

FINAL

Focused Corrective Measures Study for Groundwater at Site SS-45

Volume I



**England Air Force Base
Alexandria, Louisiana**

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Prepared For

**Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas**

and

**England Air Force Base Conversion Agency
Alexandria, Louisiana**

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FINAL

**FOCUSED CORRECTIVE MEASURES STUDY
FOR GROUNDWATER AT SITE SS-45**

**ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA**

VOLUME I

February 2000

Prepared For:

**Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas**

and

**England Air Force Base Conversion Agency
Alexandria, Louisiana**

Prepared By:

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TABLE OF CONTENTS

	Page
ACRONYMS AND ABBREVIATIONS	X
EXECUTIVE SUMMARY	ES-1
SECTION 1 - INTRODUCTION	1-1
1.1 Scope and Objectives	1-2
1.2 Background information	1-4
1.3 Summary of Previous Investigations	1-9
1.3.1 Comprehensive Background Study	1-9
1.3.2 Source Area Investigations	1-12
1.3.3 RCRA Facility Investigation	1-13
SECTION 2 - SITE CHARACTERIZATION ACTIVITIES	2-1
2.1 Drilling of Boreholes, Collection of Soil Samples and Installation of Groundwater Monitoring Wells	2-1
2.1.1 Pre-Drilling Activities	2-1
2.1.2 Drilling and Well-Installation Program	2-1
2.1.2.1 Equipment Decontamination	2-4
2.1.2.2 Collection and Analysis of Soil Samples	2-6
2.1.2.3 Monitoring Well Installation and Development	2-8
2.2 Surveying	2-9
2.3 Groundwater Monitoring	2-10
2.3.1 Scope of Monitoring Events	2-10
2.3.2 Groundwater Sampling Procedures	2-14
2.3.2.1 Cleaning and Preparation of Equipment	2-14
2.3.2.2 Measurement of Water Levels and Total Depth of Wells	2-15
2.3.2.3 Well Purging	2-15
2.3.2.4 Onsite Measurement of Chemical Parameters	2-15
2.3.2.5 Sample Collection	2-16
2.4 Sample Handling	2-16
2.5 Well Decommissioning	2-16
SECTION 3 - PHYSICAL CHARACTERISTICS OF SITE SS-45	3-1
3.1 Climate	3-1
3.2 Surface Features	3-1
3.2.1 Ground Surface Topography	3-1
3.2.2 Surface Hydrology	3-2

TABLE OF CONTENTS (Continued)

	Page
3.3 Regional Geology and Hydrogeology	3-2
3.3.1 Red River Alluvial Aquifer	3-2
3.3.2 Miocene System	3-3
3.4 Geology and Hydrogeology of Site SS-45	3-4
3.4.1 Site Hydrostratigraphy	3-4
3.4.2 Site Hydrogeology	3-11
SECTION 4 - CONTAMINANT DISTRIBUTION AND EVIDENCE OF	
BIODEGRADATION	4-1
4.1 Soil Chemistry	4-2
4.1.1 Total Organic Carbon in Soil Samples	4-2
4.1.2 Total Iron in Soil Samples	4-2
4.2 Overview of CAH Biodegradation Mechanisms	4-4
4.3 Distribution of CAHs in Groundwater at Site SS-45	4-7
4.3.1 Extent of Trichloroethene in the Intermediate Sand Unit	4-7
4.3.1.1 800 Area	4-7
4.3.1.2 2500 Area	4-8
4.3.2 Extent of Trichloroethene in the Deep Sand Unit	4-8
4.3.3 Extent of Dichloroethene Isomers in the Intermediate Sand Unit	4-12
4.3.3.1 800 Area	4-12
4.3.3.2 2500 Area	4-12
4.3.4 Extent of Dichloroethene Isomers in the Deep Sand Unit	4-13
4.3.4.1 800 Area	4-13
4.3.4.2 2500 Area	4-13
4.3.5 Extent of Vinyl Chloride in the Intermediate Sand Unit	4-14
4.3.5.1 800 Area	4-14
4.3.5.2 2500 Area	4-14
4.3.6 Extent of Vinyl Chloride in the Deep Sand Unit	4-14
4.3.7 Other VOCs in Groundwater	4-15
4.3.8 Dissolved Ethene in the Intermediate Sand Unit	4-15
4.3.9 Dissolved Ethene in the Deep Sand Unit	4-16
4.4 Migration Processes and CAH Distribution in Groundwater	4-16
4.5 RNA Evaluation	4-32
4.5.1 Contaminant Mass Losses at the Field Scale	4-33
4.5.2 Presence of Daughter Products	4-34
4.5.3 Chloride as an Indicator of Dehalogenation	4-34
4.5.4 ORP and Dissolved Hydrogen as Indicators of Redox Processes	4-39
4.5.5 Electron Donors	4-43
4.5.5.1 BTEX Constituents in Groundwater	4-43
4.5.5.2 Native Organic Carbon in Groundwater	4-45
4.5.5.3 Use of CAHs as Electron Donors	4-48

TABLE OF CONTENTS (Continued)

	Page
4.5.6 Alternate Electron Acceptors and Metabolic Byproducts	4-48
4.5.6.1 Dissolved Oxygen	4-48
4.5.6.2 Nitrate/Nitrite	4-49
4.5.6.3 Ferrous Iron and Manganese	4-49
4.5.6.4 Sulfate	4-53
4.5.6.5 Methane and Carbon Dioxide	4-56
4.5.7 Additional Geochemical Indicators	4-60
4.5.7.1 Alkalinity	4-60
4.5.7.2 pH.....	4-63
4.5.7.3 Temperature	4-63
4.6 Estimation of Biodegradation Rates	4-63
4.7 Summary of Evidence for CAH Degradation	4-69
4.7.1 Presence of Daughter Products	4-69
4.7.2 Apparent Plume Stability	4-71
4.7.3 Loss of CAH Mass	4-71
4.7.4 Availability of Electron Donors	4-71
4.7.5 Comparable Degradation Rate Estimates	4-72
4.7.6 RNA Scoring Results	4-72
 SECTION 5 - KINETICS-BASED MODEL OF CONTAMINANT FATE IN GROUNDWATER	 5-1
5.1 General Overview and Model Description	5-1
5.2 Structure of Geochemical Model	5-1
5.3 Model Parameters	5-3
5.3.1 Physical Parameters	5-3
5.3.2 Rate Constants	5-3
5.4 Initial Conditions and Assumptions	5-7
5.5 Results of Calculations	5-8
5.6 Sensitivity Analysis	5-10
 SECTION 6 - ANALYSIS OF REMEDIAL ALTERNATIVES	 6-1
6.1 Remedial Alternative Evaluation Criteria	6-1
6.1.1 Long-Term Effectiveness and Permanence	6-1
6.1.2 Implementability	6-2
6.1.3 Cost	6-2
6.2 Factors Influencing the Screening of Alternatives	6-2
6.2.1 Regulatory Requirements	6-2
6.2.2 Properties of Chemicals of Potential Concern	6-2
6.2.3 Site-Specific Conditions	6-4
6.2.3.1 Groundwater and Soil Characteristics	6-4

TABLE OF CONTENTS (Continued)

	Page
6.2.3.2 Potential Exposure Pathways	6-5
6.2.4 Data Sufficiency.....	6-6
6.2.5 Proposed Remedial Action Objectives (RAOs) for Groundwater	6-6
6.2.6 Summary of Remedial Technology Screening	6-8
6.3 Brief Description of Remedial Alternatives.....	6-13
6.3.1 Alternative 1 - MNA and Institutional Controls.....	6-13
6.3.2 Alternative 2a - MNA and Institutional Controls Combined with Containment (Low Rate) Groundwater Extraction, Treatment, and Disposal.....	6-14
6.3.3 Alternative 2b - MNA and Institutional Controls Combined with More Aggressive (High Rate) Groundwater Extraction, Treatment, and Disposal	6-15
6.4 Detailed Evaluation of Alternatives.....	6-16
6.4.1 Protectiveness	6-16
6.4.2 Long-Term Effectiveness and Permanence	6-17
6.4.3 Short-Term Effectiveness	6-19
6.4.4 Implementability	6-19
6.4.5 Cost	6-21
6.4.4.1 Alternative 1 – MNA and Institutional Controls.....	6-22
6.4.4.2 Alternative 2a – MNA with Low-Rate Groundwater Extraction, Treatment, and Disposal.....	6-22
6.5 Recommended Remedial Approach.....	6-26
SECTION 7 - LONG-TERM MONITORING AND NATURAL ATTENUATION VERIFICATION PLAN.....	
7.1 Overview.....	7-1
7.2 Monitoring Network and Sampling Frequency	7-2
7.2.1 Long-Term Monitoring Well Locations	7-2
7.2.2 Frequency of Long-Term Monitoring.....	7-2
7.3 Analytical Protocols.....	7-6
7.4 Reporting.....	7-6
7.4.1 Routine Reporting.....	7-6
7.4.2 Special 90-Day Reporting Requirement for Sentry Well Detections	7-6
7.4.3 Special Reporting for Increasing Total CAH concentrations	7-9
7.4.4 Operating Properly and Successfully Determination.....	7-9
7.5 Five-Year Review of Natural Attenuation Results and Institutional Controls.....	7-9
7.5.1 MNA Progress Review	7-9
7.5.2 Review of Institutional Controls.....	7-11
7.6 Site Closure.....	7-11
7.7 Contingency Actions.....	7-11

TABLE OF CONTENTS (Continued)

	Page
SECTION 8 - REFERENCES	8-1

VOLUME II - APPENDICES

- A - Selected Tables from the SS-45 RCRA Facility Investigation Report (LAW, 1998a)
- B - Geologic Logs, Geophysical Logs, Ambient Flow and Induced Flow Testing Records and Results, Well Construction Diagrams, Monitoring Well Development and Sampling Forms, Survey Data, Well Permits, Waste Manifests, and Well Abandonment Records
- C - Laboratory Analytical Data
- D - Properties of Chemicals of Potential Concern and Their Movement and Fate in the Environment
- E - Supporting Areal Distributions of Geochemical Indicators of CAH Degradation
- F - Estimation of First-Order Rate Constants for Chemical Degradation
- G - Evaluation of Relative Effectiveness and Cost of Remedial Alternatives
- H - Comments to Draft Report by Louisiana Department of Environmental Quality and USEPA

LIST OF TABLES

No.	Title	Page
ES-1	Summary of Remedial Alternatives Evaluation Groundwater Remediation	ES-6
1.2-1	Water-Supply Wells in Vicinity of England Air Force Base.....	1-8
2.1-1	Summary of Monitoring Well Construction Information.....	2-5
2.1-2	Analytical Protocols for Soil and Groundwater Samples	2-7
2.3-1	September 1998, February 1999, and March 1999 Groundwater Monitoring Events	2-11
2.3-2	May and July 1999 Groundwater Monitoring Events.....	2-12
3.4-1	Representative Geotechnical Properties of Soil Samples from Intermediate and Deep Sand Units.....	3-13
3.4-2	Hydraulic Conductivity Estimated for Intermediate and Deep Sand Units Using Results of Well-Displacement Tests	3-14
3.4-3	Groundwater Potentiometric Elevations Measured in Monitoring Wells.....	3-18
3.4-4	Horizontal Hydraulic Gradients and Groundwater Flow Velocities in Intermediate Sand Unit (July 1999).....	3-20
3.4-5	Calculated Vertical Hydraulic Gradients (July 1999).....	3-26
4.1-1	Concentrations of Total Organic Carbon and Total Iron in Soil Samples	4-3
4.3-1	Volatile Organic Compounds Detected in Groundwater Samples, February – July 1999	4-9

TABLE OF CONTENTS (Continued)

LIST OF TABLES (Continued)

No.	Title	Page
4.5-1	Groundwater Geochemical Data.....	4-35
4.5-2	Range of Hydrogen Concentrations for Given Terminal Electron-Accepting Processes.....	4-43
4.6-1	Estimated First-Order Degradation Rate Constants for CAHs	4-70
4.7-1	RNA Scoring Worksheet	4-73
5.3-1	Parameters used in Geochemical Models	5-4
5.4-1	Cleanup Goals for CAHs in Groundwater	5-9
5.5-1	Estimated Time to Achieve Cleanup Goals For CAHs in Groundwater	5-10
6.2-1	Properties of Selected Organic Chemicals.....	6-3
6.2-2	Final Cleanup Goals for CAH in Groundwater	6-7
6.2-3	Initial Screening of Technologies and Process Options for Groundwater Remediation	6-9
6.4-1	Estimated Time to Achieve Cleanup Goals for CAHs in Groundwater	6-18
6.4-2	Estimated Costs for Alternative 1 (MNA).....	6-23
6.4-3	Estimated Costs for Alternative 2A (Low-Rate Pump and Treat With MNA).....	6-24
6.4-4	Estimated Costs for Alternative 2B (High-Rate Pump and Treat With MNA).....	6-25
6.5-1	Summary of Remedial Alternatives Evaluation Groundwater Remediation	6-27
7.2-1	Long-Term Groundwater Monitoring Wells.....	7-5
7.3-1	Analytical Protocols for Groundwater Samples.....	7-7
7.3-2	LTM Sample Types, Analyses, and QA/QC Requirements	7-8

LIST OF FIGURES

No.	Title	Page
1.2-1	Area Location Map.....	1-5
1.2-2	Surface Drainage Features.....	1-6
1.2-3	Production Water Well Locations	1-7
1.3-1	Location of Site SS-45	1-10
1.3-2	Sampling Locations at which CAH Compounds Were Detected during Previous Investigations in Vicinity of Site SS-45.....	1-11
1.3-3	HydroPunch® Locations Sampled During the 1996 RFI.....	1-14

TABLE OF CONTENTS (Continued)

LIST OF FIGURES (Continued)

No.	Title	Page
1.3-4	Groundwater Monitoring Wells Completed in Intermediate Sand Unit During the RFI	1-15
1.3-5	Groundwater Monitoring Wells Completed in the Deep Sand Unit During the RFI	1-16
1.3-6	TCE in Groundwater Samples Collected from HydroPunch® Borings in Shallow Silt/Clay Unit	1-18
1.3-7	Total 1,2-DCE in Groundwater Samples Collected from HydroPunch® Borings in Shallow Silt/Clay Unit	1-20
1.3-8	Vinyl Chloride in Groundwater Samples Collected from HydroPunch® Borings in Shallow Silt/Clay Unit	1-21
1.3-9	TCE in Groundwater Samples Collected from HydroPunch® Borings in the Intermediate Sand Unit	1-22
1.3-10	Total 1,2-DCE in Groundwater Samples Collected from HydroPunch® Borings in the Intermediate Sand Unit.....	1-23
1.3-11	Vinyl Chloride in Groundwater Samples Collected from HydroPunch® Borings in the Intermediate Sand Unit.....	1-24
1.3-12	TCE in Groundwater Samples Collected from HydroPunch® Borings in the Deep Sand Unit	1-27
1.3-13	Total 1,2-DCE in Groundwater Samples Collected from HydroPunch® Borings in the Deep Sand Unit	1-28
1.3-14	Concentrations of CAHs in Groundwater Samples from Monitoring Wells in the Intermediate Sand Unit, June 1997 – September 1997.....	1-29
1.3-15	Concentrations of CAHs in Groundwater Samples from Monitoring Wells in the Intermediate Sand Unit, December 1997.....	1-30
1.3-16	Concentrations of CAHs in Groundwater Samples from Monitoring Wells in the Deep Sand Unit, June 1997 – September 1997	1-31
1.3-17	Concentrations of CAHs in Groundwater Samples from Monitoring Wells in the Deep Sand Unit, December 1997.....	1-33
2.1.2-1	Groundwater Monitoring Wells Completed in Intermediate Sand Unit	2-2
2.1.2-2	Groundwater Monitoring Wells Completed in Deep Sand Unit	2-3
3.4-1	Locations of Hydrogeologic Cross-Section Traces	3-5
3.4-2	Hydrogeologic Cross-Section A – A'	3-6
3.4-3	Hydrogeologic Cross-Section B – B'	3-7
3.4-4	Hydrogeologic Cross-Section C – C'	3-8
3.4-5	Extent of the Intermediate Clay Unit.....	3-10
3.4-6	Groundwater Elevations Measured in Wells in the Intermediate Sand Unit (May 24, 1999).....	3-19

TABLE OF CONTENTS (Continued)

LIST OF FIGURES (Continued)

No.	Title	Page
3.4-7	Groundwater Elevations Measured in Wells in the Intermediate Sand Unit (July 14, 1999)	3-21
3.4-8	Groundwater Elevations in the Deep Sand Unit (May 24, 1999).....	3-22
3.4-9	Groundwater Elevations in the Deep Sand Unit (July 14, 1999)	3-23
3.4-10	Vertical Hydraulic Gradients Between the Intermediate and Deep Sand Units (July 14, 1999).....	3-27
4.2-1	Reductive Dehalogenation of Chlorinated Ethenes.....	4-6
4.4-1	Conceptual Site Model	4-17
4.4-2	Distribution of TCE in Intermediate Sand Unit Groundwater	4-19
4.4-3	Distribution of <i>cis</i> -1,2-DCE in Intermediate Sand Unit Groundwater.....	4-20
4.4-4	Distribution of Vinyl Chloride in Intermediate Sand Unit Groundwater.....	4-21
4.4-5	Distribution of Ethene in Intermediate Sand Unit Groundwater.....	4-22
4.4-6	Concentrations of Total CAHs in Intermediate Sand Unit Groundwater.....	4-24
4.4-7	Concentrations of Total CAHs in Deep Sand Unit Groundwater	4-26
4.4-8	Locations of Hydrochemical Cross-Section Traces	4-28
4.4-9	Concentrations of Total CAHs in Groundwater Along Cross Section A-A'	4-29
4.4-10	Concentrations of Total CAHs in Groundwater Along Cross Section B-B'.....	4-30
4.4-11	Concentrations of Total CAHs in Groundwater Along Cross Section C-C'.....	4-31
4.5-1	Sequence of Microbially Mediated Redox Processes	4-40
4.5-2	Redox Potential in Intermediate Sand Unit Groundwater, March – July 1999	4-41
4.5-3	Redox Potential in Deep Sand Unit Groundwater, March – July 1999.....	4-42
4.5-4	Total Organic Carbon in Intermediate Sand Unit Groundwater, March - July 1999.....	4-46
4.5-5	Total Organic Carbon in Deep Sand Unit Groundwater, March - July 1999.....	4-47
4.5-6	Dissolved Ferrous Iron in Intermediate Sand Groundwater, March – July 1999	4-51
4.5-7	Dissolved Manganese in Intermediate Sand Groundwater, March – July 1999	4-52
4.5-8	Sulfate Concentrations in Intermediate Sand Unit Groundwater, March - July 1999	4-54
4.5-9	Sulfate Concentrations in Deep Sand Unit Groundwater, March - July 1999.....	4-55

TABLE OF CONTENTS (Continued)

LIST OF FIGURES (Continued)

No.	Title	Page
4.5-10	Methane Concentrations in Intermediate Sand Unit Groundwater, March - July 1999	4-57
4.5-11	Methane Concentrations in Deep Sand Unit Groundwater, March - July 1999	4-58
4.5-12	Distribution of Methane in Intermediate Sand Unit Groundwater.....	4-59
4.5-13	Carbon Dioxide Concentrations in Intermediate Sand Unit Groundwater, March - July 1999	4-61
4.5-14	Carbon Dioxide Concentrations in Deep Sand Unit Groundwater, March - July 1999	4-62
4.6-1	Groundwater Flowpath from Well #4 to A39L010PZ to A39L012PZ	4-66
5.1-1	Conceptual Structure of Kinetics-Based Geochemical Model	5-2
7.2-1	Proposed LTM Network for The Intermediate Sand Unit.....	7-3
7.2-2	Proposed LTM Network for the Deep Sand Unit.....	7-4

ACRONYMS AND ABBREVIATIONS

°C	degrees Centigrade
$\Delta G^{\circ}r$	Gibbs free energy of a reaction
$\mu\text{g/L}$	micrograms per liter
°C	degrees Celsius
°F	degrees Fahrenheit
$\mu\text{g/kg}$	micrograms per kilogram
$\mu\text{g/L}$	micrograms per liter
$\mu\text{mol/L}$	micromoles per liter
AFB	Air Force Base
AFCEE	United States Air Force Center for Environmental Excellence
amsl	above mean sea level
AOC	area of concern
ASTM	American Society for Testing and Materials
BCT	Base Conversion Team
bgs	below ground surface
BOD	biological oxygen demand
BTEX	benzene, toluene, ethylbenzene, and xylene isomers
CAH	chlorinated aliphatic hydrocarbons
CBS	comprehensive background study
cm/s	centimeters per second
CMS	Corrective Measures Study
cm/sec	centimeters per second
COD	chemical oxygen demand
DCA	dichloroethane
DCE	dichloroethene
DO	dissolved oxygen
DOC	dissolved organic carbon
EBF	electromagnetic borehole flowmeter
EBS	environmental baseline study
EE/CA	engineering evaluation/cost assessment
ERPIMS	Environmental Resources Program Information Management System
ft/day	feet per day
ft/ft	feet per foot
ft/min	feet per minute
g/cm^3	grams per cubic centimeter
gpd	gallons per day
gpm	gallons per minute
H ₂	hydrogen
ID	inside diameter
IWWTP	industrial wastewater treatment plants
K _{oc}	soil sorption coefficient

ACRONYMS AND ABBREVIATIONS (continued)

LAW	LAW Engineering and Environmental Services, Inc.
LDEQ	Louisiana Department of Environmental Quality
LTM	long-term monitoring
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNA	monitored natural attenuation
mV	millivolts
N	nitrogen
NAPL	nonaqueous-phase liquid
NAS	National Academy of Sciences
NGVD	National Geodetic Vertical Datum
nm/L	nanomoles per liter
NPDES	National Pollutant Discharge Elimination System
NPW	net present worth
NTU	nephelometric turbidity units
O&M	operations and maintenance
Ogden	Ogden Energy and Environmental, Inc.
OH ⁻	hydroxyl group
OHM	OHM Remediation Services, Inc.
ORD	Office of Research and Development
ORP	oxidation reduction potential
OSWER	Office of Solid Waste and Emergency Response
OVA	organic vapor analyzer
Parsons ES	Parsons Engineering Science, Inc.
PCE	tetrachloroethene
POC	point of compliance
POTW	publicly-owned treatment works
PQL	practical quantitation limit
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
RBSL	risk-based screening level
RCRA	Resource Conservation and Recovery Act
redox	oxidation/reduction
RFI	RCRA Facility Investigation
RNA	remediation by natural attenuation
SAP	sampling and analysis plan
SER	significant emissions rate
SVOC	semivolatile organic compound
TCA	trichloroethane
TCE	trichloroethene
TCLP	Toxicity Characteristic Leaching Procedure

ACRONYMS AND ABBREVIATIONS (continued)

TDS	total dissolved solids
TEAP	terminal electron-accepting processes
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TS	treatability study
TSS	total suspended solids
USEPA	United States Environmental Protection Agency
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound
WTP	water treatment plant

EXECUTIVE SUMMARY

The Air Force Center for Environmental Excellence (AFCEE) has retained Parsons Engineering Science Inc. (Parsons ES) to conduct additional site investigation activities and data analysis in support of the preparation of this focused corrective measures study (CMS) for groundwater at Site SS-45, England AFB, Louisiana. England AFB is undergoing closure and conversion for use as a civilian general aviation/industrial facility. The focused CMS effort at Site SS-45 is part of a multi-site AFCEE initiative to obtain site closure agreements that are protective of human health and the environment, and are cost efficient. AFCEE's position is that the level of remediation at a particular site should be commensurate with current and potential risk, and that remediation dollars should be allocated according to the degree of additional protection achieved.

In order to support the remedy selection process for Site SS-45, three primary objectives were assigned to this project:

- Complete additional site characterization activities at the 800 and 2500 Areas of the facility to define the extent of chlorinated aliphatic hydrocarbon (CAH) contamination affecting groundwater in the Intermediate and Deep Sand units;
- Assess whether natural chemical attenuation processes are sufficient to contain and eventually destroy/detoxify CAHs in groundwater and determine if monitored natural attenuation (MNA), combined with institutional controls, can provide a level of protection for human health and the environment comparable to other alternatives; and
- Complete an initial screening and final evaluation of remedial alternatives to determine the relative protectiveness, effectiveness, implementability, and cost of MNA and combinations of MNA with groundwater extraction.

Define the Extent of CAH Contamination in the Intermediate and Deep Sand Units

To meet the first objective, additional site characterization was completed to supplement remedial investigations, previously undertaken by LAW Engineering and Environmental Services, Inc. (LAW, 1998a). Previous investigations have sampled over 90 Hydropunch® locations and 20 monitoring wells to define the horizontal and vertical limits of contamination. Five of the most likely source areas within Site SS-45 were investigated using multiple Hydropunch® sampling locations. No significant source of CAH contamination was found, but low levels of trichloroethylene (TCE), dichloroethylene isomers (DCE), and vinyl chloride (VC) were encountered near former maintenance facilities, oil/water separators, and sewer lines. Based on these investigations, the current conceptual site model assumes multiple small sources of CAH contamination, minimal lateral migration in the upper silt/clay layer, and widespread, radial diffusion or advective dispersion of CAHs at dilute concentrations in the Intermediate and Deep Sand units.

One objective of additional site characterization was to define the perimeter of CAH contamination in areas where no previous sampling had occurred at this large site. To

complete this objective, two important hydrogeologic studies preceded the full-scale well installation program:

- At the suggestion of hydrogeologists affiliated with the US Environmental Protection Agency's (USEPA) R.S. Kerr Laboratory, three new wells were completed with screened intervals extending through the upper silt/clay and the entire Intermediate Sand unit. Using these wells, electromagnetic borehole flowmeter testing was completed by Quantum Engineering Inc. to determine if preferential flowpaths existed at discrete intervals within the Intermediate Sand unit. The borehole flowmeter testing revealed that hydraulic conductivity within the Intermediate Sand unit was relatively uniform and that intervals of preferential flow were unlikely.
- Previous sampling had indicated little or no hydraulic gradient across this 240-acre site. Several new wells were installed in areas where the potentiometric surface was poorly undefined. Using these wells and existing site wells, Parsons ES resurveyed the potentiometric surface to determine if a gradient could be measured at this site. The latest groundwater elevation data confirms that little or no gradient exists at Site SS-45 and that groundwater levels may be influenced by seasonal surface water changes. Based on the latest gradient information, groundwater seepage velocities of less than 0.1 to about 5 feet per year are likely in the Intermediate and Deep Sand units.

Based on these studies, there is little evidence to suggest that contaminants at Site SS-45 are being preferentially transported away from the site. In fact, the pattern of contaminant migration strongly suggests that several small, areally-distributed sources may have contributed CAH compounds to groundwater beneath Site SS-45, and that chemical diffusion may be the most important solute transport mechanism operating at the site. (Alternatively, because groundwater flow directions beneath the site are generally indeterminate, the distribution of chemicals may have occurred as a result of inconsistent or oscillating advective migration along poorly-defined flowpaths.). Using this information, 17 additional monitoring wells (12 Intermediate Sand wells and 5 Deep Sand wells) were installed at the plume perimeter and near known "hot spots" within the 800 and 2500 Areas of Site SS-45. A total of 20 new and 18 existing wells were then sampled for CAHs and a full suite of geochemical indicators for use in the natural attenuation analysis. In many of the new wells CAHs were detected at, or slightly above, detection limits but below potential regulatory action levels. Based on these data, new plume maps were produced to more accurately define the extent of CAH contamination in both the Intermediate and Deep Sand units at Site SS-45. Section 4 provides a complete review of the extent of the CAH plumes at Site SS-45.

Assessment of Natural Attenuation Potential

CAH compounds are known to attenuate through several mechanisms, including sorption, volatilization, dilution from recharge, mechanical dispersion, chemical diffusion, and abiotic and biotic degradation (USEPA, 1998). Of these mechanisms, biodegradation is the most frequently-occurring process working to transform CAHs into innocuous byproducts. Reductive dechlorination is a biologically efficient and common

pathway for degrading CAH compounds under anaerobic conditions, particularly TCE and DCE (Criddle and McCarty, 1991).

Earlier work at the site provided initial information regarding the potential for CAH remediation by natural attenuation (RNA) at Site SS-45 (LAW, 1998a). Degradation products of TCE, (i.e. DCE, VC, and ethene) were detected in patterns that indicated that reductive dechlorination was occurring at the site. Geochemical data collected by LAW (1998a) also confirmed that the general conditions for reductive dechlorination exist in all hydrogeologic units at the site.

Using available data, Parsons ES designed a sampling program to fully investigate and document the RNA mechanisms at work at Site SS-45 and to estimate the range of biodegradation rates that are transforming CAHs into innocuous byproducts. Limited soil sampling and extensive groundwater sampling at 38 wells were completed to more fully delineate site geochemistry as it relates to CAH biodegradation. The principal conclusions of the RNA evaluation are summarized below.

- Based on the USEPA (1998) scoring system for reductive dechlorination potential, the geochemical conditions and evidence of TCE daughter products at Site SS-45 produced a score of 27.5 for the 800 Area and 30.5 for the 2500 Area. The USEPA (1998) has suggested that any score exceeding 20 indicates "*strong evidence for reductive transformation of chlorinated organics*". As a point of reference, over the past 4 years the Air Force, USEPA, and Parsons ES have cooperated on many RNA investigations at CAH-contaminated sites. The maximum score achieved has been 33, with an average score of 17.
- Given the low concentrations of TCE and its daughter products at the perimeter of the 800 Area and 2500 Area plumes, the relatively low concentrations of CAH compounds in the general source areas, and the ratios of TCE breakdown products to TCE across much of the site, it appears that the plumes may have stabilized. Although the time-frame for complete removal of CAH compounds from groundwater is uncertain, RNA is expected to contain and gradually shrink the Site SS-45 plumes.
- In general, DCE (but not VC) occurs in plume perimeter wells. This indicates that the degradation of DCE to VC may be the rate-limiting step. There is significant evidence that VC is degrading to ethene based on the elevated ethene concentrations which occur in wells that also contain VC.
- Based on the high levels of natural organic matter and anaerobic background conditions in these river-bottom sediments, there appears to be an adequate supply of organic substrate to maintain geochemical conditions conducive to long-term reductive dechlorination.
- Although the historical period of monitoring groundwater for CAHs is limited, the mass of CAH compounds appears to have declined through time in several locations.

- Because only minor dispersion appears to be attributable to advective flow, first-order degradation constants could be estimated using the relative concentrations of TCE and daughter products detected in groundwater samples from individual monitoring wells. Using this method, conservative decay rates were calculated for each step of the degradation of TCE to ethene. The first-order decay constants calculated by this method were within the range of decay constants estimated for other CAH-contaminated sites. Additional long-term monitoring data will be required to refine decay-rate estimates.

Development and Evaluation of Remedial Alternatives

A focused CMS was completed in accordance with Resource Conservation and Recovery Act (RCRA) corrective action plan guidance. Multiple technical approaches, technologies, and institutional controls were initially screened using three primary criteria: effectiveness and permanence, implementability, and relative cost. Site-specific factors including physical site characteristics, potential exposure pathways, data sufficiency, and preliminary remedial action objectives also were considered in the screening process. From a long list of possible remedial options, several technologies and remedial approaches were selected and combined into three remedial alternatives:

- **Alternative 1** – Groundwater remediation by MNA and institutional controls.
- **Alternative 2a** – Groundwater remediation using MNA and institutional controls combined with containment (low-rate) groundwater extraction, treatment by air stripping, and effluent discharge to the local publicly owned treatment works (POTW).
- **Alternative 2b** – Groundwater remediation using MNA and institutional controls combined with a more aggressive, high rate of groundwater extraction, treatment by air stripping, and effluent discharge to the local POTW.

As described in Section 5, a simple, spreadsheet-based kinetic model was used to evaluate the radial plume configurations in the 800 and 2500 Areas of Site SS-45. For Alternative 1, the effects of reductive dechlorination, sorption, and diffusion were simulated over time to estimate mass removal rates and the time required to achieve final cleanup goals for all contaminants of concern. For the pumping alternatives, advective groundwater flow was added to the kinetic model to simulate the impact of groundwater extraction on overall CAH mass-removal rates. Using this model, the relative time frames for achieving cleanup goals were estimated for each alternative. Due to the much lower detections of CAH compounds in the upper silt/clay layer, the model assumed that this layer would not continue to function as a significant source. This simplifying assumption should not impact the overall effectiveness comparison between alternatives. If a continuing source of CAH compounds does exist, the remediation time frames for all alternatives would be extended, but the relative time frames for each alternative should remain the same.

Recommended Remedial Approach

The comparative evaluation of the three remedial alternatives considered for Site SS-45 is summarized in Table ES-1. The MNA and pumping alternatives would each result in permanent reductions in CAH concentration, mobility, and toxicity, but would require different time periods to attain site cleanup goals. MNA and the two pumping alternatives are all protective of human health and the environment over the long term. Alternatives 2a and 2b, which incorporate groundwater extraction with air stripping and POTW discharge, would result in air-stripper emissions of low concentrations of CAHs to the atmosphere. The alternative relying solely on RNA to remove TCE and daughter products from groundwater beneath Site SS-45 makes maximum use of *in-situ* destructive mechanisms, and will not increase the short-term potential for receptor exposure during implementation. All of the alternatives are considered implementable, though the construction and operation of Alternatives 2a and 2b components could interfere with future land use. All alternatives will require the establishment and enforcement of appropriate institutional controls to restrict deep excavations and extraction of alluvial groundwater for beneficial uses until cleanup goals are achieved. Substantial capital costs (constructing the extraction wells and treatment systems) and system operating and monitoring (O&M) costs are associated with Alternatives 2a and 2b, in addition to long-term monitoring (LTM) costs. Because MNA requires minimal capital expenditures, and incurs only LTM costs, Alternative 1 is much less costly than Alternatives 2a and 2b.

The current distribution of CAHs in the groundwater system beneath the Site SS-45 is likely the result of a 30- to 40-year history of chemical releases. Widely dispersed historical sources of chemicals in soil appear to have continuously introduced CAHs to the groundwater system in the Intermediate Sand unit. However, the site history and current extent of CAH compounds in groundwater suggests that RNA, in combination with the hydraulic characteristics of the Intermediate Sand unit, has been effective in controlling contaminant migration without engineered remediation.

Despite this history of introduction of CAH compounds to groundwater, with subsequent migration, the extent of chemical migration in the groundwater system from suspected chemical sources in the 800 and 2500 Areas is localized. Observed site conditions suggest that RNA will continue to remove chemical mass from groundwater, and that groundwater quality will continue to improve with time.

Based on the site conditions observed during the RNA evaluation, and on the results of the detailed evaluation of three remedial alternatives, Alternative 1 (MNA with Institutional Controls) is judged to be protective and effective, and is recommended as the most cost-effective method for achieving remedial action objectives for groundwater contaminated with CAHs at Site SS-45. The rationale for this recommendation are summarized as follows:

- Alternatives 1, 2a, and 2b are equally effective in protecting human health and the environment, and meet the implementability and permanence criteria;

TABLE ES-1
SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION
GROUNDWATER REMEDIATION
SITE SS-04
ENGLAND AFB, ALEXANDRIA, LOUISIANA

Remedial Alternative	Protectiveness and Effectiveness	Implementability	Constant-Dollar Cost Estimate
Alternative 1 - Natural Attenuation - Institutional Controls - Long-term Monitoring	Protective of human health and the environment. Contaminant mass, volume, and toxicity will be slowly reduced over time until final cleanup goals are attained.	Readily implementable. Groundwater quality monitoring is required for an estimated 48 years. Institutional controls, including land and groundwater use controls, are required. The potential for receptor exposure to site contaminants is negligible if institutional controls are implemented. CAHs will be degraded to innocuous byproducts.	\$1,302,700
Alternative 2a - Natural Attenuation - Institutional Controls - Long-term Monitoring - Low-Rate Pumping - Air Stripping - POTW Disposal	Protective of human health and the environment. Provides additional plume containment. Slight decrease in time required to achieve cleanup goals. Increased human exposure to CAH contaminants due to air emissions from aboveground treatment systems.	Common technical approach. Also requires institutional controls. Requires the design and installation of three extraction wells, two air strippers, and piping to the POTW sewer, plus O&M of the extraction/treatment systems for about 35 years. Aboveground structures would have some impact on land development. Additional time required for permits and OPS demonstration.	\$6,038,00
Alternative 2b - Natural Attenuation - Institutional Controls - Long-term Monitoring - High-Rate Pumping - Air Stripping - POTW Disposal	Protective of human health and the environment. Provides additional plume containment. Decreases time to achieve cleanup goals if no continuing source exists. Increased human exposure to CAH contaminants due to air emissions from aboveground treatment systems.	Common technical approach. Also requires institutional controls. Requires the design and installation of three extraction wells, two air strippers, and piping to the POTW sewer, plus O&M of the extraction/treatment systems for about 26 years. Aboveground structures would have some impact on land development. Additional time required for permits and OPS demonstration.	\$15,491,000

- The time frames to achieve site cleanup goals are comparable, but pumping alternatives could achieve final cleanup goals faster if the assumptions underlying the calculations are correct. If a continuing source exists in the upper silty/clay layer, the estimated time frames would increase, but the relative time frames for each of the alternatives should be similar. However, the cost difference between Alternative 1 and the pumping alternatives will increase as the timeframe for cleanup increases.
- Pumping alternatives have the potential to transfer contaminants from the subsurface into the atmosphere, and would present additional contaminant exposure potential and occupational hazards. This presents greater short-term risks to public health;
- The additional cost associated with pumping alternatives is not warranted given the comparability of the effectiveness, permanence, and implementability of the three alternatives. MNA with institutional controls will provide an equivalent level of protection of public health and the environment.

The LTM program proposed for Site SS-45 is described in Section 7. Three additional groundwater monitoring wells are proposed, to supplement the existing monitoring network at Site SS-45. After the first 5 years of monitoring, the England BCT could convene to evaluate whether MNA is progressing sufficiently toward achieving remedial action objectives. Performance objectives for plume stability, rates of biodegradation, and maintenance of institutional controls are described in Section 7. If at that time the BCT concurs that MNA is making adequate progress toward remediation objectives, biennial LTM could be considered for the duration of the remedy. Conversely, if RNA fails to progress toward remedial action objectives, contingency measures could be considered, including reconsideration of pumping alternatives.

SECTION 1

INTRODUCTION

This report was prepared by Parsons Engineering Science, Inc. (Parsons ES) to present the results of a focused Corrective Measures Study (CMS), including an assessment of the potential for remediation by natural attenuation (RNA) of groundwater contaminated with chlorinated aliphatic hydrocarbons (CAHs) (in essence, an RNA treatability study [RNA TS]), for Site SS-45 at the former England Air Force Base (AFB), Alexandria, Louisiana. As used in this report, RNA refers to a management strategy that relies on the evaluation and application of natural attenuation mechanisms, within the context of a carefully controlled and monitored site cleanup approach, that will reduce contaminant mass and/or concentrations to levels that are protective of human health and the environment, within a reasonable time frame. The United States Environmental Protection Agency (USEPA, 1998) defines natural attenuation as:

Naturally-occurring processes in soil and groundwater environments that act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in these media. These in-situ processes include biodegradation, dispersion, dilution, adsorption, volatilization, and chemical or biological stabilization or destruction of contaminants.

As suggested by this definition, mechanisms for natural attenuation of CAHs include non-destructive mechanisms (advection, dispersion, dilution from recharge, sorption, and volatilization) that act to reduce contaminant concentrations via dilution or transfer to another medium, and destructive mechanisms (abiotic chemical transformation and biodegradation) that actually remove contaminant mass. Of these processes, biodegradation is the mechanism that most commonly occurs to transform subsurface contaminants into innocuous byproducts. During natural biodegradation, indigenous microorganisms bring about a reduction in the total mass of contaminants in the subsurface without engineered enhancements. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

A particular emphasis of the current project was to evaluate the potential for naturally-occurring degradation mechanisms to reduce the concentrations of CAHs in groundwater to levels that are protective of human health and the environment. A secondary objective was to compare the potential effectiveness and cost of a natural attenuation remedy with the effectiveness and cost of an alternative remedy utilizing pump-and-treat technology. This evaluation is not intended to be a contamination assessment report or a remedial action plan; rather, it is provided for the use of the Base and its prime environmental

contractor(s) as information to be used for future decision-making regarding potential remedies for groundwater at Site SS-45.

1.1 SCOPE AND OBJECTIVES

Parsons ES was retained by the Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division to conduct site characterization, to complete an evaluation of the potential applicability and effectiveness of monitored natural attenuation (MNA) as a remedial option for contaminated groundwater at Site SS-45, England AFB, and to prepare a focused CMS that compares MNA with a limited subset of other potentially-applicable remedies for groundwater.

The following tasks were performed to fulfill the project objectives:

- Reviewing existing site-specific hydrogeologic information and laboratory analytical data for soil and groundwater;
- Conducting supplemental site characterization activities to more thoroughly evaluate the nature and extent of groundwater contamination;
- Collecting and evaluating geochemical data to assess the occurrence of RNA;
- Developing a conceptual hydrogeologic model of the saturated zone, including the current distribution of contaminants;
- Estimating the rates at which dehalogenation processes are transforming trichloroethene (TCE) to harmless byproducts (including chloride and ethene);
- Assessing whether natural processes are sufficient to restrict further migration of the dissolved CAH plume;
- Conducting an exposure pathway analysis for potential current and future receptors;
- Using a kinetic-based geochemical model to evaluate the potential effects of natural attenuation alone, and active groundwater extraction in combination with natural attenuation, on the dissolved CAH plume;
- Evaluating a range of model input parameters to determine the sensitivity of the model to those parameters and to consider several contaminant fate scenarios; and
- Developing a long-term monitoring (LTM) plan that identifies LTM wells and includes recommendations for groundwater sampling and analysis, to be incorporated, as appropriate, into the basewide Sampling and Analysis Plan (SAP).

Field work completed in support of this program was oriented toward the collection of supplementary hydrogeologic and chemical data necessary to document and evaluate the effectiveness of RNA for restoration of CAH-contaminated groundwater. Site characterization activities included:

- Installation of three fully-screened wells and completion of borehole flowmeter tests to evaluate variations in hydraulic conductivity with depth;
- Collection of a limited number of soil samples in the subsurface, to estimate the sorptive capacity of the local aquifer materials, and to evaluate the presence of ferric iron (Fe^{+3}) potentially available in soil to oxidize vinyl chloride (VC);
- Installation of 12 groundwater monitoring wells in the Intermediate Sand unit and 5 monitoring wells in the Deep Sand unit to more fully assess the nature and extent of dissolved CAHs in the groundwater system at Site SS-45; and
- Collection and analysis of groundwater samples from all newly-installed monitoring wells and from a subset of the existing wells, to assess the distribution of CAHs in groundwater at Site SS-45, evaluate plume stability, and estimate rates of chemical degradation.

Site-specific data were used to develop a screening-level model to evaluate the fate of dissolved CAHs in groundwater at Site SS-45. The modeling effort was used to predict the future concentrations of TCE and its daughter products within the dissolved CAH plume. Results of the chemical fate evaluation were used to assess whether RNA is an appropriate remedial option for contaminated groundwater at Site SS-45. A groundwater extraction ("pump-and-treat") remedy also was evaluated in terms of its potential effectiveness and cost as compared with the RNA alternative.

This focused CMS is organized into nine sections, including this introduction, and eight appendices. Section 2 summarizes site characterization activities, and Section 3 summarizes the physical characteristics of England AFB and Site SS-45. Section 4 describes the nature and extent of groundwater contamination, and summarizes the evidence of RNA of contaminants in groundwater at the site. Section 5 describes the conceptual hydrogeologic model for the site, and its incorporation into a kinetic-based model of chemical fate; lists model assumptions and input parameters; and describes the results of calculations and of the subsequent sensitivity analysis. Section 6 discusses the predicted effects of potential future remedial measures on the dissolved CAH plumes, and presents conclusions regarding the relative effectiveness, implementability, permanence, and cost of the potential alternatives. Section 7 presents the long-term monitoring (LTM) plan for groundwater at Site SS-45. Section 8 lists the references cited in this report.

Appendix A contains selected information from previous reports. Appendix B contains borehole logs and well-construction diagrams, monitoring-well development and sampling forms, and survey data generated in conjunction with the current investigation. Appendix C consists of a compact disk (read only – CD-ROM) containing the results of analyses (in Environmental Resources Program Information Management System [ERPIMS] format) of soil and groundwater samples collected in support of this project. Appendix D contains a discussion of the chemical properties of the constituents of potential concern at Site SS-45, and their movement and fate in the environment. Maps showing the concentrations and areal distribution of CAHs, electron donors, and electron acceptors, are included in Appendix E. Procedures used to estimate the rates of chemical degradation in the subsurface at Site SS-45 are described in detail in Appendix F. The

relative effectiveness and costs of potential remedial alternatives are detailed in Appendix G.

In September 1999, a draft of this report was submitted to the Louisiana Department of Environmental Quality (LDEQ) and the U.S. Environmental Protection Agency (USEPA) for review and comment. Comments provided by reviewers are included in Appendix H, and have been addressed in the final report, as appropriate.

1.2 BACKGROUND INFORMATION

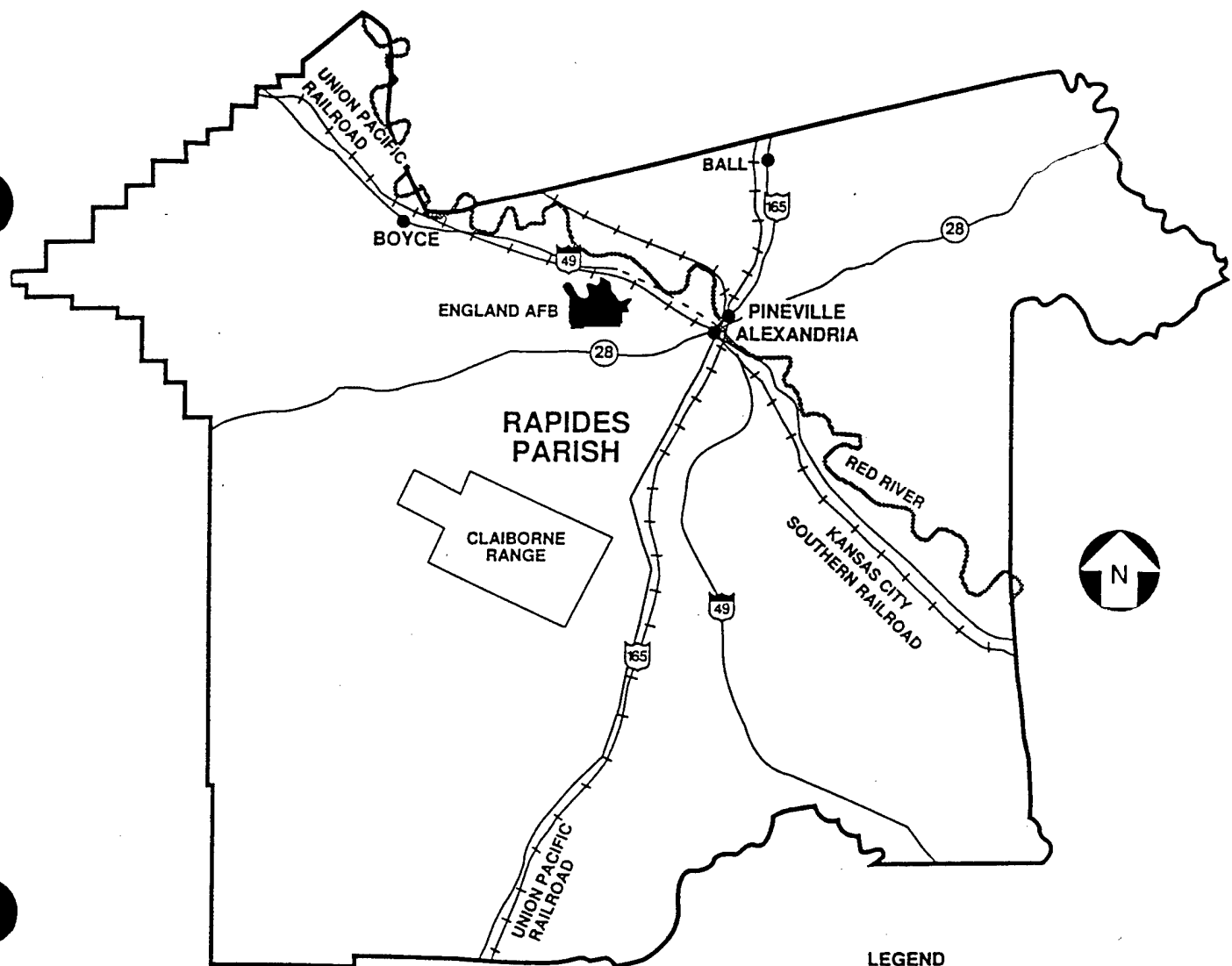
England AFB is located in Rapides Parish, the regional hub of central Louisiana. Encompassing 2,604 acres, the Base lies approximately 5 miles west of the cities of Alexandria and Pineville and about 1 mile southwest of the Red River, which flows to the southeast between Alexandria and Pineville (Figure 1.2-1). Surface drainage occurs via overland flow to Le Tig Bayou in the central part of the Base, to the northern drainage ditch, or to numerous storm sewers (Figure 1.2-2).

Potable water is provided to England AFB by the City of Alexandria. However, groundwater is produced for industrial, agricultural, or other water-supply uses from approximately 30 groundwater wells within one mile of England AFB (Figure 1.2-3 and Table 1.2-1). No well within 3,000 feet of the central part of England AFB is used as a drinking-water supply.

England AFB was originally constructed as Alexandria Municipal Airport in 1942, and was then leased to the Army Air Force by the city of Alexandria in conjunction with national mobilization for World War II. The Base was formally activated as Alexandria Army Air Base in February 1943, and was used until 1945 as a training base for B-17 and B-29 pilots. After the end of World War II, Tactical Air Command (TAC) received command of the field and placed it on inactive status (LAW Engineering and Environmental Services, Inc. [LAW], 1998a).

With the outbreak of hostilities in Korea in 1950, the Air Force re-activated Alexandria AFB, and TAC began pilot and crew training in jet fighter aircraft. The Base was officially designated as a permanent Air Force facility and renamed England AFB in honor of Lieutenant Colonel John B. England in 1955 (TetraTech, 1992). Soon after permanent designation, construction of permanent facilities began to replace many of the remaining temporary buildings constructed in the early 1940s. A 300-unit Capehart housing project, six hangars, a jet build-up area, and a GAR-8 missile assembly and maintenance building were completed by December 1958. An additional 300-unit housing project was completed by 1970, and a 75-bed hospital opened in 1971.

The Base was formally closed in December 1992; reuse of certain facilities began immediately upon closure, and a Basewide lease to the England Economic and Industrial Development District was executed in March 1995. Complete transfer of ownership of the entire Base will not occur until environmental cleanup remedies are determined to be in place and operating properly and successfully.



LEGEND



INTERSTATE HIGHWAY



U.S. HIGHWAY



STATE HIGHWAY



PARISH BOUNDARY

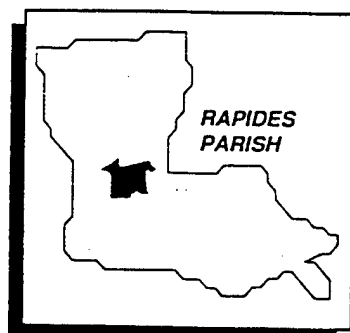


RAILROAD



HIGHWAY UNDER CONSTRUCTION

SCALE IN MILES



LOUISIANA STATE KEY MAP

FIGURE 1.2-1

AREA LOCATION MAP

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

SOURCE: LAW, 1998.

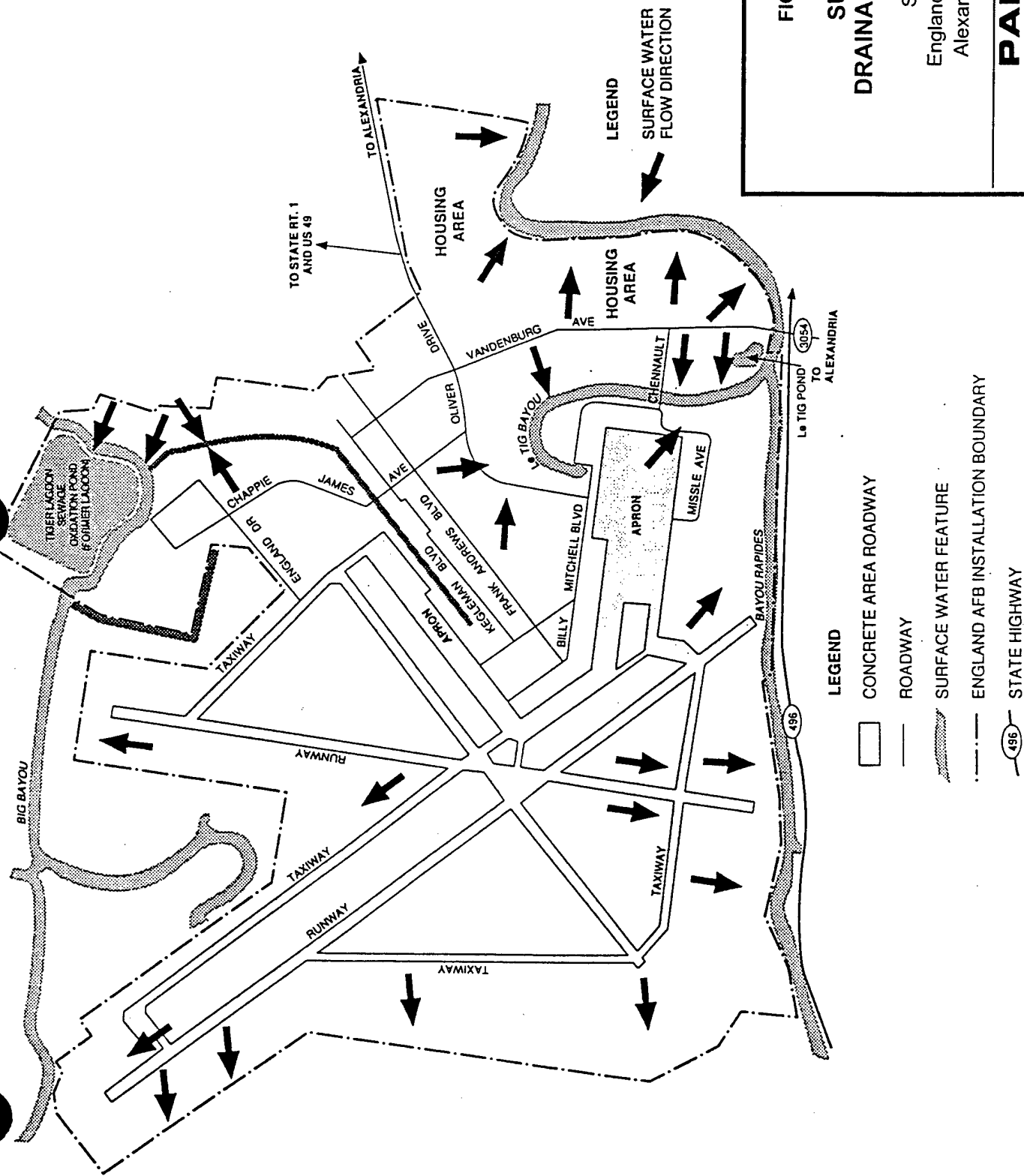
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FIGURE 1.2-2

SURFACE DRAINAGE FEATURES

Site SS-45
England Air Force Base
Alexandria, Louisiana

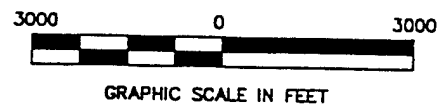
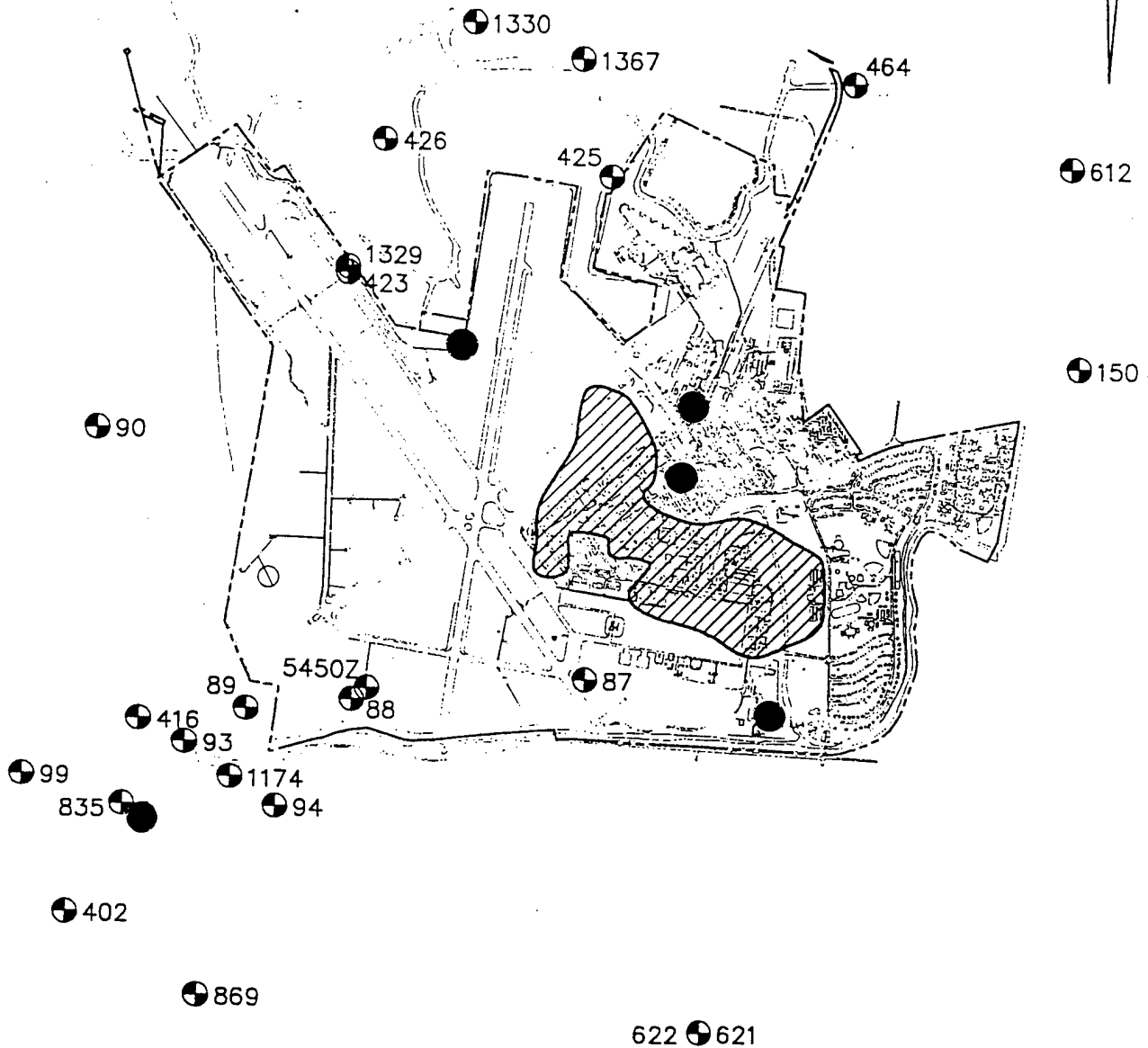
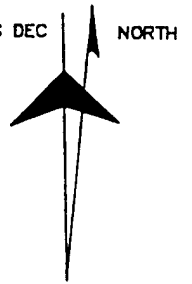
PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



SOURCE: LAW, 1998.

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APPROX. MAG DEC
7° 33'



LEGEND

● TEST AND OBSERVATION WELLS OR
ABANDONED WATER SUPPLY WELLS

⊕ 442 WELL LOCATIONS

▨ APPROXIMATE SS-45
LOCATION

--- BASE BOUNDARY

SOURCE: LAW, 1998.

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FIGURE 1.2-3

PRODUCTION WATER WELL LOCATIONS

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

TABLE 1.2-1
WATER SUPPLY WELLS IN THE VICINITY OF ENGLAND AFB
SITE SS-45
ENGLAND AIR FORCE BASE, LOUISIANA

WELL NUMBER	WELL USE	WELL DEPTH (feet)
87	Unknown	600
88	Unknown	448
89	Unknown	875
90	Unknown	370
93	Unknown	890
94	Domestic	500
99	Domestic	427
150	Domestic	390
402	Domestic	205
416	Domestic	428
423	Public Supply	994
425	Public Supply	462
426	Public Supply	968
464	Public Supply	817
612	Public Supply	577
621	Irrigation	60
622	Irrigation	60
835	Public Supply	500
869	Irrigation	80
1174	Public Supply	425
1329	Public Supply	800
1330	Public Supply	925
1367	Irrigation	75
5450Z	Irrigation	90

After Law (1998).

1.3 SUMMARY OF PREVIOUS INVESTIGATIONS

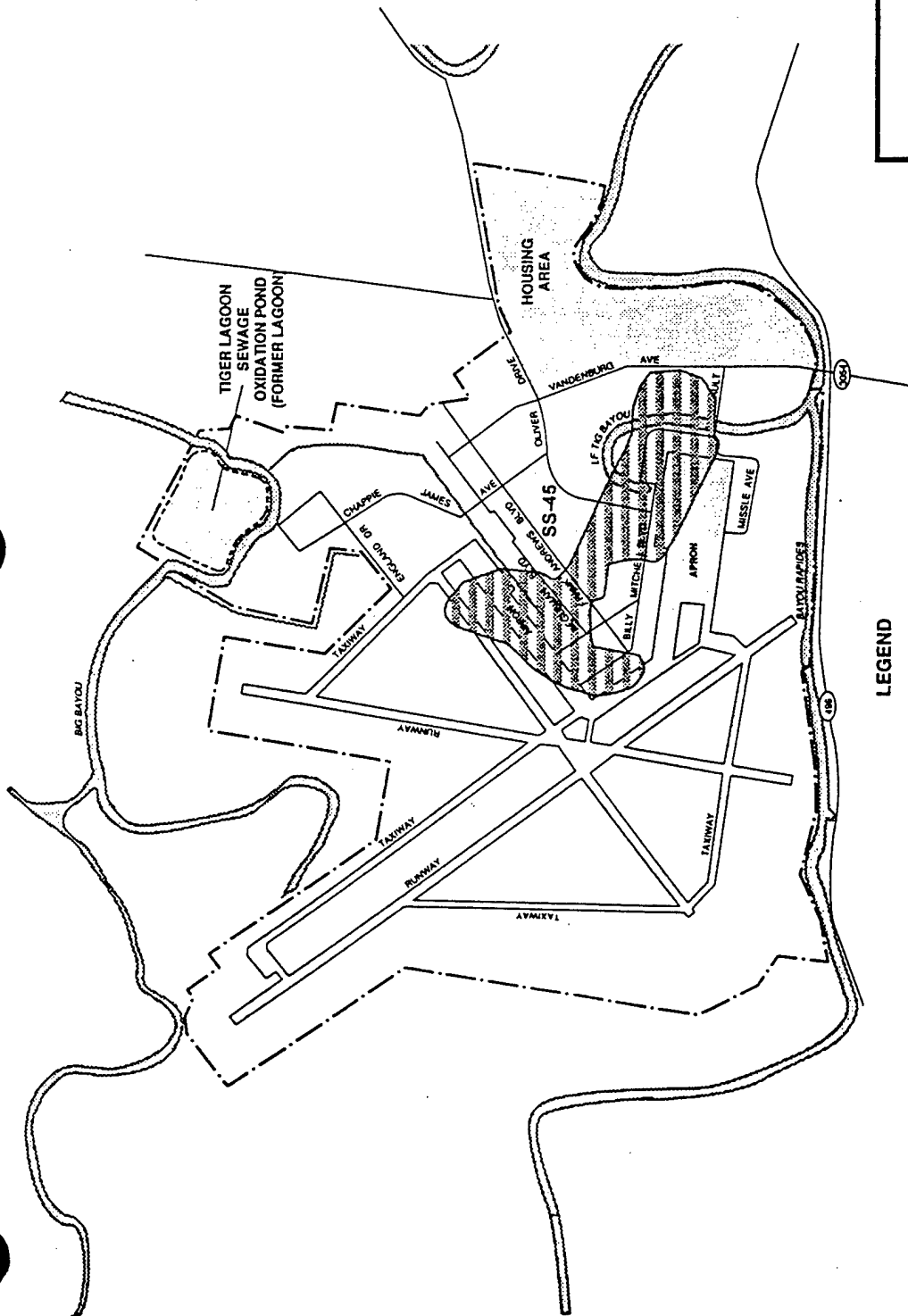
The following summary of environmental investigations is condensed from the Draft Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) report prepared and issued by LAW (1998a).

Site SS-45 is the designation for an area in the central part of England AFB that contains groundwater contaminated with CAH compounds. Site SS-45 is entirely contained within the England AFB property boundary (Figure 1.3-1) and encompasses an area of approximately 240 acres. The groundwater contamination associated with SS-45 is primarily within the intermediate depth zone of the Red River Alluvial Aquifer (the "Intermediate Sand unit"), extending from depths of about 20 to 80 feet below ground surface (bgs). Groundwater contaminants also have been detected at lower concentrations in shallow (the "Upper Clay" unit) and deep zones (the "Deep Sand" unit) of the aquifer, extending from depths of about 80 to 120 feet bgs. The groundwater contamination encountered during investigations through 1997 within the shallow silt/clay stratum that overlies the sandier intervals of the Alluvial Aquifer was heterogeneous and discontinuous in occurrence, becoming more homogeneous and dispersed with depth.

1.3.1 Comprehensive Background Study

TCE was first detected in groundwater at Site SS-45 (initially designated Area of Concern [AOC] 39), during a Comprehensive Background Study (CBS) completed in 1995 (LAW, 1998a). Three groundwater monitoring wells (BKGL039MW, BKGL040MW, and BKGL041MW) were installed in the vicinity of Building 814, near the North Apron, to evaluate the presence of chemicals in soil and groundwater that might have resulted from stormwater runoff from the North Apron (Figure 1.3-2). Soil samples were collected from each of the boreholes during drilling; and groundwater samples were collected from each of the three monitoring wells following well completion and development. Two surface soil samples (0 to 6 inches bgs) were collected near the CBS borehole drilled for well BKGL039MW (from two separate borings), and one surface soil sample was collected at each of the borings drilled for wells BKGL040MW and BKGL041MW. A total of 17 subsurface soil samples were collected from the boreholes for the three wells. No chlorinated volatile organic compounds (VOCs) were detected in any of the soil samples analyzed. Analytical data from this and other historical site investigations are provided in appendices of the LAW (1998a) RFI report. Positive results summary tables from the RFI report are presented in Appendix A.

One groundwater sample was collected from each of the three CBS monitoring wells. TCE and 1,2-dichloroethene (1,2-DCE) (a breakdown product of TCE) were detected at concentrations of 140 micrograms per liter ($\mu\text{g/L}$) and 2.7 $\mu\text{g/L}$, respectively, in the sample from well BKGL039MW. Groundwater samples from monitoring wells BKGL040MW and BKGL041MW also contained detectable concentrations of DCE (at concentrations of 13 $\mu\text{g/L}$ and 4.3 $\mu\text{g/L}$, respectively). Groundwater was re-sampled at monitoring well BKGL039MW approximately 1 month later. The reanalysis confirmed the presence of TCE at a concentration of 26.7 $\mu\text{g/L}$, and 1,2-DCE isomers at a total concentration of 0.608 $\mu\text{g/L}$.



0 2000 4000
SCALE IN FEET

LEGEND

- INTERSTATE HIGHWAY
- U.S. HIGHWAY
- STATE HIGHWAY
- PARISH BOUNDARY
- RAILROAD
- HIGHWAY UNDER CONSTRUCTION
- BASE BOUNDARY
- SS-45 LOCATION

Note: The SS-45 location is based on the extent of groundwater contamination determined from the results of the RFI Study.

SOURCE: LAW, 1998.

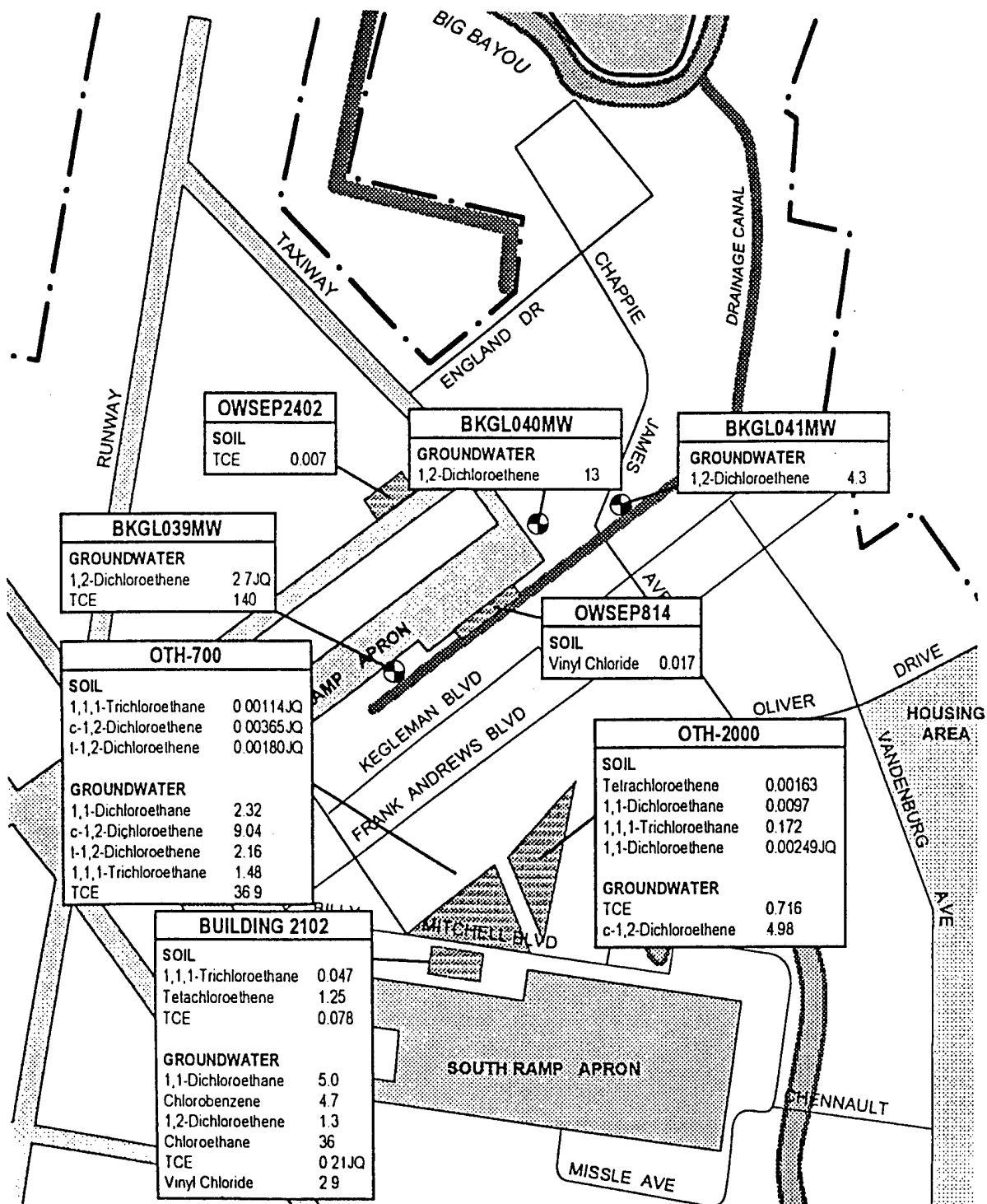
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FIGURE 1.3-1

LOCATION OF SITE SS-45

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



LEGEND

--- Base Boundary

Site Location

Monitoring Well Location

NOTE: Chemical concentrations are in $\mu\text{g/L}$ for groundwater and mg/kg for soil.

0 2000 4000

SCALE IN FEET (APPROXIMATE)

FIGURE 1.3-2

**SAMPLING LOCATIONS AT WHICH
CAH COMPOUNDS WERE DETECTED
DURING PREVIOUS INVESTIGATIONS
IN VICINITY OF SITE SS-45**

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

SOURCE: LAW, 1998.

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1.3.2 Source Area Investigations

Due to the historical pattern of TCE use at most Air Force bases (small batches of TCE disposed in sanitary sewers), it has been difficult to isolate any concentrated source of TCE at England AFB. The low permeability of soils in the shallow subsurface (primarily silty clay) and lack of horizontal hydraulic gradient compound this problem because CAH contamination tends to migrate vertically rather than displaying the morphology of classical horizontal plumes, which are easier to track to a source area. Approximately 20 environmental sites are located on the nearly 240 acres of land overlying the contaminated groundwater of Site SS-45. Low concentrations of chlorinated VOCs were detected in the soil and/or shallow groundwater samples collected at five of these sites during previous investigations (Figure 1.3-2). Areas that have been examined for potential chemical sources during past investigations are summarized below:

Building 2102 – Building 2102 (the Jet Engine Inspection and Maintenance Shop) is located north of the South Ramp Apron (Figure 1.3-2). Three underground storage tanks (USTs) that contained engine-cleaning fluids and an oil/water separator were formerly located north of the building. Ogden Energy and Environmental, Inc. (Ogden, 1994) removed the USTs in 1993, and collected confirmation samples of the soil beneath the USTs. The soil contained petroleum-related compounds; however, CAHs were not detected (Ogden, 1994). OHM Remediation Services, Inc. (OHM, 1996) performed an interim removal action with confirmatory sampling at Building 2102 in 1995 to remove the petroleum-contaminated soil in the area of the three former USTs and the oil/water separator. During the removal, a second, disconnected oil/water separator was encountered and removed. Confirmation samples were taken from the bottom and side walls of the excavation. A composite sample from a side wall of the excavation contained total petroleum hydrocarbons (TPH); 1,1,1-trichloroethane (1,1,1-TCA); tetrachloroethene (PCE); and TCE (OHM, 1996). RNA was proposed for treatment of contaminated soil left in place after the excavation had been advanced as far as practicable, and the interim removal action had been completed. The LDEQ requested that the site be included in the Base LTM program prior to a determination regarding closure of the unit.

In January 1997, LAW sampled two wells that had been installed at the site by OHM as part of the LTM program. Petroleum hydrocarbon compounds and chlorinated solvent constituents were detected in the groundwater sample collected in the monitoring well thought to be downgradient from Building 2102. Chlorinated compounds detected included 1,1-dichloroethane (1,1-DCA); 1,2-DCE; chlorobenzene; and VC, occurring at concentrations slightly above their respective practical quantitation limits (PQLs). In addition, TCE was detected at a concentration below its PQL, and chloroethane was detected at a concentration of 36 µg/L.

OWSEP 814 – In 1994, LAW (1997) investigated the oil/water separator at Building 814, the Fuels System Shop, located south of the North Ramp (Figure 1.3-2). Analytical results for a soil sample collected adjacent to the separator indicated the presence of VC, a breakdown product of TCE, at a concentration of 17 micrograms per kilograms (µg/kg). The VC concentration slightly exceeded the England AFB soil-to-groundwater screening

level but was below the direct-contact soil-screening level established for an on-Base residential scenario (LAW, 1997).

OWSEP 2402 – In 1994, LAW (1997) conducted investigations in the area around the oil/water separator at the Refueling Vehicle Maintenance Washrack, designated OWSEP 2402. OWSEP 2402 is located immediately north of the North Ramp. Analytical results for a soil sample collected adjacent to the separator indicated the presence of TCE at a concentration of 7 µg/kg, which is below the soil risk-based screening level (RBSL) for this compound (LAW, 1997).

OTH-700 – A Phase II Environmental Baseline Study (EBS) was conducted at OTH-700 by LAW in 1995. OTH-700 is located north of Billy Mitchell Boulevard (Figure 1.3-2), and was formerly a motor pool area used from 1942 through the early 1980s. During the EBS, several chlorinated compounds were detected in the soil and groundwater samples collected at OTH-700. 1,1,1-TCA was detected at a concentration below its PQL in a single surface soil sample. In addition, *cis*-1,2-DCE and *trans*-1,2-DCE were detected in subsurface soil samples at concentrations below their respective PQLs. TCE, 1,1,1-TCA, 1,1-DCA, *cis*-1,2-DCE, and *trans*-1,2-DCE were detected in the groundwater sample collected at OTH-700. Concentrations of these chemicals detected in soil and groundwater samples were below the England AFB RBSLs except for TCE, which was detected in a groundwater sample at a concentration of 36.9 µg/L (LAW, 1998a).

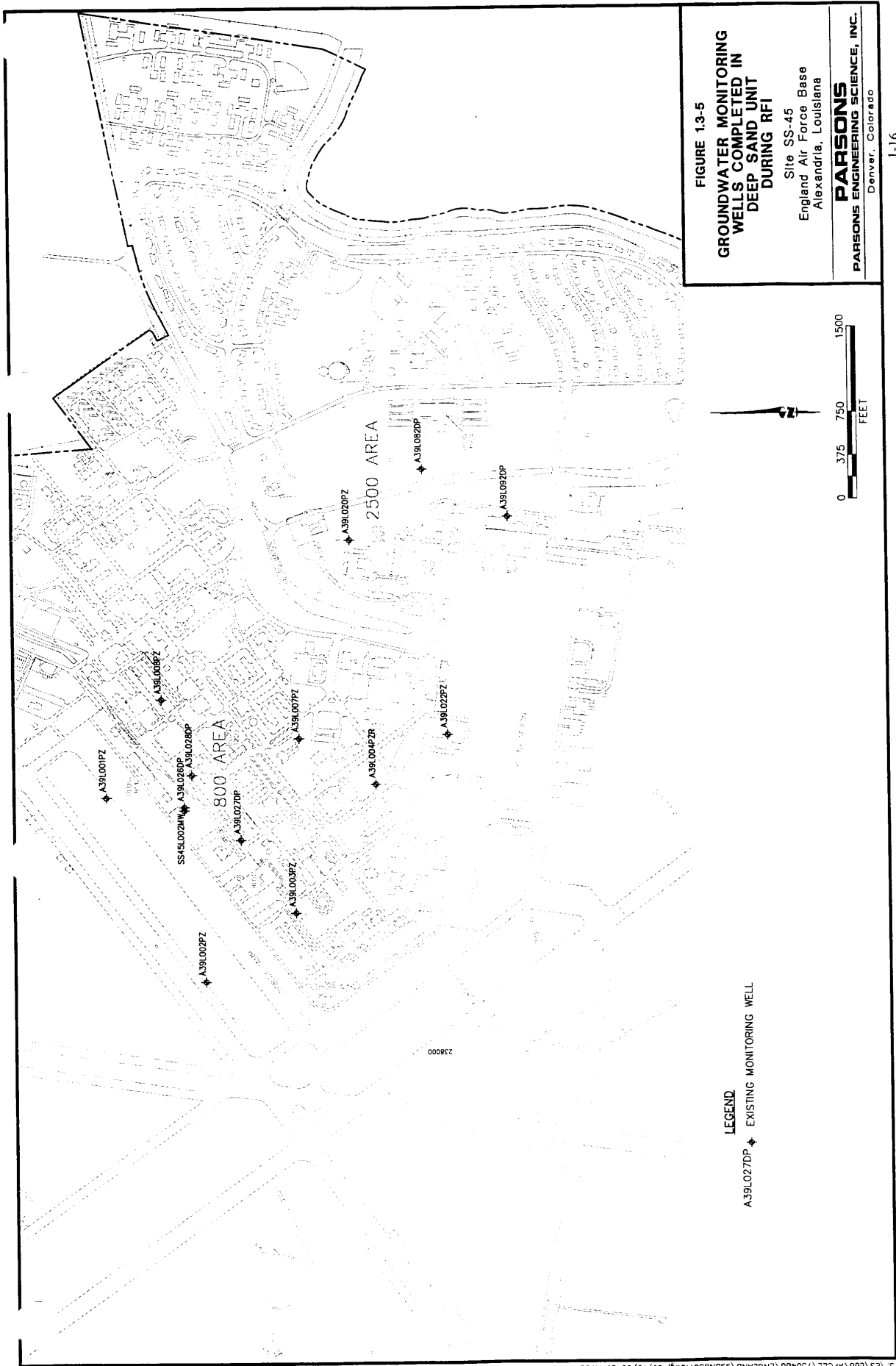
OTH-2000 – A Phase II EBS was completed at OTH-2000 by LAW in 1995. OTH-2000, a former motor pool and industrial area, is located northeast of and adjacent to OTH-700 (Figure 1.3-2). During the EBS, chlorinated compounds were detected in subsurface soil samples and groundwater samples from this site. PCE; 1,1-DCA; 1,1,1-TCA; and 1,1-DCE were detected in a single soil sample, collected from 2 to 4 feet bgs. The groundwater sample contained TCE and *cis*-1,2-DCE at concentrations below the England AFB RBSLs (LAW, 1998a).

1.3.3 RCRA Facility Investigation

An RFI was conducted for Site SS-45 by LAW (1998a) in 1996 and 1997. The investigation was conducted in two phases, with results of the Phase I investigation reported in the Phase I Findings Report (LAW, 1996). Results of the Phase II investigation were combined with Phase I results and reported in the draft RFI report, and are summarized in the following subsections.

1.3.3.1 Phase I Investigation

The purpose of the Phase I investigation was to delineate the extent of VOCs in groundwater at Site SS-45, and to complete a preliminary evaluation of the geology and hydrogeology of the study area. This was accomplished by collecting groundwater data from HydroPunch® sampling points (Figure 1.3-3) and existing monitoring wells; analyzing samples using an onsite laboratory; and installing and sampling new groundwater monitoring wells in the Intermediate and Deep Sand units (Figures 1.3-4 and 1.3-5; LAW 1996). Phase I of the investigation was initiated in February 1996, and concluded in October 1996.



1.3.3.2 Phase II Investigation

The overall purpose of the Phase II investigation was to further characterize the hydrogeology and the extent of VOCs in groundwater at Site SS-45. Specific objectives of the additional characterization activities included evaluation of potential contamination "hot spots," continued collection of hydrogeologic data, limited contaminant source-area sampling, and collection of natural attenuation chemical data on a quarterly basis. Field activities for Phase II commenced in October 1996, and continued through September 1997, and included additional collection of groundwater data from HydroPunch® sampling points (Figure 1.3-3); sampling of soil borings; installation and sampling of additional groundwater monitoring wells (Figures 1.3-4 and 1.3-6); installation of staff gages in Le Tig Bayou and the North Drainage Ditch; and conducting well-displacement ("slug") tests in a number of groundwater monitoring wells.

Near the conclusion of Phase II activities, quarterly groundwater monitoring was initiated. Groundwater monitoring events were completed in June 1997, September 1997, and December 1997 (Appendix A).

1.3.1.3 Summary of RFI Results

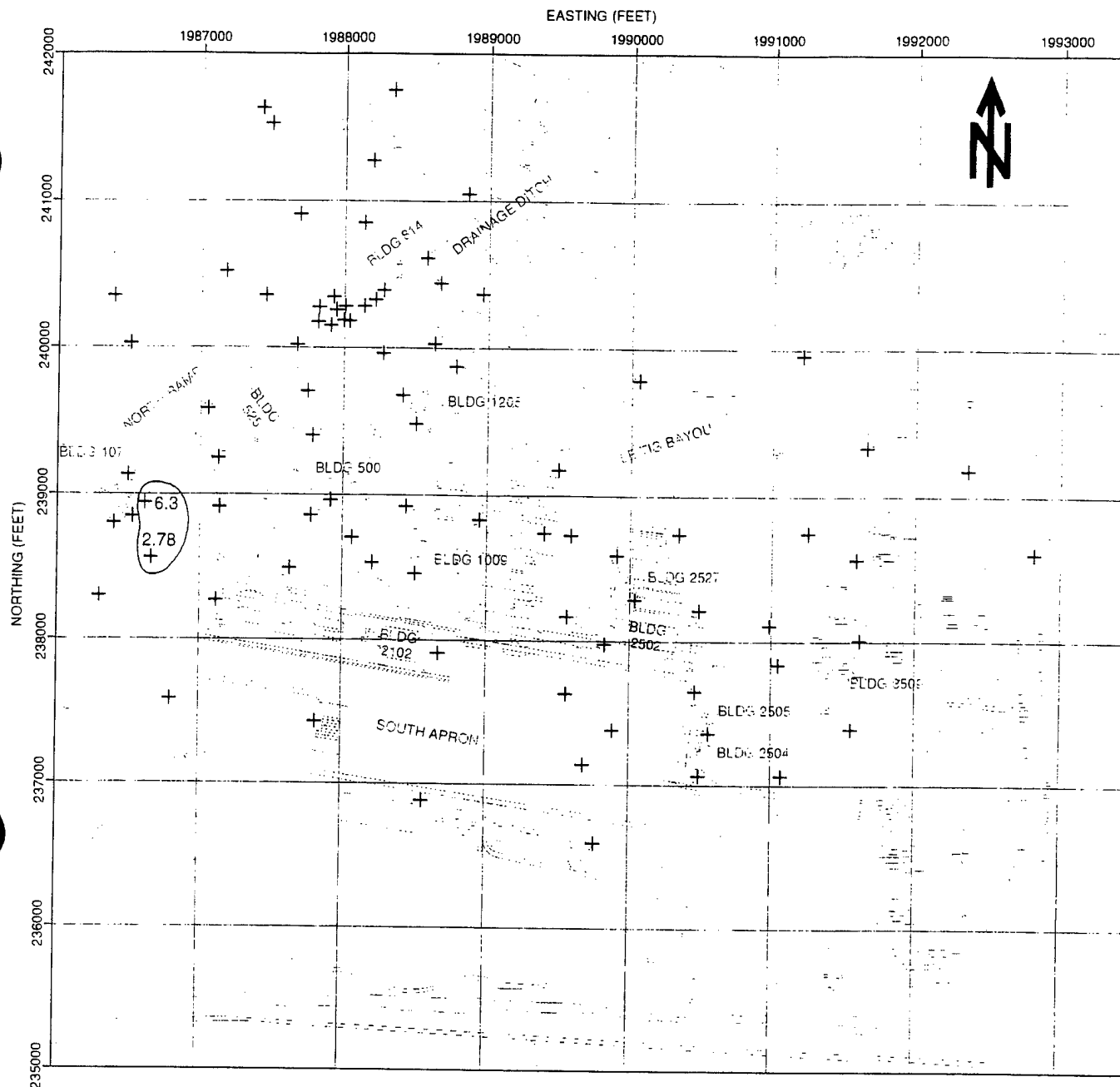
Although the RFI was conducted in phases, similar activities were completed during each phase, with the results of the Phase I investigation being used to refine the areas of investigation that were sampled more intensively during Phase II. The results of the Phase I and Phase II investigations are summarized in the following paragraphs.

Groundwater Samples from CBS Wells

At the beginning of the Phase I investigation, in mid-1996, groundwater samples collected from the three monitoring wells installed during the CBS (wells BKGL039MW, BKGL040MW, and BKGL041MW) were analyzed using an onsite laboratory to confirm previous analytical results. Chemicals detected in the groundwater samples included TCE, *cis*-1,2-DCE, methylene chloride, and chloroform (LAW, 1998). A single, additional monitoring well (well A39L001BH) was installed adjacent to well BKGL039MW, and completed within the shallow silt/clay unit. This well was installed to determine whether the TCE previously detected in groundwater samples from well BKGL039MW occurred within the shallow silt/clay or the Intermediate Sand unit (well BKGL039MW is screened across both units). CAHs were not detected in groundwater samples collected from this well, indicating that groundwater in the shallow silt/clay unit in the vicinity had not been affected by CAHs.

HydroPunch® Groundwater Samples

During the RFI, groundwater samples were collected from a number of HydroPunch® sampling points driven into the shallow silt/clay unit, Intermediate Sand, and Deep Sand units at various locations within Site SS-45. Results of the HydroPunch® investigations at Site SS-45 are summarized as follow.



LEGEND

5.5
+ HYDROPUNCH LOCATION WITH
CONCENTRATION (ug/L)

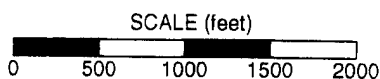
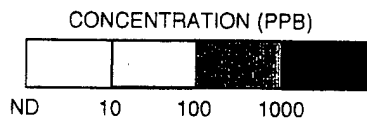


FIGURE 1.3-6 TRICHLOROETHENE IN GROUNDWATER SAMPLES FROM HYDROPUNCH BORINGS IN SHALLOW SILT/CLAY UNIT

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

SOURCE: LAW, 1998.

draw:england6.cdr nap 83099

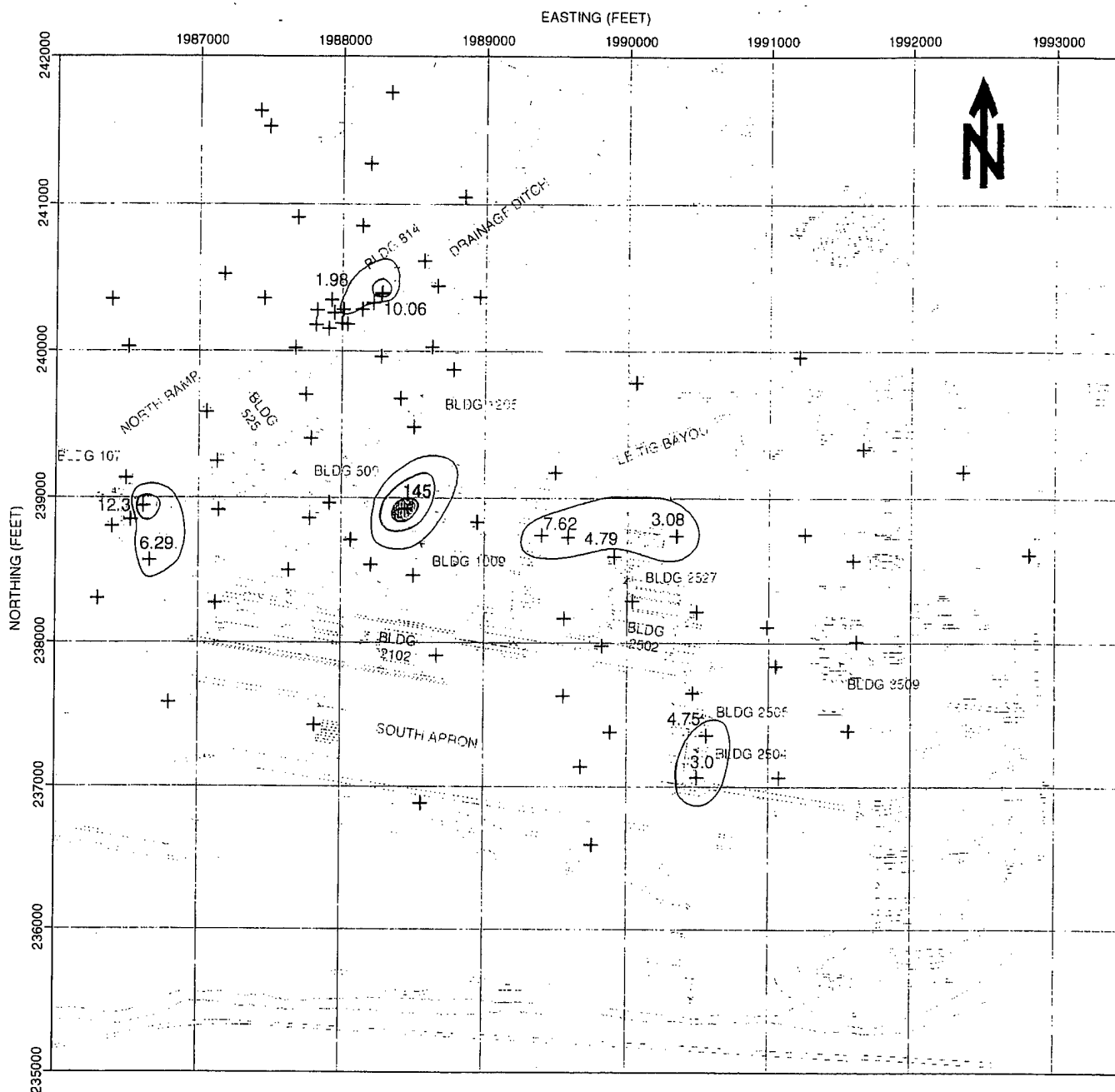
Shallow Silt/Clay Unit. A total of 96 groundwater samples were collected from 85 sampling points (Figure 1.3-3) in the shallow silt/clay unit during the (Appendix A). Groundwater samples were collected from this unit at depths ranging from 20 feet bgs to 62.5 feet bgs. Groundwater samples from 10 of the 85 locations contained chlorinated solvents including TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, 1,1-DCE, VC, and chloroform. Total concentrations of chlorinated VOCs ranged from 1.23 µg/L to 145 µg/L. The results of the HydroPunch® investigation indicated that a release of chlorinated solvents had occurred at some time in the past, and that solvent constituents had migrated to groundwater within the shallow silt/clay unit. The affected locations appeared to include the area near the control tower and central/eastern parts of Site SS-45 (Figures 1.3-6, 1.3-7, and 1.3-8).

The relatively great distances between the areas of contaminated groundwater indicated that solvent constituents within the shallow silt/clay unit at Site SS-45 probably originated at multiple sources. Former Aircraft Maintenance Hangars 111 and 114, which were located in this area from 1943 until the mid-1970s, were suspected to be the source of TCE and *cis*-1,2-DCE detected in groundwater near the control tower (Building 107). This area currently serves as a parking facility. *cis*-1,2-DCE was detected at 145 µg/L at HydroPunch® sampling location A39L046DP. Prior to 1953, the area surrounding this sampling location was occupied by several storage and minor maintenance facilities. After these facilities were moved to the area south of Buildings 814 and 816, this part of the Base was occupied by a gymnasium, a theater, a photography lab, an outdoor recreation center, academic lecture halls, and tennis courts. Most of these structures had been demolished by the late 1960s; currently, only the recreation center, with swimming pool and bath house, remains. Although the source of *cis*-1,2-DCE that was detected is unknown, VOCs in groundwater in this area could be a result of past activities at the former photography lab or maintenance facilities.

Elevated concentrations of *cis*-1,2-DCE and VC were detected in groundwater samples from HydroPunch® sampling points in the central and eastern parts of Site SS-45 (Figures 1.3-7 and 1.3-8). These breakdown products were believed to have originated at a different source(s) than CAH compounds that had been detected in groundwater in the vicinity of the control tower, because of the relatively great distance between respective sampling locations (about 3,000 feet). Possible sources of chemicals in groundwater in the central and eastern parts of Site SS-45 included OTH-700, OTH-2000, or Buildings 2102, 2502, 2504, 2505, or 2527.

Intermediate Sand Unit. A total of 253 HydroPunch® samples were collected at 22 HydroPunch® sampling locations in the Intermediate Sand unit (Figure 1.3-3). TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, VC, 1,1-DCA, 1,1-DCE, chloroform, benzene, toluene, ethylbenzene, and xylene isomers were detected in a number of these groundwater samples (Appendix A).

TCE was detected in 42 of the groundwater samples collected from the Intermediate Sand unit (Figure 1.3-9). Total 1,2-DCE (*cis* and/or *trans* isomers) was detected in 34 HydroPunch® groundwater samples (Figure 1.3-10); and *cis*-1,2-DCE was detected in 57 of the HydroPunch® samples collected from the Intermediate Sand unit. VC was detected in 24 of the samples collected from 13 HydroPunch® locations (Figure 1.3-11), and



LEGEND

5.5
+ HYDROPUNCH LOCATION WITH
CONCENTRATION (ug/L)

CONCENTRATION (PPB)



SCALE (feet)

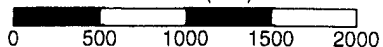


FIGURE 1.3-7

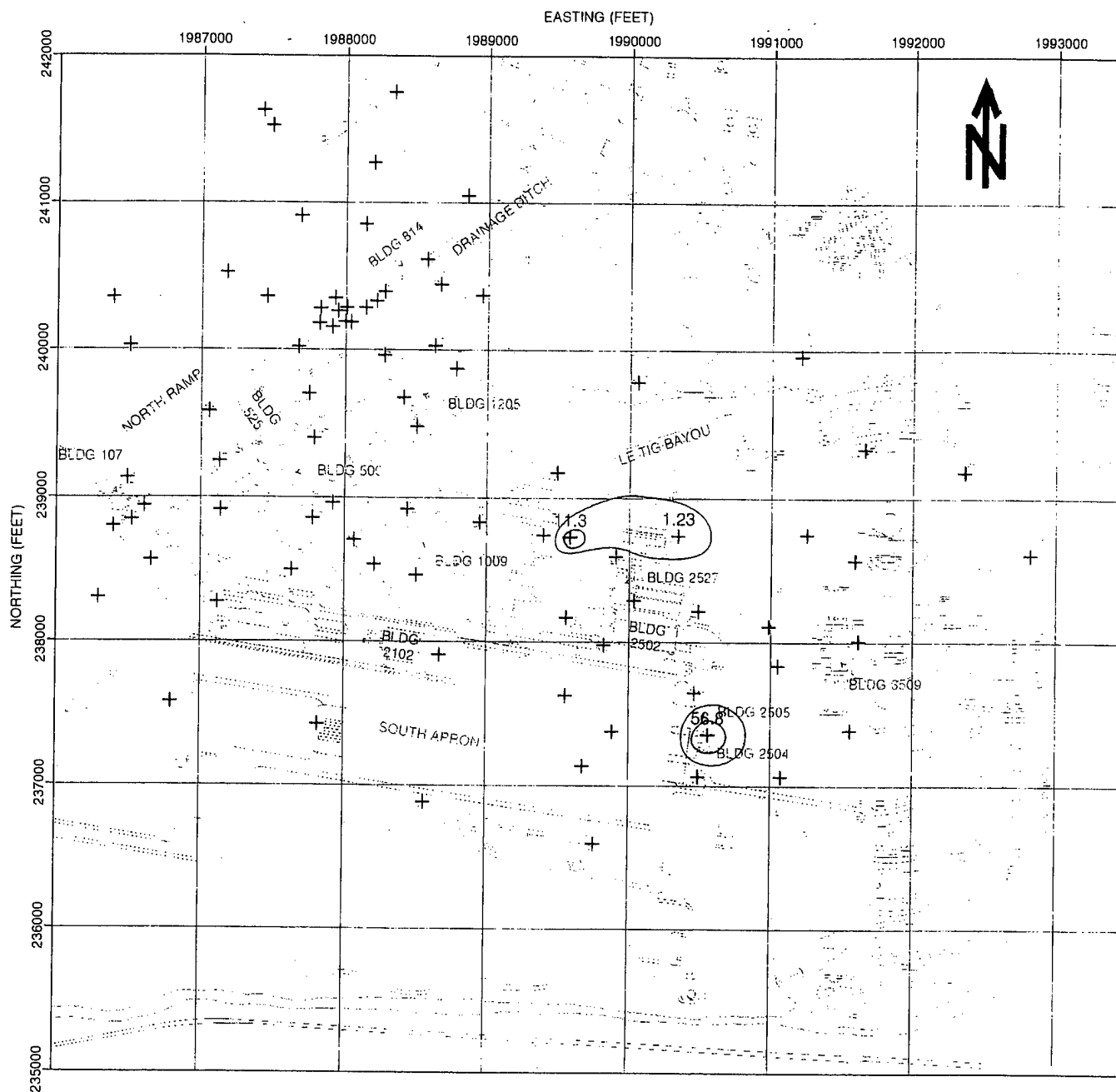
TOTAL 1,2-DICHLOROETHENE IN GROUNDWATER SAMPLES FROM HYDROPUNCH BORINGS IN SHALLOW SILT/CLAY UNIT

Site SS-45

England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

SOURCE: LAW, 1998.



LEGEND

5.5
+ HYDROPUNCH LOCATION WITH
CONCENTRATION (ug/L)

CONCENTRATION (PPB)



SCALE (feet)

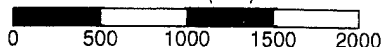


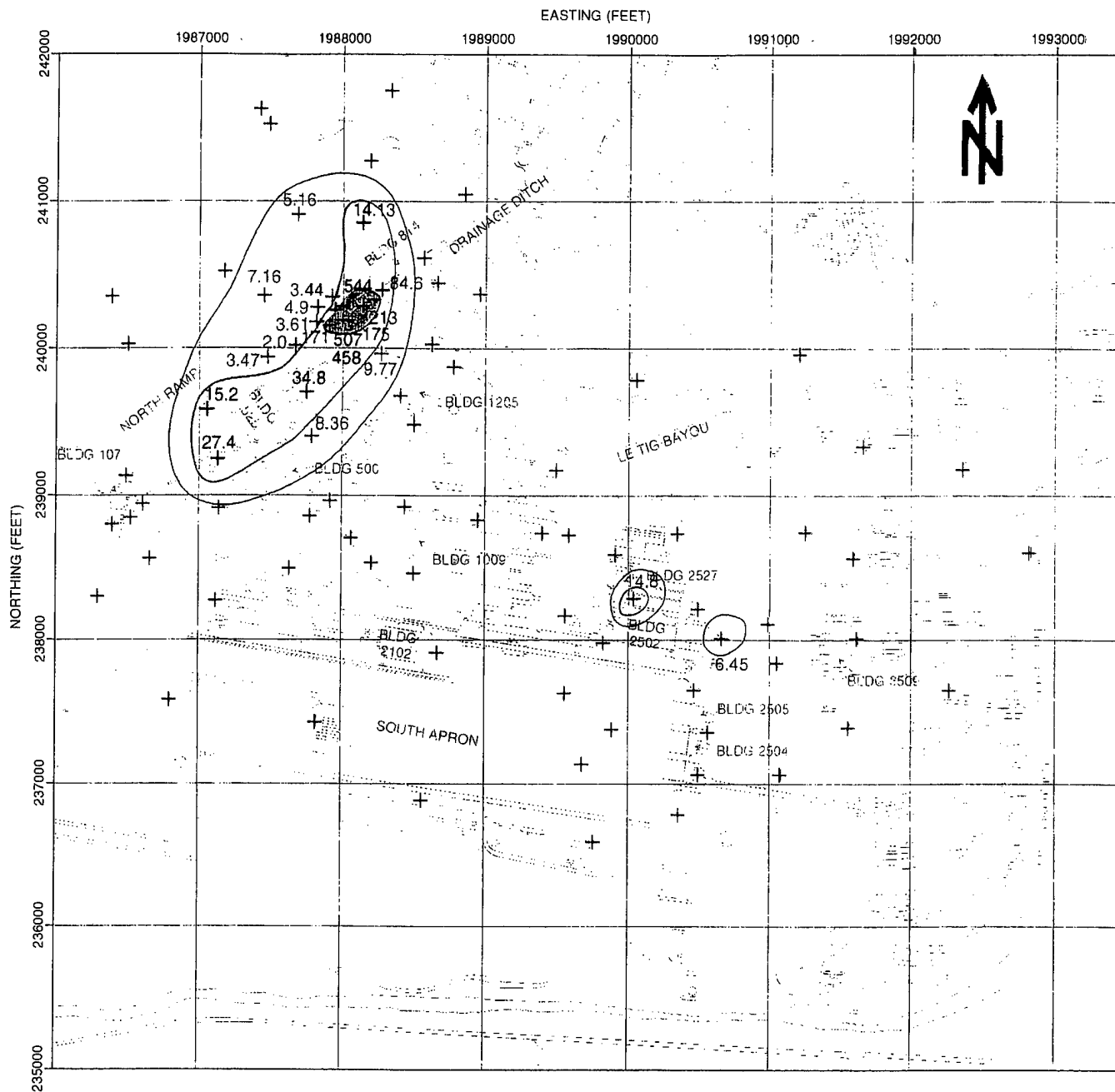
FIGURE 1.3-8 VINYL CHLORIDE IN GROUNDWATER SAMPLES FROM HYDROPUNCH BORINGS IN SHALLOW SILT/CLAY UNIT

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

SOURCE: LAW, 1998.



LEGEND

5.5
+ HYDROPUNCH LOCATION WITH
CONCENTRATION (ug/L)

CONCENTRATION (PPB)



SCALE (feet)

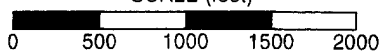
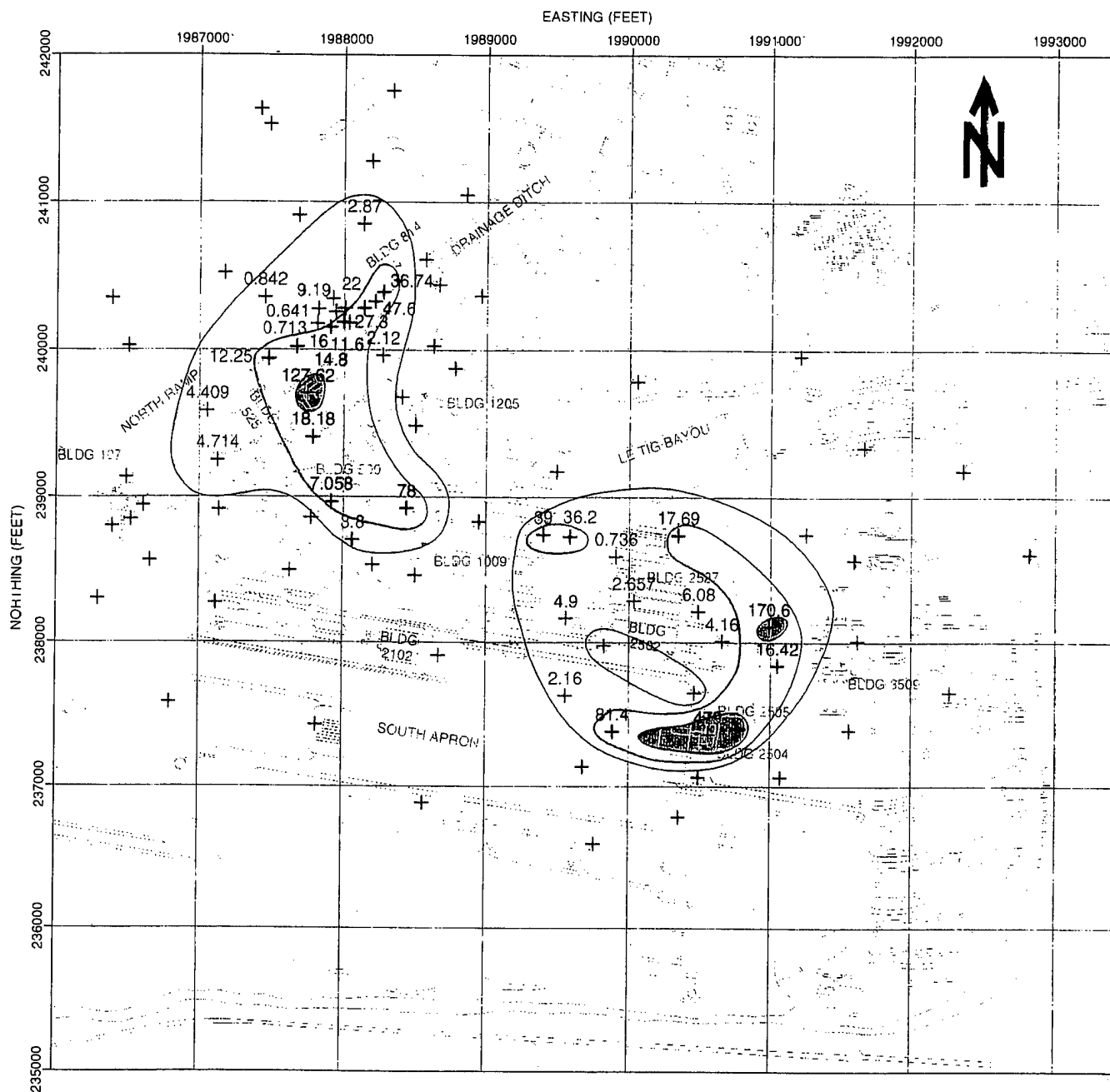


FIGURE 1.3-9 TRICHLOROETHENE IN GROUNDWATER SAMPLES FROM HYDROPUNCH BORINGS IN INTERMEDIATE SAND UNIT

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

SOURCE: LAW, 1998.



LEGEND

5.5
+ HYDROPUNCH LOCATION WITH
CONCENTRATION (ug/L)

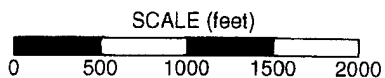
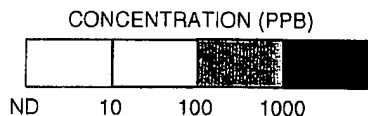
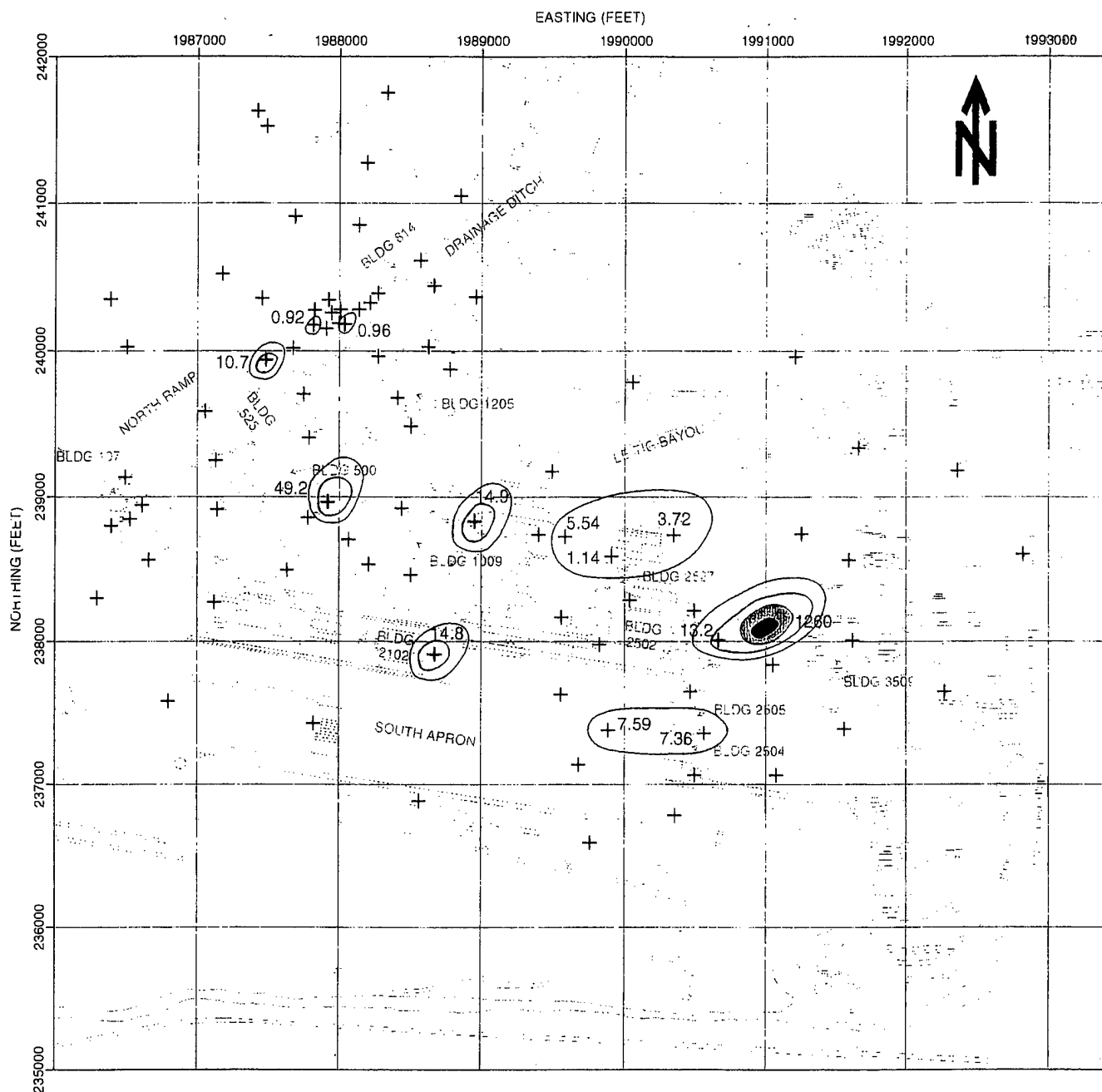


FIGURE 1.3-10 TOTAL 1,2-DICHLOROETHENE IN GROUNDWATER SAMPLES FROM HYDROPUNCH BORINGS IN INTERMEDIATE SAND UNIT

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

SOURCE: LAW, 1998.



LEGEND

5.5
+ HYDROPUNCH LOCATION WITH
CONCENTRATION (ug/L)

CONCENTRATION (PPB)



ND 10 100 1000

SCALE (feet)

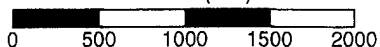


FIGURE 1.3-11 VINYL CHLORIDE IN GROUNDWATER SAMPLES FROM HYDROPUNCH BORINGS IN INTERMEDIATE SAND UNIT

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

SOURCE: LAW, 1998.

benzene, toluene, ethylbenzene, and xylene (BTEX) constituents were detected in 20 HydroPunch® groundwater samples from the Intermediate Sand unit.

Distinct differences were noted in the distribution of VOCs in groundwater within the Intermediate Sand unit. In the northwestern part of Site SS-45 (the "800 Area"), the chemical suite consisted primarily of TCE and 1,2-DCE isomers (Figures 1.3-9 and 1.3-10). The degradation of TCE into breakdown products such as *cis*-1,2-DCE and VC was indicated by the increase in concentrations of these degradation products in zones surrounding and underlying areas that contained elevated TCE concentrations. With the exception of elevated concentrations of TCE near Building 814, the CAH compounds *cis*-1,2-DCE and VC comprise the majority of the VOCs detected in groundwater within the Intermediate Sand unit. In the central and eastern parts of Site SS-45 (the "2500 Area"), detected VOCs consisted primarily of the 1,2-DCE isomers and VC.

Chlorinated solvent constituents were detected in HydroPunch® groundwater samples in an area encompassing approximately 240 acres (Figures 1.3-9, 1.3-10, and 1.3-11), and appeared to extend through the entire saturated thickness of the Intermediate Sand unit, from its upper contact with the shallow silt/clay unit at a depth of about 20 feet bgs, to the base of the Intermediate Sand unit at a depth of about 75 to 80 feet bgs. *Cis*-1,2-DCE was the CAH compound most frequently detected (Figure 1.3-10), occurring throughout the Intermediate Sand unit at depths ranging from 20 to 73 feet. The laterally discontinuous nature of the groundwater contamination at Site SS-45 indicates that multiple sources may have released chlorinated solvents to the shallow silt/slay unit, through which the solvents then migrated into the Intermediate Sand unit. These releases may have originated at one or more of the suspected source areas (Section 1.3.2); and/or along sewer lines and storm drains. No single, significant source of TCE has been identified, and in the few soil samples in which TCE was detected, the concentrations of TCE were extremely low (Sections 1.3.1 and 1.3.2).

The highest concentrations of TCE and 1,2-DCE were detected groundwater samples collected beneath a grassy area near Building 814 that is believed to have been used as a temporary aircraft washrack between 1954 and 1956 (as inferred from 1952 and 1956 Base maps). Two buildings were located in this area: Building 821 (squadron operations) built in 1953, and Building 820 (power equipment shed) constructed in the mid-1950s. By 1957, several maintenance shops had been constructed or relocated to this area. By 1983, the majority of the buildings in this area had been removed (TetraTech, 1994).

TCE and 1,2-DCE were detected in groundwater samples collected from HydroPunch® borings located southwest, northeast, and east of Building 525 at depths ranging from 40 feet to approximately 73 feet bgs. Due to the low hydraulic gradients measured in the Intermediate Sand unit, and resulting indeterminate groundwater flow direction(s) in this area, it is not known if the TCE in groundwater is a result of activities at Building 525, or if the TCE is associated with the higher concentrations near Building 814. Building 525 was constructed over a drainage canal (the Northern Ditch) that originates south of Building 525, flows northeast, and discharges to Big Bayou.

The highest concentration of VC was detected in the groundwater sample from HydroPunch® boring A39L061DP (Figure 1.3-11), approximately 500 to 750 feet northeast of the industrialized area where suspected sources of TCE exist (Buildings 2502, 2504 and 2505). VC in groundwater is a suspected degradation product resulting from the breakdown of TCE in the subsurface.

Deep Sand Unit. Thirty-two HydroPunch® samples were collected at 13 locations from the Deep Sand unit at depths ranging from 83 to 120 feet bgs. TCE and 1,2-DCE isomers were the only CAHs detected in groundwater samples from the Deep Sand unit (Figures 1.3-12 and 1.3-13). VC was not detected in HydroPunch® samples collected from the Deep Sand unit. CAHs were detected only in Deep Sand unit HydroPunch® groundwater samples from locations west of Building 814 and north across the North Ramp, within an area encompassing approximately 4 acres. In this area, a clay stratum that elsewhere on the Base separates the Intermediate and Deep Sand units appears to be thin or absent, and in the Intermediate and Deep Sand units are essentially one vertically-continuous sand unit.

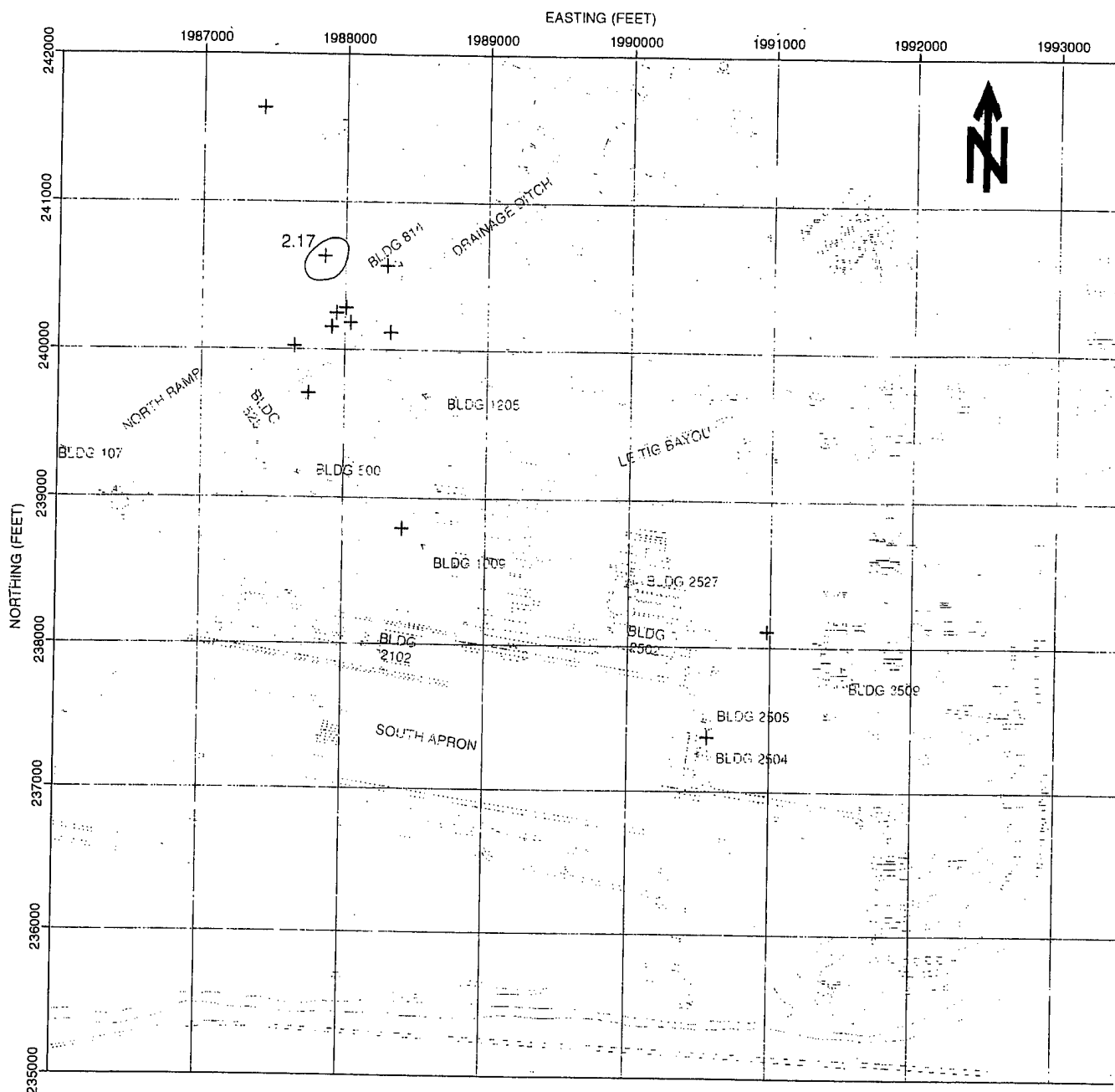
Quarterly Groundwater Monitoring

In June 1997, September 1997, and December 1997, groundwater samples were collected from 10 groundwater monitoring wells completed in the Intermediate Sand unit and from 4 monitoring wells completed in the Deep Sand unit (LAW, 1998a). Groundwater samples were analyzed to assess changes in chemical concentrations through time, and begin to evaluate the potential for RNA of CAHs. Results of analyses of the monitoring well samples were qualitatively compared with the previously-collected HydroPunch® data to confirm the extent of CAH compounds in groundwater. The results for samples collected from wells in the 800 and 2500 Areas were also compared with site-specific background data from a well cluster (wells A39L039DP and A39L002PZ) located outside of areas with CAH contamination. Comparisons with background concentrations were completed for VOCs, metals, methane, ethane, ethene, chloride, and alkalinity. The results of geochemical analyses are summarized in Section 2.1 of the Work Plan for Site SS-45 (Parsons 1998).

Intermediate Sand Unit Results. CAHs - CAH compounds (TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, 1,1-DCE, 1,1-DCA, and VC) were detected in eight groundwater samples collected from wells completed in the Intermediate Sand unit (Figures 1.3-14 and 1.3-15, and Appendix A). Benzene, toluene, and chlorobenzene also were detected.

TCE was detected in groundwater samples from three wells (wells SS45L001MW, A39L009PZ and A39L036DP) in the 800 Area at concentrations ranging from 6.9 µg/L to 697 µg/L (Table 1.3-2, and Figures 1.3-15 and 1.3-16). The highest concentration of TCE was detected in the sample from SS45L001MW, located in the grassy area west of Building 814.

Cis-1,2-DCE and/or *trans*-1,2-DCE were detected in eight samples at concentrations ranging from below the sample quantitation limit (SQL) to 197 µg/L (Figures 1.3-14 and 1.3-15). The highest detected concentration of total-1,2-DCE was reported in the sample collected from monitoring well A39L011PZ located east of Building 2505. The *cis*-



LEGEND

5.5
+ HYDROPUNCH LOCATION WITH
CONCENTRATION (ug/L)

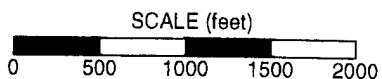
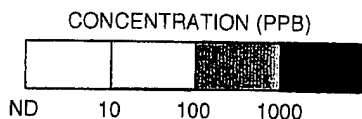


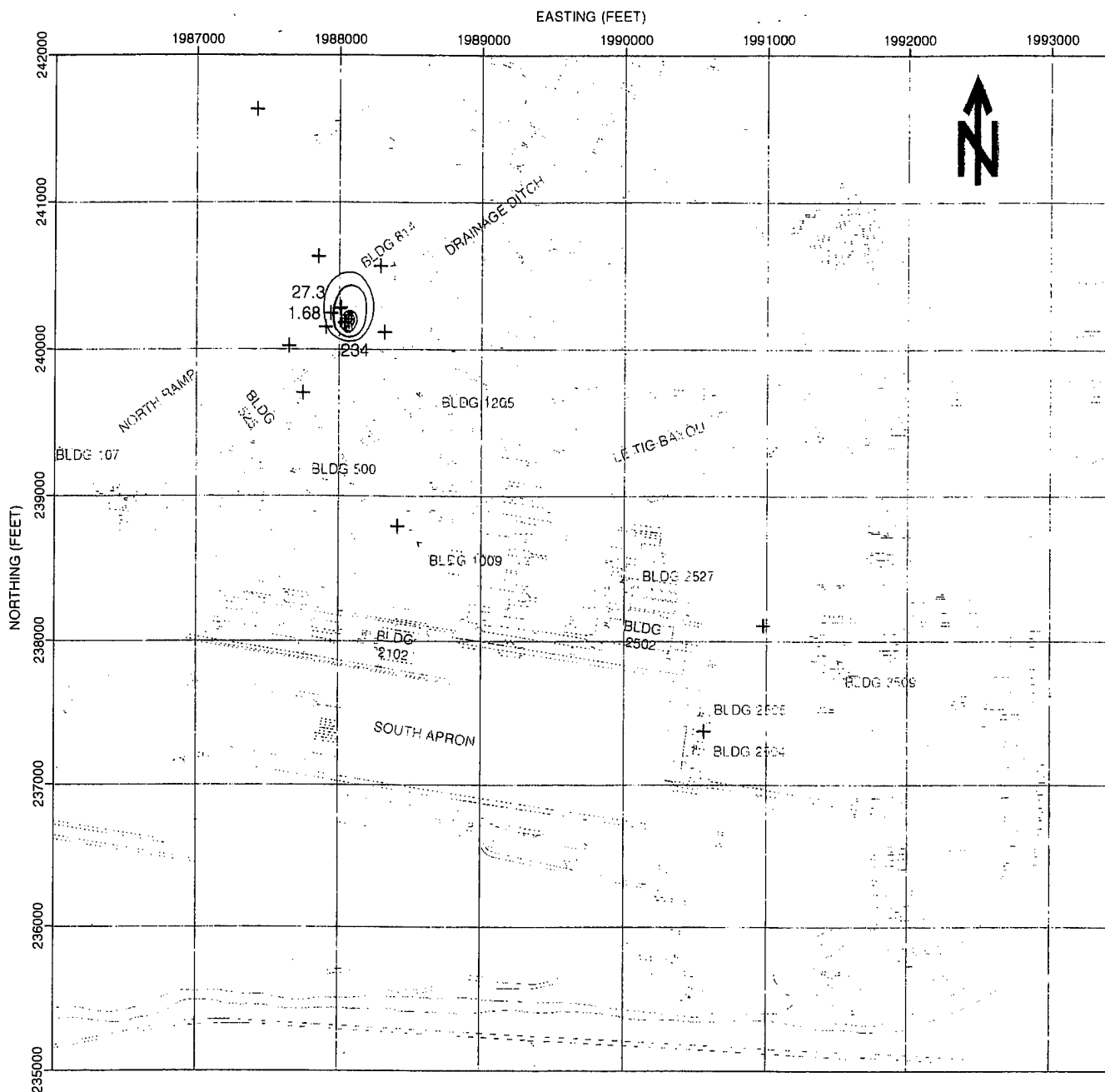
FIGURE 1.3-12 TRICHLOROETHENE IN GROUNDWATER SAMPLES FROM HYDROPUNCH BORINGS IN DEEP SAND UNIT

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

SOURCE: LAW, 1998.



LEGEND

5.5
+ HYDROPUNCH LOCATION WITH
CONCENTRATION (ug/L)

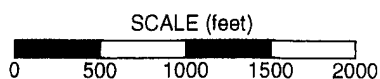
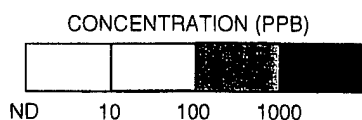


FIGURE 1.3-13 TOTAL 1,2-DICHLOROETHENE IN GROUNDWATER SAMPLES FROM HYDROPUNCH BORINGS IN DEEP SAND UNIT

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

SOURCE: LAW, 1998.

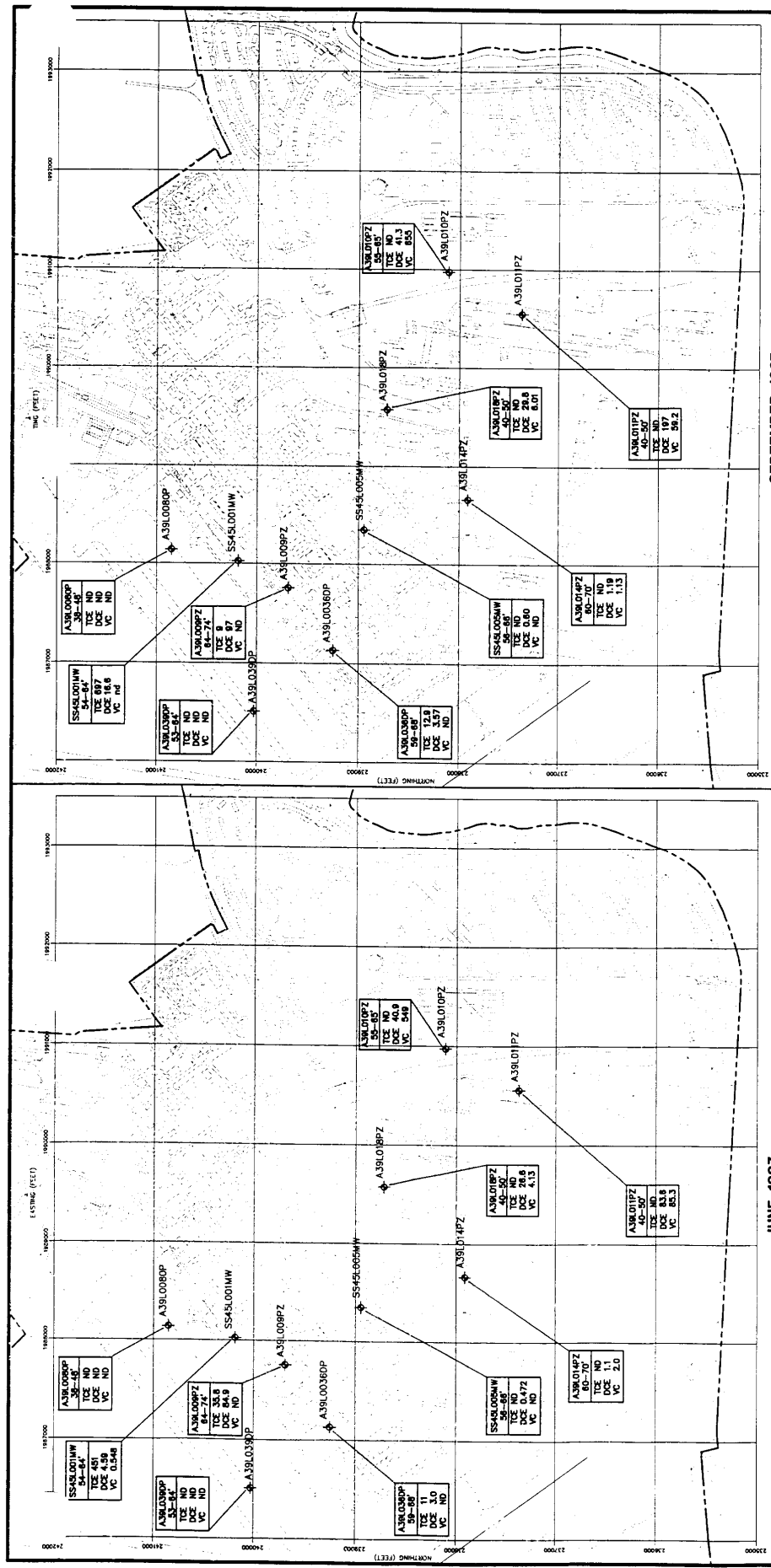


FIGURE 1.3-14

CONCENTRATIONS OF CAHs IN GROUNDWATER SAMPLES FROM MONITORING WELLS IN INTERMEDIATE SAND UNIT JUNE 1997-SEPTEMBER 1997

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

LEGEND

- MONITORING WELL
- NON DETECTED
- TCE TRICHLOROETHENE
- DCE DICHLOROETHENE
- VC VINYL CHLORIDE
- ALL CONCENTRATIONS IN µg/L

WELL ID

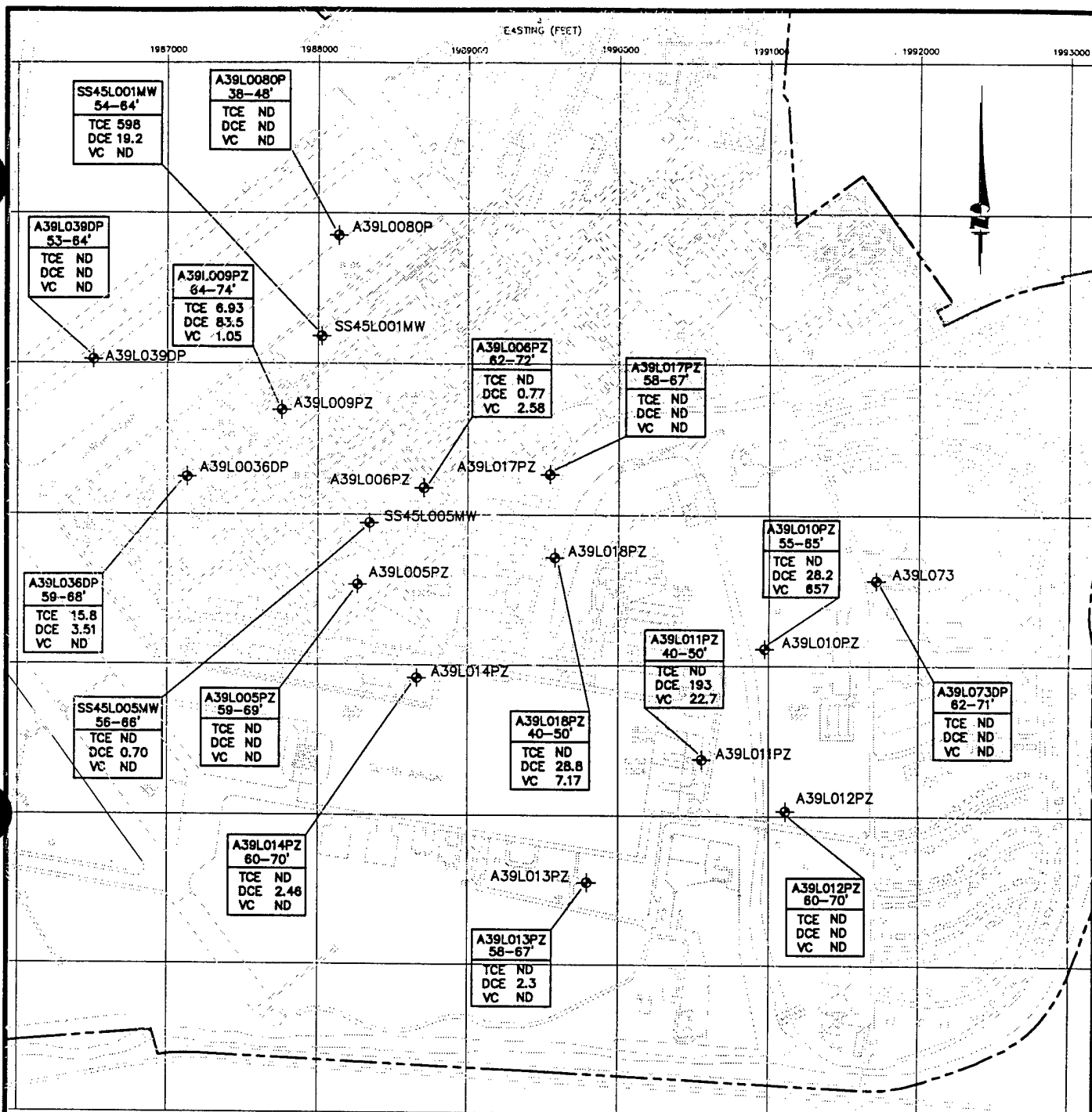
SCREENED INTERVAL
FEET BELOW GROUND SURFACE

CONCENTRATIONS
IN µg/L

BOUNDARY AREA

0 500 1000
FEET

S:\E\FCEE\730486\ENGLAND\98dn1116.dwg, 09/15/99 at 09:51



DECEMBER 1997

LEGEND

- MONITORING WELL
- ND NON DETECTED
- TCE TRICHLOROETHENE
- DCE DICHLOROETHENE
- VC VINYL CHLORIDE

ALL CONCENTRATIONS IN µg/L

A34L011PZ	WELL ID
40-50'	SCREENED INTERVAL
TCE ND	FEET BELOW GROUND
DCE 83.6	SURFACE
VC 85.3	CONCENTRATIONS
	IN µg/L

BOUNDARY AREA

0 500 1000
FEET

FIGURE 1.3-15 CONCENTRATIONS OF CAHs IN GROUNDWATER SAMPLES FROM MONITORING WELLS IN INTERMEDIATE SAND UNIT DECEMBER 1997

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

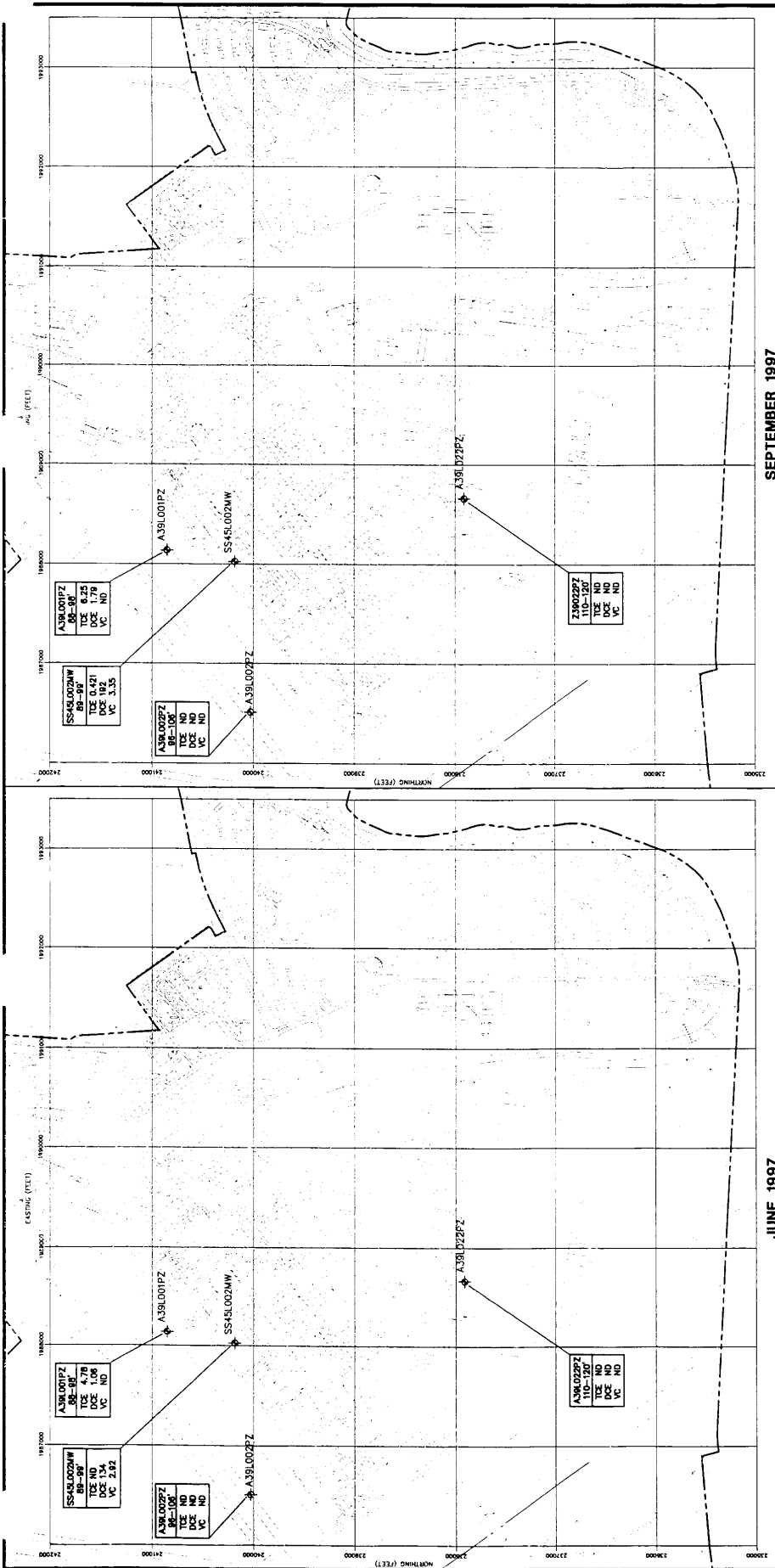


FIGURE 1.3-16
CONCENTRATIONS OF CAHs
IN GROUNDWATER SAMPLES
FROM MONITORING WELLS
IN DEEP SAND UNIT
JUNE 1997-SEPTEMBER 1997

Site SS-45
England Air Force Base
Alexandria, Louisiana

**PARSONS
ENGINEERING SCIENCE, INC.**
Denver, Colorado

isomer was generally detected at higher concentrations than the *trans*- isomer, which suggests the occurrence of reductive dechlorination of TCE (Section 4).

VC was detected in five samples at concentrations ranging from less than the SQL to 657 µg/L (Figures 1.3-14 and 1.3-15). The highest concentration of VC was detected in the sample from monitoring well A39L010PZ, located in the 2500 Area northeast of Building 2500 Area near the hospital.

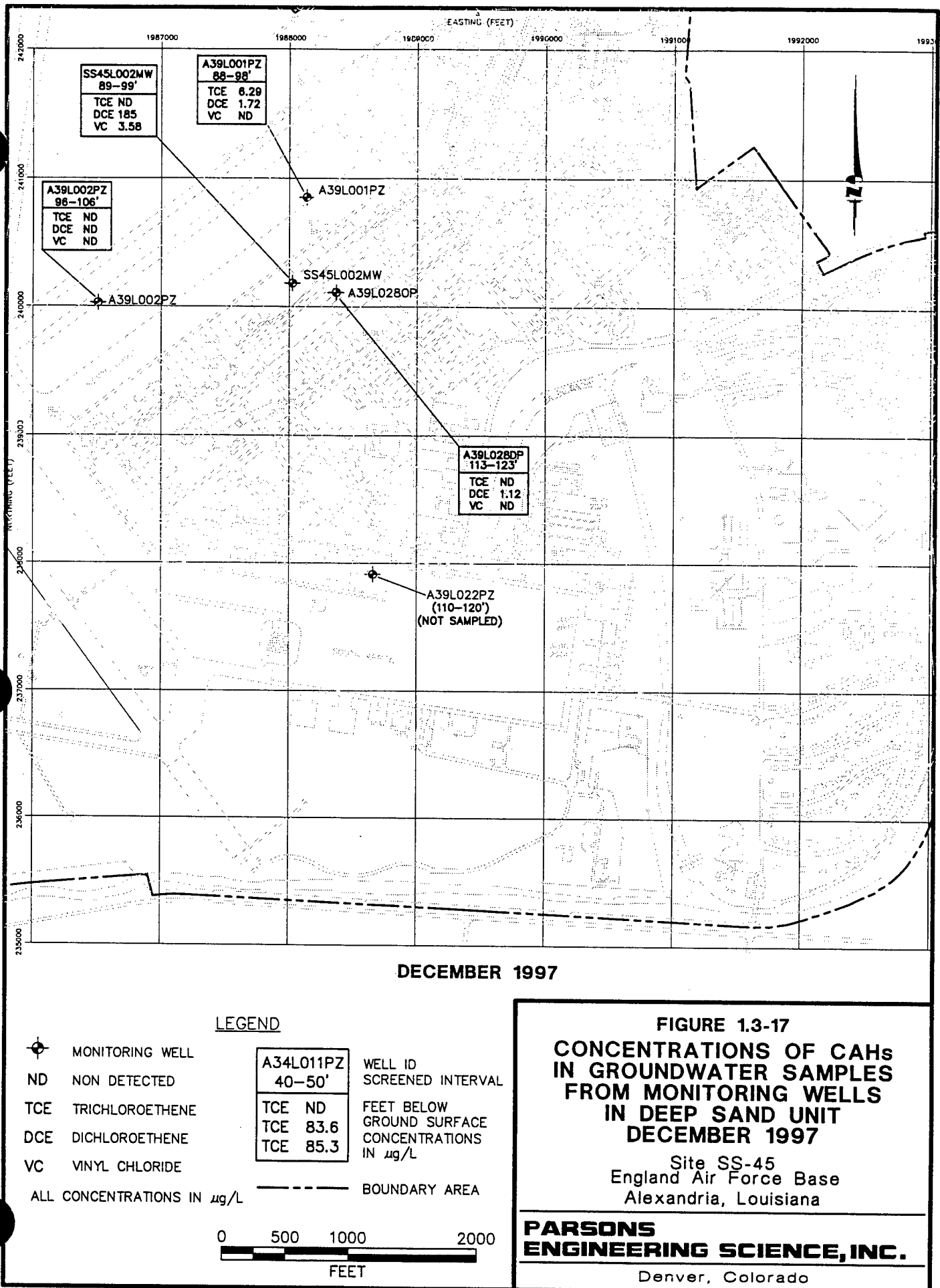
During the time period June 1997 to December 1997, the concentrations of TCE in groundwater samples collected from the Intermediate Sand Unit increased at two sampling locations (wells A39L036DP and SS45L001MW), decreased at one sampling location (well A39L009PZ), and remained below detection limits at seven sampling locations. In contrast, the concentrations of 1,2-DCE isomers (degradation products of TCE) increased in groundwater samples from six wells, decreased in samples from two wells, and remained below detection limits in groundwater samples from two wells. VC increased in samples from three wells, decreased in samples from three wells, and remained below detection limits in samples from five wells.

Deep Sand Unit Results. CAHs - CAH compounds (TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and VC) and toluene were detected in groundwater samples from three wells completed in the Deep Sand unit (Table 1.3-3, Figures 1.3-16 and 1.3-17; and Appendix A). TCE was detected at low concentrations in samples from two wells completed in the Deep Sand unit (well A39L001PZ, adjacent to the North Ramp, and well SS45L002MW, southwest of Building 814; Figures 1.3-6 and 1.3-17). DCE isomers also were detected in these wells, and at A39L028DP, at concentrations ranging from 1.06 to 192 µg/L. The highest concentration of DCE isomers was detected in the sample collected from monitoring well SS45L002MW, located in the grassy area southwest of Building 814 (Figures 1.3-16 and 1.3-17). VC was detected only in samples from a single Deep Sand unit monitoring well (well SS45L002MW) at concentrations ranging from 2.92 µg/L to 3.58 µg/L.

Summary of Results of Quarterly Groundwater Monitoring.

In general, the results of quarterly monitoring confirmed the nature, extent and spatial distribution of CAH compounds in groundwater within the Intermediate and Deep Sand units, as originally defined by the HydroPunch® investigation (LAW, 1998a). The chemical data also indicated that biodegradation of natural and/or anthropogenic carbon compounds was occurring in the Intermediate and Deep Sand units beneath Site SS-45, under conditions that promote reductive dechlorination. This observation was supported by the presence of TCE degradation products; elevated concentrations of ferrous iron, ethene, and methane (indicators of anaerobic biodegradation processes); and decreased concentrations of nitrate and sulfate, with elevated concentrations of chloride, in groundwater samples collected from areas in which CAH compounds are also present. Based on this initial geochemical information, Parsons ES, on behalf of AFCEE, undertook and completed a comprehensive RNA treatability study which is fully described in this focused CMS.

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SECTION 2

SITE CHARACTERIZATION ACTIVITIES

After reviewing the available hydrologic, geologic, and chemical information for England AFB Site SS-45, it became apparent that additional data would be required to support the evaluation of remedial alternatives, including RNA, for groundwater at the site. Accordingly, in the work plan for Site SS-45, Parsons ES (1998) proposed to conduct a field program to collect the information necessary for further evaluation of the geology, hydrogeology, and geochemistry, aquifer properties, and extent of groundwater contamination at Site SS-45. Site characterization activities undertaken included drilling boreholes, collecting soil samples, installing groundwater monitoring wells in the Intermediate and Deep Sand units, and developing and sampling the wells. Groundwater samples also were collected from a subset of the existing monitoring wells installed during previous investigations. Borehole flowmeter tests were conducted in three of the newly installed wells to assess relative hydraulic conductivity in the Intermediate Sand unit. Information that was collected during the current field program was integrated with existing information to develop the conceptual hydrogeologic model of the site, and to assist with interpretation of the physical setting (Section 3) and evaluation of the nature and extent of contaminants in the subsurface (Section 4).

The following subsections summarize the procedures for collecting site-specific data necessary for the development and evaluation of alternatives. Additional details regarding investigation activities are presented in the work plan (Parsons ES, 1998).

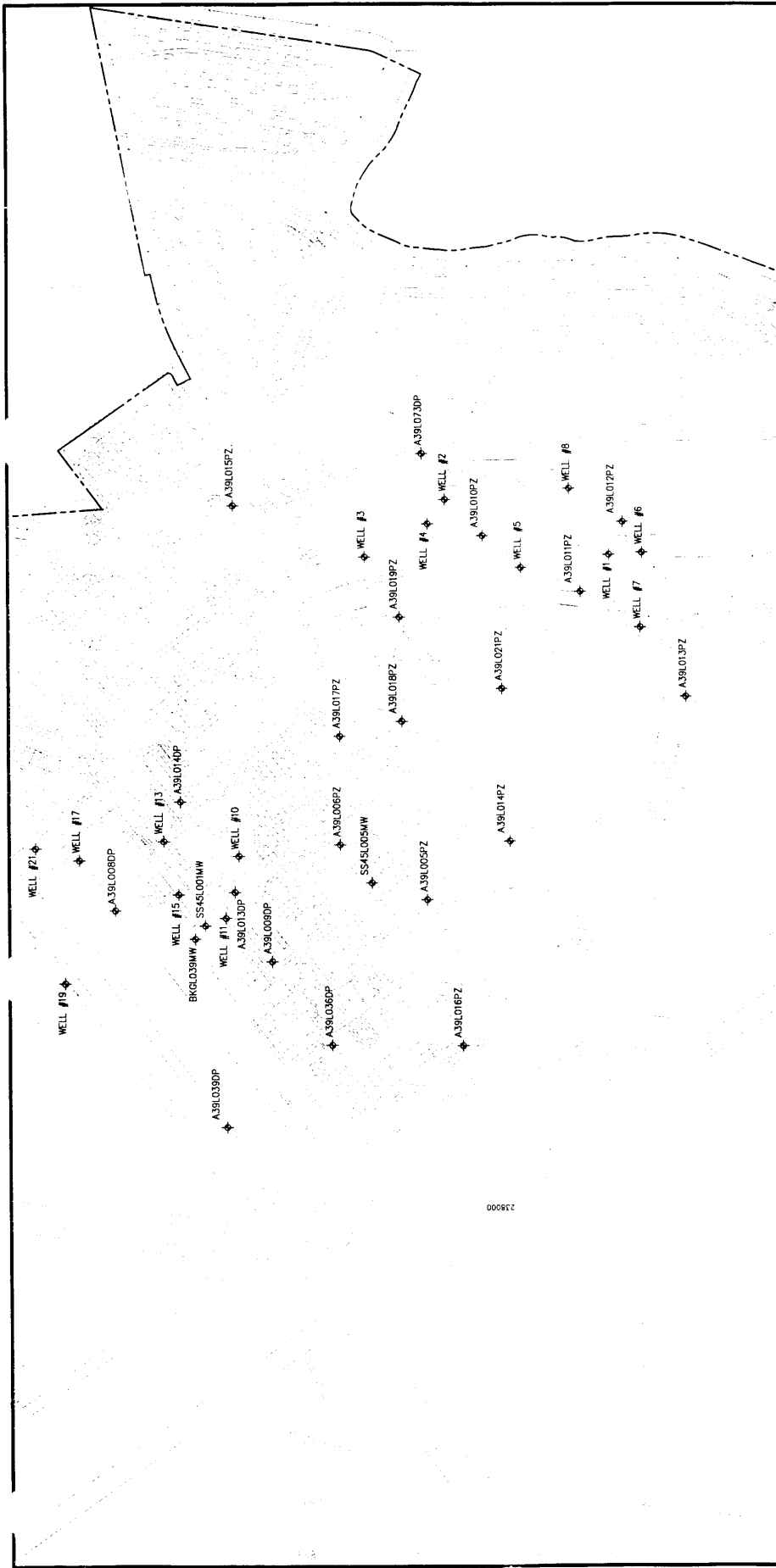
2.1 DRILLING OF BOREHOLES, COLLECTION OF SOIL SAMPLES AND INSTALLATION OF GROUNDWATER MONITORING WELLS

2.1.1 Pre-Drilling Activities

Prior to mobilization to any drilling location, utility lines and other engineered or anthropogenic features were located in the subsurface, and proposed borehole locations were cleared and approved by Base personnel. A permit for each well was obtained from the State of Louisiana, Department of Public Works and Water Resources, prior to installing the well. Copies of well permits are provided in Appendix B.

2.1.2 Drilling and Well-Installation Program

Twenty monitoring wells (Wells #1 through #8 in the 2500 Area, and Wells #10 through #21 in the 800 Area; Figures 2.1.2-1 and 2.1.2-2) were installed by Parsons ES as part of the field program. Boreholes for the first three of the new monitoring wells (Wells #1, #2, and #10) were drilled in August 1998 by Layne Western, Inc. using



LEGEND

A39L010PZ ♦ EXISTING MONITORING WELL

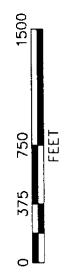
WELL #6 ♦ MONITORING WELL INSTALLED BY PARSONS ES

FIGURE 2.1-1

GROUNDWATER MONITORING WELLS COMPLETED IN THE INTERMEDIATE SAND UNIT

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado



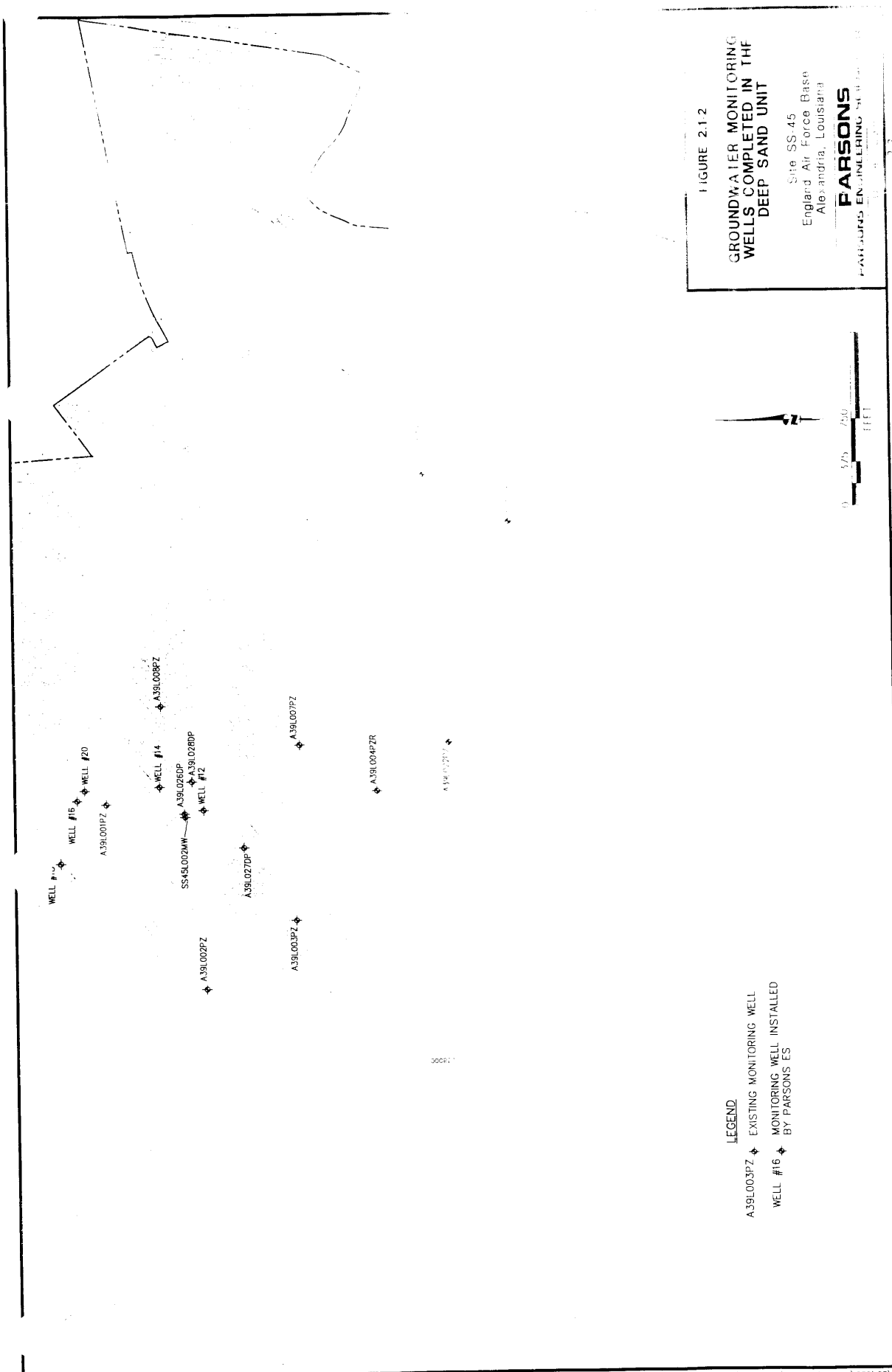


FIGURE 2.12

GROUNDWATER MONITORING
WELLS COMPLETED IN THE
DEEP SAND UNIT

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS

ENGINEERING

percussion-hammer techniques. These three wells were used for evaluating possible vertical variations in hydraulic conductivity of the water-bearing units, and consequently were screened across the full saturated thickness of the Intermediate Sand unit and the upper silt/clay unit. Installation of a fourth well was attempted in the 800 Area, north of Building 814; but drilling was abandoned when heaving sands began to cause problems with borehole stability. After installation, hydraulic conductivity tests were conducted in these wells using electromagnetic borehole flowmeter (EBF) technology. Groundwater samples were collected from several different intervals throughout the saturated section of each well.

Boreholes for 15 wells (Wells #3 through #7 in the 2500 Area, and Wells #11 through #20 in the 800 Area) were drilled by GeoEngineering/Warren Drilling using mud-rotary drilling techniques. These wells were installed during the period from January 20 through February 8, 1999. Groundwater samples were initially collected from newly-installed wells #3, #6, #13, and #15 on February 3, 1999 and were analyzed for VOCs to assist in identifying locations for additional monitoring wells. In March 1999, groundwater samples were collected from these wells, from Wells #1, #2, and #10, and from a subset of the existing monitoring-well network; and were analyzed for VOCs, dissolved gases, and inorganic constituents. Groundwater samples collected in May 1999 from 10 of the newly-installed wells and 7 wells in the existing network were analyzed for dissolved hydrogen.

Upon review of hydrologic and chemical data collected from these wells in March and May 1999, Parsons ES recommended that one additional well be installed in each of the 800 Area and 2500 Area to better define the outer limits of CAH in groundwater in these two areas. The England AFB BCT concurred with the recommendations, and during the period July 11 through 14, 1999, GeoEngineering/Warren Drilling installed Well #8 in the 2500 Area and Well #21 in the 800 Area. Concurrently, Wells #1, #2, and #10, which had been installed in August 1998 for EBF testing, were decommissioned by GeoEngineering/Warren Drilling (Section 2.5). Groundwater samples collected from the Wells #8 and #21 in July 1999 were analyzed for VOCs, dissolved gases, and inorganic constituents.

Boreholes for the monitoring wells installed in conjunction with the current investigation were drilled to varying depths in the Intermediate Sand and Deep Sand units. Boreholes were logged during drilling by a Parsons ES field geologist. A summary of monitoring-well construction information is presented in Table 2.1-1. Boring logs, well construction diagrams, and development records for the 20 new monitoring wells are presented in Appendix B.

2.1.2.1 Equipment Decontamination

Prior to arriving at a drilling site, and after each borehole had been drilled, drive casing, drilling bits, center rods, and split-spoon sampling equipment were cleaned using a steam-cleaning system and allowed to air dry. Potable water provided by the driller (Layne Western or GeoEngineering/Warren Drilling) was used to clean drilling

TABLE 2.1-1
SUMMARY OF MONITORING WELL CONSTRUCTION INFORMATION
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Well/Borehole Identification	Easting (NAD27) ^a	Northing (NAD27)	TOC ^b Elevation (feet, NGVD) ^c	Screened Interval (ft - bmp) ^c
New Monitoring Points				
Intermediate Sand Unit				
WELL #1	1990831.05	237157.42	83.44	9 - 79
WELL #2	1991248.00	238394.23	89.56	9 - 89
WELL #3	1990815.35	238988.97	87.78	65 - 75
WELL #4	1991064.89	238523.71	88.20	62 - 72
WELL #5	1990733.85	237820.99	84.73	50 - 60
WELL #6	1990843.94	236910.91	82.65	50 - 60
Staff Gauge -- Le Tig Bavou			73.33	
WELL #7	1990282.67	236924.25	90.39	50 - 60
WELL #8	1991332.48	237454.33	90.54	69 - 79
WELL #10	1988550.18	239932.20	87.25	19 - 89
WELL #11	1988082.96	240028.65	86.11	60 - 70
Staff Gauge -- North Drainage Ditch			74.71	
WELL #13	1988661.28	240491.55	86.61	70 - 80
WELL #15	1988258.48	240384.17	86.00	60 - 70
WELL #17	1988517.55	241116.22	83.16	55 - 65
WELL #19	1987589.51	241223.83	84.49	65 - 75
Deep Sand Unit				
WELL #12	1988070.16	240021.42	86.58	90 - 100
WELL #14	1988274.31	240393.75	85.54	90 - 100
WELL #16	1988156.40	241095.78	80.79	90 - 100
WELL #18	1987610.99	241239.78	84.28	90 - 100
WELL #20	1988244.33	241030.48	81.40	120 - 130
WELL #21	1988608.26	241437.57	82.66	75 - 85
Pre-existing Monitoring Wells				
Intermediate Sand Unit				
A39L005PZ	1988221.30	238537.79	85.46	59-69
A39L006PZ	1988636.65	239180.91	83.98	62-72
A39L008DP	1988138.78	240850.73	82.68	38-48
A39L009PZ	1987757.70	239690.06	83.38	64-74
A39L010PZ	1990975.23	238111.74	86.11	55-65
A39L011PZ	1990555.68	237371.80	87.52	40-50
A39L012PZ	1991877.01	237603.80	84.37	60-70
A39L013DP	1988276.17	239961.35	84.07	40-50
A39L013PZ	1989760.07	236582.83	85.43	58-67
A39L014DP	1988961.62	240366.68	84.42	40-50
A39L014PZ	1988662.65	237912.82	85.43	60-70
A39L015PZ	1991201.53	239965.47	83.15	59-69
A39L016PZ	1987126.39	238276.09	83.83	60-70
A39L017PZ	1989465.61	239179.16	84.66	58-67
A39L018PZ	1989577.99	238718.09	78.02	40-50
A39L019PZ	1990363.94	238733.96	87.03	60-70
A39L021PZ	1989824.80	237969.80	87.65	58-67
A39L036DP	1987131.17	239247.70	82.68	59-68
A39L039DP	1986510.40	240027.24	81.58	53-64
A39L073DP	1991596.95	238565.66	83.73	62-71
BKGL039MW	1987924.88	240260.60	83.35	3-13
SS45L001MW	1988025.86	240183.74	82.42	54-64
SS45L005MW	1988349.09	238944.02	84.75	56-66
Deep Sand Unit				
A39L001PZ	1988122.67	240843.76	82.41	88-98
A39L002PZ	1986519.21	240011.71	81.32	96-106
A39L003PZ	1987116.50	239237.57	82.73	110-120
A39L004PZR	1988231.29	238536.08	84.54	110-120
A39L007PZ	1988633.34	239197.72	84.03	105-115
A39L008PZ	1988975.47	240376.04	84.42	108-118
A39L020PZ	1990368.29	238744.52	87.18	110-120
A39L022PZ	1988659.38	237905.26	85.55	110-120
A39L026DP	1988038.40	240183.41	82.55	111-121
A39L027DP	1987750.38	239701.32	82.9	111-121
A39L028DP	1988319.62	240117.34	84.29	113-123
A39L082DP	1990977.93	238106.35	86.35	108-118
A39L092DP	1990563.14	237371.00	87.4	113-123
SS45L002MW	1988010.84	240184.15	82.6	89-99

^a TOC = Top of casing.

^b NAD27 = North American datum of 1927.

^b NGVD = National Geodetic Vertical Datum of 1929.

^c ft - bmp = Feet below measuring point (i.e. top of casing).

equipment. Equipment cleaning was performed at a lined decontamination pad constructed on site. Used water from the pad was collected and stored in a tank, treated onsite by passing through a granular activated carbon filter, and discharged to the Base storm sewer system.

2.1.2.2 Collection and Analysis of Soil Samples

Soil samples were collected during borehole drilling to generate visual lithologic descriptions and for use in screening for the presence of VOCs. In addition, the boreholes for monitoring Wells #8 and #21 were drilled using continuous coring techniques to enable a complete description of the stratigraphic column through the Intermediate Sand unit to be generated, and so that intervals of potential interest for collection of soil samples could be identified. Soil samples were collected from the continuous cores removed from the boreholes for Wells #8 and #21 at 5-foot intervals from ground surface to the total depth of the borehole. Each soil sample collected for laboratory analysis of soil parameters was placed unpreserved in a glass jar prepared and supplied by the analytical laboratory, sealed, stored at a temperature of 4°C in a cooler, and shipped under standard chain-of-custody procedures to the laboratory (Quanterra Environmental Services, Inc., of Arvada, Colorado), for analyses of moisture content, total iron, and total organic carbon (TOC), using ASTM Methods D2216-90, SW6010B, and SW9060, respectively (Table 2.1-2).

At each borehole location, drill cuttings were collected and logged from ground surface to the total depth of the borehole. After visual examination, a soil sample from each 5-foot interval of a borehole was placed in a glass mason jar, sealed with aluminum foil, and used for headspace screening for VOCs. Each sample collected for headspace screening was quickly sealed into a jar, and stored for a minimum of 15 minutes at the ambient temperature before headspace readings were collected using an organic vapor analyzer (OVA) calibrated to a methane standard. Semiquantitative vapor measurements were made by puncturing the aluminum foil seal with the OVA probe and determining the concentration of the headspace gases. The OVA was also used to monitor for volatile chemicals in the breathing zone during drilling and sampling activities.

The Parsons ES field geologist maintained a descriptive log of subsurface materials recovered during drilling of each borehole. The geologic logs of boreholes, including soil-sampling intervals and OVA screening results, are presented in Appendix B.

Soil removed from boreholes during drilling was stored in three 20-cubic-yard roll-off bins in a fenced and locked compound on the Base. A composite soil sample was collected from the bins, and was shipped to the analytical laboratory for analysis in accordance with the requirements of the Toxicity Characteristic Leaching Procedure (TCLP; USEPA Method SW1311). The results of the TCLP analyses are included in Appendices B and C. Based on the results of TCLP analyses, the soils were accepted for offsite disposal at the Lasalle/Grant Landfill. Waste manifests for the disposed soils are included in Appendix B.

TABLE 2.1-2
ANALYTICAL PROTOCOLS FOR SOIL AND GROUNDWATER SAMPLES
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

ANALYTE	METHOD	Field (F) or Fixed-Based (L) Analytical Laboratory
Volatile Organic Compounds	USEPA ^{a/} SW8260A	L
Methane, Ethane, Ethene; Hydrogen	NRML-147 ^{b/} ; AM19GA ^{c/}	L
Ferrous Iron (Fe+2)	Colorimetric, HACH ^a , Method 8146 (or similar)	F
Manganese	Colorimetric, HACH ^a , Method 8034	F
Sulfide	Colorimetric, HACH ^a , Method 8131	F
Sulfate	Colorimetric, HACH ^a , Method 8051 (or similar)	F
Sulfate	Waters Capillary Electrophoresis Method N-601/USEPA E300	L
Alkalinity (Carbonate [CO ₃ ⁻²] and Bicarbonate [HCO ₃ ⁻¹])	Titrimetric, HACH ^a Method 8221 (or similar)	F
Nitrate	USEPA E300/SW9056	L
Chloride	Waters Capillary Electrophoresis Method N-601/USEPA E300	L
Dissolved Organic Carbon	USEPA E415.1	L
Oxygen	Direct-reading meter	F
Carbon Dioxide	Titrimetric, HACH ^a Method 1436 (or similar)	F
Redox Potential	A2580B, direct-reading meter	F
pH	USEPA E150.1/SW9040, direct-reading meter	F
Conductivity	USEPA E120.1/SW9050, direct-reading meter	F
Temperature	USEPA E170.1, direct-reading meter	F
Turbidity	USEPA E180.1	F
Soil Moisture Content	ASTM D2216-90	L
Total Organic Carbon (in soil)	USEPA E415.1	L
Total Iron (in soil)	USEPA SW3050 (extraction) and SW6010A (analysis)	L

a/ USEPA = United States Environmental Protection Agency.

b/ NRML = USEPA National Risk Management Research Laboratory.

c/ Method developed by University of Pittsburgh Applied Research Center.

2.1.2.3 Monitoring Well Installation and Development

After a borehole had been drilled to its planned total depth, the drill string was withdrawn, and a well was constructed within the open borehole. No difficulties related to borehole collapse occurred during well installation.

Well materials and construction procedures were in general accordance with the well construction standards established by the State of Louisiana, Department of Public Works and Water Resources (LRS 38:3091 *et seq.*). Monitoring wells were constructed of flush-threaded 2-inch nominal inside diameter (ID) Schedule 40 polyvinyl chloride (PVC) riser casing and well screen. Wells #1, #2, and #10 were fully-screened across the entire saturated thickness of the Intermediate Sand unit and the Upper Clay unit for subsequent electromagnetic flowmeter testing. Screened intervals for the remaining wells were 10 feet in length, and comprised the lowermost 10 feet of each borehole. All screens were factory-slotted with 0.010-inch openings. Each monitoring well was fitted with a vented PVC or compression cap. Well materials were inspected for cleanliness prior to use. No glue or solvents were used with monitoring well materials.

After the casing string comprising the well screen and riser pipe had been placed in the open borehole, and before backfilling of the annular space, the initial stage of well development was completed. Potable water was circulated through the well screen until the turbidity decreased to approximately 100 nephelometric turbidity units (NTUs). The volumes of water flushed and the values for pH, conductivity, temperature, and turbidity readings were recorded by the field geologist, and are included in Appendix B. After initial development was completed, a graded filter pack/formation stabilizer (Lone Star 10-20 well sand) was tremied into the annular space around the well screen to a minimum depth of 2 feet above the top of the screen. A seal consisting of bentonite chips was placed above the filter pack and allowed to hydrate. The annular space between the riser pipe and the wall of the borehole was then backfilled using a grout mixture of neat cement and bentonite powder.

Because monitoring Wells #16, #17, #20, and #21 were installed near active aviation facilities, in the North Ramp area, these wells were completed flush with the ground surface. All other monitoring wells installed during the current investigation were completed above ground with a 3-foot surface stick-up. In accordance with the well construction standards established by the State of Louisiana, Department of Public Works and Water Resources (LRS 38:3091 *et seq.*), all wells completed above-ground were equipped with locking protective casings and surrounded by a 5-foot-square concrete pad. Bollards protruding a minimum of 3 feet above ground were set in the corners of each pad. Monitoring well completion diagrams are included in Appendix B.

After completion, every newly installed well was fully developed at least 24 hours prior to beginning groundwater sampling. Well development was conducted by the drilling contractor, and consisted of surging and pumping the well using a submersible pump to remove fine sediments and introduced fluids from the formation adjacent to the screened interval of the well. The well was surged so that fine-grained material was agitated and removed from the formation stabilizer and wellbore with the development water. Development continued until a volume of water equivalent to at least 5 casing

volumes had been removed from the monitoring well; the temperature, pH, oxidation-reduction potential (ORP), conductivity, and dissolved oxygen (DO) concentrations of the extracted groundwater had stabilized; and turbidity had stabilized at a value less than 10 NTU. No more than 100 gallons of water was produced from any individual monitoring well during development. Monitoring well development records are included in Appendix B. All development water was collected in a storage tank, treated onsite using a granular activated carbon filter, and discharged to the Base storm sewer system.

2.2 SURVEYING

Following well installation and completion, the wells were surveyed to a common northing, easting, and elevation datum (State Plane Coordinate System and the National Geodetic Vertical Datum of 1929 [NGVD], respectively) by a licensed surveyor (Pan American Engineers, Inc., of Alexandria, Louisiana). The point-of-beginning and survey reference for the well survey was reported by Pan American Engineers, Inc., to be the Colony benchmark near the western boundary of England AFB. Horizontal locations were surveyed to the nearest 0.5 foot. The elevation datum (top of well casing) and ground-surface elevations at each well location were surveyed to the nearest 0.01 foot. Survey results are presented in Appendix B.

At the request of Parsons ES, Pan American Engineers, Inc. included six additional wells, previously installed and surveyed by other contractors, in the initial well survey. The six wells were re-surveyed as a quality assurance/quality control (QA/QC) measure, and to serve as a reference cross-check with previous survey results. These additional six wells had originally been surveyed by Ballard & Associates, Inc., of Alexandria, Louisiana to US Geological Survey's (USGS) Benchmark No. 8238, reportedly located near the eastern boundary of England AFB.

In comparing the top-of-casing elevations for the six wells, reported for the two surveys, discrepancies were noted between top-of-casing elevations reported by Pan American Engineers, Inc., and by Ballard & Associates. The wells were resurveyed and both companies obtained results similar to their original findings.

The discrepancies in surveyed top-of-casing elevations are attributed to use of different benchmarks as points-of-beginning for the two well surveys. Top-of-casing elevations reported by Pan American Engineers, Inc. were consistently higher than those reported by Ballard & Associates, Inc., with elevation differences ranging from 0.68 to 0.84 foot. This is consistent with an elevation difference of about 0.7 foot between the two benchmarks, with the Colony benchmark (used by Pan American Engineers, Inc.) being higher than USGS Benchmark No. 8238 (used by Ballard & Associates). The AFCEE Team Chief for England AFB has directed that all future surveys be referenced to USGS Benchmark No. 8238; and that well surveys referenced to the Colony benchmark be corrected by subtracting 0.70 foot from the surveyed elevation. The England Base Conversion Team (BCT) concurred, and therefore, the surveyed top-of-casing elevations for the wells installed in August 1998 and January-February 1999 have been adjusted.

The last two wells installed (Wells #8 and #21) were surveyed using USGS Benchmark No. 8238 as the reference datum. During surveying of the final two wells,

Parsons ES requested that the surveyor use USGS Benchmark No. 8238 as the point-of-beginning and point-of-ending, but also include the Colony benchmark in the closed traverse. This was done to evaluate the relative elevation differences between the two benchmarks. The elevation recorded for USGS Benchmark No. 8238 (85.80 feet NGVD) was used as the benchmark elevation for the closed traverse. The elevation determined for the Colony benchmark during the traverse (87.83 feet NGVD); the resulting difference (0.77 ft) is in good agreement with the elevation discrepancies noted during earlier surveys. The closed traverse was concluded at USGS Benchmark No. 8238, with a closure of -0.02 feet. It therefore seems reasonable to assume that the difference in elevation between USGS Benchmark No. 8238 and the Colony benchmark is 0.77 feet ± 0.02 feet; and the elevations previously surveyed for measuring points on wells installed by Parsons ES prior to July 1999 were adjusted by that amount.

2.3 GROUNDWATER MONITORING

After wells had been installed and developed, water-level elevations were measured, and groundwater samples were collected in accordance with the procedures described in the work plan (Parsons ES, 1998) and the England AFB General Sampling and Analysis Plan (LAW, 1998b). Groundwater samples were collected during six sampling events: September 1 through 4, 1998; February 3, 1999; March 8 through March 18, 1999; May 24 through May 28, 1999; and July 20 and 21, 1999. A summary of field sampling and analysis activities conducted in support of the Site SS-45 focused CMS is provided in Tables 2.3-1 and 2.3-2.

2.3.1 Scope of Monitoring Events

September 1 – 4, 1998 - EBF Testing

The first three wells installed by Parsons ES at Site SS-45, England AFB (Wells #1, and #2, in the 2500 Area; and Well #10, in the 800 Area), were screened across the entire saturated thickness of the Intermediate Sand Unit and upper silt/clay unit (Table 2.3-1) to enable the hydraulic properties of the two units to be evaluated. To assist in the evaluation, the boreholes for the three wells were logged using geophysical techniques (temperature, natural gamma, resistivity, conductance, and AP conductance) prior to well installation. Geophysical borehole logs for Wells #1, #2, and #10 are presented in Appendix B.

After the wells had been completed and developed in August 1998, they were tested using EBF technology (Table 2.3-1), by personnel of Quantum Engineering Corporation under contract to Parsons ES. EBF technology involves measuring the groundwater flow rate using an induction flowmeter at different intervals in the saturated section of a well, under ambient conditions (no induced flow) or under induced pumping at low discharge rates. Relative values of hydraulic conductivity can be computed for each vertical interval tested using differences in flow rates measured in the different intervals of the saturated section.

Ambient-flow and induced-flow tests were completed in each of the three wells, and are described in detail in Appendix B. The results of EBF testing are discussed in Section

TABLE 2.3-2

Wells Installed by Parsons Engineering Science, Inc.

Water levels were measured at all wells for the May 1990 and July 1990 sampling events

Water levels were measured at all wells for the May 1990 and

EPA • United States Environmental Protection Agency

EPA • United States Environmental Protection Agency

[illegible]

3.4.2. In addition to EBF testing in the wells, groundwater samples were collected from several different intervals in each well to determine the vertical distribution of CAHs in groundwater within the Intermediate Sand unit. Discrete intervals within each well were sampled by installing inflatable packers bracketing the interval to be sampled, and purging and sampling the packered interval. Three intervals of the Intermediate Sand unit (30 to 40 feet bgs, 40 to 50 feet bgs, and 60 to 70 feet bgs) were sampled in Well #1; three intervals of the Intermediate Sand unit (48 to 58 feet bgs; 60 to 70 feet bgs; and 70 to 80 feet bgs) were sampled in Well #2; and two intervals of the Intermediate Sand unit (55 to 65 feet bgs and 68 to 78 feet bgs) were sampled in Well #10. Groundwater samples were analyzed for VOCs, using Method 8260A; results of the September 1998 sampling event are discussed in Section 4.

February 3, 1999

At the time that well installation activities were initiated in late January 1999, there was some uncertainty regarding the direction(s) of groundwater flow at Site SS-45. Accordingly, after approximately one-half of the new wells had been installed, water levels were measured in Wells #1, #2, #3, and #6 in the 2500 Area, and in Wells #13, #15, #18, #19, and #20 in the 800 Area, and groundwater samples were collected from four wells (Wells #3, #6, #13, and #15), and were submitted for analyses of VOCs on a rapid-turnaround basis (Table 2.3-1). Water levels were measured and groundwater samples were collected and analyzed to provide preliminary information regarding possible groundwater flow directions and the extent of VOCs in the groundwater. This information was used to identify locations for installation of the remaining groundwater monitoring wells. Results of the February 1999 sampling event are presented in Section 4.

March 8 - 18, 1999

A sitewide groundwater monitoring event was completed at Site SS-45 during the first two weeks of March 1999. Water levels were measured in groundwater monitoring wells in and near the 800 and 2500 Areas. During the first day of field activities, water levels were measured in all wells listed in Table 2.3-1 within a 6-hour period. Surface-water elevations also were measured at two staff gages, which are present in bayous within or near the 800 and 2500 Areas.

Groundwater samples were collected from the monitoring wells listed in Table 2.3-1, and analyzed for the analytes/parameters indicated in the table. Analyses of groundwater samples were conducted in accordance with the methods specified in Table 2.1-2.

Groundwater samples were collected in accordance with the provisions of Work and Test Procedure (WTP) No. 9 (*Groundwater Sampling*), presented in Appendix E of the England AFB SAP (LAW, 1998b). General procedures followed during sample collection are described in Section 2.3.3. Groundwater samples were submitted to Quanterra Environmental, Inc., of Arvada, Colorado for analysis of VOCs, using USEPA Method 8260A. Groundwater samples were also submitted for laboratory analysis of methane, ethane, ethene, and several inorganic parameters including nitrate, chloride, and dissolved organic carbon (DOC). Other inorganic constituents/parameters, including ferrous iron,

manganese, sulfide, sulfate, total alkalinity, DO, carbon dioxide, ORP, pH, specific conductance, temperature, and turbidity were analyzed in the field (Table 2.3-1). Results of the March 1999 monitoring event are discussed in Section 4.

May 24 – 28, 1999

In May 1999, groundwater samples were collected from monitoring wells listed in Table 2.3-2. The primary purpose of this monitoring event was to collect groundwater samples for hydrogen analysis. Because drilling and well installation activities upset the natural hydrogen balance, hydrogen sampling was deferred for a period greater than 3 months after well installation. Groundwater levels were measured prior to sampling and surface-water levels at staff gages were also noted.

Groundwater samples collected from the 18 monitoring wells were analyzed for the constituents/parameters listed in Table 2.3-2. Analyses of groundwater samples were conducted in accordance with the methods and equipment specified in Table 2.1-2. In accordance with procedures recommended by the USEPA, groundwater samples for analysis of dissolved hydrogen were collected using an air-driven bladder pump. Groundwater samples from 18 monitoring wells were analyzed for dissolved hydrogen by MicroSeeps, Inc., of Pittsburgh, Pennsylvania. In addition, groundwater samples from Wells #4 and #17 were submitted to Quanterra Environmental Services, Inc. for reanalysis of VOCs (Table 2.3-2) to confirm elevated concentrations of *trans*-1,2-DCE that had been detected in the March 1999 sample from Well #4 and the concentrations of TCE that had been detected in the sample from Well #17. Results of the May 1999 monitoring event are discussed in Section 4.

July 20 – 21, 1999

In July 1999, Parsons ES installed two additional groundwater monitoring wells (Wells #8 and #21) to assist in defining the maximum extent of CAHs in groundwater of the Intermediate Sand unit in the 800 Area and 2500 Area (Section 2.1.2). After the two wells had been installed and developed, groundwater samples were collected and were analyzed for VOCs, dissolved gases, and inorganic parameters (Tables 2.3-2 and 2.1-2). As in prior monitoring events, groundwater levels were measured during a single measurement event. Water levels at staff gages were also noted and recorded. Results of the monitoring event of July 1999 are discussed in Section 4.

2.3.2 Groundwater Sampling Procedures

2.3.2.1 Cleaning and Preparation of Equipment

All equipment used in groundwater sampling was assembled, properly cleaned, and calibrated (if required) prior to use in the field. All parts of sampling and test equipment that might contact a sample were thoroughly cleaned before use. This equipment included the water-level probe and cable, and equipment for measuring onsite groundwater chemical parameters. The equipment was cleaned using the following protocol:

- Rinsed with isopropyl alcohol;
- Rinsed with distilled or deionized water; and
- Air dried prior to use.

Special care was taken to prevent cross-contamination of groundwater samples through contact with improperly-cleaned equipment. In addition, a clean pair of new, disposable latex gloves was worn each time a different well was sampled. Any deviations from these procedures were documented in the field scientist's field notebook and on the groundwater sampling form. Analytical instruments and equipment used in the field was calibrated according to the manufacturers' specifications prior to field use.

Prior to the commencement of sampling at a particular location, the area around the well was cleared of foreign materials (brush, rocks, and other debris) to prevent sampling equipment from inadvertently contacting such material during sampling activities in the vicinity. Each monitoring well also was inspected visually, to evaluate well integrity; any irregularities in the visible portions of the wells, protective covers, or concrete pads were noted.

2.3.2.2 Measurement of Water Levels and Total Depth of Wells

The static water level was measured in each monitoring well prior to removing any water from the well. A Solinst® electrical water-level probe was used to measure the depth to groundwater below the well datum to the nearest 0.01 foot. After the static water level had been measured, the water-level probe was lowered to the bottom of the well for measurement of total depth (recorded to the nearest 0.1 foot). The saturated casing volume for each well was calculated based on these measurements, or using total depths recorded on well-construction logs.

2.3.2.3 Well Purging

Prior to sampling, each monitoring well was purged to remove stagnant water from the well casing. A decontaminated Grundfos® low-flow submersible pump was used to purge all wells that were sampled. At a minimum, the volume of water removed from each well was three times the calculated saturated casing volume. Purging continued until instrument readings of pH, DO concentration, ORP, conductivity, and temperature had stabilized. All water generated during purging of monitoring wells was collected in a storage tank, treated onsite by passing through a granular activated carbon filter, and discharged to the Base storm sewer system.

2.3.2.4 Onsite Measurement of Chemical Parameters

Groundwater samples were analyzed in the field by Parsons' ES personnel for pH, conductivity, temperature, DO, ORP, total alkalinity, ferrous iron, sulfate, hydrogen sulfide, manganese, and carbon dioxide (Tables 2.3-1 and 2.3-2). Analyses for VOCs, total iron, nitrate, chloride, sulfate, methane, ethane, ethene, dissolved TOC, and alkalinity were performed by Quanterra Environmental Services, Inc., of Arvada,

Colorado. Analyses for dissolved hydrogen were performed by Microseeps, Inc., of Pittsburgh, Pennsylvania.

DO measurements were collected using an Orion® Model 840 or a YSI® Model 55 DO meter. The meter probe was placed in a flow-through cell on the outlet side of the purge pump, and DO concentrations were recorded after the readings had stabilized and in all cases represent the lowest DO concentration observed.

Because the pH, electrical conductivity, ORP, and temperature of the groundwater can change significantly within a short time following sample acquisition, these parameters were measured in the field, in the same flow-through cell used for DO measurements.

Total alkalinity and carbon dioxide concentrations in groundwater were determined by titrimetric analyses using USEPA-approved Hach® Method 8221 and CHEMetrics® Method 4500, respectively (Table 2.1-2). Sulfate, hydrogen sulfide, ferrous iron, and manganese concentrations in groundwater were determined by colorimetric analyses using USEPA-approved Hach® Methods 8051, 8131, 8146, and 8034, respectively. All measured values were recorded on the groundwater sampling records (Appendix B).

2.3.2.5 Sample Collection

Dedicated or decontaminated Grundfos® low-flow submersible pumps and tubing were used to collect groundwater samples from monitoring wells. (As previously noted, groundwater samples for analyses of dissolved hydrogen were collected using air-driven bladder pumps.) The samples were transferred directly from the discharge line into the analyte-appropriate sample containers prepared and supplied by the analytical laboratory. Care was taken during sample collection to minimize aeration of the sample. Sample containers for VOCs and dissolved gases (methane, ethane, and ethene) were filled so that no headspace or air bubbles remained within the container. Samples for dissolved hydrogen analyses were collected by continuously pumping groundwater through proprietary gas-sampling equipment, supplied by Microseeps, Inc. Analytical methods are summarized in Table 2.1-2, and groundwater sampling records are provided in Appendix B.

2.4 SAMPLE HANDLING

The fixed-base analytical laboratories (Quanterra Environmental Services, Inc., and MicroSeeps, Inc.) provided pre-preserved sample containers, as appropriate for the requirements of the analytical methods. The sample containers were filled as described in the previous sections, and were labeled in accordance with the requirements of the work plan (Parsons ES, 1998). After the samples were sealed and labeled, they were transported in accordance with standard Chain-of-Custody procedures to the appropriate laboratory via overnight delivery.

2.5 WELL DECOMMISSIONING

The first three wells installed by Parsons ES in conjunction with the current investigation at Site SS-45 (Wells #1, #2, and #10) were screened across the entire

saturated thickness of the Intermediate Sand unit and the upper silt/clay unit to evaluate hydraulic properties and the vertical distribution of dissolved CAH compounds in the two uppermost hydrogeologic units at Site SS-45 (Sections 2.1 and 2.3.1). Under certain hydrogeologic conditions, groundwater flow or chemical stratification may occur preferentially in one or more localized intervals of a water-bearing unit. Such an occurrence may render wells screened across the entire unit unsuitable for use in evaluating hydrologic or chemical conditions in that unit, because sampling groundwater drawn from several different intervals within a saturated unit could potentially generate misleading results. Accordingly, in the work plan, Parsons ES (1998) proposed to decommission the three fully-screened wells upon completion of the planned field activities.

Wells #1, #2, and #10 were decommissioned in conjunction with the installation of Wells #8 and #21 during the period from July 11 through 14, 1999, by GeoEngineering/Warren Drilling, under the supervision of a Parsons ES field geologist. The wells were decommissioned in accordance with the requirements of standards established by the State of Louisiana, Department of Public Works and Water Resources (LRS 38:3091 *et seq.*). The three wells were decommissioned by overdrilling a borehole around the well casing, withdrawing the well riser and screen through the drill string, and backfilling the borehole with a grout mixture of neat cement and bentonite, from the total depth of the borehole to ground surface. Well decommissioning records are included in Appendix B.

SECTION 3

PHYSICAL CHARACTERISTICS OF SITE SS-45

This section describes the physical characteristics of England AFB Site SS-45. This section includes information originally reported by TetraTech (1992a) and LAW (1998a). Existing site-specific data were reviewed and supplemented with data collected by Parsons ES from July 1998 through July 1999 to develop a synopsis of the physical characteristics of Site SS-45.

3.1 CLIMATE

England AFB and the surrounding area have a humid, subtropical climate characterized by long, hot summers and short, mild winters. The Gulf of Mexico is located about 100 miles south of England AFB and strongly influences meteorological conditions in the region. Monthly relative humidity averages range from 48 to 87 percent. The annual average temperature at the Base is 67 degrees Fahrenheit (°F), with an average daily maximum of 77°F and average daily minimum of 56°F (Engineering-Science, Inc., 1983). Average monthly high temperatures range from 58°F in January to 92°F in July and August. Frost and freezing temperatures can be expected to occur approximately 25 times per year.

Average annual precipitation at the Base is 56.8 inches, with precipitation in the area generally occurring more often during the winter months. The lowest monthly rainfall occurs in October, and the highest occurs in December. Heavy thunderstorms are common during the summer months and occur an average of 69 days per year. This area also is subject to hurricanes, which usually occur between June and November (TetraTech, 1992).

3.2 SURFACE FEATURES

3.2.1 Ground Surface Topography

England AFB is located in the Red River Valley subdivision of the West Gulf Coastal Plain Physiographic Province. The topography of the Base and surrounding areas of the Red River Valley is level to gently sloping. Streams in the region have developed nearly level, broad floodplains. The dissected terraces along the valley (the remnants of former floodplains) are the most prominent regional topographic feature. Surface elevations vary from 75 feet above mean sea level (amsl) in the channel of Le Tig Bayou adjacent to the golf course to 90 feet amsl along the western boundary of the Base. Changes in ground-surface elevation are slight and normally occur as gentle slopes. The greatest relief is along major watercourses, such as Big Bayou or Bayou Rapides.

3.2.2 Surface Hydrology

England AFB is drained by Bayou Rapides, Big Bayou, and their tributaries. Big Bayou lies just outside the northern boundary of the Base, and Bayou Rapides forms the southern boundary (Figure 1.2-2). Small, intermittent channels drain into the bayous. Big Bayou is connected with Bayou Rapides outside the northeast boundary of the Base by Irish Ditch No. 2. The Red River, located approximately 1 mile northeast of the Base, is the major surface drainage in the area. Surface water velocities are generally very slow due to low channel gradients.

Three distinct surface water bodies, Tiger Lagoon, Le Tig Bayou, and Le Tig Pond, are located on the Base. Tiger Lagoon is a pond covering an area of approximately 50 to 55 acres on the northern side of the Base, and formerly was used as a sewage disposal and treatment lagoon. This lagoon has been inactive since 1982. Le Tig Pond covers approximately 1 acre on the Base golf course near the South Gate. Le Tig Bayou is located adjacent to Le Tig Pond and the golf course in the southeast area of the Base, and flows south into Bayou Rapides. The area surrounding Le Tig Bayou is reported (Mr. Jon Grafton, oral comm., September 1999) to have originally been wetlands, that were subsequently drained and filled during construction activities on the Base in the 1950s and 1960s.

Parts of the Base are within the 100-year floodplains of Big Bayou and Bayou Rapides. The floodplain areas are located primarily along the bayous and drainage areas.

Overland discharges to surface water occur at the Base via surface run-off into the bayous. Stormwater sewers typically discharge into open drainage canals that feed into the bayous. Big Bayou and Bayou Rapides are designated by the LDEQ as general-use waters suitable for aquatic life habitat, recreation, and agricultural or industrial water supply. Currently, periodic surface-water sampling from stormwater sewer discharge areas is conducted by the city of Alexandria.

3.3 REGIONAL GEOLOGY AND HYDROGEOLOGY

3.3.1 Red River Alluvial Aquifer

The uppermost geologic units in the vicinity of England AFB consist of Holocene and/or Pleistocene alluvium of the Red River Valley ("Red River Alluvium"), which is underlain by unconsolidated sediments of Miocene age. The uppermost unit within the Red River Alluvium is a clayey silt to clay, extending from ground surface to depths as great as several tens of feet bgs (Newcome and Sloss, 1966). The upper silt/silty clay overlies unconsolidated alluvium consisting of coarser-grained deposits of sand and gravel with interbedded and intercalated clays. The sand units are the primary water-bearing strata of the Red River Alluvial Aquifer. The upper silt/silty clay unit has little water-bearing capacity, and partially confines groundwater in more permeable, sandy strata that underlie the silt/clay. Near Alexandria and in the vicinity of England AFB, the average thickness of the Red River Alluvium is approximately 90 feet (Rogers, 1983).

In some areas north of England AFB, the Red River and its major tributaries have incised the confining unit of the alluvium and cut through part of the underlying alluvial aquifer (Rogers, 1983). This places the Red River and the alluvial aquifer in hydraulic communication. Water enters the Red River Alluvial Aquifer through infiltration and downward percolation of rainfall, recharge from adjacent or underlying formations, or recharge from surface-water bodies.

Regionally, groundwater movement in the Red River Alluvial Aquifer is generally from the south and southwest to the north-northeast, toward the Red River (LAW, 1998a). During most of the year, groundwater discharges from the alluvial aquifer to the Red River and contributes to the river's base flow. When the river is in flood stage, groundwater flow gradients reverse in areas adjacent to the river, and the groundwater system is recharged by the river.

3.3.2 Miocene System

The Miocene-age deposits beneath the Red River Alluvium include clays, silts, sands, gravels, and shale. These deposits range from 0 to 500 feet thick in the northwestern part of Rapides Parish to an aggregate thickness greater than 5,300 feet in the southeastern corner of the Parish (Newcome and Sloss, 1966). The Miocene section is divided into the Fleming Formation at the top and the Catahoula Formation below.

The primary water-bearing units at depth within the Miocene section beneath Rapides Parish are thick sand members of the Miocene Fleming and Catahoula Formations (Newcome and Sloss, 1966). The individual sand members are numbered and grouped into aquifers designated by the typical depths at which they are encountered in the Alexandria area. For example, the 400-foot, 700-foot, and 1,000-foot sands are the most widely used and prolific aquifers in the area. These sands typically are separated by interbedded clayey strata. All water-supply wells in the vicinity of England AFB are completed in the Miocene system and withdraw groundwater from sand members several hundred feet below the base of the Red River Alluvial aquifer (Table 1.2-1). The Miocene aquifer is recharged from rainfall on its outcrop area in northwestern Rapides Parish. Depending on local hydraulic gradients, some recharge may occur from overlying alluvium or from Pleistocene deposits in highland areas north and west of Alexandria.

Groundwater within the Miocene sands usually occurs under artesian conditions. However, in some areas, Miocene water levels have been reduced so drastically that a reversed hydraulic gradient has been created between the Miocene sediments and the overlying alluvium (Newcome and Sloss, 1966), with the overlying alluvium recharging the Miocene sands.

Groundwater flow directions and velocities in the Miocene aquifers are strongly influenced by pumping of large-capacity water supply wells. Movement of groundwater in the Miocene sands is directed toward the large drawdown features created by concentrated pumping, and natural discharge areas have been reduced in size. On a regional scale, the movement of groundwater within the Miocene sands beneath the Base is primarily to the northeast, toward the Bayou Rapides Well Field north of the Base. Groundwater velocities

in the area are variable depending upon recharge occurrence and pumping rates (Newcome and Sloss, 1966).

3.4 GEOLOGY AND HYDROGEOLOGY OF SITE SS-45

The geologic and hydrogeologic features of Site SS-45 and nearby areas were initially evaluated during the RFI (LAW, 1998a) using HydroPunch® borings at 93 locations (Figure 1.3-3), and boreholes drilled during installation of 37 groundwater monitoring wells (Figures 1.3-4 and 1.3-5). Twenty additional groundwater monitoring wells were installed in conjunction with the current investigation (Figures 2.1-1 and 2.1-2), and borehole logs generated during drilling and installation of these wells were used in conjunction with the RFI data (LAW, 1998a) to interpret conditions in the subsurface at Site SS-45. Depth to groundwater, hydraulics and directions of groundwater flow, and hydraulic parameters have been evaluated using water levels measured in groundwater monitoring wells during the current, and previous investigations; the results of well-displacement ("slug") tests conducted by others in 17 groundwater monitoring wells (LAW, 1998a); and the results of EBF tests, completed in three wells as part of the field activities for the current investigation (Section 2.3).

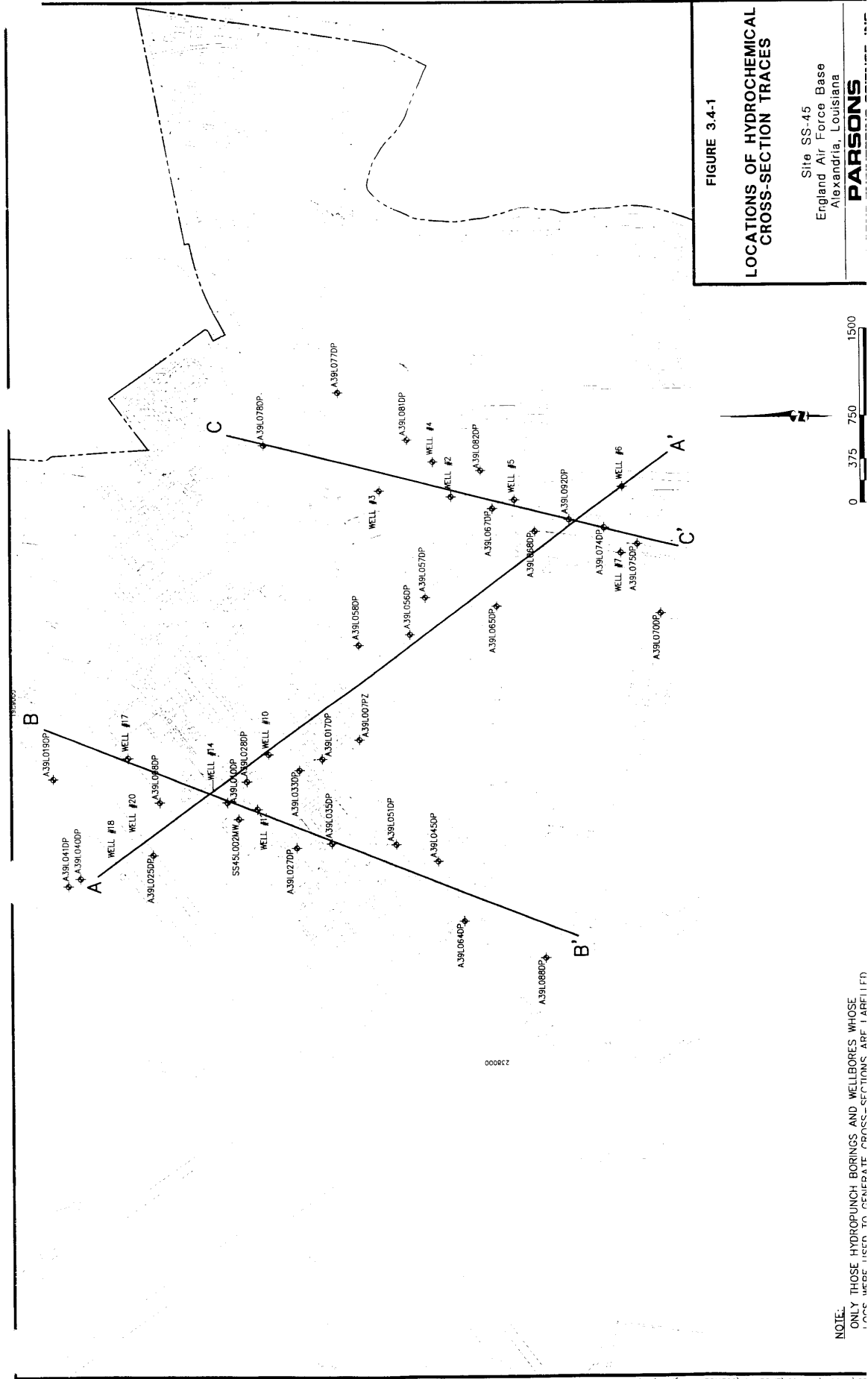
3.4.1 Site Hydrostratigraphy

Regionally, the Red River Alluvium consists of two primary units: 1) fine-grained deposits in the shallow subsurface, having an average thickness of approximately 40 feet, and consisting primarily of silts, clays, and sandy silts; and 2) coarser-grained deposits, primarily fine-grained sand, occasionally grading to gravel, extending from depths of approximately 40 feet bgs to approximately 120 feet bgs. Discontinuous clay or silty clay units, sometimes several feet thick, occur within the sands and gravels.

Based on the results of site investigations completed to date, the hydrostratigraphic section at Site SS-45 consists of four separate units, each relatively continuous laterally, and widespread in the subsurface (Figures 3.4-1 through 3.4-4). The uppermost unit (the "upper silt/clay unit") consists primarily of reddish brown silts, clays, and sandy silts. Newcome and Sloss (1966) interpreted this unit as Holocene in age. The thickness of the upper silt/clay unit ranges from 0 to 62.5 feet at Site SS-45, with an average thickness of approximately 40 feet. The unit is absent at the locations of some HydroPunch® borings in the southeastern part of the Base. It appears to be thickest in the south-central part of the Base, near the 2500 Area, and thins somewhat to the north, beneath the 800 Area (Figures 3.4-2 through 3.4-4).

Units at greater depth within the Red River Alluvium consist of fine- to coarse-grained deposits (primarily sand and some gravel) with interbedded clays. Newcome and Sloss (1966) interpreted this unit as Pleistocene in age. The upper contact of this sequence has been encountered at depths ranging from 0 to 62.5 feet bgs, and it extends to depths of approximately 120 feet bgs. Locally, three distinct units can be identified within the lower Red River Alluvium at England AFB:

Intermediate Sand: The Intermediate Sand unit underlies the upper silt/clay. The upper contact of the Intermediate Sand unit occurs at depths ranging from the surface in



NOTE:
ONLY THOSE HYDROPUNCH BORINGS AND WELLBORES WHOSE
DATA WERE USED TO GENERATE PARCEL-SECTIONS ARE IDENTIFIED

FIGURE 3.4-1
**LOCATIONS OF HYDROCHEMICAL
CROSS-SECTION TRACES**
Site SS-45
England Air Force Base
Alexandria, Louisiana
PARSONS

NORTHWEST

SOUTHWEST

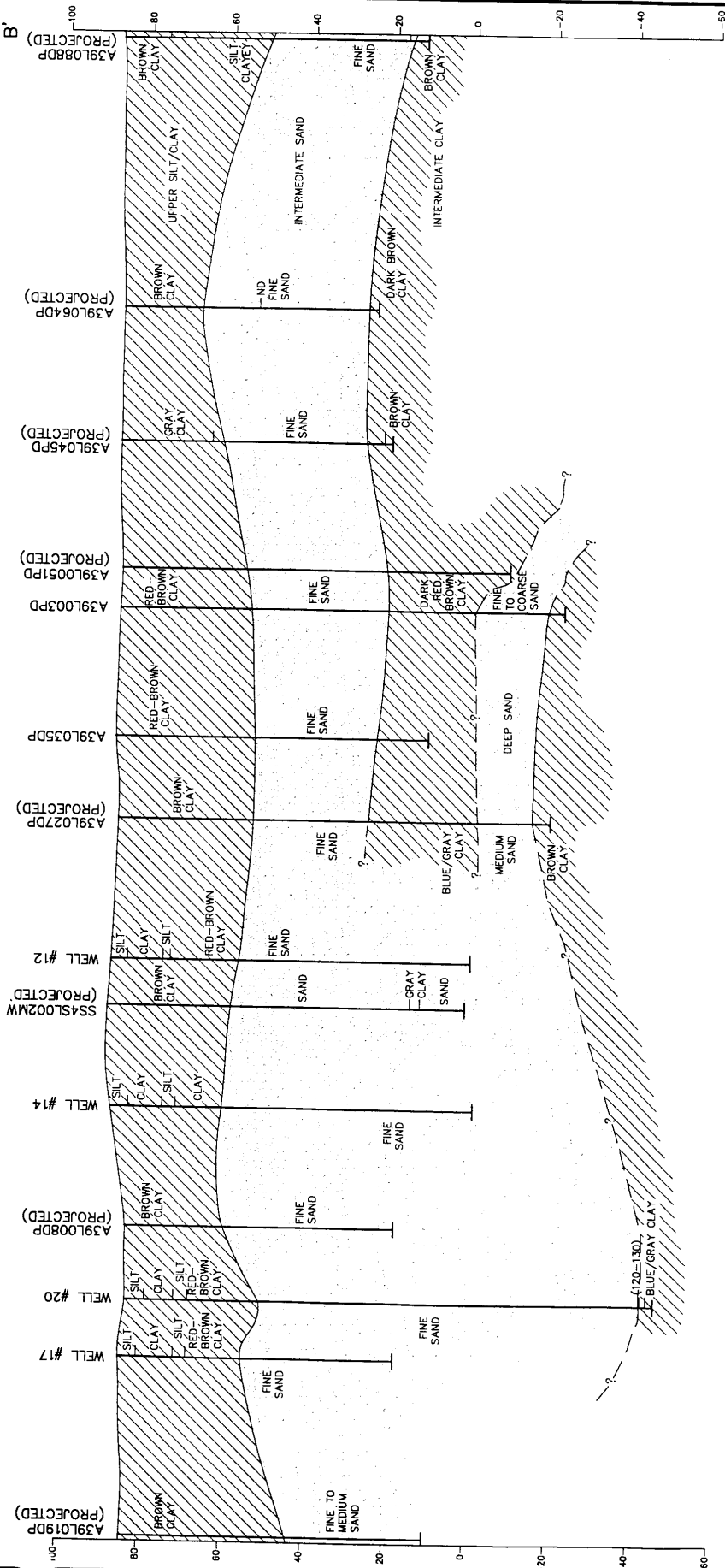


FIGURE 3.4-3
HYDROGEOLOGIC
CROSS-SECTION
B-B'

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

the southeastern part of the Base to 62.5 feet bgs, and it extends to depths ranging from 65 to 95 feet bgs (Figures 3.4-2 through 3.4-4). The upper part of the Intermediate Sand unit consists of brown clayey to silty fine-grained sand. Grain size increases with depth, and soils become a medium- to coarse-grained sand, with thin, discontinuous and intercalated strata of gray silt and clay. One or more distinctive intervals of wood debris were encountered within the Intermediate Sand unit in boreholes drilled in the 800 Area, at depths ranging from about 60 to 70 feet bgs. The Intermediate Sand unit ranges in thickness from 11 to 79 feet, with an average thickness of 37 feet.

Intermediate Clay: The Intermediate Sand unit is underlain by a distinctive stratum of dark brown to gray or olive clay, silty clay, and clayey silt (the Intermediate Clay unit). This unit ranges in thickness from 0 to 31 feet, with an average thickness of about 12 feet. The Intermediate Clay unit appears to be absent beneath the northern part of Site SS-45 (Figure 3.4-5), but can be distinguished in the logs of boreholes in the central part of the 800 Area (e.g., at A39L028DP; Figure 3.4-2), and thickens toward the south. At some locations the unit appears to be relatively uniform in composition and texture through its complete vertical section, and interfingers laterally with sandy horizons. At other locations, the Intermediate Clay unit consists of discontinuous clay-rich strata of varying thickness, separated by relatively thin, sandier intervals. Overall, the Intermediate Clay unit seems to be laterally discontinuous, and does not completely separate the Intermediate and Deep Sand units (Figure 3.4-2).

Deep Sand: Across much of the Base, the Deep Sand unit of the Red River Alluvium underlies the Intermediate Clay unit. The upper contact of the Deep Sand unit is gradational with the Intermediate Clay unit in that the upper part of the Deep Sand unit consists of gray to grayish-brown, silty fine-grained sand, interbedded with discontinuous lenses of greenish-gray to gray silt and clay. The grain size of clastic material in the Deep Sand unit increases with depth, so that the lithology of the Deep Sand unit is primarily coarse-grained sand and fine-grained, pebbly conglomerate at its base. Where it can be distinguished, the upper contact of the Deep Sand unit occurs at depths of 68 to 110 feet bgs, and the base of the unit occurs at depths of 116 to 132 feet bgs (Figures 3.4-2 through 3.4-4). However, as noted, the Intermediate Clay does not appear to be present beneath the northern part of the 800 Area, and the upper contact of the Deep Sand unit is gradational with the base of the Intermediate Sand unit in this area. The Deep Sand unit ranges in thickness from 15 to 45 feet, with an average thickness of 32 feet.

The Red River Alluvium beneath Site SS-45 is underlain by sediments of probable Miocene age. The top of the Miocene clay/sand unit was identified at depths of 116 to 132 feet bgs in the few borings that completely penetrated the overlying Red River Alluvium. The top of the Miocene section represents an erosional unconformity created between Miocene and Pleistocene times, with subsequent deposition of the overlying Red River alluvial sediments occurring during the Pleistocene epoch. The few data available from the Base show little relief on the Miocene surface.

Although the upper surface of the Miocene-age deposits was encountered in several borings, borings were not advanced more than a few feet into Miocene strata during the RFI investigation (LAW, 1998a) or during drilling activities completed during the current CMS investigation. As a consequence of the termination of drilling whenever the Miocene

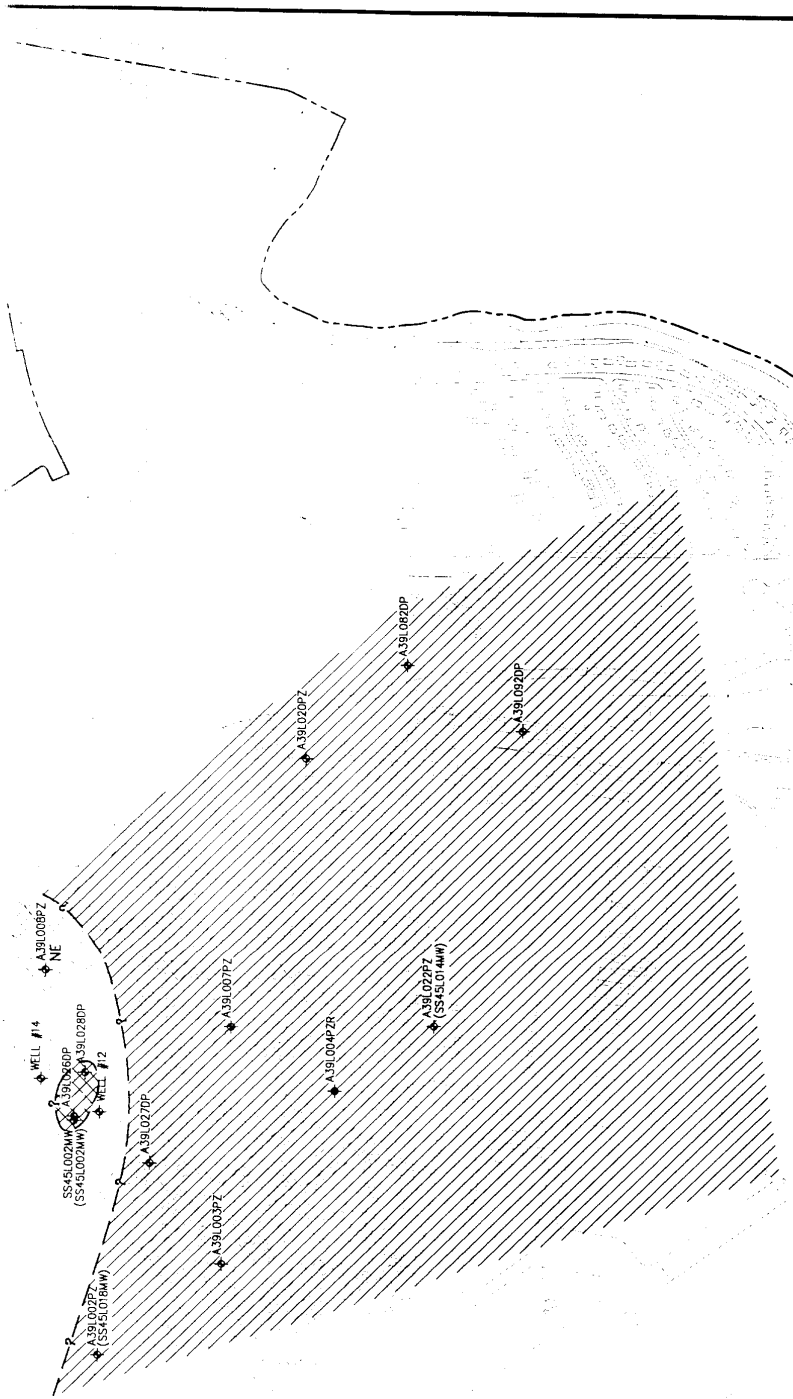
FIGURE 3.4-5
EXTENT OF THE
INTERMEDIATE CLAY

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS



LEGEND
PRESENCE OF INTERMEDIATE CLAY



deposits were encountered, the lithology and thickness of these materials beneath Site SS-45 are not known. Where they were encountered, the Miocene deposits consisted of primarily greenish-gray silt and clay, with a greenish-gray sand encountered at the upper contact of the Miocene deposits in a few borings.

3.4.2 Site Hydrogeology

The differences in physical properties (grain size, degree of sorting, clay content) of the hydrostratigraphic units at Site SS-45 affect their hydraulic characteristics, and consequently affect the local hydrogeology. Most groundwater occurs in the coarse-grained, sandy units (the Intermediate and Deep Sand units), with the fine-grained, or clay-rich strata functioning as confining units or aquitards.

Upper Silt/Clay. The upper silt/clay unit extends from ground surface to depths greater than 60 feet. Groundwater is generally encountered within the upper silt/clay unit at depths of about 5 to 10 feet bgs. Laboratory measurements of vertical hydraulic conductivity (Appendix A) conducted by LAW (1998a) on samples collected from three locations within the upper silt/clay unit ranged from 8×10^{-8} to 4×10^{-6} feet per minute (ft/min) (equivalent to 1×10^{-4} to 6×10^{-3} feet per day [ft/day]). *In situ* tests of horizontal hydraulic conductivity (well-displacement, or "slug" tests) conducted within the upper silt/clay unit during previous investigations were unsuccessful, because the hydraulic conductivity of the upper silt/clay unit was too low to be measured using well-displacement techniques (LAW, 1998a). Based on the nature of the materials that comprise the unit and the slow recharge to monitoring wells installed within the unit, the horizontal hydraulic conductivity of the upper silt/clay unit is anticipated to be about 1×10^{-5} to 1×10^{-3} ft/day (Wolff, 1982).

The relatively low hydraulic conductivity of the upper silt/clay unit suggests that it may function to some degree as a confining stratum for the underlying Intermediate Sand unit. This is confirmed by observations of water levels during drilling at some locations. When groundwater is first encountered in the Intermediate Sand unit, it may on occasion rise several feet higher than the initial water level in the borehole, stabilizing at some level within the confining unit.

Horizontal hydraulic gradients within the upper silt/clay unit are extremely low, and vary locally with no clear direction. The only information regarding vertical hydraulic gradients in the upper silt/clay unit has been obtained from wells A39L001BH and BKGL039MW, which are screened from 3 to 13 feet bgs and 11 to 16 feet bgs, respectively. Water levels measured in well A39L001BH were approximately 0.3 to 1.2 feet higher than water levels in well BKGL039MW (Appendix A). Based on the low hydraulic conductivity of the upper silt/clay unit, the negligible horizontal hydraulic gradients, and the limited data demonstrating a vertically-downward gradient in this unit, lateral groundwater flow is anticipated to occur at very low rates and over a limited distance, and the principal component of groundwater movement in the upper silt/clay will be downward. With a downward flowpath, groundwater likely enters the underlying Intermediate Sand unit after having traveled only a short lateral distance (probably tens of feet or less) in the upper silt/clay unit. The limited lateral extent of CAHs in the upper silt/clay unit, and the apparent occurrence of vertical migration of chemicals through the

upper silt/clay into the Intermediate Sand unit at Site SS-45 support this hydrogeologic interpretation.

Intermediate and Deep Sand Units. The Intermediate Sand unit underlies the upper silt/clay, and consists of a relatively uniform stratum of silty, fine-grained sand, extending through depths of about 40 to 80 feet bgs beneath Site SS-45, with an average thickness of about 40 feet. The Deep Sand unit extends from depths of about 90 to greater than 120 feet bgs (Figures 3.4-2 and 3.4-3), and averages about 20 feet in thickness. Beneath much of England AFB, the Intermediate Sand unit is separated from the underlying Deep Sand unit by the intervening Intermediate Clay unit; however, beneath the northern part of the 800 Area the Intermediate Clay apparently is not present, and the Intermediate Sand grades into the Deep Sand unit, with the two different stratigraphic intervals comprising a single hydrostratigraphic unit in that area. The clastic material of the Intermediate and Deep Sand units ranges in texture from fine- to coarse-grained sand with some gravel, and the two units contain relatively little clay or other fine-grained material. Consequently, the hydraulic conductivity of the Intermediate and Deep Sand units is expected to be much greater than that of the upper silt/clay unit (Wolff, 1982). Most groundwater within the Red River Alluvial system occurs within and moves through the sands.

Three samples collected from the Intermediate Sand unit during the RFI, and three samples from the Deep Sand unit, were analyzed in a geotechnical laboratory for bulk density, total porosity, and effective porosity (LAW, 1998a). The results of laboratory analyses of geotechnical properties are summarized in Appendix A. The mean bulk density of the samples from the Intermediate Sand unit was 1.63 grams per cubic centimeter (g/cm^3); the mean total porosity was 37.3 percent, and the mean effective porosity was 27.6 percent (Table 3.4-1). The mean bulk density of samples from the Deep Sand unit was 1.74 g/cm^3 ; the mean total porosity was 34.9 percent, and the mean effective porosity was 17.0 percent. The samples from the Deep Sand unit displayed a greater range in effective porosity than those from the Intermediate Sand unit, probably due to greater variability in the textures of the samples.

Well-displacement ("slug") tests were completed during the RFI (LAW, 1998a) in 12 wells completed in the Intermediate Sand unit, and in 5 wells completed in the Deep Sand unit (Table 3.4-2). The hydraulic conductivity of the Intermediate Sand unit, estimated using the results of well-displacement tests, ranged from 1.1×10^{-4} ft/min (0.16 ft/day) to 2.4×10^{-2} ft/min (about 35 ft/day) with a geometric mean value of 2.6×10^{-3} ft/min (3.7 ft/day) and a median value of about 5.5 ft/day. Assuming an average 40-foot saturated thickness for the Intermediate Sand unit, these values of hydraulic conductivity correspond to a median value for transmissivity of the Intermediate Sand unit (hydraulic conductivity multiplied by saturated thickness) of about 220 feet squared per day (ft^2/day), with a maximum value of about 1,400 ft^2/day . The hydraulic conductivity estimated for the Deep Sand unit ranged from 6.9×10^{-4} ft/min (one ft/day) to 1.4×10^{-2} ft/min (about 20 ft/day), with a geometric mean value of 6.4×10^{-3} ft/min (9 ft/day). These ranges of hydraulic conductivity are two to three orders of magnitude greater than the hydraulic conductivity of the upper silt/clay unit (preceding section), confirming that most groundwater (and associated dissolved-phase chemical; Appendix D) migration at Site SS-45 occurs in the Intermediate and Deep Sand units.

TABLE 3.4-1
REPRESENTATIVE GEOCHEMICAL PROPERTIES OF
SOIL SAMPLES FROM INTERMEDIATE AND DEEP SAND UNITS

SITE SS-45
ENGLAND AFB, LOUISIANA

Moisture Retention Tests

Boring Location	Sample Interval	Total Porosity (%)	Effective Porosity (%)	Bulk Density (g/cm ³) ^{a/}
Intermediate Sand Unit				
A39L097DP	79.5-81 ft	46.6*	0.7*	1.41*
SS45L001MW	59-60.5 ft	34.4	27.4	1.63
SS45L002MW	54-55.5 ft	37	27.7	1.64
Mean	--	35.7	27.6	1.64
Deep Sand Unit				
A39L022DP	113-115 ft	34.8	28.3	1.73
A39L097DP	107-108.5 ft	35.6	7.4	1.77
SS45L002MW	95-95.5 ft	37.6	15.2	1.72
Mean	--	36	17	1.74

^{a/} g/cm³ = grams per cubic centimeter.

*Results are suspect, sample may be silt or clay.
 After LAW (1998).

TABLE 3.4-2
HYDRAULIC CONDUCTIVITY ESTIMATED FOR
INTERMEDIATE AND DEEP SAND UNITS USING RESULTS
OF WELL-DISPLACEMENT TESTS
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Test Location	Hydraulic Conductivity (ft/day) ^{a/}	
	Slug In	Slug Out
Intermediate Sand Unit		
A39L009PZ	4.9	5.6
A39L010PZ	1.3	1.4
A39L011PZ	6.8	10.4
A39L012PZ	5.5	5.04
A39L013PZ	0.4	0.504
A39L018PZ	0.72	0.16
A39L021PZ	18.7	34.6
A39L036PZ	5.7	6.6
A39L039PZ	4.2	12.5
A39L073PZ	15.8	23.04
SS45L005MW	0.89	0.91
Deep Sand Unit		
A39L001PZ	9.8	11.5
A39L002PZ	NA ^{b/}	15.8
A39L008PZ	21.6	18.7
A39L022PZ	24.5	20.2
SS45L002MW	1.01	0.99

^{a/} ft/day = Feet per day.

^{b/} NA = Not available.

After LAW (1998).

Slug test results are usually taken to be "point" measurements applicable only to the specific interval tested, and not necessarily representative of the entire water-bearing thickness of the unit. The range of hydraulic conductivity values computed for the Intermediate and Deep Sand units is an indicator of the variation in lithologies of the screened intervals. High values are probably associated with wells completed in coarse-grained intervals, and low values are more likely to be associated with wells completed in finer-grained or silty intervals. In addition, the computed hydraulic conductivities are approximations of the magnitude of this parameter, and do not necessarily represent the actual hydraulic conductivity of the tested interval.

As part of the current investigation, Quantum Engineering Corporation, a subcontractor to Parsons ES, completed EBF testing of the Intermediate Sand unit to evaluate the vertical distribution of hydraulic conductivity in specific intervals within the unit (Section 2.3.1). Three, 2-inch-diameter wells (Wells #1, #2, and #10) were specifically constructed for EBF testing (Table 2.1-1 and Figure 2.1.2-1). Boreholes for the EBF test wells were drilled using percussion hammer equipment and methods, to prevent the introduction of drilling fluids or other material which could alter the natural hydraulic characteristics of the Intermediate Sand unit adjacent to the borehole. The screened intervals for the wells were extended through the upper clay/silt unit and the Intermediate Sand unit, and were terminated several feet into the Intermediate Clay. Because the unconsolidated sands of the Intermediate Sand unit flowed into the borehole immediately following withdrawal of the drill string, no artificial sand pack or formation stabilizer was used in constructing the wells, except for those sections of the screened intervals completed in the upper clay/silt unit. Well logs for each of these three wells are included in Appendix B.

Two EBF tests were conducted at each well: an ambient-flow test to evaluate whether vertical flow gradients were present in the formation, and an induced-flow test to assess the relative horizontal hydraulic conductivities between small (two-foot) vertical increments within the formation. During an ambient-flow test, the EBF probe is lowered to the bottom of the well to be tested, and hydraulic conditions are allowed to stabilize. The EBF probe is then slowly withdrawn from the well, and the rate of water movement past the probe is measured. After the measured flowrates are corrected to account for the movement of the probe up the wellbore, the remaining measured flowrate is attributed to the movement of water up (or down) the wellbore, in response to naturally-occurring gradient conditions. In an induced-flow test, the well is pumped at a low discharge rate as the EBF probe is withdrawn from the well, and differences in flowrates are noted at small incremental intervals as the probe moves up the wellbore. Increasing flow within an interval is attributed to a relatively greater hydraulic conductivity of the formation in that interval; decreasing flowrates occur as a result of relatively lower hydraulic conductivity. A complete report of the results of EBF testing in the Intermediate Sand unit was generated by Quantum Engineering Corporation and is included in Appendix B. The principal results the EBF tests are summarized below.

The results of ambient-flow tests indicated that virtually no groundwater entered the wells from the upper silt/clay unit. By contrast, groundwater entered the test wells from some intervals screened in the Intermediate Sand unit, and moved upward or downward in the wellbore, under the influence of vertical gradients existing between different

intervals within the Intermediate Sand unit. For example, in Well #1, groundwater appeared to enter the well at a depth of 60 feet bgs and moved upward and downward from that interval. Water moving upward from that interval exited the well at a depth of about 30 feet bgs (the contact at the base of the upper silt/clay unit); and water moving downward in the wellbore moved back into the Intermediate Sand unit at a depth of 70 to 75 feet bgs (Appendix B). Similar communication between different zones within the Intermediate Sand unit was observed during ambient-flow testing completed in Wells #2 and #10, indicating that vertical mixing of contaminants within the Intermediate Sand unit may be a component of dissolved contaminant migration.

No groundwater flow from the upper clay/silt unit into the wellbores was measured during induced-flow testing. All flow induced into the wellbores occurred from the Intermediate Sand unit. The relative hydraulic conductivities estimated for different intervals within the Intermediate Sand unit during induced-flow testing varied by a factor of five. In each of the three test wells, relative hydraulic conductivity was consistently higher in the lower part of the Intermediate Sand unit, and appeared to peak in the interval from 68 to 78 feet bgs (Appendix B). However, the variation in hydraulic conductivity is regarded as small, and indicates that the sands comprising the Intermediate Sand unit are relatively uniform, an observation verified by examination of borehole logs. Furthermore, although certain intervals of the Intermediate Sand unit display relatively greater permeability, the bulk hydraulic characteristics of the unit, at scales greater than the diameter of a wellbore, are also likely to be quite uniform. The Intermediate Sand unit is therefore regarded as homogeneous, with groundwater movement occurring through the entire saturated thickness of the unit, and little tendency for preferential movement to occur through more permeable intervals.

Specific capacity tests were completed at the end of induced flow tests by increasing the pumping rate and measuring the drawdown at each well. Well #1 was pumped at a rate of 6.5 gallons per minute (gpm); Well #2 was pumped at a rate of 7.1 gpm; and Well #10 was pumped at a rate of 11 gpm (Appendix B). Based on these tests, the average hydraulic conductivity in the Intermediate Sand unit varied from 3.8×10^{-2} to 3.2×10^{-1} ft/min (55 to 460 ft/day). However, the low discharge rates at which the wells were pumped during the tests probably did not sufficiently stress the Intermediate Sand unit aquifer to enable a realistic determination of transmissivity to be made (Driscoll, 1986). Accordingly these values of hydraulic conductivity are regarded as somewhat higher than the actual hydraulic conductivity of the Intermediate Sand unit.

Intermediate Clay Unit. Where present in the subsurface (Figure 3.4-5), the Intermediate Clay unit consists of a dark clay to silty clay, or clayey silt, lying between the Intermediate and Deep Sand units and ranging up to about 20 feet in thickness. Vertical hydraulic conductivities were determined in a laboratory for samples of the Intermediate Clay unit, collected from three locations during the RFI (LAW, 1998a). The vertical hydraulic conductivity values ranged from 3.8×10^{-8} to 1.2×10^{-7} centimeters per second (cm/s), equivalent to a range of about 0.0001 to 0.0003 ft/day. The horizontal hydraulic conductivity of this unit has not been evaluated, but based on the fine-grained nature of the materials that comprise the unit, the hydraulic conductivity of the Intermediate Clay is anticipated to be low (in the range of 1×10^{-8} to 1×10^{-6} cm/s according to Wolff, [1982]). The low vertical hydraulic conductivity of the Intermediate Clay

indicates that where present, the unit will restrict or prevent hydraulic communication between the Intermediate and Deep Sand units.

Groundwater Hydraulic Potential. The occurrence and movement of groundwater in the subsurface beneath Site SS-45 is generally controlled by local stratigraphy and groundwater hydraulic potential. Groundwater hydraulic potential in turn is affected to a certain extent by surface-water features (primarily the Red River). Because the Red River Alluvial Aquifer is in hydraulic communication with the Red River (Section 3.3.1), the general direction of groundwater movement and temporal water-level fluctuations in the Intermediate and Deep Sand units at Site SS-45 are probably a consequence of stage changes in the Red River. Periodic changes in river stage, occurring as a function of seasonal variation in river discharge, can produce significant temporal variability in groundwater flow directions, with no clearly-defined hydraulic gradient during some periods of time. For example, during low-stage periods, most groundwater movement along the Red River channel will be from the alluvial groundwater system into the river (the Red River "gains" from the groundwater system). During high-stage periods, the gradient is reversed, and water moves from the river into the subsurface, as the Red River discharges ("loses") to the alluvial groundwater system. These periodic fluctuations in stage, with consequent fluctuations in groundwater elevations, are capable of produce a groundwater potentiometric surface with no clearly-defined gradient(s), or with gradients that display temporal variation, possibly causing fluctuating or "oscillating" groundwater flow directions.

These trends are evident in the potentiometric surface of the Intermediate Sand unit at England AFB. Groundwater levels in the Intermediate Sand unit fluctuate over a range of 1.5 feet throughout the year (Table 3.4-3 and Figures 3.4-6 and 3.4-7). However, despite fluctuations in potentiometric elevations, the aspect of the potentiometric surface remains quite flat through time, with few if any well-defined groundwater flow direction(s). Depending on the season of measurement and location within Site SS-45, the hydraulic gradient within the Intermediate Sand unit, as determined from the potentiometric surface, ranges from less than 0.0001 feet per foot (ft/ft) to about 0.001 ft/ft (Table 4.3-4). Groundwater hydraulic gradients are steepest south of the 800 Area, and are flattest (nearly 0.000 ft/ft) in the 800 Area and 2500 Area, where no clearly-defined groundwater flow directions appear to exist.

Groundwater elevations in the Intermediate Sand unit are below the base of Le Tig Bayou and the Northern Ditch during most of the year, and about 15 to 30 feet of the Upper Silt/Clay unit is present between the base of Le Tig Bayou and the upper part of the Intermediate Sand unit. Hydraulic communication between Le Tig Bayou and the groundwater in the Intermediate Sand unit is therefore unlikely.

Potentiometric surfaces of the groundwater within the Deep Sand unit could not be constructed due to the lack of sufficient groundwater measuring points; currently only 19 wells have been completed in the Deep Sand unit, and the majority of those are located near the 800 Area (Figure 1.3-6). Therefore, only groundwater elevations are presented on Figures 3.4-8 and 3.4-9. Nevertheless, groundwater elevation data are sufficient to demonstrate that the hydraulic gradient within the Deep Sand unit also is very low, and that groundwater flow directions within the Deep Sand unit are unclear.

TABLE 3.4-3
GROUNDWATER LEVELS MEASURED IN MONITORING WELLS
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Well/Borehole Identification	Measuring Point Elevation (feet, NGVD)*	Depth to Groundwater (3/10/99) (ft - bmp)	Groundwater Elevation (3/10/99) (feet, NGVD)	Depth to Groundwater (3/11/99-3/17/99) (ft - bmp)	Groundwater Elevation (3/11/99-3/17/99) (feet, NGVD)	Depth to Groundwater (3/18/99) (ft - bmp)	Groundwater Elevation (3/18/99) (feet, NGVD)	Depth to Groundwater (5/24/99) (ft - bmp)	Groundwater Elevation (5/24/99) (feet, NGVD)	Depth to Groundwater 7/14/1999 (ft - bmp)	Groundwater Elevation 7/14/1999 (feet, NGVD)
Intermediate Sand Unit											
WELL#1	83.44	6.78	76.66	6.70	76.74	6.52	76.92	7.88	75.56	NM	Abandoned
WELL#2	89.56	12.72	76.84	12.74	76.82	12.33	77.23	14.13	75.43	NM	Abandoned
WELL#3	87.78	10.86	76.92	10.89	76.89	10.41	77.37	12.39	75.39	10.39	77.39
WELL#4	88.20	11.25	76.95	11.24	76.96	10.86	77.34	12.68	75.52	10.86	77.34
WELL#5	84.73	7.82	76.91	7.66	77.07	7.53	77.20	9.03	75.70	7.52	77.21
WELL#6	82.65	6.04	76.61	6.06	76.59	5.78	76.87	7.11	75.54	5.79	76.86
Staff Gauge -- 1	73.26	0.90	72.36	0.90	72.36	0.90	72.36	NM	NM	NM	NM
WELL#7	90.39	13.84	76.55	13.64	76.75	13.51	76.88	14.90	75.49	13.56	76.83
WELL#8	90.54	NM	NM	NM	NM	NM	NM	NM	NM	15.84	74.70
WELL#10	87.25	10.23	77.02	9.59	77.66	9.57	77.68	12.08	75.17	NM	Abandoned
WELL#11	86.11	9.47	76.64	8.72	77.39	8.76	77.35	11.33	74.78	9.92	76.19
Staff Gauge -- 1	74.64	1.60	73.04	1.60	73.04	1.66	72.98	1.66	72.98	1.66	72.98
WELL#13	86.61	9.63	76.98	9.97	76.64	8.95	77.66	11.55	75.06	10.16	76.45
WELL#15	86.00	8.98	77.02	8.24	77.76	8.29	77.71	10.92	75.08	9.58	76.42
WELL#17	83.16	6.03	77.13	5.28	77.88	5.32	77.84	8.04	75.12	6.72	76.44
WELL#19	84.49	7.58	76.91	6.86	77.63	6.81	77.68	9.67	74.82	8.34	76.15
WELL#21	82.66	NM	NM	NM	NM	NM	NM	NM	NM	8.66	74.00
A39L005PZ	84.76	NM	NM	NM	NM	NM	NM	8.02	76.74	6.71	78.05
A39L006PZ	83.98	NM	NM	NM	NM	NM	NM	8.45	75.53	7.09	76.89
A39L008DP	82.68	5.80	76.88	5.07	77.61	5.08	77.60	7.79	74.89	6.45	76.23
A39L009DP	83.38	NM	NM	NM	NM	NM	NM	7.95	75.43	6.65	76.73
A39L010PZ	86.11	9.29	76.82	9.06	77.05	8.95	77.16	10.62	75.49	8.99	77.12
A39L011PZ	87.52	NM	NM	NM	NM	NM	NM	11.78	75.74	10.37	77.15
A39L012PZ	84.37	7.65	76.72	7.68	76.69	7.42	76.95	8.77	75.60	7.41	76.96
A39L013DP	84.07	NM	NM	NM	NM	NM	NM	8.81	75.26	7.5	76.57
A39L013PZ	85.43	NM	NM	NM	NM	NM	NM	10.10	75.33	8.78	76.65
A39L014DP	84.42	NM	NM	NM	NM	NM	NM	9.36	75.06	8.01	76.41
A39L014PZ	85.43	NM	NM	NM	NM	NM	NM	8.80	76.63	7.47	77.96
A39L015PZ	83.15	NM	NM	NM	NM	NM	NM	7.77	75.38	6.45	76.70
A39L016PZ	83.83	NM	NM	NM	NM	NM	NM	6.95	76.88	5.64	78.19
A39L017PZ	84.66	NM	NM	NM	NM	NM	NM	8.97	75.69	7.63	77.03
A39L018PZ	78.02	NM	NM	NM	NM	NM	NM	1.99	76.03	0.41	77.61
A39L019PZ	87.03	9.96	77.07	9.92	77.11	9.58	77.45	11.36	75.67	9.57	77.46
A39L021PZ	87.65	NM	NM	NM	NM	NM	NM	11.52	76.13	10.18	77.47
A39L036DP	82.68	NM	NM	NM	NM	NM	NM	6.88	75.80	5.56	77.12
A39L039DP	81.58	NM	NM	NM	NM	NM	NM	6.10	75.48	4.78	76.80
A39L073DP	83.73	NM	NM	NM	NM	NM	NM	7.97	75.76	6.64	77.09
BKGL039MW	83.35	NM	NM	NM	NM	NM	NM	7.46	75.89	6.12	77.23
SS45L001MW	82.42	NM	NM	NM	NM	NM	NM	7.28	75.14	5.96	76.46
SS45L005MW	84.75	NM	NM	NM	NM	NM	NM	8.67	76.08	7.33	77.42
Deep Sand Unit											
WELL#12	86.58	9.11	77.47	8.39	78.19	8.42	78.16	11.03	75.55	9.81	76.77
WELL#14	85.54	8.53	77.01	7.79	77.75	7.83	77.71	10.47	75.07	9.14	76.40
WELL#16	80.79	2.88	77.91	3.13	77.66	2.14	78.65	4.84	75.95	3.54	77.25
WELL#18	84.28	7.36	76.92	6.85	77.43	6.60	77.68	9.45	74.83	8.11	76.17
WELL#20	81.40	3.89	77.51	2.11	79.29	3.17	78.23	5.89	75.51	4.55	76.85
A39L001PZ	82.41	5.50	76.91	4.69	77.72	4.74	77.67	7.47	74.94	6.16	76.25
A39L002PZ	81.32	NM	NM	NM	NM	NM	NM	6.55	74.77	5.24	76.08
A39L003PZ	82.73	NM	NM	NM	NM	NM	NM	7.79	74.94	6.45	76.28
A39L004PZR	84.54	NM	NM	NM	NM	NM	NM	9.43	75.11	8.10	76.44
A39L007PZ	84.03	NM	NM	NM	NM	NM	NM	8.83	75.20	7.48	76.55
A39L008PZ	84.42	7.45	76.97	6.83	77.59	6.80	77.62	9.35	75.07	8.01	76.41
A39L020DP	87.18	NM	NM	NM	NM	NM	NM	11.87	75.31	10.47	76.71
A39L022PZ	85.55	NM	NM	NM	NM	NM	NM	10.31	75.24	8.96	76.59
A39L026DP	82.55	NM	NM	NM	NM	NM	NM	7.44	75.11	6.11	76.44
A39L027DP	82.9	NM	NM	NM	NM	NM	NM	7.91	74.99	6.58	76.32
A39L028DP	84.29	NM	NM	NM	NM	NM	NM	9.19	75.10	7.83	76.46
A39L082DP	86.35	9.61	76.74	9.35	77.00	9.19	77.16	11.12	75.23	11.12	75.23
A39L092DP	87.4	NM	NM	NM	NM	NM	NM	12.22	75.18	10.27	77.13
SS45L002MW	82.6	NM	NM	NM	NM	NM	NM	7.37	75.23	6.05	76.55

* NGVD = National Geodetic Vertical Datum of 1929.

ft - bmp = feet below measuring point (i.e. top of casing).

NM = Not measured.

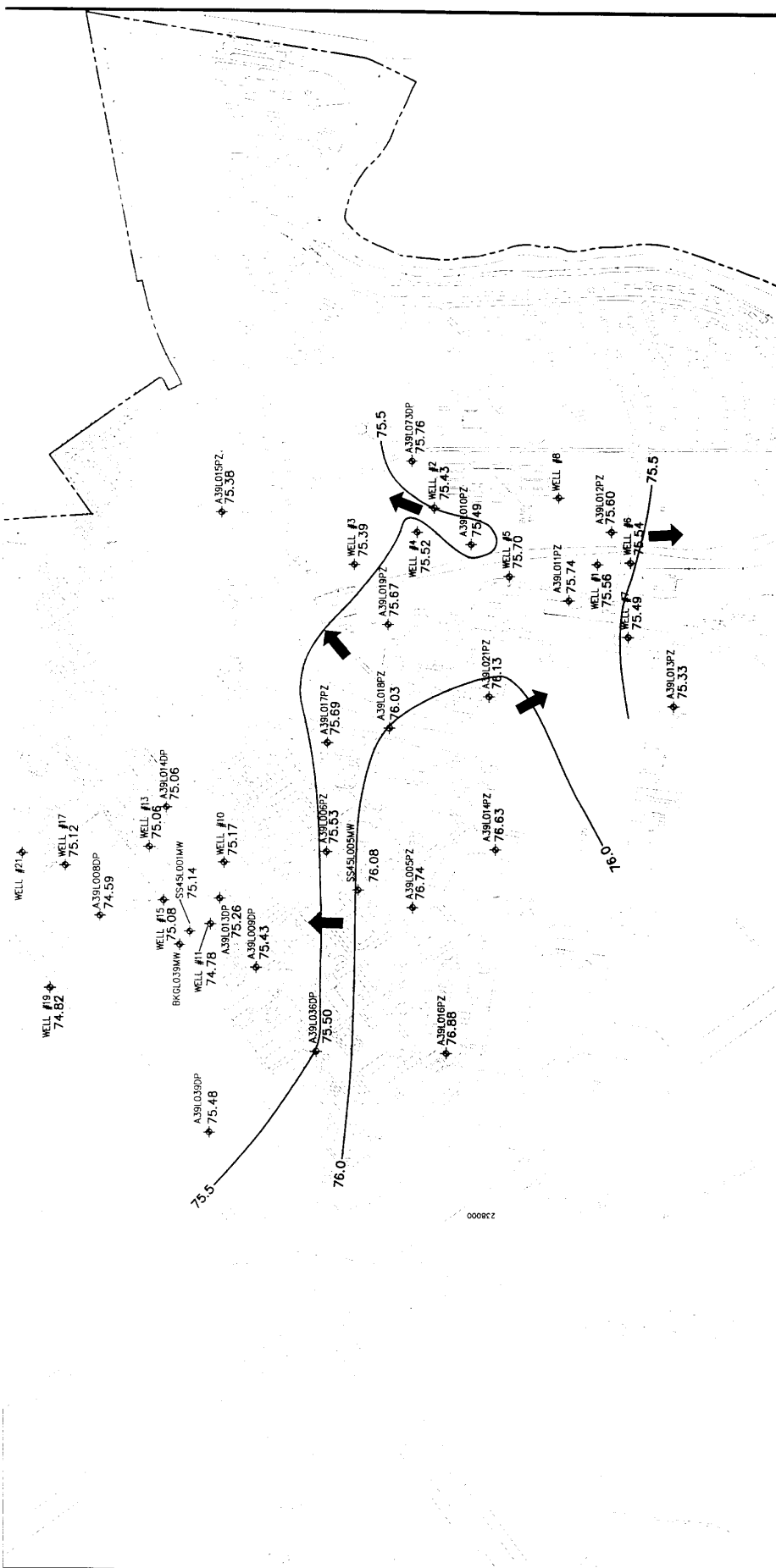


TABLE 3.4-4
HORIZONTAL HYDRAULIC GRADIENTS AND GROUNDWATER FLOW
VELOCITIES IN INTERMEDIATE SAND UNIT (JULY, 1999)

SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Flow Path Between Boreholes	Distance between		Hydraulic Gradient Between Wells (foot/foot)	Location-Specific Groundwater Flow Velocity ^{a/} (feet/day)	Generic Groundwater Flow Velocity ^{b/} (feet/day)
	Wells (feet)	Difference in Hydraulic Head (feet)			
SS45L005MW to SS45L001MW	1281.2	0.96	7.5E-04	NA ^{c/}	1.5E-02
SS45L005MW to WELL #13	1578.7	0.97	6.1E-04	NA	1.2E-02
SS45L001MW to WELL #19	1127.9	0.31	2.7E-04	NA	5.4E-03
WELL #13 to WELL #17	641.0	0.01	1.6E-05	NA	3.1E-04
A39L018PZ to WELL #3	1266.7	0.22	1.7E-04	5.6E-04	3.4E-03
A39L018PZ to WELL #4	1499.6	0.27	1.8E-04	5.8E-04	3.5E-03
A39L018PZ to WELL #5	1463.2	0.40	2.7E-04	9.3E-03	5.4E-03
A39L018PZ to A39L011PZ	1663.8	0.46	2.8E-04	1.2E-02	5.4E-03

^{a/} Location-specific groundwater velocity was calculated using average hydraulic conductivities (where available) from the area where the gradients were calculated, and an effective porosity of 0.28.

^{b/} Generic Groundwater flow velocities were calculated using the site median hydraulic conductivity of 5.5 feet/day, and an effective porosity of 0.28.

^{c/} NA = not

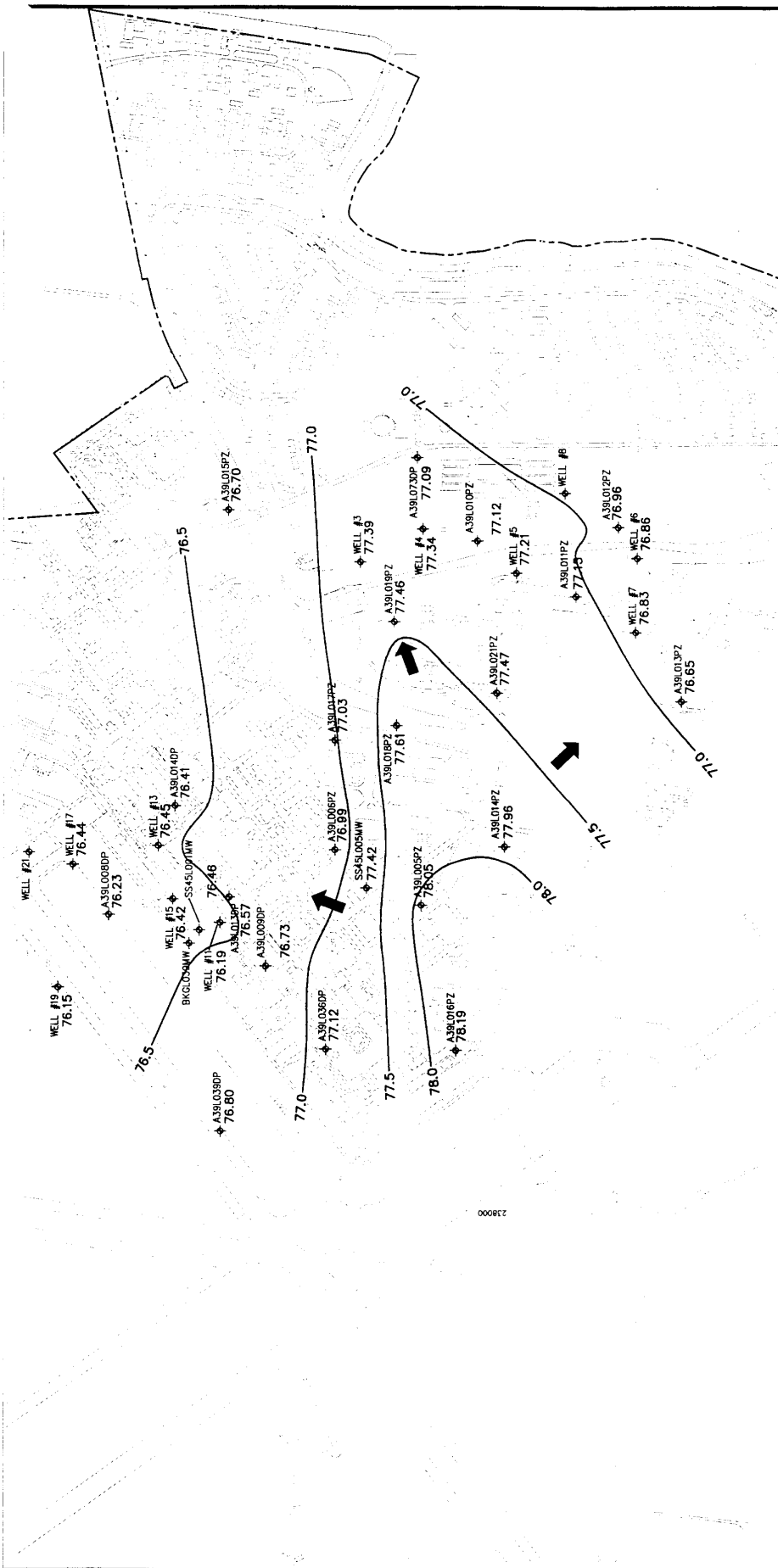


FIGURE 3.4-7
GROUNDWATER ELEVATIONS
MEASURED IN WELLS IN THE
INTERMEDIATE SAND UNIT
JULY 1999
 Site SS-45
 England Air Force Base
 Alexandria, Louisiana
PARSONS
 PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado
 3-21

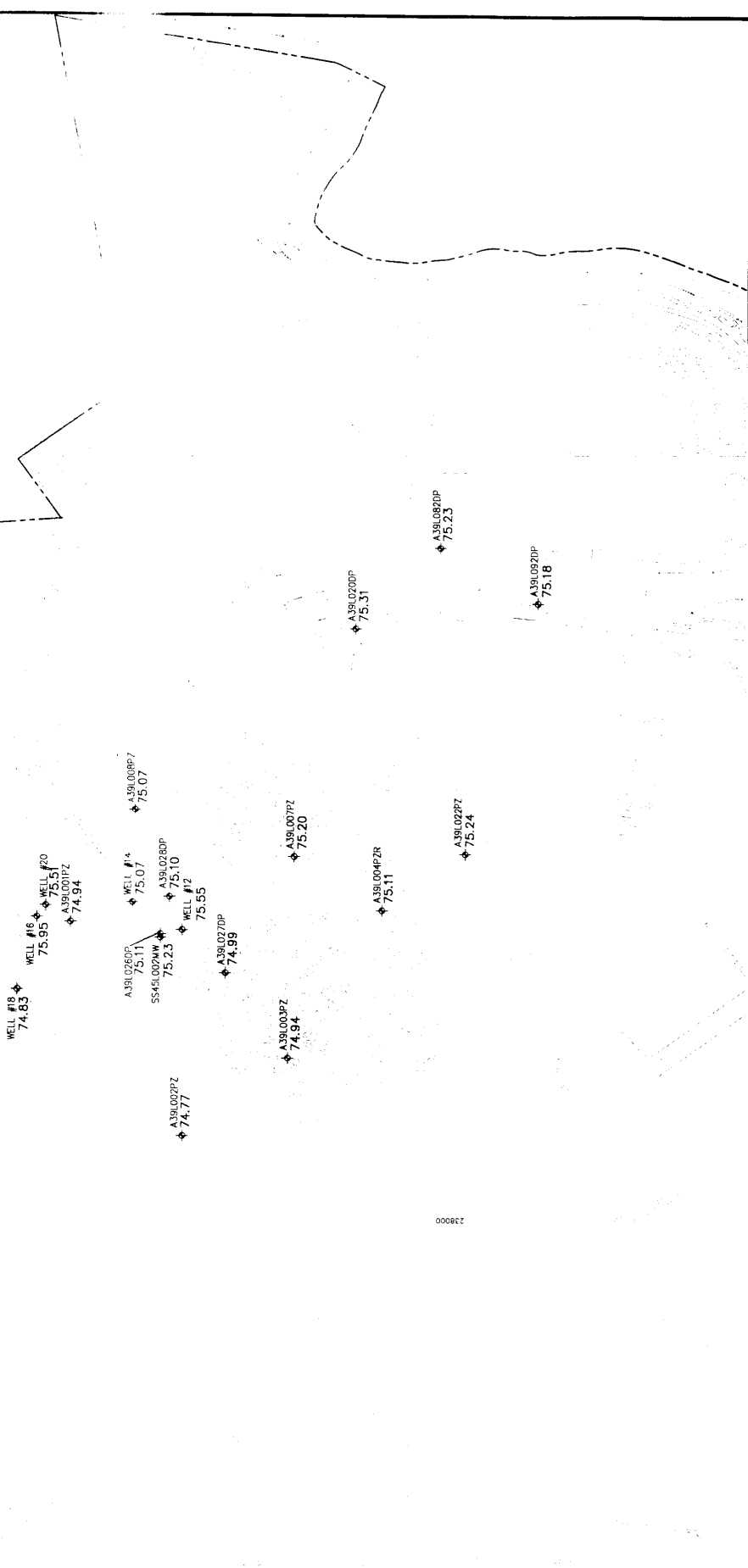
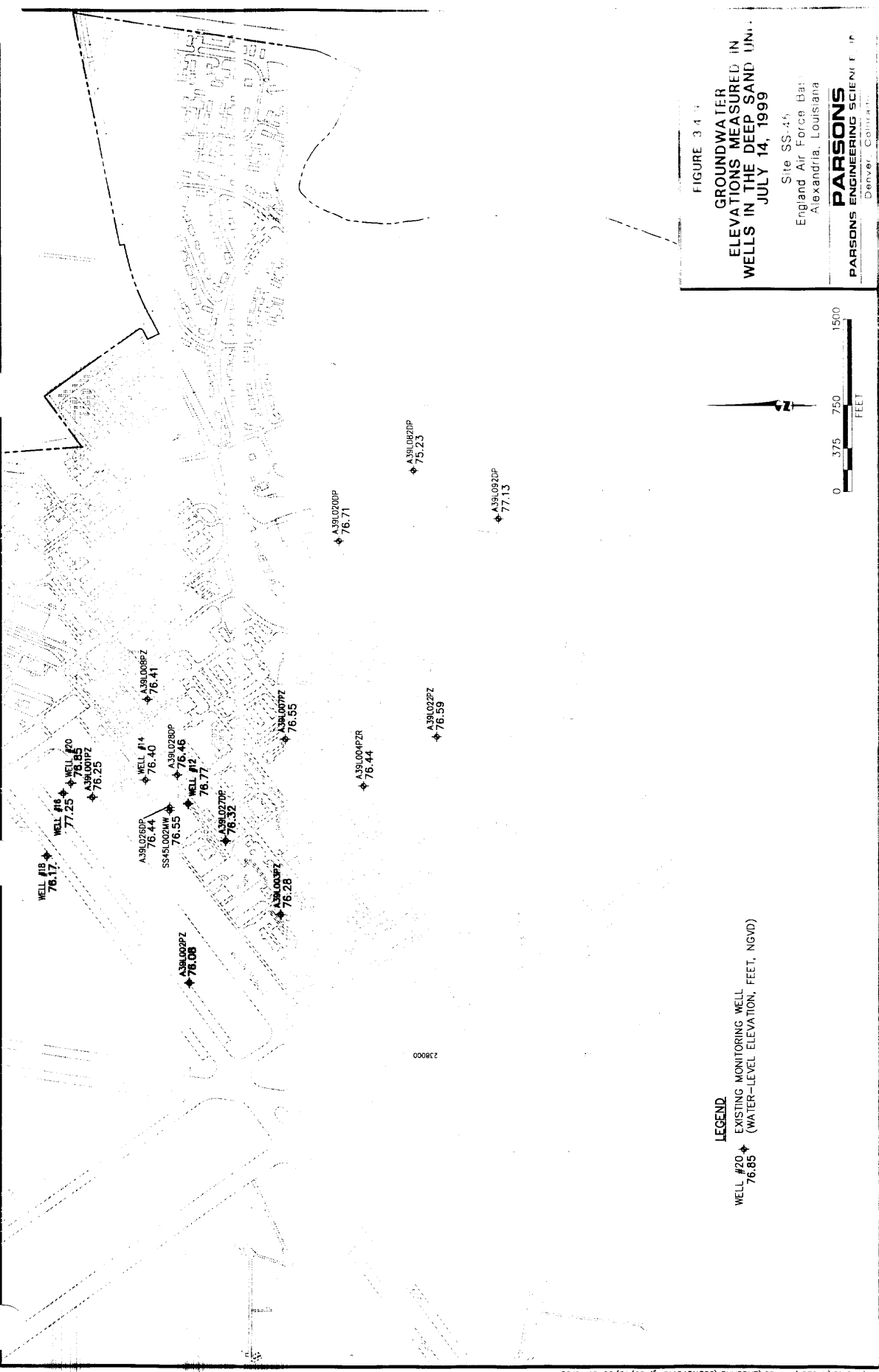


FIGURE 3.4-8
**GROUNDWATER
 ELEVATIONS MEASURED IN
 WELLS IN THE DEEP SAND UNIT
 MAY 24, 1999**
 Site SS-45
 England Air Force Base
 Alexandria, Louisiana
PARSONS
 PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado

LEGEND
 WELL #20 75.51
 EXISTING MONITORING WELL
 (WATER-LEVEL ELEVATION, FEET, NGVD)



S:\CS\cod\FCEE\730486\ENGLAND\9900767.dwg, 09/16/99 at 10:03



Groundwater Flow Velocities. The velocity of a "particle" of groundwater through a porous medium depends on the hydraulic conductivity, hydraulic gradient, and effective porosity of the saturated medium. The modified Darcy equation (Freeze and Cherry, 1979) was used to estimate groundwater particle flow velocities along selected flowpaths between wells in the 800 Area and 2500 Area at Site SS-45:

$$\bar{v} = \frac{K}{n_e} \times \frac{dh}{dl}$$

where:

$\bar{v}$ = average advective particle velocity (ft/day);

K = hydraulic conductivity (ft/day);

dh/dl = hydraulic gradient (ft/ft); and

n_e = effective porosity (dimensionless).

It is evident (Table 3.4-2) that estimates of the hydraulic conductivity of the Intermediate and Deep Sand units at Site SS-45, England AFB, vary spatially, even within the same unit. Where hydraulic conductivity values were available for an individual well on a groundwater flowpath, that value was used, together with the gradient between the two wells on the flowpath and an effective porosity of 0.28, to calculate the groundwater flow velocity along that flowpath (Table 3.4-4).

In order to apply estimates of hydraulic conductivity derived using "point" measurements over large areas (e.g., the entire 800 Area or 2500 Area), it is necessary to derive some type of "average" value of hydraulic conductivity. The median value of hydraulic conductivity for the Intermediate Sand unit was used in calculations, because unless the distribution of the underlying population (the value of hydraulic conductivity at every point in the subsurface at Site SS-45) is known to be Normal, use of the arithmetic mean to estimate the "average" value of a particular variable (e.g., hydraulic conductivity) is inappropriate (Rock, 1988; de Marsily, 1986). Rather, if the population distribution is not known, the median is statistically the most robust estimator of the "average" value (Rock, 1988, p. 86ff). Therefore, the median value of hydraulic conductivity was used to compute generic, "average" groundwater velocities (Table 3.4-4).

Using the median hydraulic conductivity value for the Intermediate Sand unit (5.5 ft/day), the values of hydraulic gradient along particular flowpaths, and an effective porosity of 0.28, the average linear advective groundwater particle velocities are estimated to range between 0.0003 ft/day and 0.015 ft/day within the Intermediate Sand unit. These velocities are extremely low, and are a consequence of the low (nearly flat) hydraulic gradients, existing at nearly every point within the Intermediate and Deep Sand units. It is emphasized that the average linear velocity does not necessarily equal the actual velocity of water moving between two particular points in the water-bearing unit. Furthermore, constituents dissolved in groundwater often migrate more slowly than the groundwater particle velocity, as a consequence of the effects of retardation (Appendix D).

Vertical Hydraulic Gradients. Several wells completed within the Deep Sand unit have been installed in close proximity to wells that are completed within the Intermediate Sand unit (e.g., wells SS45L001MW and SS45L002MW in the 800 Area; Figures 1.3-5 and 1.3-6). Such wells function as a well pair, enabling water levels to be measured and groundwater samples to be collected, in two different hydrostratigraphic intervals of the groundwater system at the same location. The differences in water-level elevations measured in the two adjacent wells provide an indication of the difference in hydraulic potential and consequent vertical hydraulic gradient between the Intermediate and Deep Sand units at that location.

Across most of Site SS-45, groundwater elevations in the Deep Sand unit are lower than or nearly equal to groundwater elevations in the Intermediate Sand unit (Table 3.4-3). The hydraulic potential ("head") difference is about 2 feet in the southern part of Site SS-45, and decreases to nearly zero toward the north and northwest. The range of hydraulic-potential differences may reflect the relative effectiveness of the Intermediate Clay unit in providing hydraulic separation between the Intermediate and Deep Sand units at different locations within Site SS-45.

Vertical hydraulic gradients were calculated for all Site SS-45 well pairs using water-level data collected in July 1999. The vertical distances between screen midpoints of well pairs, differences in potentiometric elevations between paired wells, and the calculated vertical gradients for July 1999 are listed in Table 3.4-5. The vertical gradient is taken to be the difference in groundwater elevations in the two wells divided by the vertical distance between the midpoints of the screened intervals. Negative values indicate downward gradients (recharge areas), and positive values indicate upward gradients (discharge areas). The relative sense of vertical hydraulic gradients (up and down) is presented on Figure 3.4-10, with upward gradients depicted in red and downward gradients in blue. In the northern part of Site SS-45 where the Intermediate Clay unit is absent, most well pairs exhibit slight upward gradients. However, a vertical gradient of 0.000 ft/ft exists between well pair A39L008PZ/A39L014DP, and the vertical gradient between Wells #14 and #15 is very slightly downward. Vertical hydraulic gradients are primarily downward at other locations within Site SS-45.

Although the vertical gradients are small, with absolute magnitudes ranging from 0.000 ft/ft to about 0.036 ft/ft, they are much larger than the horizontal hydraulic gradients in the groundwater system at Site SS-45, suggesting that in some areas of Site SS-45, vertical mixing may be an important component of groundwater and contaminant movement. Where the Intermediate Clay unit is absent beneath the 800 Area, the low, upwardly-directed hydraulic gradients indicate that groundwater movement will be primarily upward, from the Deep Sand unit to the Intermediate Sand unit. In other areas of Site SS-45, vertical hydraulic gradients are primarily downward, but the relatively thick Intermediate Clay unit should restrict hydraulic communication between the Intermediate and Deep Sand units in those locations.

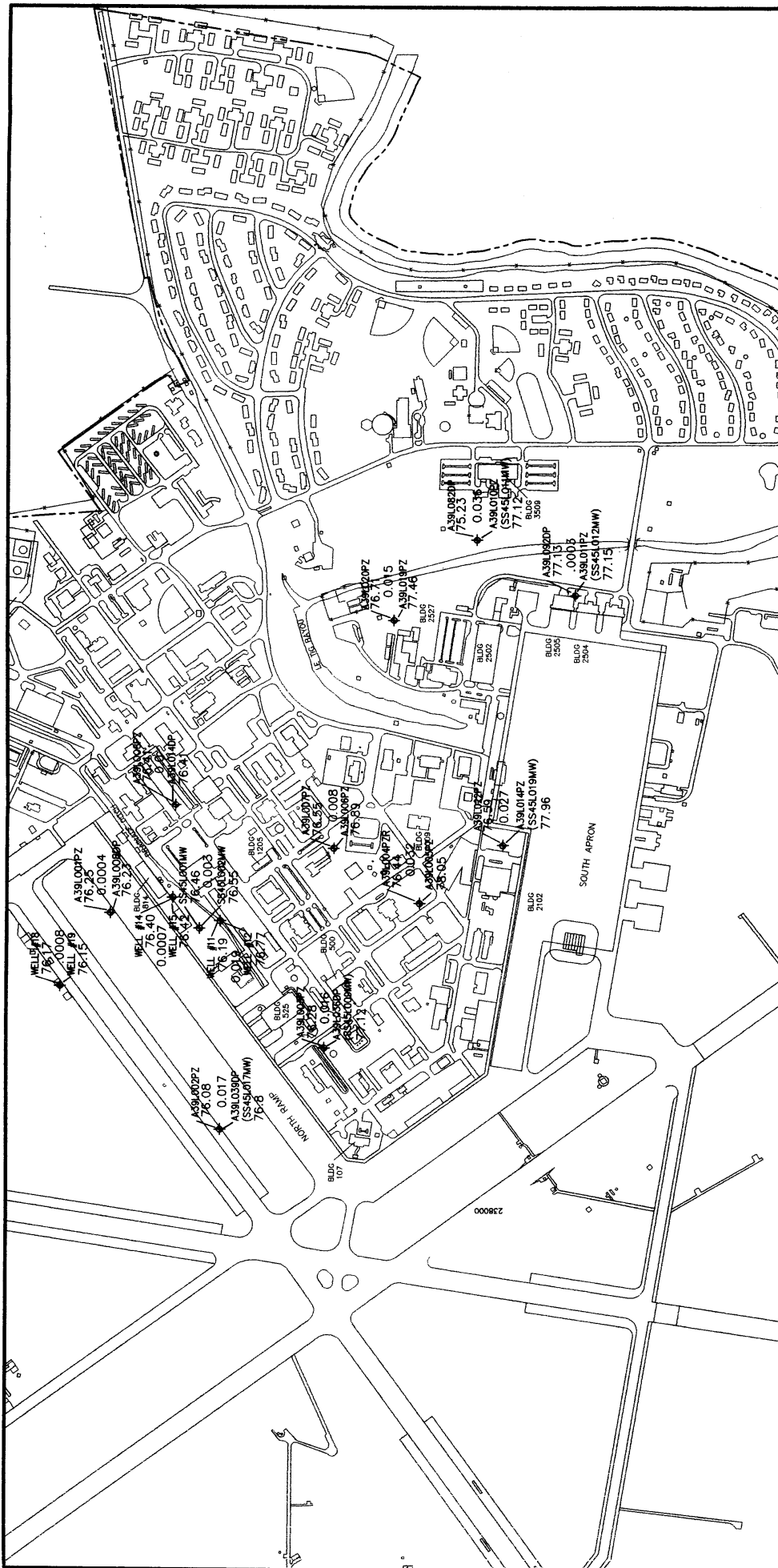
TABLE 3.4-5
CALCULATED VERTICAL HYDRAULIC GRADIENTS (JULY, 1999)
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Well Pairs	Water Level Elevation at Well 1 (feet, NGVD) ^a	Water Level Elevation at Well 2 (feet, NGVD)	Difference in Water Level Elevation Between Wells (feet)	Screen Midpoint Elevation at Well 1 (feet, NGVD)	Screen Midpoint Elevation at Well 2 (feet, NGVD)	Distance Between Screen Midpoints (feet)	Hydraulic Gradient (July 1999) (ft/ft) ^b
A39L0092DP - A39L011PZ	77.13	77.15	-0.02	118	45	73	-0.0003
A39L0082DP - A39L010PZ	75.23	77.12	-1.89	113	60	53	-0.036
A39L020PZ - A39L019PZ	76.71	77.46	-0.75	115	65	50	-0.015
A39L022PZ - A39L014PZ	76.59	77.96	-1.37	115	65	50	-0.027
A39L004PZR - A39L005PZ	76.44	78.05	-1.61	115	64	51	-0.032
A39L003PZ - A39L036DP	76.28	77.12	-0.84	115	63.5	51.5	-0.016
WELL #12 - WELL #11	76.77	76.19	0.58	95	65	30	0.019
WELL #14 - WELL #15	76.4	76.42	-0.02	95	65	30	-0.0007
A39L008PZ - A39L014DP	76.41	76.41	0.00	113	45	68	0.0
A39L002PZ - A39L039DP	76.08	76.8	-0.72	101	58.5	42.5	-0.017
WELL #18 - WELL #19	76.17	76.15	0.02	95	70	25	0.0008
A39L007PZ - A39L006PZ	76.55	76.89	-0.34	110	67	43	-0.008
SS45L002MW - SS45L001MW	76.55	76.46	0.09	94	59	35	0.003
A39L001PZ - A39L008DP	76.25	76.23	0.02	93	43	50	0.0004

^a NGVD = National Geodetic Vertical Datum.

^b ft/ft = foot per foot.

Note: Negative gradients indicate downward flow components and vice versa.



LEGEND

WELL #14 ♦ GROUNDWATER ELEVATION
76.40 (FEET, NGVD)

0.0077 ♦ DOWNWARD GRADIENT
(FOOT/FOOT)

0.0002 ♦ UPWARD GRADIENT
(FOOT/FOOT)

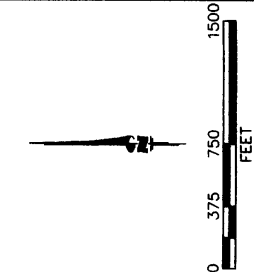


FIGURE 3.4-10
VERTICAL GRADIENT
BETWEEN INTERMEDIATE AND
DEEP SAND UNITS
JULY 14, 1999

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

SECTION 4

CONTAMINANT DISTRIBUTION AND EVIDENCE OF BIODEGRADATION

As noted in Section 1, the discontinuous distribution of CAH compounds in the subsurface at Site SS-45 indicates that multiple sources may have released chlorinated solvents to the upper silt/clay unit, and that the solvents eventually migrated vertically downward, entering groundwater within the Intermediate Sand unit. These releases may have originated at one or more suspected source areas at or near Buildings 814, 525, 2102, 2502, 2504, 2505 and 2527; other areas such as OTH-700, OTH-2000, OWSEP 2401; and/or industrial drain lines. No single, significant TCE release or source area has been identified.

Work completed in support of the RFI (LAW, 1998a) provided some information regarding the nature and extent of CAH compounds in groundwater at the site. The understanding of the occurrence and distribution of contaminants has been refined as a consequence of the RNA TS, completed in conjunction with the current CMS investigation. The following discussion of the nature and extent of groundwater contamination at Site SS-45 is based on the information collected in support of the focused CMS during the period from August 1998 through July 1999, and supplemented as appropriate using the results of previous investigations (LAW, 1998a). This section also includes a discussion of information useful for evaluating RNA of CAHs in site groundwater.

During field investigation activities completed by Parsons ES in support of this focused CMS, soil samples collected from two boreholes were analyzed for TOC and total iron content (Section 2.1); groundwater samples collected from 26 wells completed in the Intermediate Sand unit and from 12 wells completed in the Deep Sand unit were analyzed for VOCs, methane, ethane, ethene, chloride, ferrous iron, manganese, nitrate, sulfate, sulfide, dissolved organic carbon, carbon dioxide, total alkalinity, DO, ORP, temperature, specific conductance, and turbidity (Section 2.3); and groundwater samples collected from 14 wells completed in the Intermediate Sand unit and from 4 wells completed in the Deep Sand unit were analyzed for dissolved hydrogen (Section 2.3). Laboratory analytical results are provided in ERPIMS electronic format, as required by AFCEE, on a compact disk in Appendix C. These data are reviewed and interpreted in this section.

4.1 SOIL CHEMISTRY

4.1.1 Total Organic Carbon in Soil Samples

Concentrations of TOC in soil can be used to estimate the amount of organic matter sorbed to soil particles or trapped in the interstitial passages of a soil matrix. The TOC concentration in the saturated zone is an important parameter used to estimate the amount of contaminant that could potentially be sorbed to the aquifer matrix. Sorption of chemical mass results in retardation of contaminant plume migration relative to the average advective groundwater velocity. In addition, TOC can be used as a gross indicator of naturally-occurring organic material that is available as a source of carbon and electron donors (or substrate) to support microbial activity.

During the RFI (LAW, 1998a), soil TOC concentrations were measured in 21 soil samples collected from boreholes in the 800 Area and 2500 Area, and in parts of Site SS-45 not associated with the 800 or 2500 Areas (Table 4.1-1). During the current investigation, soil samples collected at 5-foot intervals from the boreholes for Wells #8 and #21 in the 2500 and 800 Areas, respectively (Appendix B), were analyzed for TOC using USEPA Method SW415.1 (Table 4.1-1 and Appendix C).

TOC concentrations detected in soil samples collected in the 800 Area (Table 4.1-1) ranged from not detected to 16,300 milligrams per kilogram (mg/kg). The highest TOC concentrations generally occurred in soil samples collected from the upper silt/clay interval in the borehole for Well #21; TOC concentrations show an abrupt decrease in samples collected from the Intermediate Sand unit, to concentrations about half those detected in the overlying upper silt/clay unit. The median TOC concentration in soil samples collected from the upper silt/clay unit was about 3,190 mg/kg (0.32 percent by weight), while the median TOC concentration in soil samples collected from the Intermediate Sand unit in the 800 Area was about 1,055 mg/kg (about 0.1 percent by weight). TOC concentrations detected in soil samples collected in the 2500 Area (Table 4.1-1) ranged from not detected to 6,060 mg/kg. Again, the highest TOC concentrations occurred in soil samples collected from the upper silt/clay interval in the borehole for Well #8, which had a median TOC concentration of about 2,740 mg/kg. By comparison, the median TOC concentration in soil samples from the Intermediate Sand unit was about 1,280 mg/kg, corresponding to about 0.13 percent by weight (Table 4.1-1).

4.1.2 Total Iron in Soil Samples

Ferric iron (Fe^{3+}) in an aquifer matrix can function as an electron acceptor for oxidation of VC, with ferrous iron generated as a reaction product (USEPA, 1998). Under the proper geochemical conditions, ferric iron in the soil matrix may be available for dissolution as the reduced species (ferrous iron, Fe^{2+}), which can function as an electron acceptor during biologically-mediated chemical reactions (subsequent section). Therefore, the total iron content in soil samples from the 800 and 2500 Areas was assessed, in order to provide a qualitative indication of the potential for *in situ* degradation of TCE and its daughter products through complete mineralization of VC (Appendix D).

TABLE 4.1-1
CONCENTRATIONS OF TOTAL ORGANIC CARBON AND TOTAL IRON IN SOIL SAMPLES
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Well/Borehole Identification	Depth Interval	Date Collected	Hydrogeologic Unit	Total Organic Carbon (mg/kg) ^a	Flag	Total Organic Carbon (wt fraction)	Total Iron (mg/kg)
Boreholes in 800 Area							
SS45L001MW	59.5 -- 60.0	6/1/1997	Intermediate Sand	ND ^b		< 0.00029	N/A ^c
SS45L002MW	94.5 -- 95.0	5/30/1997	Deep Sand	740		0.00074	N/A
Well #21	0.0 -- 5.0	7/12/1999	Upper Silt/Clay	2,770		0.00277	3.6
	5.0 -- 10.0	7/12/1999	Upper Silt/Clay	8,950		0.00895	4.3
	10.0 -- 15.0	7/12/1999	Upper Silt/Clay	16,300		0.0163	3.9
	15.0 -- 20.0	7/12/1999	Upper Silt/Clay	3,890		0.00389	4.1
	20.0 -- 25.0	7/12/1999	Upper Silt/Clay	3,190		0.00319	4.1
	25.0 -- 30.0	7/12/1999	Upper Silt/Clay	3,160		0.00316	3.8
	30.0 -- 35.0	7/12/1999	Upper Silt/Clay	2,870		0.00287	3.8
	35.0 -- 40.0	7/12/1999	Intermediate Sand	1,670	F ^d	0.00167	3.7
	40.0 -- 45.0	7/12/1999	Intermediate Sand	1,310	F	0.00131	3.7
	45.0 -- 50.0	7/12/1999	Intermediate Sand	1,300	F	0.0013	3.7
	50.0 -- 55.0	7/12/1999	Intermediate Sand	810	F	0.00081	3.6
	55.0 -- 60.0	7/12/1999	Intermediate Sand	712	F	0.000712	3.6
	60.0 -- 65.0	7/12/1999	Intermediate Sand	1,710	F	0.00171	3.7
	65.0 -- 70.0	7/12/1999	Intermediate Sand	1,570	F	0.00157	3.5
	70.0 -- 75.0	7/12/1999	Intermediate Sand	ND		< 0.00235	3.5
	75.0 -- 80.0	7/12/1999	Intermediate Sand	ND		< 0.00237	3.6
	80.0 -- 85.0	7/12/1999	Deep Sand (?)	880	F	0.00088	3.6
Boreholes in 2500 Area							
A39L010PZ	55.0 -- 57.0	9/9/1996	Intermediate Sand	1,000		0.001	N/A
A39L011PZ	45.0 -- 47.0	9/10/1996	Intermediate Sand	880		0.00088	N/A
A39L011PZ	45.0 -- 47.0	9/10/1996	Intermediate Sand	820		0.00082	N/A
A39L012PZ	63.0 -- 65.0	9/18/1996	Intermediate Sand	ND		< 0.0050	N/A
A39L012PZ	63.0 -- 65.0	9/18/1996	Intermediate Sand	ND		< 0.0050	N/A
A39L014PZ	63.0 -- 65.0	9/18/1996	Intermediate Sand	6,060		0.00606	N/A
A39L017PZ	63.0 -- 65.0	9/21/1996	Intermediate Sand	2,860		0.00286	N/A
A39L018PZ	43.0 -- 45.0	9/23/1996	Intermediate Sand	1,230		0.00123	N/A
A39L019PZ	63.0 -- 65.0	9/23/1996	Intermediate Sand	994		0.000994	N/A
A39L020PZ	90.0 -- 92.0	10/3/1996	Deep Sand	820		0.00082	N/A
A39L021PZ	63.0 -- 65.0	9/23/1996	Intermediate Sand	ND		< 0.0050	N/A
A39L073DP	72.0 -- 74.0	9/6/1996	Intermediate Sand	3,000		0.003	N/A
A39L092DP	114.0 -- 116.0	9/8/1996	Deep Sand	1,600		0.0016	N/A
Well #8	0.0 -- 5.0	7/13/1999	Upper Silt/Clay	2,340		0.00234	3.4
	5.0 -- 10.0	7/13/1999	Upper Silt/Clay	3,140		0.00314	3.5
	10.0 -- 15.0	7/13/1999	Upper Silt/Clay	5,250		0.00525	3.9
	15.0 -- 20.0	7/13/1999	Upper Silt/Clay	ND		< 0.00252	3.8
	20.0 -- 25.0	7/13/1999	Upper Silt/Clay	1,500		0.0015	3.8
	25.0 -- 30.0	7/13/1999	Upper Silt/Clay	4,710		0.00471	4.0
	30.0 -- 35.0	7/13/1999	Upper Silt/Clay	3,960		0.00396	3.9
	35.0 -- 40.0	7/13/1999	Upper Silt/Clay	4,480		0.00448	4.1
	40.0 -- 45.0	7/13/1999	Upper Silt/Clay	1,390	F	0.00139	3.8
	45.0 -- 50.0	7/13/1999	Upper Silt/Clay	1,950	F	0.00195	3.8
	50.0 -- 55.0	7/13/1999	Intermediate Sand	2,950		0.00295	4.1
	55.0 -- 60.0	7/13/1999	Intermediate Sand	ND		< 0.00257	3.9
	60.0 -- 65.0	7/13/1999	Intermediate Sand	1,280	F	0.00128	3.8
	65.0 -- 70.0	7/13/1999	Intermediate Sand	720	F	0.00072	3.8
	70.0 -- 75.0	7/13/1999	Intermediate Sand	2,810		0.00281	3.8
	75.0 -- 80.0	7/13/1999	Intermediate Sand	3,010		0.00301	3.8
Other Boreholes							
A39L013PZ	63.0 -- 65.0	9/18/1996	Intermediate Sand	ND		< 0.0050	N/A
A39L015PZ	63.0 -- 65.0	9/21/1996	Intermediate Sand	603		0.000603	N/A
A39L016PZ	63.0 -- 65.0	9/21/1996	Intermediate Sand	ND		< 0.0050	N/A
A39L022PZ	115.0 -- 117.0	10/5/1996	Deep Sand	ND		< 0.0050	N/A
A39L022PZ	115.0 -- 117.0	10/5/1996	Deep Sand	ND		< 0.0050	N/A
SS45L005MW	53.0 -- 55.0	6/10/1997	Intermediate Sand	640		0.00064	N/A

^a mg/kg = milligrams per kilogram.

^b ND = Not detected.

^c N/A = Not analyzed.

^d F = The analyte was positively identified, but the associated value is below the reporting limit.

Ferric iron (occurring as oxy-ferrihydroxide) is nearly insoluble, and generally remains sorbed to soil; depending on local mineralogy, determination of total iron content in soil samples can therefore be an indicator of the content of ferric iron in soil. The soil samples collected from the boreholes for Wells #8 and #21 were analyzed for total iron using Method SW6010A (Table 4.1-1 and Appendix C). Concentrations of total iron detected in soil samples collected in the 800 Area (Table 1.4-1) fell within a very narrow range (3.5 to 4.3 mg/kg). The concentrations of total iron in soil samples collected in the 2500 Area were within the same general range (3.4 to 4.1 mg/kg). There was no apparent difference in concentrations of total iron among samples collected from the upper silt/clay unit and the Intermediate and Deep Sand units.

Iron speciation (ferric/ferrous iron) was not conducted during analyses of soil samples for total iron. However, the ubiquitous detection of dissolved (ferrous) iron in groundwater samples collected at Site SS-45, at concentrations ranging to several milligrams per liter (mg/L; Section 4.5.6.3) indicates that at least some of the iron in soil at Site SS-45 is available for dissolution, and is probably ferric iron.

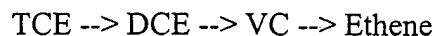
4.2 OVERVIEW OF CAH BIODEGRADATION MECHANISMS

Mechanisms for RNA of CAHs include biodegradation, dispersion, dilution from recharge, sorption, and volatilization. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. Intrinsic bioremediation occurs when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. A detailed review of the major bioremediation processes that act upon CAHs is provided in Appendix D, and summarized briefly in this subsection.

Microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous reduction/oxidation (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors may be natural organic carbon, fuel hydrocarbon compounds, and less-chlorinated solvents (e.g., VC, DCE, or DCA). Fuel hydrocarbons or solvents are completely degraded or detoxified if they are utilized as the primary electron donor (i.e., as a primary substrate or carbon source) for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states, and may include oxygen, nitrate, ferric iron, sulfate, manganese, carbon dioxide, and highly chlorinated solvents (e.g., PCE, TCE, TCA).

Microorganisms preferentially utilize electron acceptors while metabolizing hydrocarbon substrates (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors in the following order of preference: nitrate, manganese, ferric iron hydroxide, sulfate, and finally carbon dioxide. CAHs generally are used as electron acceptors when aquifer conditions favor sulfate reduction or methanogenesis (i.e., where carbon dioxide is the preferred electron acceptor).

Halogenated compounds are known to undergo chemical transformations, or degradation, in natural systems principally through the mechanism of sequential reductive dehalogenation under anaerobic conditions (Vogel and McCarty, 1985; Vogel *et al.*, 1987; Lesage *et al.*, 1990; Barbee, 1994). During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom at each reaction step (Criddle and McCarty, 1991). A typical reductive halogenation transformation sequence begins with a highly chlorinated alkene such as TCE (Figure 4.2-1 and Appendix D). Through sequential reductive reactions, TCE is first transformed to 1,1-DCE or to either the *cis*- or *trans*- isomer of 1,2-DCE. DCE isomers are then transformed to VC. In the final reductive dehalogenation step, VC is mineralized to ethene and then to carbon dioxide, water, and hydrogen chloride. Minor amounts of other chlorinated chemicals (e.g., 1,1-DCA) can also be generated during reductive dehalogenation reactions; however, the sequence



is most typical (Vogel *et al.*, 1987; Barbee, 1994). The relative proportions of TCE and its daughter products, and the locations at which these chemicals have been detected in groundwater at Site SS-45, indicate that TCE was the primary chemical originally introduced to the subsurface, and the other halogenated chemicals have gradually appeared as the parent TCE has degraded (Figure 4.2-1).

In addition to being controlled by the energy yield of the reaction, the expected sequence of redox processes also is a function of the oxidizing potential of the groundwater. This potential is a measure of the relative tendency of a solution or chemical reaction to accept or transfer electrons. As each subsequent electron acceptor is utilized in microbially-mediated redox reactions, the groundwater becomes more reducing, and the ORP of the water decreases. ORP can be used as an indicator of which redox reactions may be operating at a particular site. Environmental conditions and microbial competition ultimately determine which processes will dominate.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, sulfate, carbon dioxide), pH conditions, and ORP, anaerobic biodegradation can occur by denitrification, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese or nitrate reduction may dominate if the physical and chemical conditions in the subsurface favor use of alternate electron acceptors. Vroblesky and Chapelle (1994) show that the dominant terminal-electron-accepting process can vary both temporally and spatially in an aquifer that contains dissolved CAHs.

In a pristine aquifer, native organic carbon is utilized as an electron donor, and DO is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or less-chlorinated CAHs) is present, it also may be utilized as an electron donor. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distributions of these electron acceptors can provide evidence of where and how biodegradation of chlorinated

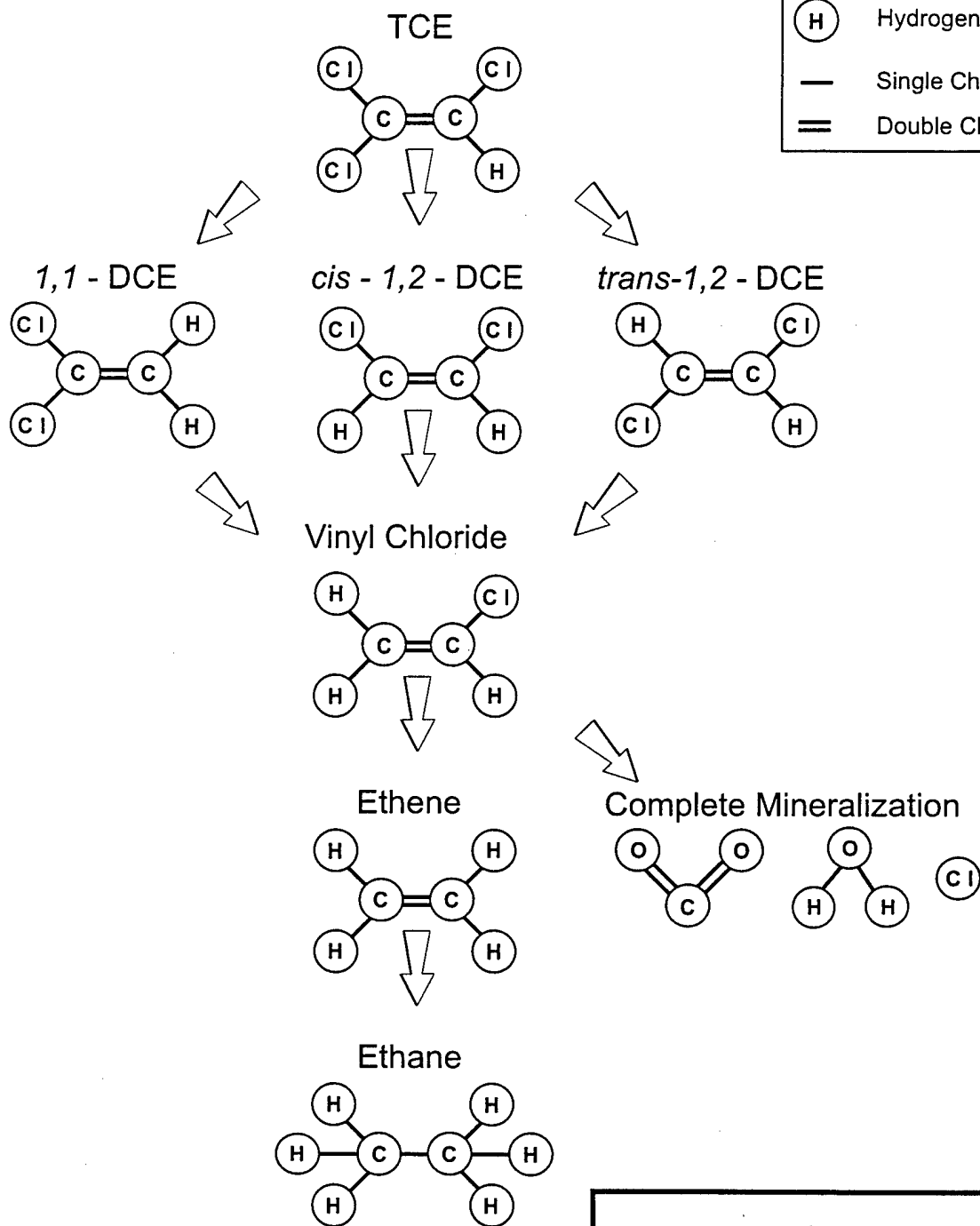


FIGURE 4.2-1
REDUCTIVE
DEHALOGENATION OF
CHLORINATED ETHENES

Site SS-45
England Air Force Base
Alexandria, Louisiana

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solvents is occurring. In addition, because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of these compounds also will provide evidence of the types of biodegradation processes acting at a particular site.

4.3 DISTRIBUTION OF CAHS IN GROUNDWATER AT SITE SS-45

One of the most straightforward methods of evaluating the occurrence and specific biodegradation processes of CAHs is to examine the distribution of parent CAHs and their spatial and temporal relationship(s) to degradation products. At the same time, it is also useful to examine the spatial distribution of native organic carbon or other contaminants (e.g., BTEX) that may be acting as sources of electron donors.

Because reductive dehalogenation is the most commonly occurring biodegradation reaction, a typical pattern (e.g., as presented by Vogel, 1994) would have TCE concentrations highest near the chemical source area, with elevated DCE concentrations (consisting mostly of *cis*-1,2-DCE) within and just downgradient from (or surrounding) the source area. VC concentrations could be present throughout the CAH plume, with the highest VC concentrations likely to be found in areas that are neither strongly reducing or oxidizing. If VC is being degraded via reductive dehalogenation processes, dissolved ethene also will be present downgradient from (or surrounding) the source area in the vicinity of the highest VC concentrations. The degree to which this pattern is observed at Site SS-45 is evaluated in this section.

The groundwater sampling events conducted by Parsons ES during the period from February 3, 1999 through July 21, 1999 represent the most comprehensive monitoring record available for Site SS-45, in that groundwater samples were collected from a greater number of wells, providing more detailed information over a larger area, than during previous events. Groundwater samples collected in March 1999 from 23 monitoring wells completed in the Intermediate Sand unit, and from 13 wells completed in the Deep Sand unit, were analyzed for VOCs, dissolved methane, ethane, and ethene, and inorganic constituents (Section 2). Groundwater samples collected in May 1999 from 14 monitoring wells completed in the Intermediate Sand unit and from 4 wells completed in the Deep Sand unit were analyzed for dissolved hydrogen. Groundwater samples collected in July 1999 from Wells #8 and #21 (the final two wells installed in the Intermediate Sand unit) were analyzed for VOCs, dissolved methane, ethane, and ethene, and inorganic constituents. The results of sampling are discussed in the following subsections, and plots of distributions of constituents are provided in Section 4.4 and Appendix E.

4.3.1 Extent of Trichloroethene in the Intermediate Sand Unit

4.3.1.1 800 Area

TCE has historically been the CAH compound most frequently detected in groundwater samples from the Intermediate Sand unit in the 800 Area (Section 1.3, Appendix A, and Figures 1.3-9, 1.3-14, and 1.3-15). The previously observed extent and magnitude of TCE concentrations in groundwater were generally confirmed by the results

of the 1999 investigation. TCE was detected in samples from seven wells completed in the Intermediate Sand unit at concentrations ranging from 0.2J to 560 µg/L (Table 4.3-1 and Appendix E). The highest concentration of TCE (560 µg/L) was detected in the sample from well SS45L001MW, completed in the Intermediate Sand unit from 54 to 64 feet bgs near the center of the 800 Area (Figure E.1, Appendix E). Four other Intermediate Sand wells in which TCE was detected in groundwater samples are located in the 800 Area in the general vicinity of monitoring well SS45L001MW (Table 4.3-1).

TCE was also detected at a concentration of 9.8 µg/L in the groundwater sample collected from Well #17 in March 1999 (Figure E.1, Appendix E). This well was originally installed to establish the northernmost extent of CAH compounds in groundwater of the Intermediate Sand unit within the 800 Area. Accordingly, Parsons ES installed and sampled Well #21 in July 1999 to better define the northern boundary of the 800 Area plume. TCE was detected at this well at a concentration of 0.19J µg/L. This extremely low concentration of TCE suggests that Well #21 represents the northernmost extent of TCE in the Intermediate Sand unit at the 800 Area.

4.3.1.2 2500 Area

Since 1996, TCE has been detected at only three Intermediate Sand unit groundwater sampling locations in the 2500 Area at Site SS-45 (Figures 1.3-9, 1.3-14, 1.3-15, and 4.3-1). TCE was detected at concentrations of 0.2J µg/L in the samples collected in March 1999 from Wells #2 and #8 (Figure E.1, Appendix E).

4.3.2 Extent of Trichloroethene in the Deep Sand Unit

TCE has historically been detected in a limited number of Deep Sand unit groundwater samples. All detections in this unit have been in groundwater samples from wells in the 800 Area at Site SS-45 (Figures 1.3-12, 1.3-16, and 1.3-17 and Appendix A). Well SS45L002MW is completed in the Deep Sand unit at 89 to 99 feet bgs, about 25 to 30 feet deeper than the completion interval of adjacent Intermediate Sand well SS45L001MW. Even though TCE was detected at 560 µg/L in paired well SS45L001MW (Table 4.3-1), TCE has not been detected in well SS45L002MW during any sampling event. Rather, DCE isomers are the primary CAH compounds detected in groundwater samples from the Deep Sand unit in this part of the 800 Area (Section 4.3.4).

During the 1999 investigation, TCE was detected at a concentration of 5.1 µg/L at well A39L001PZ, and also was detected in samples from Wells #14, #16, and #20, at concentrations of 15 µg/L, 1.4 µg/L, and 1.1 µg/L, respectively (Table 4.3-1 and Figure E.2, Appendix E). These Deep Sand unit wells are located in the northeastern and northwestern quadrants of the 800 Area in the vicinity of well pair SS45L001MW/SS45L002MW.

TABLE 4.3-1
VOLATILE ORGANIC COMPOUNDS IN GROUNDWATER SAMPLES
FEBRUARY-JULY, 1999
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Site Area	Monitoring Well ID	Sample Date	TCE ^a (µg/L) ^d	1,1-DCE ^b (µg/L)	cis- 1,2-DCE (µg/L)	trans- 1,2-DCE (µg/L)	Vinyl Chloride (µg/L)	Ethene (µg/L)	Ethane (µg/L)	1,1-DCA ^c (µg/L)	1,2-DCA (µg/L)
Intermediate Sand Unit											
800 Area	WELL#13	Feb-1999	ND ^a	ND	ND	ND	ND	0.76	1.4	ND	ND
	WELL#13	Mar-1999	0.48 J ^b	ND	ND	ND	ND	NA ^a	NA	ND	ND
	WELL#15	Feb-1999	ND	ND	ND	ND	ND	NA	NA	ND	ND
	WELL#15	Mar-1999	110	ND	110	4	3.1 J	3.9 J	2.6 J	ND	4
	WELL#15 (DUP) ^b	Mar-1999	110	ND	110	4	3 J	3.1 J	3.4 J	ND	4
	WELL#17	Mar-1999	9.8	ND	1	ND	ND	ND	ND	ND	ND
	WELL#17	May-1999	9.7	0.12 J	1	ND	ND	NA	NA	ND	0.13 J
	WELL#19	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	WELL#21	Jul-1999	0.13	ND	ND	ND	ND	0.92	0.17	ND	ND
	A39L008DP	Mar-1999	ND	ND	ND	ND	ND	0.18 J	ND	ND	ND
	A39L009PZ	Mar-1999	34	0.69 J	57	2.7	1.4 J	0.84 J	0.36 J	ND	0.39 J
	A39L009PZ (DUP)	Mar-1999	34	0.73 J	58	2.8	1.4 J	0.53 J	0.39 J	ND	0.39 J
	SS45L001MW	Mar-1999	560	ND	12 J	ND	ND	0.74 J	0.31 J	ND	ND
	WELL#1	Mar-1999	ND	ND	150	6.8	ND	ND	ND	ND	ND
2500 Area	WELL#2	Mar-1999	0.2 J	ND	7.4	4.4	0.52 J	NA	8.4 J	ND	ND
	WELL#3	Feb-1999	ND	ND	ND	ND	ND	ND	1.8	ND	ND
	WELL#3	Mar-1999	ND	ND	3.7	ND	ND	NA	NA	ND	ND
	WELL#4	Mar-1999	ND	ND	140	320	ND	ND	1.2	ND	ND
	WELL#4 (DUP)	Mar-1999	ND	ND	150	330	ND	NA	NA	ND	ND
	WELL#4	May-1999	ND	ND	40	71	0.46 J	NA	NA	ND	ND
	WELL#4	May-1999	ND	ND	40	71	0.46 J	NA	NA	ND	ND

Site Area	Monitoring Well ID	Sample Date	Chloro- benzene (µg/L)	Methylene Chloride (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl- benzene (µg/L)	m-,p Xylene (µg/L)	o-Xylene (µg/L)	1-,2-,4-TMB ^a (µg/L)	1-,3-,5-TMB (µg/L)
Intermediate Sand Unit											
800 Area	WELL#13	Feb-1999	ND	ND	ND	ND	ND	NA	ND	ND	ND
	WELL#13	Mar-1999	ND	0.32	ND	ND	ND	ND	ND	ND	ND
	WELL#15	Feb-1999	ND	ND	ND	ND	ND	NA	ND	ND	ND
	WELL#15	Mar-1999	ND	1.7	ND	ND	ND	ND	ND	ND	ND
	WELL#15 (DUP)	Mar-1999	ND	1.6	ND	ND	ND	ND	ND	ND	ND
	WELL#17	Mar-1999	ND	0.33	ND	ND	ND	ND	ND	ND	ND
	WELL#17	May-1999	ND	ND	ND	0.14 J	ND	ND	ND	ND	ND
	WELL#19	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	WELL#21	Jul-1999	ND	0.36	NA	NA	NA	NA	NA	NA	NA
	A39L008DP	Mar-1999	ND	0.46	ND	ND	ND	ND	ND	ND	ND
	A39L009PZ	Mar-1999	ND	0.54	ND	ND	ND	ND	ND	ND	ND
	A39L009PZ (DUP)	Mar-1999	ND	0.51	ND	ND	ND	ND	ND	ND	ND
	SS45L001MW	Mar-1999	ND	7.7	ND	ND	ND	ND	ND	ND	ND
	WELL#1	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
2500 Area	WELL#2	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	WELL#3	Feb-1999	ND	ND	ND	ND	ND	NA	ND	ND	ND
	WELL#3	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	WELL#4	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	WELL#4 (DUP)	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	WELL#4	May-1999	ND	1.3 J	ND	0.48 J	ND	ND	ND	ND	ND
	WELL#4	May-1999	ND	1.3 J	ND	0.48 J	ND	ND	ND	ND	ND

TABLE 4.3-1 (Continued)
VOLATILE ORGANIC COMPOUNDS IN GROUNDWATER SAMPLES
FEBRUARY-JULY, 1999
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Site Area	Monitoring Well ID	Sample Date	TCE ^a (µg/L) ^ψ	1,1-DCE ^b (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)	Ethene (µg/L)	Ethane (µg/L)	1,1-DCA ^c (µg/L)	1,2-DCA (µg/L)
	WELL#5	Mar-1999	ND	ND	39	16	120	13	1.2	0.21 J	0.34 J
	WELL#5 (DUP)	Mar-1999	ND	ND	48	17	110	11	1	ND	ND
	WELL#6	Feb-1999	ND	ND	ND	ND	ND	NA	NA	ND	ND
	WELL#6	Mar-1999	ND	ND	0.32 J	ND	ND	ND	7.3 J	ND	ND
	WELL#7	Mar-1999	ND	ND	0.67 J	2	ND	0.16J	0.069 J	ND	ND
	WELL#8	Jul-1999	0.2	ND	0.19	ND	ND	ND	ND	ND	ND
	WELL#10	Mar-1999	0.51 J	ND	26	5.7	0.7 J	0.15 J	0.33 J	ND	ND
	WELL#11	Mar-1999	ND	ND	120	4	2.4 J	0.15 J	2.6	ND	1.4 J
	A39L010PZ	Mar-1999	ND	0.53 J	2.8	8.5	420	1,100	5.7	ND	ND
	A39L011PZ	Mar-1999	ND	ND	44	4.2	80	2.9	ND	0.69 J	ND
	A39L012PZ	Mar-1999	ND	ND	1	ND	ND	ND	ND	ND	ND
	A39L013PZ	Mar-1999	ND	ND	3.4	ND	ND	ND	ND	ND	ND
	A39L018PZ	Mar-1999	ND	ND	29	0.47	5.2	ND	7.2 J	ND	ND
	A39L019PZ	Mar-1999	ND	ND	1.1	0.36 J	ND	ND	1.7	ND	ND
Deep Sand Unit											
800 Area	A39L022PZ	Mar-1999	ND	ND	ND	ND	ND	ND	0.63	ND	ND
	A39L082DP	Mar-1999	ND	ND	0.22	ND	ND	NA	NA	ND	ND
	A39L092DP	Mar-1999	ND	ND	0.14	ND	0.93 J	5.6	0.074 J	ND	ND

Site Area	Monitoring Well ID	Sample Date	Chloro-benzene (µg/L)	Methylene Chloride (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	m,p Xylene (µg/L)	o-Xylene (µg/L)	1,-2,-4-TMB [†] (µg/L)	1,-3,-5-TMB (µg/L)
	WELL#5	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	WELL#5 (DUP)	Mar-1999	ND	5	ND	ND	ND	ND	ND	ND	ND
	WELL#6	Feb-1999	ND	0.31 J	ND	ND	0.22 J	NA	0.55	0.9 J	0.37 J
	WELL#6	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	WELL#7	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	WELL#8	Jul-1999	ND	0.38	NA	NA	NA	NA	NA	NA	NA
	WELL#10	Mar-1999	ND	0.23	ND	ND	ND	ND	ND	ND	ND
	WELL#11	Mar-1999	ND	1.4	ND	ND	ND	ND	ND	ND	ND
	A39L010PZ	Mar-1999	ND	ND	0.57	ND	ND	ND	ND	ND	ND
	A39L011PZ	Mar-1999	ND	1.4	0.61 J	ND	ND	ND	ND	ND	ND
	A39L012PZ	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	A39L013PZ	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	A39L018PZ	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	A39L019PZ	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
Deep Sand Unit											
800 Area	A39L022PZ	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	A39L082DP	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	A39L092DP	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND

TABLE 4.3-1 (Continued)
VOLATILE ORGANIC COMPOUNDS IN GROUNDWATER SAMPLES
FEBRUARY-JULY, 1999
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Site Area	Monitoring Well ID	Sample Date	TCE ^w (µg/L) ^u	1,1-DCE ^w (µg/L)	<i>cis</i> -1,2-DCE (µg/L)	<i>trans</i> -1,2-DCE (µg/L)	Vinyl Chloride (µg/L)	Ethene (µg/L)	Ethane (µg/L)	1,1-DCA ^c (µg/L)	1,2-DCA (µg/L)
2500 Area	WELL#12	Mar-1999	ND	ND	1	ND	ND	0.16 J	ND	ND	ND
	WELL#14	Mar-1999	15	ND	44	8.9	0.91 J	1.5 J	0.2 J	ND	0.93 J
	WELL#16	Mar-1999	1.4	ND	0.67 J	ND	ND	ND	0.069 J	ND	ND
	WELL#18	Mar-1999	ND	ND	0.13	ND	ND	0.12 J	ND	ND	ND
	WELL#20	Mar-1999	1.1	ND	0.77 J	ND	ND	0.068 J	0.086 J	ND	ND
	A39L001PZ	Mar-1999	5.1	ND	1.6	ND	ND	0.16 J	0.076 J	ND	ND
	A39L002PZ	Mar-1999	ND	ND	ND	ND	ND	0.16 J	ND	ND	ND
	A39L008PZ	Mar-1999	ND	ND	ND	ND	ND	ND	0.21 J	ND	ND
	A39L028DP	Mar-1999	ND	ND	1.5	ND	ND	2.9 J	ND	ND	ND
	A39L039DP	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	SS45L002MW	Mar-1999	ND	ND	210	6.2	3.6 J	3.9 J	ND	ND	ND

Site Area	Monitoring Well ID	Sample Date	Chloro-benzene (µg/L)	Methylene Chloride (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	m-p Xylene (µg/L)	o-Xylene (µg/L)	1,2,4-TMB ^b (µg/L)	1,3,5-TMB (µg/L)
2500 Area	WELL#12	Mar-1999	ND	0.24	ND	ND	ND	ND	ND	ND	ND
	WELL#14	Mar-1999	ND	0.75	ND	ND	ND	ND	ND	ND	ND
	WELL#16	Mar-1999	ND	0.34	ND	ND	ND	ND	ND	ND	ND
	WELL#18	Mar-1999	ND	0.21	ND	ND	ND	ND	ND	ND	ND
	WELL#20	Mar-1999	ND	0.4	ND	ND	ND	ND	ND	ND	ND
	A39L001PZ	Mar-1999	ND	0.4	ND	ND	ND	ND	ND	ND	ND
	A39L002PZ	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	A39L008PZ	Mar-1999	ND	0.21	ND	ND	ND	ND	ND	ND	ND
	A39L028DP	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	A39L039DP	Mar-1999	ND	ND	ND	ND	ND	ND	ND	ND	ND
	SS45L002MW	Mar-1999	ND	3.1	ND	ND	ND	ND	ND	ND	ND

TCE = Trichloroethene.

DCE = Dichloroethene.

DCA = Dichloroethane.

^u µg/L = micrograms per liter.

^c ND = Not detected.

^j J = The analyte is qualified as an estimated value.

^w NA = Not analyzed.

^h DUP = Duplicate sample.

ⁱ TMB = Trimethylbenzene.

4.3.3 Extent of Dichloroethene Isomers in the Intermediate Sand Unit

4.3.3.1 800 Area

DCE isomers have been detected historically at Intermediate Sand unit wells in the 800 Area (Figures 1.3-10, 1.3-14, and 1.3-15 and Appendix A). DCE isomers were detected in 6 of 11 groundwater samples collected during the 1999 investigation from Intermediate Sand unit wells in this area (Table 4.3-1 and Figures E.3 through E.5, Appendix E). *cis*-1,2-DCE was detected at concentrations ranging from 1 µg/L (Well #17) to 120 µg/L (Well #11). *trans*-1,2-DCE also was detected at 4 of the 6 wells in which *cis*-1,2-DCE was detected, although at much lower concentrations (2.8 to 5.7 µg/L; Table 4.3-1). 1,1-DCE was detected at estimated concentrations in samples from two 800-area wells (Table 4.3-1).

Historically, DCE isomers have been detected at Intermediate Sand unit wells in the 800 Area that also contain TCE (e.g., wells SS45L001MW and A39L009PZ; Figures 1.3-14 and 1.3-15 and Appendix A). With only a few exceptions, groundwater samples that contained TCE also contained DCE isomers, and if TCE was not detected in a groundwater sample from the Intermediate Sand unit, DCE also was generally not detected. The relative ratios of TCE and DCE isomers detected in groundwater samples from the Intermediate Sand unit in the 800 Area are noteworthy: samples that contained relatively elevated concentrations of TCE generally contained much lower concentrations of DCE isomers (e.g., concentrations of hundreds of µg/L of TCE and about 10 to 20 µg/L of DCE isomers at well SS45L001MW), and samples that contained relatively elevated concentrations of DCE isomers generally contained much lower concentrations of TCE (e.g., concentrations of 80 to 90 µg/L of DCE isomers and 10 to 36 µg/L of TCE at well A39L009PZ). Wells #11 and #15 appear to represent exceptions to these general observations: TCE was not detected at Well #11, but *cis*-1,2-DCE was detected at a concentration of 120 µg/L, and TCE and *cis*-1,2-DCE each were detected at a comparable concentration (110 µg/L) in the groundwater sample from Well #15.

The history of solvent use at England AFB suggests that TCE was the primary contaminant initially release into the subsurface at Site SS-45, and that other CAHs have gradually appeared as TCE has degraded (Section 4.2 and Appendix D; Figure 4.2-1). This observation is strongly supported by the co-occurrence of TCE, DCE isomers, and other TCE daughter products in groundwater samples from the same wells, and by the increasing proportion of DCE to TCE in deeper wells.

4.3.3.2 2500 Area

DCE isomers also were detected in groundwater samples collected from the Intermediate Sand unit in the 2500 Area during previous investigations (Figures 1.3-4, 1.3-10, 1.3-14, and 1.3-15 and Appendix A). Prior to the 1999 investigation, the highest concentrations of DCE isomers in the 2500 Area (about 100 to 200 µg/L) were consistently detected in samples from well A39L011PZ (HydroPunch® location A39L069DP).

DCE isomers were detected in the 14 Intermediate Sand unit groundwater samples collected during the 1999 investigation from the 2500 Area (Table 4.3-1 and Figures E.3 through E.5, Appendix E). *cis*-1,2-DCE was detected at concentrations ranging from 0.19 µg/L (Well #8) in the eastern part of the 2500 Area to 150 µg/L (Wells #1 and #4, in the southern and northern parts of the 2500 Area, respectively). *trans*-1,2-DCE also was detected in groundwater samples from 9 of the 13 wells in which *cis*-1,2-DCE was detected (Table 4.3-1 and Figures E.3 and E.4, Appendix E). Although *trans*-1,2-DCE was generally detected at lower concentrations than *cis*-1,2-DCE in the same sample, the concentrations of *trans*-1,2-DCE in groundwater samples from wells A39L010PZ and Well #4 were approximately double the concentrations of the *cis*- isomer (Table 4.3-1). The elevated concentration of *trans*-1,2-DCE detected in the groundwater sample collected from Well #4 in March 1999 was subsequently confirmed by May 1999 results for the same well (Table 4.3-1). 1,1-DCE was detected only at Intermediate Sand well A39L010PZ in the 2500 Area at 0.53J µg/L (Table 4.3-1).

4.3.4 Extent of Dichloroethene Isomers in the Deep Sand Unit

4.3.4.1 800 Area

DCE isomers were detected at concentrations up to about 200 µg/L in 1996 and 1997 in the Deep Sand unit at the 800 Area (Figures 1.3-13, 1.3-16, and 1.3-17 and Appendix A). *cis*-1,2-DCE was detected during the 1999 investigation at concentrations of 210 µg/L and 44 µg/L in the samples from wells SS45L002MW and #14, respectively (Table 4.3-1 and Figure E.6, Appendix E). Well #14 is the deeper well in well pair #13/#14. TCE was detected in the sample from Intermediate Sand unit Well #13, but DCE isomers were not detected in that sample (Table 4.3-1). This suggests that although there is a component of vertical migration of chemicals in groundwater from the Intermediate Sand unit downward into the Deep Sand unit, there also is some component of chemical migration within the Deep Sand unit that is independent of migration within the Intermediate Sand unit.

Low concentrations (6.2 µg/L and 8.9 µg/L) of *trans*-1,2-DCE also were detected in groundwater samples from wells SS45L002MW and #14, respectively (Table 4.3-1 and Figure E.7, Appendix E). *cis*-1,2-DCE was detected at concentrations up to 1.6 µg/L in samples from Deep Sand wells A39L001PZ, A39L028DP, #12, #16, #18, and #20 in the 800 Area. DCE isomers were not detected in groundwater samples from Deep Sand unit wells A39L002PZ and A39L008PZ, west and east, respectively, of the 800 Area (Figures E.6 and E.7, Appendix E).

4.3.4.2 2500 Area

DCE isomers were not detected in the Deep Sand unit during groundwater sampling prior to the 1999 investigation (Appendix A). During the 1999 investigation, groundwater samples were collected from two Deep Sand unit monitoring wells in the 2500 Area (wells A39L082DP and A39L092DP). Low concentrations of *cis*-1,2-DCE were detected in groundwater samples from both wells (Table 4.3-1 and Figure E.6, Appendix E). Neither *trans*-1,2-DCE nor 1,1-DCE was detected in either sample (Table 4.3-1).

4.3.5 Extent of Vinyl Chloride in the Intermediate Sand Unit

4.3.5.1 800 Area

VC was detected during the RFI in Intermediate Sand unit groundwater samples collected from the 800 Area (Figures 1.3-14 and 1.3-15, and Appendix A). During the 1999 investigation, VC was detected at low, estimated concentrations at the four Intermediate Sand unit monitoring wells that also contained the highest concentrations of DCE isomers (Wells #10, #11, #15, and A39L009PZ; Table 4.3-1 and Figure E.8, Appendix E). These four wells generally surround well pair SS45L001MW/SS45L002MW, the location where the highest concentrations of TCE in the Intermediate Sand unit have historically been detected. VC was probably not used as a solvent at England AFB, and its co-occurrence at low concentrations with DCE isomers, and its general geographic association with TCE, indicate that VC is being generated during the reductive dehalogenation of TCE and DCE (Section 4.2 and Appendix D).

4.3.5.2 2500 Area

VC had been detected at concentrations up to 1,260 µg/L in the Intermediate Sand unit at the 2500 Area (Figures 1.3-14 and 1.3-15, and Appendix A). During the 1999 investigation, the highest concentration of VC in the Intermediate Sand unit (420 µg/L) was detected in a groundwater sample from well A39L010PZ (Table 4.3-1 and Figure E.8, Appendix E). Lower concentrations of VC (up to 120 µg/L) were detected in samples from five other wells in the 2500 Area. These wells also contained DCE isomers (Section 4.3.3).

If DCE was not detected in a groundwater sample from the Intermediate Sand unit, VC also was absent. Groundwater samples that contained relatively elevated concentrations of DCE isomers generally contained much lower concentrations of VC (compare DCE and VC concentrations for Well #4, Table 4.3-1); groundwater samples that contained relatively low concentrations of DCE isomers generally contained much higher concentrations of VC (compare *cis*-1,2-DCE and VC concentrations for well A39L010PZ; Table 4.3-1). The co-occurrence of DCE isomers and VC, and the inverse concentrations exhibited, provide additional evidence that VC is being generated during the reductive dehalogenation of DCE. VC was not detected in groundwater samples from Wells #3 and A39L019PZ, which bound the 2500 Area to the north, or in samples from Wells #1, #6, #7, #8, A39L012PZ, and A39L013PZ, which bound the 2500 Area to the south and east (Figure E.8, Appendix E).

4.3.6 Extent of Vinyl Chloride in the Deep Sand Unit

VC was detected previously at Deep Sand unit well SS45L002MW in the 800 Area (Figures 1.3-16 and 1.3-17, and Appendix A). VC was detected during the 1999 investigation in samples from three Deep Sand unit monitoring wells. The groundwater sample from well SS45L002MW contained VC at a concentration of 3.6J µg/L; and the samples from Wells #14 and A39L092DP contained VC at concentrations of 0.91J µg/L and 0.93J µg/L, respectively (Table 4.3-1 and Figure E.9, Appendix E).

4.3.7 Other VOCs in Groundwater

Other CAHs detected since 1996 at Site SS-45 (and the range of detected concentrations) included 1,1-DCA (0.21J to 4.9 µg/L) and 1,2-DCA (0.13J to 4 µg/L) (Appendix A and Table 4.3-1). These compounds have been detected in groundwater samples from both the 800 and 2500 Areas; however, detections have been sporadic, with no apparent spatial or temporal association. Detected concentrations of DCA isomers have not exceeded USEPA maximum contaminant levels (MCLs; USEPA, 1993a) or State of Louisiana groundwater quality standards.

Acetone, benzene, bromodichloromethane, carbon disulfide, chlorobenzene, chloroform, dibromochloromethane, methylene chloride, and toluene have been sporadically detected in groundwater samples collected at Site SS-45. Acetone, carbon disulfide, and methylene chloride are common laboratory contaminants (USEPA, 1994) that may be introduced to environmental samples during sample handling or analyses. Halomethanes, including chloroform, bromodichloromethane, and dibromochloromethane, are generated in water during chlorination of water supplies (Merck, 1996; National Academy of Science [NAS], 1978). Although not commonly found in laboratory settings, halomethanes may be introduced to the laboratory as constituents of tap water, serving as another potential source of laboratory contamination. The sporadic and random nature of detections of acetone, carbon disulfide, chloroform, dibromochloromethane, and methylene chloride, at low concentrations, indicates that they were probably introduced to samples as contaminants in the laboratory.

Benzene and toluene are petroleum fuel constituents. These chemicals have been detected at a few wells in the 2500 Area at concentrations below 1 µg/L (Appendix A and Table 4.3-1). These chemicals can serve as electron donors during microbially mediated redox reactions, and are discussed further in Section 4.5.5.

4.3.8 Dissolved Ethene in the Intermediate Sand Unit

Ethene is the final product in the series of reductive dehalogenation reactions involving chlorinated ethenes (Section 4.2 and Appendix D). Ethene was detected in groundwater samples from the Intermediate Sand unit at Site SS-45 at concentrations ranging up to 1,100 µg/L (Table 4.3-1 and Figure E.10, Appendix E). The areas within which ethene was detected coincide with the areas where VC occurs in groundwater in the Intermediate Sand unit (Table 4.3-1), and the highest concentrations of ethene were detected at wells that also contained the highest concentrations of VC (Wells #5, A39L010PZ, and A39L011PZ in the 2500 Area).

The presence of ethene implies that VC in groundwater at those locations is undergoing reductive dehalogenation. As previously described, the rate of reductive dehalogenation usually decreases as the number of chlorine atoms in the molecules decreases. Therefore, the reaction that produces ethene from VC can be the slowest in the series of reductive dehalogenation reactions involving chlorinated ethenes.

4.3.9 Dissolved Ethene in the Deep Sand Unit

Ethene also was detected in groundwater samples from the Deep Sand unit at Site SS-45, at concentrations ranging up to 5.6 µg/L (Table 4.3-1 and Figure E.11, Appendix E). Monitoring wells in which ethene was detected in the Deep Sand unit corresponded in general with wells in which VC was also detected. In particular, VC was detected at wells SS45L002MW and #14 in the 800 Area and at well A39L092DP in the 2500 Area (Section 4.3.6 and Table 4.3-1). However, ethene was detected in groundwater samples from Deep Sand unit wells covering a broader area than was VC. Ethene has by far the highest Henry's Law constant and molecular diffusion coefficient of any of the TCE daughter products, indicating that ethene can readily migrate in the subsurface in the volatile phase or via diffusive mechanisms (Appendices D and F). The relatively broad areal distribution of ethene may be a consequence of its relatively greater mobility in the environment.

4.4 MIGRATION PROCESSES AND CAH DISTRIBUTION IN GROUNDWATER

The historical pattern of solvent disposal at most Air Force bases (small batches of solvents, including TCE, disposed in sanitary sewers, or discharged directly onto the ground) suggests that CAHs likely entered the upper silt/clay unit from multiple surface or near-surface sources as pure-phase TCE, TCE dissolved in water, or a multiphase liquid consisting of water with an undissolved component of pure-phase TCE. The multiphase liquid could have originated from several sources, including leaking sanitary sewer lines, stormwater outfalls, equipment or aircraft wash water, or limited surface spills. A diagram of this conceptual site model is provided on Figure 4.4-1.

Several transport processes control the physical movement of chemicals through soils as nonaqueous-phase liquid (NAPL), dissolved (aqueous) phase, and sorbed (solid) phase. At Site SS-45, CAHs were most likely introduced to the subsurface as small amounts of NAPL and dissolved chemicals leaking from oil/water separators and sewer lines. Once a chemical has been introduced into the environment, it interacts with the surrounding media. The major processes affecting chemicals in the subsurface include sorption to soil, diffusion, dissolution, chemical and biological degradation, and volatilization (Appendix D).

Subsurface transport of chemicals as NAPL, or in the dissolved or vapor phase, is driven by gravitational, hydraulic, and/or chemical potential gradients. In the unsaturated zone, gravitational and hydraulic potential gradients are primarily vertical, so that the direction of movement is generally downward. As water percolates through the unsaturated zone in the upper silt/clay unit at Site SS-45, chemicals present as a NAPL or in a sorbed or vapor phase can dissolve into and migrate with the infiltrating water to the water table via advective transport.

However, under conditions of very low groundwater flow velocities, such as occur at Site SS-45, chemical diffusion, driven by chemical concentration gradients and controlled primarily by site-specific chemical diffusion coefficients, may be the primary transport mechanism in the subsurface (Gillham and Cherry, 1982). Molecular diffusion occurring

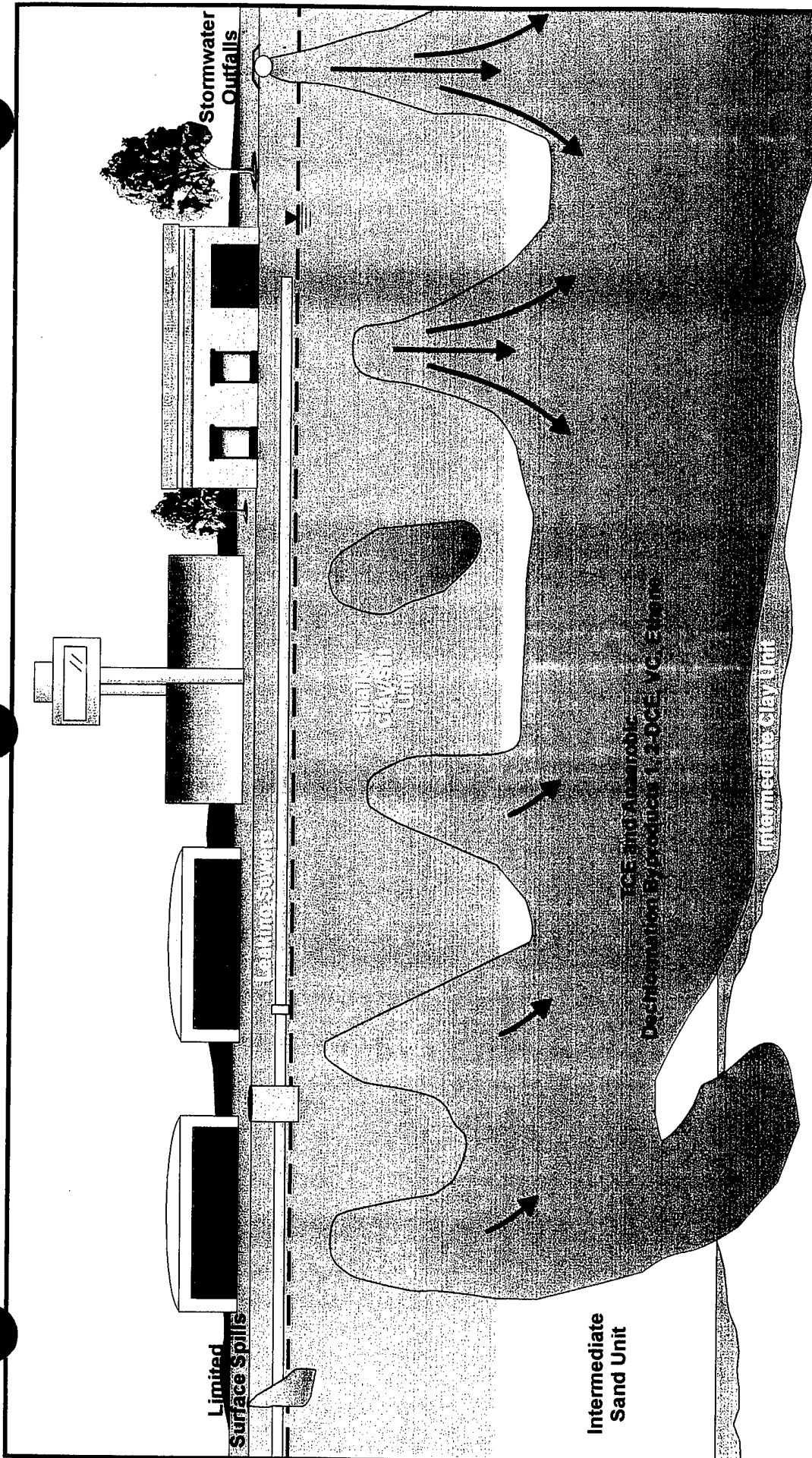


FIGURE 4.4-1
CONCEPTUAL SITE MODEL

SITE SS-45
Site SS-45

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in the presence of a chemical concentration gradient causes dissolved chemicals to migrate from areas of relatively higher concentration to areas of relatively lower concentration. Alternatively, because groundwater flow directions beneath the 800 Area and 2500 Area are generally indeterminate (in that the potentiometric surface is nearly flat, and hydraulic gradients do not appear to extend continuously over appreciable distances in any direction), the current distribution of chemicals in groundwater may have occurred as a result of inconsistent or oscillating advective migration along poorly-defined flowpaths.

In any case, the resulting chemical distribution is the same – CAH compounds are present in groundwater, at relatively low concentrations across a broad area, with no well-defined hydraulic relationship between “source” and “downgradient” areas. The net effect of dispersive processes (advection or diffusion) acting on the dissolved chemical as it migrates through a porous medium is that the mass of chemical becomes distributed through an ever-increasing volume of aquifer material. This results in a decrease in chemical concentration with increasing distance from areas of relatively higher chemical concentrations.

The extremely low groundwater flow velocities estimated for groundwater at Site SS-45, the relatively greater magnitude of diffusive processes (see Appendix D), and the observed distributions of chemicals in the subsurface (Appendix E) indicate that chemical diffusion may be the primary transport mechanism influencing the migration of dissolved TCE and its daughter products in groundwater at Site SS-45. As a consequence of the extremely low groundwater gradients and moderate values of hydraulic conductivity, groundwater flow velocities at Site SS-45 range from less than 0.1 foot per year to perhaps 4 feet per year (Section 3), and chemical retardation lowers the migration velocity of TCE by a factor of about 1.6. In contrast, dissolved TCE moving via chemical diffusive processes alone is capable of migrating at rates of several feet per year (Gillham and Cherry, 1982), and this contaminant could migrate at detectable concentrations to distances of several hundred feet from its point of introduction to groundwater during a 40-year time period (assuming TCE was released into site groundwater in the 1950s or 1960s). TCE migrating from several different, areally-distributed source areas, could move via chemical diffusive processes alone at even lower rates, to produce the observed distribution of chemicals. If advective transport of CAH compounds occurs in groundwater at Site SS-45, seasonally-varying, or oscillating, groundwater flow directions might also be capable of distributing dissolved chemicals in groundwater.

The spatial distributions of TCE and daughter products in the 800 Area and 2500 Area support this mode of chemical migration (Figures 4.4-2 through 4.4-5). These figures were generated using the commercial software package MapInfo™, developed by Northwood Geoscience, Inc., which enables measured data (e.g., chemical concentrations) to be interpolated across large areas. Figures 4.4-2 through 4.4-5 were generated by combining historical chemical data collected since 1996 (LAW, 1998a) with data collected during the 1999 investigation. Historical data were included to provide more detailed spatial coverage across a broader area than could be obtained using 1999 data alone. After the data were posted, shaded color contours were generated using an inverse-distance interpolation algorithm (Jones and Hamilton, 1992), and a search radius

LEGEND

- MARCH 1999 SAMPLING LOCATION WITH TCE CONCENTRATION (µg/L)
- HYDROPUNCH SAMPLING LOCATION WITH TCE CONCENTRATION (µg/L) and DATE OF SAMPLING EVENT
- HISTORICAL SAMPLING LOCATION WITH TCE CONCENTRATION (µg/L) and DATE OF SAMPLING EVENT

ND = Not detected above the reported sample quantitation limit.

J = The result is qualified as an estimated value because it is greater than the method detection limit and less than the practical quantitation limit.

Conceptual TCE Concentration

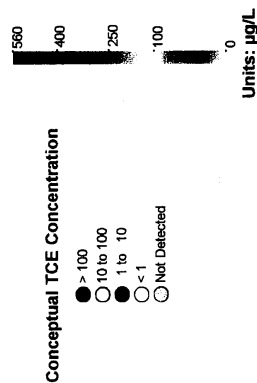


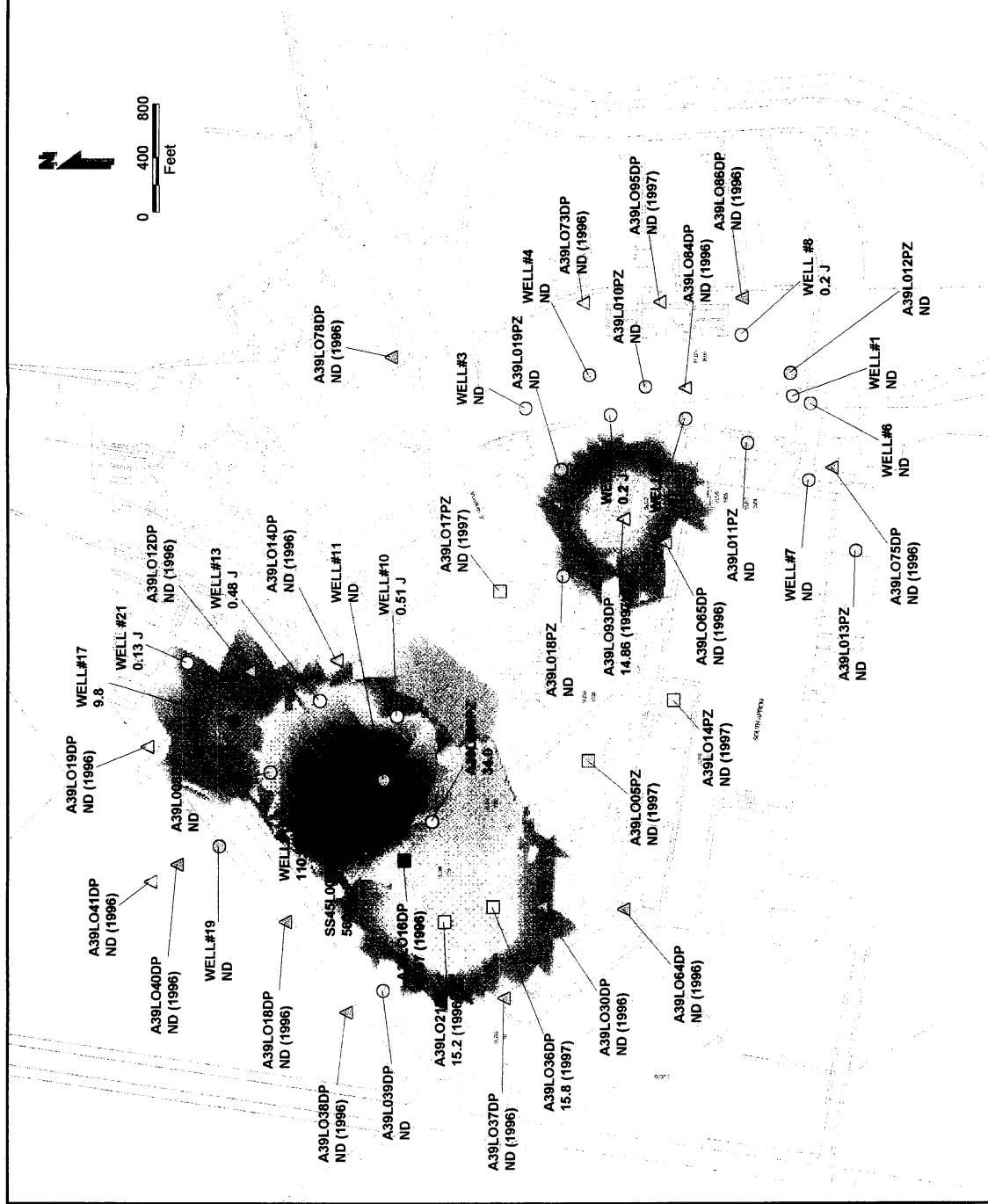
FIGURE 4.4-2

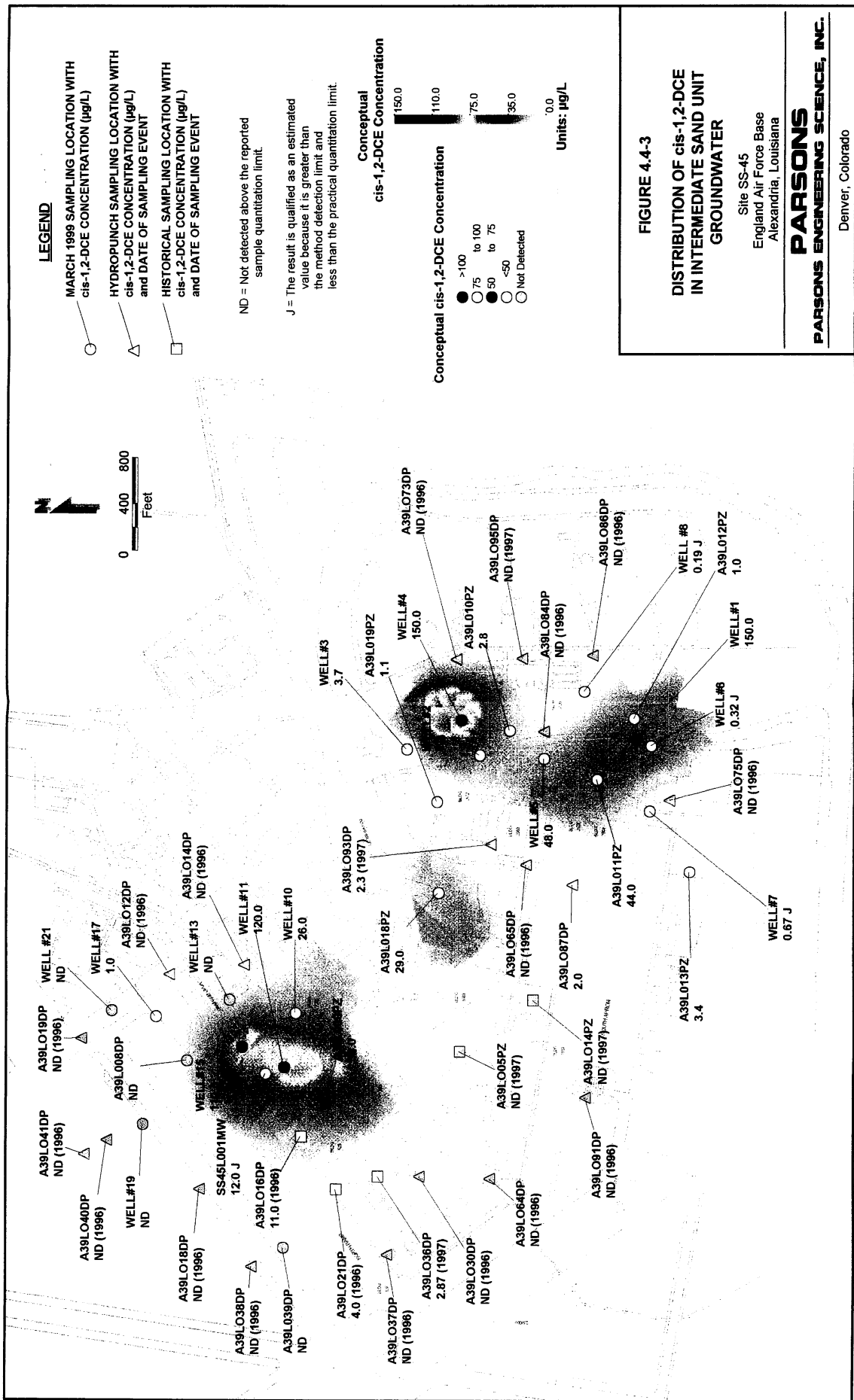
DISTRIBUTION OF TCE IN INTERMEDIATE SAND UNIT GROUNDWATER

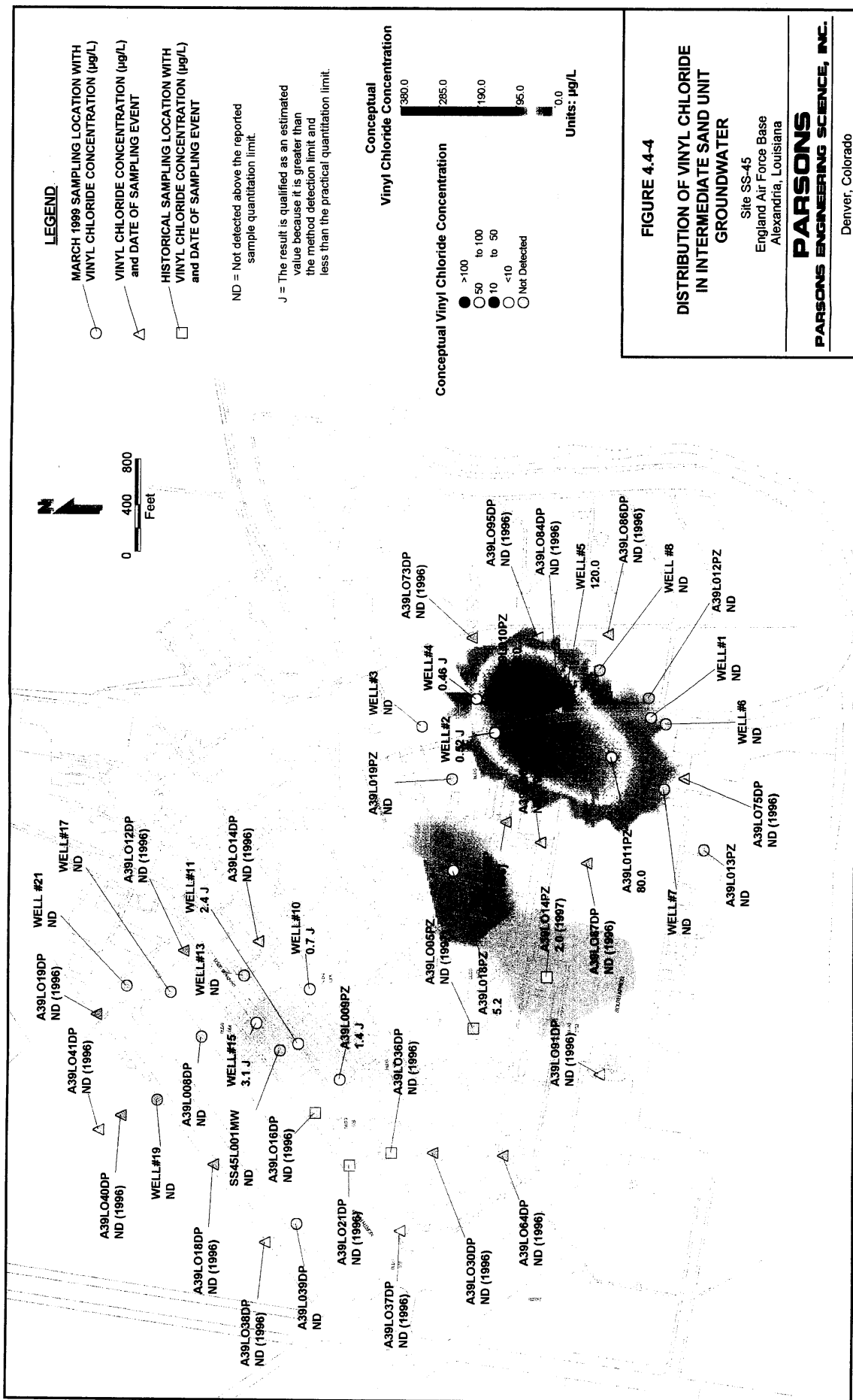
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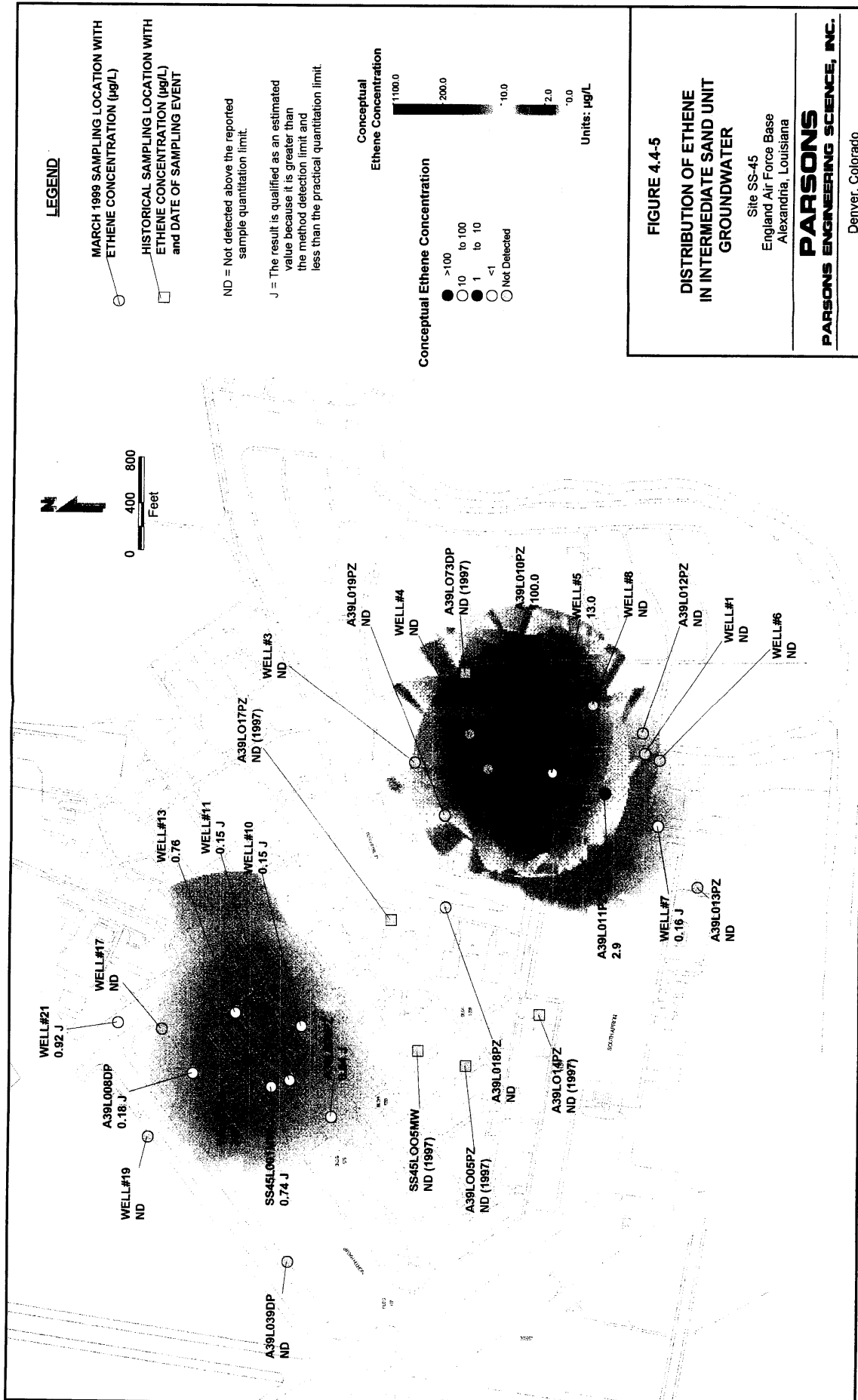
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that ranged between 750 and 1,200 feet, depending on the chemical. Although the resulting estimates of chemical distributions provide a reasonable, general picture of the distributions of TCE, *cis*-1,2-DCE, VC, and ethene in groundwater of the Intermediate Sand unit, interpolation routines are not capable of actually interpreting data. Therefore, the color-shaded portions of these figures must be regarded as conceptual representations only.

If chemical migration had occurred as a consequence of advective transport along a well-defined flowpath from a single, distinct source, a migration direction corresponding to the direction of groundwater flow would be apparent in the distribution of chemicals. Examination of the spatial distribution of TCE, *cis*-1,2-DCE, VC, and ethene indicates that there is no preferential direction of chemical migration from zones of relatively elevated chemical concentrations in either the 800 Area or the 2500 Area (Figures 4.4-2 through 4.4-5). Rather, chemical concentrations in groundwater decrease gradually and uniformly within a volume of generally axi-symmetrical or radially-symmetrical aspect centered on zones of relatively higher chemical concentrations. This is characteristic of migration that occurs as a result of chemical diffusion because chemical concentration gradients, which drive diffusive transport, are established from areas of higher chemical concentration to areas of lower concentration with no directional preference.

The distributions of other CAHs in groundwater of the Intermediate and Deep Sand units also correspond to the general aspects of the spatial distribution of TCE. The appearance of DCE isomers, VC, and ethene in direct association with TCE provides clear evidence that TCE is degrading in the subsurface. Little or no TCE remains in groundwater in the 2500 Area (Figure 4.4-2), indicating that the reductive dehalogenation of TCE has proceeded to its conclusion within the period of 40 to 50 years since TCE was first introduced to groundwater. The concentrations of the *cis*-1,2-DCE isomer in groundwater are, in general, substantially greater than concentrations of *trans*-1,2-DCE and 1,1-DCE. These observed proportions of the DCE isomers are common in environments where reductive dehalogenation of TCE occurs. As discussed in Section 4.2.3.1, *cis*-1,2-DCE is the primary metabolic intermediate of this process (Bouwer, 1994).

The appearance of DCE isomers in groundwater of the 800 Area indicates that TCE is also being degraded there; and the occurrence of VC in both the 800 and 2500 Areas provides confirmation of the degradation of DCE. Finally, ethene has been detected in groundwater samples collected within the 800 Area and the 2500 Area, but has not been detected in samples collected at locations outside those areas. The appearance of ethene is considered to be conclusive evidence of the degradation of VC (USEPA, 1998; Wiedemeier *et al.*, 1999).

Introduction of the TCE to groundwater in the 800 Area and 2500 Area apparently occurred at different times, and/or chemical degradation in the two Areas has proceeded at different rates as a consequence of differing geochemical conditions in the subsurface (Section 4.5). This has produced a distinct chemical suite in groundwater in each of the two areas. Within the central portion of the 800 Area (Figure 4.4-6), chemical concentrations are relatively elevated, and TCE (red shading) is the principal component of the suite of chemicals in groundwater in the Intermediate Sand unit, with DCE isomers

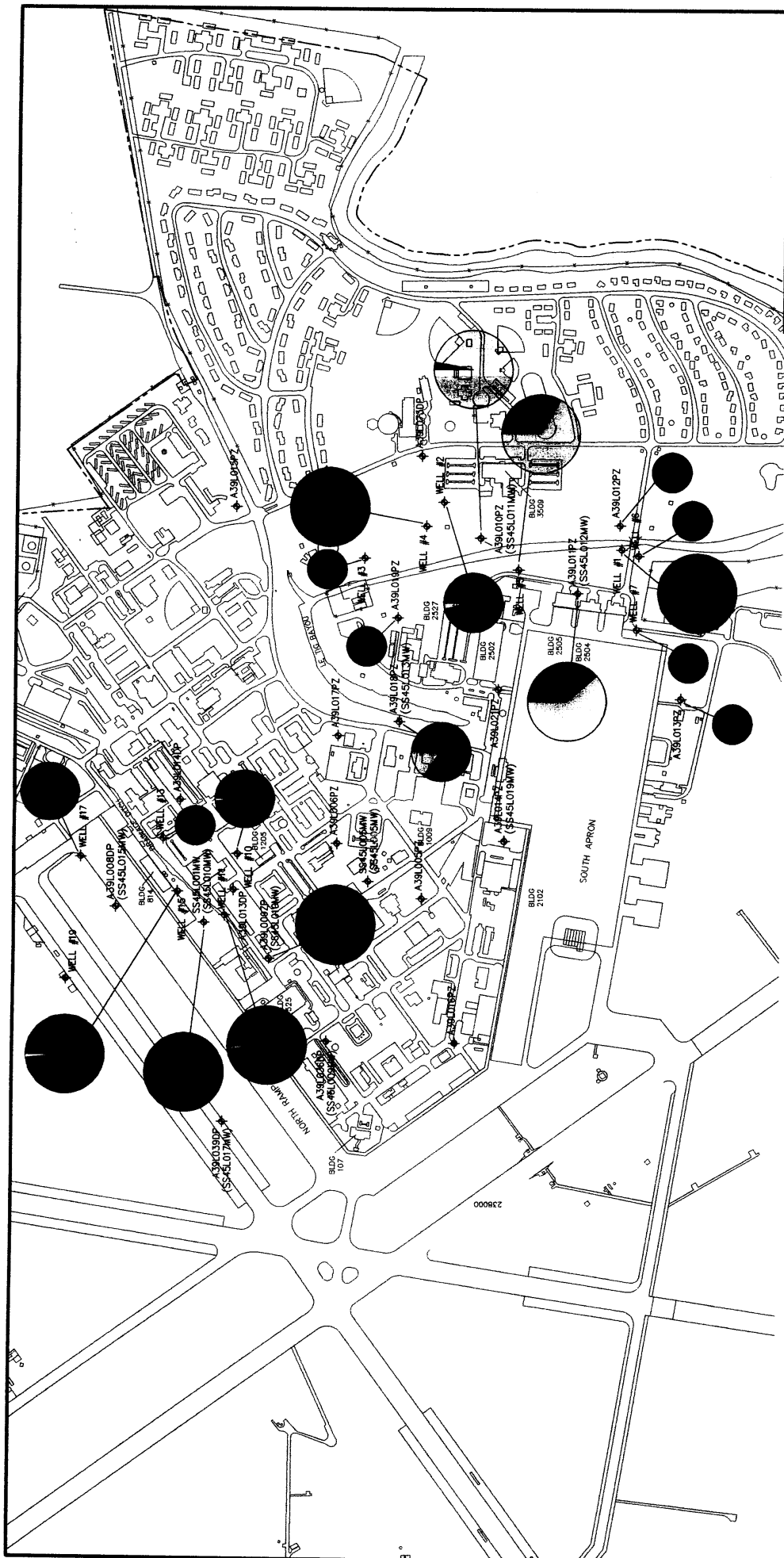
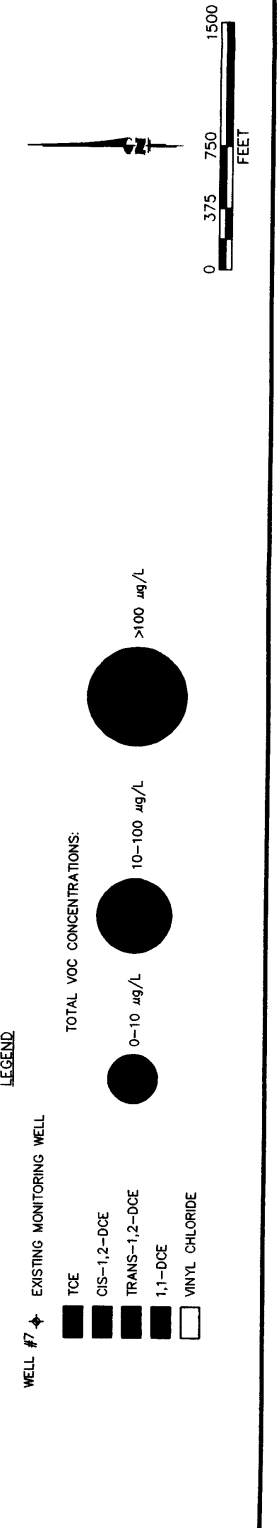


FIGURE 4.4-6

CONCENTRATIONS OF TOTAL CAHs IN INTERMEDIATE SAND UNIT GROUNDWATER

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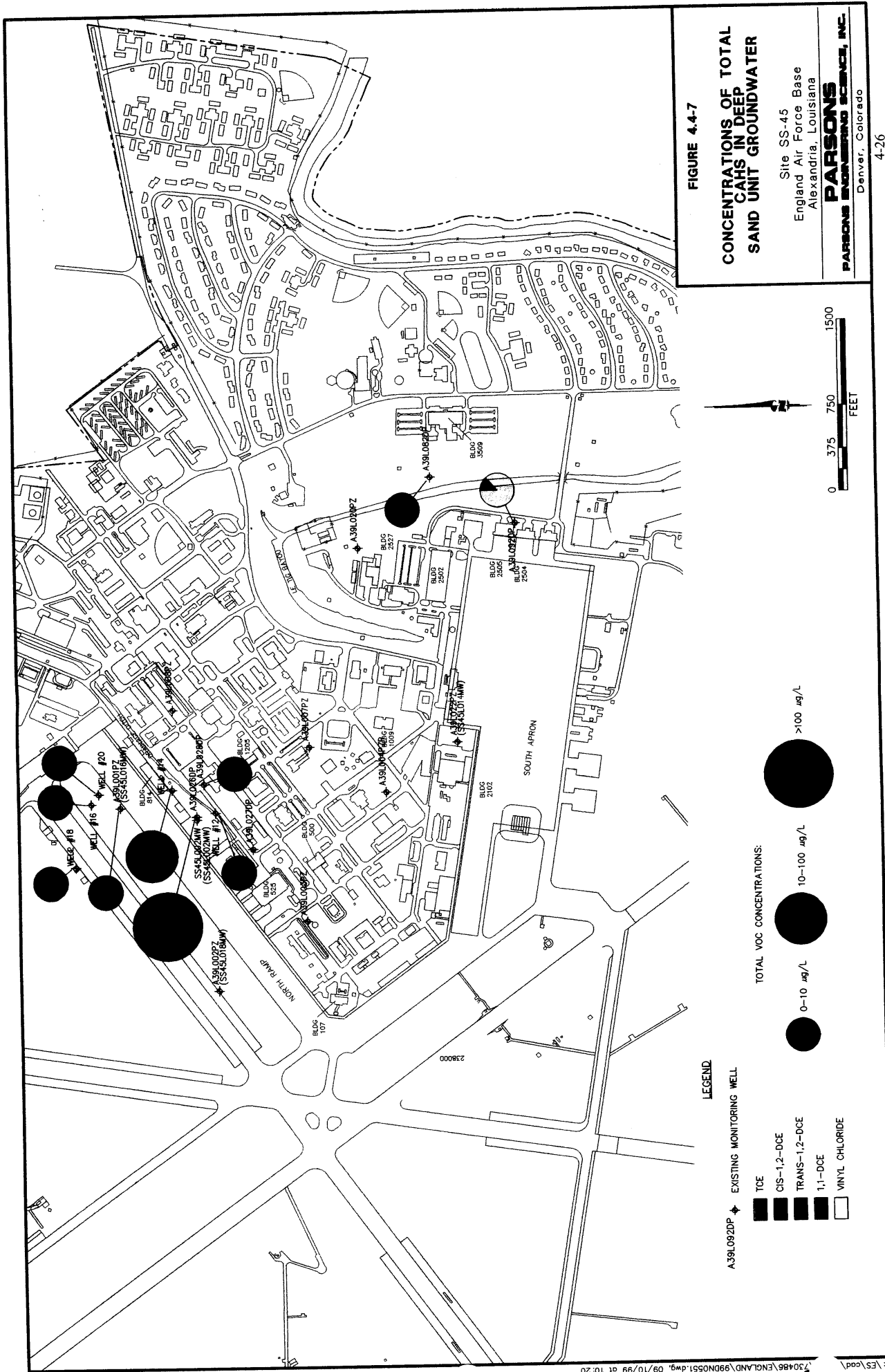
(blue and green shading) present at concentrations that are lower than or subequal to the TCE concentrations. Chemical concentrations generally decrease with increasing distances from the zones of elevated concentrations (hot spots), and the chemical suite changes, becoming primarily DCE isomers. This change in composition of the chemical suite is an indirect indication of the time required for dissolved CAHs to migrate from chemical sources while concurrently degrading.

DCE isomers and VC are the principal CAHs in groundwater within the Intermediate Sand unit in the 2500 Area (Figure 4.4-6). As previously noted, groundwater samples with elevated DCE concentrations generally contain much lower concentrations of VC, and groundwater samples in which VC is the primary CAH contain lower DCE concentrations. This also is an indication of the time required for migration of DCE from original TCE sources in the 2500 Area, or in the overlying upper silt/clay, and its degradation to VC. The lack of any consistent pattern in the evolution of chemical suites, other than the general observation that chemical concentrations decrease with increasing radial distance from chemical source zones, provides further evidence of the diffusive nature of chemical migration in groundwater at Site SS-45.

Diffusive transport mechanisms cause chemicals to migrate vertically through the groundwater system, as well as radially outward from chemical sources. The effects of vertical diffusive migration are apparent in the suites of chemicals detected in groundwater samples from the Deep Sand unit (Figure 4.4-7). In the 800 Area, where the Intermediate Clay unit is absent, chemical diffusion has caused CAHs to migrate from the Intermediate to the Deep Sand unit, against the generally upward vertical hydraulic gradient. As a consequence of the time required for diffusive migration of CAHs from the Intermediate Sand unit to the Deep Sand unit, the chemical suite in groundwater of the Deep Sand unit has evolved so that it consists primarily of DCE isomers, with occasional detections of VC, and near-ubiquitous, low detections of ethene.

This process can be examined in detail using the data for well pair SS45L001MW/002MW. These two wells are located within 15 feet of each other in the 800 Area (Figures 4.4-6 and 4.4-7). Well SS45L001MW is screened in the Intermediate Sand unit from 54 to 64 feet bgs, and well SS45L002MW is screened in the Deep Sand unit from 89 to 99 feet bgs. The results of water-level measurements collected in the two wells (Section 3.4) indicate that a very slight, but persistent, upward hydraulic gradient is present from the Deep Sand to the Intermediate Sand system.

Historically, TCE has been the principal CAH in groundwater samples from well SS45L001MW (the Intermediate Sand unit well), having been detected at concentrations ranging from about 45 $\mu\text{g/L}$ to about 700 $\mu\text{g/L}$ (Appendix A and Table 4.3-1). Lower concentrations of *cis*-1,2-DCE, *trans*-1,2-DCE, 1,1-DCE, and VC also have been detected in groundwater samples from this well. If mass-based concentrations are converted to molar-based concentrations for these analytical results, the total molar concentrations of CAHs detected in groundwater samples from well SS45L001MW appear to have declined during the period from September 1997 through March 1999, from a concentration of about 5.5 micromoles per liter ($\mu\text{mol/L}$) to a total molar concentration of about 4.4 $\mu\text{mol/L}$ (refer to Appendix F).

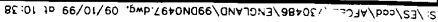


In contrast, the DCE isomers and VC are the principal CAHs detected in samples from well SS45L002MW (the adjacent Deep Sand unit well). *cis*-1,2-DCE has been detected in samples collected during every sampling event at concentrations ranging from about 11 µg/L to about 21 µg/L (Appendix A and Table 4.3-1). Lower concentrations of *trans*-1,2-DCE and VC have also been detected in groundwater samples from this well. TCE was detected on only one occasion, at a low, estimated concentration. The total molar concentrations of CAHs in well SS45L002MW samples appear to have increased during the period from June 1997 through March 1999, from a concentration of about 1.2 µmol/L to about 2.3 µmol/L.

The changes in total molar concentrations of TCE and daughter products in groundwater samples from the two wells are equivalent through approximately the same period of time: molar concentrations in groundwater samples from well SS45L001MW decreased by about 1.1 µmol/L, while molar concentrations in groundwater samples from well SS45L002MW increased by about 1.1 µmol/L. The similar magnitudes of concentration changes, together with the spatial proximity of the two wells, suggest that TCE daughter products detected in groundwater samples from the Deep Sand unit at well SS45L002MW were generated as TCE was degraded during migration in groundwater from shallower intervals in the Intermediate Sand unit.

The slight upward hydraulic gradient at this location supports the hypothesis that chemical diffusion, rather than advection, may be an important transport mechanism, acting to move chemicals from the Intermediate Sand unit to the Deep Sand unit. In diffusive transport, chemicals migrate on the molecular level in response to chemical gradients (which do not necessarily coincide with hydraulic gradients), whereas advection causes chemicals to migrate in response to hydraulic gradients, from areas of higher hydraulic potential to lower hydraulic potential. The 25-foot vertical separation between the screened intervals of the two wells is therefore a spatial surrogate representing the length of time required for TCE (or its daughter compounds) to migrate via diffusive transport mechanisms from the Intermediate Sand unit to the Deep Sand unit. The two wells thus sample different segments of a diffusive transport path from the Intermediate Sand unit into the Deep Sand unit. The gradual decrease in chemical concentrations in the source area (the Intermediate Sand unit adjacent to the screened interval of well SS45L001MW), the gradual increase in chemical concentrations in the vertically downgradient direction (in the Deep Sand unit adjacent to the screened interval of well SS45L002MW), and the evolution of the suite of halogenated chemicals along the transport path, are typical manifestations of chemical transport accompanied by dispersion and degradation that would be expected during chemical migration in a more conventional plume driven by advective transport mechanisms.

The general pattern of continued evolution of the suite of CAH compounds with increasing distance and depth is evident at other locations within Site SS-45 as well (Figures 4.4-8 through 4.4-11). Although CAH compounds have been detected only sporadically at low concentrations in groundwater samples from the Deep Sand unit in the 2500 Area, the chemical suite in the Deep Sand unit consists exclusively of *cis*-1,2-DCE and VC (Table 4.3-1 and Figures 4.4-7, 4.4-9, and 4.4-10). CAHs were also occasionally detected in groundwater samples collected in HydroPunch® borings within the upper silt/clay unit (Table 1.3-1). In locations where the upper silt/clay unit is



LOCATIONS OF HYDROCHEMICAL CROSS-SECTION TRACES

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NOTE: ONLY THOSE HYDROPUNCH BORINGS AND WELLBORES WHOSE LOGS WERE USED TO GENERATE CROSS-SECTIONS ARE LABELLED.

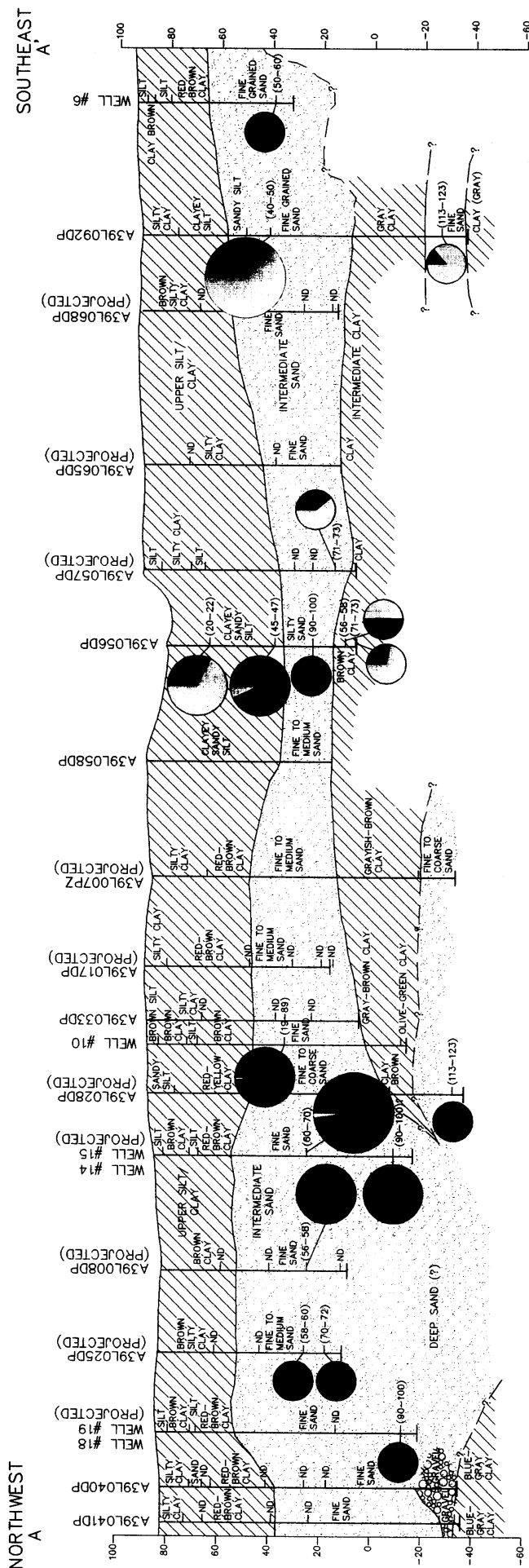


FIGURE 4.4-9
CONCENTRATIONS OF TOTAL
CAHS IN GROUNDWATER
ALONG CROSS-SECTION
A-A

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particularly thick or contains elevated concentrations of organic carbon (e.g., the 2500 Area), DCE isomers and VC were the CAH compounds most frequently detected in samples from the upper silt/clay and the underlying Intermediate Sand and Intermediate Clay units (e.g., at Hydropunch® location A39L056DP, Table 1.3-1). This suggests that in parts of the 2500 Area, TCE percolating through the upper silt/clay unit has been completely degraded to daughter products by the time CAHs reach the Intermediate Sand unit.

The observation that chemical migration at Site SS-45 results primarily from diffusive processes has implications that affect the predictions of the future extent of TCE and daughter products dissolved in groundwater. In the absence of a well-defined hydraulic gradient, where chemical migration is driven primarily by chemical gradients, or by seasonally-varying advective transport along poorly-defined groundwater flowpaths, dissolved CAH compounds will move from areas of relatively higher concentration to areas of relatively lower concentration (Appendix D). With increasing time since introduction of CAHs to groundwater and increasing migration distance from source areas, chemical concentrations at the leading edge of the diffusive plume decrease as chemicals are spread through an ever-increasing volume of groundwater, and are thereby diluted. If additional chemical mass is not continuously introduced to groundwater in source areas, the concentrations in these areas also will decrease with time as diffusive migration or other processes gradually remove chemical mass from the source area. As the chemical concentration gradient decreases with time, and the affected volume of aquifer increases, the chemical concentration gradient will become so small that further migration from source areas proceeds at declining rates, and chemical migration at the distal edges of the plume occurs at concentrations that are below detection limits. At that point, the plume is said to have stabilized, and will remain stationary, or will shrink, as degradation processes gradually remove chemical mass from groundwater, further lowering chemical concentrations and concentration gradients. Given the low concentrations of CAHs at the edges of the plumes in the 800 Area and the 2500 Area, the relatively low concentrations of CAHs near the centers of the plumes (about 500 µg/L or less), and the relatively long period since the initial introduction of CAH compounds to groundwater, it is possible that chemical concentration gradients and/or net advective transport velocities are sufficiently low that advective-diffusive migration has ceased, and the diffusive "plumes" have stabilized.

4.5 RNA EVALUATION

All available information indicates that after TCE was introduced to the subsurface environment it began to degrade in accordance with well-understood mechanisms and processes (Appendix D). The occurrence and distributions of TCE, its daughter products (Figures 4.4-2 through 4.4-7, and 4.4-9 through 4.4-11), and other geochemical indicator parameters are a consequence of those degradation processes.

The CAH plumes in the 800 and 2500 Areas exhibit mixed (Type 1 and Type 2) behavior (Appendix D), with sufficient natural and anthropogenic carbon available as a substrate to result in complete degradation and ultimate mineralization of TCE and its daughter products. The naturally-occurring organic carbon content in soil in both the 800 Area and 2500 Area is relatively high (median value of 0.1 percent or greater; Section

4.1.1). Fuel hydrocarbons also have occasionally been detected in groundwater samples from the 2500 Area (Appendix A and Table 4.3-1). These sources of carbon indicate that the electron donor supply is adequate to allow continued microbial reduction of CAHs (Section 4.5.5).

The role of electron acceptors (e.g., DO, nitrate, ferric iron, manganese, and sulfate) that may compete with CAHs is described in Section 4.5.6. The mixed Type 1 and Type 2 conditions are resulting in extensive degradation of the TCE and DCE. Degradation of VC also is occurring, as evidenced by the relatively elevated concentrations of ethene in groundwater in areas that also contain VC (Figures 4.4-4 and 4.4-5) and by the general lack of VC detections at distances greater than about 800 feet from CAH hot spots in groundwater (Sections 4.3.5, 4.3.6, and 4.4).

4.5.1 Contaminant Mass Losses at the Field Scale

Changes in dissolved concentrations of CAH compounds through time at a particular location or with increasing distance from chemical sources are a line of evidence for evaluation of the possible occurrence of RNA of CAHs in groundwater at Site SS-45 (USEPA, 1998). Removal of chemical mass from the subsurface via RNA will be manifested as a decrease in chemical concentrations through time at a given sampling location, as a decrease in chemical concentrations with increasing distance from chemical source areas, and/or as a change in the suite of chemicals through time or with increasing migration distance.

Of the monitoring wells associated with Site SS-45, the most extensive monitoring histories have been recorded for wells A39L009PZ, SS45L001MW, and SS45L002MW in the 800 Area, and wells A39L010PZ and A39L011PZ in the 2500 Area (Appendix A and Table 4.3-1). The monitoring histories for these five wells were examined for evidence of trends of increasing or decreasing chemical concentrations through time. The results of the trend analysis are summarized in Appendix F.

Although visual inspection of the temporal trends in chemical concentrations suggests that concentrations of CAHs in groundwater samples from wells A39L009PZ, SS45L001MW, A39L010PZ, and A39L011PZ have generally decreased through time, decreasing trends in concentrations could be confirmed statistically only for *cis*-1,2-DCE and total CAHs in samples from well A39L009PZ in the 800 Area, and for *cis*- and *trans*-1,2-DCE in samples from well A39L010PZ in the 2500 Area (Appendix F). A trend of increasing VC concentrations in groundwater samples from Deep Sand well SS45L002MW in the 800 Area also was confirmed statistically.

Groundwater samples have been collected from these wells during a maximum of only five sampling events over a 4-year period (1996 through 1999). The apparent absence of statistically demonstrable trends of decreasing chemical concentrations through time is probably a result of the limited historical monitoring record for groundwater at Site SS-45. Therefore, a full assessment regarding the degree to which the plume is at equilibrium (neither expanding nor receding) cannot be made on the basis of the available data. However, the site's hydrogeologic characteristics and the evidence of decreasing

concentrations of CAH compounds at several wells since 1996 suggest that the plumes in the 800 and 2500 Areas are at or near equilibrium.

4.5.2 Presence of Daughter Products

As described in Sections 4.3 and 4.4, the presence of daughter products, particularly *cis*-1,2-DCE, VC, and ethene, is strong evidence that TCE (the parent solvent) is being reductively dehalogenated. Furthermore, the anaerobic dehalogenation processes occurring in groundwater at Site SS-45 appear to be proceeding sufficiently rapidly to transform the bulk of the contaminant mass to non-chlorinated, non-toxic end products. TCE is present only sporadically in groundwater at the 2500 Area, and TCE and DCE isomers co-occur in groundwater in the 800 Area. This indicates that TCE is degrading relatively rapidly to DCE isomers. DCE isomers and VC co-occur in groundwater at several locations in the 800 and 2500 Areas, indicating that DCE is degrading to VC. In areas where VC is the primary CAH (parts of the 2500 Area), relatively elevated concentrations of ethene also occur, indicating that VC degradation also is occurring.

4.5.3 Chloride as an Indicator of Dehalogenation

Chlorine is removed from CAHs during reductive dehalogenation and enters solution as an anionic species. Therefore, chloride concentrations in groundwater should increase above background levels in areas where reductive dehalogenation is taking place. Concentrations of chloride in 1999 groundwater samples are presented in Table 4.5-1 and on Figures E.12 and E.13 in Appendix E. CAH compounds were not detected in groundwater samples from Intermediate Sand unit monitoring well A39L039DP, located southwest of the 800 Area. Chloride concentrations in groundwater samples from this well (4.8 mg/L) may therefore be representative of conditions in areas unaffected by CAH degradation (background conditions).

Concentrations of chloride elevated relative to the assumed background concentration were detected in samples from several Intermediate Sand unit wells in the 800 and 2500 Areas (Table 4.5-1). In general, the groundwater samples in which elevated chloride concentrations were detected also contained CAH compounds. However, because of the range of detected concentrations of chloride at Site S-45 (4.8 mg/L to 32.8 mg/L), this is not regarded as definitive evidence of the generation of chloride during dehalogenation of CAHs.

Similar observations can be made for chloride in groundwater of the Deep Sand unit. CAH compounds were not detected in samples from Deep Sand wells A39L002PZ, west of the 800 Area, or A39L022PZ, southwest of the 2500 Area. Chloride concentrations at these wells were 2.7J mg/L and 19.6 mg/L, respectively, and could represent background conditions in the Deep Sand unit. Concentrations of chloride from all Deep Sand wells within the 800 and 2500 Areas were elevated relative to the assumed background levels (Table 4.5-1). Again, however, this is not regarded as definitive evidence of the generation of chloride during dehalogenation of CAHs.

TABLE 4.5-1
GROUNDWATER GEOCHEMICAL DATA
MARCH-JULY, 1999
SITE SS-45
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Site Area	Monitoring Well ID	Sample Date	Temperature (°C) ^v	pH (SU) ^v	Conductivity (uS/cm) ^v	Dissolved Oxygen (mg/L) ^u	Redox Potential (mV) ^u	Total Alkalinity (mg/L)	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (Fixed-Based Lab) (mg/L)
Intermediate Sand Unit											
800 Area	WELL#10	Mar-1999	21.5	7	NA ⁰	0.15	-47	560	16.6	ND ^u	33.6
	WELL#10	May-1999	21.33	6.69	1.17	2.14	-46.6	NA	NA	NA	NA
	WELL#11	Mar-1999	22.0	6.84	0.90	0.41	-49	560	16.9	ND	3.4 J ⁿ
	WELL#13	Mar-1999	21.8	7	NA	0.11	57	480	11.8	ND	14.6
	WELL#13(DUP) ^v	Mar-1999	NA	NA	NA	NA	NA	480	NA	NA	NA
	WELL#13	May-1999	21.67	6.84	0.934	2.03	-116.8	NA	NA	NA	NA
	WELL#15	Mar-1999	21.8	6.84	0.82	0.49	-156	480	17.4	ND	52.7
	WELL#15(DUP)	Mar-1999	NA	NA	NA	NA	NA	NA	11.8	ND	15.9
	WELL#15	May-1999	21.1	6.76	0.861	0.23	-78.1	NA	NA	NA	NA
	WELL#17	Mar-1999	22.4	7	NA	0.21	88	1,280	8.8	0.26 J	47.4
	WELL#17(DUP)	Mar-1999	NA	NA	NA	NA	NA	NA	NA	NA	NA
	WELL#17	May-1999	22.3	6.7	0.9	0.3	67.0	NA	NA	NA	NA
	WELL#19	Mar-1999	21.8	7	NA	0.11	277	560	22.4	ND	81.3
	WELL#21	Jul-1999	21.4	6.69	0.95	0.28	53	NA	14.7	ND	38.4
	A39L008DP	Mar-1999	23.0	6.65	1.31	0.74	-26	640	13	ND	54.8
	A39L008DP(DUP)	Mar-1999	NA	NA	NA	NA	NA	NA	NA	NA	NA
	A39L009PZ	Mar-1999	21.7	6.85	0.85	0.58	-54	400	32.8	ND	19.2
	A39L009PZ(DUP)	Mar-1999	NA	NA	NA	NA	NA	400	32.4	ND	19.2
	A39L039DP	Mar-1999	20.8	7	NA	0.13	-162	380	4.8	ND	21
	SS45L001MW	Mar-1999	21.5	6.89	0.87	0.31	-14	560	18.6	ND	44.4
	SS45L001MW	May-1999	20.62	6.78	1.028	0.23	-89.4	NA	NA	NA	NA
2500 Area	WELL#1	Mar-1999	20.8	6.86	0.96	0.32	-149	560	6.5	ND	ND
	WELL#1	May-1999	20.28	6.74	1.059	0.33	-146.9	NA	NA	NA	NA
	WELL#2	Mar-1999	20.7	6.86	0.91	0.33	-162	560	7.2	ND	2.7 J
	WELL#2	May-1999	20.6	6.81	0.925	1.77	-123.8	NA	NA	NA	NA
	WELL#3	Mar-1999	21.1	6.88	0.87	0.43	-138	560	8.4	ND	1.5 J
	WELL#3(DUP)	Mar-1999	NA	NA	NA	NA	NA	480	NA	NA	NA
	WELL#3	May-1999	20.11	6.7	0.922	0.25	-151.8	NA	NA	NA	NA
	WELL#4	Mar-1999	20.8	6.89	0.93	0.3	-149	640	16.4	ND	1.2 J
	WELL#4	May-1999	20.2	6.8	0.95	0.1	-145	NA	NA	NA	NA
	WELL#4 (DUP)	May-1999	NA	NA	NA	NA	NA	NA	NA	NA	NA
	WELL#5	Mar-1999	22.1	6.42	1.06	0.24	-123	160	27.6	ND	1.5 J
	WELL#5(DUP)	Mar-1999	NA	NA	NA	NA	NA	NA	27.2	ND	1.5 J
	WELL#5	May-1999	21.79	6.53	1.061	0.12	-155.6	NA	NA	NA	NA
	WELL#6	Mar-1999	21.7	6.99	0.86	0.27	-136	720	10	ND	ND
	WELL#7	Mar-1999	22.4	6.74	1.03	0.41	-79	620	7.9	ND	2.8 J
	WELL#8	Jul-1999	20.6	6.387	0.92	0.32	-18	640	12.3	ND	1.6
	A39L010PZ	Mar-1999	19.8	7	NA	0.14	-170	640	14.9	0.25 J	ND
	A39L011PZ	Mar-1999	20.8	7	NA	0.11	-193	720	8.9	0.38 J	1.2 J
	A39L011PZ(DUP)	Mar-1999	NA	NA	NA	NA	NA	720	NA	NA	NA
	A39L011PZ	May-1999	21.5	6.63	1.117	0.06	-152.41	NA	NA	NA	NA
	A39L012PZ	Mar-1999	20.5	6.84	0.91	0.35	-180	620	6.2	NA	ND
	A39L012PZ(DUP)	Mar-1999	NA	NA	NA	NA	NA	NA	23.4	0.38 J	2 J
	A39L013PZ	Mar-1999	21.6	6.9	0.98	0.34	-130	640	13.7	ND	1.8 J
	A39L013PZ(DUP)	Mar-1999	NA	NA	NA	NA	NA	NA	NA	NA	NA
	A39L013PZ	May-1999	20.68	6.77	1.079	1.9	-128.6	NA	NA	NA	NA

TABLE 4.5-1 (CONTINUED)
GROUNDWATER GEOCHEMICAL DATA
MARCH-JULY, 1999
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Site Area	Monitoring Well ID	Sample Date	Sulfate (Field Lab) (mg/L)	Sulfide (mg/L)	Manganese (mg/L)	Ferrous Iron (mg/L)	Carbon Dioxide (mg/L)	TOC ^v (mg/L)	Dissolved Hydrogen (nM/L) ^v	Methane (µg/L) ^v	Turbidity (NTU) ^{iv}
Intermediate Sand Unit											
800 Area	WELL#10	Mar-1999	115.6	ND	2.4	1.73	105	0.84 J	NA	580	38
	WELL#10	May-1999	NA	NA	NA	NA	NA	NA	0.92	NA	144
	WELL#11	Mar-1999	ND	0.021	2.2	4.02	170	1.1	NA	1,500	NA
	WELL#13	Mar-1999	6.3	0.01	1.1	2.84	160	0.36 J	NA	170	1.1
	WELL#13(DUP)	Mar-1999	2.4	ND	1	2.77	160	NA	NA	NA	NA
	WELL#13	May-1999	NA	NA	NA	NA	NA	NA	1.02	NA	57
	WELL#15	Mar-1999	8.9	0.012	0.8	2.50	140	ND	NA	1,100	0.6
	WELL#15(DUP)	Mar-1999	NA	NA	NA	NA	NA	ND	NA	1,100	NA
	WELL#15	May-1999	NA	NA	NA	NA	NA	NA	64.2	NA	38
	WELL#17	Mar-1999	66.2	0.009	0.7	ND	95	ND	NA	10	0.5
	WELL#17(DUP)	Mar-1999	64.6	0.016	0.4	ND	NA	NA	NA	NA	NA
	WELL #17	May-1999	NA	NA	NA	NA	NA	NA	2.65	NA	72
	WELL#19	Mar-1999	116	ND	1	1.59	85	ND	NA	9.6	0.7
	WELL#21	Jul-1999	ND	NA	NA	NA	NA	NA	NA	83	0.8
	A39L008DP	Mar-1999	73.5	0.008	0.9	0.35	180	ND	NA	18	0.5
	A39L008DP(DUP)	Mar-1999	73.8	ND	0.9	0.35	160	NA	NA	NA	NA
	A39L009PZ	Mar-1999	18.8	0.013	1.5	3.88	95	ND	NA	160	0.6
	A39L009PZ(DUP)	Mar-1999	17.8	0.013	1.6	4.13	100	ND	NA	130	NA
	A39L039DP	Mar-1999	22.5	0.012	0.7	2.16	120	0.54 J	NA	NA	40.2
	SS45L001MW	Mar-1999	52.5	ND	0.33	2.15	160	ND	NA	170	NA
	SS45L001MW	May-1999	NA	NA	NA	NA	NA	NA	0.71	NA	6
2500 Area	WELL#1	Mar-1999	ND	0.012	1.1	4.60	48	1.4	NA	4,000	4.8
	WELL#1	May-1999	NA	NA	NA	NA	NA	NA	1.04	NA	32
	WELL#2	Mar-1999	ND	0.022	1.1	4.70	54	0.91 J	NA	3,800	8.6
	WELL#2	May-1999	NA	NA	NA	NA	NA	NA	1.23	NA	8.6
	WELL#3	Mar-1999	ND	0.012	1.7	4.20	46	0.91 J	NA	3,400	6.6
	WELL#3(DUP) ^v	Mar-1999	ND	0.016	1.7	4.40	55	NA	NA	NA	NA
	WELL#3	May-1999	NA	NA	NA	NA	NA	NA	0.92	NA	NA
	WELL#4	Mar-1999	ND	ND	1.5	4.42	50	0.97 J	NA	3,300	5.2
	WELL#4	May-1999	NA	NA	NA	NA	NA	NA	0.79	NA	485
	WELL#4 (DUP)	May-1999	NA	NA	NA	NA	NA	NA	0.84	NA	NA
	WELL#5	Mar-1999	ND	ND	3	4.70	65	2.3	NA	1,600	6.7
	WELL#5(DUP)	Mar-1999	NA	NA	NA	NA	NA	2.4	NA	770	NA
	WELL#5	May-1999	NA	NA	NA	NA	NA	NA	4.03	NA	45
	WELL#6	Mar-1999	ND	ND	1.7	4.64	55	127	NA	4,200	5.3
	WELL#7	Mar-1999	ND	0.008	4.9	3.43	70	1.1	NA	240	6.9
	WELL#8	Jul-1999	ND	ND	2.6	4.06	80	NA	NA	8,300	0.6
	A39L010PZ	Mar-1999	ND	0.009	4.1	4.40	85	1.3	NA	3,100	2.6
	A39L011PZ	Mar-1999	ND	0.021	3.1	4.23	50	1.3	NA	1,600	4.6
	A39L011PZ(DUP)	Mar-1999	ND	0.013	3.4	4.68	90	NA	7.26	NA	NA
	A39L011PZ	May-1999	NA	NA	NA	NA	NA	NA	NA	NA	316
	A39L012PZ	Mar-1999	ND	ND	2.2	4.33	85	1.3	NA	4,700	2.9
	A39L012PZ(DUP)	Mar-1999	NA	NA	NA	NA	NA	NA	NA	NA	NA
	A39L013PZ	Mar-1999	ND	ND	3	4.04	60	141	NA	3,800	6.9
	A39L013PZ(DUP)	Mar-1999	ND	ND	3	4.32	80	NA	NA	NA	NA
	A39L013PZ	May-1999	NA	NA	NA	NA	NA	NA	1.11	NA	0.11

TABLE 4.5-1 (CONTINUED)
GROUNDWATER GEOCHEMICAL DATA
MARCH-JULY, 1999
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Site Area	Monitoring Well ID	Sample Date	Temperature (°C)	pH (SU)	Conductivity (uS/cm)	Dissolved Oxygen (mg/L)	Redox Potential (mV)	Total Alkalinity (mg/L)	Chloride (mg/L)	Nitrate (mg/L)	Sulfate (Fixed-Based Lab) (mg/L)
	A39L015PZ	May-1999	NA	NA	NA	NA	NA	NA	NA	NA	NA
	A39L018PZ	Mar-1999	22.0	6.88	0.92	0.35	-156	560	13.9	0.26 J	ND
	A39L019PZ	Mar-1999	21.3	6.83	0.97	0.37	-151	640	8.6	NA	ND
	A39L019PZ(DUP)	Mar-1999	NA	NA	NA	NA	NA	NA	28	0.3 J	1.8 J
	A39L019PZ	May-1999	20.72	6.59	0.992	0.22	-153.7	NA	NA	NA	NA
Deep Sand Unit											
800 Area	WELL#12	Mar-1999	21.8	6.84	0.84	0.35	-17	480	13.5	ND	2 J
	WELL#14	Mar-1999	21.7	6.8	0.84	0.45	-163	480	10.6	ND	2.4 J
	WELL#14	May-1999	20.94	6.74	0.879	0.24	-100.5	NA	NA	NA	NA
	WELL#16	Mar-1999	21.5	7	NA	0.26	-78	480	23.3	ND	62
	WELL#18	Mar-1999	21.6	7	NA	0.12	-97	480	13.6	ND	43.9
	WELL#20	Mar-1999	21.0	7	NA	0.14	-41	560	11.8	ND	15.6
	WELL#20	May-1999	21.06	6.67	0.996	0.26	-99.3	NA	NA	NA	NA
	A39L001PZ	Mar-1999	22.4	7	NA	0.32	-85	400	17.7	ND	47.5
	A39L002PZ	Mar-1999	18.8	7.6	NA	0.1	-126	100	2.7 J	ND	10.4
	A39L008PZ	Mar-1999	22.0	7	NA	0.11	-198	560	10.8	ND	10.2
	A39L028DP	Mar-1999	22.0	6.89	0.87	0.51	-76	480	10.5	ND	2 J
	A39L039DP	Mar-1999	20.8	7	NA	0.13	-162	380	NA	NA	NA
	A39L039DP	May-1999	20.35	6.88	0.755	1.9	-83.9	NA	NA	NA	NA
	SS45L002MW	Mar-1999	21.6	6.83	0.93	0.43	-30	480	32.3	ND	10.3
	SS45L002MW(DUP)	Mar-1999	NA	NA	NA	NA	NA	480	NA	NA	NA
2500 Area	SS45L002MW	May-1999	20.64	6.72	1.073	0.26	-110.9	NA	NA	NA	NA
	A39L022PZ	Mar-1999	21.8	6.86	0.87	0.21	-87	520	19.6	ND	1.2 J
	A39L082DP	Mar-1999	20.0	7	NA	0.17	-178	560	35.6	8	4 J
	A39L092DP	Mar-1999	20.7	7	NA	0.14	-187	640	40.8	ND	11

TABLE 4.5-1 (CONCLUDED)
GROUNDWATER GEOCHEMICAL DATA
MARCH-JULY, 1999
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Site Area	Monitoring Well ID	Sample Date	Sulfate (Field Lab) (mg/L)	Sulfide (mg/L)	Manganese (mg/L)	Ferrous Iron (mg/L)	Carbon Dioxide (mg/L)	TOC (mg/L)	Dissolved Hydrogen (nM/L)	Methane (µg/L)	Turbidity (NTU)
	A39L015PZ	May-1999	NA	NA	NA	NA	NA	NA	1.36	NA	NA
	A39L018PZ	Mar-1999	ND	0.013	1.4	4.82	50	2.7	NA	6,900	16.1
	A39L019PZ	Mar-1999	ND	ND	1.7	4.71	61	0.93 J	NA	4,600	6.2
	A39L019PZ(DUP)	Mar-1999	ND	ND	1.6	4.43	NA	NA	NA	NA	NA
	A39L019PZ	May-1999	NA	NA	NA	NA	NA	NA	8.48	NA	24
Deep Sand Unit											
800 Area	WELL#12	Mar-1999	ND	ND	0.8	2.79	160	1.7	NA	1,200	0.8
	WELL#14	Mar-1999	ND	0.009	0.9	3.27	150	0.29 J	NA	540	0.5
	WELL#14	May-1999	NA	NA	NA	NA	NA	NA	16.1	NA	15
	WELL#16	Mar-1999	85.3	0.009	0.5	3.07	90	ND	NA	15	1.4
	WELL#18	Mar-1999	47.9	ND	0.8	2.79	65	0.26 J	NA	18	0.6
	WELL#20	Mar-1999	73.8	0.017	1.2	0.85	80	ND	NA	19	16.3
	WELL#20	May-1999	NA	NA	NA	NA	NA	NA	8.58	NA	39
	A39L001PZ	Mar-1999	66.3	ND	0.4	1.26	85	ND	NA	8.5	1.3
	A39L002PZ	Mar-1999	ND	0.014	ND	ND	100	16	NA	1.1	2.9
	A39L008PZ	Mar-1999	ND	ND	0.4	3.84	120	ND	NA	230	0.6
	A39L028DP	Mar-1999	ND	ND	0.7	4.29	140	0.28 J	NA	730	0.6
	A39L039DP	Mar-1999	22.5	0.012	0.7	2.16	120	NA	NA	8.9	40.2
	A39L039DP	May-1999	NA	NA	NA	NA	NA	NA	0.86	NA	187
	SS45L002MW	Mar-1999	ND	0.024	1	4.14	105	0.99 J	NA	610	2.9
	SS45L002MW(DI)	Mar-1999	ND	0.019	1.2	3.88	120	NA	NA	NA	NA
2500 Area	SS45L002MW	May-1999	NA	NA	NA	NA	NA	NA	0.9	NA	22
	A39L022PZ	Mar-1999	ND	0.014	3.5	5.92	60	130 J	NA	1,900	4.4
	A39L082DP	Mar-1999	ND	ND	0.1	3.95	48	1	NA	NA	2.3
	A39L092DP	Mar-1999	ND	ND	0.2	4.10	55	0.98 J	NA	66	2.9

[°] °C = degrees Centigrade.

^u SU = Standard units.

^u S/cm = microsiemens per centimeter.

^g mg/L = milligrams per liter.

^v mV = millivolts.

^v NA = Not analyzed.

^v ND = not detected.

^h J = The analyte is qualified as an estimated value.

^v DUP = Duplicate sample.

^u TOC = Total organic carbon.

^u nM/L = nanomoles per liter.

^u µg/L = micrograms per liter.

^u NTU = Nephelometric turbidity units.

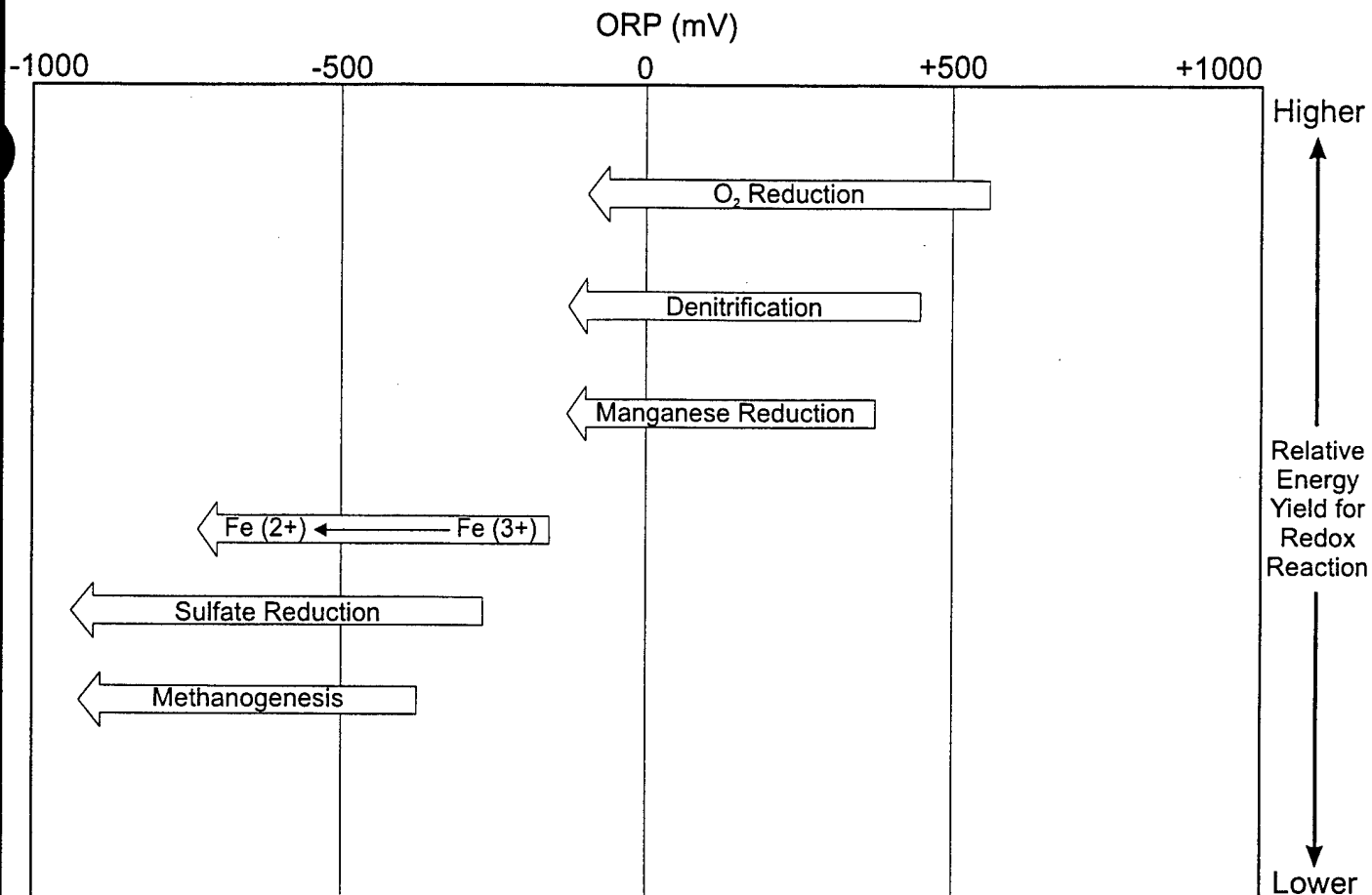
4.5.4 ORP and Dissolved Hydrogen as Indicators of Redox Processes

As described in Section 4.2.1, microorganisms will facilitate only those redox reactions that yield energy. For example, by coupling the oxidation of fuel hydrocarbon compounds or native organic carbon, which requires energy, to the reduction of other compounds (e.g., DO, nitrate, manganese, ferric iron, sulfate, carbon dioxide, and possibly *cis*-1,2-DCE), which yields energy, the overall reaction will yield energy.

Figure 4.5-1 illustrates the sequence of microbially mediated redox processes and identifies the approximate ranges of ORPs that are favorable for each process. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981; Godsey, 1994; Reinhard, 1994). As shown on Figure 4.5-1, oxygen reduction would be expected to occur in an aerobic environment with microorganisms capable of aerobic respiration because oxygen reduction yields significant energy (Bouwer, 1992; Chapelle, 1993). However, once the available DO is depleted and anaerobic conditions dominate in the interior regions of a contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate (denitrification), manganese (manganese reduction), ferric iron (iron reduction), sulfate (sulfate reduction), and finally carbon dioxide (methanogenesis). Each successive redox reaction provides less energy to the system, and each step down in redox energy yield would have to be paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

Values of ORP were measured at groundwater monitoring wells during the period through July 1999 sampling event. These data are summarized in Table 4.5-1, and the areal distribution of ORP values in groundwater in the Intermediate and Deep Sand units is illustrated on Figures 4.5-2 and 4.5-3, respectively. As expected, ORP values are quite low (below -130 millivolts [mV]) in the 2500 Area, and remain negative (generally in the range of -10 mV to -80 mV) in the central part of the 800 Area. Areas of low ORP thus coincide with areas of decreased sulfate and elevated ferrous iron and methane concentrations (subsequent sections). The larger, negative values of ORP measured in groundwater within the 2500 Area versus those measured within the 800 Area may be an indicator of differing geochemical conditions, or may occur because of the greater extent to which reductive dehalogenation has proceeded in the 2500 Area.

Dissolved hydrogen (H_2) concentrations also can be used to determine the dominant terminal electron-accepting process (TEAP) in an aquifer. This method has been shown to provide a direct, independent measurement that identifies which redox reactions are taking place in anaerobic groundwater (Lovley and Goodwin, 1988; Lovley *et al.*, 1994; Vroblesky and Chapelle, 1994; Chapelle *et al.*, 1995). The efficiency of reductive dehalogenation increases as a system becomes more reducing (i.e., proceeds from denitrifying conditions to ferric-iron-reducing, sulfate-reducing, and methanogenic conditions). Therefore, it is helpful to define redox conditions more accurately than can be determined using field redox meters when evaluating the potential for RNA of CAHs in groundwater. When dissolved H_2 concentrations are measured using the methods presented by the aforementioned authors, the concentrations directly indicate which TEAP is dominant in a given location at a given time, as outlined in Table 4.5-2.



Notes

ORP = Oxidation Reduction Potential

1. These reactions would be expected to occur in sequence if the system is moving toward equilibrium.
2. These redox processes occur in order of their energy-yielding potential (provided microorganisms are available to mediate a specific reaction). Reduction of a highly oxidized species decreases the ORP of the system.
3. The ORP of the system determines which electron acceptors are available for organic carbon oxidation.
4. Redox sequence is paralleled by an ecological succession of biological mediators.

FIGURE 4.5-1

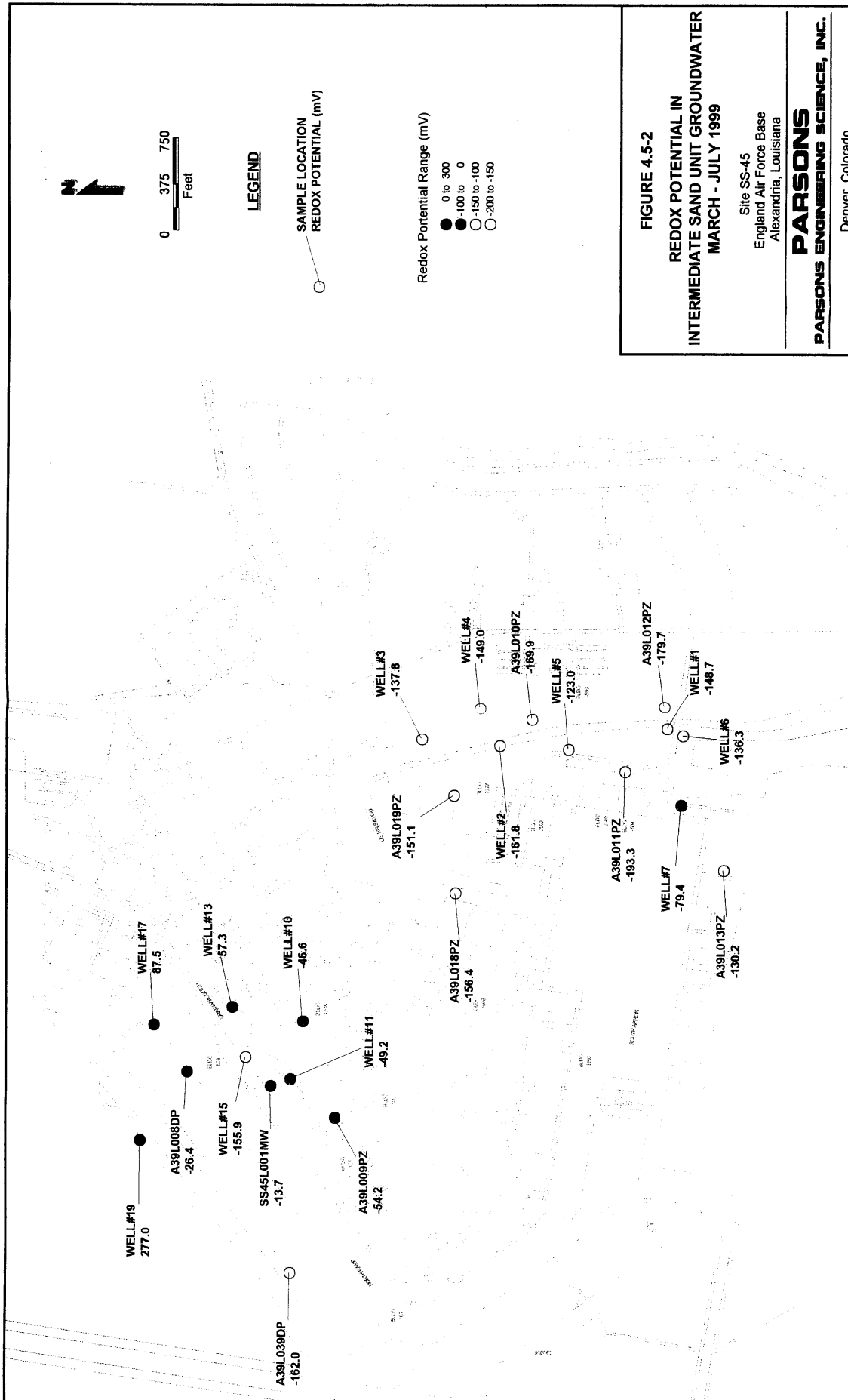
SEQUENCE OF MICROBIOLOGICALLY MEDIATED REDOX PROCESSES

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

Adapted from Stumm and Morgan, 1981 and Norris *et al.*, 1994.



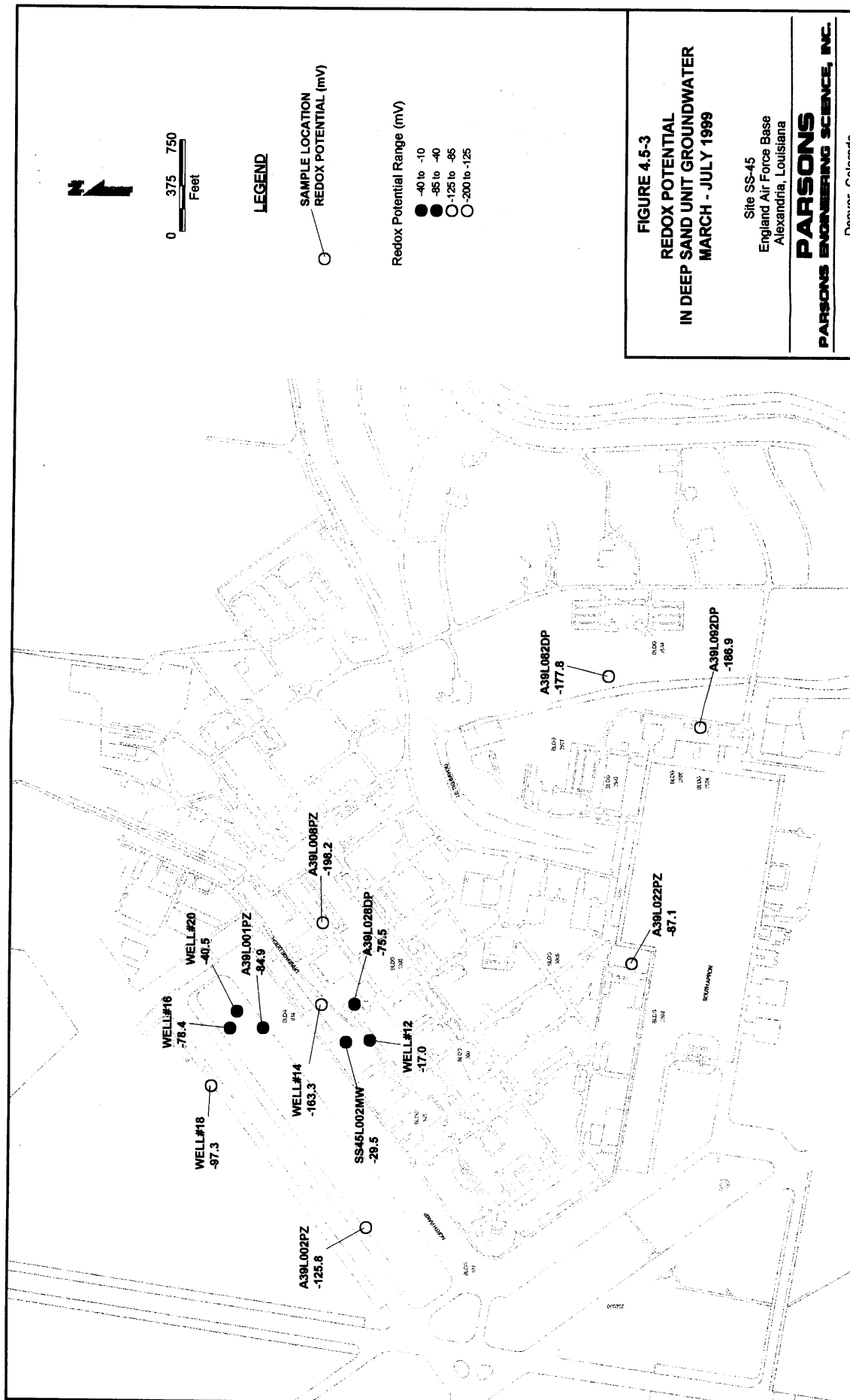


FIGURE 4.5-3
REDOX POTENTIAL
IN DEEP SAND UNIT GROUNDWATER
MARCH - JULY 1999

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

TABLE 4.5-2
RANGE OF HYDROGEN CONCENTRATIONS FOR GIVEN
TERMINAL ELECTRON-ACCEPTING PROCESSES

SITE SS-45
 ENGLAND AIR FORCE BASE
 ALEXANDRIA, LOUISIANA

Terminal Electron-Accepting Process	Hydrogen Concentration (nM/L)
Denitrification	<0.1
Ferric Iron Reduction	0.2 to 0.8
Sulfate Reduction	1 to 4
Methanogenesis	>5

Source: Chapelle *et al.*, 1995.

Groundwater samples for H₂ analysis were collected from 15 Intermediate Sand unit monitoring wells and 3 Deep Sand unit wells at Site SS-45, in May 1999 (Section 2.3). The results of these analyses are summarized in Table 4.5-1, and displayed on Figures E.14 and E.15 in Appendix E. Measured H₂ concentrations ranged from 0.71 nanomole per liter (nM/L) to 64.19 nM/L, and confirm anaerobic aquifer conditions in both background and plume wells. The magnitudes of the detected H₂ concentrations indicate that iron reduction or sulfate reduction were the dominant TEAPs in most parts of the 800 Area and 2500 Area at the time of sample collection, while methanogenesis was favored at some locations (Wells #2, A39L011PZ, and A39L019PZ in the 2500 Area and well pair #14/#15 in the 800 Area). Vroblesky and Chapelle (1994) note that TEAPs can vary both spatially and temporally within a plume, with shifts taking place in as little as 10 days.

4.5.5 Electron Donors

When investigating the biodegradation of CAHs, it is also necessary to examine the distribution of other compounds that are used in the microbially mediated reactions that facilitate CAH degradation. The distributions of potential electron donors, including BTEX compounds, dissolved native organic carbon, and CAHs themselves, are useful for evaluating the feasibility of reductive dehalogenation, aerobic biodegradation, or cometabolism (i.e., CAH degradation reactions involving another substrate).

4.5.5.1 BTEX Constituents in Groundwater

The presence of fuel constituents (including BTEX) in the same area as a CAH plume can create favorable conditions for reductive dehalogenation, because the petroleum compounds provide a source of electron donors and facilitate microbial reactions that decrease the local groundwater ORP. It is possible that the release of fuel hydrocarbon compounds in the same general areas as TCE releases stimulated additional microbial

activity and encouraged reductive dehalogenation of CAHs at Site SS-45. However, the concentrations of BTEX compounds that have been detected in groundwater at Site SS-45 are, in general, much lower than CAH concentrations; and these compounds have been detected in site groundwater only sporadically (Appendix A and Table 4.3-1). Therefore, BTEX and other fuel constituents in groundwater at Site SS-45 are not regarded as chemicals of potential concern. Rather, given the conditions at the site, the presence of BTEX constituents in site groundwater is considered to be a favorable factor in promoting biodegradation of CAHs.

Experience implementing the AFCEE *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater* (Wiedemeier *et al.*, 1995) at nearly 40 locations at Air Force bases nationwide suggests that biodegradation of fuel hydrocarbons, including BTEX, is essentially ubiquitous in a wide variety of hydrogeologic settings. Fuel constituents at Site SS-45 are therefore expected to readily biodegrade, and thereby to promote the concurrent degradation of CAH compounds in groundwater.

BTEX constituents were detected in groundwater at 22 HydroPunch® locations in 1996 and 1997 (Appendix A). Where detected, the concentrations of individual constituents ranged from < 1 µg/L to several hundred µg/L (326 µg/L of benzene and 605 µg/L of ethylbenzene at Intermediate Sand unit boring A39L089DP), located between the 800 Area and 2500 Area (Figure 1.3-4). The remaining HydroPunch® locations at which BTEX constituents were detected were in the central and western parts of the 2500 Area.

After monitoring wells were installed at Site SS-45, low concentrations of BTEX constituents were detected regularly at wells A39L010PZ and A39L0112PZ in the 2500 Area; and benzene was detected once at Deep Sand well SS45L093DP in the 800 Area (Table 1.3-2). Low concentrations of benzene (< 1 µg/L) were detected in samples from wells A39L010PZ and A39L011PZ during the 1999 sampling event (Table 4.3-1), and ethylbenzene, xylenes, and trimethylbenzenes (common fuel constituents) were detected in the February 1999 sample from Well #6. These wells are completed in the Intermediate Sand unit in the 2500 Area. Toluene was detected at estimated concentrations in two wells (Well#17 in the 800 Area and Well#4 in the 2500 Area) during the 1999 sampling.

The presence of fuel constituents dissolved in groundwater at the 2500 Area is important because biodegradation of those compounds helps generate conditions that favor CAH dehalogenation. In addition, the petroleum compounds provide a source of electron donors and carbon (i.e., a substrate) for the microbial population, supplementing native organic carbon already present in the Intermediate and Deep Sand units. The coincidence of dissolved BTEX with the highest concentrations of the reductive dehalogenation daughter products (VC and ethene) at the 2500 Area may explain some of the apparent differences in the suites of CAH compounds in groundwater within the two areas at Site SS-45.

4.5.5.2 Native Organic Carbon in Groundwater

Dissolved native organic carbon also can act as a source of electron donors during reductive dehalogenation of CAHs. Dissolved TOC concentrations in wells outside of the area containing dissolved organic chemicals can be used as an indicator of the presence of native carbon compounds (anthropogenic organic compounds, such as CAHs or petroleum hydrocarbons, also are measured by the TOC analytical method).

TOC was measured in groundwater samples collected during the period from March through July 1999 (Table 4.5-1). Dissolved TOC concentrations in the Intermediate Sand system ranged from "not detected" to 141 mg/L (Figure 4.5-4). In general, dissolved TOC was not detected in groundwater samples from Intermediate Sand unit wells in the 800 Area. Dissolved TOC concentrations in Intermediate Sand unit wells in the 2500 Area were typically in the range of 1 to 2 mg/L. The dissolved TOC concentration was elevated at Well #6 (127 mg/L) in the 2500 Area, which also contained trimethylbenzenes (see Section 4.5.5.1).

Dissolved TOC concentrations in groundwater within the Deep Sand system ranged from "not detected" to 130 mg/L (Figure 4.5-5). Dissolved TOC was not detected in groundwater samples from four Deep Sand unit wells in the 800 Area. Southwest of the 800 Area, dissolved TOC was detected at a concentration of 16 mg/L at well A39L002PZ (Figure 4.5-5), which lies outside the zone affected by CAH compounds in groundwater at the 800 Area. Therefore, the dissolved TOC concentration at this well may be representative of background TOC concentrations in groundwater of the Deep Sand unit in the 800 Area.

Dissolved TOC concentrations were most elevated in the groundwater sample from well A39L022PZ (130 mg/L), located between the 800 and 2500 Areas. Organic chemicals have not been detected in groundwater samples from this well, and it is outside the zone affected by CAHs in groundwater at the 2500 Area. The dissolved TOC concentration detected in the sample from this well may therefore be representative of background TOC concentrations in groundwater of the Deep Sand unit in the 2500 Area.

The significantly elevated dissolved TOC concentrations in areas where organic chemicals have historically been detected in groundwater are possibly an indicator of the presence of organic contaminants, as well as native TOC. The elevated "background" concentrations of dissolved TOC are noteworthy because they represent additional organic matter that is available for use as a substrate in biodegradation reactions. The assumed background concentrations likely represent compounds dissolved from naturally-occurring organic matter dispersed throughout the Intermediate and Deep Sand units. The wetland deposits originally present in the 2500 Area (Section 3.2.2) and the stratum of wood debris within the Intermediate Sand unit (Section 3.4.1) may serve as sources of naturally-occurring organic matter in the subsurface. In addition to TOC in soil (Table 4.1-1), the dissolved native carbon should provide a continuing source of electron donors to be used in microbial redox reactions.

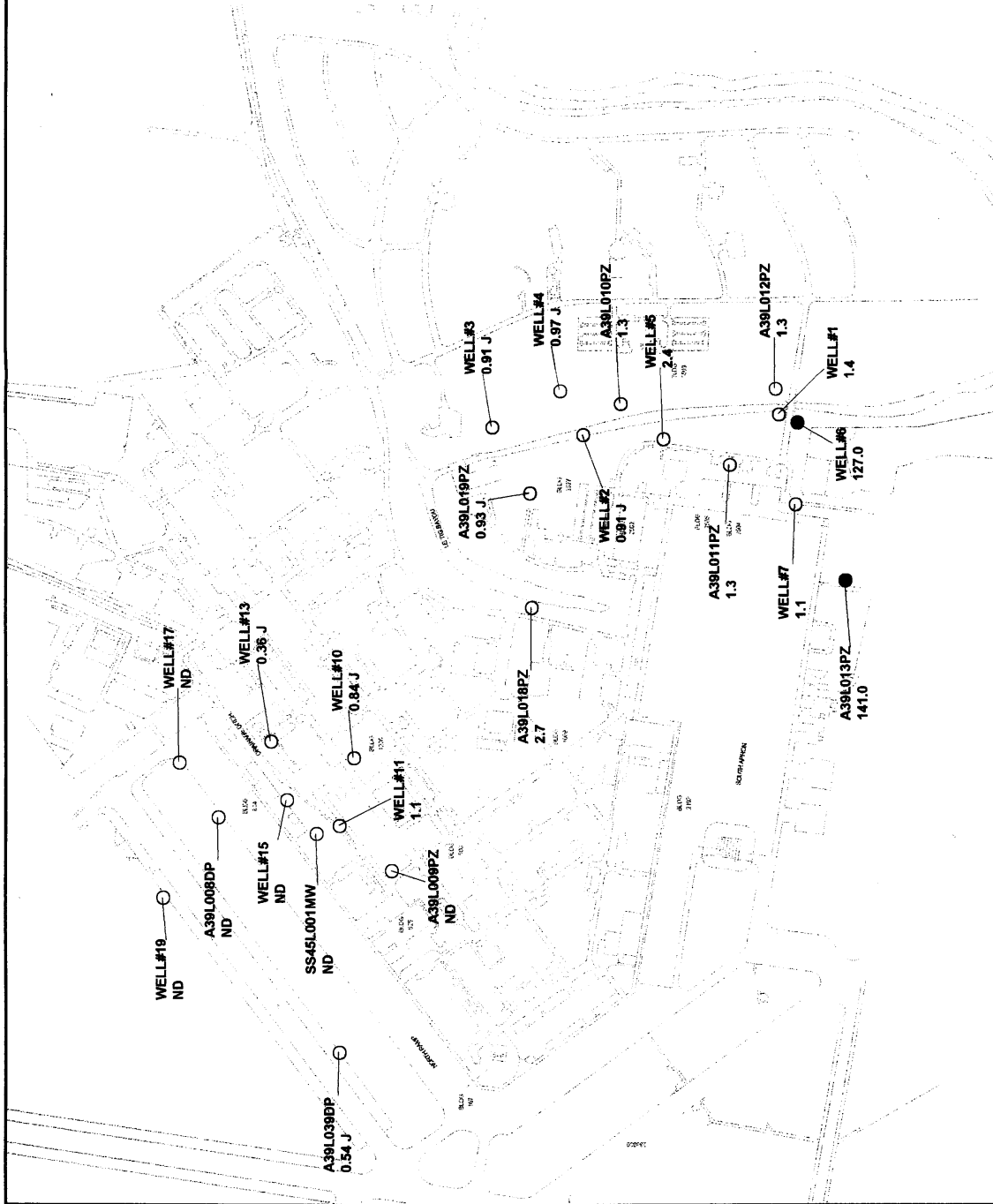


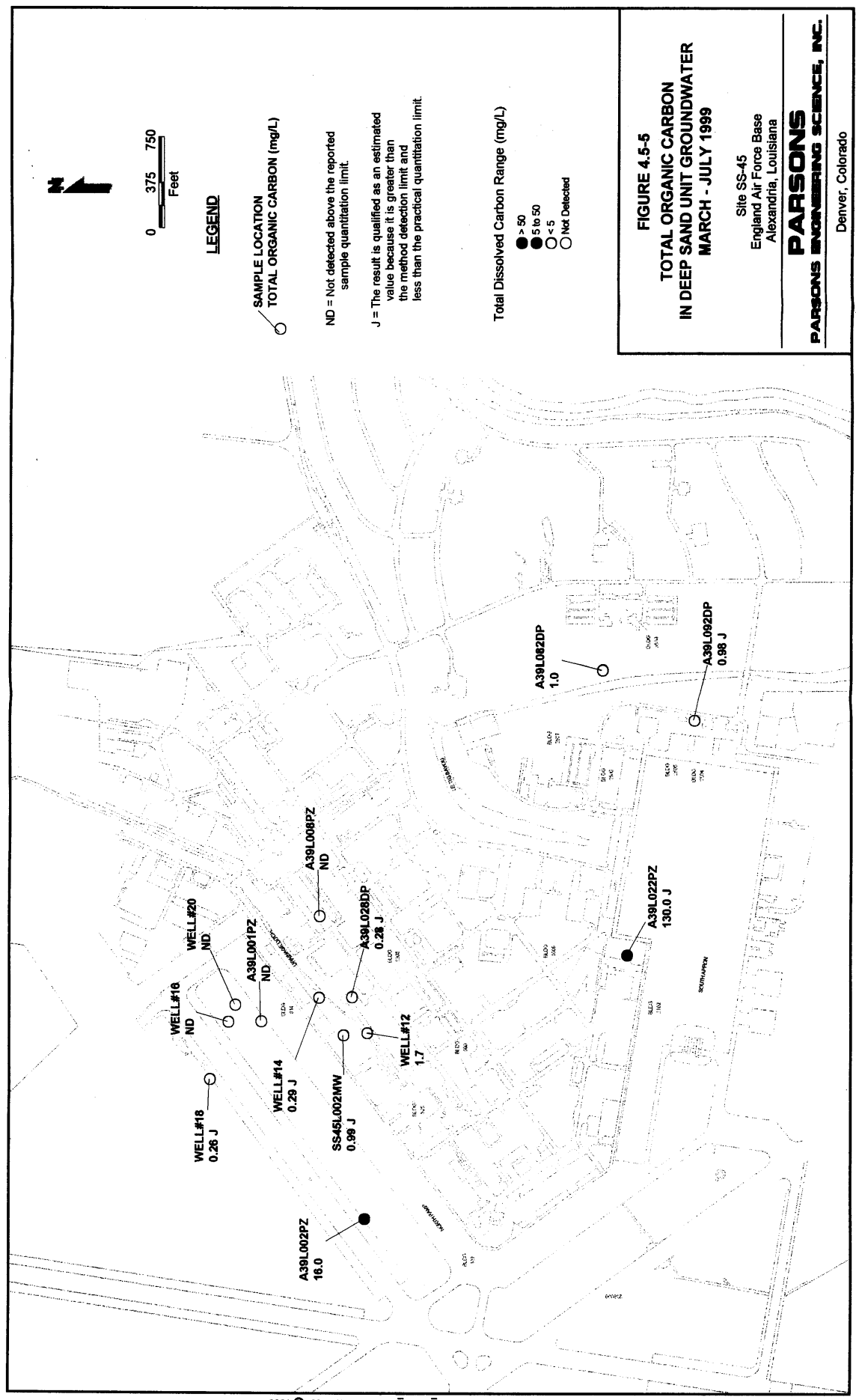
FIGURE 4.5-4

**TOTAL ORGANIC CARBON IN
INTERMEDIATE SAND UNIT GROUNDWATER
MARCH - JULY 1999**

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4.5.5.3 Use of CAHs as Electron Donors

As described in Section 4.2.3.2, less-chlorinated CAHs (e.g., DCE and VC) can be used as the primary substrate ("electron donors") in aerobic environments, resulting in biodegradation of the CAHs (USEPA, 1998). Although the concentrations of native organic carbon (the microbially-preferred substrate) are relatively high (Tables 4.1-1 and 4.5-1), it is possible that DCE and VC are being degraded through use as the primary substrate ("electron donors") in microbially-mediated redox reactions.

4.5.6 Alternate Electron Acceptors and Metabolic Byproducts

Biodegradation of organic compounds, whether natural or anthropogenic, brings about measurable changes in the chemistry of groundwater in the affected area. Concentrations of compounds used as electron acceptors (e.g., DO, nitrate, and sulfate) are depleted, and byproducts of electron acceptor reduction (e.g., ferrous iron, methane, and sulfide) are increased. By measuring these changes, it is possible to evaluate the relative importance of natural attenuation mechanisms occurring at a site.

4.5.6.1 Dissolved Oxygen

Reductive dechlorination is an anaerobic process; therefore, the presence of DO may suppress the reductive dechlorination pathway. Highly chlorinated compounds, such as TCE, are biologically recalcitrant under aerobic conditions. However, all three isomers of DCE can be biodegraded in aerobic systems, with *cis*-1,2-DCE being degraded more rapidly than the other isomers (Klier *et al.*, 1996). In addition, aerobic biodegradation of VC is rapid relative to other mechanisms of VC degradation, especially reductive dechlorination.

DO concentrations were measured during collection of 1999 groundwater samples (Table 4.5-1). The concentrations of DO in groundwater samples from the Intermediate Sand unit ranged from 0.11 mg/L to 0.74 mg/L, and DO concentrations in the Deep Sand unit ranged from 0.10 mg/L to 0.51 mg/L (Figures E.16 and E.17, Appendix E). These DO measurements indicate that anaerobic conditions prevail in groundwater throughout Site SS-45, in both the Intermediate and Deep Sand units. Such conditions throughout Site SS-45 promote the occurrence of reductive dechlorination of CAH compounds in groundwater.

The site-wide anaerobic conditions suggest that DO is being consumed, most likely as microbes use native organic carbon as a substrate. This provides additional, indirect evidence that the elevated concentrations of dissolved organic carbon in groundwater samples from presumed background wells may be correct. As demonstrated by the results of analyses of soil samples (Section 4.1.1), considerable organic carbon is naturally present in soil at Site SS-45, and wood debris was noted at several intervals in the Intermediate and Deep Sand units during drilling of boreholes in the 800 Area (Section 3).

4.5.6.2 Nitrate/Nitrite

After DO has been depleted in the subsurface, nitrate may be used as an electron acceptor for anaerobic biodegradation of organic carbon via denitrification. Nitrate concentrations below possible background levels in areas with high organic carbon concentrations and low DO are indicative of denitrification. The oxidation of organic carbon via the process of denitrification (using nitrate as an electron acceptor) yields a relatively large amount of free energy to microorganisms, and therefore is energetically preferable to the use of CAHs as electron acceptors. In areas where nitrate concentrations exceed 1 mg/L, the microorganisms may then use nitrate instead of CAHs as an electron acceptor during energy-producing reactions (Wiedemeier *et al.*, 1996b).

Concentrations of nitrate as nitrogen were analyzed in groundwater samples collected in 1999 (Table 4.5-1). Nitrate was not detected in most groundwater samples collected from Intermediate Sand unit wells (Figure E.18, Appendix E). In those samples in which nitrate was detected, the concentrations were low (below the PQL). No pattern is apparent in the distribution of nitrate in groundwater samples from the Intermediate Sand unit; and the low nitrate concentrations suggest either that little nitrate is naturally present in groundwater at Site SS-45, or that nitrate in groundwater has been depleted as a consequence of denitrification reactions.

Nitrate was detected, at a concentration of 8 mg/L, in the groundwater sample from well A39L082DP, completed in the Deep Sand unit in the 2500 Area (Table 4.5-1 and Figure E.19, Appendix E). Nitrate was not detected in any other Deep Sand unit groundwater sample collected during the period from March through July, 1999. The generally low concentrations of nitrate in groundwater samples suggest that nitrate is probably not competing with degradation of CAH compounds via the reductive pathway.

4.5.6.3 Ferrous Iron and Manganese

Although relatively little is known about the anaerobic metabolic pathways involving the reduction of ferric iron (Fe^{3+}), this process has been shown to be a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). The reduction of ferric iron (which is relatively insoluble) generates soluble ferrous iron (Fe^{2+}), which can remain in solution in groundwater. Elevated concentrations of ferrous iron are often found in anaerobic groundwater systems. The occurrence of ferrous iron in groundwater has in the past been attributed to the spontaneous and reversible reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as BTEX, trimethylbenzenes, and naphthalene. However, recent evidence suggests that the reduction of ferric iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988 and 1991; Chapelle, 1993). In most of its chemical and physical properties, including speciation and dissolution, manganese is regarded as an analogue of iron (Weast *et al.*, 1989), and is expected to be utilized as an electron acceptor in a manner similar to ferric iron (USEPA, 1998).

Ferrous iron and manganese were analyzed in 1999 groundwater samples to assess whether ferric iron and/or manganese are being used as electron acceptors for CAH biodegradation at Site SS-45 (Table 4.5-1). Ferrous iron concentrations in groundwater

samples from the Intermediate Sand unit ranged from "not detected" to 4.82 mg/L (Figure 4.5-6); and manganese concentrations in groundwater samples from Intermediate Sand unit monitoring wells ranged from 0.7 mg/L to 4.82 mg/L (Figure 4.5-7). In general, the concentrations of ferrous iron and manganese in Intermediate Sand unit groundwater in the 800 Area were about half the concentrations the same unit in the 2500 Area (Figures 4.5-6 and 4.5-7).

Southwest of the 800 Area, dissolved ferrous iron was detected at 2.16 mg/L at well A39L039DP (Figure 4.5-6), and manganese was detected in the same well at 0.7 mg/L (Figure 4.5-7). Organic chemicals have not been detected in this well, and it is outside the zone affected by CAH compounds in groundwater at the 800 Area. The dissolved ferrous iron and manganese concentrations detected in the sample from this well may therefore be representative of background concentrations in groundwater of the Intermediate Sand unit in the 800 Area.

If well A39L039DP is representative of background conditions, then iron- and/or manganese-reducing processes may be occurring in groundwater with higher concentrations of dissolved ferrous iron and manganese. This is apparently the case at Wells #10, #11, #13, #15, and A39L009PZ, where dissolved ferrous iron and/or manganese concentrations were greater than at well A39L039DP. Iron- and/or manganese-reducing processes may also be occurring in groundwater through much of the 2500 Area because ferrous iron and/or manganese at concentrations at most wells in this area were slightly greater than those detected at well A39L039DP (Figures 4.5-6 and 4.5-7).

Neither dissolved ferrous iron nor manganese were detected in the groundwater sample from well A39L002PZ, a possible "background" well completed in the Deep Sand unit, southwest of the 800 Area (Table 4.5-1 and Figures E.20 and 21 in Appendix E). By contrast, dissolved ferrous iron and manganese were detected in groundwater samples from all of the Deep Sand unit wells in the 800 Area. Dissolved ferrous iron and manganese were detected at concentrations of 2.96 mg/L and 3.5 mg/L, respectively, at well A39L022PZ, located about midway between the 800 Area and 2500 Area. If the concentrations of ferrous iron and manganese in groundwater of the Deep Sand unit at this location are representative of background conditions in the Deep Sand unit within the 2500 Area, then the concentrations of dissolved ferrous iron are slightly elevated, and the concentrations of manganese are depleted in groundwater within the Deep Sand unit relative to background conditions (Figures E.20 and E.21, Appendix E).

Areas in which groundwater contains dissolved ferrous iron and manganese at concentrations that are slightly elevated with respect to assumed background conditions coincide with areas that also contain dissolved CAHs. The elevated concentrations of ferrous iron and manganese are indicators of microbial activity, and suggest that ferric iron hydroxide is being reduced to ferrous iron during biodegradation of native organic carbon and BTEX compounds. Bradley and Chapelle (1996) present evidence of direct biological oxidation of VC (i.e., use of VC as a substrate) under iron-reducing conditions so long as there is sufficient bioavailable iron. Considering the relatively uniform total iron concentrations detected in soil samples collected at several intervals within the Intermediate and Deep Sand units (Section 4.1.1), and the occurrence of dissolved ferrous

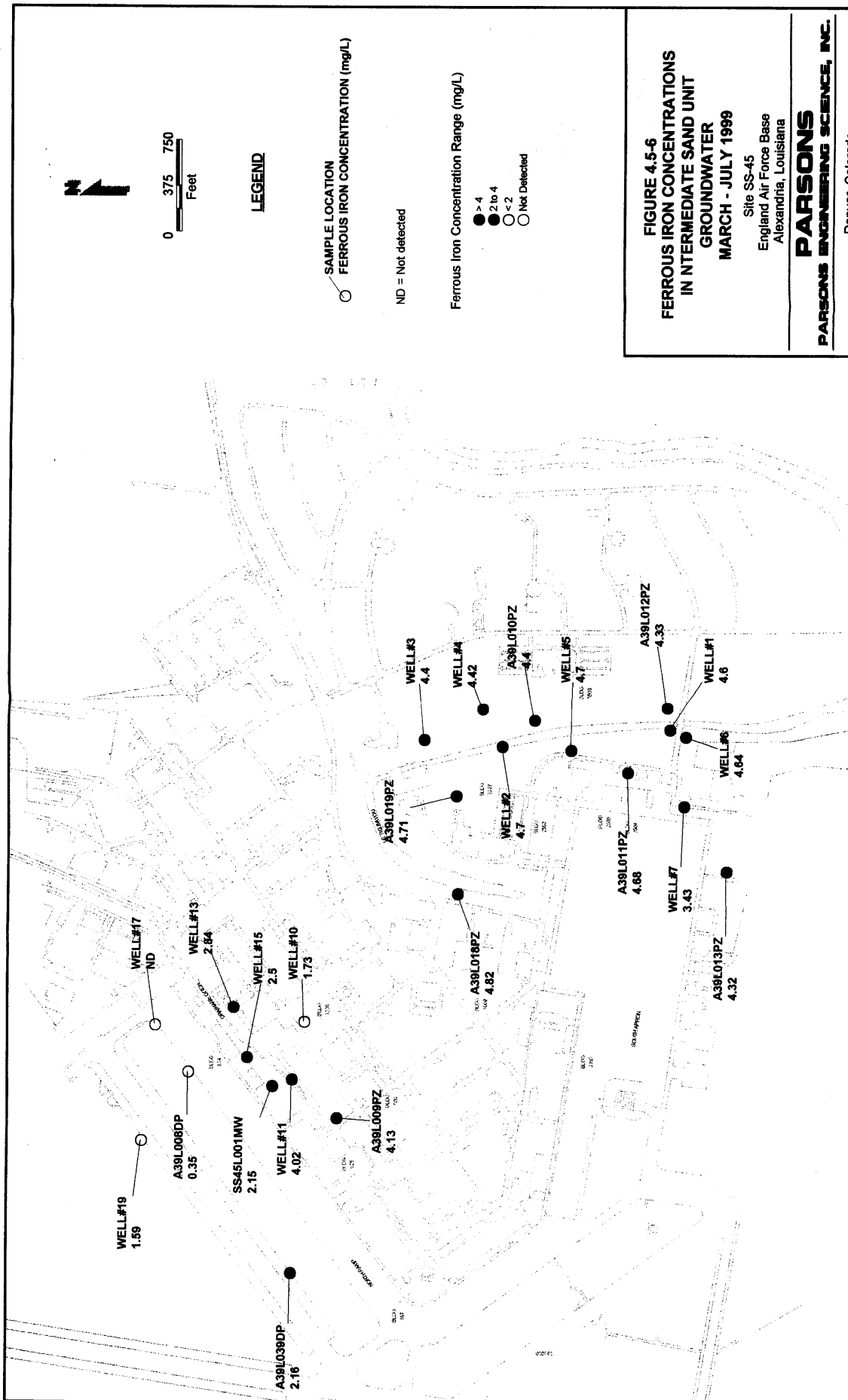


FIGURE 4.5-6
FERROUS IRON CONCENTRATIONS
IN INTERMEDIATE SAND UNIT
GROUNDWATER
MARCH - JULY 1999

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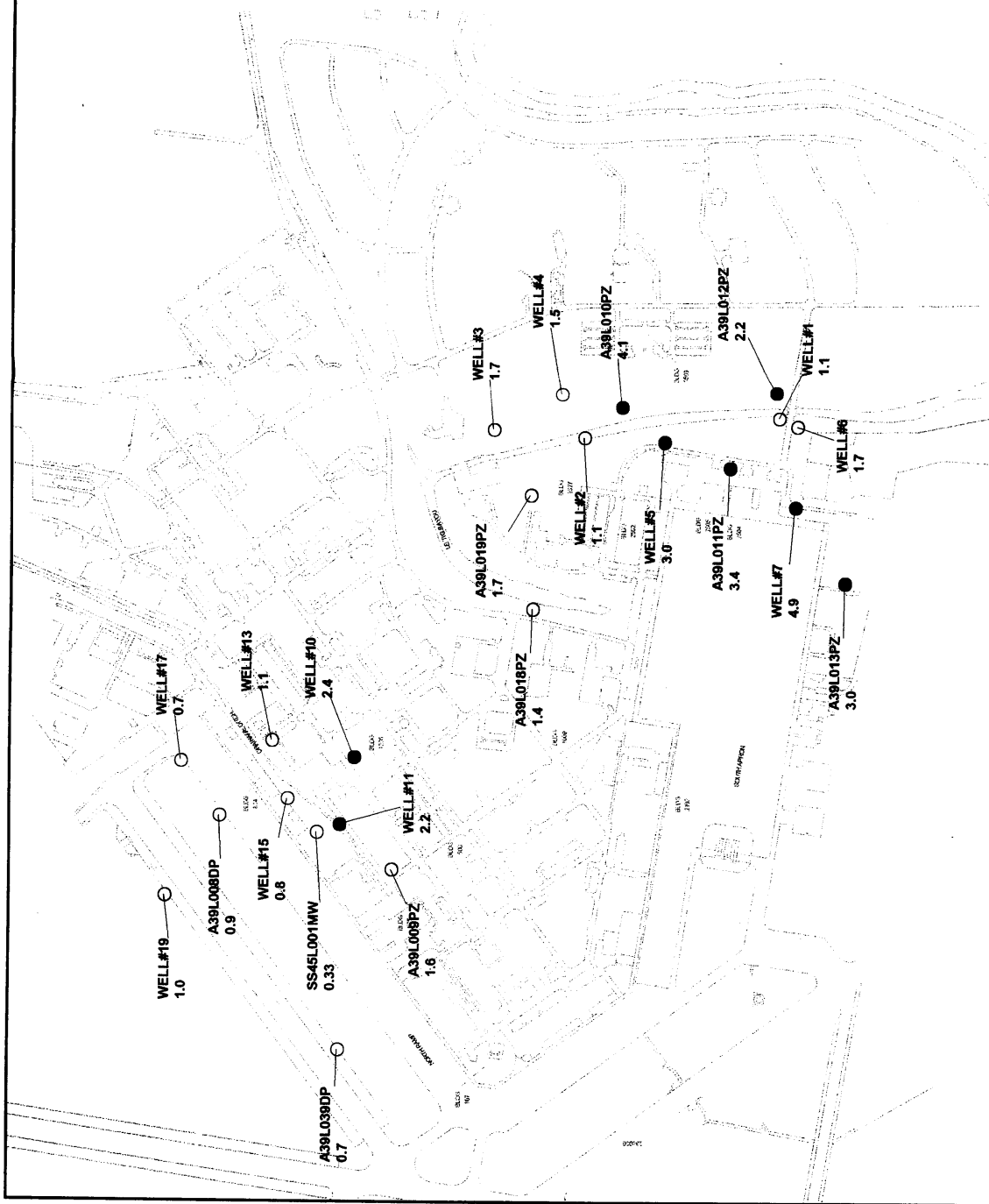


FIGURE 4.5-7

**DISSOLVED MANGANESE
CONCENTRATIONS IN INTERMEDIATE
SAND UNIT GROUNDWATER
MARCH - JULY 1999**

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iron and manganese in groundwater within both the 800 Area and 2500 Area (Table 4.5-1), it is possible that DCE and/or VC are being oxidized under iron-reducing conditions in both locations.

4.5.6.4 Sulfate

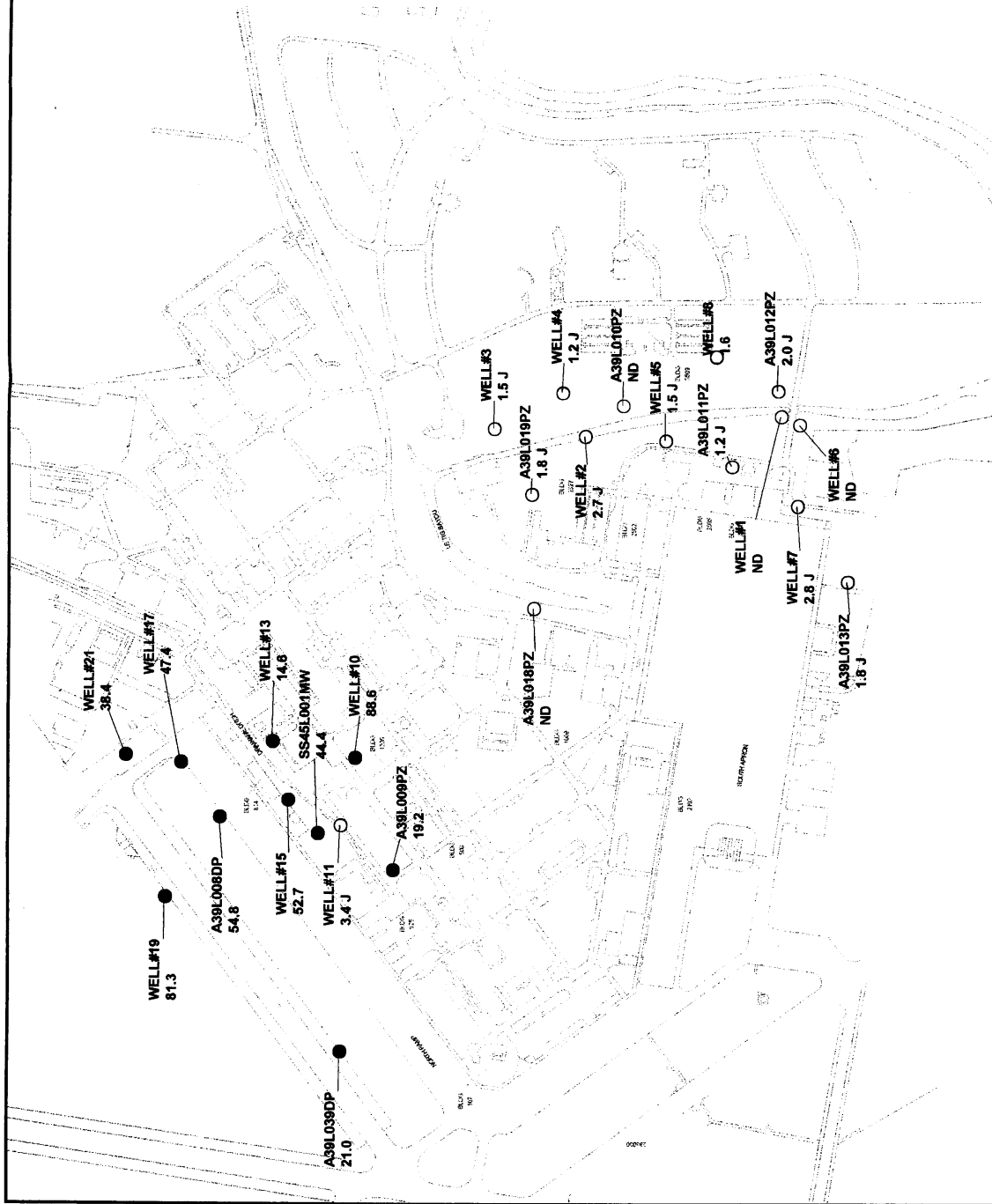
Sulfate also may be used as an electron acceptor during microbial degradation of organic carbon under anaerobic conditions (Grbic-Galic, 1990). This redox reaction is commonly called sulfate reduction. Sulfate is reduced to sulfide during the oxidation of natural or anthropogenic carbon. Wiedemeier *et al.* (1996b) report that sulfate may compete with CAHs as an electron acceptor (i.e., sulfate may be preferentially used by microorganisms instead of CAHs) if sulfate concentrations exceed 20 mg/L.

To evaluate the potential for sulfate reduction in groundwater at Site SS-45, the concentrations of sulfate and sulfide were analyzed in groundwater samples collected during the period March through July 1999. Sulfate concentrations in the Intermediate Sand unit ranged from 3.4J mg/L to 88.6 mg/L at the 800 Area, and from not detected to 2.8J mg/L at the 2500 Area (Table 4.5-1 and Figure 4.5-8). The concentrations of sulfate in the Intermediate Sand unit at the 2500 Area are thus about one-tenth (or less) the concentrations of sulfate in groundwater within the Intermediate Sand unit in the 800 Area (Figure 4.5-8).

The hydrochemical differences between the 800 Area and 2500 Area are also apparent in the sulfate results for the Deep Sand unit (Table 4.5-1 and Figure 4.5-9). The concentrations of sulfate detected in groundwater samples from the Deep Sand unit ranged from 2J to 62 mg/L in the 800 Area, and from 1.2J to 11 mg/L in the 2500 Area. If the concentrations of sulfate in groundwater within the Intermediate and Deep Sand units at the 800 Area are more nearly similar to background concentrations of dissolved sulfate, then the much lower sulfate concentrations in groundwater at the 2500 Area may be an indication of sulfate depletion. However, other than the large-scale differences between groundwater in the two areas, no spatial trends in sulfate concentrations can be identified with certainty.

The widespread detection of sulfate at concentrations greater than 20 mg/L in the Intermediate and Deep Sand units at most locations in the 800 Area indicates that use of CAHs as electron acceptors in the 800 Area could be inhibited as a consequence of the preferential utilization of sulfate by microbes. On the other hand, sulfate concentrations in groundwater at the 2500 Area are sufficiently low that preferential utilization of sulfate probably does not occur.

The reducing conditions prevalent in groundwater at Site SS-45 are confirmed by the appearance of sulfide, at detectable concentrations in a number of groundwater samples from the Intermediate and Deep Sand units (Table 4.5-1; Figures E.22 and E.23, Appendix E). As a general rule, sulfide is an unstable sulfur species under oxidizing conditions, and can persist only under reducing conditions. Detectable concentrations of sulfide in groundwater is regarded as an indication of strongly reducing conditions (Hounslow, 1995).



0 375 750
Feet

LEGEND

○ SAMPLE LOCATION
● LAB SULFATE CONCENTRATION (mg/L)

ND = Not detected above the reported sample quantitation limit

J = The result is qualified as an estimated value because it is greater than the method detection limit and less than the practical quantitation limit

Lab Sulfate Concentration Range (mg/L)

- > 50
- 10 to 50
- 0 to 10
- Not Detected

FIGURE 4.5-3 SULFATE CONCENTRATIONS IN INTERMEDIATE SAND UNIT GROUNDWATER MARCH - JULY, 1999

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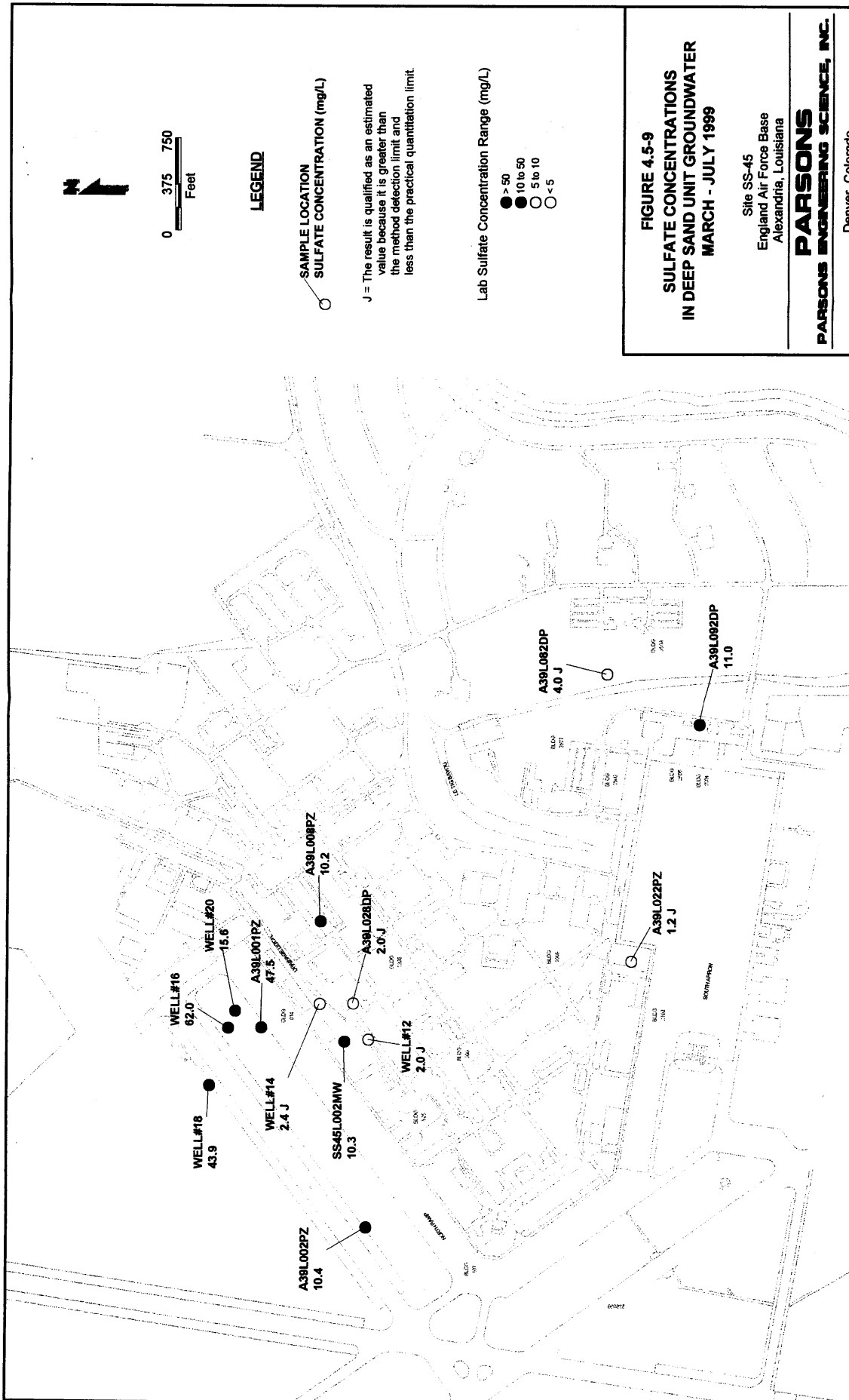


FIGURE 4.5-9
SULFATE CONCENTRATIONS
IN DEEP SAND UNIT GROUNDWATER
MARCH - JULY 1999

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4.5.6.5 Methane and Carbon Dioxide

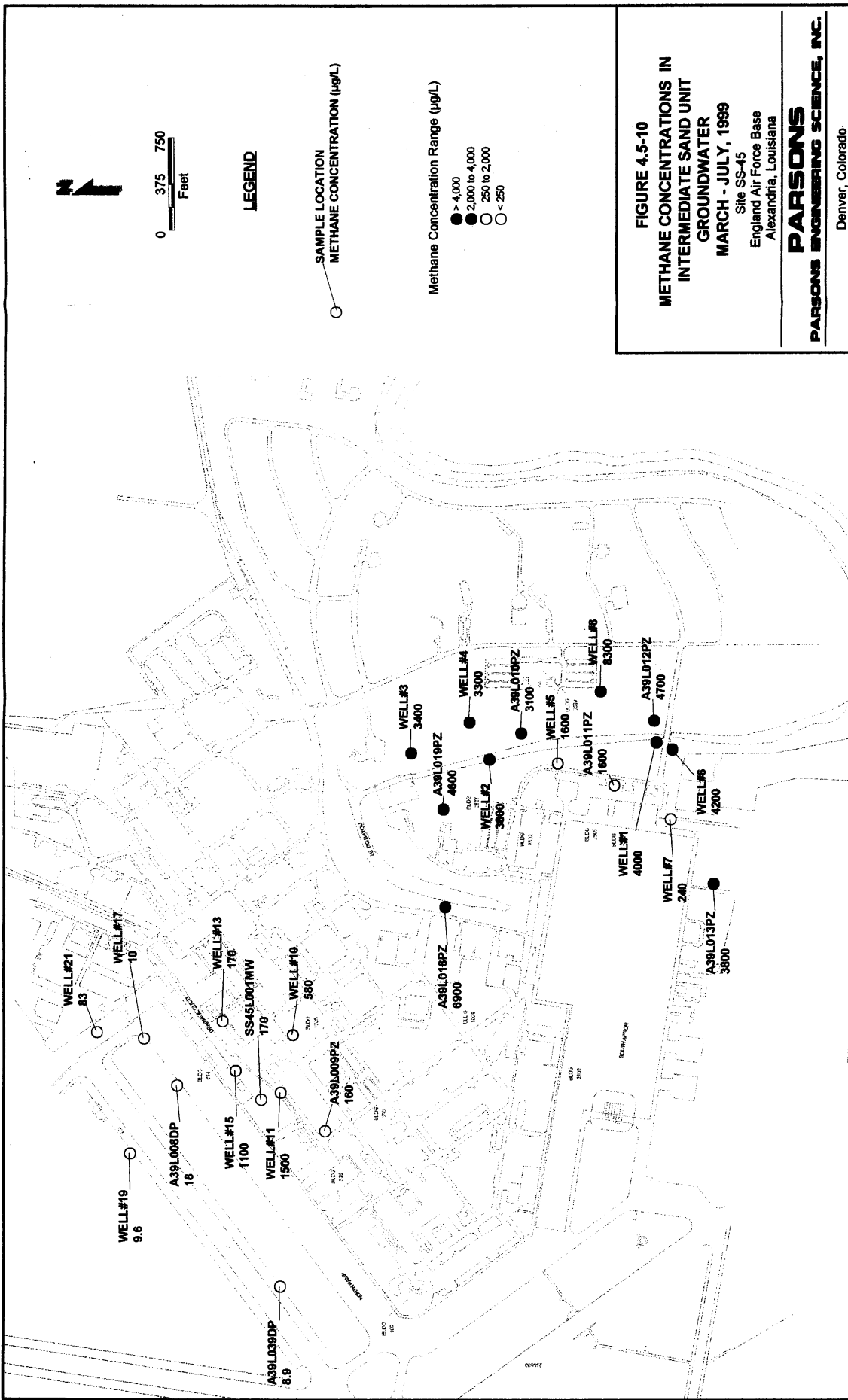
Although reductive dehalogenation may occur under nitrate- and sulfate-reducing conditions (Vogel *et al.*, 1987; Chapelle, 1996), the most rapid dehalogenation rates, affecting the widest ranges of CAHs, occur under methanogenic conditions (Bouwer, 1994). Methane and carbon dioxide were analyzed in 1999 groundwater samples, (Table 4.5-1) to evaluate the potential for methanogenesis.

The concentrations of methane in groundwater samples from the Intermediate Sand unit ranged from 9.6 to 1,500 $\mu\text{g/L}$ in the 800 Area, and from 240 to 6,900 $\mu\text{g/L}$ in the 2500 Area (Figure 4.5-10). These concentrations are in sharp contrast to the concentrations of methane detected at possible background well A39L039DP, where the lowest concentration of methane (8.9 $\mu\text{g/L}$) was measured. Furthermore, the highest concentrations of methane in groundwater coincided in general with the areas in which the highest concentrations of CAH compounds have been detected in groundwater. These data suggest that methanogenic conditions have been established in the CAH plumes in the 800 and 2500 Areas.

Similar conditions appear to occur in groundwater within the Deep Sand unit (Figure 4.5-11). The concentrations of methane detected in Deep Sand unit wells ranged from 8.5 to 1,200 $\mu\text{g/L}$ in the 800 Area, and from 66 to 1,900 $\mu\text{g/L}$ in the 2500 Area (Table 4.5-1). The concentration of methane detected at possible Deep Sand unit background well A39L002PZ was 1.1 $\mu\text{g/L}$, the lowest Deep Sand unit methane concentration detected. Methanogenic conditions have apparently also been established in the Deep Sand unit in both the 800 and 2500 Areas.

In the 2500 Area, methane concentrations are greatest in groundwater samples from those wells at which relatively higher concentrations of CAH compounds have also been detected (c.f., Wells #1, #4, and A39L010PZ, Table 4.3-1). Elevated concentrations of methane (greater than 1,000 $\mu\text{g/L}$) were also detected in groundwater samples from wells in the immediate vicinity of well pair SS45L001MW/002MW, although methane concentrations at those two wells were somewhat lower (170 $\mu\text{g/L}$ and 610 $\mu\text{g/L}$, respectively). The presence of methane in groundwater in areas where CAH compounds are also present (Figure 4.5-12) indicates that conditions are sufficiently reducing that native organic matter, and possibly petroleum hydrocarbons are being used to support methanogenesis.

Figure 4.5-12 was generated by combining 1997 and 1999 methane concentration data to provide more detailed spatial coverage across a broader area than could be obtained using 1999 data alone. After the data had been combined and posted, shaded color contours were generated using MapInfo™ and applying an inverse-distance interpolation algorithm (Jones and Hamilton, 1992) with a search radius of 850 feet. The resulting portrayal is a reasonable, general picture of the occurrence of methane in groundwater of the Intermediate Sand unit; but it should be recognized that interpolation routines are not capable of actually interpreting data. Therefore, Figure 4.5-12 must be regarded as a conceptual representation only. The fact that methanogenesis is prevalent and continuing indicates that conditions in both the 800 Area and 2500 Area are highly reducing and therefore favorable for reductive dehalogenation of CAHs. This supports the general



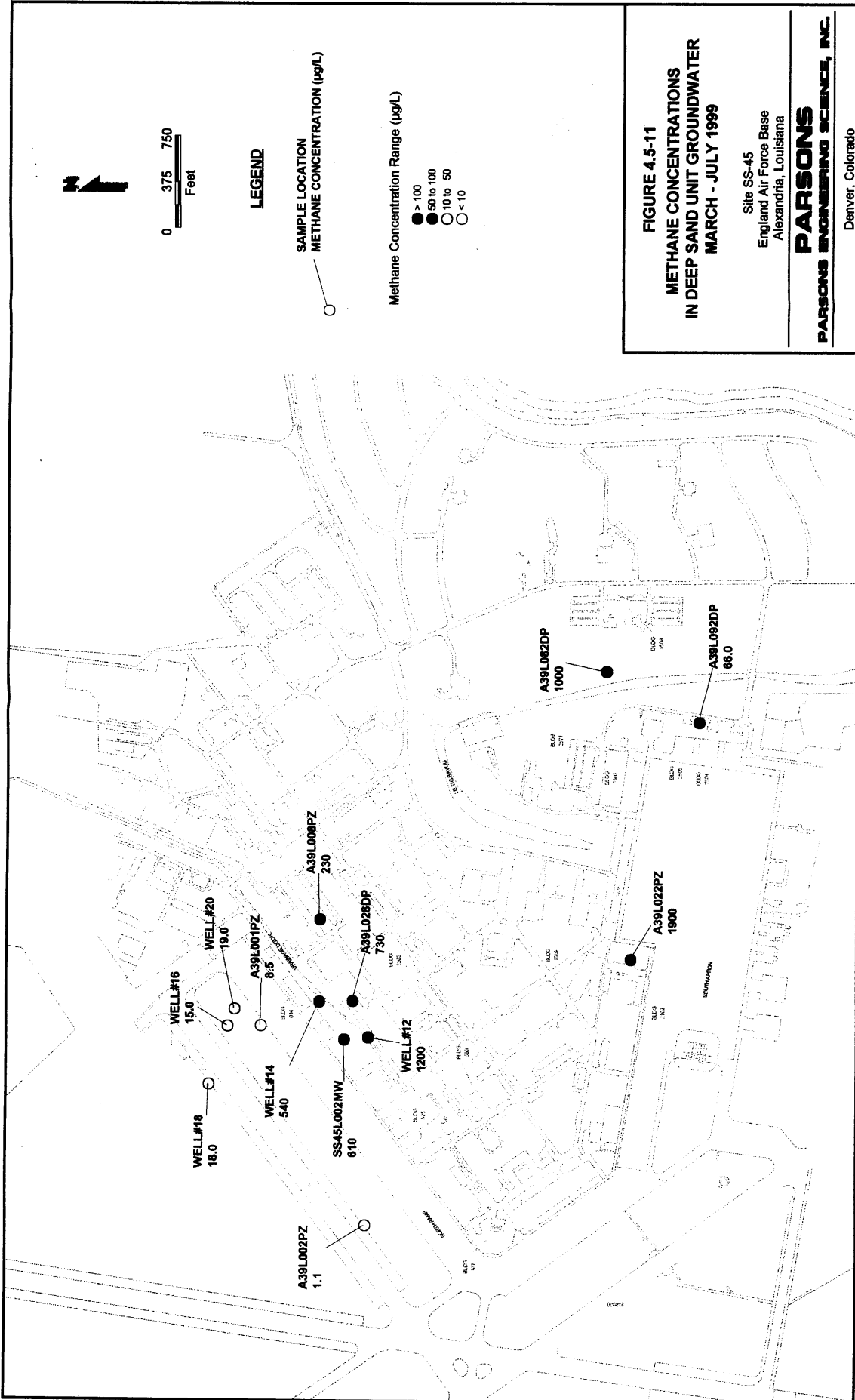
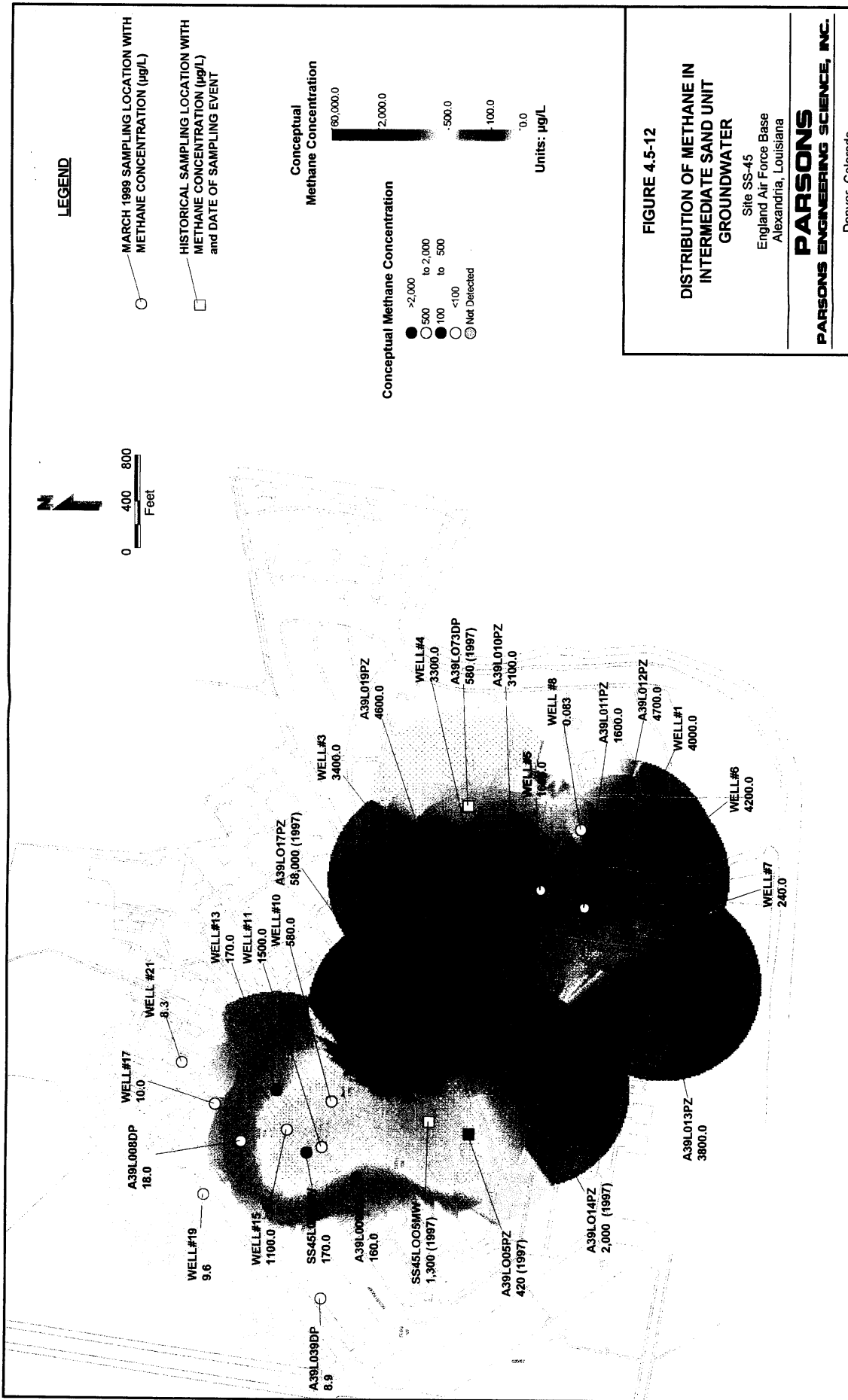


FIGURE 4.5-11
METHANE CONCENTRATIONS
IN DEEP SAND UNIT GROUNDWATER
MARCH - JULY 1999

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conclusions derived from examination of the results of analyses of groundwater samples for dissolved hydrogen (Section 4.5.4) that the dominant TEAPs are iron and sulfate reduction and methanogenesis.

Carbon dioxide concentrations also were analyzed in 1999 groundwater samples (Table 4.5-1). Carbon dioxide concentrations in groundwater samples collected from Intermediate Sand unit monitoring wells in the 800 Area ranged from 85 mg/L to 170 mg/L (Figure 4.5-13). The concentrations of carbon dioxide in groundwater samples collected from the Intermediate Sand unit in the 2500 Area were about one-half those detected in the 800 Area, and ranged from 50 mg/L to 90 mg/L. Similar ranges of carbon dioxide concentrations were detected in groundwater samples collected from Deep Sand unit monitoring wells in the two areas (Figure 4.5-14), and again, the concentrations of carbon dioxide in the Deep Sand unit in the 2500 Area were about one-half the concentrations of carbon dioxide in groundwater in the 800 Area. The decreased concentrations of carbon dioxide in the 2500 Area, and the elevated concentrations of methane relative to groundwater in the 800 Area, suggest that methanogenesis may be the principal TEAP in groundwater at the 2500 Area. Methanogenesis produces more carbon dioxide than it uses; therefore, an unlimited supply of carbon dioxide is theoretically available once the process of methanogenesis has been initiated. Thus, as long as a sufficient supply of electron donors is available, the process is not limited by the source of electron acceptors, but only by the rate of reaction. The presence of significantly elevated carbon dioxide concentrations in groundwater in areas where CAH compounds are also present is an indication of biologic activity.

4.5.7 Additional Geochemical Indicators

Other geochemical data collected for this evaluation can be used to further interpret and support the contaminant, electron donor, electron acceptor, and byproduct data previously discussed. These parameters provide additional qualitative indications of what processes may be operating at the site.

4.5.7.1 Alkalinity

Carbon dioxide also is produced during the biodegradation of petroleum fuel constituents and native organic carbon compounds. In water-bearing hydrogeologic units that have carbonate minerals as part of the matrix, carbon dioxide forms carbonic acid, which dissolves these minerals and increases the alkalinity of the groundwater. An increase in groundwater alkalinity, measured as calcium carbonate (CaCO_3), in an area with BTEX constituents or another organic carbon source can be used to infer that petroleum hydrocarbons (or native organic carbon) have been destroyed through aerobic or anaerobic microbial respiration.

Total alkalinity (as CaCO_3) was measured in groundwater samples collected during the period from March through July 1999. Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused by the addition of biologically generated acids. Total alkalinity in groundwater ranged from 160 to 1,280 mg/L for the Intermediate Sand unit, and from 100 to 640 mg/L for the Deep Sand unit (Table 4.5-1 and Figures E.24 and E.25, Appendix E). This range of alkalinity is sufficient to buffer

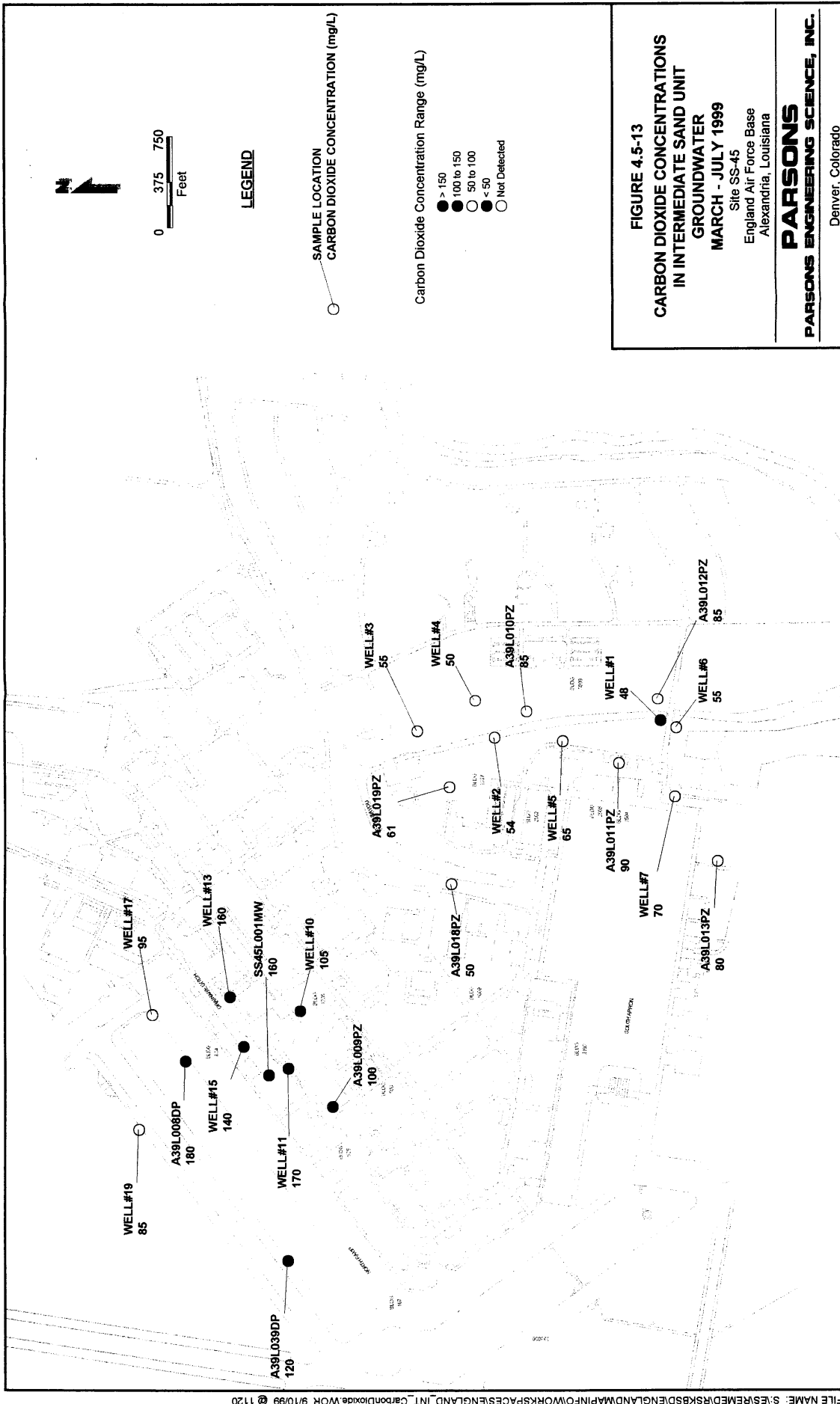


FIGURE 4.5-13
CARBON DIOXIDE CONCENTRATIONS
IN INTERMEDIATE SAND UNIT
GROUNDWATER
MARCH - JULY 1999

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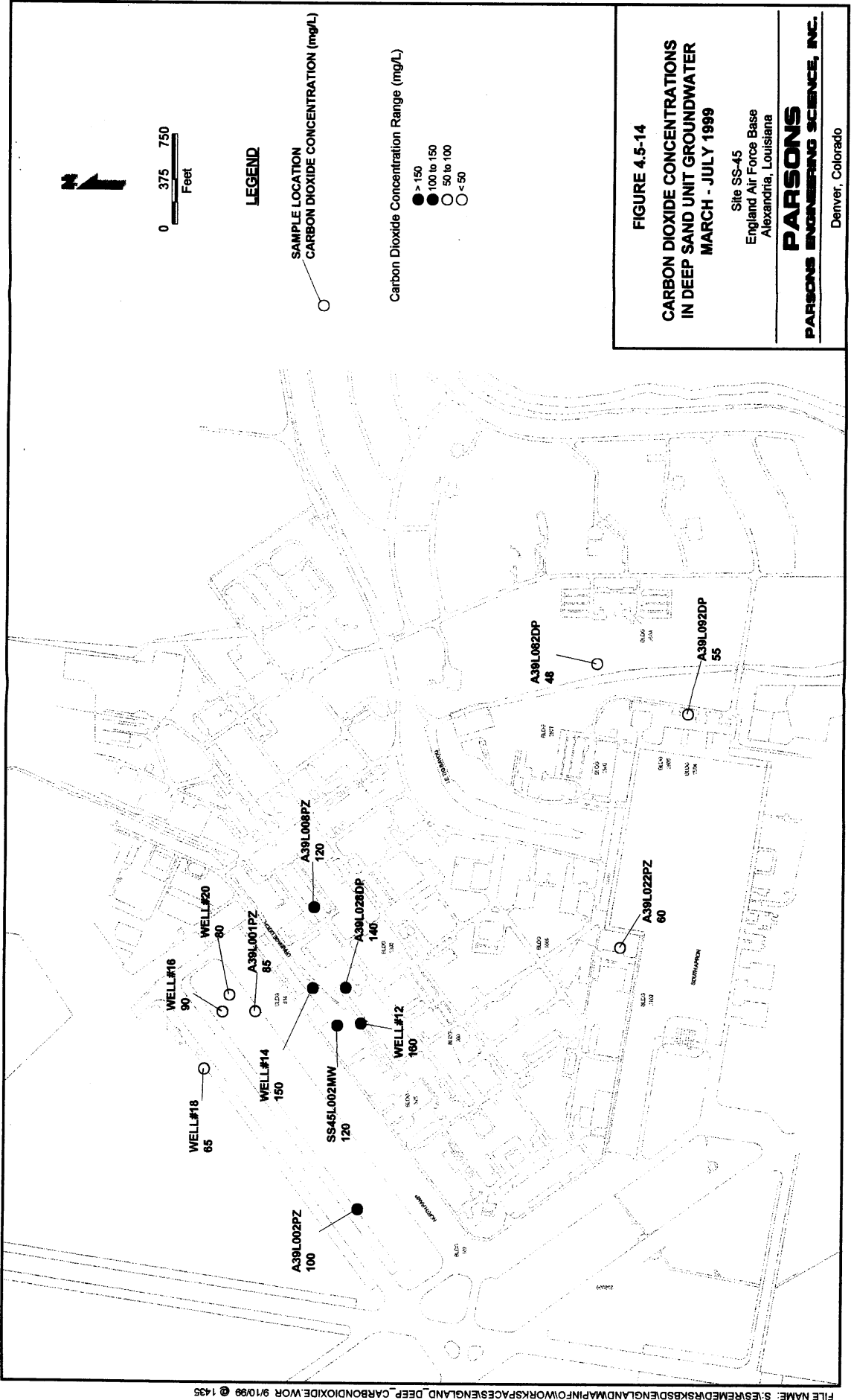


FIGURE 4.5-14

**CARBON DIOXIDE CONCENTRATIONS
IN DEEP SAND UNIT GROUNDWATER
MARCH - JULY 1999**

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potential changes in pH caused by biologically mediated reactions and suggests that anaerobic biodegradation processes should not cause potentially-detrimental shifts in groundwater pH (Section 4.5.7.2). No differences in total alkalinity of groundwater are apparent between the 800 Area and 2500 Area; and no spatial trends in total alkalinity were identified.

4.5.7.2 pH

The pH of groundwater was measured in 1999 samples (Table 4.5-1). The pH of a solution is the negative logarithm of the hydrogen ion concentration $[H^+]$. pH measured at Site SS-45 ranged from 6.65 to 7.0 standard units for the Intermediate Sand unit, and from 6.8 to 7.6 standard units for the Deep Sand unit (Figures E.26 and E.27, Appendix E). This range of pH is within the optimal range of 5 to 9 for microbial activity. The limited and relatively neutral range of pH also indicates that microbial reactions have a minimal effect on groundwater pH, likely due to the moderately high alkalinity of groundwater at Site SS-45 (Section 4.5.7.1).

4.5.7.3 Temperature

Groundwater temperature was measured at all groundwater monitoring wells that were sampled during the period March through July, 1999 (Table 4.5-1). Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures generally resulting in higher growth rates. The temperature of groundwater at Site SS-45 ranged from 19.8°C to nearly 23°C in the Intermediate Sand unit, and from 18.8°C to 22.4°C in the Deep Sand unit (Figures E.28 and E.29, Appendix E). Wiedemeier *et al.* (1996b) report that biochemical processes are accelerated when groundwater temperatures exceed 20°C. The relatively elevated groundwater temperatures in the Intermediate and Deep Sand units at Site SS-45 are expected to promote microbiological activity in the subsurface.

4.6 ESTIMATION OF BIODEGRADATION RATES

Chemical degradation via biotic or abiotic mechanisms may be the most important process acting to remove chemical mass from the subsurface (Appendix D). Therefore, estimation of the rates of chemical degradation is necessary to properly evaluate the ultimate fate of TCE and its daughter products at Site SS-45. For reductive dehalogenation of CAHs, first-order rates are not necessarily an accurate representation because the degradation of CAHs depends on the concentrations of electron donors (e.g., fuel hydrocarbons or native organic material) as well as electron acceptors (including inorganic acceptors and CAHs) (Moutoux *et al.*, 1996). Second-order rates would therefore allow more accurate calculations to be made of the fate of CAHs in the environment, but at this time, methods of evaluating or applying second-order rate constants are not well developed. Therefore, first-order rates must be used for such calculations.

First-order degradation rate constants may be calculated using field data, or by using representative samples of the aquifer material and groundwater in microcosm studies (USEPA, 1998). Microcosm studies can be used to demonstrate that the microorganisms

necessary for biodegradation are present and to estimate rates of biodegradation. However, because microcosm studies are time consuming and expensive, they are undertaken only at sites where there is considerable uncertainty concerning the occurrence of contaminant biodegradation. Furthermore, the results of microcosm studies can be influenced by changes in the aquifer material collected for the microcosm, the physical properties of the microcosm, the sampling strategy, and the duration of the study. The rates of biodegradation determined on the basis of microcosm studies often are much higher than those observed in the field. Microcosms are most appropriate as indicators of the potential for natural bioremediation, and to evaluate whether losses of chemical mass are a result of biological activity, but it may be inappropriate to use them to generate rate constants. The preferred method of evaluating degradation rate constants is by use of field data.

Two methods for determining first-order rate constants for BTEX compounds are described by Wiedemeier *et al.* (1996b); both methods can be adapted to estimate rate constants for CAHs. One method involves the use of a biologically recalcitrant compound found in the dissolved contaminant plume that can be used as a conservative tracer. For many CAH plumes, chloride that is released to the groundwater during dehalogenation reactions can be used as a tracer. However, at Site SS-45, chloride is not suitable for use as a tracer because migration of constituents in groundwater at Site SS-45, including chloride, occurs primarily as a consequence of chemical diffusion, and migration pathways are therefore not well defined. Furthermore, background chloride concentrations are similar to those in groundwater in areas where CAH compounds are present (Section 4.4.3).

The other method, proposed by Buscheck and Alcantar (1995), involves interpretation of a steady-state contaminant plume and is based on the one-dimensional, steady-state analytical solution to the advection/dispersion equation presented by Bear (1979). Decay rates computed using this method account for chemical (abiotic) decay and biological (aerobic and anaerobic) decay. Application of this method may not be appropriate in situations where a well-defined source area cannot be identified, or where more than one chemical source may be present (in this situation, the suites and concentrations of chemicals in groundwater at several locations may not be related), or where the migration and distribution of chemicals are controlled by processes other than advection. As a consequence of the extremely low hydraulic gradients in the groundwater system beneath England AFB, the distribution of chemicals in most parts of Site SS-45 may be a result of molecular diffusion processes from small multiple sources (Appendices D and F). Alternatively, because groundwater flow directions beneath the 800 Area and 2500 Area are generally indeterminate (in that the potentiometric surface is nearly flat, and hydraulic gradients do not appear to extend continuously over appreciable distances in any direction), the distribution of chemicals may have occurred as a result of inconsistent or oscillating advective migration along poorly-defined flowpaths. Therefore, because isolated, well-defined chemical sources may not be present, and because advection of dissolved constituents is, at most, a minor component of the current chemical migration process, the method of Buscheck and Alcantar (1995) is probably not applicable to evaluation of chemical decay in groundwater in most areas of Site SS-45.

To test the potential applicability of the Buscheck and Alcantar (1995) method at the site, a possible flowpath in the Intermediate Sand unit was selected. The flowpath begins at Well #4, located in a part of the 2500 Area containing relatively higher concentrations of CAHs, and parallels Le Tig Bayou southward to wells A39L010PZ and A39L012PZ, located in areas of generally lower chemical concentrations in the southern part of the 2500 Area (Figure 4.6-1). During much of the year, this flowpath apparently is aligned with the hydraulic gradient near Le Tig Bayou (Figure 3.4-7), although the gradient is low enough that under certain conditions flow reversal may occur.

Using the concentrations of CAHs detected in groundwater samples collected from these wells in March 1999 (Table 4.3-1), first-order rate constants of 0.000013 percent per day (day^{-1}), 0.000018 day^{-1} , and 0.000031 day^{-1} were calculated for *cis*-1,2-DCE, *trans*-1,2-DCE, and VC, respectively (Appendix F), using the method of Buscheck and Alcantar (1995). These correspond to half-lives of about 146, 105, and 60 years, respectively. However, no TCE has been detected at wells in the 2500 Area, and the molar concentrations of VC detected in groundwater samples from well A39L010PZ have historically been more than 20 times the molar concentrations of DCE isomers detected in the same samples (Appendix F). This indicates that the estimated first-order rate constants are unrealistically low (i.e., half-lives are unrealistically long). If the degradation rates were this slow, TCE would still be present in groundwater at the 2500 Area, and TCE or DCE isomers would be the principal chemical species. The unrealistically low estimates for first-order rate constants suggest that one or more of the implicit assumptions of the method of Buscheck and Alcantar (1995) have not been met.

The method of Buscheck and Alcantar (1995) requires that the chemical suites and concentrations in groundwater near two or more monitoring points be related by having a common source of chemicals and by lying along a single flowpath originating at the source, along which the groundwater flow velocity is well-defined and constant (i.e., chemical concentrations are related by distance and time). In situations where the necessary relationships among several monitoring points are not defined or do not exist, the self-similarity of the suites and concentrations of chemicals in groundwater near a single monitoring point, through time, may be greater than the similarities among the suites and concentrations of chemicals in groundwater near several, spatially separated monitoring points at a single point in time. This means that the changes in chemical composition and concentrations in groundwater at a particular location through time may depend more strongly on previous conditions at that location than on conditions at other locations in the groundwater system. In the absence of significant mass reduction resulting from processes other than chemical degradation (e.g., advection), this situation is equivalent to a large-scale, *in-situ* microcosm, and periodic groundwater monitoring events can be regarded as samples collected to track the progress of the "microcosm" in degrading CAH compounds through time.

All available evidence indicates that DCE in groundwater originated as a degradation product of TCE, and that the DCE isomers are degrading to VC (Sections 4.3 through 4.5 and Appendix F). This observation suggests that in the absence of significant mass loss due to processes other than chemical degradation (e.g., volatilization or advective transport), first-order degradation rate constants can be estimated using the relative concentrations of TCE and daughter products detected in groundwater samples from a

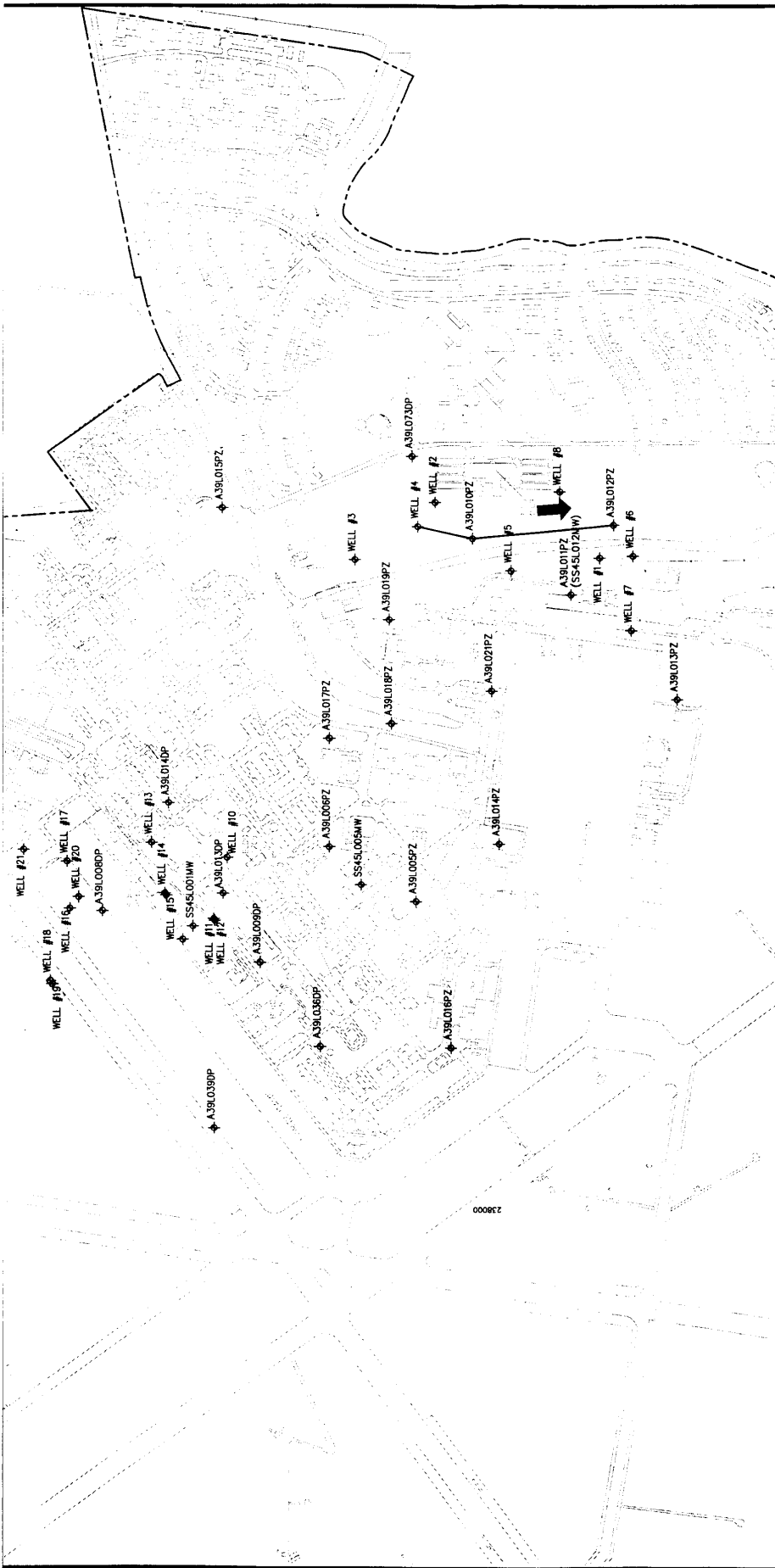
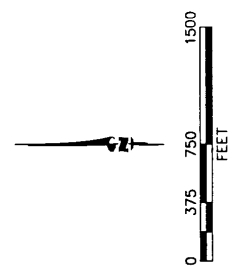


FIGURE 4.6-1
GROUNDWATER FLOWPATH
FROM WELL
#4 TO A39L010PZ
TO A39L012PZ

Site SS-45
 England Air Force Base
 Alexandria, Louisiana

PARSONS
 PARSONS ENGINEERING SCIENCE, INC.
 Denver, Colorado



LEGEND

WELL #4 ♦ EXISTING MONITORING WELL

➔ INFERRED GROUNDWATER FLOW DIRECTION
 IN THE INTERMEDIATE SAND UNIT

monitoring well through its monitoring history, with application of simplifying assumptions to account for the time of chemical introduction, initial mass of chemical introduced, and chemical mass attenuation resulting from processes other than degradation.

Therefore, as an alternative to application of the method of Buscheck and Alcantar (1995), the sequential degradation of TCE in groundwater at selected monitoring locations ("*in situ* microcosms"), through its chain of daughter products to complete mineralization of VC, was simulated using a series of first-order rate calculations (Appendix F). The objective of the history-matching calculations was to obtain estimates of first-order degradation rate constants for TCE and its daughter products, by adjusting the values of the degradation rate constants so that introduction of TCE in a single "slug" at an assumed, initial concentration on a particular date, would reproduce the concentrations of TCE and daughter products detected in groundwater samples from a particular well during historic sampling events. The procedure is discussed in detail in Appendix F and described briefly in the following paragraphs.

The history of TCE use at England AFB suggests that:

- Chemical discharge probably occurred over several decades;
- Chemicals were discharged in unknown, but probably different quantities at several different locations;
- The soils at each discharge site served as a secondary source for continuing contribution of chemicals to groundwater; and
- The rates of dispersal of CAHs to groundwater varied among the discharge sites because of variations in quantities of chemicals, depth of discharge, and local soil composition.

As a consequence, neither the initial concentration of TCE in groundwater at each discharge site, nor the time elapsed since the introduction of TCE to groundwater, can be precisely quantified. However, if several simplifying assumptions are made, the relative proportions of historic concentrations of TCE and its daughter products at individual monitoring points can be used to generate estimates of the ranges of first-order degradation rate constants that could have produced the observed chemical concentrations. The assumptions that were made for the purpose of estimating degradation rate constants are as follow:

- TCE was assumed to be only CAH initially released in groundwater as a single slug on January 1, 1960 (i.e., all DCE and VC present are degradation products of TCE). This is near the beginning of the suspected history of TCE use at the Base, and is within the time frame during which TCE may have been introduced to groundwater in the 800 and 2500 Areas (about 1960 through the early to mid-1980s; see Section 1). This assumption also is conservative in that if TCE were introduced to groundwater at a date later than January 1, 1960, less time would be available to

degrade the TCE and daughter products, generating the observed daughter-product concentrations; and a faster rate estimate would result.

- The degradation of TCE, through its chain of daughter products, was assumed to proceed as a series of first-order degradation reactions.
- The historical concentrations of TCE, DCE isomers, and VC detected in groundwater samples from wells A39L009PZ and SS45L001MW were assumed to be representative of the CAH concentrations in groundwater near chemical sources in the 800 Area. The historical concentrations of DCE isomers and VC at wells A39L010PZ and A39L011PZ were assumed to be representative of the CAH concentrations in groundwater near chemical sources in the 2500 Area. These wells were selected because they have the most extensive monitoring records at Site SS-45, have historically been associated with the highest concentrations of CAHs detected at Site SS-45, or both.
- The total molar concentration of CAHs detected in the groundwater sample from each well in June 1996 was assumed to be representative of the concentration of TCE originally introduced to groundwater at that well location. For example, the total molar concentration of TCE daughter products in the sample from well A39L010PZ in June 1996 (about 31 µg/L *cis*-1,2-DCE, 140 µg/L *trans*-1,2-DCE, and 1,260 µg/L VC) was about 21.9 µmol/L. The total molar concentration represents the concentrations of TCE daughter products that could be produced by completely degrading an initial concentration of TCE in water (21.9 µmol/L) equivalent to about 3,000 µg/L (Appendix F). This does not account for any additional, equivalent mass of TCE that may have been removed from the system as a result of complete mineralization. This estimated, initial concentration of TCE in groundwater is the minimum concentration required to produce the observed concentrations of TCE daughter compounds in the groundwater sample from well A39L010PZ (i.e., a total concentration of at least 21.9 µmol/L [3,000 µg/L] of TCE must have been introduced to the groundwater system at this location). Furthermore, this is a conservative assumption in that application of the assumption produces estimates of first-order decay rate constants that are lower than would result if other assumptions were used. For example, if TCE were introduced to the groundwater system at an initial concentration greater than 3,000 µg/L, degradation of TCE and all of its daughter products would have to proceed at a faster rate to remove all of the TCE and generate the observed concentrations of daughter compounds than the rate calculated assuming an initial concentration of 3,000 µg/L.
- Attenuation of TCE and its daughter products in the groundwater system via mechanisms other than chemical decay (e.g., volatilization, advection, diffusion), was assumed to be minimal. This assumption is in accordance with the observation that diffusion is probably the primary mechanism of dissolved solute transport in the subsurface. The rates of chemical attenuation estimated to result from diffusive transport beneath SS-45 are several orders of magnitude lower than the possible ranges of chemical removal resulting from chemical decay, indicating that under

most circumstances, chemical removal via diffusion mechanisms can be disregarded (Appendix F).

Using these assumptions, first-order rate constants were adjusted until the calculated concentrations of TCE and its daughter products reasonably matched the concentrations detected in the wells during historical monitoring events. The first-order rate constants developed (Table 4.6-1) are within ranges reported in the literature for TCE, DCE isomers, and VC, (Dragun, 1988; Wilson *et al.*, 1994; Sivavec and Horney, 1995; Anthony *et al.*, 1997; Wiedemeier *et al.*, 1999). It must be recognized that although some uncertainty is associated with these estimates, the estimated degradation rates are consistent with the discharge history of TCE at the Base, and with the relative concentrations of TCE and its daughter products detected in groundwater samples from the 800 and 2500 Areas at Site SS-45.

Estimates of first-order rate constants also were generated by examining short-term trends in CAH concentrations in groundwater samples from individual monitoring wells, and using the above-described method with a series of kinetic calculations under the assumption that both sorbed and aqueous phases are present. These calculations are described in detail in Appendix F. Application of several different estimation techniques to historical chemical concentration data from several monitoring wells produced ranges of first-order degradation rate constants (Table 4.6-1). The median value of first-order degradation rate constant from the range of rate-constant estimates generated for each CAH compound was selected as the representative value for use in subsequent calculations (see Section 5).

4.7 SUMMARY OF EVIDENCE FOR CAH DEGRADATION

Several lines of chemical and geochemical evidence indicate that dissolved CAHs in the 800 and 2500 Areas of Site SS-45 are undergoing biologically facilitated reductive dehalogenation. These lines of evidence are summarized in the following subsections.

4.7.1 Presence of Daughter Products

The presence of *cis*- and *trans*-1,2-DCE, VC, and ethene in groundwater of the Intermediate and Deep Sand units, accompanied by a decrease in concentrations, or total elimination of TCE (the parent chemical), are the primary lines of chemical evidence that TCE is being reductively dehalogenated. Furthermore, the anaerobic dehalogenation processes occurring in groundwater at Site SS-45 appear to be proceeding sufficiently rapidly to transform the bulk of the contaminant mass to non-chlorinated, non-toxic end products. TCE has been detected in groundwater samples from only two wells in the 2500 Area, at low, estimated concentrations (Section 4.3). TCE and its daughter products co-occur in groundwater in the 800 Area. This indicates that TCE is degrading relatively rapidly to DCE. DCE isomers and VC co-occur in groundwater at several locations in the 800 and 2500 Areas, indicating that DCE is degrading to VC. In areas where VC is the primary CAH compound (parts of the 2500 Area), relatively elevated concentrations of ethene also occur, indicating that VC degradation is also occurring, though possibly at a slower rate than the degradation of DCE to VC.

LE 4.6-1
ESTIMATED FIRST-ORDER RATE CONSTANT RADIATION RATE CONSTANTS FOR CAH
SITE SS-44
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Rate Constants and Half-Lives for TCE and Daughter Compounds
Total Attenuation Rate Constants by Direct Calculation

Groundwater Analytical Results Used in Calculation	Time Period Used in Calculation	TCE		cis-1,2-DCE		trans-1,2-DCE		Total DCE Isomers		Vinyl Chloride	
		Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)
A39L009PZ	6/16/1997 -- 3/17/1999	--	--	0.0009	2.0	0.0032	0.6	0.0011	1.7	--	--
A39L010PZ	6/17/1996 -- 6/16/1997	--	--	0.0033	0.6	0.0041	0.5	0.0039	0.5	0.0023	0.8
	6/16/1997 -- 12/9/1997	--	--	0.0020	1.0	0.0021	0.9	0.0021	0.9	--	--
	12/9/1997 -- 3/14/1999	--	--	0.0019	1.0	0.0020	0.9	0.0020	0.9	0.0011	1.7
A39L011PZ	6/17/1996 -- 3/14/1999	--	--	0.0024	0.8	0.0028	0.7	0.0027	0.7	0.0011	1.7
	8/21/1996 -- 3/14/1999	--	--	0.0026	0.7	--	--	0.0024	0.8	--	--
SS45L001MW	9/16/1997 -- 12/11/1997	0.0018	1.1	--	--	--	--	--	--	--	--
	12/11/1997 -- 3/17/1999	0.0001	13.3	0.0007	2.6	--	--	0.0011	1.7	--	--
	9/16/1997 -- 3/17/1999	0.0004	4.7	0.0004	5.1	--	--	0.0007	2.8	--	--

Rate Constants by Method of Buscheck and Alcantar

Flowpath in March 1999:	Chemical Concentrations in March 1999 (mg/L)	cis-1,2-DCE		trans-1,2-DCE		Total DCE Isomers		Vinyl Chloride	
		Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)
Well # 4	150	--	--	0.000013	146.0	0.000018	105.4	0.000017	111.6
A39L010PZ	2.8	--	--	0.000013	146.0	0.000018	105.4	0.000017	111.6
A39L012PZ	1	ND (< 0.5)	ND (< 1)	--	--	--	--	0.000031	61.2

Rate Constants by First-Order Curve Matching (Aqueous Phase Only)

Groundwater Analytical Results Used in Curve Matching	Starting Date	Initial Concentration (mg/L)	TCE		cis-1,2-DCE		trans-1,2-DCE		Total DCE Isomers		Vinyl Chloride	
			Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)
A39L009PZ	1/1/1960	0.21	0.00014	13.6	NA	--	NA	--	0.00002	94.9	0.0007	2.7
A39L010PZ	1/1/1960	3	0.00066	2.9	NA	--	NA	--	0.00022	8.6	0.00006	31.6
A39L011PZ	1/1/1960	0.70	0.00055	3.5	NA	--	NA	--	0.00005	38.0	0.0002	9.5
SS45L001MW	1/1/1960	0.75	0.00002	94.9	NA	--	NA	--	0.0004	4.7	0.004	0.5

Rate Constants by First-Order Curve Matching (Kinetic Model with Sorbed and Aqueous Phases, and Chemical Diffusion)

Groundwater Analytical Results Used in Curve Matching	Starting Date	Initial Concentration (mg/L)	TCE		cis-1,2-DCE		trans-1,2-DCE		Total DCE Isomers		Vinyl Chloride	
			Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)
A39L009PZ	1/1/1960	0.21	0.00014	13.6	NA	--	NA	--	0.00006	31.6	0.00035	0.5
A39L010PZ	1/1/1960	3	0.00066	2.9	NA	--	NA	--	0.0003	6.3	0.00015	12.7
A39L011PZ	1/1/1960	0.70	0.00055	3.5	NA	--	NA	--	0.00011	17.3	0.00035	5.4
SS45L001MW	1/1/1960	0.75	0.00002	94.9	NA	--	NA	--	0.0001	19.0	0.0045	0.4

Summary Statistics for Estimates of Rate Constants and Half-Lives

Groundwater Analytical Results Used in Calculation	Time Period Used in Calculation	TCE		cis-1,2-DCE		trans-1,2-DCE		Total DCE Isomers		Vinyl Chloride	
		Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)	Rate Constant (days ⁻¹)	Half-Life (years)
A39L009PZ	6/16/1997 -- 3/17/1999	--	--	0.0009	2.0	0.0032	0.6	0.0011	1.7	--	--
A39L010PZ	6/17/1996 -- 6/16/1997	--	--	0.0033	0.6	0.0041	0.5	0.0039	0.5	0.0023	0.8
A39L011PZ	6/16/1997 -- 12/9/1997	--	--	0.0020	1.0	0.0021	0.9	0.0021	0.9	--	--
SS45L001MW	12/9/1997 -- 3/14/1999	--	--	0.0019	1.0	0.0020	0.9	0.0020	0.9	0.0011	1.7
	6/17/1996 -- 3/14/1999	--	--	0.0024	0.8	0.0028	0.7	0.0027	0.7	0.0011	1.7
	8/21/1996 -- 3/14/1999	--	--	0.0026	0.7	--	--	0.0024	0.8	--	--
	9/16/1997 -- 12/11/1997	0.0018	1.1	--	--	--	--	--	--	--	--
	12/11/1997 -- 3/17/1999	0.0001	13.3	0.0007	2.6	--	--	0.0011	1.7	--	--
	9/16/1997 -- 3/17/1999	0.0004	4.7	0.0004	5.1	--	--	0.0007	2.8	--	--

Maximum First-Order Rate Constant

Minimum First-Order Rate Constant

Median First-Order Rate Constant

Literature Values of First-Order Rate Constants^a

Literature values for First-order rate constants (TCE and vinyl chloride) from Wiedemer *et al.* (1999) and Anthony *et al.* (1997, DCE isomers)

4.7.2 Apparent Plume Stability

Chemical migration at Site SS-45 may result from diffusive processes, or from limited advective transport along poorly-defined and temporally-discontinuous flowpaths. Under diffusion, chemical migration is driven primarily by chemical gradients, and dissolved CAH compounds will move from areas of relatively higher concentration to areas of relatively lower concentration. Given the low concentrations of CAH compounds at the edges of the plumes in the 800 Area and the 2500 Area (Figures 4.4-2 through 4.4-4); the current, relatively low concentrations of CAHs near the centers of the plumes; and the relatively long period since the initial introduction of CAH compounds to groundwater, it seems likely that chemical concentration gradients and/or net advective transport velocities are sufficiently low that advective-diffusive migration has ceased, and the dispersed "plumes" have stabilized.

4.7.3 Loss of CAH Mass

If chemical migration in groundwater has slowed or ceased, chemical concentrations in groundwater at particular locations should remain constant or decline through time as biodegradation removes chemical mass from groundwater. As described in Section 4.5.1, available concentration-versus-time data for TCE and its daughter products in samples from five wells suggest that the concentrations of CAH compounds in groundwater at the 800 and 2500 Areas are gradually decreasing over time, solely as a result of biodegradation processes. However, because the monitoring history at Site SS-45 is relatively limited, additional data are needed to confirm this observation.

4.7.4 Availability of Electron Donors

Microbial consumption of native and anthropogenic organic carbon compounds creates conditions favorable for reductive dehalogenation. Anthropogenic carbon compounds are present as petroleum hydrocarbons (e.g., BTEX) dissolved in groundwater in the 2500 Area, and native carbon compounds are present in soil throughout the soil column in both the 800 Area and 2500 Area, and also as organic matter that has dissolved into groundwater. These compounds function also as electron donors in redox reactions that are also consuming electron acceptors such as DO, ferric iron, sulfate, carbon dioxide, and CAHs. Plots of these electron donors, electron acceptors, and byproducts of these reactions (Section 4.5 and Appendix E) provide strong qualitative evidence of the occurrence of these processes. Additional indicators, such as ORP, dissolved hydrogen, and alkalinity (Appendix E), further confirm that biodegradation reactions are ongoing and have created reducing conditions that foster reductive dehalogenation.

The same advection-diffusion processes that have resulted in the slow spread of TCE and daughter products through groundwater as a dispersed plume also are the processes that cause electron acceptors (primarily sulfate) to migrate in groundwater from surrounding uncontaminated areas into the plumes. The extremely low concentrations of sulfate in groundwater within the 2500 Area (about 1 to 2 mg/L) are about one-tenth the concentrations of sulfate detected in samples from other areas of Site SS-45. This suggests that groundwater in the 2500 Area has become depleted in sulfate, possibly

because consumption of sulfate in electron-acceptor reactions is proceeding more rapidly than sulfate can be replenished through slow, advective-diffusive migration. If inorganic electron acceptors, such as sulfate, are not replenished at a rate comparable to the rate of their consumption, then CAH compounds in groundwater will become the preferred electron acceptors for biologically mediated redox reactions, which are on-going. It therefore seems possible that the rates of reductive dehalogenation of CAH compounds could increase through time as other electron acceptors become depleted.

The native organic carbon content of soil in the 800 and 2500 Areas (about 0.001; Section 4.1) is sufficiently elevated that carbon depletion will probably not slow the rates of CAH degradation. The extremely anaerobic and reducing conditions in groundwater at Site SS-45 are unlikely to change, indicating that reductive dehalogenation processes will continue. Furthermore, methanogenesis appears to be the predominant TEAP active in groundwater at the 2500 Area, and is important in groundwater at the 800 Area. Because methanogenesis produces more carbon dioxide than it uses, the process is not limited by the source of electron acceptors, but only by the rate of reaction. Methanogenesis, with associated reductive dehalogenation of CAH compounds used as alternate electron acceptors, is not likely to cease.

4.7.5 Comparable Degradation Rate Estimates

As discussed in Section 4.6, the estimated rates of CAH degradation based on historical monitoring data range from $2 \times 10^{-5} \text{ day}^{-1}$ to $1.8 \times 10^{-3} \text{ day}^{-1}$ for TCE, $1.7 \times 10^{-5} \text{ day}^{-1}$ to $3.9 \times 10^{-3} \text{ day}^{-1}$ for total DCE isomers, and $2.5 \times 10^{-5} \text{ day}^{-1}$ to $4.5 \times 10^{-3} \text{ day}^{-1}$ for VC, with median estimates of rate constants ranging from $4 \times 10^{-4} \text{ day}^{-1}$ for TCE, $4 \times 10^{-4} \text{ day}^{-1}$ for DCE, and $9 \times 10^{-4} \text{ day}^{-1}$ for VC (equivalent to half-lives of 4.6 years, 4.6 years, and 2.1 years) (Table 4.6-1). These rates are similar to field-scale biodegradation rates for TCE and its daughter products derived from a number of other sites and reported by Wiedemeier *et al.* (1999). These reported rates range from 0.0002 day^{-1} to 0.004 day^{-1} (half-lives of 7.9 years to 0.5 years).

4.7.6 RNA Scoring Results

The USEPA (1998) presents a worksheet to allow an initial assessment to be made of the relative importance of RNA as a fate mechanism for CAH compounds at a particular site. The worksheet completed for Site SS-45, including the scoring values assigned to the 800 Area and 2500 Area, is presented as Table 4.7-1. The interpretation of points awarded during the screening process also is outlined in the table. The score for the 800 Area is 27.5, and the score for the 2500 Area is 30.5, indicating that there is strong evidence of the occurrence of reductive dechlorination of CAH compounds in groundwater at both areas. Table 4.7-1 effectively summarizes the available hydrological and geochemical information for Site SS-45, all of which supports the continuing degradation of CAHs in groundwater at both the 800 Area and 2500 Area through relatively rapid biologically mediated reductive mechanisms.

TABLE 4.7-1
RNA SCORING WORKSHEET
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Analyte	Concentration in Most Contaminated Zone	Interpretation	Maximum Possible Score ^{b/}	Site SS-45	
				800 Area	2500 Area
Oxygen	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	3	3	3
	>1 mg/L	VC may be oxidized aerobically	-3	0	0
Nitrate	<1 mg/L	At higher concentrations may compete with reductive pathway	2	2	2
Ferrous Iron	>1 mg/L	Reductive pathway possible	3	3	3
Sulfate	<20 mg/L	At higher concentrations may compete with reductive pathway	2	0	2
Sulfide	>1 mg/L	Reductive pathway possible	3	1	1
Methane	<0.5 mg/L	VC oxidizes	0	0	0
	>0.5 mg/L	Ultimate reductive daughter product, VC accumulates	3	3	3
Oxidation/Reduction Potential	<50 mV	Reductive pathway possible	1	--	--
	<-100mV	Reductive pathway likely	2	2	2
pH	5 < pH < 9	Optimal range for reductive pathway	0	0	0
	5 > pH > 9	Outside optimal range for reductive pathway	-2	0	0
Total Organic Carbon	> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2	0	1
Temperature	> 20°C	At T >20°C biochemical processes are accelerated	1	1	1
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	1	1	0
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	1	.5	.5
Chloride	>2x background	Daughter product of organic chlorine	2	1	1
Hydrogen	>1 nM/L	Reductive pathway possible, VC may accumulate	3	3	3
Hydrogen	<1 nM/L	VC oxidized	0	0	0

TABLE 4.7-1 (Continued)
RNA SCORING WORKSHEET
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Analyte	Concentration in Most Contaminated Zone	Interpretation	Maximum Possible Score ^{b/}	Site SS-45	
				800 Area	2500 Area
BTEX	> 100 µg/L	Carbon and energy source; drives dechlorination	2	0	1
TCE		Material released	0	0	0
		Daughter product of PCE	2 ^{a/}	0	0
DCE		Material released	0	0	0
		Daughter product of TCE	2 ^{a/}	2	2
VC		Material released	0	0	0
		Daughter product of DCE	2 ^{a/}	2	2
Ethene	>10 µg/L	Daughter product of VC	2	0	0
	>100 µg/L		3	3	3
Chloroethane		Daughter product of VC under reducing conditions	2	0	0
		TOTAL		27.5	30.5

^{a/} From USEPA (1998). Partial points are awarded in cases where the stated condition is partially fulfilled (e.g., when the condition is fulfilled within a portion of the area of interest, but not throughout the entire area).

^{b/} Per USEPA (1998), total scores are interpreted as follows:

Score	Interpretation
0 to 5	Inadequate evidence for reductive transformation of chlorinated organics
6 to 14	Limited evidence for reductive transformation of chlorinated organics
15 to 20	Adequate evidence for reductive transformation of chlorinated organics
>20	Strong evidence for reductive transformation of chlorinated organics

^{c/} Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

SECTION 5

KINETICS-BASED MODEL OF CONTAMINANT FATE IN GROUNDWATER

Estimation of the time required for natural attenuation to reduce the concentrations of TCE and its daughter products to regulatory or risk-based levels in groundwater is a necessary component of the evaluation of the fate of CAH compounds in the environment. A kinetics-based geochemical model, developed in Appendices F and G, was used to estimate the ranges of time required for the concentrations of TCE and its degradation daughter products to be reduced to specified levels in groundwater at Site SS-45 via natural attenuation mechanisms only, and via RNA supplemented by an active groundwater extraction (pump-and-treat) system.

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

The results of investigations at Site SS-45, England AFB, indicate that TCE was the precursor (parent) chemical initially released into groundwater in the 800 and 2500 Areas. After TCE migrates to groundwater, diffusion (or limited advective migration along temporally-discontinuous flowpaths) is the primary mechanism acting to distribute TCE in groundwater, and biodegradation is the primary process acting to remove TCE and its daughter products from groundwater. The kinetics-based model was structured to incorporate these processes (Figure 5.1-1).

The modeling effort had two primary objectives: 1) predict the changes in concentrations through time of CAHs dissolved in groundwater in the 800 and 2500 Areas by modeling the combined effects of diffusion, sorption, and biodegradation, with no active remedial measures implemented; and 2) evaluate the relative differences in time required to achieve specified concentrations with RNA only, and with a groundwater pump-and-treat system operating at two pumping rates. The model was developed using site-specific data and conservative assumptions regarding the governing physical and chemical processes.

5.2 STRUCTURE OF GEOCHEMICAL MODEL

The primary mechanisms controlling the movement and fate of CAHs in the environment include dissolution, dispersion, sorption, and chemical decay (Appendix D). Most methods of simulating the movement of chemicals in the environment utilize relatively simplistic methods of accounting for the various fate mechanisms, including in particular sorption and chemical decay (*c.f.*, Spitz and Moreno, 1996). Furthermore, dissolved chemical migration in the groundwater system at Site SS-45 may occur

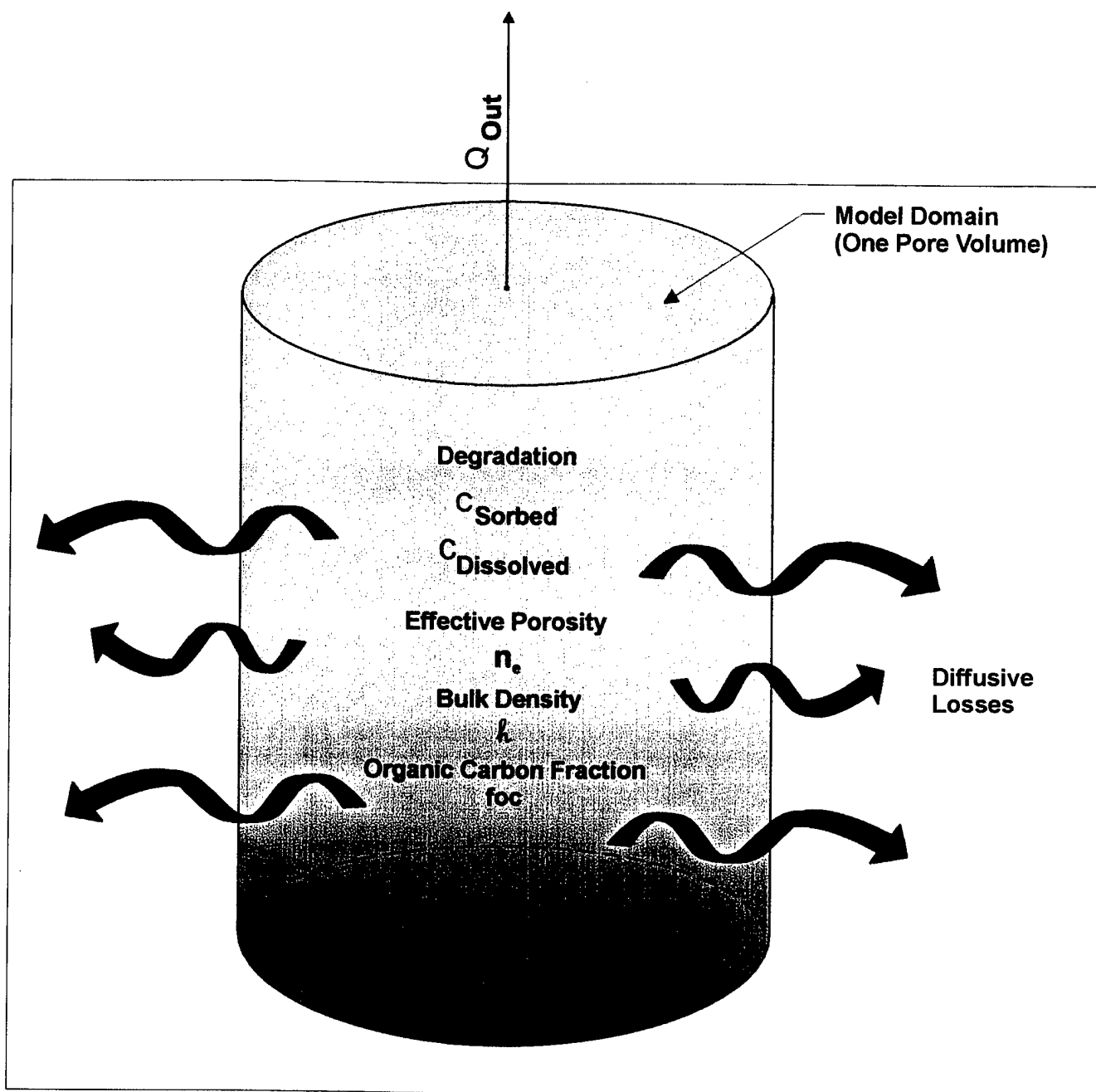


FIGURE 5.1-1

**CONCEPTUAL STRUCTURE
OF KINETICS BASED
GEOCHEMICAL MODEL**

Site SS-45
England Air Force Base
Alexandria, Louisiana

PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

primarily as a result of chemical diffusion (possibly with some component of advection), and most numerical codes are not designed to simulate diffusive migration. Accordingly, application of a numerical model to the evaluation of the migration and fate of CAHs in groundwater at Site SS-45 was judged to be inappropriate. Rather, a series of kinetics-based geochemical calculations was completed to compare the potential effectiveness of RNA with a groundwater pump-and-treat system in removing chemical mass from groundwater, and to provide estimates of the times required to achieve cleanup goals.

The system of differential equations (the "model") used in the calculations depicts the changes in chemical concentrations through time in groundwater in a two-phase system (soil and groundwater) in which sorption, chemical diffusion, advective mass loss, and chemical degradation occur. The model simulates the sequential degradation of TCE to the DCE isomers, DCE to VC, and finally VC to its mineralization products (ethene, carbon dioxide gas, hydrogen gas, and water). Development of the kinetic model, together with the governing differential equations and assumptions, is described in detail in Appendices F and G.

5.3 MODEL PARAMETERS

5.3.1 Physical Parameters

Geochemical calculations were conducted using site-specific physical and chemical parameters that had been measured or estimated during this and other investigations (LAW, 1998a). The physical parameters required to define the system include:

- Bulk density of the soil,
- Effective porosity of the soil,
- The fraction of organic carbon in the soil;
- A distribution coefficient for each CAH, and
- An effective chemical diffusion coefficient for each CAH.

A bulk density of 102 pounds per cubic foot (lbs/ft³), equivalent to 1.63 g/cm³; an effective porosity of 28 percent; and the median values for the fractions of organic carbon detected in 800 and 2500 Area were used to define the physical characteristics of the soil in each of the two Areas (Table 5.3-1). Distribution coefficients (K_d s) for TCE, *cis*-1,2-DCE, and VC were estimated using the method of Karickhoff *et al.* (1979) (Appendix F). A retardation factor was calculated for each compound using the site-specific values for bulk density and effective porosity and the chemical-specific distribution coefficients presented in Table 5.3-1.

5.3.2 Rate Constants

Estimates of first-order degradation rate constants were obtained from a series of calculations using the relative concentrations of TCE and its daughter products in groundwater samples through time (Appendix F). Ranges of first-order degradation rate

TABLE 5.3-1
PARAMETERS USED IN GEOCHEMICAL MODELS
 SITE SS-45
 ENGLAND AIR FORCE BASE
 ALEXANDRIA, LOUISIANA

800 AREA MODEL PARAMETERS			
Physical Parameters			
Soil Bulk Density [lbs/ft ³] ^{a/}	102		
Effective Porosity [percent] ^{a/}	0.28		
Fraction of Organic Carbon ^{a/}	0.001		
Chemical-Specific Parameters	TCE	DCE	VC
Chemical Organic Carbon Partition Coefficient [mL/g] ^{b/}	107	45	2.5
Distribution Coefficient [mL/g] ^{c/}	0.107	0.045	0.002
Retardation Factor	1.62	1.26	1.01
Action-Level Concentration [µg/L]	5	70	2
Estimated Chemical Degradation Rates (1/year) ^{c/}			
Degradation Rate for TCE → DCE {R3}	0.15		
Degradation Rate for DCE → VC {R7}		0.15	
Degradation Rate for VC → ETHENE (or other) {R11}			0.33

TABLE 5.3-1 (Continued)
PARAMETERS USED IN GEOCHEMICAL MODELS
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

2500 AREA MODEL PARAMETERS			
Physical Parameters			
Soil Bulk Density [lbs/ft ³] ^{a/}	102		
Effective Porosity [] ^{a/}	0.28		
Fraction of Organic Carbon ^{a/}	0.0013		
Chemical-Specific Parameters	TCE	DCE	VC
Chemical Organic Carbon Partition Coefficient [mL/g] ^{b/}	107	45	2.5
Distribution Coefficient [mL/g] ^{c/}	0.139	0.058	0.003
Retardation Factor	1.81	1.34	1.02
Action-Level Concentration [µg/L]	5	70	2
Estimated Chemical Degradation Rates (1/year) ^{e/}			
Degradation Rate for TCE → DCE {R3}	0.15		
Degradation Rate for DCE → VC {R7}		0.15	
Degradation Rate for VC → ETHENE (or other) {R11}			0.33

^{a/} Results of geotechnical analysis of field samples collected during the RFI (LAW, 1998a) and the RNA field investigation (Sections 3 and 4).

^{b/} Chemical properties for TCE from Montgomery and Welkom (1990). Chemical properties for DCE and VC from Howard (1990).

^{c/} Distribution coefficients for TCE, DCE, and VC obtained by calculation (refer to text).

^{d/} The term {R#} represents the variable name for the rate constant used in the computer code.

^{e/} Chemical degradation rates were estimated in Appendix F in units of 1/day, and 1/year.

constants were estimated for TCE and its daughter products using historical concentration data from several different sampling locations. The median value of the first-order rate constant estimated for each compound was then used in the kinetics-based modeling because the distribution of the underlying population (the values of rate constants at every point in the subsurface at Site SS-45) is unknown. Use of the arithmetic mean to estimate the "average" value of a particular variable (e.g., rate constant) is inappropriate unless the underlying distribution is known to be normal (Rock, 1988; de Marsily, 1986). The estimated first-order degradation rates were originally generated (Appendix F) in units of days⁻¹; however, for the purposes of kinetics-based geochemical calculations, days⁻¹ were converted to years⁻¹ (Table 5.3-1).

To account for mass losses resulting from chemical diffusion, an effective first-order diffusion rate constant was calculated for each chemical (Appendix F). Because an

inwardly directed hydraulic gradient established by pumping will overwhelm any outward chemical diffusion gradient, chemical diffusion was assumed to occur only in those situations for which no pumping was specified.

In addition to removal of chemical mass via biodegradation mechanisms at Site SS-45, TCE and daughter products in water also can be removed from the system by induced advective flow at a rate controlled by the rate of water movement through the system, expressed in terms of an advective removal ("pumping") rate. This representation of the system assumes that mass flux out of the system via advective transport due to pumping occurs only in the aqueous phase, and that the system always contains one unit volume of water (i.e., the system is never "pumped dry"). Consequently, the advective (or pumping) removal rate can be represented by a term for rate of removal of water (as pore volumes per unit of time).

The maximum sustained pumping rate for a well completed in the Intermediate Sand unit at the Base was estimated to range between about 20 and 120 gallons per minute (gpm) (Appendix F). The results of screening-level capture-zone calculations using analytical methods indicated that the radius of capture for a single well, pumping in a homogeneous, isotropic, infinite aquifer at a sustained rate of 20 gpm, would be on the order of 2,000 feet. A single extraction well, located near well SS-45L001MW and having a 2,000-foot radius of capture, would be capable of capturing all the dissolved CAHs in the 800 Area. Two extraction wells, located near Well #1 and Well #4 and each having a 2,000-foot radius of capture, would be capable of capturing all the dissolved CAHs in the 2500 Area. The saturated thickness of the Intermediate Sand unit is about 40 feet; the volume of water contained within the capture zone of a single well ("one pore volume") is therefore about 140,750,000 cubic feet (ft³) of water, assuming a 2,000-foot radius of capture, a 40-foot saturated thickness, and an effective porosity of 28 percent (Appendix F). A single well pumping at a rate of 20 gpm would extract about 1,400,000 ft³ of water in a 1-year period. The rate of pore-volume removal for a single well completed in the Intermediate Sand unit on England AFB and pumping at a rate of 20 gpm is therefore approximately 0.01 pore volume per year.

The radius of capture of a well pumping at a rate of 120 gpm in the Intermediate Sand unit is somewhat larger (about 5,000 feet). However, because a radius of capture greater than 2,000 feet is not necessary to control chemical migration or increase mass removal rates, it was assumed that a single well, pumping at a rate of 120 gpm, would also withdraw water from a capture zone having a radius of 2,000 feet. The rate of pore-volume removal for a single well completed in the Intermediate Sand unit and pumping at a rate of 120 gpm is therefore approximately 0.06 pore volume per year. The initial calculations assumed that groundwater was removed from the subsurface surrounding a particular extraction well at the rate of 0.01 pore volume per year. This extraction rate later was increased to 0.06 pore volume per year in some simulations to evaluate the effects of pumping at a higher rate.

The set of differential equations describing the conceptual system (the "model") was solved simultaneously, using a fourth-order Runge-Kutta method (Rice, 1993). The original solution routine was written in *BASIC*.

5.4 INITIAL CONDITIONS AND ASSUMPTIONS

The objective of the kinetics-based modeling was to estimate the amount of time required to reduce the concentrations of TCE, DCE isomers, and VC in groundwater of the Intermediate Sand unit to target cleanup concentrations. The rates of chemical mass removal for TCE and its daughter products (DCE and VC) were calculated for a system in which chemical removal occurs through first-order degradation and diffusion (i.e., RNA) only, and then for a system in which chemical removal occurs through a combination of RNA and pumping. The initial chemical concentrations for model simulations were the concentrations detected in groundwater samples from Wells #1, #4, and SS45L001MW at the site. The concentrations of TCE in groundwater samples from well SS45L001MW (in the 800 Area) historically have been among the highest concentrations detected at Site SS-45. Therefore, because the time required for TCE to degrade completely through its chain of daughter products (TCE to DCE to VC) is greater than the time required simply to degrade the daughter products (e.g., mineralize VC), the time required for chemical concentrations to decrease to levels below the target concentrations at well SS45L001MW represents the maximum amount of time that would elapse before all target concentrations were achieved. Although the concentrations of CAHs detected in groundwater samples from Wells #1 and #4 (in the 2500 Area) are lower than concentrations historically detected in samples from well SS45L001MW, groundwater samples from Wells #1 and #4 contained the highest concentrations of DCE isomers detected the 2500 Area. The concentrations of DCE isomers and VC in samples from Wells #1 and #4 were therefore selected to represent chemical conditions within the 2500 Area.

This method of specifying initial chemical concentrations for the calculations assumes that the chemical concentrations are uniform throughout the pore volume surrounding a well, and that no additional chemical mass will be introduced to groundwater in the Intermediate Sand unit (i.e., the current concentrations in groundwater of the Intermediate Sand unit are representative of the total amount of chemical mass in the system). In reality, CAHs may persist for some time in the upper silt/clay unit, and may gradually migrate into groundwater of the Intermediate Sand unit, thereby functioning as a continuing source of chemical mass being contributed to groundwater. The contribution of chemical mass from the upper silt/clay unit to groundwater within the Intermediate Sand unit may continue (for some unknown period of time) until the upper silt/clay unit is depleted in CAHs. Therefore, the estimates of time required to reduce the concentrations of CAHs to below specified concentrations can be regarded as relative rather than absolute. In other words, the relative timeframes and costs for MNA and pumping alternatives will remain the same even if a continuing source was assumed.

Mass-based chemical concentrations were converted to molar concentrations (Appendix F) for use in geochemical calculations. Accordingly, the concentration of TCE in groundwater samples from well SS45L001MW (560 $\mu\text{g/L}$) is equivalent to a molar concentration of 4.26 $\mu\text{mol/L}$; and the concentration of DCE isomers in groundwater samples from well SS45L001MW (12J $\mu\text{g/L}$) is equivalent to a molar concentration of 0.124 $\mu\text{mol/L}$. VC was not detected in the groundwater sample from well SS45L001MW. The chemical concentrations in groundwater samples from Wells #1 and #4 were similarly converted to molar concentrations.

LDEQ (1998) has adopted federal MCLs for TCE, the DCE isomers, and VC as risk-based screening levels (RBSLs) under their risk-based corrective action (RBCA) guidance. The England AFB BCT has concurred with the use of these promulgated groundwater standards as conservative, long-term cleanup goals for groundwater at Site SS-45. For the purpose of these calculations, the MCLs for TCE, *cis*-1,2-DCE, and VC were the target concentrations specified (Table 5.4-1). Because all of the DCE isomers will eventually degrade to VC, the concentrations of 1,1-DCE, *cis*-1,2-DCE, and *trans*-1,2-DCE, detected during each sampling event, were summed to produce a concentration of "total DCE isomers" during that event. Although the concentration of "total DCE isomers" includes the concentrations of 1,1-DCE, *cis*-1,2-DCE, and *trans*-1,2-DCE, the drinking-water standard for *cis*-1,2-DCE was used as the target concentration for DCE isomers, because *cis*-1,2-DCE has historically comprised greater than 90 percent of the total mass of DCE isomers detected in groundwater samples from most wells at Site SS-45 (Table 4.3-1, Figures 4.4-6 and 4.4.7, and Appendix A).

The geochemical calculations were structured to simulate a two-phase system, consisting of soil and water (Figure 5.1-1). This conceptualization is similar to a batch-flushing model. In this situation, dissolved chemicals can sorb to soil, so the soil acts as a source of additional CAHs as chemicals partition to soil from the aqueous phase, and are free to partition from the aqueous phase to soil. All organic chemicals in the system are assumed to be present initially in the sorbed and aqueous phases, but mass-transfer reactions with the sorbed phase permit a redistribution of chemical mass between the two phases. In essence, this simulates conditions in which chemicals, dissolved in groundwater are in equilibrium with chemicals sorbed to soil within a plume in which chemical sorption and retardation occur.

5.5 RESULTS OF CALCULATIONS

Three simulations were completed using the most recently measured chemical concentrations at each of the three wells (well SS45L001MW, Well #1, and Well #4) as the initial concentrations. The first simulation at each well assumed that no pumping would occur, and that all chemical mass removal was solely a result of chemical degradation and diffusion (RNA). The second simulation at each well assumed that a pumping system, extracting water at the rate of 0.01 pore volume per year, would operate at that location until the MCL for each chemical was attained. The third simulation assumed a higher extraction rate of 0.06 pore volume per year. Because of uncertainties regarding the initial chemical concentrations in each part of the 800 Area and 2500 Area and possible ranges of groundwater extraction rates, simulations were conducted using a range of chemical concentrations (actual concentrations detected at each well; median and maximum concentrations in the vicinity of each well), and a range of possible extraction rates (no pumping, 0.01 pore volume per year, and 0.06 pore volume per year; Appendix G).

As TCE and its DCE daughter compounds are removed from the groundwater system by degradation, VC is generated. Because VC is the penultimate daughter product in the chain of degradation reactions that begins with TCE, and will probably be the last contaminant to degrade at Site SS-45. Furthermore, the cleanup goal for VC (2 µg/L) is the lowest of any compound in the TCE degradation chain (Table 5.4-1). Therefore, the

TABLE 5.4-1
CLEANUP GOALS FOR CAHs IN GROUNDWATER
SITE SS-45
ENGLAND AFB, ALEXANDRA, LOUISIANA

Chemical of Concern	Target Cleanup Goal ($\mu\text{g/L}$) ^{a/}
TCE	5
<i>cis</i> -1,2-DCE	70
<i>trans</i> -1,2-DCE	100
VC	2

^{a/} Based on USEPA (1996) maximum contaminant levels and LDEQ (1998) RBSLs.

time required to achieve the VC cleanup goal in groundwater is correspondingly longer than the times required to achieve the cleanup goals for TCE or the DCE isomers. Consequently, it was assumed that the time required to achieve the VC cleanup goal represents the time required to achieve MCLs for all CAH compounds. The calculated times required to achieve the VC cleanup in groundwater near Wells #1, #4, and SS45L001MW, for RNA alone and for RNA supplemented by two pumping tests, are summarized in Table 5.5-1 and described below:

- RNA alone in the southern part of the 2500 Area (near Well #1) would require a period of about 27 years to achieve the VC cleanup goal;
- RNA alone in the northern part of the 2500 Area (near Well #4) would require a period of about 34 years to achieve the VC cleanup goal; and
- RNA alone, in the 800 Area, would require a period of about 48 years to achieve the VC cleanup goal.
- Estimates of the period of time required to achieve the VC cleanup goal in groundwater in the vicinity of Well #1 with RNA and groundwater pump-and-treat alternatives range from 18 to about 22 years.
- RNA supplemented with groundwater pump-and-treat would require a period ranging between 18 and about 20 years to achieve cleanup goals in groundwater in the in the northern part of the 2500 Area near Well #4.
- RNA supplemented with groundwater pump-and-treat would require from 26 to about 35 years to achieve the VC cleanup goal in groundwater in the 800 Area near well SS45L001MW.

TABLE 5.5-1
ESTIMATED TIME TO ACHIEVE
CLEANUP GOALS FOR CAHs IN GROUNDWATER
SITE SS-45
ENGLAND AFB, ALEXANDRIA, LOUISIANA

Plume Area and Alternative	Estimated Time to Attain Cleanup Goal ^{a/} (years)
Southern 2500 Area Near Well #1	
Alternative 1 – MNA	27
Alternative 2a – Low-Rate P&T w/ MNA	22
Alternative 2b – High-Rate P&T w/MNA	18
Northern 2500 Area Near Well #4	
Alternative 1 – MNA	34
Alternative 2a – Low-Rate P&T w/MNA	20
Alternative 2b-High-Rate P&T w/MNA	18
800 Area Near Well SS45L001MW	
Alternative 1 – MNA	48
Alternative 2a – Low-Rate P&T w/ MNA	35
Alternative 2b-High-Rate P&T w/MNA	26

^{a/} Based on cleanup goal for vinyl chloride (2 µg/L). Assumes that no continuing source of CAHs from the upper silt/clay layer.

As indicated in Table 5.5-1, there is relatively little difference between natural attenuation alone and natural attenuation with groundwater pump-and-treat in the times required to reach CAH cleanup goals within any given portion of the plume. This occurs because chemical sorption hinders the removal of chemicals via pumping (Appendix F).

5.6 SENSITIVITY ANALYSIS

A detailed sensitivity analysis was conducted in Appendix G to evaluate which of the input parameters to the kinetics-based geochemical model might have the greatest effect on model predictions. The purpose of such an analysis is to identify those parameters that should be the focus of continuing investigations in order to minimize the uncertainties associated with model predictions.

The parameters of primary interest in the sensitivity analysis were the first-order degradation rate constants for TCE, DCE isomers, and VC; the fraction of organic carbon in soil; and the rates of groundwater extraction. The total length of time required to achieve the VC cleanup goal of 2 µg/L (or less) in groundwater at each of three possible

extraction-well locations (well SS45L001MW in the 800 Area and Wells #1 and #4 in the 2500 Area) was selected as the predictive result to be compared in the analysis.

The sensitivity analysis was conducted using a standard variational technique in which the value of a particular input parameter is changed within some specified range, and a new predictive simulation is made using the new initial conditions. The predicted result is then compared with the original result. Each of the parameters (first-order degradation rate constants, fraction of organic carbon in soil, groundwater pumping rates) was varied in turn between its maximum and minimum values. The calculated result was then compared with the results obtained using median values of each parameter (the "base case").

The results of the sensitivity analysis indicate that the model predictions are most sensitive to changes in the values used for the first-order degradation rate constant for VC, and are slightly less sensitive to the first-order degradation rate constants for TCE and DCE isomers (Appendix G). Predictions of the time required to achieve action-level concentrations of VC in groundwater are not sensitive to the rates of groundwater extraction, indicating that higher extraction rates would be only marginally more effective in achieving action-level concentrations of chemicals.

As additional chemical concentration data are collected, and concentration trends are evaluated during long-term monitoring, future predictions can be refined using better estimates of the parameter to which the calculations are most sensitive (first-order degradation rate constants), thereby reducing the uncertainty associated with estimation of cleanup times.

SECTION 6

ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the screening and evaluation of remedial alternatives and selection of remedial measures for CAH-contaminated groundwater at Site SS-45, England AFB. This section presents the findings of a focused CMS to determine whether MNA may be a protective and cost-effective remedial approach for Site SS-45, in particular when compared to engineered pump-and-treat alternatives.

Section 6.1 presents the criteria used for initial screening of groundwater remedial alternatives, and Section 6.2 discusses the development of the three remedial alternatives considered in this focused CMS. Section 6.3 provides a brief description of each of these alternatives, and Section 6.4 provides a more detailed analysis of the remedial alternatives using the defined evaluation criteria. The selection of a recommended alternative is summarized in Section 6.5.

6.1 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

The criteria used to evaluate the candidate remedial alternatives for CAH-contaminated groundwater at Site SS-45 were adapted from those recommended by USEPA guidance for RCRA Corrective Action Plans (Office of Solid Waste and Emergency Response [OSWER] Directive 9902.3) and USEPA guidance for selecting remedies under Superfund (Office of Solid Waste and Emergency Response [OSWER] Directive 9355.3). Primary screening criteria include (1) long-term effectiveness and permanence, (2) technical and administrative implementability, and (3) relative cost. The following sections briefly describe the scope and purpose of each evaluation criterion.

6.1.1 Long-Term Effectiveness and Permanence

Each remedial approach or remedial alternative (which can be a combination of remedial approaches) was analyzed to determine how effectively it would decrease the concentrations of CAHs in groundwater at Site SS-45 so that groundwater quality standards can be achieved. The expected remedial effectiveness was evaluated based on site conditions and case histories from other sites. The ability of each remedial alternative to protect human health and environmental receptors from potential exposures to site-related contamination in groundwater within the Intermediate Sand unit was qualitatively assessed. The ability to minimize potential impacts on surrounding areas, facilities, and operations was considered. This evaluation criterion also includes permanence and the ability to reduce contaminant mass, toxicity, and volume. Time to implementation and

time until the remedial action objectives are achieved were estimated. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and potential safety issues were also evaluated.

6.1.2 Implementability

The technical and administrative implementation of each remedial technology/approach or alternative was evaluated in terms of technical feasibility and availability. Potential logistical shortcomings and difficulties in construction, operations, and monitoring are presented and weighed against perceived benefits. Requirements for any post-implementation site controls such as LTM and land or groundwater use restrictions are described. Administrative feasibility in terms of public acceptance and the ability to obtain necessary regulatory approvals is discussed.

6.1.3 Cost

The total cost of each remedial alternative (in 1999 constant dollars) was estimated for comparison. Estimates of capital costs and post-implementation costs for site operations, maintenance, and monitoring (OM&M) are provided.

6.2 FACTORS INFLUENCING THE SCREENING OF ALTERNATIVES

Several factors were considered during the identification and screening of remedial technologies for addressing groundwater contamination at Site SS-45. These factors included the requirements of a CMS under RCRA; contaminant, groundwater, and soil properties; current and future land uses; and potential receptor exposure pathways and proposed remedial action objectives. The following subsections briefly describe each of these factors and how they were used to screen potentially applicable remedial technologies for development of the remedial alternatives.

6.2.1 Regulatory Requirements

Site SS-45 is under the jurisdiction of the State of Louisiana RCRA program and the remedial alternative screening and selection process described in this section ascribe to the basic requirements for a CMS. The effort has been termed a "focused CMS" because its primary purpose is evaluate RNA as a likely component any remedial alternative, and to compare the relative merits of RNA to a short list of other alternatives (pump and treat options). This approach, and the scope of the Parsons ES effort, has been approved by the England AFB BCT which is comprised of representatives from the Louisiana Department of Environmental Quality, Region 6 of the USEPA, and the Air Force.

6.2.2 Properties of Chemicals of Potential Concern

The results of investigations (Section 4) indicate that CAHs, including TCE and its degradation daughter products (DCE isomers and VC), are the contaminants of primary concern at Site SS-45. Groundwater contamination at Site SS-45 is a consequence of the migration of solvent constituents to the water table from small, geographically dispersed source areas, with subsequent dispersion throughout portions of the Intermediate and

TABLE 6.2-1
PROPERTIES OF SELECTED ORGANIC CHEMICALS
SITE SS-45
ENGLAND AIR FORCE BASE
ALEXANDRIA, LOUISIANA

Compound ^a	Molecular Weight (g/mol) ^a	Henry's Law Constant (atm-m ³ /mol) ^a	Vapor Pressure (mm Hg @ 20°C) ^a	Density (g/cm ³) ^a	Solubility (mg/L) ^b	Vapor-Air Diffusion Coefficient (cm ² /day) ^b	Water-Liquid Diffusion Coefficient (cm ² /day)	K _{ow} (mL/g) ^c	log K _{ow}	First Order Decay Constant in Water (1/days) ^d
Methane	16.04	1.83E+01	2.08E+04	0.420	24 ^m	17,680	1.55	7.60E+02	2.88	N/A
Ethane	30.07	1.92E+01	2.93E+04	0.561	60.4 ^m	11,870	1.12	4.58E+02	2.66	N/A
Ethene	28.05	8.60E+00	3.08E+04	0.566	131	12,510	1.22	2.99E+02	2.48	0.006 - 0.17
1,1-DCA	98.96	4.32E-03	1.80E+02	1.176	5,500 ^m	7,690	0.79	3.00E+01	1.48	0.002
1,2-DCA	98.96	9.77E-04	6.10E+01	1.235	8,690 ^m	7,680	0.79	1.90E+01	1.28	0.002
TCE	131.39	7.19E-03	6.00E+01	1.464	1,100 ^m	7,603	0.72	1.07E+02	2.03	0.0001 - 0.001
1,1-DCE ^e	96.94	2.07E-02	5.00E+02	1.218	2,250 ^q	8,122	0.82	6.50E+01	1.81	0.005
cis-1,2-DCE	96.94	2.97E-03	2.00E+02	1.284	800 ^m	9,245	0.82	4.47E+01	1.65	0.0001 - 0.004
trans-1,2-DCE	96.94	7.26E-03	3.40E+02	1.257	600 ^m	7,860	0.83	5.90E+01	1.77	0.0001 - 0.004
Vinyl Chloride	62.50	2.18E-02	2.66E+03	0.911	1,100 ^m	9,245	0.98	2.50E+00	0.40	0.0002
Benzene	78.11	5.43E-03	7.60E+01	0.877	1,780 ^m	7,980	0.94	9.12E+01	1.96	0.001
Toluene	92.14	5.94E-03	2.20E+01	0.867	515 ^m	7,344	0.82	1.51E+02	2.18	0.001
Ethylbenzene	106.17	8.44E-03	7.00E+00	0.867	152 ^m	6,566	0.78	2.57E+02	2.41	0.001
o-Xylene	106.17	5.10E-03	5.00E+00	0.880	175 ^m	6,307	0.61	1.29E+02	2.11	0.002
m-Xylene	106.17	7.68E-03	6.00E+00	0.864	146 ^r	5,962	0.61	1.59E+03	3.20	0.01
p-Xylene	106.17	7.68E-03	6.50E+00	0.861	198 ^m	5,789	0.61	2.04E+02	2.31	0.01

^a K_{ow} = Organic carbon partition coefficient.

^b DCA = dichloroethane, TCE = trichloroethene, DCE = dichloroethene.

^c grams/mole.

^d atmospheres-cubic meters per mole.

^e millimeters mercury at 20 degrees Centigrade.

^f grams per cubic centimeter.

^g milligrams per liter.

^h square centimeters per day.

ⁱ milliliters per gram.

^j per day.

^k West *et al.*, 1989.

^v estimated using: Lynatt *et al.*, 1990.

^m Verschueren, 1983.

ⁿ Howard *et al.*, 1991.

^o Gossett, 1987.

^p Tetra Tech, Inc., 1988.

^q Monigony and Welton, 1990.

^r Howard *et al.*, 1990.

^s Wiedeneier *et al.*, 1999.

^t Anthony *et al.*, 1997.

^u Howard *et al.*, 1990.

Deep Sand units of the Red River Alluvial Aquifer. The physicochemical characteristics of the CAH compounds greatly influence the effectiveness and selection of remedial technologies.

CAHs are highly volatile, moderately soluble in water, and are adsorbed to soil to a moderate degree (Table 6.2-1 and Appendix D). These characteristics allow the CAH compounds to leach from contaminated soil and dissolve in and migrate with groundwater (Lyman *et al.*, 1992). All of the CAH compounds are susceptible to *in situ* degradation through biotic and abiotic mechanisms; in fact, *in situ* biological degradation is the most important fate process acting to remove dissolved CAH compounds from the subsurface environment at Site SS-45. The degradation of CAH compounds is reviewed in Sections 4.2 and 4.4, and is described in detail in Appendix D. On the basis of the chemical characteristics listed in Table 6.2-1, MNA, enhanced biodegradation, air sparging, groundwater extraction with aboveground air stripping or carbon adsorption could be effective options for removing CAHs from groundwater at Site SS-45.

6.2.3 Site-Specific Conditions

Two general categories of site-specific characteristics were considered when identifying remedial technologies for CMS screening. The first category is physical site characteristics such as groundwater depth, gradient, flow direction, and soil type, which influence the types of remedial technologies most appropriate for the site. The second category involves assumptions about future land uses and potential receptor exposure pathways.

6.2.3.1 Groundwater and Soil Characteristics

Site geology and hydrogeology have profound effects on the movement and fate of contaminants, and the effectiveness and scope of required remedial technologies at a particular site. For example, the effectiveness of pump and treat and air sparging technologies is greatly restricted in hydrogeologic units that comprised of silt and clay material. The depth to groundwater and saturated thickness of the affected hydrogeologic unit also can influence the selection of appropriate technologies. In most areas of Site SS-45, the Intermediate Sand unit is overlain by 20 to 40 feet of silty clay (the upper silt/clay unit), and the base of the Intermediate Sand unit is about 80 feet bgs. These characteristics were considered during the screening of potential remedial alternatives.

In most circumstances, hydraulic conductivity can be the most important aquifer parameter governing groundwater flow and contaminant transport in the subsurface. Slug tests conducted at Site SS-45 indicate that hydraulic conductivity ranges from very low in the upper silty clay zone (<1 ft/day) to moderate hydraulic conductivity in the Intermediate and Deep Sand units (1 ft/day to about 35 ft/day). Although low hydraulic conductivities can limit plume expansion and migration, this same characteristic also will reduce the effectiveness of some remedial approaches (e.g., groundwater extraction, air sparging).

Low hydraulic conductivity and low gradients decrease the amount of contaminant mass traveling through an *in situ* treatment zone within a given time period. In conditions where contaminant migration is primarily a result of chemical diffusion (e.g., Site SS-45), chemical migration is only indirectly related to hydraulic conductivity, in that diffusive migration is driven by chemical concentration gradients, but will occur preferentially in zones having relatively greater porosity (Jury *et al.*, 1983). Although diffusive migration generally occurs at a much slower rate than advection, diffusive processes alone can cause CAHs to migrate at detectable concentrations to distances hundreds of feet from sources of chemical discharge to groundwater over a period of 40 to 50 years (Gillham and Cherry, 1982).

Groundwater geochemistry is by far the most important site characteristic influencing the natural attenuation of CAH compounds. The natural reducing conditions found in both the silt/clay zone and Intermediate and Deep Sand units below England AFB are near optimal for the reductive dechlorination of CAH compounds. Microorganisms capable of degrading CAH constituents are present in most shallow subsurface environments. Examination of geochemical trends and the relative proportions of TCE and its daughter products in groundwater in the 800 and 2500 Areas of Site SS-45 indicates that biodegradation of CAHs by indigenous microorganisms is ongoing at Site SS-45 (Section 4).

6.2.3.2 Potential Exposure Pathways

An exposure pathways analysis identifies the human and ecological receptors that could potentially come into contact with site-related chemicals and the contaminant migration pathways through which these receptors might be exposed. To have a completed exposure pathway, there must be a source of contamination, a mechanism(s) of release, a pathway of transport to an exposure point, an exposure point, and a receptor. If any of these elements does not exist, the pathway is considered incomplete, and receptors will not be exposed to site-related chemicals.

Evaluation of the potential long-term effectiveness of remedial approaches or technologies for Site SS-45 must determine if the approach will be sufficient to reduce the toxicity and minimize plume expansion so that potential receptor exposure pathways involving contaminants in groundwater remain incomplete. Assumptions about current and future land uses at a site form the basis for identifying potential receptors, potential exposure pathways, reasonable exposure scenarios, and appropriate remediation goals. USEPA (1991) advises that the land use associated with the highest (most conservative) potential level of exposure and risk that can reasonably be expected to occur should be used to guide the identification of potential exposure pathways and to determine the level to which the site must be remediated.

Site SS-45 is located within the boundaries of the former England AFB, which is currently in the process of conversion and redevelopment as an industrial park and general aviation facility. Site SS-45, with the rest of the Base, is under the jurisdiction of the England Economic and Industrial Development District, and excavation or other activities in the subsurface on the Base are controlled. The depth to the upper contact of the CAH-contaminated Intermediate Sand unit is generally greater than 20 feet bgs, and

alluvial groundwater beneath the Base is not utilized as a drinking-water source (Sections 3 and 4). Only minor detections of CAH compounds have been identified in the upper 15 feet of the soil and groundwater at Site SS-45 (Section 1). Known levels of contamination should pose no risk to workers involved in shallow excavations. In light of current institutional and physical constraints, no receptors are likely to be exposed to CAHs in groundwater within the Intermediate or Deep Sand units.

Assumptions about hypothetical future land uses must also be made to ensure that the remedial technologies or alternatives considered for groundwater at Site SS-45 are adequate and sufficient to provide long-term protection. The future use of Site SS-45, and the surrounding area, is projected to be unchanged from the current use described above (industrial park/general aviation). Therefore, no potential future receptor exposure pathways are likely to be completed, provided groundwater originating in the Intermediate or Deep Sand units is not used to meet potable or industrial water demands. Both the MNA approach and engineered remediation technologies would require some level of institutional control and worker protection during remediation.

6.2.4 Data Sufficiency

Based on past and current site investigations summarized in Sections 1-4, there is sufficient data to move forward with remedial action decisions.

- Data are sufficient to complete a conceptual site model of Site SS-45 that describes site hydrology and the degree of interaction between groundwater and surface water.
- Data are sufficient to identify chemicals which exceed potentially applicable regulatory criteria and to define the extent of migration within the Intermediate and Deep Sand units within Site SS-45.
- Data are sufficient to identify potential pathways of chemical migration and potential receptors.
- Data are sufficient to confirm reductive dechlorination as an important component of RNA and to make initial estimates of CAH decay rates and cleanup times.

6.2.5 Proposed Remedial Action Objectives (RAOs) for Groundwater

Proposed remedial action objectives for Site SS-45 groundwater have been developed based current and future exposure pathways with protection of human health as the primary objective. A complete list of ARARs has not been developed. Federal MCLs and LDEQ (1998) risk-based screening levels (RBSLs) have been referenced as chemical-specific ARARs and state and local regulations have been referenced at site-specific ARARs for aboveground treatment of groundwater and discharge standards. Proposed RAOs for Site SS-45 groundwater include:

1. Ultimately reduce concentrations of TCE, cis-1,2 DCE, trans-1,2 DCE, and VC to Federal Drinking Water MCLs and LDEQ RBSLs;

2. Prevent extraction of contaminated groundwater for domestic or industrial use to eliminate potential exposure pathways;
3. Contain the contaminant plumes to prevent migration beyond England AFB boundaries at levels exceeding MCLs, and,
4. Comply with applicable federal and state regulations governing the treatment and discharge of contaminated groundwater if aboveground treatment options are selected.

USEPA (1996) has established maximum contaminant levels (MCLs) for chemicals in groundwater under the Safe Drinking Water Act. LDEQ (1998) has adopted the federal MCLs for TCE, the DCE isomers, and VC as RBSLs under their risk-based corrective action (RBCA) guidance. The England AFB BCT has concurred with the use of these promulgated groundwater standards as conservative long-term cleanup goals for site groundwater. These goals, summarized in Table 6.2-2, were used as a basis for evaluating the potential long-term effectiveness of remedial technologies and alternatives.

TABLE 6.2-2
FINAL CLEANUP GOALS FOR CAH IN GROUNDWATER
SITE SS-45

ENGLAND AFB, ALEXANDRA, LOUISIANA

Chemical of Concern	Target Cleanup Goal ($\mu\text{g/L}$) ^{a/}
TCE	5
cis-1,2-DCE	70
trans-1,2-DCE	100
VC	2

^{a/}Based on USEPA (1996) maximum contaminant levels and LDEQ (1998) RBSLs.

TCE and its daughter products *cis*- and *trans*-1,2-DCE and VC have been detected in groundwater samples from Site SS-45 at concentrations that exceed the site cleanup goals listed in Table 6.2-2. Consequently, remedial approaches and technologies were screened based on their ability to control and reduce the toxicity of TCE, DCE isomers, and VC.

Although one remedial action objective for groundwater at Site SS-45 is to ultimately reduce the concentrations of TCE, DCE isomers, and VC in groundwater to levels below the cleanup levels listed in Table 6.2-2, short-term compliance with promulgated drinking water standards is not necessary if groundwater will not be used as a potable water supply. Thus, the rate of remediation required in areas with institutional groundwater controls is different than what might be required in areas where groundwater use is not restricted (e.g., for drinking water-aquifers). Institutional controls are therefore a necessary component of any groundwater remediation strategy for this site.

Effective long-term land-use planning and zoning can be used to assure that the selected remedial action is compatible with future land uses. Zoning restrictions could include specifying types and density of development, and restrictions on construction of potable-water wells. The required duration of such institutional controls may vary,

depending on the effectiveness of the selected remedial alternative at reducing contaminant mass and concentrations in the groundwater.

The third remedial action objective is to prevent the migration of contaminants of concern beyond the current boundaries of England AFB at levels that exceed the MCLs. The purpose of this RAO is to ensure that any contaminants from sources on England AFB do not migrate under surrounding properties where institutional controls can not be enforced. Of potential concern is the Bayou Rapides municipal well field that is located over 3,000 feet north of Site SS-45. All remedial alternatives must demonstrate containment of the contaminant plume within the Intermediate and Deep sand units.

The final RAO calls for compliance with all ARARs. In addition to the cleanup goals for *in situ* groundwater, process streams from any *ex situ* treatment processes must meet all applicable discharge requirements. These requirements vary based on the treatment and disposal options selected for the pump-and-treat alternative. Discharges to waters of the United States are regulated under the Clean Water Act, and are subject to National Pollutant Discharge Elimination System (NPDES) permitting. The State of Louisiana administers the NPDES program. Discharges of water to industrial wastewater treatment plants (IWWTPs) or publicly owned treatment works (POTWs) may be governed by the operating permits of the receiving treatment plant. Air emissions are regulated under the Clean Air Act and various state and local laws. Therefore, technology options were screened in part on their ability to consistently comply with discharge requirements under the groundwater pump-and-treat alternative.

6.2.6 Summary of Remedial Technology Screening

Several remedial technologies for treating CAH-contaminated groundwater at the site were identified and screened using the primary evaluation criteria (Section 6.1) and remedial action objectives (Section 6.2.5). Screening also considered the physicochemical properties of the chemicals of concern, site-specific characteristics including hydrogeology, land use assumptions, and potential exposure pathways. All of these factors influence the technical effectiveness, permanence, implementability, and relative cost of technologies for remediating groundwater underlying Site SS-45. The initial remedial technologies considered as part of this demonstration and those retained for detailed comparative analysis are identified in Table 6.2-3.

Following the initial screening process, several approaches and technologies were retained for development of remedial alternatives and comparative analysis. Retained approaches/technologies included: institutional controls, MNA, minimum pumping for containment, maximum pumping for CAH removal, *ex-situ* treatment via air stripping, and discharge of the treated water to the local POTW. The rationales for eliminating other technologies from consideration are included in Table 6.2-3.

TABLE 6.2-3
INITIAL SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS
FOR GROUNDWATER REMEDIATION

SITE SS-45
 ENGLAND AFB
 ALEXANDRIA, LOUISIANA

General Response Action	Technology Type	Process Option	Implementability and General Comments	Effectiveness	Relative Cost	Retain?
Long-Term Monitoring	Periodic Groundwater Monitoring	Long-Term Monitoring Wells	Numerous existing wells are available to confirm the progress of remediation	Necessary for all remediation strategies	Low	Yes
Institutional Controls	Groundwater Use Control	Land Use Control/Regulate Well Permits	The plume currently lies within the Base boundary and is under the jurisdiction of the England Economic and Industrial Development District. Regulation of land use should not be difficult.	Necessary component of LTM program	Low	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the current or predicted plume area. Some monitoring wells may be abandoned in the future.	Not required at this site	Low	No
		Point-of-Use Treatment	No groundwater is extracted from the plume area for any use.	Not required at this site	Moderate	No
Extraction/Containment of Plume	Public Education	Meetings/Newsletters	Base public relations and environmental management offices have many information avenues to workers and other potentially affected populations.	Necessary for all remediation strategies	Low	Yes
		Groundwater Extraction Wells (High Rate)	Groundwater extraction wells could be installed in areas of relatively higher chemical concentrations and pumped at high rates to remove maximum contaminant mass. Aboveground treatment required.	Moderate	High	Yes
	Physical Controls	Groundwater Extraction Wells (Low Rate)	Groundwater extraction wells could be installed in areas of higher chemical concentrations and pumped at minimum rates to contain and more slowly remove contaminant mass. Aboveground treatment required.	Moderate	Moderate to High	Yes
		Slurry Walls/Grout Curtains	Could be installed as part of a funnel and gate system to direct plume through a relatively short treatment zone; however, the lack of defined flow directions and great depth to the base of the Intermediate Sand unit renders this option infeasible.	Not implementable	Very High	No

TABLE 6.2-3 (Continued)
INITIAL SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS
FOR GROUNDWATER REMEDIATION

SITE SS-45
ENGLAND AFB
ALEXANDRIA, LOUISIANA

General Response Action Extraction/ Containment of Plume	Technology Type Physical Controls	Process Option	Implementability	Effectiveness	Relative Cost	Retain?
<i>In Situ</i> Groundwater Treatment	Biological/ Chemical/ Physical	Sheet Piling	Could be installed as part of a funnel and gate system to direct plume through a relatively short treatment zone. May have more long-term integrity than slurry wall; however, the relatively great depth to the base of the Intermediate Sand unit renders this option infeasible.	Not implementable	Very High	No
		Remediation by Natural Attenuation (RNA)	A combination of natural biological, chemical, and physical removal mechanisms that occur to varying degrees at all sites. Groundwater sampling at the site indicates that this is an effective ongoing remediation process (see Section 4).	- Moderate in 800 Area - High in 2500 Area	Low	Yes
	Enhanced Biological	Electron Donor (Carbon) Addition	Attempts to enhance reductive dechlorination process by adding carbon substrate and drive down redox potential. This promotes the use of CAH compounds as electron acceptors (dehalogenation). Significant reductive dechlorination is already occurring in 2500 Area, so benefit would be minimal. 800 Area could receive some benefit, but the great volume of contaminated groundwater and lack of gradient would make it impossible to distribute carbon substrate without an aggressive injection and pumping system.	Low in 2500 Area to moderate in 800 Area	High	No
	Chemical/ Physical	Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of CAH into air bubbles and into vadose zone. Limited radius of influence and short-circuiting are common problems; and presence of Upper Clay unit renders this option infeasible.	Low, given site geological constraints	Moderate	No
		Permeable Reaction Wall (Iron Filings Trench)	A permeable reaction wall can be installed around the contaminant plume. Same installation problems as slurry walls. New, relatively unproven technology. Potential problems with clogging, and effective lifespan not known.	Not implementable given site constraints	High	No

TABLE 6.2-3 (Continued)
INITIAL SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS
FOR GROUNDWATER REMEDIATION

SITE SS-45
 ENGLAND AFB
 ALEXANDRIA, LOUISIANA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain?
Ex situ Groundwater Treatment	Chemical/Physical	Air Stripping	Cost-effective technology for removing varying concentrations of VOCs at higher flow rates and concentrations. Potential permitting requirements for air emissions.	High	High	Yes
		Activated Carbon	More cost effective than air stripping for low VOC concentrations and/or low flow rates, but ineffective for removal of vinyl chloride. Creates secondary waste stream that requires offsite treatment.	Moderate to Low	Moderate	No
		Ultra Violet Light/Ozone Reactors	May require excessive retention times and large, expensive reactors.	Moderate	High	No
		Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)	Viable option when an IWWTP is readily available and capable of handling CAH constituents and hydraulic loading. No known facility in reasonable proximity to Base. Could exceed influent concentration limits; therefore, not retained.	Probably not implementable	Moderate	No
Treated Groundwater Disposal	Discharge to IWWTP or Sanitary Sewer	IWWTP	Viable option when an IWWTP is available and capable of handling hydraulic loading. No known facility in reasonable proximity to Base.	Probably not implementable	Moderate	No
		Sanitary Sewer	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable. Sanitary sewer is potentially available; and ultimate discharge would be to Publicly Owned Treatment Works (POTW).	High	Moderate to High	Yes

TABLE 6.2-3 (Concluded)
INITIAL SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS
FOR GROUNDWATER REMEDIATION

SITE SS-45
 ENGLAND AFB
 ALEXANDRIA, LOUISIANA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain?
Treated Groundwater Disposal (cont.)	Treated Groundwater Reinjection	Vertical Injection Wells	Not recommended due to clogging and high maintenance.	Moderate	High	No
		Injection Trenches	Require large trenches and can be subject to injection well permitting. The depth to and the low hydraulic conductivity of Intermediate Sand unit make this option infeasible.	Not implementable	High	No
	Discharge to Surface Waters	Storm Drains or Discharge Ditches	Generally requires NPDES discharge permit. Anticipated volume of water to be discharged makes this option less attractive.	High	Low	No
Source Removal/Soil Remediation	Excavation/ Treatment	Landfilling	Excavation is not appropriate at this site because source areas have not been identified.	Low	High	No
		<i>Ex situ</i> soil vapor extraction	Excavation is not appropriate at this site because source areas have not been identified.	Low	High	No
		Thermal Desorption	Excavation is not appropriate at this site because source areas have not been identified.	Low	High	No
	<i>In Situ</i> Treatment	Surfactant Flushing	Additional pore volumes of water and/or surfactant solution are forced through aquifer material to enhance the partitioning of contaminants into the groundwater. Potential method to remove free-phase product. Not applicable at this site.	Low	High	No

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained through the screening process were combined into three remedial alternatives for Site SS-45. Screening was conducted systematically by considering the program objectives of the effectiveness/permanence, implementability, and cost in Section 6.4. Three remedial alternatives were developed for detailed evaluation:

1. Groundwater remediation by MNA with institutional controls; and
- 2a. Groundwater remediation using MNA and institutional controls combined with containment (low rate) groundwater extraction, treatment by air stripping, and effluent discharge to the POTW.
- 2b. Groundwater remediation using MNA and institutional controls combined with high rate groundwater extraction, treatment by air stripping, and effluent discharge to the POTW.

These alternatives are briefly described in the following subsections.

6.3.1 Alternative 1 - MNA and Institutional Controls

RNA is achieved when naturally occurring attenuation mechanisms reduce the total mass of a contaminant in soil or groundwater. RNA results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Destructive attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include adsorption, diffusion, dilution (caused by dispersion and infiltration), and volatilization.

The MNA alternative assumes that no active groundwater remediation would be conducted. Rather, the alternative relies on natural attenuation mechanisms to limit plume expansion and remove CAHs from groundwater in the Intermediate and Deep Sand units. As indicated by examination of the evidence of RNA presented in Section 4, these processes are occurring in both the 800 and 2500 Areas of Site SS-45, and will continue to reduce the mass of contaminants in the subsurface. LTM would be required to document CAH removal from the groundwater system, and to verify that RNA is proceeding at an acceptable rate. Periodic site reviews also could be conducted using LTM data to evaluate the extent and magnitude of contamination, assess contaminant migration and attenuation through time, document the effectiveness of institutional controls at the site, and reevaluate the need for additional remedial actions at the site.

MNA offers several distinct advantages over engineered treatment systems. Advantages include:

- Chemicals are actually mineralized (broken down to harmless compounds) *in situ* by RNA, whereas *ex situ* treatment systems often merely transfer chemicals from one phase and medium to another.

- Current technologies that involve active groundwater extraction (i.e., pump-and-treat systems) are energy-intensive and generally not as effective in reducing *in situ* residual contamination;
- MNA is nonintrusive and allow full and continuing use of infrastructure during remediation;
- Current engineered remedial technologies may pose a greater risk to potential receptors than RNA (e.g., contaminants may be transferred into another medium during remediation activities); and
- MNA is generally less costly than conventional, engineered remedial technologies. With the exception of regular monitoring to verify RNA and occasional well maintenance, the passive nature of MNA minimizes O&M expenses.
- No contaminated media are extracted from the subsurface, so air and water treatment, discharge, and permitting issues are eliminated with MNA.

A potential disadvantage of MNA is that, in some cases, natural attenuation rates are too slow to make MNA a practical remedial alternative. In addition, biodegradation of highly chlorinated compounds (e.g., TCE) can produce daughter products that are relatively toxic (e.g., VC).

Alternative 1 would require implementation of institutional controls, such as restrictions on the use of groundwater, together with LTM. Land use restrictions would include enforcing long-term restrictions on deep excavations (>15 feet bgs) and on the installation of beneficial-use groundwater wells within and near affected parts of the 800 and 2500 Areas. The intent of these restrictions would be to reduce potential receptor exposures to site-related contaminants until plume concentrations are reduced below MCLs.

Public education programs regarding the selected alternative would be developed to inform industrial workers and nearby residents of the scientific principles underlying RNA. Education could be accomplished through public meetings, presentations, fact sheets, press releases, and posting of signs where appropriate

6.3.2 Alternative 2a - MNA and Institutional Controls Combined with Containment (Low Rate) Groundwater Extraction, Treatment, and Disposal

Alternative 2a incorporates the elements of Alternative 1, and adds a low rate of groundwater extraction and treatment in portions of Site SS-45 that contain relatively elevated concentrations of dissolved CAHs. A minimum pumping rate would be used to ensure containment of the Intermediate Sand plume surrounding sources in the 800 Area and 2500 Area. Extraction wells would be installed in the Intermediate Sand unit at depth intervals that correspond to the contaminant plume and that would enable effective pumping (Hinchee *et al.*, 1987; Mercer *et al.*, 1990; Sanderson *et al.*, 1993; USEPA, 1988; *ibid.*, 1989a; *ibid.*, 1989b; *ibid.*, 1992). Contaminated groundwater would be pumped to an aboveground air stripper for treatment, and treated water would be disposed of in a

sanitary sewer that discharges to the local POTW. As described in Appendix G, a minimum pumping rate of 20 gpm from each of three wells (one in the 800 Area and two in the 2500 Area), would provide hydraulic containment of the existing plume and gradually reduce the mass and concentrations of CAHs in the groundwater. Relative capital costs to implement a small, three-well pump-and-treat system would be moderate. Health and safety precautions would be necessary when drilling into contaminated aquifers, and O&M would include pumping, treatment, effluent sampling, and permitting/disposal costs.

Air stripping is the treatment technology selected for Alternative 2a. Air stripping is a proven technology for removing CAHs from solution, and removal efficiencies greater than 99 percent can be achieved (Armstrong and Sammons, 1986; Brown *et al.*, 1991; Mercer *et al.*, 1990; Stover *et al.*, 1986; USEPA, 1992; *ibid.*, 1993a). This technology is applicable across a broad range of VOC concentrations, but is generally most cost-effective when dissolved chemical concentrations are greater than 100 ppb. For low flow rates, water is pumped to the top of the stripper and cascaded over perforated trays while air is blown counter-current into the cascading water. This results in mixing of the air and water so that VOCs are transferred (stripped) from the aqueous (dissolved) phase to the gas phase. The air-to-water ratio is dependent on the compounds being removed and the ambient operating temperature. Higher air-to-water ratios will provide better removal rates, but will require increased blower horsepower and associated operating costs.

Under Alternative 2a, treated groundwater would be discharged to the municipal sewer system for subsequent offsite treatment by the local POTW. A permit would be required prior to initiating discharges to the POTW, and effluent sampling would be required to ensure that discharged waters meet the POTW's operating license requirements (USEPA, 1990). Capital costs associated with POTW treatment are expected to be moderate to low, and would be associated primarily with constructing piping to convey treated water from the treatment system to the POTW hookup. An air emissions permit also could be required if air stripper off-gases contain VOCs in excess of allowable amounts. O&M costs would be moderate, and would result primarily from regular monitoring of the water and air effluent streams.

6.3.3 Alternative 2b - MNA and Institutional Controls Combined with More Aggressive (High Rate) Groundwater Extraction, Treatment, and Disposal

Alternative 2b combines MNA with a more aggressive groundwater pumping strategy. The objective of this alternative is to remove contaminants from the Intermediate Sands at a higher rate, and reduce the timeframe to achieve MCLs. As described in Appendix G, a maximum pumping rate of 120 gpm from three wells (one in the 800 Area and two in the 2500 Area), would create excess hydraulic containment but would increase the number of pore volumes of groundwater passing through the contaminated aquifer material. The relative capital costs to implement a 120 gpm in the 800 Area, and a 240 gpm pump-and-treat system in the 2500 Area, would be high. Health and safety precautions would be necessary when drilling into contaminated aquifers, and O&M would include pumping, treatment, effluent sampling, and permitting/disposal costs.

Air stripping was also the treatment technology selected for Alternative 2b, however, a larger, packed-tower air stripper would be required for the 240 gpm flowrate. Power requirements for the larger pumps and blowers associated with the Alternative 2b system would significantly increase O&M costs.

Under Alternative 2b, treated groundwater could be discharged to the municipal sewer system for subsequent offsite treatment by the local POTW. However, at these flow rates, the local sewer lines could be hydraulically overloaded and the POTW could refuse to accept this quantity of relatively clean water. Other options such as a separate NPDES permit and discharge to surface water could be explored.

6.4 DETAILED EVALUATION OF ALTERNATIVES

The remedial alternatives developed for Site SS-45 were next evaluated using additional criteria specified for RCRA Corrective Measures Studies. These criteria include:

- Overall protectiveness of human health and the environment;
- Long-term effectiveness and permanence, including reduction of toxicity, mobility or volume of contamination;
- Short-term effectiveness;
- Implementability, including regulatory and community acceptance;
- Cost

The three alternatives are evaluated in the following subsections using these evaluation criteria.

6.4.1 Protectiveness

Both alternative 1 (MNA only) and the pumping alternatives (2a and 2b) were judged to be equally protective. MNA will continue to destroy contaminants of concern and limit plume expansion under both alternatives. While pumping may reduce the timeframe required to achieve final cleanup goals, the pumping alternative will remove contaminants from the groundwater and release them to the atmosphere or POTW system. This surface discharge will expose site workers to low levels of contaminants, including vinyl chloride. Exposure of ecological receptors should not occur under either alternative. Contaminated groundwater is not expected to discharge to surface waters.

Possible routes of exposure to chemicals in groundwater at Site SS-45 are ingestion, dermal contact, or inhalation of chemicals volatilized from groundwater. Such exposures can occur only if groundwater is extracted from a well or is encountered in a deep excavation within the plume boundaries. Current land use plans call for the Base to be used as an industrial park/general aviation facility under the jurisdiction of the England Economic and Industrial Development District. Institutional controls (i.e., zoning and deed restrictions limiting deep excavations and groundwater extraction for beneficial

use), are proposed as part of all remedial alternatives. Institutional controls should be effective in reducing or eliminating the possibility for exposure of potential receptors, and are expected to be equally reliable for both alternatives. Louisiana's environmental cleanup laws require that institutional controls be weighted equally with active remedial measures in evaluating effectiveness (LDEQ, 1998). Institutional controls would be the same under each alternative, though the duration of such controls would be slightly different for Alternatives 1, 2a and 2b.

6.4.2 Long-Term Effectiveness and Permanence

As described in Section 4 and Appendix G, RNA ultimately will reduce CAH concentrations in the subsurface to non-detectable levels, even in the absence of engineered remedial measures. Groundwater in the Intermediate and Deep Sand units beneath Site SS-45 is not currently a source of drinking water (Sections 3 and 4). Detectable concentrations of CAHs occur in groundwater within a well-defined area of the Base, have migrated only short distances from potential source areas.

Parsons ES completed a series of calculations to evaluate the possible rates of chemical removal from the groundwater system under each alternative (Appendix G). If the pump-and-treat alternative is capable of removing chemicals from the groundwater system significantly faster than RNA alone, active remediation could be considered more "effective" than the MNA alternative. The rates of mass removal for TCE and its daughter products (DCE isomers and VC) were calculated for a system in which chemical removal occurs through RNA only, and for a system in which chemical removal occurs through RNA and extraction/treatment.

For the purposes of these calculations, the groundwater cleanup goals for TCE, *cis*-1,2-DCE, and VC (Table 6.2-2) were assumed to be protective of human health and the environment. The objective of the calculations (Appendix G) was to estimate the amount of time required to reduce the CAH concentrations in the groundwater system below these cleanup goals. The initial chemical concentrations for the calculations were the concentrations measured in groundwater samples from three of the most contaminated wells in potential source areas (Wells #1 and #4 in the 2500 Area, and well SS45L001MW in the 800 Area).

As TCE and its DCE daughter compounds are removed from the groundwater system by degradation, VC is generated. Because VC is the last contaminant of concern to be formed in the reductive degradation process, it will be more persistent than TCE and DCE. Consequently, it was assumed that the time required to achieve the VC cleanup goal represents the full implementation period for either groundwater alternative. The calculated times required to achieve the VC cleanup goal in groundwater near Wells #1, #4, and SS45L001MW for the three alternatives are summarized in Table 6.4-1.

As indicated in Table 6.4-1, there is some time advantage gained by pumping the aquifer under both the low- and high-rate pumping scenario. If a continuing source of CAH contaminants are entering the Intermediate Sand unit from the upper silt/clay layer, the timeframes for cleanup would be extended, but the relative timeframes for each alternative would be similar. Kinetic model calculations indicate that the bulk of

TABLE 6.4-1
ESTIMATED TIME TO ACHIEVE
CLEANUP GOALS FOR CAHs IN GROUNDWATER
SITE SS-45
ENGLAND AFB, ALEXANDRIA, LOUISIANA

Plume Area and Alternative	Estimated Time to Attain Cleanup Goal ^{a/} (years)
Southern 2500 Area Near Well #1	
Alternative 1 – MNA	27
Alternative 2a – Low-Rate P&T w/ MNA	22
Alternative 2b – High-Rate P&T w/MNA	18
Northern 2500 Area Near Well #4	
Alternative 1 – MNA	34
Alternative 2a – Low-Rate P&T w/MNA	20
Alternative 2b-High-Rate P&T w/MNA	18
800 Area Near Well SS45L001MW	
Alternative 1 – MNA	48
Alternative 2a – Low-Rate P&T w/ MNA	35
Alternative 2b-High-Rate P&T w/MNA	26

^{a/} Based on cleanup goal for vinyl chloride (2 µg/L). Assumes that no continuing source of CAHs from the upper silt/clay layer.

chemical mass removal under Alternatives 2a and 2b would occur during the first decade of pumping. The effects of chemical desorption from the Intermediate Sand unit would significantly hinder the removal of chemicals after the first 10-15 years of pumping (Appendix G), with RNA then becoming the dominant mass removal mechanism.

All of these factors suggest that over the long term, the remedial alternative relying solely on MNA with institutional controls should be as effective at toxicity and mass reduction as alternatives that include groundwater extraction and treatment. RNA of CAHs in the subsurface is expected to reduce the concentrations of chemicals to levels below MCLs, whether or not active remedial measures are implemented (Appendices E and F). The magnitude of residual risks, and the long-term potential for human or environmental exposure, are expected to be similar.

USEPA (1992) and the State of Louisiana (LDEQ, 1998) regard remedial measures that utilize permanent solutions and alternative technologies or resource recovery as

preferable to measures that require offsite transport or disposal of contaminated materials. However, if a remedial measure requiring offsite transport or disposal is more effective or more readily implementable than remedial measures utilizing resource recovery or an alternative technology, this option may be preferable to other alternatives, if other weighting factors (e.g., cost) are equal.

During the evaluations of RNA in the early 1990s, MNA remedies generally were regarded as unproven. However, with the success of field-scale treatability studies and the recent publication of guidance documents (USEPA, 1998; Wiedemeier *et al.*, 1998), MNA has gained regulatory approval and acceptance, and is regarded as a potentially applicable alternative remedy in many circumstances.

For the purpose of evaluating the degree to which the remedial alternatives are permanent solutions, any alternative that actively destroy or degrade CAHs is considered to be more permanent than alternatives that merely transfer chemicals to another medium or location. Using this criterion, MNA is preferable to groundwater extraction followed by air stripping because the latter alternative would transfer VOCs from one medium (water) to another (ambient air). The MNA alternative would destroy CAHs without transferring them to another medium.

6.4.3 Short-Term Effectiveness

Based on the kinetic model presented in Section 5 and Appendices F and G, pumping alternatives will be more effective at removing CAH mass during the initial 10-15 years of operation, but will become increasingly ineffective as contaminant removal becomes desorption limited. Over time, RNA should account for an ever increasing fraction of the total CAH removed from the subsurface.

The short-term risks arising from implementation of remedial alternatives vary between the alternatives. The MNA alternative would present fewer short-term risks than extraction of groundwater for *ex situ* treatment using air stripping. Air stripping, which removes chemicals from water and releases them to the atmosphere, could present short-term inhalation risks. There are also electrical hazards associated with pumping and aboveground treatment systems. Spills or breaks in transfer lines could discharge CAH contaminated groundwater directly to storm drains and surface waters.

6.4.4 Implementability

Implementability encompasses the technical and administrative feasibility of the remedial alternative. Technical implementability was used as a criterion during the initial technology screening to eliminate those technologies and process options that clearly would be ineffective or unworkable at Site SS-45. Standard construction equipment and techniques would be used for Alternatives 1, 2a, and 2b; therefore, equipment and worker availability is presumed to be similar for both alternatives. Operations, maintenance and monitoring of pump and treat systems are available skills, however, at England AFB these skills will require a permanent contractor presence at the facility. MNA will require only annual monitoring of selected wells and reporting. Pumping alternatives will also require permanent structures to house treatment equipment, pumping wells, and

monitoring wells. This will impact land development options. Alternative 1 will only require monitoring wells which can be flush-mounted to minimize the disturbance to future development. Alternatives 2a and 2b will require sewerlines capable of transmitting up to 240 gpm of additional flow. Alternative 1 places no new demands on existing infrastructure.

Administrative aspects of implementability include such factors as acceptability to regulatory agencies and the public, an Air Force demonstration that the remedial alternative is Operating Properly and Successfully (OPS), and the ability to obtain necessary permits for the proposed remedial measures.

Because perception plays a large part in the acceptance of remedial measures, alternatives that are perceived to be most effective will probably be more acceptable to regulatory agencies and the general public. The relative rankings of alternatives on implementability and effectiveness are closely related. In large measure, public acceptance also depends on the compatibility of a remedial alternative with the planned future use of the property. England AFB will be used as an industrial park/general aviation facility; the alternative that least interferes with this planned use without endangering public health or the environment may be judged to be more implementable. Alternative 1 will require a high level of regulatory confidence that CAH destruction is occurring and the RNA alone is capable of containing and eventually attaining cleanup goals (MCLs). The Air Force has dedicated significant resources to complete a RNA TS described in Sections 4 and 5. Following regulatory review and acceptance of this document, the England Economic and Industrial Development District and the general public near England AFB would need to be briefed and educated on the MNA alternative and its implications for future land and groundwater use. Alternatives 2a and 2b would likely have positive public support because they provide an extra assurance of plume containment and would somewhat shorten the time to achieve final cleanup goals.

Certification that the selected alternative is operating successfully and properly (OPS) is required before Base properties can be transferred to private ownership. The EPA has developed criteria for OPS demonstrations for both RNA and for pump and treat systems (USEPA, 1993b). Because the destruction of CAH compounds has been demonstrated at Site SS-45 and RNA is effectively limiting dissolved CAH migration, and because existing institutional controls are preventing receptor exposures to affected groundwater, the BCT could request an OPS certification on the basis of the information presented in this focused CMS. OPS certification for the pump-and-treat systems would not be possible until the systems have been designed, installed, optimized, and demonstrated to be achieving design efficiencies.

No special permits would be required for the MNA only alternative, however, purge water from monitoring events would require sampling and possible batch carbon treatment before discharge to the sanitary sewer. The pump-and-treat alternative may require two types of permits: a permit to discharge VOCs in the air stripper off-gas to the atmosphere, and a permit to discharge treated water to the local POTW sewer. Point-source discharges of VOCs to the atmosphere at a significant emissions rate (SER) are regulated under the Clean Air Act, which is administered in Louisiana by LDEQ. The SER for total VOCs is > 40 tons per year. For evaluation purposes, the proposed

Alternative 2b air stripper was assumed to operate at an average throughflow rate of 240 gallons per minute (gpm), and the influent groundwater was assumed to have an average CAH concentration of 100 µg/L. Using these assumptions, it was estimated that the air stripper would emit less than 1000 pounds of VOCs per year. Therefore, an air emissions permit should not be required.

Under Alternatives 2a and 2b, it is assumed that treated groundwater would be discharged to the local POTW via the sanitary sewer system. The chemical removal efficiencies for air strippers are generally 95-99 percent and would meet the anticipated discharge permit requirements.

6.4.5 Cost

During the evaluation of alternatives, the cost analysis is made based on a conceptual design for each alternative. In the absence of fully-developed designs, the associated cost estimates must also be regarded as conceptual; however, the conceptual nature of the design does not preclude the development of relatively detailed cost estimates that include both capital construction and O&M costs.

The cost criterion can also be used to evaluate the extent to which an alternative's short- and long-term costs are proportionate to its effectiveness. LDEQ (1998) requires that the least expensive of the effective remedial alternatives be preferred. RNA of groundwater CAHs is occurring, and will continue to reduce the concentrations of chemicals to non-detectable levels, whether or not active remedial measures are implemented (Section 4). Therefore, over the long term, the results of each alternatives examined are expected to be the same (i.e., the remedial alternatives are nearly equal in long-term effectiveness). Consequently, the association between projected expenditures and projected benefits are not discussed in this cost evaluation; rather, in accordance with the LDEQ (1998) requirements, the alternatives were evaluated on estimated total cost alone.

For the purpose of the cost evaluation, total cost was assumed to include the cost of initial equipment and materials purchased and installation (capital costs) plus long-term maintenance, monitoring, and reporting costs (O&M costs). Cost estimates (Appendix G) were derived from the literature (Yang *et al.*, 1987; Means, 1995; USEPA, 1993c), from vendor quotes, and/or from engineering estimates. O&M costs were generated as an estimate of total annual expenditures for operation, maintenance, monitoring, reporting, and ancillary activities. Annual O&M costs were then projected through the full length of the anticipated remediation and monitoring period in constant- (1999) dollar amounts.

Traditionally, long-term costs have been estimated and reported as net present worth (NPW) costs, in which the lump-sum value that must be invested at the present time was calculated using an adjustment rate that accounts for inflation and the cost of funds (i.e., interest) in order to meet future expenditures to be paid over time. However, federal funding for specific projects is obtained via annual appropriations that must be authorized by Congress for each fiscal year. Therefore, NPW cost estimates are not appropriate for long-term remediation projects such as the cleanup of groundwater at Site SS-45. The option of investing the NPW value of long-term O&M costs, to be drawn on as necessary

to meet expenditures throughout the full O&M period, is simply not available for federally-funded projects. It is important to realize that the long-term O&M costs presented have not been adjusted for inflation over the long time periods (decades) required for remediation projects. The actual costs will be greater in inflation-adjusted dollars than in constant (1999) dollars.

6.4.4.1 Alternative 1 – MNA and Institutional Controls

No active groundwater remediation would be conducted under the MNA alternative. Rather, the alternative would rely on naturally occurring processes to remove CAHs from Site SS-45 groundwater in the Intermediate and Deep Sand units. Periodic monitoring would be conducted (Section 7) to assess whether further migration of chemicals from source areas is occurring, and to verify the predicted rates of CAH removal from the groundwater system.

It was assumed for this cost estimate that existing site wells would be sufficient to conduct groundwater LTM, and that no additional monitoring wells would be installed. Therefore, there are no capital costs associated with Alternative 1. LTM would include visual inspection of wells at Site SS-45, measurement of water levels in all wells within the Site SS-45 plume, and collection and analyses of groundwater samples from approximately 38 monitoring wells (Section 7). Groundwater samples would be analyzed for CAHs and a suite of geochemical indicators for RNA. Over the longer term, the frequency of monitoring might be adjusted based on monitoring results and an assessment of the continued effectiveness of RNA. For the purpose of developing the conceptual cost estimate, it was assumed that monitoring would be conducted on an annual basis for the first 5 years of monitoring, and that the frequency of monitoring would be reduced to once every 2 years (biennial monitoring) for the remaining 43 years of the total 48-year remediation period required to achieve the VC cleanup goal of 2 µg/L (Table 6.4-1). Details of the cost estimate are provided in Appendix G.

LTM costs were estimated on an annual basis, and are referenced to constant (1999) dollars. The total cost of monitoring and reporting for the MNA alternative, assuming that monitoring activities would be conducted over a 48-year period, is estimated to be \$1,302,700 (Table 6.4-2).

6.4.4.2 Alternative 2a – MNA with Low-Rate Groundwater Extraction, Treatment, and Disposal

For the purpose of this cost evaluation, this alternative assumes the installation of a three-well groundwater extraction system. One extraction well would be installed near existing groundwater monitoring well SS45L001MW in the 800 Area. A second extraction well would be installed near existing Well #1, and a third extraction well would be installed near existing groundwater monitoring Well #4, in the southern and northern parts of the 2500 Area, respectively. Each of the three wells would pump at a rate of 20 gpm. Extracted groundwater would be treated by air stripping, and treated effluent would be discharged to a local POTW via the sanitary sewer. Because of the distance between the 800 and 2500 Area extraction wells, two air strippers would be required – one for each area. Each treatment system would consist of an equalization

TABLE 6.4-2
ESTIMATED COSTS FOR ALTERNATIVE 1 (MNA)
SITE SS-45
ENGLAND AFB, LOUISIANA

<u>Capital Costs (rounded)</u>	<u>Constant-Dollar Cost ^{a/}</u>
None	\$0
<u>Operation and Maintenance Costs (rounded)</u>	
Annual LTM, 1999 – 2004 (38 Wells)	\$201,000
Biennial LTM, 2005 – 2033 (38 Wells)	\$603,500
Biennial LTM, 2034 – 2047 (24 Wells)	\$210,700
Site Management and Reporting (48-Year Period)	\$288,000
Total Constant-Dollar Cost of Alternative 1	\$1,302,700

^{a/} Based on 1999 dollars with no inflation adjustment.

tank, and a low-profile air stripper with ancillary equipment (piping, pumps, electrical equipment, and controls). Electrical service would be required to provide power for the pumps and the air-stripping equipment. Piping from the treatment systems to a POTW-approved sewer inlet would be installed. Pump controls would be automated to the extent possible.

Well construction costs would include costs for drilling, well materials, and well development. The total dynamic head to be overcome by each pump, including possible well inefficiencies and head losses due to pipe friction, is anticipated to be no greater than 50 feet. The selection of pumps for the wells and holding tank would be based on the anticipated equipment performance and useful life in a groundwater environment having low CAH concentrations.

Total discharge of treated water to the POTW is estimated to be about 90,000 gallons per day (gpd) for the first 20 years of operation. After the 2500 Area had achieved cleanup goals in 22 years, the discharge rate from the 800 Area alone would be approximately 30,000 gallons per day. Groundwater extraction and treatment would continue in the 800 Area until chemical concentrations in groundwater in this portion of the plume have decreased to levels below cleanup goals (calculated to occur after another 13-year period of pumping, ending in year 2034).

Water samples would be collected from the influent and effluent treatment streams and analyzed for VOCs to ensure that POTW standards are met, and to assess the effectiveness of air stripping. It is anticipated that a permit-fee equivalent, or one-time hookup fee, would be assessed by the local waste water district prior to initiating discharge to the POTW; this fee would be in addition to the annual POTW fees that would be assessed according to the volume of water discharged. The total initial capital and construction costs for the groundwater extraction and treatment alternative are estimated to be \$565,000 (Table 6.4-3 and Appendix G).

TABLE 6.4-3
ESTIMATED COSTS FOR ALTERNATIVE 2A
(LOW-RATE PUMP AND TREAT WITH MNA)
 SITE SS-45
 ENGLAND AFB, ALEXANDRIA, LOUISIANA

<u>Capital Costs (rounded)</u>	<u>Constant-Dollar Cost ^{a/}</u>
Installation of 3 groundwater extraction wells, 2 treatment systems, and ancillary equipment	\$565,000
<u>Operation and Maintenance Costs (rounded)</u>	
LTM and Site Management 1999 – 2034	\$1,023,700
Annual O&M, 2000 – 2021 (800 and 2500 Areas)	\$3,446,800
Annual O&M, 2021 – 2034 (800 Area only)	\$1,002,300
<u>Total Constant Dollar Cost of Alternative 2A</u>	<u>\$6,038,000</u>

^{a/} Based on 1999 dollars with no adjustment for inflation.

O&M activities would include inspection, maintenance, and permitting of the system, chemical analyses of water and effluent airstream samples, groundwater monitoring for CAHs and RNA parameters, and reporting. The groundwater extraction and treatment system would be inspected on a weekly basis; water samples, collected bi-weekly from the influent and effluent treatment streams during inspections, would be analyzed for VOCs to ensure that the required treatment efficiencies are attained. Groundwater LTM would be conducted as described for Alternative 1, and would include measurement of water levels in all wells in the plume, and collection and analyses of groundwater samples from approximately 38 monitoring wells. For purposes of this cost estimate, it was assumed that the monitoring programs for the MNA and the pump-and-treat alternatives would be identical. In reality, groundwater monitoring for Alternative 2a would probably be conducted more frequently than biennially after the first 5 years of monitoring, but could cease after 35 years (Table 6.4-1). Costs for O&M activities were estimated on an annual basis and are referenced to constant (1999) dollars (Appendix G). The estimated constant-dollar value of O&M costs for the groundwater extraction and treatment alternative, assuming that O&M activities would be conducted through a 35-year period (Table 6.4-3), is about \$5,358,000. The total, constant-dollar cost of Alternative 2a (Low-Rate Groundwater Extraction and Treatment with MNA), including capital costs, O&M, and LTM, is \$6,038,000 (Table 6.4-3).

6.4.4.3 Alternative 2b – MNA with High-Rate Groundwater Extraction, Treatment, and Disposal

For the purpose of the cost evaluation, it was assumed that this alternative would also include a three-well groundwater extraction system using the same wells as Alternative 2b, but each well would be pumped at the maximum rate of 120 gpm. Extracted groundwater would be treated by air stripping, and treated effluent would be discharged

to a local POTW via the sanitary sewer. Two large air strippers would be required – one for each area. The pumping and treatment system would be identical to Alternative 2a except that larger pumps and treatment equipment would be required.

Total discharge of treated water to the POTW is estimated to be about 540,000 gallons per day (gpd) for the first 18 years of operation. After the 2500 Area had achieved cleanup goals in 18 years, the discharge rate from the 800 Area alone would be approximately 180,000 gallons per day. Groundwater extraction and treatment would continue in the 800 Area until chemical concentrations in groundwater in this portion of the plume have decreased to levels below cleanup goals (calculated to occur after another 8-year period of pumping, ending in year 2025).

It is anticipated that a permit-fee equivalent, or one-time hookup fee, would be assessed by the local waste water district prior to initiating discharge to the POTW; this fee would be in addition to the annual POTW fees that would be assessed according to the volume of water discharged. This assumes that the local sewer lines could handle this additional flow and that new sewer lines are not needed. The total initial capital and construction costs for the groundwater extraction and treatment alternative are estimated to be \$685,000 (Table 6.4-3 and Appendix G).

Operations, maintenance and monitoring activities would be similar to the smaller air stripping systems described in Alternative 2a, except that more time would be required for system checks and maintenance. For purposes of this cost estimate, it was assumed that the monitoring programs for the MNA and the pump-and-treat alternatives would be identical. In reality, groundwater monitoring for Alternative 2b would probably be conducted more frequently than biennially after the first 5 years of monitoring, but could cease after 26 years (Table 6.4-1). The estimated constant-dollar value of O&M costs for the groundwater extraction and treatment alternative, assuming that O&M activities would be conducted through a 26-year period (Table 6.4-3), is about \$14,720,000. The total, constant-dollar cost of Alternative 2b (High-Rate Groundwater Extraction and Treatment with MNA), including capital costs, O&M, and LTM, is \$15,491,000 (Table 6.4-4).

TABLE 6.4-4
ESTIMATED COSTS FOR ALTERNATIVE 2B
(HIGH-RATE PUMP AND TREAT WITH MNA)
SITE SS-45
ENGLAND AFB, ALEXANDRIA, LOUISIANA

<u>Capital Costs (rounded)</u>	<u>Constant-Dollar Cost ^{a/}</u>
Installation of 3 groundwater extraction wells, 2 treatment systems, and ancillary equipment	\$685,000
<u>Operation and Maintenance Costs (rounded)</u>	
LTM and Site Management, 1999 – 2025	\$758,800
Annual O&M, 2000 – 2017 (800 and 2500 Areas)	\$11,998,800
Annual O&M, 2017 – 2025 (800 Area only)	\$2,048,000
<u>Total Constant Dollar Cost of Alternative 2B</u>	\$15,491,000

^{a/} Based on 1999 dollars with no adjustment for inflation.

6.5 RECOMMENDED REMEDIAL APPROACH

The comparative evaluation of the three remedial alternatives considered for Site SS-45 is summarized in Table 6.5-1. Both MNA and pumping alternatives would result in permanent reductions in CAH concentration, mobility, and toxicity, and would require different time periods to attain site cleanup goals. Both MNA and the two pumping alternatives are protective of human health and the environment over the long term. Alternatives 2a and 2b, which incorporate groundwater extraction followed by air stripping and POTW discharge, would result in air-stripper emission of low concentrations of VOCs to the atmosphere. The alternative relying solely on RNA to remove TCE and daughter products from groundwater beneath Site SS-45 makes maximum use of *in situ* destructive mechanisms, and will not increase the short-term potential for receptor exposure during implementation. Both alternatives are considered implementable, though the construction and operation of Alternatives 2a and 2b components could interfere with future land use. Both alternatives will require the enforcement of institutional controls to restrict deep excavations and extraction of alluvial groundwater for beneficial uses until cleanup goals are achieved. Alternatives 2a and 2b have substantial capital costs (for constructing the extraction wells and treatment systems) and system O&M costs in addition to LTM costs. Because MNA requires minimal capital expenditures, and incurs only the LTM costs, Alternative 1 is less costly than Alternatives 2a and 2b.

The site history suggests that RNA, in combination with the hydraulic characteristics of the Intermediate Sand unit, has been effective in controlling contaminant migration without engineered remediation. The current distribution of CAHs in the groundwater system beneath the Site SS-45 is likely the result of a 30- to 40-year history of chemical releases. Widely dispersed historical sources of chemicals in soil appear to have been continuously introducing VOCs to the groundwater system in the Intermediate Sand unit.

Despite this site history, the extent of chemical migration in the groundwater system from suspected chemical sources in the 800 and 2500 Areas is localized (Section 4). Observed site conditions suggest that RNA will continue to remove chemical mass from groundwater, and that groundwater quality will continue to improve with time.

Based on the site conditions observed during the RNA TS (Sections 3 and 4), and on the results of this detailed evaluation of three remedial alternatives (Table 6.5-1), Alternative 1 (MNA with Institutional Controls) is recommended as the more cost-effective method for achieving remedial action objectives for groundwater contaminated with CAHs at Site SS-45. The rationale for this recommendation can be summarized as follows:

- Alternatives 1, 2a, and 2b are equally effective in protecting human health and the environment, and meet the implementability and permanence criteria;

TABLE 6.5-1
SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION
GROUNDWATER REMEDIATION
SITE SS-04
ENGLAND AFB, ALEXANDRIA, LOUISIANA

Remedial Alternative	Protectiveness and Effectiveness	Implementability	Constant-Dollar Cost Estimate
Alternative 1 - Natural Attenuation - Institutional Controls - Long-term Monitoring	Protective of human health and the environment. Contaminant mass, volume, and toxicity will be slowly reduced over time until final cleanup goals (Table 6.2-2) are attained.	Readily implementable. Groundwater quality monitoring is required for an estimated 48 years. Institutional controls, including land and groundwater use controls, are required. The potential for receptor exposure to site contaminants is negligible if institutional controls are implemented. CAHs will be degraded to innocuous byproducts.	\$1,302,700
Alternative 2a - Natural Attenuation - Institutional Controls - Long-term Monitoring - Low-Rate Pumping - Air Stripping - POTW Disposal	Protective of human health and the environment. Provides additional plume containment. Slight decrease in time necessary to achieve cleanup goals. Increased human exposure to CAH compounds due to discharge from aboveground treatment systems.	Common technical approach. Also requires institutional controls. Requires the design and installation of three extraction wells, two air strippers, and piping to the POTW sewer, plus O&M of the extraction/treatment systems for about 35 years. Aboveground structures would have some impact on land development. Additional time required for permits and OPS demonstration.	\$6,038,00
Alternative 2b - Natural Attenuation - Institutional Controls - Long-term Monitoring - High-Rate Pumping - Air Stripping - POTW Disposal	Protective of human health and the environment. Provides additional plume containment. Decreases time to achieve cleanup goals if no continuing source exists. Increased human exposure to CAH compounds due to discharge from aboveground treatment systems.	Common technical approach. Also requires institutional controls. Requires the design and installation of three extraction wells, two air strippers, and piping to the POTW sewer, plus O&M of the extraction/treatment systems for about 26 years. Aboveground structures would have some impact on land development. Additional time required for permits and OPS demonstration.	\$15,491,000

- The timeframes to achieve site cleanup goals are comparable, but pumping alternatives could achieve final cleanup goals faster if the model assumptions are correct. If a continuing source exists from the upper silty/clay layer, the estimated timeframes will increase, but the relative timeframes for each alternatives should be similar. However, the cost difference between Alternative 1 and the pumping alternatives will increase as the timeframe for cleanup increases. For example, if a continuing source in the 800 Area results in a 70-year timeframe for Alternative 1 and a 50-year timeframe for Alternative 2a, the total cost for Alternative 1 increases from \$1.3M to \$1.6M, while the total cost for Alternative 2a increases from \$6.0M to \$7.4M (1999 dollars).
- Pumping alternatives have the potential to transfer contaminants from the subsurface into the atmosphere creating additional exposure to contaminants and occupational hazards. This presents greater short-term risks to public health;
- The additional cost associated with pumping alternatives is not warranted given the comparability of effectiveness, permanence, and implementability of the two alternatives. MNA and institutional controls will provide equal protection of public health and the environment.

The LTM program proposed for Site SS-45 is described in detail in Section 7. After the first 5 years of monitoring, the England BCT could convene to evaluate whether MNA is continuing to progress toward achieving the remedial action objectives. If at that time the BCT concurs that MNA is making adequate progress toward remedial action objectives stated in Section 6.2.5, biennial LTM could be considered for the duration of the remedy. Conversely, if RNA fails to progress toward remedial action objectives, contingency measures could be considered, including reconsideration of pumping alternatives. (See Section 7)

SECTION 7

LONG-TERM MONITORING AND NATURAL ATTENUATION VERIFICATION PLAN

7.1 OVERVIEW

A plan for conducting long-term monitoring (LTM) of groundwater was developed to address the requirements of the recommended MNA remedial alternative for Site SS-45 at the former England AFB (Section 6). This LTM plan was developed with significant input from both LDEQ and EPA Region 6. The purpose of the LTM plan for Site SS-45 is to assess site conditions over time so that the effectiveness of natural attenuation at reducing contaminant mass and minimizing contaminant migration can be verified, and the need for additional remediation can be periodically evaluated.

The LTM plan developed for Site SS-45 is based on currently available site information and on the results of kinetic-based modeling (Appendix G). This analysis indicated that the CAHs of primary concern in groundwater (TCE and daughter products) could attenuate to concentrations below cleanup goals over a period of 40 to 50 years. The LTM plan therefore assumes that monitoring will continue until cleanup goals are reached. As MNA proceeds at Site SS-45, the LTM program may be progressively revised as additional information becomes available.

The LTM plan identifies the locations of LTM wells and develops a groundwater monitoring strategy to accomplish the following objectives:

- Monitor changes in site conditions, including concentrations and extent of TCE and daughter products in groundwater through time;
- Continue to evaluate the degradation rates for TCE and its daughter products, and assess the effectiveness of MNA in reducing the mass of solvent constituents and minimizing constituent migration;
- Regularly assess the viability of institutional controls, such as well pumping restrictions, to ensure that the public and environment remained protected;
- Assess the need for contingency remedial measures should MNA fail to adequately destroy and contain contaminants of concern.

7.2 MONITORING NETWORK AND SAMPLING FREQUENCY

7.2.1 Long-Term Monitoring Well Locations

The LTM network proposed for Site SS-45 consists of 51 monitoring wells, including 27 wells in the 800 Area, 18 wells in the 2500 Area, and 6 wells located between the two areas (Figures 7.2-1 and 7.2-2), and the staff gages in Le Tig Bayou and the North Drainage Ditch. During every monitoring event, groundwater levels will be measured at each of the 51 wells in the network, and surface-water levels will be measured at the two staff gages. Groundwater samples will be collected from a subset of 38 wells in the proposed 51-well network: 24 wells in the 800 Area, and 14 wells in the 2500 Area. Monitoring wells to be sampled include wells completed in the Intermediate Sand unit and in the Deep Sand unit. This number includes one new well in the 800 Area approximately 750 feet east of Well #10 and two new wells in the 2500 Area; one approximately 750 feet north-northeast of Well #4, and a second well to replace piezometer A39L095DP. The monitoring locations to be sampled are listed in Table 7.2-1, together with the rationale for inclusion of each monitoring well/gauging point in the LTM network.

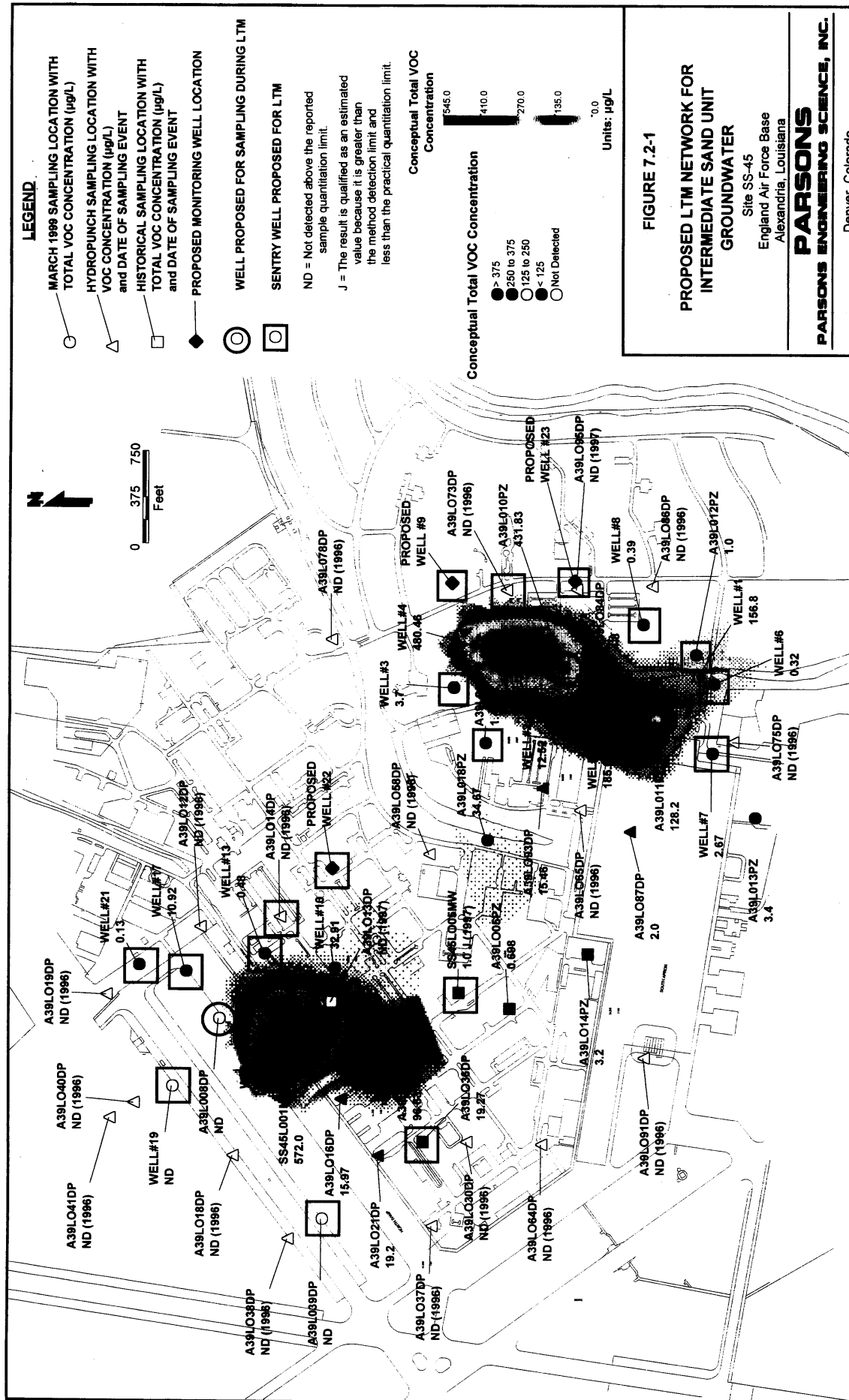
Sentry Wells – Of the 38 wells that will be regularly sampled for contaminants of concern, 26 of these wells are located at the perimeter of the plume in areas where contaminants have not been previously detected. These “sentry” wells will be monitored to ensure that the natural attenuation processes are adequately containing the CAH plume and preventing additional migration. A detection of contaminants at levels exceeding the MCL at one of these wells could signal undesirable plume movement. Contingency actions for expanding plume conditions are discussed in Section 7.7.

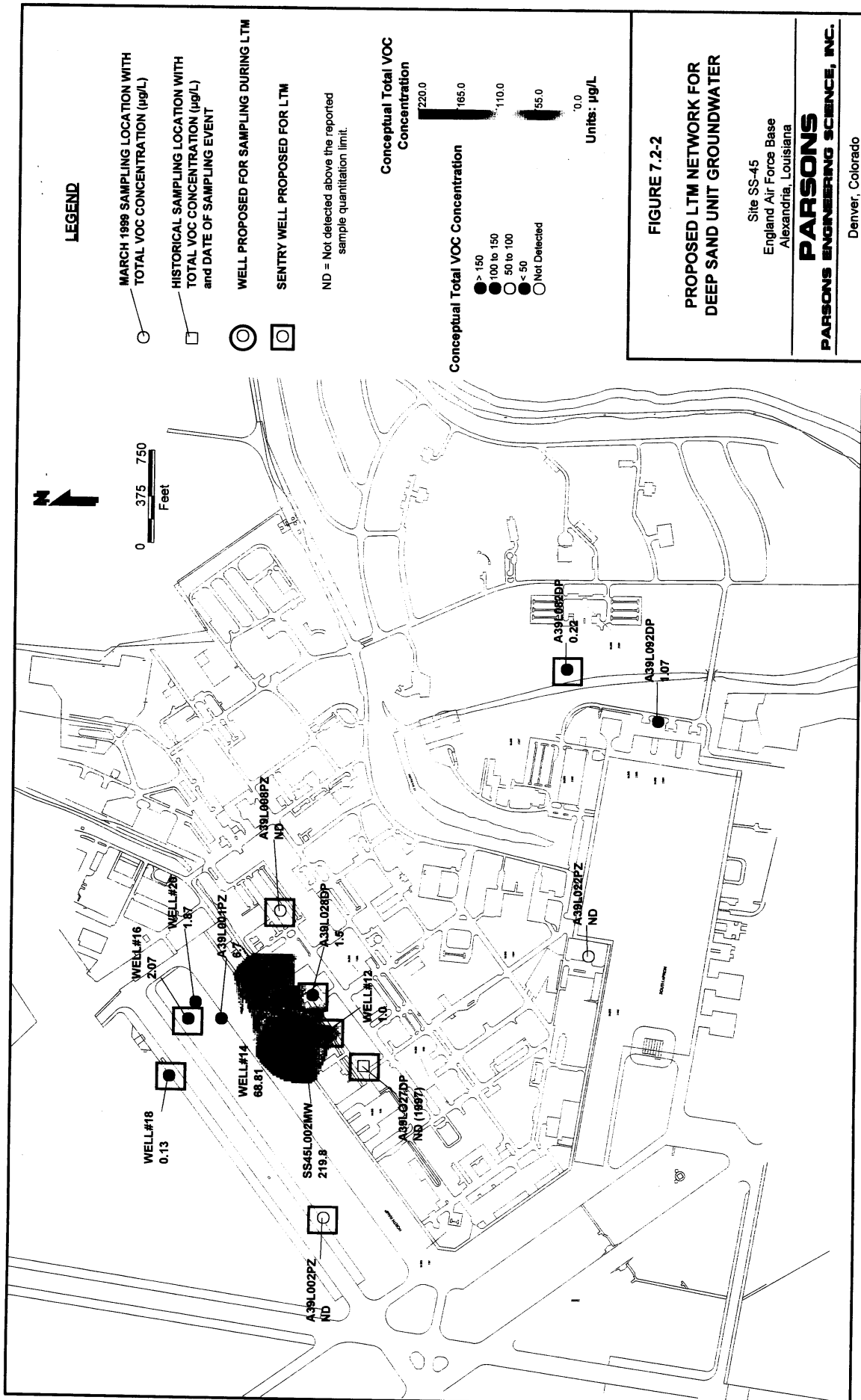
7.2.2 Frequency of Long-Term Monitoring

In order to maintain consistency with the historical monitoring record, and to minimize possible variances in water-level elevations and chemical concentrations attributable to seasonal fluctuations in the groundwater system, annual monitoring should be conducted during the month of March throughout the required period of monitoring.

During the year 2000, all new LTM wells will be sampled each quarter to establish a baseline concentration and to determine if seasonal variations exist. All LTM wells that have at least four previous sampling events will be sampled once in March 2000. In years 2001 through 2003, all wells in the LTM network will be sampled once each year in the March timeframe. In the year 2004, all wells in the LTM network will be sampled once each quarter to provide a more statistically valid average concentration of contaminants of concern. The average 2004 concentrations of contaminants of concern will be compared to the 5-year predicted concentrations based on the natural attenuation biodegradation rate estimates.

At the conclusion of the 5-year period, the results of the LTM program will be evaluated. A discussion of the MNA validation procedure is included in section 7.5. If the results indicate that natural attenuation is containing the plume and making progress toward the remediation goals for Site SS-45 (Table 6.2-2), the frequency of monitoring





GROUNDWATER MONITORING WELLS TO BE SAMPLED DURING LONG-TERM MONITORING EVENTS
TABLE 7.2-1
SITE SS-45
ENGLAND AFB, LOUISIANA

Sampling Location	Area	Completion Interval ^d	Screened Interval (feet bgs) ^e	Measure Water Levels	Chemical Analysis/Parameter Measurements (Analysis Method)				Monitoring Frequency (year)				Rationale
					VOCs ^a (USEPA SW8260B) ^f	Ethene (NRML-147) ^g	Natural Attenuation Parameters ^h	Field Parameters ⁱ (meters)	2000	2001 - 2003	2004		
											Q ^j	A ^k	
Wells In 800 Area													
WELL#11	800 Area, central	IS	60 - 70	X ^l	X	X	X	X	X	X	X	X	Monitor CAH ⁿ concentrations and trends in south-central part of main 800-Area plume
WELL#13	800 Area, east	IS	70 - 80	X	X	X	X	X	X	X	X	X	"Sentry" well east of main 800-Area plume
WELL#15	800 Area, central	IS	60 - 70	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and degradation in area of relatively elevated concentrations
WELL#17	800 Area, north	IS	55 - 65	X	X	X	X	X	X	X	X	X	"Sentry" well northeast of main 800-Area plume
WELL#19	800 Area, north	IS	65 - 75	X	X	X	X	X	X	X	X	X	"Sentry" well north of main 800-Area plume
WELL#21	800 Area, north	IS	75 - 85	X	X	X	X	X	X	X	X	X	"Sentry" well northeast of main 800-Area plume
WELL#22 ^l	800 Area, north	IS	Proposed - 40 - 50	X	X	X	X	X	X	X	X	X	"Sentry" well southeast of main 800-Area plume
A39L0082P	800 Area, central	IS	38 - 48	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and trends in northern part of main 800-Area plume
A39L0092Z	800 Area, central	IS	64 - 74	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and trends in south-central part of main 800-Area plume
A39L0130P	800 Area, east	IS	40 - 50	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and trends in south-central part of main 800-Area plume
A39L0140P	800 Area, northeast	IS	40 - 50	X	X	X	X	X	X	X	X	X	"Sentry" well east of main 800-Area plume
A39L0360P	800 Area, south	IS	59 - 68	X	X	X	X	X	X	X	X	X	"Sentry" well south of main 800-Area plume
A39L0390P	800 Area, west	IS	54 - 64	X	X	X	X	X	X	X	X	X	"Sentry" well west of main 800-Area plume
SS45L001MW	800 Area, central	IS	54 - 64	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and degradation in area of relatively elevated concentrations
SS45L003MW	800 Area, central	IS	56 - 66	X	X	X	X	X	X	X	X	X	"Sentry" well south of main 800-Area plume
WELL#12	800 Area, central	IS	90 - 100	X	X	X	X	X	X	X	X	X	"Sentry" well in Deep Sand south of main 800-Area plume
WELL#14	800 Area, central	IS	90 - 100	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and degradation in Deep Sand in area of relatively elevated concentrations
WELL#16	800 Area, north	IS	90 - 100	X	X	X	X	X	X	X	X	X	"Sentry" well in Deep Sand northwest of main 800-Area plume
WELL#18	800 Area, north	IS	90 - 100	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
WELL#20	800 Area, north	IS	120 - 130	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L001PZ	800 Area, north	IS	88 - 98	X	X	X	X	X	X	X	X	X	"Sentry" well in Deep Sand west of main 800-Area plume
A39L002PZ	800 Area, southwest	IS	86 - 96	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L003PZ	800 Area, southwest	IS	100 - 110	X	X	X	X	X	X	X	X	X	"Sentry" well in Deep Sand east of main 800-Area plume
A39L004PZ	800 Area, east	IS	108 - 118	X	X	X	X	X	X	X	X	X	"Sentry" well in Deep Sand southwest of main 800-Area plume
A39L0270P	800 Area, southeast	IS	111 - 121	X	X	X	X	X	X	X	X	X	"Sentry" well in Deep Sand east of main 800-Area plume
A39L0280P	800 Area, east	IS	113 - 123	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and degradation in Deep Sand in area of relatively elevated concentrations
SS45L002MW	800 Area, central	IS	89 - 99	X	X	X	X	X	X	X	X	X	"Sentry" well north of main 2500-Area plume
Wells In 2500 Area													
WELL#3	2500 Area, north	IS	65 - 75	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and degradation in area of relatively elevated concentrations
WELL#4	2500 Area, northeast	IS	62 - 72	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and trends in south-central part of main 2500-Area plume
WELL#5	2500 Area, west	IS	50 - 60	X	X	X	X	X	X	X	X	X	"Sentry" well south of main 2500-Area plume
WELL#6	2500 Area, south	IS	50 - 60	X	X	X	X	X	X	X	X	X	"Sentry" well southwest of main 2500-Area plume
WELL#7	2500 Area, south	IS	50 - 60	X	X	X	X	X	X	X	X	X	"Sentry" well east of main 2500-Area plume
WELL#8	2500 Area, south	IS	70 - 80	X	X	X	X	X	X	X	X	X	"Sentry" well northeast of main 2500-Area plume
WELL#9 ^l	2500 Area, south	IS	Proposed - 65 - 75	X	X	X	X	X	X	X	X	X	"Sentry" well east of main 2500-Area plume
WELL#23 ^l	2500 Area, south	IS	Proposed - 61 - 71	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and degradation in area of relatively elevated concentrations
A39L010PZ	2500 Area, northeast	IS	55 - 65	X	X	X	X	X	X	X	X	X	Monitor CAH concentrations and degradation south of area of relatively elevated concentrations
A39L011PZ	2500 Area, south	IS	40 - 50	X	X	X	X	X	X	X	X	X	"Sentry" well south of main 2500-Area plume
A39L012PZ	2500 Area, south	IS	60 - 70	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L013PZ	2500 Area, south	IS	58 - 67	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L018PZ	2500 Area, north	IS	40 - 50	X	X	X	X	X	X	X	X	X	"Sentry" well west of main 2500-Area plume
A39L019PZ	2500 Area, north	IS	60 - 70	X	X	X	X	X	X	X	X	X	"Sentry" well east of main 2500-Area plume
A39L020PZ	2500 Area, east	IS	62 - 71	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L021PZ	2500 Area, west	IS	110 - 120	X	X	X	X	X	X	X	X	X	"Sentry" well in Deep Sand east of main 2500-Area plume
A39L022PZ	2500 Area, central	IS	108 - 118	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L023PZ	2500 Area, south	IS	113 - 123	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
Between 800 and 2500 Areas													
A39L0092Z	Between 800 and 2500 Areas	IS	59 - 69	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L0069Z	Between 800 and 2500 Areas	IS	62 - 72	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L014PZ	Between 800 and 2500 Areas	IS	60 - 70	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L017PZ	Between 800 and 2500 Areas	IS	58 - 67	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L007PZ	Between 800 and 2500 Areas	IS	105 - 115	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
A39L023PZ	Between 800 and 2500 Areas	IS	110 - 120	X	X	X	X	X	X	X	X	X	Measure groundwater elevations
Staff Gauge	South of 2500 Area	Le Tig Bayou	N/A ^m	X	X	X	X	X	X	X	X	X	Measure water surface elevations to evaluate interactions between groundwater and surface water
Staff Gauge	North of 800 Area	North Ditch	N/A	X	X	X	X	X	X	X	X	X	Measure water surface elevations to evaluate interactions between groundwater and surface water

^a VOCs - Volatile organic compounds
^b Natural Attenuation Parameters include Sulfate (USEPA 300), Ferrous Iron (HACH 8146), Dissolved Organic Carbon (USEPA 4151), and Alkalinity (HACH 8221)
^c Field Parameters include Redox Potential (meter), pH (meter), Conductivity (meter), Temperature (meter), and Turbidity (USEPA 180.1)
^d Completion intervals: IS = Intermediate; Sand unit; DS = Deep Sand unit
^e feet bgs = feet below ground surface
^f USEPA = United States Environmental Protection Agency
^g NRML = USEPA National Risk Management Research Laboratory
^h "Q" denotes that the indicated well will be sampled quarterly
ⁱ "X" denotes that the indicated parameter will be measured or sampled at that corresponding well staff page
^j "Q" denotes that the indicated well will be sampled annually
^k CAHs - Chlorinated Aliphatic Hydrocarbons
^l Proposed Monitoring Well
^m Screened Interval not applicable for surface-water staff page

could be reduced to biennial (every other year) until groundwater cleanup goals are achieved. However, any change in monitoring frequency will require regulatory approval.

7.3 ANALYTICAL PROTOCOLS

Groundwater samples collected during LTM will be analyzed to assess compliance with chemical-specific cleanup goals and to verify the continuing effectiveness of MNA at Site SS-45. All sampling will be completed following the procedures outlined in the General Sampling and Analysis Plan for England AFB (Law, 1998a). Water-level measurements will be collected at each monitoring well and surface-water gage at the beginning of each sampling event. Groundwater samples from 31 wells will be analyzed for the parameters listed in Table 7.3-1. QA/QC samples will be collected and analyzed for the parameters and at the frequencies specified in Table 7.3-2.

7.4 REPORTING

7.4.1 Routine Reporting

The results of each monitoring event will be documented and provided to LDEQ and EPA Region 6 in a letter report to be issued within 120 days of completion of field monitoring activities. At a minimum, each letter report will include:

- A brief narrative of the sampling procedures and an explanation of any deviation from the General Sampling and Analysis Plan for England AFB;
- A general analysis of CAH plume movement (is it stable, expanding or receding);
- A table of validated laboratory data and field data will be provided describing the analytical results from each well
- For all annual sampling events, the potentiometric surface of the intermediate aquifer and deep aquifer will be illustrated on a site map;
- Following each annual sampling event, trend charts will be prepared showing the historical concentrations of TCE, 1,2-DCE, and vinyl chloride at key plume wells. These wells include 800 Area wells SS45L001MW, #11, #15, SS45L002MW, and A39L009PZ. Trend charts should also be prepared for wells #4, #5, A39L010PZ and A39L011PZ in the 2500 Area.
- Each annual report will include a statement regarding the institutional controls that are in place to prevent groundwater extraction on England AFB and that these restrictions are being enforced.

7.4.2 Special 90-Day Reporting Requirement for Sentry Well Detections

At anytime that a contaminant of concern is detected at concentrations exceeding an MCL in a perimeter (sentry) well listed in Table 7.2-1, the Air Force must provide a letter report to LDEQ and EPA Region 6 within 90 days of the sampling event. The sentry

TABLE 7.3-1
ANALYTICAL PROTOCOLS FOR GROUNDWATER SAMPLES
SITE SS-45
ENGLAND AFB, LOUISIANA

Analyte	Method	Field (F) or Fixed-Based (L) Analytical Laboratory
Volatile Organic Compounds	USEPA ^{a/} SW8260B	L
Methane, Ethane, Ethene	NRML-147 ^{b/}	L
Ferrous Iron (Fe+2)	Colorimetric, HACH, Method 8146 (or similar)	F
Sulfate	Colorimetric, HACH, Method 8051 (or similar)	F
Sulfate	Waters Capillary Electrophoresis Method N-601/USEPA E300	L
Alkalinity (Carbonate [CO ₃ ⁻²] and Bicarbonate [HCO ₃ ⁻¹])	Titrimetric, HACH, Method 8221 (or similar)	F
Dissolved Organic Carbon	USEPA E415.1	L
Dissolved Oxygen	Direct-reading meter	F
Redox Potential	A2580B, direct-reading meter	F
pH	USEPA E150.1/SW9040, direct-reading meter	F
Conductivity	USEPA E120.1/SW9050, direct-reading meter	F
Temperature	USEPA E170.1, direct-reading meter	F
Turbidity	USEPA E180.1	F

^{a/} USEPA = United States Environmental Protection Agency.

^{b/} NRML = USEPA National Risk Management Research Laboratory.

TABLE 7.3-2
SAMPLE TYPES, SAMPLE ANALYSIS, AND QA/QC REQUIREMENTS
LONG-TERM MONITORING PLAN
ENGLAND AIR FORCE BASE, LOUISIANA

Sample Matrix and Location	Sample Type				
	Primary Samples	Trip Blanks	Field Blanks	Field Rinse Blanks	Duplicates
Groundwater from Monitoring Wells	32 samples (quarterly) 40 samples (annual) Volatile organic compounds using USEPA Method SW8260B	1 per cooler Volatile organic compounds using USEPA Method SW8260B	1 sample Volatile organic compounds using USEPA Method SW8260B	1 per event Volatile organic compounds using USEPA Method SW8260B	3 samples Volatile organic compounds using USEPA Method SW8260B
					2 samples Volatile organic compounds using USEPA Method SW8260B
	32 samples (quarterly) 40 samples (annual) Dissolved gases and inorganic constituents using various methods				3 samples Dissolved gases and inorganic constituents using various methods

well in question will be resampled. Within 135 days of the original sampling event, a follow-up letter report will be submitted to LDEQ and EPA Region 6 providing the analytical results of the confirmatory sample taken from the well in question.

7.4.3 Special Reporting for Increasing Total CAH concentrations

If the past three monitoring events indicate an increasing trend in total $\mu\text{mole/liter}$ concentration of CAHs at any well, the Air Force will clearly identify this trend to the LDEQ and EPA in the annual LTM report.

7.4.4 Operating Properly and Successfully Determination

The Air Force is required by CERCLA § 120 (h) to demonstrate that the remedy at the site is operating properly and successfully (OPS) before transfer of property by deed (as opposed to lease) to an entity outside of the federal government. A stable or shrinking plume, decreasing CAH concentrations, and appropriate institutional controls are some of the key requirements for obtaining an OPS determination. The Air Force may choose to pursue an OPS determination at any time, however several years of MNA data will be required to meet OPS requirements.

7.5 FIVE-YEAR REVIEW OF NATURAL ATTENUATION RESULTS AND INSTITUTIONAL CONTROLS

A comprehensive review of the MNA remedy will be completed following the first five years of monitoring at Site SS-45. This review is necessary to ensure that the selected remedy remains protective of human health and the environment and is progressing toward site cleanup. The review may also be used to determine if the selected remedy has satisfied the criteria for an Operating Properly and Successfully (OPS) determination from the EPA. The review will consist of two primary components:

- An evaluation of the progress of MNA in containing the plume and reducing CAH contaminant levels;
- A review of the status of institutional controls that prevent human contact with contaminated groundwater on England AFB.

7.5.1 MNA Progress Review

The progress of the MNA will be reviewed following the first five years of LTM. Two primary criteria will be addressed in this MNA progress review. The first criterion is the ability of MNA to prevent unacceptable migration of CAH contaminants. Contaminant plume maps and groundwater potentiometric surface maps will be compared to the historical information presented in this CMS to determine if contaminant migration is stable, expanding, or receding.

The second review criteria will examine the rates of CAH degradation that were predicted in this CMS. Due to a lack of historical data at this site, biodegradation rates presented in the CMS are considered approximations that will require refinement as more long-term monitoring data becomes available. One purpose of the five-year review will

be to refine these rate estimates and determine if the MNA is making sufficient progress in CAH destruction. Based on the biodegradation rate estimates presented in Table 5.3-1, an approximate 50-percent reduction in TCE should occur within each 800 Area well by the end of 2004. Similarly, a 50-percent reduction in 1,2-DCE should occur in each 2500 Area well.

Specific Evaluation Criteria: EPA has recommended a specific method for re-estimating the overall biodegradation rate for CAH compounds:

1. CAH data from each of the following wells will be used: 800 Area wells SS45L001MW, #11, #15, SS45L002MW, and A39L009PZ; 2500 Area wells #4, #5, A39L010PZ and A39L011PZ;
2. The combined μ mole/liter concentrations of TCE, all three DCE isomers and vinyl chloride for each well will be calculated for each sampling event;
3. The μ mole/liter concentration for each monitoring event will be plotted as a log linear regression of concentration versus elapsed time to calculate a first-order rate;
4. Based on estimates presented in this CMS, the decay rate over the five-year period should equal or exceeds 0.15 per year, with 80% confidence.

In their 13 January 2000 approval letter (see Appendix H), LDEQ stated that if these rates of degradation are achieved, the five-year review can be "limited in scope to data analyses and evaluation of compliance with restricted land use." However, if this rate of total CAH reduction is not supported by the data "a full five-year review must be conducted. The evaluation must include new rate calculations and project cleanup times, as well as other potential remedies available at that time, with a review to determine whether the MAN remedy is appropriate or, or should be modified or replaced." LDEQ has specified that this review be submitted to them within 180 days of the last sampling event in the year 2004.

In addition to the review criteria specified by LDEQ and the EPA, there are general trends that should be observed if MNA is occurring on the site. Observations useful in tracking the progress of remediation include:

- Absolute decreases in the concentrations of TCE and daughter products through time, in groundwater samples from the same well;
- Absolute decreases in the concentrations of TCE and daughter products through time, in groundwater samples from several wells in the same general area;
- Decreases through time in the relative concentrations of TCE compared with its daughter products, and increases in the relative concentrations of TCE daughters, compared with TCE, in groundwater samples from the same well, or from several wells in the same general area;

- Decreases through time in the areal extent of groundwater that contains detectable concentrations of CAHs;
- Maintenance of geochemical conditions that favor reductive dehalogenation;

Potential for Stable Concentrations: It is important to note that, CAHs may persist for some time in the Upper Silt/Clay unit, and gradually migrate into groundwater of the Intermediate Sand unit, thereby functioning as a continuing source of chemical mass being contributed to groundwater. Continued contribution of chemical mass could cause the absolute concentrations of TCE and daughter products to remain relatively constant for some time, and create the appearance of slower than expected biodegradation rates. However, even if TCE and its daughter products continue to migrate into the Intermediate Sand unit, the concentrations of TCE daughter compounds should continue to increase, relative to TCE concentrations. This decreasing TCE:DCE ratio is proof that chemical degradation is proceeding and may be the most important overall trend observed during the next five years of natural attenuation.

7.5.2 Review of Institutional Controls

Strict enforcement of institutional controls is a critical component of the remedy described in this CMS. Because withdrawal of groundwater will change the hydraulic conditions of the site and create a potential exposure pathway, land use restrictions are required to prevent the use of groundwater in the Intermediate and Deep Sand Units of the Red River Alluvium Aquifer beneath the former England AFB. Even pumping wells installed outside of the existing contaminated area could cause plume migration if extraction rates were high enough. Easements, lease restrictions and deed restrictions can all be used to eliminate well installations and/or pumping from the alluvial aquifer.

Each year the Air Force should evaluate the effectiveness of these institutional controls and ensure that no groundwater wells have been installed in the alluvium aquifer. During the five-year review, existing land use restrictions should be reviewed by the Air Force legal staff to ensure they are up-to-date and enforceable. The Air Force should also complete a well survey every five years to ensure that no breach of these restrictions has occurred.

7.6 SITE CLOSURE

When LTM results indicate that site cleanup goals for CAHs in groundwater have been achieved, or when results indicate groundwater poses no threat to human health or the environment, the Air Force will prepare appropriate documentation to prove groundwater remediation is complete. When regulatory approval is granted, the Air Force will terminate LTM and properly abandon LTM wells

7.7 CONTINGENCY ACTIONS

The need for contingency actions will normally be reviewed as a part of the five-year progress review. There are several potential events that could trigger the need for contingency actions:

- An increasing trend of the total $\mu\text{mole/liter}$ concentration of CAHs in groundwater samples from the same well, or from several wells in the same general area. This could indicate a significant source of TCE has not been identified.
- Refined biodegradation rates estimates which are considerably slower than the estimates developed in the CMS. Based on current rate estimates, CAHs could persist 40 to 50 years in the 800 Area. The Air Force and regulatory community will need to reevaluate the MNA remedy if they determine that slower degradation rates will result in an unacceptably long cleanup time.
- Long-term increases in vinyl chloride concentrations in groundwater samples from the same well, or from several wells in the same general area.
- Increases in the areal extent of the CAH plumes in the 800 Area or 2500 Area. Increasing areal extent of the plumes would be indicated by the appearance of concentrations of CAHs in previously "clean" sentry wells. LDEQ and EPA have requested that they be notified whenever a sentry well becomes contaminated at concentrations exceeding a MCL. Contingency actions may not be required unless CAH contamination is expected to migrate into an area that is outside of England AFB land used restrictions prohibiting groundwater pumping in the alluvial aquifer.
- Changes in the geochemistry of the groundwater system to conditions that are unfavorable to the occurrence of reductive dehalogenation (e.g., increase in oxygen content, depletion of native or anthropogenic organic carbon).

The results of the CMS screening of possible remedial alternatives indicate that only limited remediation methods are potential contingencies for Site SS-45. At the time of this writing, groundwater extraction and treatment is the only viable treatment alternative to MNA. Therefore, depending on the nature of the problem, the Air Force and BCT could decide to implement one or more of the following contingencies:

- Re-evaluation of the conceptual site model, particularly the concept of multiple, small source areas with minimum plume migration;
- Installation of additional LTM wells to better track CAH migration beyond existing sentry wells and reevaluated the timeframe to achieve site closure using MNA;
- Design and install a pump-and-treat system to either contain the plume or accelerate mass removal. Alternatives 2a and 2b in this CMS describe the benefits and limitations of two pumping options;
- Evaluate another innovative technical approach that becomes available after this document is published.

SECTION 8

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