

- Soil: PAH concentrations range from tens to thousands of ppm
- Groundwater: VOCs ranged from 355 - 2990 ppb. BNAs range from 0.065 - 270 ppm. Total PAHS ranged from 4-31 ppm with carcinogenic PAHS ranging from non-detect to 1700 ppb.

Source: EPA 1995a

impermeable clay layer that separates the shallow aquifer from the deep aquifer. The clay layer prevented contamination from entering the deep aquifer, which is the local drinking water source. A freshwater pond located on the property also became highly contaminated with PAHs and VOCs as contaminated groundwater and surface runoff discharged into the pond.

Remedial Action

Cleanup levels were designed in anticipation of residential land use in the future, including use of groundwater from the shallow aquifer (USEPA 1995a). Cleanup standards relevant to this report are shown in Table 12.1.

Table 12.1 ROD Cleanup Standards for COCs at SMWT Site (ppm)

Media	B(a)P equivalence*	
Surface Soils	0.1	
Subsurface Soils	1	
Sediment**	low molecular weight PAHs	high molecular weight PAHs
	3.2	9.6

*Carcinogenic PAHs found on site were benzo(a)pyrene, benzo(k)flouranthene, benzo(a)anthracene, and carbazole chrysene

**All sediment cleanup levels are on a dry weight basis

Source: USEPA 1995a

Phase One of the remedy sought to contain the groundwater plume and contaminated soil. In 1990, a sheet pile wall was constructed in conjunction with the impermeable clay layer in order to contain groundwater and DNAPL in the most highly contaminated areas of the site—the former wastewater lagoons. In 1993, various immediate threat removal actions took place such as disposal of drums and tanks containing hazardous materials, and building demolition. An underflow dam was also constructed at this time to collect contaminated groundwater and possibly DNAPL. A water treatment plant (WTP-1) meant to treat water from the freshwater pond was completed in 1994. WTP-1 treated pond water at a rate of 25 gallons per minute (USEPA 1999a).

As part of Phase Two, which addressed DNAPL and soil within the sheet pile wall, two thermal desorption units with vapor recovery systems were installed and began operating in 1998. The thermal units treated excavated material from all five designated areas of onsite contamination, referred to Pits 1 through 5. When the 1999 Five Year Review was issued, the two systems had treated approximately 160,000 tons out of the estimated 245,000 tons of contaminated soil and sediment at the site. By October 2000 when soil treatment operations were complete, approximately 270,600 tons had been treated (USEPA 2005). Once the entire area was sufficiently treated, it was backfilled with the newly cleaned soil.

A second, larger WTP (WTP-2) was built to process the high volumes of condensate produced during thermal desorption, in addition to other groundwater and surface waters in the containment area. In 1999, WTP-2 was treating up to 70 gallons of condensate per minute and operating non-stop. A third, mobile WTP (WTP-3) was constructed in 1999 after Hurricane Floyd caused Pit 4 (the containment area) to overflow (USEPA 2005).

Results

The sheet pile wall effectively contained and prevented migration of DNAPL and its dissolved-phase constituents from Pit 4, allowing for its subsequent treatment by thermal desorption. The thermal desorption systems met all performance standards, and 100 percent of the treated soils in all five pits met cleanup standards shown in Table 12.1. Monitoring well samples collected from 2000 to 2002 confirmed that the remedial action objectives established in the 1995 ROD, including cleanup levels for PAHs, PCP and SVOCs, had been met. Wetlands and uplands have undergone complete restoration (USEPA 2005). Photographs of restored wetlands are provided in Figure 12.2.

USEPA deleted the SMWT site from the NPL on April 5, 2005. The total project cost estimated in the Final Close-Out Report was approximately \$60,700,000 in 2005 dollars (USEPA 2005). No institutional controls or additional activity are required at SMWT, as unlimited use and unrestricted exposure are now permitted site-wide.

Figure 12.1 Before and After Photos of SMWT

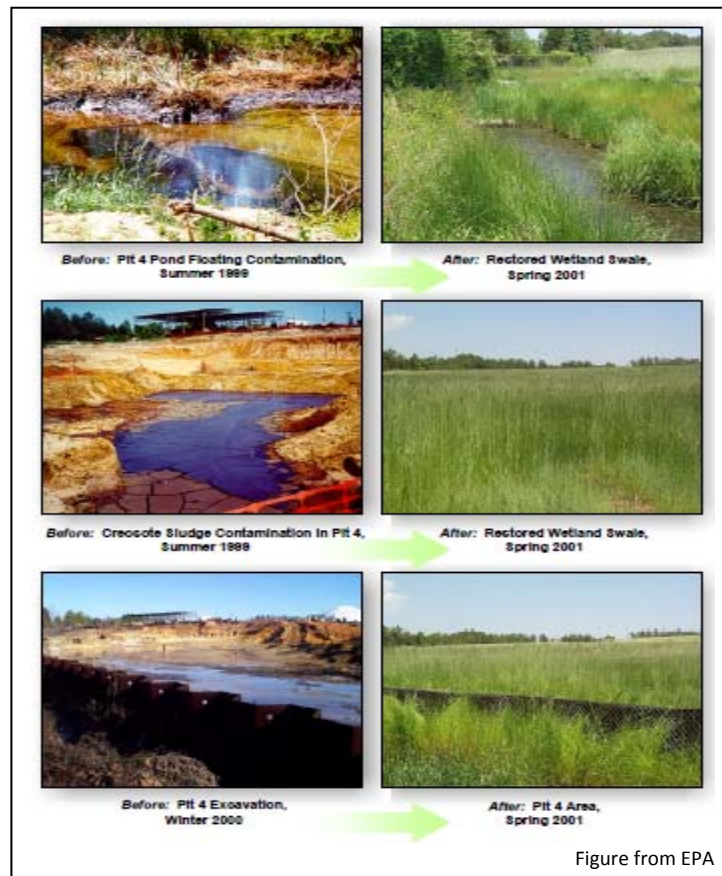
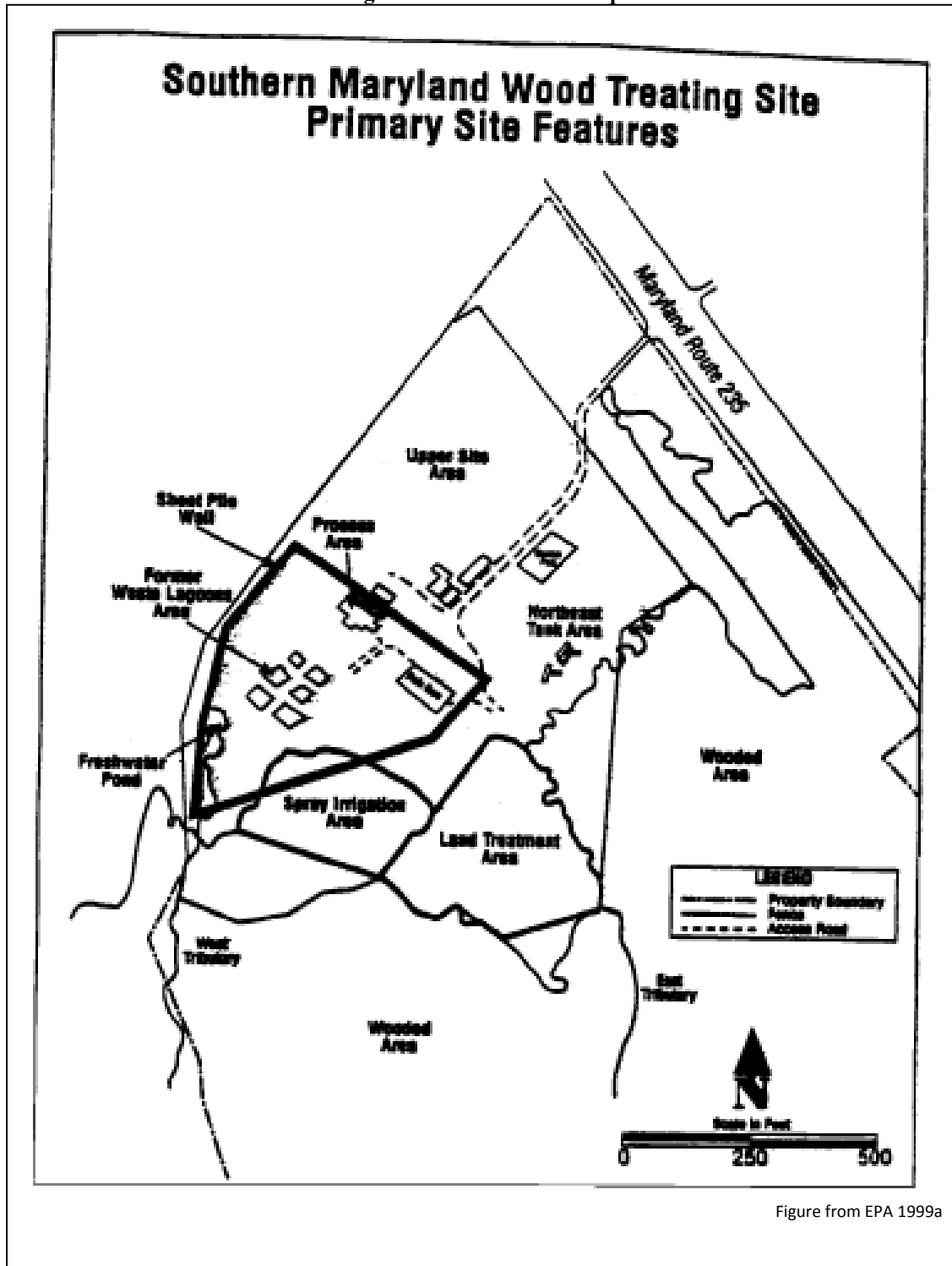


Figure 12.2 SMWT Site Map



APPENDIX B

SUSPECTED DNAPL THRESHOLDS BASED ON SOLUBILITY RELATIVE TO ONE PERCENT OF AQUEOUS SOLUBILITY

Chlorinated Solvent (CAS Number)	Aqueous Solubility (µg/L @ 20°C)	1% of Aqueous Solubility (µg/L @ 20°C)
PCE (127-18-4)	150,000	1,500
TCE (79-01-6)	1,100,000	11,000
<i>cis</i> -DCE (156-59-2)	3,500,000	35,000
<i>trans</i> -1,2-DCE (156-60-5)	600,000	6,000
1,1-DCE (75-35-4)	400,000	4,000
1,1,1-TCA (71-55-6)	1,360,000	13,600
1,1,2-TCA (79-00-5)	4,500,000	45,000
1,2-DCA (107-06-2)	8,690,000	86,900
1,1-DCA (75-34-3)	5,500,000	55,000
Carbon Disulfide(75-15-0)	2,100,000	21,000
Carbon Tetrachloride (56-23-5)	800,000	8,000
Chlorobenzene (108-90-7)	500,000	5,000
Chloroform (67-66-3)	8,000,000	80,000
Hexachlorobutadiene (87-68-3)	2,550	25
Methylene Chloride (75-09-2)	20,000,000	200,000
Trichlorofluoromethane (75-69-4)	1,100,000	11,000
1,1,2-Trichlorotrifluoroethane (76-13-1)	200,000	2,000

Notes:

1. The source for all Aqueous Solubility and 1 Percent Rule except 1,2 *cis* DCE: Cohen, R. and J. Mercer. 1993. DNAPL Site Evaluation, EPA 600/R-93/022.
<http://www.cluin.org/download/contaminantfocus/dnapl/600r93022.pdf>
2. Source for 1,2-*cis* DCE solubility datum: Howard, P. (ed.).1989. Handbook of Environmental Fate and Exposure Data for Organic Chemicals. Lewis Publishers.
3. DCA (dichloroethane), DCE (dichloroethene) PCE (tetrachloroethene), TCA (trichloroethane), TCE (trichloroethene)

If the chemicals are part of a mixture, then their solubility will be less than the solubility of the pure substances. The effective solubility of each component can be estimated using Raoult's Law and is equal to the mole fraction of the component in the NAPL times its pure form solubility (Cohen and Mercer 1993).

Table from USEPA 2009

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