FINAL REPORT

Using Advanced Analysis Approaches to Complete Long-Term Evaluations of Natural Attenuation Processes on the Remediation of Dissolved Chlorinated Solvent Contamination

SERDP Project ER-1348

OCTOBER 2008

J. Steven Brauner
Douglas C. Downey
Ross Miller
Parsons Infrastructure and Technology Group

DoD EPA DOE SERDP
Strategic Environmental Research and
Development Program

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
OCT 2008

2. REPORT TYPE

3. DATES COVERED
00-00-2008 to 00-00-2008

4. TITLE AND SUBTITLE
Using Advanced Analysis Approaches to Complete Long-Term Evaluations of Natural Attenuation Processes on the Remediation of Dissolved Chlorinated Solvent Contamination

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Parsons Infrastructure and Technology Group,100 West Walnut Street,Pasadena,CA,91124

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**462**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

Page

This page left blank intentionally.

LIST OF FIGURES

Page

LIST OF FIGURES (continued)

This page left blank intentionally.

LIST OF TABLES

Page

LIST OF TABLES (continued)

This page left blank intentionally.

ACRONYMS AND ABBREVIATIONS

µg/L	micrograms per liter
3-D	three-dimensional
AFB	Air Force Base
AFCEE	Air Force Center for Engineering and the Environment
AMIBA	Aqueous Mineral Intrinsic Bioremediation Assessment
ARAR	applicable or relevant and appropriate requirement
BTEX	benzene, toluene, ethylbenzene, and xylene isomers
CAH	chlorinated aliphatic hydrocarbons
CCAFS	Cape Canaveral Air Force Station
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMS	Corrective Measures Study
COC	contaminant of concern
DCA	dichloroethane
DCE	cis-1,2-dichloroethene
DNAPL	dense nonaqueous phase liquid
DoD	Department of Defense
DOE	Department of Energy
EEC	Environmental Engineering Committee
EISB	enhanced in-situ bioremediation
ESRI	Environmental Systems Research Institute
FDEP	Florida Department of Environmental Protection
FPTA	Fire Protection Training Area
FS	feasibility study
ft/day	feet per day
ft/ft	foot per foot
ft/yr	feet per year
GIS	geographic information system
GMS	Groundwater Monitoring System
GSI	Groundwater Services, Inc.
GWE	groundwater extraction
HNUS	Haliburton NUS
LLNL	Lawrence Livermore National Laboratory
LTM	Long-term Monitoring
LTMO	Long Term Monitoring Optimization
MAROS	Monitoring and Remediation Optimization System

ACRONYMS AND ABBREVIATIONS (continued)

MCL	Maximum Contaminant Level
mg/L	milligrams per liter
MK	Mann-Kendall
MNA	monitored natural attenuation
NA	natural attenuation
NPL	National Priorities List
NRC	National Research Council
OU	operable unit
PCE	perchloroethene/tetrachloroethene
RABITT	Reductive Anaerobic Biological In-situ Treatment Technology
RAOs	remedial action objectives
RCRA	Resource Conservation and Recovery Act
Redox	oxidation-reduction
RI	remedial investigation
RNA TS	Remediation by Natural Attenuation Treatability Study
RPO	remedial process optimization
SAB	Science Advisory Board
SERDP	Strategic Environmental Research and Development Program
SS	Spill Site
SVE	soil vapor extraction
SVOC	semivolatile organic compounds
TCA	trichloroethane
TCE	trichloroethene
TEAP	terminal electron acceptor process
TIN	triangular irregular network
TNRCC	Texas Natural Resource Conservation Commission
TOC	total organic carbons
USAF	U.S. Air Force
USEPA	U.S. Environmental Protection Agency
USZ	upper saturated zone
VC	vinyl chloride
VOC	volatile organic compounds
WTF	Working Task Force

This page left blank intentionally.

EXECUTIVE SUMMARY

The methodology, case-study examples, and recommendations described in this report are intended to provide restoration program managers, their support staff, and the regulatory community with descriptions of methods and tools that can be used to advance the state-of-practice for monitoring and documenting the long-term sustainability of monitored natural attenuation (MNA)-based remedies for chlorinated solvent-impacted groundwater. Specifically, this report 1) presents a strategy and framework for quantitatively assessing the sustainability of MNA-based remedies for groundwater at chlorinated solvent-impacted sites, 2) provides case-study reviews using existing long-term monitoring (LTM) data sets from multiple United States Air Force (USAF) sites where chlorinated solvents exceed closure criteria, and 3) summarizes observations and recommendations that were developed when working through the case-study examples.

The context for developing this report is summarized in the following general observations from a review of data from multiple USAF sites where MNA is either a primary or secondary remedy component for remediation of chlorinated solvents in groundwater:

- Closure has remained elusive at a large number of sites where chlorinated solvents have been detected in groundwater at concentrations above applicable standards;

- A wide variety of in situ treatment approaches have been tested and implemented for chlorinated solvents, but no single technology or combination of technical approaches has emerged as the most effective approach to achieve site closure in terms of overall cost or performance;

- MNA is likely to remain an important component of low-cost remediation alternatives because there are significant technical and/or cost limitations encountered with all active remedial strategies that attempt to achieve typical site clean-up objectives; and

- The technical performance and cost evaluation associated with LTM of MNA-based remedies can benefit from 1) LTM programs that are designed to support site-specific closure strategies and 2) data analysis methods that quantify the long-term sustainability of MNA-based remedies.

The three principal components of the sustainability assessment framework described in this report are 1) analysis of plume stability, 2) estimation of remediation timeframes, and 3) estimation of the longevity of specific chlorinated aliphatic hydrocarbon (CAH) degradation processes. Based on the site data reviews performed as part of the current study, sufficient data were available from multiple sites to support development of 1) recommended methods for advancing the state-of-practice for quantitative assessments of plume stability and 2) low-cost estimates for remediation timeframe. However, a review of available data from 35 candidate sites did not yield any sites with existing data sets that contained all of the data required to

perform the type of analysis that is believed to be needed to make a quantitative assessment of MNA sustainability where biodegradation is a significant contributor to contaminant mass degradation and protection of site-specific receptors.

The purpose of evaluating various techniques for assessing plume stability was to advance the state-of-practice toward quantitative, rather than purely qualitative, metrics of plume stability. As part of the current effort, both concentration-based and mass-based metrics of plume dynamics were evaluated. The findings of the current study indicate that concentration-based and mass-based analyses of plume dynamics provide complementary information that can not readily be quantified by either method alone. For example, results of the current study confirm that statistical trend analysis of compliance well concentrations will continue to be important for documenting protectiveness of downgradient receptors. When looking at different areas within the dissolved plume, however, statistical trends in CAH concentrations may produce conflicting results that make it difficult to assess the overall 'strength' and stability of the CAH plumes. By visually or statistically analyzing changes in dissolved CAH plume total mass and mass distribution by CAH species over time, the current study describes and demonstrates an approach for categorizing dissolved CAH plumes as 'strengthening' (dissolved mass increasing), 'sustaining' (dissolved mass stable), or 'weakening' (dissolved mass decreasing). In this context, the main plume assessment advantage gained by performing mass-based analyses is quantification of changes in dissolved plume 'strength' over time.

The second part of the proposed sustainability assessment framework is a reliable estimate of remediation timeframe. Reliable estimates of remediation timeframe are important for 1) evaluating whether an MNA-based remedy is capable of achieving an acceptable remediation endpoint in a timeframe that is reasonable when compared to other alternatives, 2) calculating life-cycle costs of LTM for an MNA-based remedy, and 3) providing a target timeframe that can be used to evaluate whether current and future natural attenuation (NA) processes are likely to be sustained over the entire duration of contaminants in the subsurface. Using the assumption that the duration of the remediation timeframe will most often be controlled by the time required for CAH concentrations in the source area to reach site-specific regulatory targets, the current study recommends that the best available tools for estimating source duration (and, therefore, remediation timeframe) at CAH-impacted sites are empirical, first-order (exponential) decay models that are 'fitted' to available source area well data. While it is acknowledged that mechanistic models of source decay may one day offer a more accurate estimate of remediation timeframe, the accuracy of mechanistic models is limited in practice by the current inability to measure necessary input parameters that result in a 'singular' solution for source duration. In addition, the current study suggests that even a decade of regular source area monitoring is too short to confidently estimate site-specific weathering rates, particularly when these degradation rates suggest that it will take decades to centuries for natural weathering processes to achieve CAH concentrations less than applicable standards. The basis of this last conclusion is that the variability in source well monitoring data was larger than what would be expected for a typical range of source area degradation rates (e.g., 2 to 10 percent per year). Given this uncertainty, the collection of additional data over time is a necessary precursor to evaluating if current source decay models provide accurate predictions for remediation timeframe.

In addition to these big-picture observations, the current report provides multiple observations and recommendations that summarize lessons learned on the mechanics of applying the various methods described in this study to actual site data. These lessons-learned can be broken into the following three general categories: 1) handling of below detection and low concentration measurements; 2) understanding of method limitations and how off-the-shelf programs implement these methods; and 3) criteria for choosing which data to include in a particular data analysis method. Of these three categories, the recommendations on how to select data for inclusion in a particular analysis method have the largest impact on the design of future LTM programs and on the data that should be entered into ‘black box’ plume stability assessment programs (e.g., Monitoring and Remediation Optimization Software [MAROS]; Air Force Center of Environmental Excellence [AFCEE], 2002). Specifically, the recommendations on how to select data for each analysis method provide a rationale for collecting more samples at regular, but infrequent events, and less samples during interim compliance monitoring events that are specified in site-specific regulatory decision documents.

While the original intent of the current study was to apply the methods described in this report solely to sites where MNA was the primary remedy, it was recognized during the implementation of the plume stability evaluation process that these methods can also be used for the assessment of active remedies. In the current study, a case study example that applies the plume stability analysis methods described in this report to data from a pump-and-treat remedy is provided to illustrate the flexibility of the proposed approach for evaluating active remedy performance. Implementation of these methods to other sites where active remedies (e.g., chemical oxidation, chemical reduction, enhanced bioremediation) have been implemented is a recommended next step for evaluating the robustness of the methods described in this report. Specific goals of this sort of future study could include an evaluation of 1) whether initial estimates of the remediation timeframe for MNA-based remedies truly are longer than those estimated for active remediation and 2) how the rate of contaminant mass loss changes over time during continued implementation of the active remedy or when the active remedy is discontinued and MNA is used as a ‘polishing’ technology.

This page left blank intentionally.

1.0 INTRODUCTION

The United States Air Force (USAF) has expended significant resources towards collection and analysis of chemical concentration data in soil and groundwater to support the assessment, design, and performance evaluation of remedies where monitored natural attenuation (MNA) is part of the environmental restoration strategy. Over the next several decades, USAF will continue to commit significant resources evaluating and defending the performance of various groundwater remedies that already have been implemented but have not attained clean-up goals. Based on a review of existing data and regulatory status of multiple USAF sites where MNA is either a primary or secondary remedy component for remediation of chlorinated solvents in groundwater, the following general observations were made:

- Closure has remained elusive at a large number of sites where chlorinated solvents have been detected in groundwater at concentrations above applicable standards;
- A wide variety of in situ treatment approaches have been tested and implemented for chlorinated solvent technologies, but no single technology or combination of technical approaches has emerged as the most effective technology to achieve site closure, in terms of either cost or performance;
- Due to technical and/or cost limitations inherent to all engineered remedial strategies in achieving typical site clean-up objectives, it is likely that MNA will remain an important component of low-cost remediation alternatives; and
- The technical performance evaluation and associated long-term monitoring (LTM) cost of MNA remedies can benefit from 1) LTM programs that are designed to support site-specific closure strategies and 2) data analysis methods that move forward the state-of¬practice for demonstrating protectiveness, estimating the remediation timeframe, and identifying concerns to long-term sustainability of MNA-based remedies.

The work presented in this report describes 1) a review of existing LTM data sets from multiple USAF sites where chlorinated solvents exceed closure criteria in groundwater and 2) how various methods of evaluating dissolved plume stability, remediation timeframes, and long-term sustainability of MNA processes can be applied to these existing data sets. The results of this effort have been summarized into observations and recommendations on 1) how to design LTM plans that support the site-specific closure strategy and 2) why, how, and when to apply various analytical techniques to document the effectiveness of MNA-based remedies using existing and/or future time series data sets. The findings of this report are intended to provide site managers, their support staff, and the regulatory community with a description of various methods and tools that can be used to move forward the state-of-practice for monitoring and documenting the performance of MNA-based remedies.

This report has been developed by Parsons under the direction of the Air Force Center for Environmental Excellence (AFCEE) through Task Order 0024 of Contract F41624-00-D-8024.

1.1 STUDY OBJECTIVES

Based on a review of published literature, feedback from senior review panels on existing technical protocols (National Research Council [NRC], 2000; United States Environmental Protection Agency [USEPA], 2001), and surveys of environmental professionals, Parsons has identified seven objectives for investigation as part of the current study. Table 1.1 lists these study objectives and the associated outcomes of the project described in this report. Specific sections discussing each of these study objectives and project outcomes are also indicated in Table 1.1.

Table 1.1 Study Objectives and Project Outcomes

Study Objectives	***Project Outcome***
Evaluation and Prediction of MNA Sustainability	
• Document type(s) and frequency of organic carbon, electron acceptor, and reaction endproduct measurements that have been collected during initial MNA evaluations and/or LTM at selected Department of Defense (DoD) sites. Determine whether site-specific predictions of organic carbon source duration have been made and, if so, how accurately these estimates have predicted future organic carbon availability. • At sites where plume stability and/or CAH mass loss appear to be independent of organic carbon loading, determine if other 'controlling' factors (e.g., other indicators of degradation, local groundwater hydraulics, abiotic processes) of CAH plume behavior can be identified.	• Provided description of a potential method for evaluating and monitoring changes in organic carbon/electron donor loading and the impact of changes in this loading on the sustainability of MNA processes. • Reviewed available data from case study sites, and determined that there are insufficient data to demonstrate proposed technique for evaluating MNA sustainability. In lieu of demonstration, developed recommendations on how to obtain sufficient data to support future evaluations of MNA sustainability.
Chlorinated Aliphatic Hydrocarbon (CAH) Plume Stability and Mass Reduction	
• Evaluate advantages, disadvantages, and data input requirements for various methods of evaluating dissolved plume stability using dissolved CAH concentrations. • Evaluate advantages, disadvantages, and data input requirements for various methods of estimating and reporting changes in CAH plume mass metrics over space and time.	• Described and evaluated methods for documenting plume stability. • Developed recommendations on how and when to apply different stability analysis methods to varying site conditions and data availability. • Developed recommendations on the design of LTM programs for supporting comprehensive MNA performance evaluations and verification plans.
timating Remediation Timeframe	
• Establish the current state-of-practice for estimating CAH source duration. • Evaluate whether current state-of-practice procedures for estimating CAH source depletion are accurate measures of remediation timeframe.	• Developed recommendations on methods and associated data input requirements for improving our understanding of source decay terms and estimates of remediation timeframe. • Provided examples of how existing empirical models can be used to develop a range of remediation timeframe estimates.

1.2 LIMITATIONS ON PROJECT SCOPE

Data used in the analyses performed in the current study were compiled from various types of data reports available to Parsons for a particular site. These data reports included remedial investigation (RI) and feasibility study (FS) reports, MNA treatability study reports, and LTM data that was either collected directly by Parsons or provided by the available base contact in response to a request from the Parsons team.

In all cases, the data considered in this report consisted of chlorinated solvent concentration data from monitoring wells that were collected over multiple sampling events. The availability and consistency of groundwater sampling for other contaminants of concern (COCs), oxidation-reduction potential (redox) chemistry data, and related natural attenuation (NA) indicator data varied widely by site, as will be discussed in later sections of this report. On a case-by-case data, measurements of solid-phase and/or sorbed chemical concentrations were used if the data was available and could be used to support the methods described in this report.

Note that the available site investigation and LTM data were not specifically collected in support of applying several of the advanced analysis techniques applied in this report. The consequence of not incorporating the desired analysis techniques into previous plans for LTM means that some of the planned analyses could not be applied appropriately to data from some sites. These data limitations are discussed in the method development and case study sections of this report. Suggestions on how to design future LTM plans to support the analyses described in this report are included in the recommendations section at the end of each case study.

Further, the fact that the data were not specifically collected in support of applying the advanced analysis techniques in the study impacted the way that the techniques were evaluated. The underlying assumption, particularly for the statistical analyses, was that a practitioner who was relatively unsophisticated in statistical procedures would apply statistical software packages (e.g., MAROS) to existing data sets primarily using default software options. The evaluation of the statistical methods was as much about identifying potential ways that application of "blackbox" statistical software could generate misleading results as it was a side-by-side evaluation of quantitative and qualitative methods for evaluating plume stability.

1.3 DOCUMENT ORGANIZATION

This document is comprised of six sections and four appendices. Following this introduction, Section 2 describes the background and technical approach developed and applied in the current study. Section 3 summarizes potential methods for performing advanced assessments of MNA-based remedies and subsequently describes in detail the methods investigated and applied as part of the current study. Section 4 reviews data from five case study sites, presents results of applying each data analysis method that is valid for the available data set, and summarizes how the knowledge gained from applying these advanced analysis techniques can be used to improve our understanding of the performance of MNA-based remedies. Section 5 provides 1) a summary of information provided in the previous sections, 2) describes general conclusions and lessons learned during the current study, and 3) provides recommendations on how LTM programs and/or site data analyses can be improved by explicitly linking these two activities. Section 6 lists references used in preparation of this report.

Four appendices are also included in this report. Appendix A provides mathematical descriptions of plume stability analysis methods. Appendix A also contains the process and supporting calculations used to verify the geographic information system (GIS) algorithms for estimate contaminant plume mass. Appendix B provides a detailed description and review of various models for simulating CAH source depletion. Appendix C is comprised of tables that support the case studies presented in Section 4. Specific tables included in Appendix C are 1) results statistical trend analyses, 2) historical CAH concentrations used in the current study, and 3) results of mass-based analyses. Appendix D provides selected figures which summarize various CAH trends from previous studies at Columbus AFB, Mississippi. Appendix E contains a technical report that addresses advanced analytical approaches to determining the time-of-remediation for natural attenuation of chlorinated solvent sites.

2.0 BACKGROUND AND TECHNICAL APPROACH

This section provides an overview of the current state-of-practice for evaluating and supporting MNA-based remedies for dissolved CAH plumes, followed by a process description that is intended to aide in advancing the state-of-practice. The state-of-practice overview in Section 2.1 includes descriptions of: 1) the regulatory context for MNA-based remedies; 2) previous studies of CAH plume stability assessment and the sustainability of NA processes; and 3) critiques of the current state-of-practice by various technical review panels. The results of this overview were used to inform the logic process described in Section 2.2. The purpose of developing and demonstrating the logic process presented in Section 2.2 is to provide site restoration project managers with a means to identify the scientific questions that are most important to evaluating or defending an MNA-based remedy for site-specific conditions. The remainder of this document describes methods and provides case study examples that can be used to support the logic process presented in Section 2.2.

2.1 MNA ASSESSMENT AT CAH-IMPACTED SITES: CURRENT STATE-OF-PRACTICE

2.1.1 Existing Regulatory Guidance on MNA Evaluation Requirements

Consideration of the influence of NA processes on the fate and transport of contaminants in the subsurface has long been a part of USEPA guidance. For example, early Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance (USEPA, 1988a and 1988b) acknowledged that NA of contaminants may be the most appropriate groundwater remedy at a site. More recently, the Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater (USEPA, 1998a) was published to provide guidance on how to perform site characterization and screening activities for demonstrating whether reductive dechlorination processes are active at a site. USEPA (1999) also published a directive on MNA that provides a general framework for the type of data collection and analysis that is recommended for supporting MNA remedy assessments. Specifically, the USEPA (1999) directive lists the following three lines of evidence that can be used to support MNA evaluations:

1. Documentation of historical decreases in contaminant mass and/or concentration at the field scale over time;
2. Hydrogeologic and geochemical data that indirectly demonstrate the type(s) of NA processes active at a site, and the rate at which such processes will reduce contaminant concentrations to the required level; and
3. Data from field or microcosm studies that provide direct microbiological evidence that the COCs are being degraded at the site.

In practice and in accordance with the aforementioned USEPA guidance, demonstration of the appropriateness of MNA-based remedies should be based on documentation of 1) current and anticipated future protectiveness of site-specific receptors, 2) contaminant plume stability or contraction, 3) contaminant mass loss over time, and 4) remediation timeframe estimates for MNA-based remedies that are reasonable when compared to other potential remedial alternatives. Because some degradation pathways for parent CAHs lead to production of intermediate degradation products that are also regulated compounds, demonstration that conditions at CAH-impacted sites meet all four of the criteria described above tends to be more complicated than at sites where the COCs (e.g., petroleum hydrocarbons) degrade to non-regulated compounds. For example, plume stability and mass loss of both parent CAHs (e.g., trichloroethene [TCE]) and regulated intermediate degradation products (e.g., cis-1,2-dichloroethene [DCE], vinyl chloride [VC]) need to be demonstrated as part of the MNA evaluation process for CAHs.

The existing USEPA (1998a) technical protocol provides guidance on 1) using concentration measurements to demonstrate plume stability, 2) how to use redox chemistry data to document the occurrence of reductive dechlorination, and 3) when microcosm studies may be appropriate. However, no formal technical guidance exists on recommended procedures for documenting CAH mass loss or evaluating the long-term sustainability of NA processes that are currently active. The result of activities described in this document are intended to supplement existing technical guidance through case study examples of comprehensive, field-scale analyses of data collected at sites with existing MNA-based remedies.

2.1.2 Previous Investigations of CAH Plume Dynamics and MNA Sustainability

During the 1990s, AFCEE spearheaded efforts to define innovative site characterization methods and initial data analysis approaches that could be used by DoD environmental managers to determine whether NA processes could be reasonably relied upon, solely or in conjunction with engineered remedies, to provide in situ treatment and/or containment of dissolved fuel hydrocarbon and CAH contamination. Initially, the targeted objectives of these technology demonstration efforts were to 1) determine whether literature-reported degradation processes could be documented as occurring at the field scale and 2) create a simple baseline characterization decision framework that could be used by DoD environmental managers to quickly assess whether NA processes were likely to significantly impact dissolved CAH fate and transport. These efforts led to the development of two technical protocol documents (AFCEE, 1995; USEPA, 1998a) that generally emphasized the baseline characterization and analysis requirements required to evaluate whether MNA could and should be considered as part of selecting and designing a cost-effective groundwater remediation remedy. These technical protocol documents served as the first comprehensive effort to describe various screening-level or initial-assessment-stage methods to compile and assess field-scale evidence of natural degradation processes. The broad impact of these initial assessment technical protocols was underscored when USEPA (1998a) published its own technical guidance (based, in large part, on AFCEE-led initiatives) to help the regulatory community understand and initially evaluate remedy designs for CAHs that included an MNA component.

These technical protocol documents set the stage for more comprehensive CAH plume comparison studies (e.g., McNab et al., 1999), where the primary objective was to determine whether field-scale plume behavior could be generalized on the basis of specific hydrogeologic conditions and release scenarios. These studies theorized that the results of "plume-a-thon" evaluations could potentially be used for identifying 1) behavioral trends that define appropriate and cost-effective generic site characterization and analysis requirements and 2) potential data gaps or areas requiring additional evaluation, if specific behavioral trends are related to 'characteristic' site conditions.

The Department of Energy (DOE) sponsored the largest "plume-a-thon" study for chlorinated sites to date (McNab et al., 1999). This study, coordinated by Lawrence Livermore National Laboratory (LLNL), was a significant first step toward collecting the field-scale data relevant to determining the long-term sustainability of CAH NA processes. Data from several CAH groundwater sites at DoD facilities were incorporated into the analysis report (McNab et al., 1999), and AFCEE representatives served on both the Working Task Force (WTF) and the Peer Review Panel (Peer Review Panel). The McNab et al. (1999) study used historical data from 65 sites to statistically evaluate chlorinated VOC plume behavior (defined as plume length and plume growth rate) in terms of hydrogeologic, biogeochemical, and physicochemical variables (e.g., hydraulic conductivity, groundwater velocity, the presence of intermediate degradation products. The findings of the McNab et al. (1999) study that are most relevant to the current study were that 1) source strength and groundwater hydraulics were found to 'dominate' overall plume dimensions, 2) mixed CAH plumes that included definitive VC plumes were statistically smaller than those that did not, and 3) intermediate degradation product plumes were generally found to be contained within, or roughly coincide with, respective parent compound plumes. However, a short-coming of the McNab et al. (1999) methodology was that it did not include application of statistical trends to predict future plume behavior.

The finding that source strength and groundwater hydraulics may dominate CAH plume dynamics is directly relevant to the current study because it is now evident that the nature and persistence of a particular contaminant source area is likely to dominate estimates for the remediation timeframe at CAH-impacted sites (e.g., Chapelle et al., 2003). The finding that VC formation correlates to overall smaller CAH plumes could provide field evidence to confirm that reductive dechlorination of parent compounds through cis-1,2-DCE is the critical degradation requirement for achieving effective (complete) CAH mass removal though NA processes. Finally, the finding that dissolved plumes of intermediate degradation products (e.g., cis-1,2-DCE, VC) are generally found within, or close to the boundaries of parent (e.g., TCE) plumes requires further evaluation because Parsons is aware of multiple dissolved CAH plumes at DoD facilities where the intermediate degradation product plume, primarily the cis-1,2-DCE plume, is significantly larger than the parent CAH plume.

The conclusions of the McNab et al. (1999) study recognized several limitations that should be considered during future efforts for evaluating CAH plume dynamics and long-term performance of MNA. The limitations imposed by the approaches used in the McNab et al. (1999) study and the basis for concern about these limitations are summarized in Table 2.1.

Table 2.1 Limitations of a Previous Study (McNabb et al., 1999) on Plume Dynamics and Long-Term Sustainability of MNA for CAH Plumes

Description of Limitation	Basis of Potential Concern
• The impact of reductive dechlorination driven by natural sources of organic carbon (i.e., Type II conditions in the USEPA [1998a] protocol) may have been underrepresented, relative to what could be expected across the entire United States, because the majority of sites in the McNabb *et al.* (1999) study were from Western states.	The mass of natural organic carbon loading to shallow groundwater is likely to be lower in the western United States (where moderate to sparse vegetative cover prevails) than it is in groundwater in the eastern United States (where the landscape consists of relatively lush vegetative cover and organic-rich river valleys). A difference in natural organic carbon loading in soil and groundwater can affect natural attenuation processes by impacting sorption, reductive dechlorination, and/or geochemical conditions that may lead to abiotic degradation processes.
• Use of an average dissolved plume behavior characteristic (i.e., plume length) that does not account for impacts to site-specific receptors could lead to erroneous conclusions on the effectiveness of MNA-based approaches.	While smaller CAH plumes can be expected to be, on average, less likely to reach receptors than longer plumes, the acceptability and appropriateness of an MNA-based remedy will require demonstration of protectiveness for site-specific receptors. A conclusion that MNA is likely to be an effective remedy simply because the plume is shorter than some average could lead to an erroneous conclusion that MNA is an appropriate remedy, even if the plume is likely to impact site-specific receptors. Conversely, MNA could erroneously be considered inappropriate at a site where the dissolved CAH plume is relatively long even if the distance to potential receptors (or property boundaries) is large and fate and transport analysis suggest that CAHs are unlikely to impact site-specific receptors.
• For the historical case studies evaluated, the methodology used by McNab *et al.* (1999) to evaluate historical plume dynamics was not amenable to developing a recommended approach for predicting future plume dynamics.	The ability to make realistic future predictions of plume dynamics based on a review of historical plume characteristics is a critical component of acceptance of MNA-based remedies for dissolved CAH plumes. The absence of a cause-and-effect explanation for dissolved CAH plume sustainability and longevity limits the practical utility of the McNab *et al.* (1999) approach for individual sites.

2.1.3 Summary of Current Understanding of MNA Processes for CAHs

In general, CAH degradation reactions can be categorized as either oxidizing (losing electrons) or reducing (gaining electrons). These reactions may occur as part of abiotic or biotic processes that depend on localized environmental conditions including presence/absence of specific aqueous or solid minerals and microbial activity. Two of the major objectives of the USEPA (1998) technical protocols were 1) to provide a detailed description of how geochemical indicator data can be used to 'screen' local conditions and 2) determine whether existing conditions are conducive to biodegradation mechanisms. As described in these protocols, up to three types of biological mechanisms - reductive dechlorination (electron acceptor reactions), direct oxidation (electron donor reactions), and/or cometabolic reactions - may be active at a given site. In concert with this view of potential degradation mechanisms, these protocols segregated CAH sites by the presence (and type) or absence of an organic carbon source to produce reducing conditions. While these protocols acknowledge that it is likely that multiple degradation processes may be active in degrading CAH compounds at a given site, it was argued that biotic reductive dechlorination is the dominant mechanism for degrading highly oxidized compounds such as perchloroethene (PCE) and TCE. These protocols also recognized that some sites may have a ‘mixed’ degradation condition where sufficient electron donor is present in the source area to produce reductive dechlorination to cis-1,2-DCE and/or VC, while downgradient areas (characterized by oxidizing conditions with little or no electron donor present) may be conducive to relatively rapid degradation of cis-1,2-DCE and VC through biotic and/or abiotic direct oxidation.

In the seven years since publication of the USEPA (1998a) technical protocol, the current state of science on both biotic and abiotic degradation processes has advanced. In the area of biologically-based degradation, for example, microbial populations capable of complete reductive dechlorination of chloroethene compounds, either as a single species (e.g., Maymo-Gatell et al., 1995) or mixed consortia (e.g., Flynn et al., 2000), have been identified and isolated, thereby supporting the observation that biotic reductive dechlorination is one mechanism for complete CAH degradation to innocuous end products. Unfortunately, many microbial populations isolated to date have been observed to have a limited degradation potential. For example, microbial populations isolated from several sites appear to rapidly degrade PCE and TCE by reductive dechlorination, but appear to have limited or no ability to degrade DCE isomers or VC. Other researchers have investigated mechanisms of cometabolic and/or direct oxidation (biotic or abiotic) of partially oxidized (i.e., more reduced) CAH compounds such as cis-1,2-DCE and VC.

AFCEE has been a leader in advancing understanding and measuring abiotic degradation processes for CAHs through funding and publication of the Aqueous Mineral Intrinsic Bioremediation Assessment (AMIBA) Protocol (AFCEE, 2000a) and associated demonstration projects (e.g., AFCEE, 2003). Advances in understanding of abiotic degradation processes that have flowed out of the AMIBA protocol effort include 1) development of procedures for differentiating solid-phase iron species and 2) use of this information to evaluate whether moderately reducing (e.g., iron (III)-reducing) conditions are active or can be created (e.g., Kennedy et al., 2003) for degradation of cis-1,2-DCE and/or VC via direct oxidation or abiotic reductive dechlorination. In addition to these AFCEE initiatives, other research is currently being conducted to determine if other minerals, such as magnetite (e.g., Wilson et al., 2003; Ferry et al., 2004), may be providing a reactive ‘sink’ for CAH compounds, and whether the presence of aqueous iron(II) is required for reactive degradation processes to occur.

Other efforts have focused on how to evaluate diagnostic tools for understanding and enhancing NA at the field-scale. For example, the distribution and variation in degradation capabilities of the microbial consortia at CAH-impacted sites is still not well-understood, and is an area of continued investigation by multiple researchers. However, test methods for detecting the presence or absence of specific CAH-degrading microbes are now commercially available. The USEPA and other researchers (e.g., Hendrickson et al., 2002; Ritalahti et al., 2003) are currently using these test methods to evaluate the site-wide CAH-degrading potential at multiple sites. Improvements in the state-of-science of developing, implementing, and interpreting results of these biological test methods offers the future potential of improving our ability to qualitatively and quantitatively evaluate the potential for complete biological degradation of CAHs under existing redox conditions. In addition, these biological monitoring tools have the potential to improve diagnostic capabilities by 1) helping identify site-specific reasons for incomplete CAH degradation and 2) guiding decisions on how these limitations can be overcome by the engineered enhancement of existing conditions (e.g., substrate addition) and/or the addition of specific microbial populations (i.e., bioaugmentation).

2.1.4 Critiques of the Current State-of-Practice

The publication of the USEPA (1998a) technical protocol prompted several oversight agencies and independent panels to question the appropriateness of relying on screening-level assessment techniques to support remedy selection and long-term performance evaluation within the context of the formal regulatory decision-making process. These reviews generally concluded that the scientific basis for supporting MNA-based remedies for dissolved CAH plumes was not sufficiently developed and/or articulated in existing technical guidance documents to meet the same level of scientific and engineering scrutiny applied to other major groundwater remediation techniques (e.g., pump and treat). For example, the NRC (2000) concluded that the simple screening framework and techniques included in the USEPA (1998a) technical protocol were not sufficient to conclusively document a cause-and-effect relationship between observed contaminant mass/concentration loss and various attenuation processes. Of specific concern to the NRC was the absence of defensible field-scale evidence of the sustainability of NA processes. The NRC report further suggested that better guidance is needed on how to evaluate the sensitivity of existing NA processes to future environmental changes or other complicating factors, such as engineered source treatment.

The Environmental Engineering Committee (EEC) of the USEPA Science Advisory Board (SAB) elaborated on the NRC critique by identifying specific research recommendations designed to address the current uncertainty inherent in most MNA data sets collected and evaluated using the USEPA (1998a) technical protocol paradigm (USEPA, 2001). The SAB clearly specified the need to develop and field test methods 1) to distinguish various attenuation processes, 2) to account for the temporal and spatial variability in attenuation rates, and 3) to incorporate sustainability analyses into long-term performance evaluations to verify that MNA could achieve targeted regulatory endpoints. Specific areas of investigation that the SAB identified as needing further investigation included 1) the identification of site conditions that lead to the complete transformation of CAHs to innocuous end products within a reasonable timeframe, 2) demonstrations of the collection and analysis of site-specific data that can be incorporated into improved predictive models by reflecting variability in biodegradation rates over time and over space, 3) identification of NA processes that are effective in complete degradation of chlorobenzenes, chloromethanes, and chloroethanes and how this behavior is similar or different to NA of chloroethanes, 4) evaluation of the effect of source strength and dense non-aqueous phase liquids (DNAPL) presence on degradation potential and remediation timeframe, and 5) evaluation of CAH degradation mechanisms other than reductive dechlorination and how these mechanisms may be affecting CAH fate and transport.

2.2 PROCESS FOR EVALUATING MNA SUSTAINABILITY AT CAH¬IMPACTED SITES

Recognizing that the current state-of-science appears to prevent complete (or at least cost-effective) understanding of the relative contribution of various degradation processes at specific sites, the current effort evaluates new approaches for analyzing existing aqueous phase data that can be used to improve the assessment of CAH plume stability and the long-term sustainability of NA processes. Figure 2.1 presents a flow chart for assessing long-term sustainability of MNA for dissolved CAH plumes. The process description presented in this figure provides the context and purpose for each CAH plume analysis methodology described in the current study. The major components of the logic process presented on Figure 2.1 include:

1. Demonstration of protectiveness and plume stability;
2. Evaluation of CAH source characteristics; and
3. Evaluation of MNA sustainability.

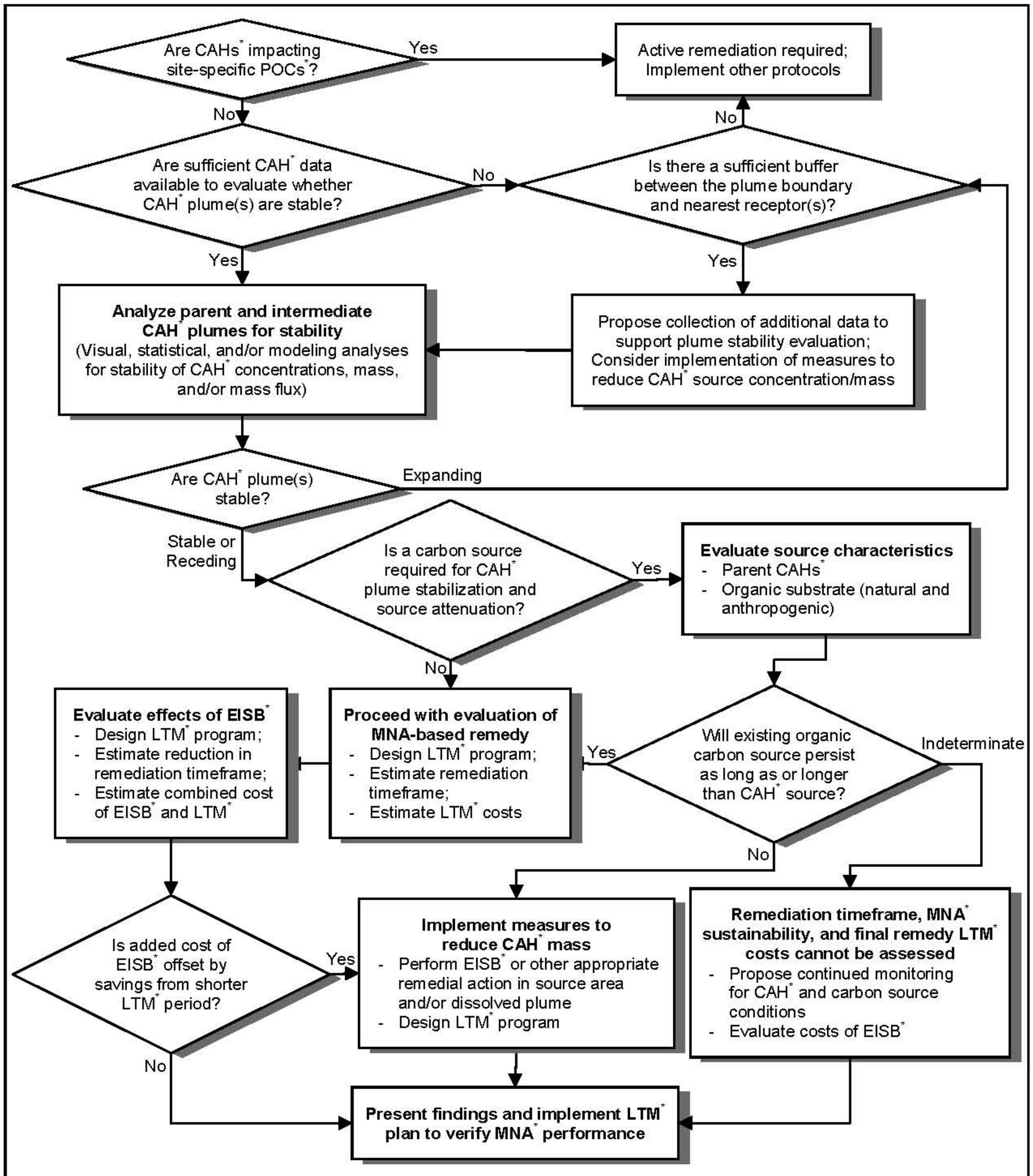
The relevance of each of these components to performing comprehensive MNA evaluations is discussed below.

2.2.1 Protectiveness and CAH Plume Stability

Because intermediate degradation products of parent CAHs are also regulated compounds, regulatory acceptance of an MNA-based remedy will typically require demonstration of protectiveness and plume stability for both parent CAHs and their intermediate degradation products. If protectiveness and dissolved plume stability cannot be demonstrated and documented for all regulated CAHs, it generally will not be possible to defend a remedial approach based on MNA without implementation of source control, source removal, or other active remedial approaches. One possible exception to this statement is that the distance to potential receptors may be sufficiently large at some sites to allow for expanding CAH plumes if 1) these plumes are not projected to cross a downgradient property boundary and 2) modeling work can be performed to show that downgradient receptors are unlikely to ever be impacted.

A site-specific, two-step process is used to document that a remedy is protective of current or future potential receptors. The first part of this process is to develop regulatory targets that are appropriate for the current and future site land use. Methods for identifying potential receptors and establishing appropriate regulatory targets (e.g., applicable or relevant and appropriate requirements [ARARs] at National Priorities List [NPL] sites) or risk-based regulatory targets have been described in numerous USEPA documents, so the mechanics of this process will not be described here. It is critical to understand the potential pathways and receptors at a CAH site so that appropriate remedial action objectives (RAOs) can be developed for the site before completing a thorough evaluation of any remedy (MNA-based or otherwise) for a particular site. After these targets have been established, the second part of the process – installation and monitoring of impacted media (i.e., surface water, groundwater, air, soil) is used to demonstrate whether these RAOs are being met.

At sites where groundwater has been impacted by CAHs, MNA is commonly used as part of the remedial action for reducing contaminant mass in groundwater. The first step in supporting the use of MNA as either a primary or secondary (i.e., polishing) remedy component will be to evaluate whether the current dissolved plume is expanding, stable, or receding. In the event that the plume is expanding, active remediation that 1) reduces the rate of contaminant release to groundwater (i.e., source reduction) and/or 2) increases the rate of contaminant degradation typically will be required to establish plume stability or contraction. Under this scenario, MNA will necessarily be a secondary, or complementary, component of the overall site remedy. In the



Notes: CAH = chlorinated aliphatic hydrocarbon; EISB = enhanced *in situ* bioremediation; LTM = long term monitoring; MNA = monitored natural attenuation; POC = point of compliance (e.g., receptor, property boundary)

Figure 2.1 Conceptual Framework for Assessing Appropriateness of MNA-Based Remedies at CAH-Impacted Sites.

event that existing conditions show that the plume is stable or receding, it may be possible to propose and defend an MNA-based approach as the primary remedy, with the decision to augment MNA with an active remedy determined by separate evaluations of whether 1) the remediation timeframe estimated for existing conditions is acceptable to the land owner, regulatory agency, and other stakeholders and 2) available data can be used to show that MNA processes are likely to continue to maintain plume stability/contraction over the entire duration of the remediation timeframe.

To date, the most common method for documenting plume stability has been the visual evaluation of whether the size of dissolved plume concentration ‘footprints’ has changed over time. Methods of using visual isoconcentration contour maps for demonstrating dissolved CAH plume stability has been described in previous protocol documents (e.g., USEPA, 1998a), and were the basis for the plume stability calculations made in the McNab et al. (1999) CAH plume study described in Section 2.1.2. Use of isoconcentration contour maps will remain a compelling method for documenting dissolved plume stability during initial MNA evaluations and subsequent comprehensive remedy performance reviews (e.g., CERCLA 5-year reviews). However, the visual isocontour comparison approach is unlikely to be the most technically-sound and cost-effective approach for evaluating plume dynamics during interim monitoring events. From a technical perspective, development of individual isoconcentration contour maps typically 1) involves a subjective interpretation processes that tends to be insensitive to small changes in contaminant concentrations and 2) yields results that are qualitative, rather than quantitative. From a cost perspective, this process can be more expensive than other trend analysis approaches because it generally requires 1) more well locations to be sampled than may be required to support other approaches and 2) more time to develop the isoconcentration contour maps that are used as the basis of evaluation.

Two approaches for evaluating plume stability that are alternatives to the isoconcentration contour map approach are 1) visual/statistical evaluation of CAH concentration trends in individual wells and 2) evaluation of changes in plume-wide contaminant mass characteristics over time. Visual and/or statistical trend analyses have been applied to CAH concentration data from individual monitoring points for a variety of reasons at many sites. Potential benefits of the individual well trend analysis approach to plume stability analysis include that this approach 1) is relatively straightforward and inexpensive to implement, 2) can be focused on wells that existing information suggest are ‘critical’ for defining plume dynamics, and 3) can, in some cases, also be used in support of future predictions of plume dynamics, estimations of remediation timeframe, and achievement of quantifiable MNA performance metrics. Some of the significant challenges to using the statistical trend analysis approach for assessing plume stability are 1) selecting the most appropriate statistical method for assessing a particular data set and 2) presenting a large set of statistical results, which may or may not be in agreement between methods for any given well, in a comprehensive and compelling demonstration of plume stability. The current study attempts to extend the state-of-practice of using this approach by demonstrating how statistical trend analyses of individual monitoring points can be applied, documented, and interpreted as part of overall plume stability analysis. The current study uses the statistical analysis approach offered in MAROS for implementing statistical analysis using linear regression and the Mann-Kendall (MK) test for trends that are described in Section 3 of this report. The authors acknowledge that the statistical analyses available in MAROS represent only one approach to statistical trend analysis. At some sites, the use of different or additional statistical criteria, such as confidence intervals for defining trend significance, should be considered. The evaluation of a wide variety of statistical methods and criteria was considered beyond the scope of the current project. Readers that choose to explore different statistical approaches that are available in MAROS are encouraged to engage an environmental professional with experience in statistics to assist with data analysis.

MNA performance evaluations that use site-wide monitoring well data to quantify CAH mass loss and/or CAH plume movement over time are used much less frequently for evaluating CAH plume stability than the concentration-based approaches described above. Mass-based considerations are important because the relationship between the rates of CAH mass release from the source area and CAH mass degradation in the dissolved plume will control whether a plume is stable, expanding, or contracting. Perhaps the single greatest benefit of mass-based plume stability analysis is that this approach allows the calculation of two numbers – estimated dissolved plume mass and location of the geographic centroid of this mass – to be used for a quantitative evaluation of whether individual (or total) CAH plumes are, on average, stable, receding, or expanding over time. The current study attempts to extend the state-of-practice for applying mass-based approaches to plume stability analysis by reviewing and demonstrating various methods for performing mass-based analyses, summarizing approaches for displaying and interpreting results, and comparing the results of this approach with interpretations from the more commonly-used approaches described above.

Section 3.1 describes 1) three statistical methods of trend analysis for changes in contaminant concentration over time and 2) a recommended approach for evaluating changes in dissolved plume mass metrics. Section 4 summarizes the results of applying each of these methods to five different sites with historical CAH concentration data. Note that, for some of the sites, one or more of the methods described in Section 3.1 could not be applied because the historical data was incompatible with the input requirements of a particular method. Section 4 also includes tables and figures that were found useful in summarizing and interpreting the results of the current plume stability evaluations, and compares these results with previous analyses (i.e., available isoconcentration contour maps, previous quantitative and quantitative historical trend analyses) to document whether current techniques produced results that were in agreement with previous assessments. Section 5 summarizes observations of this study to develop recommendations on how and when concentration-based and/or mass-based trend analyses can be used to supplement or, in some cases, replace isoconcentration contour map-based approaches for documenting plume stability.

2.2.2 Estimating Remediation Timeframe

After plume stability and protectiveness of current receptors has been documented by analysis of existing data or defensible modeling predictions, estimates for remediation timeframe and the long-term sustainability of MNA processes will be needed. Reliable estimates of remediation timeframe are important for 1) evaluating whether an MNA-based remedy is capable of achieving an acceptable remediation endpoint in a timeframe that is reasonable when compared to other alternatives, 2) calculating life-cycle costs of LTM for an MNA-based remedy, and 3) providing a target timeframe that can be used to evaluate whether current and future NA processes are likely to be sustained over the duration of contamination in the subsurface.

It is anticipated that the remediation timeframe at most CAH-impacted sites will be defined as the time required for CAH concentrations in the source area to reach site-specific regulatory targets. The timeframe for CAH concentrations in the source areas to reach specified regulatory targets will be dependent on the various factors that contribute to 'source strength'. The term 'source strength' has historically been used as a generally qualitative assessment of source condition. Sources designated as 'high strength' or 'persistent' typically refer to sites where dissolved contaminant concentrations have remained at or above a specified percentage (e.g., between one and ten percent) of pure-phase aqueous solubility for an extended time period. Sources designated as 'low strength' or 'diminished' typically refer to sites where concentrations of parent CAHs have steadily decreased over time to relatively low levels (e.g., less than one percent of pure-phase solubility). Physical conditions that are most likely to control source strength include the type and mass of CAH release and local hydrogeology.

Chemical conditions, including the presence, type, and availability of carbon sources and various electron acceptors, will also affect CAH source duration because local groundwater chemistry has a major influence on biotic and abiotic degradation processes. In addition, any engineered remediation of the source area and/or dissolved plume that is currently underway (or was previously performed) will affect source strength characteristics and should therefore be accounted for when estimating remediation timeframes.

Section 3.2 describes 1) multiple approaches that can be used for estimating remediation timeframes and 2) which of these approaches are offered as models in software programs available through the public-domain or as part of the DoD-sponsored Groundwater Monitoring System (GMS) platform. The case study examples in Section 4 include 1) a description of how remediation timeframes were estimated during historical MNA assessments, 2) an assessment of whether these remediation timeframes estimates have accurately tracked with monitoring data collected after the initial prediction, and 3) recommendations on how empirical models can be used with LTM data to evaluate or refine remediation timeframe estimates.

2.2.3 Evaluation and Prediction of MNA Sustainability

Once an estimate for the remediation timeframe has been developed, knowledge of the dominant, site-specific NA processes could be used to predict whether receptor protectiveness and CAH plume stability (or contraction) are likely to be sustained over the duration of CAH impacts to subsurface media. The goals of evaluating and documenting NA process sustainability are to 1) provide a level of assurance that future receptors will not be impacted, 2) identify which parameters are most important to monitor as an indicator that current conditions may be changing, and 3) predict if changes in current conditions are likely to have a positive or negative impact on the processes controlling plume stability and receptor exposure. Note that changes in current conditions may occur naturally or as part of active engineering activities.

MNA-based remedies can be considered knowledge-based remedies in that they rely more on knowledge of natural systems than on active engineered controls (e.g., operating specifications of groundwater extraction systems or hydraulic containment structures) to control site contaminants. Although the NRC (2000) has asserted that the success of pump and treat systems in attaining final cleanup goals is more quantifiable and predictable than MNA-based remedies, it has been Parsons observation that this assertion has proven not to be the case at hundreds of pump and treat sites where closure has not been attained within the timeframe predicted during the design of the pump-and-treat remedy. Based on this observation, there exists a need to improve the state-of-practice in predicting whether any groundwater remedy – MNA-based or otherwise – is likely to achieve site-specific RAOs and how long it will take the remedy to achieve these goals. If multiple remedies are reliably predicted to achieve RAOs within an acceptable remediation timeframe, this timeframe estimate can then be used to estimate the life-cycle cost to achieve site closure over the duration of remedy operation and monitoring.

At the outset of this project, the envisioned approach for advancing the state-of-practice for long-term sustainability assessments of MNA was to evaluate whether existing LTM data sets could be used to predict how long biodegradation processes could be counted on to maintain plume stability. Of particular interest was the development and demonstration of a procedure for analyzing dissolved organic carbon, electron acceptor, and reaction endproduct data from monitoring wells in the source area and along the plume axis. The objective of this procedure development was to help move the state-of-practice beyond the 20 milligrams per liter (mg/L) 'rule-of-thumb' described in USEPA (1998a) as the threshold below which dissolved organic carbon concentrations are likely to limit the beneficial effects of biodegradation. Unfortunately, a review of available data from 35 candidate sites did not yield any sites with existing data sets that contained all of the data required to perform this type of analysis. In addition, site-specific predictions of dissolved organic carbon source duration do not appear to have been made for any of the candidate sites reviewed. The text provided in the remainder of this section describes a process for evaluating long-term sustainability of MNA processes at sites where biodegradation is a significant contributor to plume stability. The purpose of providing this text is to serve as a road map for designing future LTM programs that could be used to support MNA sustainability estimates.

Figure 2.2 is a conceptual representation of how the timeframe for maintaining current redox conditions could be estimated. The concepts presented on Figure 2.2 rely on the estimation of two phenomena, namely 1) the rate of organic carbon consumption and 2) the threshold organic carbon loading that is required to maintain existing degradation conditions. The envisioned process for estimating the rate of organic carbon consumption is to 1) compile site monitoring data for one or more organic carbon indicator parameters (e.g., dissolved organic carbon) that have been measured over three or more monitoring events and 2) apply an empirical model to organic carbon indicator concentrations from each well with sufficient data to determine the best-fit trends over time. Ideally, data to support this procedure would be available from monitoring wells in the source area and along the plume axis. The process for estimating the threshold organic carbon requirement would be to use measured concentrations of native (inorganic) electron acceptors and reaction endproducts with stoichiometric coefficients for organic carbon utilization to estimate how much organic carbon is required to maintain the redox condition for each major terminal electron acceptor process (TEAP). At a minimum, the native electron acceptors that should be included in these calculations should include oxygen, nitrate, ferric iron, sulfate, and carbon dioxide. Examples of how these calculations have been performed for petroleum hydrocarbons and organic substrates can be found in the Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater (AFCEE, 1995) and Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents (AFCEE et al., 2004), respectively. The anticipated sustainability of existing redox conditions could then be estimated by determining when (or if) existing organic carbon indicators are predicted to decrease below the calculated threshold value.

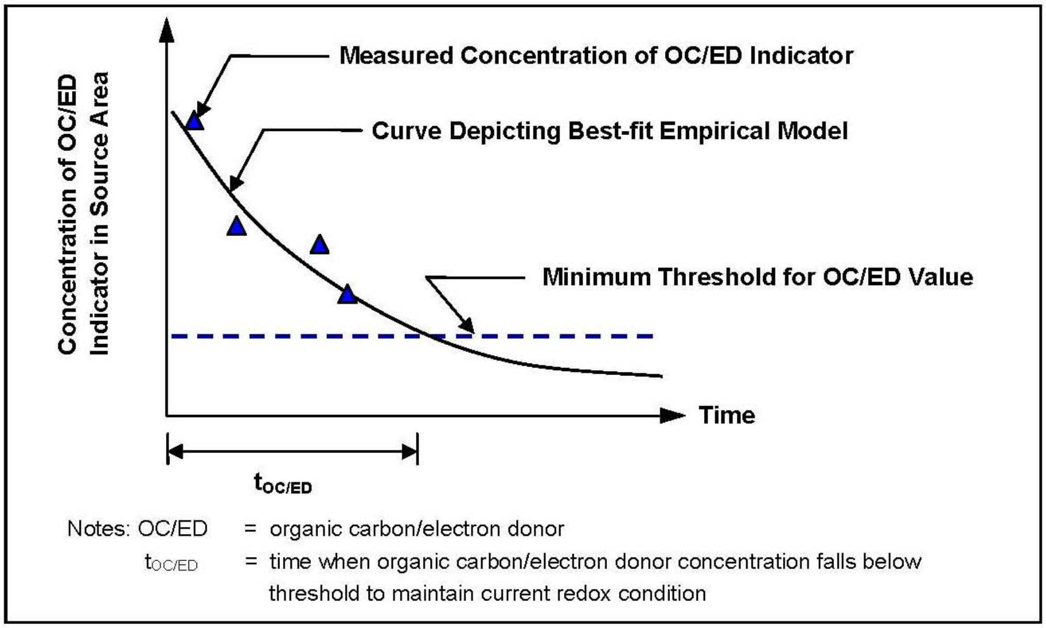


Figure 2.2 Schematic Representation of a Method for Estimating Duration of Organic Carbon/Electron Donor Control of Local Redox Conditions

It is important to note that the state-of-science for calculating electron acceptor demand when the carbon source is either native organic carbon and/or weathered anthropogenic carbon (i.e., weathered fuels) has not advanced to the point where there is a widely-accepted chemical composition that can be broadly used as the basis for stoichiometric calculations. Current research funded by Strategic Environmental Research and Development Program (SERDP; e.g., Widdowson et al., 2004) is attempting to advance the state-of-science in this area.

The minimum data required to support an estimate of the timeframe for maintaining current redox conditions include concentrations of dissolved organic carbon, anthropogenic carbon sources (e.g., benzene, toluene, ethylbenzene, xylene isomer [BTEX] concentrations), aqueous phase inorganic electron acceptors (e.g., dissolved oxygen, nitrate, sulfate, carbon dioxide), and selected reaction endproducts (e.g., ferrous iron, methane, alkalinity). Collection techniques for each of these parameters are described in existing MNA protocols (e.g., AFCEE, 1995; USEPA, 1998a). The purpose of collecting the electron acceptor data (i.e., dissolved oxygen, nitrate, sulfate, carbon dioxide) is to directly estimate organic carbon demand by a particular TEAP through the use of a stoichiometric use coefficient. For solid phase electron acceptors (e.g., ferric iron), it may be possible to use the dissolved reaction endproduct of a particular reaction (e.g., ferrous iron) to estimate electron donor demand by that particular TEAP. Alternately, ferric iron can be measured directly using the AMIBA protocol (AFCEE, 2000a) to estimate electron donor demand by this TEAP. Considering that the current state-of-practice for measuring ferric iron requires collection and analysis of soil samples, the additional cost of mobilizing drilling equipment to collect these soil samples at multiple events will need to be balanced against the potential benefit of improving the estimate of electron donor demand.

Importantly, the data needed to support the proposed method of estimating MNA sustainability need to be collected as a full suite during at least three separate monitoring events (and preferably more). Based on experience with observed NA processes at multiple sites, it is anticipated that an adequate sampling frequency for this full suite of parameters would be once per year or once every two years. During Parsons review of available data from candidate sites where MNA is the primary remedy, it was noted that that a full suite of MNA evaluation parameters (excluding ferric iron) was collected during two monitoring events at several sites, but was not replicated during a third monitoring event. The absence of this third collection event made it impossible to demonstrate the concepts described here, and to either validate or refute whether this proposed approach yields a meaningful estimate for MNA sustainability.

3.0 ADVANCED METHODS FOR ASSESSMENT OF MONITORED NATURAL ATTENUATION-BASED REMEDIES

As described in Section 2.2, the three key decision criteria are: 1) demonstrating plume stability, 2) estimating remediation timeframe, and 3) evaluating the sustainability of MNA processes for maintenance of plume stability. This section provides a summary of several methods that are currently available for evaluating the first two of these three key decision criteria related to the appropriateness of MNA-based remedies for CAHs in groundwater. Table 3.1 summarizes the data input requirements and options for data analysis for monitoring-based approaches to demonstrating plume stability and estimating remediation timeframes. Note that some of the methods listed in Table 3.1 and described in this section are advancements of the analysis methods previously described in the USPEA (1998a) protocol. Other methods listed in Table 3.1 and described in this section are adaptations of geostatistical analysis approaches and solution techniques that have been applied to other types of environmental data, but are not commonly being used as analysis techniques for evaluation and performance monitoring of MNA-based remedies. Case study examples illustrating the application of these methods to historical site data are provided in Section 4.

Table 3.1 Monitoring-Based Approaches for Assessing CAH Plume Stability and Long-Term Sustainability of Natural Attenuation Processes

Metric	Data Input Requirements	Options for Data Evaluation
Plume Stability (Concentration-based)	• Monitoring well locations and screen interval information • Historical CAH concentrations over time in monitoring wells across the site (i.e., within the contaminant plume and at downgradient sentry locations)	• Contaminant isoconcentration contour maps over time • Visual plots of changes in monitoring well concentrations over time • Statistical evaluation of changes in concentrations over time at individual monitoring wells
Plume Stability (Mass-based)	• Monitoring well locations and screen interval information • Historical CAH concentrations over time in monitoring wells across the site	• Changes in estimated • contaminant plume mass over time • Changes in location of contaminant plume center of mass over time • Changes in mass-flux over time
Remediation Timeframe	• CAH concentrations in source area monitoring wells over time • Release type • Source morphology	• Extrapolation of source area well concentration data versus time • Application of empirical or mechanistic models of DNAPL dissolution

3.1 EVALUATING PROTECTIVENESS AND CHLORINATED SOLVENT PLUME STABILITY

Historical CAH concentrations in groundwater can be used to develop either concentration-based or mass-based evaluations of CAH plume stability. This section describes the methods that were used to evaluate CAH plume stability using concentration-based metrics (Section 3.1.1) and mass-based metrics (Section 3.1.2).

3.1.1 Concentration-Based Metrics

The objective of performing concentration-based evaluations of dissolved CAH plume stability during the current study was to evaluate advantages, disadvantages, and data input requirements for three statistical trend analysis methods. The three statistical methods implemented as part of this study were the MK test for trends (Mann, 1945; Kendall, 1975; Gilbert, 1987), linear regression analyses, and Sen's Estimator of Slope (Sen, 1968; Gilbert, 1987) calculations to evaluate temporal trends in CAH concentrations. A description of each of these methods is provided in Section A.1 of Appendix A.

The general approach for completing statistical trend analyses of CAH concentration data was a three-step procedure that consisted of 1) data compilation, 2) performance of statistical analyses, and 3) evaluation and presentation of results. The data compilation process focused on the creation of a comprehensive data table that listed 1) well name, 2) well installation date, 3) well location relative to the dissolved CAH plume, and 4) the dates that each well was sampled for CAHs. Data sources used to compile this information included text, tables, and figures from RI/FS reports, MNA assessment reports, and LTM reports. As part of the data compilation process, available data was assembled into a format that was compatible with the input requirements of the Monitoring and Remediation Optimization System (MAROS) software package (AFCEE, 2002). Performance of statistical analyses for the MK test and linear regression analysis was implemented using the data trend analysis component of MAROS. Statistical trend analysis using Sen's Estimator of Slope (a.k.a., Sen's method) was implemented by modifying an Excel spreadsheet developed and described by Brauner (1997). For all of the statistical trend analysis methods, trends were defined according to decision logic inherent to MAROS. This includes the statistical trends evaluated by Sen's method; though not a compenent of MAROS, the Sen's method decision logic was defined to be consistent with the MAROS approach. The MAROS decision logic is internally consistent, but has not been universally accepted and other approaches to trend analyses exist. Trend analysis results for each method were then entered into summary tables and sorted by CAH and monitoring well location. The primary method for evaluating and presenting statistical analysis results performed as part of the current effort was to plot trend analysis results on an isoconcentration contour map to help identify whether there was a spatial correlation to wells with increasing, decreasing, or stable trends. A more detailed description of how existing site data was compiled, analyzed, and presented is provided in Section A.1 of Appendix A.

The results of the statistical analyses performed as part of the current study were compared between methods and with available contaminant isoconcentration contour maps, visual data plots, and trend analysis conclusions presented in historical site reports. The purpose of these comparisons was to evaluate whether different methods produced similar assessments of CAH plume stability. In cases where different methods were observed to lead to different assessments of plume stability, both individual data points and the analysis method employed were examined to understand why these differences occurred. Discussion of site-by-site assessment differences is provided in the text of individual case studies in Section 4.1. A summary of findings on concentration-based plume stability analysis methods and a description of how these findings might impact LTM program design and future data analysis are provided in Section 5. The emphasis of this study's evaluation of statistical methods was as much about identifying potential ways that application of "blackbox" statistical software could generate misleading results as it was a side-by-side evaluation of quantitative and qualitative methods for evaluating plume stability.

3.1.2 Mass-Based Metrics

The primary objective of performing mass-based evaluations of dissolved CAH plume stability during the current study was to evaluate whether mass-based metrics can be used to either replace or complement concentration-based evaluations of plume stability. During project execution, a secondary objective became documentation of recommended implementation practices for using historical CAH concentration data to develop plume-based metrics. In the current study, the method of moments was the mathematical technique that was used to estimate dissolved plume mass and the spatial location of the center of mass. A detailed mathematical descripton of the method of moments is provided in Appendix A for those readers that are interested in ty bases of using zero-order and first-order moments to estimate that total mass and center of mass for dissolved contaminant plumes. Note that the second order moment, as used in MAROS as an analog for plume spreading, can also be calculated using the method of moments. Values for the second order moment were not reported as part of this study because these numbers can not be readily compared with a physical measurement of dissolved plumes.

The general approach for completing mass-based analyses of dissolved CAH plume data was to apply a three-step procedure that consisted of 1) data compilation, 2) implementation of mass-based metric calculations, and 3) evaluation and presentation of results. The data compilation process used the comprehensive data table described for the concentration-based analysis to identify the number of sampling events where 'common well sets' of at least eight wells were sampled. In this study, the common well set for a site was defined as the subset of wells that were sampled during each and every sampling event where at least eight wells were sampled. As described under recommendations in Section 5, the choice to use a common well set of at least eight wells was based on experience gained during the current study that this procedure tended to reduce the 'noise' associated with using data sets that had a different number of wells and/or a different extent of spatial coverage (i.e., a different model "hull", as described in Section A.2 of Appendix A). The advantage of reducing 'noise' in the calculation results was that it was easier to identify trends in mass-based metrics over time.

Implementation of mass-based metric calculations was performed using two approaches for applying the method of moments to CAH monitoring well concentration data. The first implementation method was the Theissen polygon method, originally described for environmental data by Chow et al. (1988) and applied to groundwater contaminant plume concentration data by USEPA (1998b). The second implementation method was use of a triangular irregular network (TIN) grid method. In both methods, a model boundary (i.e., a model hull) was established and the mass in discrete volumes of aquifer are estimated after assigning a ‘representative’ contaminant concentration to each discrete volume. To estimate the total dissolved plume mass within the domain hull, the CAH mass in each of these discrete volumes is summed across the model hull. The coordinates of the center of mass for the dissolved plume were calculated by first multiplying the mass of each discrete volume by the coordinate (e.g., northing, easting) of the spatial center of the discrete volume, and then dividing the sum of these products by the total mass estimated from the zero order moment. Section A.2 of Appendix A provides a detailed description of how the method of moments was implemented in ArcGIS for both the Theissen polygon and TIN methods. Section A.2 also describes the steps used to 1) validate the ArcGIS (Environmental Systems Research Institute [ESRI], 2001) algorithms and 2) assess how the zero order and first order moment calculations were affected by the method of mass allocation. In cases where sufficient data were available from four or more data sets to perform method of moments calculations, both the MK-test and linear regression analysis were applied to determine if there was a statistically-significant trend in contaminant mass over time.

The primary methods for presenting mass-based metric results performed as part of the current effort were to 1) graph CAH mass over time and 2) plot changes in the location of the center of mass on a site base map that showed the direction of groundwater flow and a recent isoconcentration contour map. The purpose of graphing CAH mass over time was to aid in the visual observation of trends, both in total CAH mass and in CAH speciation. The purpose of plotting the location of the CAH center of mass on a site base map that showed the direction of groundwater flow was to identify whether the dissolved CAH center of mass appeared to be advancing, stable, or receding with respect to the direction of groundwater flow.

The results of the mass-based analysis were then compared with the results of the concentration-based analyses to evaluate whether mass-based metrics produced a similar assessment of CAH plume stability. In cases where differences in mass-based plume stability assessment was observed, either between methods or when comparing mass-based methods to concentration-based methods, both individual data points and the analysis methods were examined to explain why these differences occurred. As with the concentration-based analysis, discussion of site-by-site assessment differences is provided in the text of individual case studies in Section 4.1. A summary of findings on mass-based plume stability analysis, recommended methods of applying mass-based methods, and how these findings might impact LTM program design and future data analysis is provided in Section 5.

3.2 ESTIMATING REMEDIATION TIMEFRAMES

As described in Section 2.2.1, CAH source duration is likely to be the dominant factor in developing realistic estimates of remediation timeframes at most CAH-impacted sites. Based on this assumption, estimates of CAH source duration can serve as a scientifically-defensible method for estimating the remediation timeframe for MNA-based remedies. The text presented in this section establishes the current state-of-practice for estimating remediation timeframes using estimates for CAH source duration. The discussion in this section starts with a brief review of the state-of-science for conceptual models of CAH release to groundwater (Section 3.2.1) and continues with a description of the types of modeling approaches that can be used to simulate CAH sources over time (Section 3.2.2). Section 3.2.3 describes the methods used in the current study to evaluate remediation timeframes using source well concentrations data. Supporting information on how various models estimate the duration of various CAH sources to groundwater is provided in Appendix B.

3.2.1 Conceptual Models of CAH Sources

The following review of the current state-of-knowledge of CAH sources is provided in preparation for identifying and describing the advantages and limitations of various models for simulating CAH source duration. Figure 3.1 is a schematic representation of the current state-of-knowledge of the processes that affect DNAPL fate and transport in the subsurface. Note that this schematic assumes that CAH was released to the subsurface as a DNAPL, and that the mass of release was sufficient to penetrate the water table and accumulate at a low permeability layer that is at some depth below the water table. In reviewing Figure 3.1, notice that the two processes that cause CAH to dissolve into groundwater are DNAPL dissolution (Processes 1 and 2 on Figure 3.1) and diffusion/desorption of CAH contamination from low-permeability (e.g., clay) layers (Processes 3 and 4 on Figure 3.1).

Having a basic understanding of the phenomena that can control CAH dissolution to groundwater can help improve the accuracy of site-specific remediation timeframe estimates because some models may be better at 1) predicting future CAH source area concentrations for one phenomena, but not for another phenomena and 2) accounting for a change in the phenomena controlling CAH release to groundwater. Section B.1 of Appendix B provides a description of the two processes that control CAH release to groundwater at most sites: 1) DNAPL dissolution (Section B.1.1) and 2) desorption/diffusion from low permeability zones (Section B.1.2).

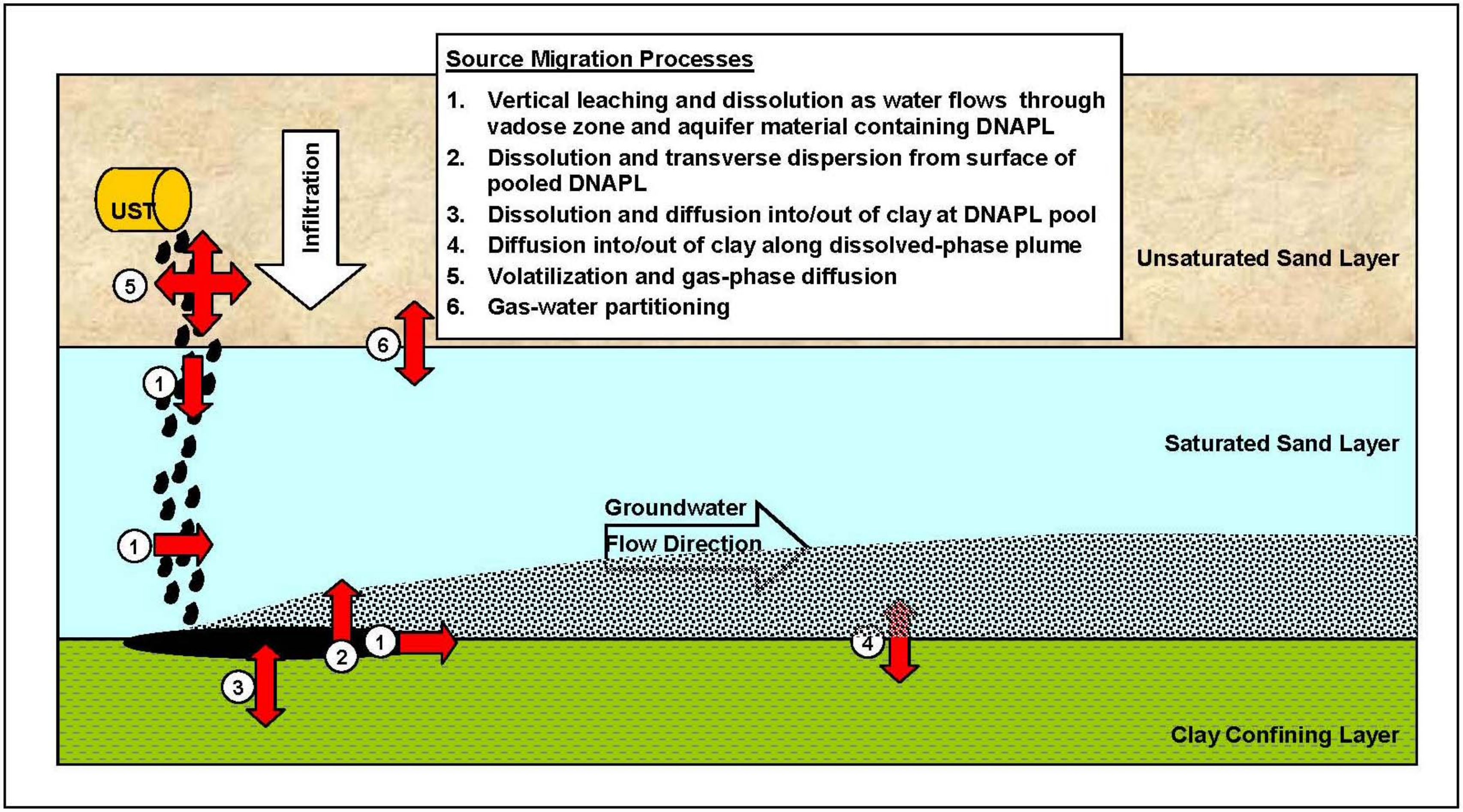
3.2.2 Overview of Modeling Techniques

Methods for estimating CAH source duration can be separated into two broad categories: mechanistic models and empirical models. The following text describes these model types and the types of input parameters required to implement each model type.

3.2.2.1 Mechanistic Modeling of CAH Sources

Modeling techniques that employ a mechanistic, or explicit, approach attempt to explicitly model one or more specific processes that affect the mass of CAH in the source zone (e.g., dissolution, advection, dispersion, diffusion, sorption/desorption). Mechanistic models of CAH release to groundwater are based on one or more of the following fundamental concepts: 1) conservation of mass, 2) NAPL dissolution processes, 3) sorption/desorption/diffusion processes, and 4) kinetics. Section B.2 of Appendix B provides a detailed description of each of these concepts and how they have been applied to develop mechanistic models for various sources of CAHs to groundwater.

In general, mechanistic modeling techniques and the software packages that employ them require measurements or reasonable assumptions for a relatively large number of site-specific parameters, some of which can be difficult to accurately estimate. For example, mechanistic models based on a conservation of mass approach require an estimate of the contaminant mass



Source Migration Processes

1. Vertical leaching and dissolution as water flows through vadose zone and aquifer material containing DNAPL
2. Dissolution and transverse dispersion from surface of pooled DNAPL
3. Dissolution and diffusion into/out of clay at DNAPL pool
4. Diffusion into/out of clay along dissolved-phase plume
5. Volatilization and gas-phase diffusion
6. Gas-water partitioning

Figure 3.1 Conceptual Model of Mechanisms Affecting DNAPL Migration and Dissolution and the distribution of this mass (i.e., source morphology) in the source area for at least one point in time. Because mechanistic models are mass conservative, the uncertainty in specifying the mass and distribution of contaminant as DNAPL has a direct impact on the uncertainty of the remediation timeframe. Mechanistic models also require multiple site-specific input parameters to characterize the subsurface environment (e.g., particle size distribution, average pore-throat thickness, immobile and mobile porosity) and groundwater contaminant properties (e.g., partitioning coefficients, diffusion coefficients, solubility). While some of these parameters can reasonably be estimated using published literature values in geologic reference books and chemical handbooks, other parameters, such as average pore throat thickness and immobile porosity, are difficult or impossible to measure given the current state-of-science.

Section B.3 of Appendix B provides a review of selected current software packages that can be used to simulate mechanistic modeling of CAH sources. While purely mechanistic models may one day offer a more accurate method of simulating CAH release to groundwater, the current state of practice, in terms of model development and the ability to measure input parameters, limits the practical application of these models for existing data sets of parameters that have commonly been collected at CAH-impacted sites. As an example of the limitation on modeling capabilities, the authors of this study are unaware of any publicly-available models that currently offer a suitable method of mechanistically modeling diffusion and sorption processes in low-permeability formations that may be controlling source area CAH concentrations in groundwater at some sites. Considering that the input requirements for mechanistic models are significantly beyond typical LTM data at CAH source areas, the remainder of this study will focus on empirical techniques for predicting CAH source duration as a method of estimating remediation timeframes.

3.2.2.2 Empirical Modeling of CAH Sources

Unlike mechanistic models, empirical, or implicit, modeling techniques do not attempt to model NAPL dissolution, CAH desorption, or any other physical process. Rather, empirical modeling techniques use a mathematical function to simulate a trend in the contaminant source. The function used to simulate the contaminant source may be ‘fitted’ to available site data (e.g., concentrations in a well near the source zone) or based on an assumed function if insufficient data are available. Note that the mathematical functions used by empirical models to predict future contaminant concentrations do not directly account for CAH source mass depletion, and are therefore not considered mass conservative.

Historically, empirical models of changes in source condition over time have been used primarily for specifying the contaminant loading boundary condition for numerical models of contaminant fate and transport. Boundary conditions are used to describe the interaction between the system being modeled and its surroundings. Table 3.2 lists three types of boundary conditions commonly used to introduce contaminant mass into contaminant fate and transport models. As can be observed from the mathematical expressions in Table 3.2, model boundary conditions that simulate CAH source concentrations can be defined 1) explicitly using a specified-concentration boundary, 2) indirectly as a mass flux (contaminant concentration influx over time), or 3) as a mixed condition.

Table 3.2 Description of Boundary Conditions in Contaminant Fate and Transport Models

Boundary Condition	Formal Name	General Mathematical Description
Specified-concentration	Dirichlet	$C = f(x,y,z,t)$
Specified-flux	Neumann	$dC/dn = f(x,y,z,t)$
Concentration-dependant Flux	Cauchy	$dC/dn + m*C = f(x,y,z,t)$

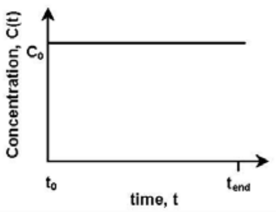
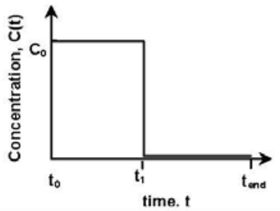
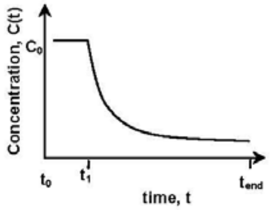
Notes: C = CAH concentration; n = spatial direction (x, y, or z); t = time; m = constant

A review of MNA assessment studies indicates that modelers have employed specified concentration and specified flux boundary conditions to simulate NAPL sources. Although modelers have historically used each of the three boundary conditions listed in Table 3.2 to simulate CAH sources, the boundary conditions that can most directly be 'fitted' to existing source well concentration data is the user-specified concentration boundary. Some of the more common functions used to simulate specified concentration boundary conditions include:

- Constant-load boundary condition starting at the time of release (i.e., t0) and continuing for the duration of the simulation (i.e., tend);
- Pulsed-load boundary condition specifying a constant concentration or flux for one user-specified period of time (i.e., t0 through t1), then dropping this concentration or flux to zero at a user-specified time (t1); and
- Decaying-load boundary condition, specifying a constant concentration or flux for one user-specified period of time (i.e., t0 through t1), followed by a concentration or flux term that decays over time (i.e., t1 through tend), often following an exponential decay model.

Table 3.3 provides a mathematical description and schematic representation of how concentrations commonly are simulated to vary with time for each of the three boundary conditions described above.

Table 3.3 Common Mathematical Functions for Simulating CAH Source Area Concentrations over Time

<table>
<tr><th>Empirical Model</th><th>General Mathematical Description</th><th>Schematic Representation of Function over time</th></tr>
<tr><td>Constant Concentration (Zero-order)</td><td>$C(t)$ = constant concentration (C_0) between t_0 and t_{end}</td><td>
</td></tr>
<tr><td>Pulse loading (Zero-order step function)</td><td>$C(t)$ = constant concentration (C_0) between t_0 and t_1
$C(t)$ = zero between t_1 and t_{end}</td><td>
</td></tr>
<tr><td>Constant Concentration (Zero-order) followed by Exponential (First-order) Decay</td><td>$C(t)$ = constant concentration (C_0) between t_0 and t_1
$C(t) = C_0 * e^{-kt}$ between t_1 and t_{end}, where k is the exponential decay rate</td><td>
</td></tr>
</table>

While a user-specified concentration boundary can be compared directly to CAH concentration data in source area monitoring wells, Abriola (1996) reports that it is difficult to estimate contaminant mass flux from NAPL into groundwater because this estimate is dependant on several parameters, most of which cannot be measured. Without an accurate field-estimate of contaminant flux into groundwater, it is difficult to assess how accurately a simulated mass flux boundary condition compares with observed conditions. As will be described in more detail in the case studies of Section 4, the ability to assess how well a source model fits field-measured data is an important consideration when evaluating the confidence in future predictions of CAH source duration as a metric for remediation timeframe.

Perhaps the most important advantages of empirical models over mechanistic models for estimating CAH source duration is that these models typically 1) require a small number of input parameters (e.g., a starting concentration and one or two decay rate coefficients) and 2) are not explicitly dependent on an estimate of the contaminant mass in the system at any point in time. The simplicity of these models, however, leads to uncertainty in the appropriateness of these models for long-term predictions of CAH source concentrations. For example, a first-order decay rate that is estimated using source area well concentrations that have historically been controlled by residual DNAPL dissolution may not accurately represent a future source area concentration trend that is controlled by the rate of CAH release from low permeability zones. In addition, empirical models are not well-suited for predicting the effects of a change in source condition caused by active source remediation. In spite of these limitations, empirical models offer a defensible method of estimating remediation timeframes from data commonly collected as part of most LTM programs.

3.2.3 Description of Approach

The objective of this portion of the current study is to evaluate the benefits and identify the limitations of applying empirical models to CAH source area concentrations over time to predict remediation timeframes. Of specific interest is whether empirical models that are fitted to available CAH data can be used to provide a reasonable and defensible estimate of remediation timeframe.

The process used to evaluate the appropriateness of empirical models for estimating remediation timeframes consisted of two steps: 1) review of existing modeling studies of CAH sources and 2) evaluation of the remediation timeframe estimate predicted by the CAH source models. The review of existing modeling studies was completed by compiling input parameters and supporting information for ten sites where models were used to simulate CAH contaminant fate and transport. Section 4.2.1 provides case study reviews for these ten sites. The evaluation of remediation timeframe estimate was completed by first estimating the remediation timeframe using the modeled source decay rate and then evaluating the confidence in this estimate by graphically comparing the predicted source area concentrations with recently-collected LTM data. Because the reliability of the estimated remediation timeframe was evaluated by comparing model predictions to data from source area wells, the site selection criteria for this portion of the study were that 1) data was collected from source area monitoring wells that were unaffected by active remedial activities (if any) and 2) that this data was available to Parsons. Section 4.2.2 compares the modeled CAH source area concentrations with recently collected data from three of these sites that met the above criteria. Section 4.2.2 also provides the results of how varying source area modeling parameters (e.g., decay constants) affected the remediation timeframe, and how these variations in the modeling parameters affects the time of remediation. The results of this effort are summarized in Section 5 through provision of summary of findings on the benefits and limitations of using empirical models for estimating remediation timeframes, and how these findings might impact the selection, implementation, and monitoring of remedial alternatives.

4.0 CASE STUDY REVIEWS AND EXAMPLES

This section presents the results of applying the methods described in Section 3 to available data from the sites listed in Table 4.1. The decision on the six sites to perform advanced plume stability analysis was based on sufficient data availability, as described in Section 4.1. The sites included in the CAH source model review were selected based on the availability of sufficient information on modeling assumptions and configuration. The CAH source model review is described in Section 4.2.1. Estimation of remediation timeframe was performed on the three sites indicated in the last column of Table 4.1. These sites were selected based on 1) availability of sufficient source well data over time and 2) the absence of the influence of active remediation on source area CAH concentrations. The results of the remediation timeframe evaluation for these sites are described in Section 4.2.2.

Table 4.1 Evaluations Performed at Case Study Sites

Site Name	Advanced Plume Stability Analysis	Remediation Timeframe Evaluation	
		Review of CAH Source Model	Estimation of Remediation Timeframe
OU1, Altus Air Force Base (AFB), Oklahoma		X	X
FPTA-2, Brooks City-Base, Texas	X		
LF03, F.E. Warren AFB, Wyoming		X	
OU1, Hill AFB, Utah		X	
OU5, Hill AFB, Utah		X	
Building 301, Offutt AFB, Nebraska		X	
OU4, Shaw AFB, South Carolina		X	
Site FTA-2, Tinker AFB, Oklahoma	X	X	X
Area A, Travis AFB, California		X	
Site LF-06, Columbus AFB, Mississippi	X		
SS-45, England AFB, Louisiana (2 plumes)	X		
Facility 1381, Cape Canaveral AFS, Florida	X	X	X

4.1 EVALUATION OF PLUME STABILITY

A total of six sites located at five bases were selected for evaluation of plume stability using the advanced analysis methods described in Section 3.1. Sites that have been selected for analysis, and the rationale behind their selection, are summarized in Table 4.2. Sites were selected from a variety of hydrogeological settings. Documentation of how assessments of current and future plume stability, through data analysis or fate and transport modeling, was also a pre-requisite for site selection because these historical assessments were used as the baseline to compare the results of the advanced analysis methods developed in the current study. Sites were required to have a minimum of four sampling events spread over at least a five year timeframe. Greater value was placed on sites with more sampling events over longer periods of time.

Table 4.2 Sites Selected for Plume Stability Analysis

Site Name	Rationale for Selection
FPTA-2, Brooks City-Base (Texas)	Extensive historical groundwater quality data set
Site FTA-2, Tinker AFB (Oklahoma)	No engineered remediation; MNA only; numerical fate and transport modeling was performed
Site LF-06, Columbus AFB (Mississippi)	Illustrate effects on plume stability analysis of variability in location of wells sampled over time; analytical fate and transport modeling was performed
SS-45, England AFB (Louisiana) (2 plumes)	No engineered remediation; MNA only; diffusion-dominated groundwater system; two adjacent plumes having substantially different characteristics
Facility 1381, Cape Canaveral AFS (Florida)	Good historical data set; MNA remedy for northern lobe of the plume; numerical fate and transport modeling was performed and can be used for comparison purposes

The MK and linear regression methods described in Section 3.1.1 were applied to monitoring well data sets for six sites to illustrate their use and evaluate their utility in plume stability analyses. Only two sites (FPTA-2, Brooks City-Base and LF-06, Columbus AFB) had data in approximately equally-spaced increments; therefore, the Sen's slope method was used only for these two sites. The MK and linear regression analyses were performed using MAROS (AFCEE, 2002), and the Sen's slope calculations were performed using a Microsoft EXCEL spreadsheet developed by Brauner (1997). Data input for each method consisted of historical CAH concentrations measured in groundwater monitoring well samples and the accompanying sampling dates. Temporal trends determined using these methods are compound-specific, and were determined on a well-by-well basis. Sites having monitoring data from at least four sampling events were selected to enable use of the MK and linear regression tests. The data from these case study sites were not specifically collected in support of applying the advanced analysis techniques, and this fact impacted the way that the techniques were evaluated. The emphasis of the evaluation of the statistical methods was as much about identifying potential ways that application of "blackbox" statistical software could generate misleading results as it was a side-by-side evaluation of quantitative and qualitative methods for evaluating plume stability.

Mass-based plume stability metrics were calculated using the Theissen polygon and TIN grid methods described in Section 3.1.2. Both of these methods were applied to monitoring well data sets from five of the six sites where concentration-based stability analysis was performed. As described in detail in Section 4.1.2.4, mass-based plume metrics were not performed on LF-06, Columbus AFB because of insufficient data. Mass-based metric calculations were implemented using ArcGIS scripts developed by Parsons and described in Appendix A. Data input for mass-based metrics consisted of historical CAH concentrations measured in groundwater monitoring well samples, the accompanying sampling dates, and spatial coordinates for each monitoring well. As with concentration-based analyses, temporal trends determined using these methods are compound-specific. At four of the five sites, sufficient data was available to perform mass-based calculations for four or more monitoring events. For these four sites, MK and linear regression trend analysis was applied to dissolved mass estimates to evaluate if any visually apparent trends were statistically significant. For the fifth site (FTA-2, Tinker AFB), statistical analysis of the estimated dissolved plume mass were not performed because available data limited calculation of mass-based metrics to three sampling events.

4.1.1 Case Study: Site FTA-2, Tinker Air Force Base, Oklahoma

4.1.1.1 Site Overview and Summary of Available Data

Site Description

Site FTA-2 is located in the south-central portion of Tinker AFB, located near Oklahoma City, Oklahoma. FTA-2 was established as a temporary, unlined pit and was used infrequently for fire training exercises between 1962 and 1966. Standard operating procedures reportedly included adding water to the pit to saturate the soil and reduce fuel infiltration. Fuel was then brought in by truck, placed on top of the water, ignited, and extinguished using water and foam. Any residuals were left in the pit either to evaporate into air or infiltrate into the subsurface until the next training exercise. Drums of waste oils and solvents were often staged near FTAs and mixed with fuels prior to ignition. Currently, the site is a gently sloping, grassy area with no visible evidence of former training practices.

Plume Description

The CAH plume that was analyzed as part of the current study is primarily present in the uppermost water-bearing zone, termed the upper saturated zone (USZ). The USZ has been subdivided into upper and lower sands that are separated in the southern portion of the site by a continuous 3- to 5-foot-thick clay layer. Parsons (1999a) reports that semi-confined to confined conditions may exist locally within the lower USZ sand interval. Measured hydraulic conductivities in the upper USZ sand interval range from 6.5 to 28 ft/day (mean = 14 ft/day), horizontal hydraulic gradient was about 0.006 foot per foot (ft/ft) toward the west-southwest, and groundwater seepage velocity was calculated to average about 152 ft/yr. In the lower USZ sand interval, measured hydraulic conductivities range from 0.9 to 44 ft/day (mean = 15 ft/day), horizontal hydraulic gradient was 0.006 ft/ft to the southwest, and the average groundwater seepage velocity was calculated to be about 167 ft/yr. Groundwater in both the upper and lower sands is contaminated with CAHs, and available data suggest that the footprints of the CAH plume in both the upper and lower sands are similar in both size and concentration distribution.

As reported in Demonstration of Remediation by Natural Attenuation for Groundwater at Site FTA-2 (Parsons, 1999a) and the addendum to that report (Parsons, 1999b), the highest concentration of CAHs were measured in the vicinity of well 2-62B, which is located in the upper portion of the USZ, approximately 100 to 120 feet upgradient from the former fire pit. The primary source COCs is TCE with lesser concentrations of PCE. High concentrations of cis-1,2-dichloroethene (cis-1,2-DCE) are being produced as a result of the reductive dechlorination of PCE and TCE. In addition, low concentrations of VC are being produced via the reductive dechlorination of cis-1,2-DCE. The distributions of TCE and cis-1,2-DCE in groundwater within the upper portion of the USZ are shown on Figures 4.1 and 4.2. The presence of a secondary solvent source, located further upgradient from the former fire pit along another access road near the flight line (well 2-65B), was suggested by increasing concentrations of CAHs at that location. Groundwater quality data indicate that the CAH plume has migrated from the inferred source area toward the northwest within both the upper and lower portions of the USZ.

The Parsons (1999a,b) reports concluded that, although dissolved CAHs are undergoing biologically-facilitated reductive dechlorination, the occurrence of this process is limited and localized to the source area(s). The presence of the intermediate degradation products cis-1,2¬DCE and VC provides strong evidence that parent solvents (TCE and/or PCE) are being reductively dechlorinated. However, the relatively low concentrations of VC and ethene suggest that the process does not significantly proceed past the transformation of TCE to DCE. Molar fractions of chlorinated ethenes along the apparent CAH plume migration pathway indicate little, if any, degradation of TCE to DCE outside the immediate source area(s). Geochemical data indicate that biodegradation of native or anthropogenic carbon is occurring via aerobic respiration and methanogenesis in the suspected source areas; but as of April 1999 nitrate-, ferric iron-, and sulfate-reduction were not considered significant degradation processes.

Description of Engineered Remediation

No engineered remediation occurred at FTA-2 prior to October 2003. During October 2003, a pilot test of enhanced anaerobic biodegradation using vegetable oil as a substrate was initiated in the source area to rapidly reduce and potentially remove the TCE/PCE residual source.

Nature of Historical Data and Current LTM Program

The scope of previous groundwater monitoring events for VOCs performed at FTA-2 from December 1993 to May 2002 is summarized in Table 4.3.

Rationale for Selection as a Case Study

FTA-2 was selected as a case study based on two criteria: 1) the lack of engineered remediation at the site prior to October 2003 and 2) a total of six wells were sampled for VOCs at least four times over a minimum time period of nearly six years.

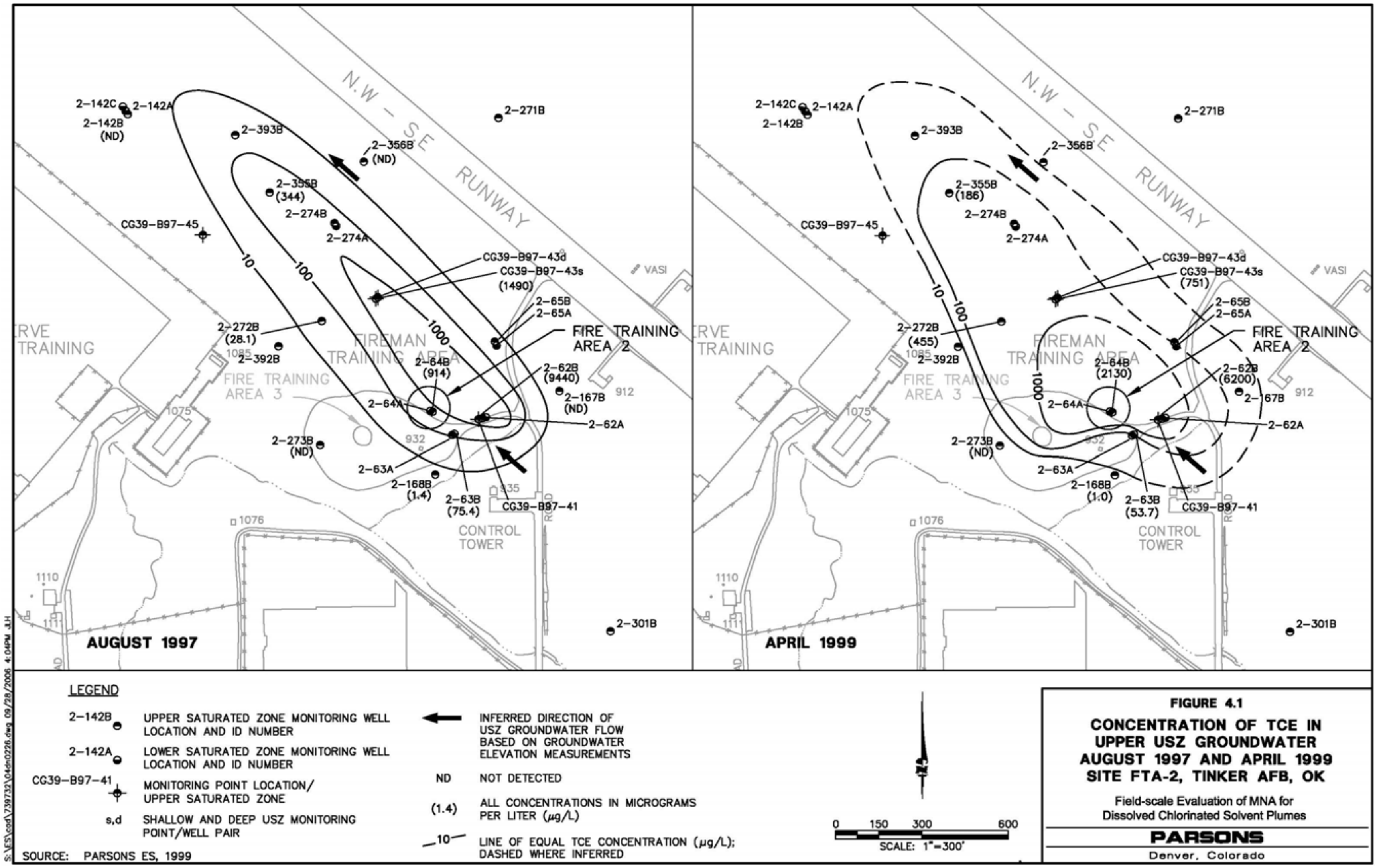


Figure 4.1 Concentration of TCE in Upper USZ Groundwater August 1997 and April 1999 Site FTA-2, Tinker AFB, Oklahoma.

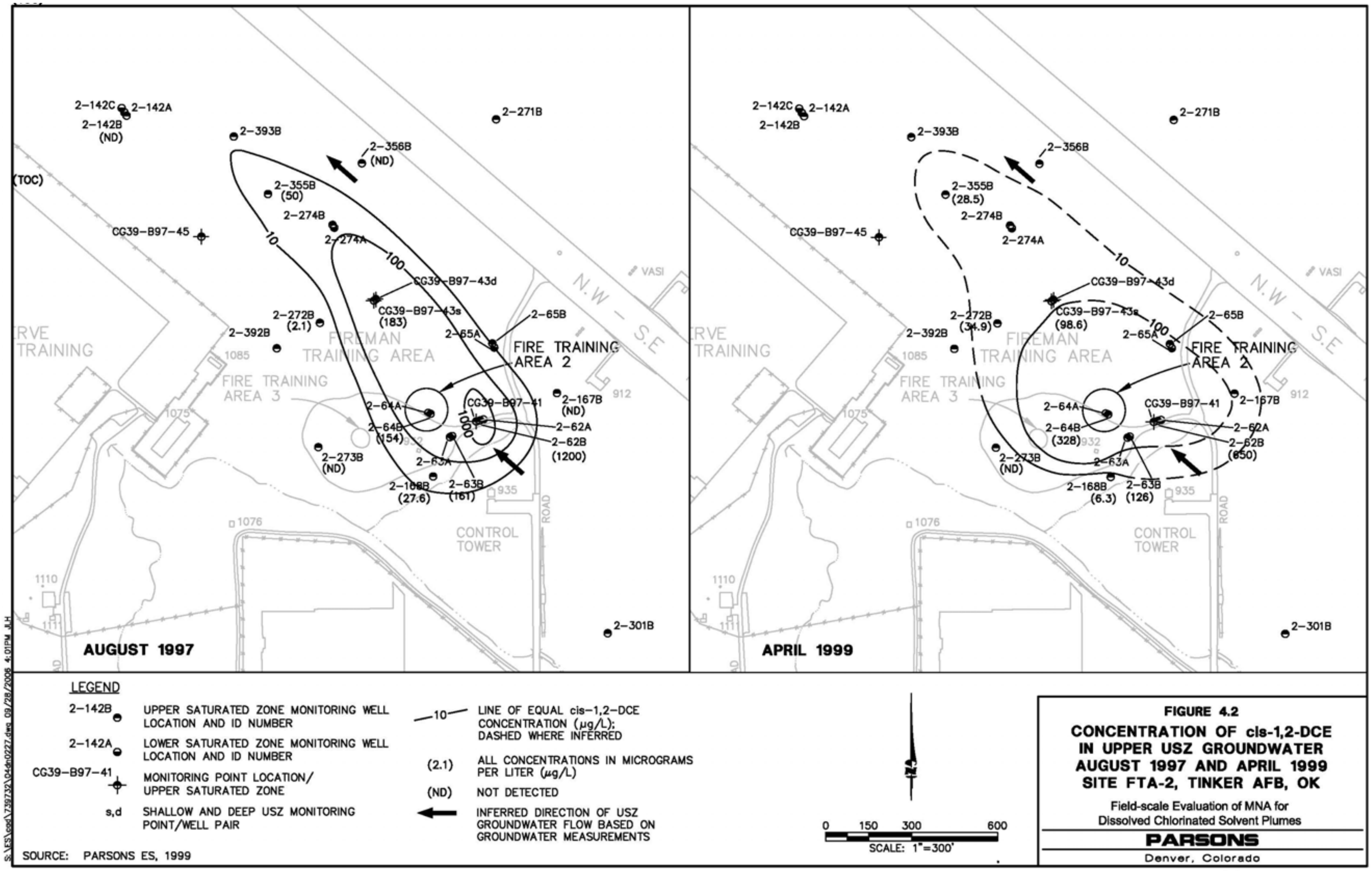


Figure 4.2 Concentration of cis-1,2-DCE in Upper USZ Groundwater August 1997 and April 1999 Site FTA-2, and Tinker AFB, Oklahoma.

Table 4.3 Summary of Groundwater Sampling for VOCs Site FTA-2, Tinker AFB, Oklahoma

Well	Completion Date	Hydrogeologic Unit	Plume Position	Used in Statistical Analyses?	Sampling Date for VOCsa/					
					Dec-93	Sep-95	Jul/Aug 96	Jul/Aug 97	Apr-99	May-02
2-62B	Nov-93	Upper Sand	Source	Yes	X	X	X	X	X	X
2-63B	Nov-93	Upper Sand	Source	Yes	X	X	X	X	X	X
2-64B	Nov-93	Upper Sand	Source	Yes	X	X	X	X	X	X
B97-41	Jul-97	Upper Sand	Source	No				X	X	
2-272B	Aug-96	Upper Sand	Plume	Yes			X	X	X	X
B97-43S	Jul-97	Upper Sand	Plume	No				X	X	X
B97-43D	Jul-97	Upper Sand	Plume	No				X	X	X
2-65B	Nov-93	Lower sand	Plume	Yes	X	X	X	X	X	
2-274B	Jul-96	Lower sand	Plume	Yes			X	X	X	X
2-355B	Jul-97	NA b/	Plume	No				X	X	X
2-393B	Jul-97	NA	Plume	No				X	X	X
2-167B	Aug-95	Upper Sand	Sentry	No			X	X		
2-168B	Aug-95	Upper Sand	Sentry	No			X	X	X	
2-392B	Unknown	Upper Sand	Sentry	No				X	X	
2-356B	Unknown	Upper Sand	Sentry	No				X		
B97-45	Jul-97	Upper Sand	Sentry	No				X		
2-142B	May-95	NA	Sentry	No		X		X		
2-273B	Jun-96	Unknown	Sentry	No				X		
2-301B	Jun-96	Upper Sand	Upgradient Sentry	No			X			X

4.1.1.2 Summary of Historic Plume Stability Assessment

Historical plume stability evaluations based on visual analysis of tabular or graphed monitoring data have focused primarily on the upper sand unit of the USZ, and have not specifically addressed potential variations in plume stability between the upper and lower sand units. The three-dimensional (3D) numerical groundwater flow and contaminant transport model described in Parsons (1999a) was used to predict future TCE plume dynamics in both the upper and lower sands. The results of historical plume stability evaluations are summarized in Table 4.4.

As indicated by the variety of temporal CAH concentration trends and plume stability-related conclusions listed in Table 4.4, the stability of the CAH plume at FTA-2 has not been determined with confidence. Decreasing concentration trends identified for downgradient wells 3-355B and 2-274B are not consistent with increasing trends identified for source area wells and for downgradient wells 2-272B and 2-274B (Figures 4.1 and 4.2). The 3D numerical model (Parsons, 1999a) predicted substantial plume expansion toward the northwest in both the upper and lower sand units of the USZ. Overall, the weight of evidence presented in Table 4.4 strongly indicates the potential for plume expansion.

4.1.1.3 Results of Current Concentration-based Stability Analysis

Concentration-based stability analysis results obtained for the current project are summarized and compared to historical stability analysis results in Table 4.5, on Figure 4.3, and in the following paragraphs. Numerical results of the linear regression and MK analyses for individual wells are provided in Appendix C. For this study, statistical testing was performed on data sets using two different methods. However, the most rigorous approach to statistical analysis is to perform data distribution testing (including possible assessment of log-transformed data) prior to selecting a statistical test. The current version of MAROS does not offer the option of selecting a statistical test based on data distribution analyis or the existence of non-detect data, but rather provides the user with both linear regression and MK statistical results. Users of MAROS will be faced with the decision of having to select from the two test results, whether or not both results are desired. It is recommended that users of MAROS evaluate data distribution at locations where the parametric and nonparametric test results conflict to evaluate which statistical test result is most appropriate. Although data distribution analysis was performed for data sets used in this study, most of the results were inconclusive; an artifact of small data sets and large numbers of non-detect values. This indicates that the non-parametric MK approach is probably an appropriate, conservative choice in many cases.

Source Area

Temporal concentration trends at three source area wells (2-62B, 2-63B, and 2-64B) screened in the upper sand unit of the USZ at FTA-2 were evaluated using linear regression and the MK test. TCE and cis-1,2-DCE are present at high concentrations relative to PCE and VC, and are the primary COCs in site groundwater. Therefore, temporal trends in the concentrations of these two CAHs were considered to be the primary indicators of current and/or future plume

Table 4.4 Results of Previous Concentration-Based Plume Stability Analyses Site FTA-2, Tinker AFB, Oklahoma

Evaluation Method	Data Used for Trend Assessment		Results of Trend Assessment	Plume Stability Conclusion	Related Conclusion(s) and Notes	Source[a/]
	Monitoring Wells	Period of Sampling				
Temporal changes in source well concentrations [b/]						
Visual inspection of graphed total chlorinated ethene data	2-62B 2-63B 2-64B	12/93 to 8/97	• Stable for 2-62B • Increasing for 2-63B and 2-64B	Probable plume expansion	• Indicates continuing contaminant source	(1)
Visual inspection of graphed total chlorinated ethene data	2-62B 2-63B 2-64B	12/93 to 4/99	• Stable for 2-62B and 2-63B • Increasing for 2-64B	Plume expanding	• Indicates continuing contaminant source	(2)
Temporal changes in plume well concentrations [c/]						
Visual inspection of graphed total chlorinated ethene data	2-65B	12/93 to 8/97	• Increasing	Potential plume expansion	--	(1)
Visual inspection of graphed total chlorinated ethene data	2-65B	12/93 to 4/99	• Increasing	Potential plume expansion	--	(2)
Visual inspection of tabular data	2-272B 2-274B	8/96 to 8/97	• Increasing	Probable plume expansion	• Insufficient data available to assess plume stability	(1)
Visual inspection of tabular data	2-272B 2-274B 2-355B 2-393B	8/97 to 4/99	• Increasing for 2-272B and 2-274B • Decreasing for 2-355B and 2-393B	Potential plume expansion near 2-272B and 2-274B; Plume may be stable or receding near 2-355B/2-393B	• Potential secondary source near 2-272B and 2-274B	(2)
Temporal changes in sentry well concentrations [d/]						
Not performed due to absence of data	--	--	--	--	• Insufficient data available to assess plume stability	--
Numerical model simulation of contaminant transport						
Visual inspection of model-generated isoconcentration contour maps	Wells listed in Table 4.2 as sampled prior to 8/97	12/93 to 8/97	Not applicable	Plume expansion predicted in both upper and lower sand units	• Model predicts downgradient migration of TCE at least 1,000 feet beyond 1997 plume toe	(1)

Table 4.5 Comparison of Historical and Current Concentration-Based Plume Stability Analyses
Site FTA-2, Tinker AFB, Oklahoma

Evaluation Method	Data Available at Time of Assessment		Results of Trend Assessment	Plume Stability Conclusion	Related Conclusion(s) and Notes	Source a/	Comparison of Historical and Current Plume Stability Conclusions
	Monitoring Wells	Period of Sampling					
Temporal changes in source well concentrations b/							
Visual inspection of graphed total chlorinated ethene data	2-62B 2-63B 2-64B	12/93 to 8/97	• Stable for 2-62B • Increasing for 2-63B and 2-64B	Probable plume expansion	• Indicates continuing contaminant source	(1)	Both historical (qualitative) and current (quantitative) trend analysis results support potential CAH plume expansion based on increasing source area concentrations in two out of three source area wells. Quantitative analysis provides statistical confidence in the accuracy of this assessment
Visual inspection of graphed total chlorinated ethene data	2-62B 2-63B 2-64B	12/93 to 4/99	• Stable for 2-62B and 2-63B • Increasing for 2-64B	Plume expanding	• Indicates continuing contaminant source	(2)	
Statistical analysis of primary COCs (i.e., TCE and DCE) using linear regression	2-62B 2-63B 2-64B	12/93 to 5/03	• 'No trend' (TCE) and 'probably decreasing' (DCE) for 2-62B • 'Increasing' for 2-63B and 2-64B	Linear regression and MK statistical analyses suggest potential plume expansion based on increasing CAH concentrations in two of three source area wells	• Indicates continuing contaminant source	Appendix C of current study	
Statistical analysis of primary COCs (i.e., TCE and DCE) using the Mann-Kendall Test	2-62B 2-63B 2-64B	12/93 to 5/03	• 'No trend' (TCE) and 'stable' (DCE) for 2-62B • 'Probably increasing' for 2-63B (TCE and DCE) and 2-64B (DCE) • 'Increasing' for 2-64B (TCE)		• Indicates continuing contaminant source	Appendix C of current study	
Temporal changes in plume well concentrations c/							
Visual inspection of graphed or tabular total chlorinated ethene data	2-65B 2-272B 2-274B	12/93 to 8/97 for 2-65B; 8/96 and 8/97 otherwise	• Increasing for 2-65B, 2-272B, and 2-274B	Potential plume expansion	• Plume stability assessment not appropriate for 2-272B and 2-274B because data set was limited to two monitoring events.	(1)	Both historical (qualitative) and current (quantitative) trend analysis results support increasing concentrations and potential CAH plume expansion near plume wells 2-65B and 2-272B. Statistical 'no trend' results for lower sand well (2-274B) outweigh previous 'increasing' trend due to use of larger data set for the current (statistical) analyses. Trend analysis suggests reduced expansion potential in lower sand relative to upper sand. Additional sampling would allow derivation of statistical conclusions for additional plume wells (e.g., 2-355B, 2-393B), thereby increasing the quantitative assessment of plume wells and confidence in plume stability evaluation.
Visual inspection of graphed or tabular total chlorinated ethene data	2-65B 2-272B 2-274B 2-355B 2-393B	12/93 to 4/99 for 2-65B; 8/97 to 4/99 otherwise	• Increasing for 2-65B, 2-272B, and 2-274B • Decreasing for 2-355B and 2-393B	Potential plume expansion near 2-272B and 2-274B; plume stable or receding near 2-355B and 2-393B	• Potential secondary source near 2-272B and 2-274B	(2)	
Statistical analysis of primary COCs (i.e., TCE and DCE) using linear regression	2-65B 2-272B 2-274B	12/93 to 5/03 for 2-65B; 8/96 to 5/03 otherwise	• 'Increasing' for 2-65B (DCE) and 2-272B (TCE and DCE) • 'No trend' for 2-65B (TCE) and 2-274B (TCE and DCE)	Linear regression and MK statistical analyses support potential plume expansion in upper sand based on 'increasing' concentration trends at 2-65B (DCE) and 2-272B (TCE and DCE); 'no trend' results for lower sand well 2-274B suggest a lack of plume expansion in that unit.	• Insufficient data available (i.e., less than four sampling events) to statistically assess plume stability for 2-355B and 2-393B	Appendix C of current study	
Statistical analysis of primary COCs (i.e., TCE and DCE) using the Mann-Kendall Test	2-65B 2-272B 2-274B	12/93 to 5/03 for 2-65B; 8/96 to 5/03 otherwise	• 'Increasing' for 2-65B (DCE) and 2-272B (TCE and DCE) • 'No trend' for 2-65B (TCE) and 2-274B (TCE and DCE)		• Insufficient data available (i.e., less than four sampling events) to statistically assess plume stability for 2-355B and 2-393B	Appendix C of current study	
Temporal changes in sentry well concentrations c/							
Not performed due to absence of data							

[a/] Sources: (1) Remediation by Natural Attenuation Treatability Study (Parsons, 1999a); 2) Remediation by Natural Attenuation Treatability Study Addendum (Parsons, 1999b).
[b/] Source wells selected based on proximity to inferred source area.
[c/] Sentry wells are located downgradient, crossgradient, above, or below the plume extents to monitor plume stability.
Notes: CAH = chlorinated aliphatic hydrocarbon; COC = contaminant of concern; TCE = trichloroethene; DCE = cis-1,2- dichloroethene.

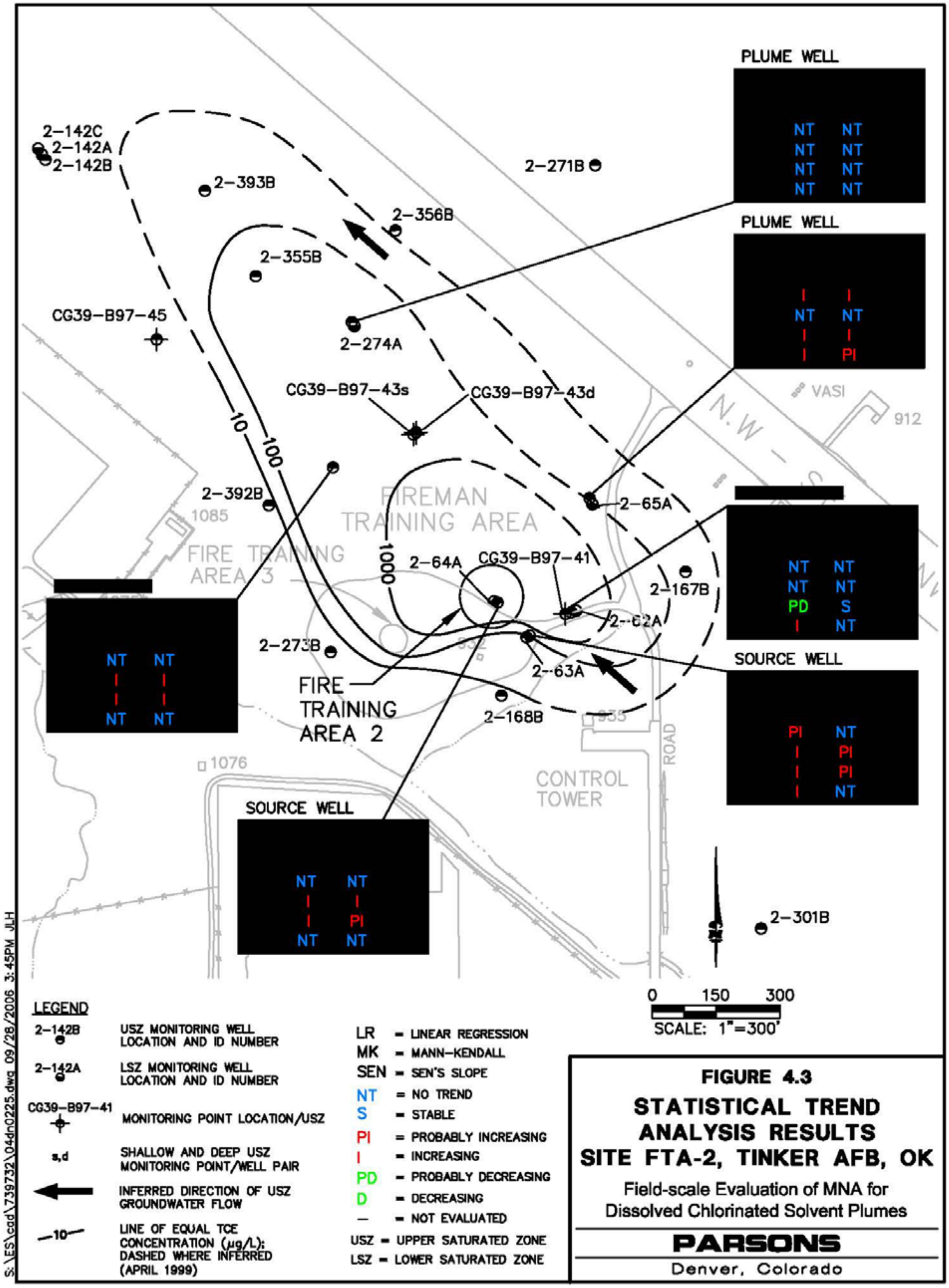


Figure 4.3 Statistical Trend Analysis Results, Site FTA-2, Tinker AFB, Oklahoma.

dynamics. Overall, the trend analysis results for source area wells indicate that the CAH mass dissolved in source area groundwater is increasing over time, suggesting the potential for plume expansion.

Except for the linear regression analysis results for cis-1,2-DCE and VC (Figure 4.3 and Appendix C), both historical (qualitative) and current (statistical) stability analyses indicate either a ‘stable’ trend or ‘no trend’ at well 2-62B. In contrast, both current and historical trend analyses indicate increasing TCE and cis-1,2-DCE concentrations over time at source area wells 2-63B and 2-64B.

The MK analysis indicates that ‘no trend’ is exhibited for PCE and VC in source wells, whereas the linear regression analysis that showed a probable increase of PCE in one well and an increase of VC in two of the wells. In general, the MK results do not indicate CAH concentration increases within the source area as consistently as the linear regression results do.

Plume Area

The ‘plume area’ is defined as the area within the dissolved CAH plume but outside of the primary source area. Temporal trends in dissolved CAH concentrations were previously determined in a qualitative manner for four downgradient wells (2-272B [upper sand], 2-274B [lower sand], 2-355B, and 2-393B) and one crossgradient well screened in the lower sand (2-65B) (Table 4.5). Only two of the four downgradient wells (2-272B and 2-274B) had sufficient data to perform statistical trend analyses. These wells are termed ‘downgradient’ in the sense that they are located northwest of the primary source area, which is in the apparent direction of contaminant transport. While it was noted that concentrations of TCE and cis-1,2-DCE have steadily decreased at both 2-355B and 2-393B in measurements from 1997 to 2002, the absence of a fourth monitoring point disqualified these two data points from statistical analysis at this time. Nevertheless, the observation of steadily decreasing concentrations in these two wells does provide evidence that the plume is not expanding in the northwest direction. Also note that monitoring wells 2-355B and 2-393B were not assigned to either the upper or lower sand units on Table 4.3 because it appears that the upper and lower sands form a single hydraulically connected unit because the silt/clay aquitard separating the two units is absent or very intermittent in the vicinity of these wells.

As shown on Figure 4.3, well 2-274B, located along the inferred longitudinal axis of the CAH plume approximately half-way between the primary source area and the downgradient plume toe, did not exhibit a statistical trend for any of the four CAHs evaluated. This finding differs from Parsons (1999b), where an increasing trend for concentrations of TCE and cis-1,2-DCE in this well was identified based on comparison of concentrations measured in 1997 and 1999. In this case, the ‘no trend’ determination is considered to be more valid given that it is based on a larger data set that encompasses a longer time period. It should be noted that well 2-274B has a relatively short screen length (5 feet) compared to the thickness of the USZ at that location (approximately 30 feet). Therefore, it is conceivable that water quality data for this well may not be fully representative of contaminant trends in the USZ, and analysis of these data should not be interpreted to be a definitive indicator of a lack of plume expansion to the northwest.

Both the linear regression and MK analyses determined the presence of an ‘increasing’ trend for TCE and DCE concentrations at downgradient well 2-272B. This determination is consistent with historical, qualitative trend analysis results for this well, which also identified increasing CAH concentrations, and is a further indication that the CAH plume is expanding. However, this well is located crossgradient to the inferred longitudinal axis of the CAH plume, as shown on Figures 4.1 and 4.2, and future trend analyses should also include wells CG39-B97-43S/43D, screened in the upper and lower sand units of the USZ, respectively. There were insufficient data for these two wells to perform statistical trend analyses for the current project.

Both the linear regression and MK analyses determined the presence of an ‘increasing’ trend for PCE, DCE, and VC at crossgradient well 2-65B. This determination is consistent with historical, qualitative trend analysis results for this well, which also identified increasing CAH concentrations. Parsons (1999b) interpreted increasing CAH concentrations at 2-65B to be indicative of both a secondary contaminant source and plume expansion in the vicinity of this well.

Plume Exterior

CAH concentrations detected in groundwater samples from sentry wells were not statistically evaluated as part of the current study due to a lack of sufficient historical sampling data. For the purposes of this report, ‘sentry’ wells are defined as wells located upgradient, crossgradient, or downgradient from the plume that can be used to monitor plume stability. Periodic sampling of sentry wells is critical to an evaluation of plume stability; therefore, selected sentry wells (especially well 2-393B, Figure 4.3) should be included in the LTM program for this site.

Summary

The results of the MK and linear regression analyses for FTA-2 are summarized for comparative purposes in Table 4.6. Although both sets of results indicate the presence of ‘increasing’ concentration trends and suggest the potential for plume expansion, the MK results do not indicate these trends as strongly as the linear regression results do.

Table 4.6 Summary of Linear Regression and Mann-Kendall Results
Site FTA-2, Tinker AFB, Oklahoma

Statistical Analysis Method	Number of Instances Exhibiting the Indicated Trend					
	Decreasing	Probably Decreasing	Stable	No Trend	Probably Increasing	Increasing
Linear Regression	0	1	0	11	1	11
MK	0	0	1	14	4	5

4.1.1.4 Results of Current Mass-based Stability Analysis

Figure 4.4 shows the monitoring wells, model domain hull, and Theissen polygons used in the mass-based stability analyses for FTA-2. The monitoring wells used for the mass-based analyses were chosen by reviewing the groundwater sampling history for VOCs summarized in Table 4.3 and selecting the time periods that had the largest number of wells sampled in common. As indicated on Figure 4.4, the ‘common well set’ for FTA-2 consisted of eight wells in the upper sand of the USZ. As indicated on Table 4.3, all eight of these wells were sampled during three monitoring events that spanned over six years (i.e., 1997, 1999, and 2002).

Dissolved CAH Mass

Figure 4.5 plots the CAH mass (by individual species and total CAH, as TCE) over time for each of the three sampling events and by analysis method (i.e., Theissen polygon or TIN kriging). The results of visual inspection of Figure 4.5 for trends in CAH mass over time suggests that both the total CAH mass and the CAH mass distribution between compounds has remained relatively constant over time. As can be observed on this data plot, the majority of dissolved CAH mass at FTA-2 is found as TCE, with most of the remaining mass present as cis-1,2-DCE. Table 4.7 lists the CAH mass by percentage of the total contaminant mass. As indicated on this table, TCE consistently comprised 85 to 86 percent of the total CAH mass, with cis-1,2-DCE making up most of the remaining 14 to 15 percent. Also note that, while the Kriging method generally resulted in slightly higher mass estimates than the Theissen method, the method of analysis did not appear to affect the assessment of mass trends over time or the percentage that each CAH species contributed to the CAH mass.

In terms of plume stability assessment, the observation of a relatively constant CAH mass, in terms of both total mass and mass distribution, suggests that the CAH plumes at this site have reached a steady state of balance between TCE dissolution to groundwater and the NA mechanisms impact CAH fate and transport. The observation that the majority of CAH mass has remained as TCE suggests that the CAH source has remained constant over time, and suggests that the overall size of the CAH plume is not likely to recede in the next decade. Because the estimated CAH mass does not appear to have changed significantly over the six years of monitoring, and there currently are only three monitoring events for which CAH mass was calculated, it is not possible to develop a reliable estimate of when CAH mass may start to decline.

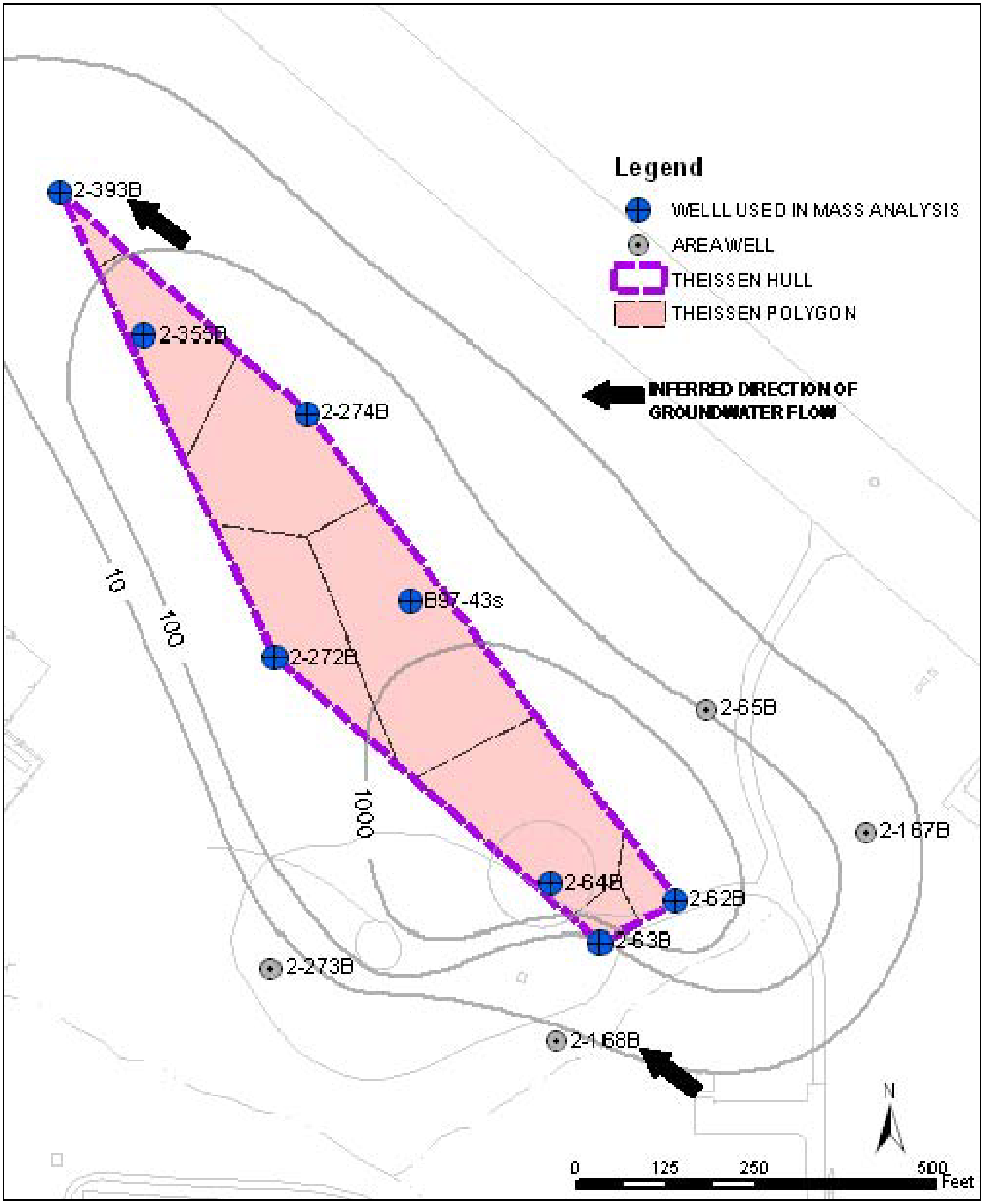


Figure 4.4 Model Domain and Common Wells for Mass-Based Calculations
Site FTA-2, Tinker AFB, Oklahoma

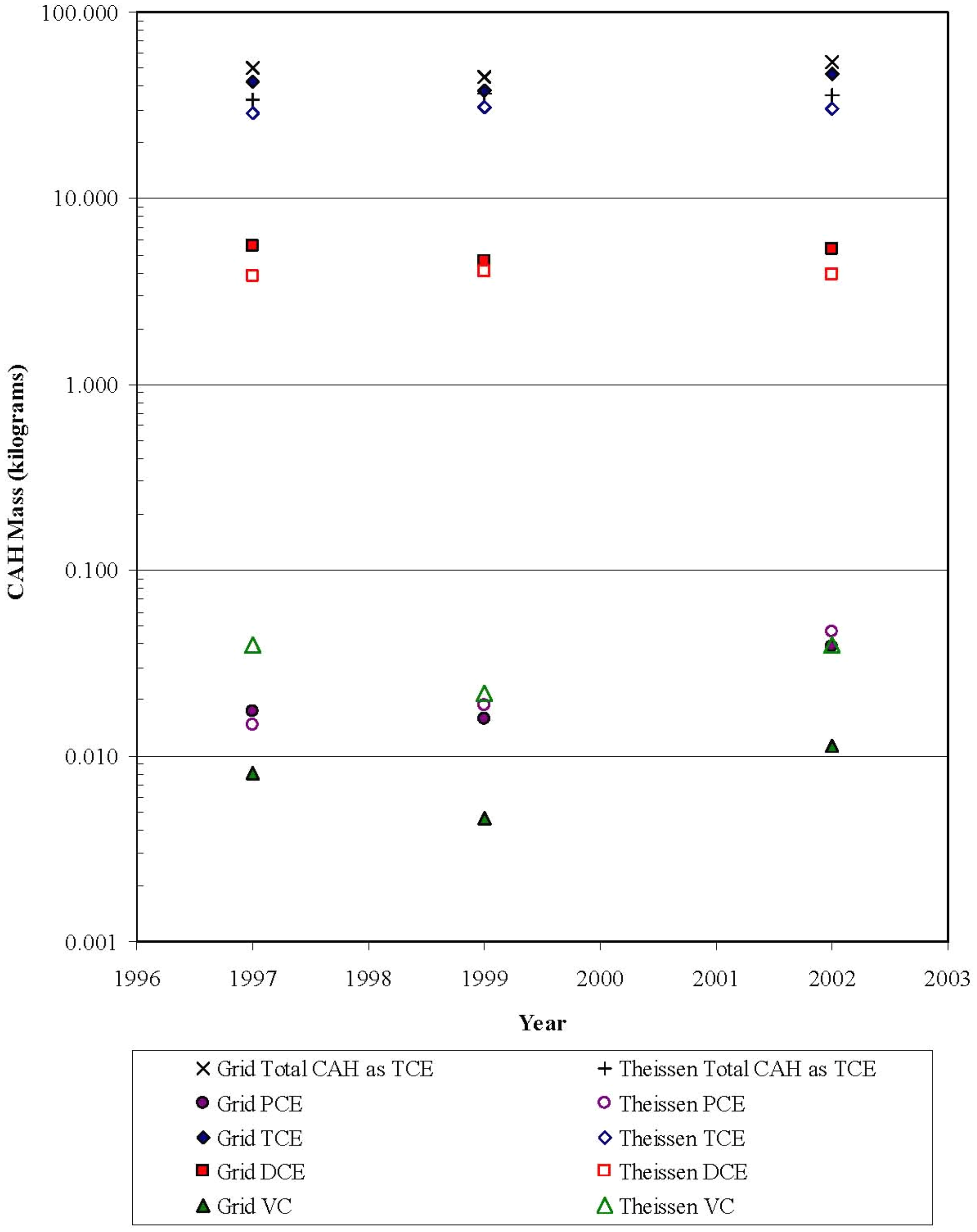


Figure 4.5 Estimated Dissolved Mass of CAH Compounds Site FTA-2, Tinker AFB, Oklahoma

Table 4.7 Summary of CAH Distribution by Mass Percentage Site FTA-2, Tinker AFB, Oklahoma

Sampling Date	PCE		TCE		DCE		VC	
	Kriging	Theissen	Kriging	Theissen	Kriging	Theissen	Kriging	Theissen
Jul/Aug 1997	0.03%	0.03%	84.9%	84.4%	15.0%	15.3%	0.03%	0.24%
Apr 1999	0.03%	0.04%	86.0%	84.7%	14.0%	15.1%	0.02%	0.13%
May 2002	0.06%	0.10%	86.4%	85.0%	13.5%	14.7%	0.04%	0.23%

Center of Dissolved CAH Mass

Figure 4.6 plots the location of the center of dissolved TCE mass over time for each of the three sampling events and by analysis method (i.e., Theissen polygon or TIN kriging) on a site base map. For both methods, the center of mass for the TCE plume was calculated to be in a relatively constant location between the source area wells and the nearest downgradient wells. The location of the center of mass for TCE calculated using the Theissen method appears to be slowly receding back toward the source area, while the location of the TCE center of mass calculated using the Kriging method has been relatively constant over time. In terms of plume stability assessment, a stationary to slightly receding center of TCE mass suggests that the overall TCE plume is generally stable, and that the rate of TCE dissolution from the source area may be roughly equivalent to the TCE attenuation rate across the dissolved CAH plume.

Summary

The results of the mass based assessment of plume stability for CAHs at FTA-2 suggest that the CAH plume at this site is generally at steady state for the monitoring period between July 1997 and May 2002. The observation that both the total dissolved CAH mass and the percentage of this mass that is found as TCE has remained relatively constant over time suggests that TCE is continuing to be released to groundwater, but also that the rate of NA appears to currently be in balance with the rate of TCE release to groundwater. The observation that the location of the center of mass for the dissolved TCE plume has not moved appreciably over time also suggests that the CAH plume is currently at steady state.

Because sufficient data to perform CAH mass calculation was available from only three of the six monitoring events performed at this site through May 2002, a statistical analysis for trends in CAH mass over time was not performed. Two tangible benefits of performing this statistical analysis would be to 1) statistically demonstrate that the dissolved CAH mass is increasing, decreasing, or stable over time and 2) predict when CAH mass would reach a specified threshold value if linear regression predicted a decreasing CAH mass trend over time. The data required to allow performance of this statistical analyses is sampling of all eight ‘common’ wells shown on Figure 4.4 on a periodic basis during future monitoring events. An initial recommendation on the frequency for sampling all eight common wells would be every 2 to 3 years to support periodic evaluation of the statistical change in CAH mass and center of mass location over time.

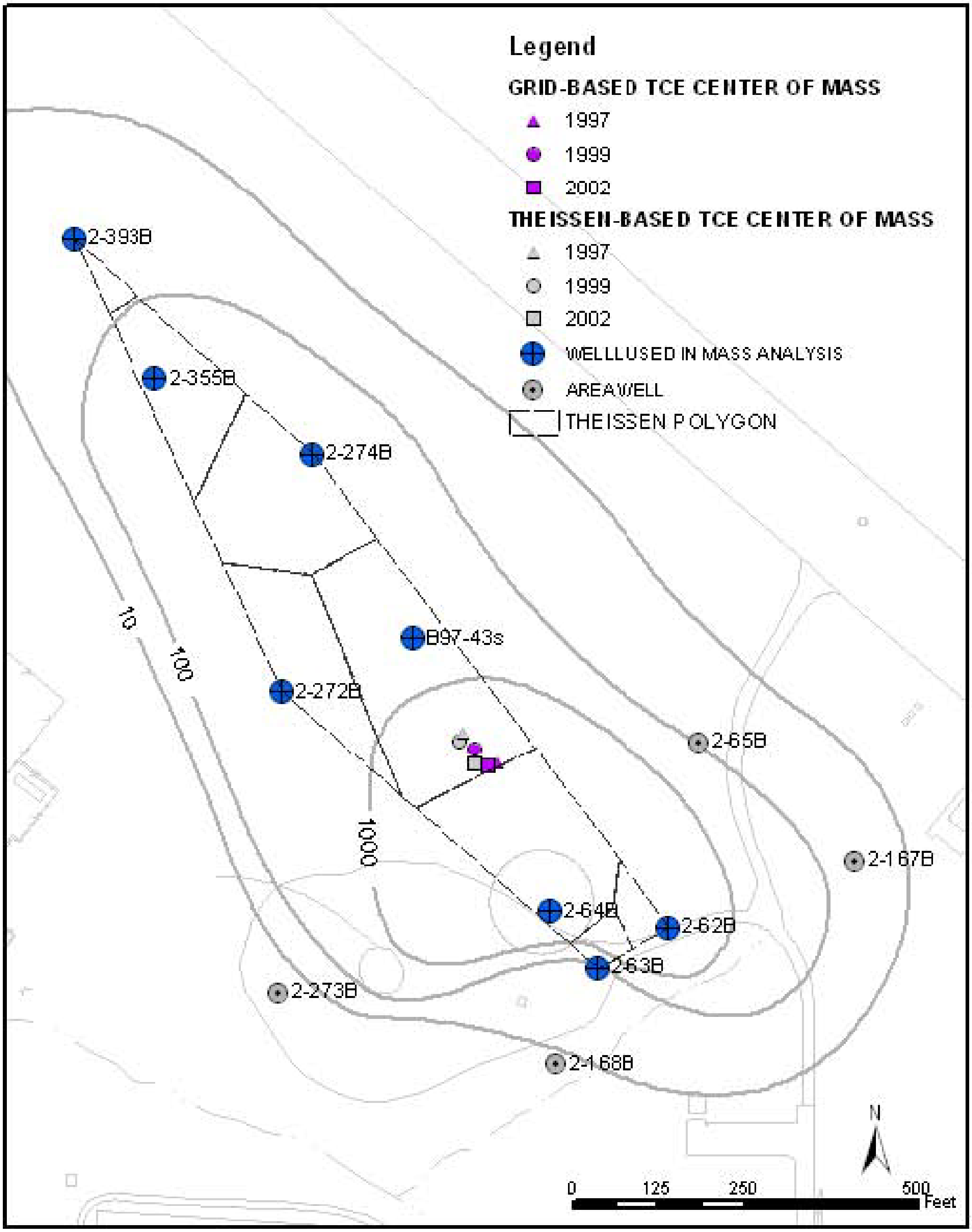


Figure 4.6 Location of Center of Mass for TCE
Site FTA-2, Tinker AFB, Oklahoma

4.1.1.5 Plume Stability Analysis Summary

Both historical and current trend concentration-based analyses indicate current plume expansion in the upper sand unit, and/or the potential for future expansion. In this case, performance of statistical trend analyses did not alter the plume stability assessment relative to the more qualitative analyses performed in the past. The results of mass-based analyses suggest that the CAH plumes at this site are currently stable, but that the potential for plume expansion exists because the CAH mass has remained constant over time, and that the majority of this CAH mass is found as TCE. It is important to note, however, that the relatively short monitoring period and limited number of wells that have been consistently monitored introduces significant uncertainty into the current trend analyses.

4.1.1.6 Recommendations

As the length of the monitoring period and the number of data points for a given well increase, performance of statistical analyses will facilitate obtaining more definitive trend analysis results and increase the confidence in plume stability-related conclusions, especially in cases where temporal changes in monitoring well concentration or CAH mass are not obvious from visual inspection of data trend plots. The lack of sufficient historical data for wells located along the inferred longitudinal axis of the CAH plume, and especially plume toe wells, limits the scope and usefulness of concentration-based trend analyses. While available data for these wells should be assessed using visual/graphical techniques to supplement the statistical analysis results, it is recommended that future monitoring to support concentration-based plume stability analyses focus on wells in the source area and to the northwest along the inferred longitudinal axis of the CAH plume migration. In addition, sampling of well 2-392B (Figure 4.3) should be performed given the identified increases in TCE and DCE concentrations in nearby well 2-272B to determine whether the plume is expanding toward the west. The data required to support future statistical analyses of CAH plume mass can be gathered by sampling of all eight ‘common’ wells shown on Figure 4.4 on a periodic basis during future monitoring events. With this data in hand at a future date, it would be possible to revise the current plume stability evaluation with more statistical certainty.

Note that the October 2003 source reduction pilot test may alter CAH concentrations in one or more monitoring wells used in the current study. Any impacts of this pilot test on monitoring wells used in the current study should be considered and accounted for during future analyses. For example, the expected reduction in TCE source mass is expected to result in decreasing TCE concentrations in both source area and downgradient plume area monitoring wells. However, concentrations of cis-1,2-DCE may be observed to temporarily increase in source area and plume wells if the rate of enhanced TCE degradation is greater than the rate of enhanced cis-1,2-DCE degradation. Finally, the historic measurement of low VC concentrations at the site suggests that VC accumulation will not be a major concern at this site, and concentrations are not likely to increase in downgradient plume area monitoring wells.

4.1.2 Case Study: LF-06, Columbus Air Force Base, Mississippi

4.1.2.1 Site Overview and Summary of Available Data

Site Description

Site Landfill 06 (LF-06) is located directly south of the main runway and near the main gate at the southeastern corner of Columbus AFB, Columbus, Mississippi. The landfill was operated as a disposal area for sanitary trash, ferrous metal debris, and concrete debris from 1964 to 1974. North-south trenches, 8 to 10 feet in depth, were used for trash disposal. Initial trenches were created on the western side of the landfill and subsequent filling occurred in an easterly direction. No trenches were excavated on the east side of the landfill due to a near-surface water table. LF-06 was identified as a contaminated site in 1985. Soil and groundwater samples were first collected within the landfill in April 1988 and at the nearby Base boundary in May 1989.

Hydrogeologic conditions at LF-06 include hydraulic conductivity estimated conservatively at 100 ft/day. The horizontal hydraulic gradient ranged between 0.0013 and 0.059 ft/ft, generally toward the west with a northwest component in the southern-most part of the site. Average groundwater seepage velocity was estimated to be about 185 ft/yr (Parsons, 2001a).

Plume Description

Per the Supplemental Feasibility Study Evaluation (Parsons, 2001b), generally low concentrations of volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and metals have been detected in site groundwater since 1988. VOCs detected have included benzene, toluene, ethylbenzene, and xylenes (BTEX); trimethylbenzenes; chlorobenzenes; TCE; 1,2-DCE; VC; 1,1-dichloroethane (1,1-DCA); and 1,1,1-trichloroethane (1,1,1-TCA). Of these, benzene, VC, TCE, and chlorobenzene have been detected at concentrations exceeding their respective federal MCLs (Parsons, 2001b). As of the 2001 sampling event however, only TCE and VC exceeded regulatory standards in groundwater (Columbus AFB, 2001). Historically, the 5-micrograms per liter (µg/L) MCL for TCE has been exceeded almost exclusively at well W21; the maximum TCE concentration detected in 2000 to 2002 was 16 µg/L in December 2001. In contrast, the 2-µg/L MCL for VC has been exceeded at several locations. The maximum VC concentration detected in 2000 to 2002 was 10 µg/L in December 2001.

The statistical plume stability analysis performed for this project focused on TCE, cis-1,2-DCE, and VC. The TCE, cis-1,2-DCE, and VC plumes, as defined by groundwater quality data collected from 1995 to 1997, are shown on Figures 4.7 (TCE and DCE) and 4.8 (VC). The leading edges of the CAH plumes extend in a westerly to southwesterly direction from the landfill boundary. In 1997, the dissolved VC plume had migrated the farthest distance from the landfill and was present at concentrations that exceed the MCL of 2 µg/L (Parsons, 1997a). There is no evidence that CAHs have discharged from groundwater into the drainage ditch in the southern portion of the site (Parsons, 2001a).

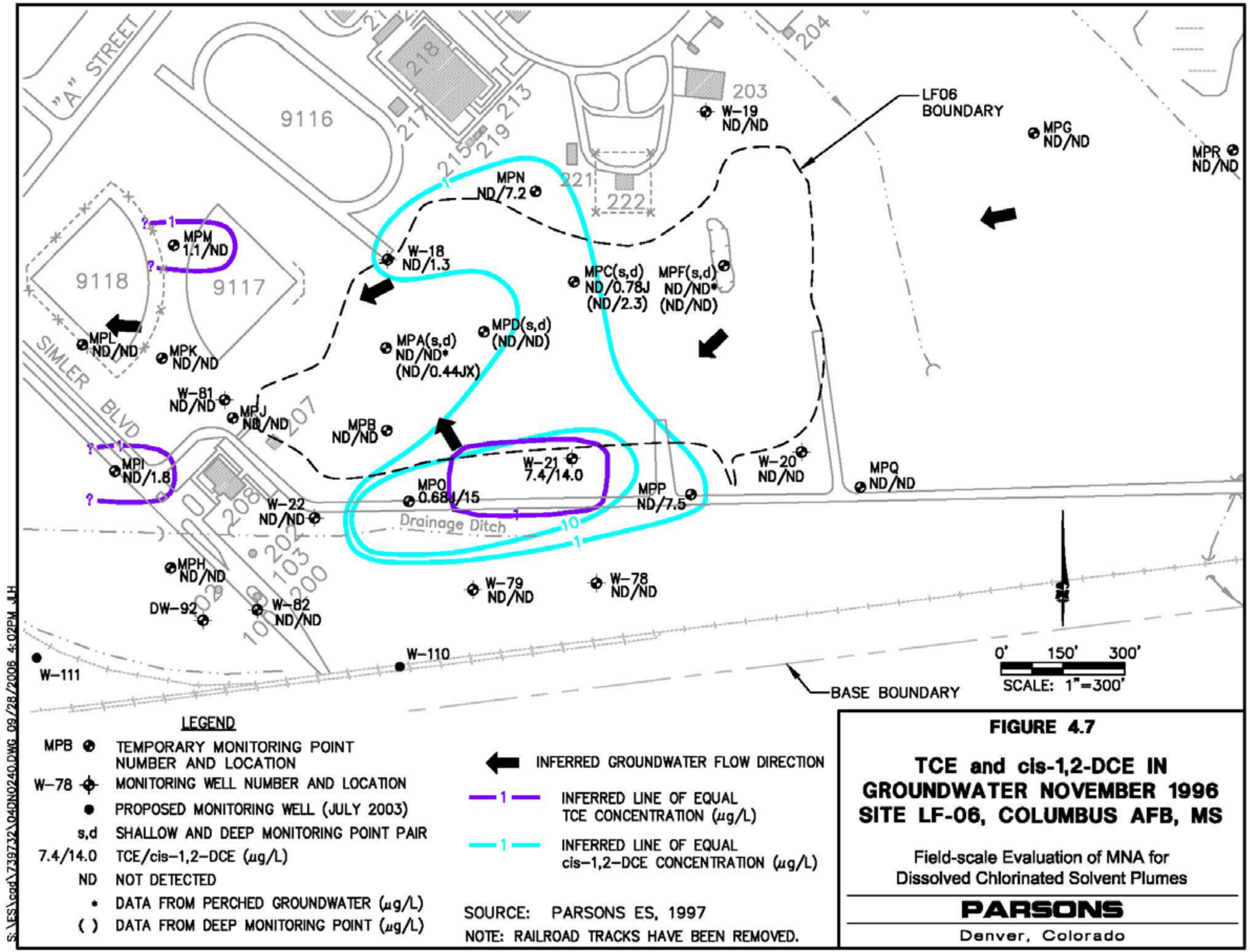


Figure 4.7 TCE and cis-1,2-DCE in Groundwater November 1996, Site LF-06, Columbus AFB, Mississippi

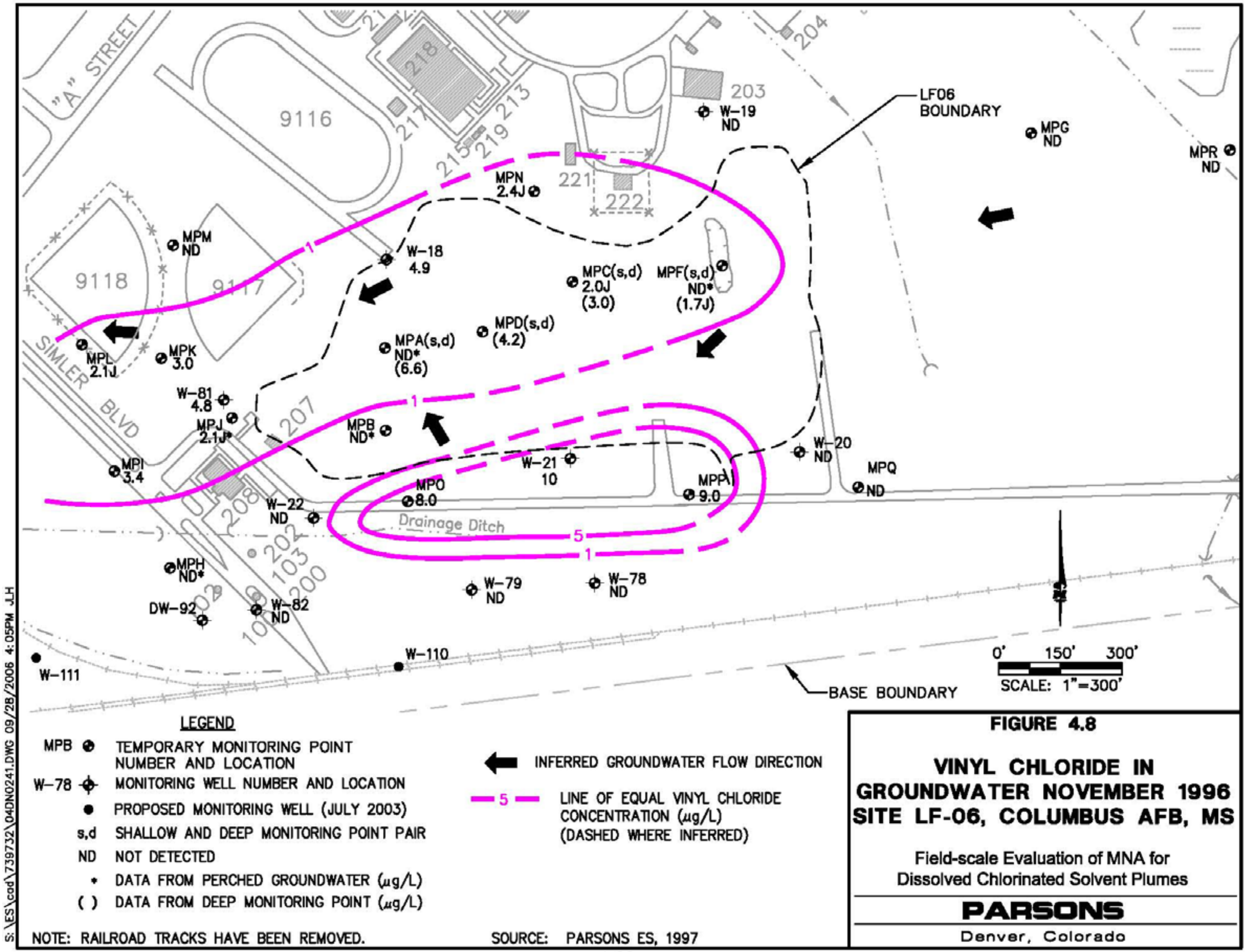


Figure 4.8 Vinyl Chloride in Groundwater November 1996, Site LF-06, Columbus AFB, Mississippi.

Table 4.8 Summary of Groundwater Sampling for VOCs Site LF-06, Columbus AFB, Mississippi

Well	Completion Date	Hydrogeologic Unit	Relative Depth in Surficial Aquifer[a]	Plume Position	Used in Statistical Analyses?	Sampling Date for VOCs[b]																			
						Apr-88	Jul-88	Dec-88	May-89	Nov-91	Nov-94	Sep-95	Aug-96	Nov-96	Apr-97	Dec-97	Mar-98	Sep-98	Apr-99	Jun-00	Dec-00	May/Jun-01	Dec-01	May-02	Nov-02
W21	Feb-88	Surfical aquifer	intermediate	Source	Yes	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MPO	Nov-96	Surfical aquifer	shallow	Plume	No									X											
MPA(S)	Nov-96	Surfical aquifer	shallow	Plume	No									X											
MPC(S)	Nov-96	Surfical aquifer	shallow	Plume	No									X											
MPF(S)	Nov-96	Surfical aquifer	shallow	Plume	No									X											
MPJ	Nov-96	Surfical aquifer	shallow	Plume	No									X											
MPK	Nov-96	Surfical aquifer	shallow	Plume	No									X											
MPL	Nov-96	Surfical aquifer	shallow	Plume	No									X											
MPN	Nov-96	Surfical aquifer	shallow	Plume	No									X											
MPP	Nov-96	Surfical aquifer	shallow	Plume	No									X											
W18	Feb-88	Surfical aquifer	shallow	Plume	Yes								X	X	X	X	X	X	X	X	X	X	X	X	X
W22	Mar-88	Surfical aquifer	shallow	Plume	Yes								X	X	X	X	X	X	X	X	X	X	X	X	X
W81	Nov-94	Surfical aquifer	shallow	Plume	Yes						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MPC(D)	Nov-96	Surfical aquifer	intermediate	Plume	No									X											
MPD(D)	Nov-96	Surfical aquifer	intermediate	Plume	No									X											
MPI	Nov-96	Surfical aquifer	intermediate	Plume	No									X											
MPA(D)	Nov-96	Surfical aquifer	deep	Plume	No									X											
MPF(D)	Nov-96	Surfical aquifer	deep	Plume	No									X											
MPB	Nov-96	Surfical aquifer	shallow	Sentry	No									X											
MPG	Nov-96	Surfical aquifer	shallow	Sentry	No									X											
MPH	Nov-96	Surfical aquifer	shallow	Sentry	No									X											
MPM	Nov-96	Surfical aquifer	shallow	Sentry	No									X											
MPQ	Nov-96	Surfical aquifer	shallow	Sentry	No									X											
W19	Mar-88	Surfical aquifer	shallow	Sentry	No									X											
W20	Mar-88	Surfical aquifer	shallow	Sentry	Yes	X	X		X		X	X		X											
W78	May-89	Surfical aquifer	shallow	Sentry	Yes									X								X	X	X	X
W79	May-89	Surfical aquifer	shallow	Sentry	Yes									X								X	X	X	X
W82	Nov-94	Surfical aquifer	shallow	Sentry	Yes									X								X	X	X	X
MPR	Nov-96	Surfical aquifer	intermediate	Sentry	No									X											
DW92	Unknown	Confined aquifer	deep	Sentry	Yes																	X	X	X	X

[a] shallow = screened mostly within 10 feet of water table; intermediate = screened mostly between 10 and 20 feet below water table; deep = screened mostly > 20 feet below water table.

[b] VOCs = volatile organic compounds.

Specific source areas for the contaminants detected in site groundwater have not been identified within the overlying soils or landfill deposits. It has been assumed that the dissolved VOCs originated from waste petroleum fuels and solvents disposed of at the landfill. Fuel-related compounds and chlorinated benzenes were detected in soil samples collected from monitoring point MPF in 1996. Two additional possible source areas for CAH contamination were inferred based on dissolved CAH concentrations, one near monitoring point MPN and one near well W21, along the southern boundary of the site (Figures 4.7 and 4.8; Parsons, 1997a).

Description of Engineered Remediation

No engineered remediation has occurred at site LF-06 at Columbus AFB.

Nature of Historical Data and Current LTM Program

The scope of previous groundwater monitoring events for VOCs performed at Site LF-06 from April 1988 to November 2002 is summarized in Table 4.8. As shown in this table, the temporary monitoring points installed within the landfill (MP-series monitoring points shown on Figures 4.7 and 4.8) were sampled once in 1996 following their installation, but have not been sampled since then. They have not been maintained, and only approximately 50 percent of these monitoring points could be located during a 2002 site visit. Columbus AFB currently conducts semi-annual groundwater monitoring of permanent monitoring wells installed around the perimeter of LF-06 and along the nearby Base boundary for VOCs, SVOCs, and Resource Conservation and Recovery Act (RCRA) metals. A Long-term Monitoring Optimization Plan was prepared in July 2003 (CH2M Hill, 2003); the plan proposes semiannual sampling of 10 wells, all of which are located around the perimeter of, or hydraulically downgradient from, the landfill.

Rationale for Selection as a Case Study

Columbus AFB LF-06 was selected as a case study because: 1) no engineered remedial activities have occurred at the site since the original MNA treatability study was completed in 1997, and 2) a total of 15 wells were sampled for VOCs at least four times over a time period ranging from 1.5 to 4.5 years.

4.1.2.2 <u>Summary of Historic Plume Stability Assessments</u>

The results of historical plume stability evaluations are summarized in Table 4.9. These evaluations generally indicated that the CAH plume at the time that the evaluations were performed were stable or diminishing. However, as described in Table 4.8, the analytical modeling results for VC reported by Parsons (1997a) could also be interpreted to indicate the potential for expansion of the VC plume in the southern portion of the site.

The Remediation by Natural Attenuation Treatability Study for LF-06 (Parsons, 1997a) presented the following conclusions related to CAH plume stability:

Table 4.9 Results of Previous Concentration-Based Plume Stability Analyses
Site LF-06, Columbus AFB, Mississippi

Evaluation Method	Data Used for Trend Assessment		Reported Results of Trend Assessment	Reported Plume Stability Conclusion	Related Conclusion(s) and Notes	Source[a/]
	Monitoring Wells	Period of Sampling				
Temporal changes in source well concentrations[b/]						
Visual inspection of tabular data and data plotted on a site map	Multiple Site Wells	3/88 to 11/96	Concentrations have fluctuated over time with no clear overall trend apparent (i.e., some increase, some decrease, some are relatively constant)	Plume stable	Temporal trends in source area wells were not specifically assessed. However, an overall trend conclusion for site groundwater in general was presented	(1)
Statistical analysis of primary COCs (i.e., TCE and VC) using the Mann-Kendall Test	W-21	4/88 to 9/98	'Decreasing' trends for both TCE and VC	Plume stable to receding	--	(2)
Statistical analysis of TCE and VC using linear regression and Mann-Kendall test	W-21	9/95 to 12/00	'Decreasing' trends for both TCE and VC using both tests	Not addressed	--	(3)
Examination of time-series plots for TCE and VC	W-21	9/96 to 11/02	'Decreasing' trends for TCE and VC	Not addressed, although the inference is that the CAH plume is stable to diminishing	Best-fit trend lines were not fit to graphed data	(4)
Temporal changes in plume well concentrations[c/]						
Visual inspection of tabular data and data plotted on a site map	Multiple Site Wells	3/88 to 11/96	Concentrations have fluctuated over time with no clear overall trend apparent (i.e., some increase, some decrease, some are relatively constant)	Plume stable	Temporal trends in plume wells were not specifically assessed. However, an overall trend conclusion for site groundwater in general was presented	(1)

Table 4.9 Results of Previous Concentration-Based Plume Stability Analyses (continued)
Site LF-06, Columbus AFB, Mississippi

Evaluation Method	Data Used for Trend Assessment		Reported Results of Trend Assessment	Reported Plume Stability Conclusion	Related Conclusion(s) and Notes	Source[a]
	Monitoring Wells	**Period of Sampling**				
Statistical analysis of TCE and VC using linear regression and Mann-Kendall test	W-18, W-22, W-81	9/95 to 12/00	TCE concentrations are 'decreasing' at W-18 and W-81 and 'increasing' at W-22. VC is 'decreasing' at W-21, 'stable' (Mann-Kendall) to 'decreasing' (linear regression) at W-81, and 'increasing' slightly at W-18.	Not addressed	Except for VC at W-81, results of Mann-Kendall and linear regression analyses indicated similar trends	(3)
Temporal changes in sentry well concentrations[d]						
Analysis not performed	--	--	--	--	Limited sentry well data were available, but not specifically evaluated in sources (1), (2), (3), or (4)	--
Numerical model simulation of contaminant transport						
Qualitative discussion of analytical model results	MPN, W-18, and MPK used for contaminant decay rate calculation; W21 used for source area concentrations	11/96	Not Applicable	Plume at or near steady-state equilibrium	The conclusion derived from the model results and presented in sources (1) and (2) was that the plume was stable or nearly stable. However, source (1) states that the VC model predicted that VC concentrations could exceed the state groundwater standard of 2 µg/L for approximately 1,000 feet downgradient from the point source well W21. The observed VC plume actually had migrated approximately 500 feet downgradient from W21, suggesting the potential for additional expansion. This possibility was not discussed in either site report.	(1) and (2)

[a] Sources: (1) Treatability Study in Support of Remediation by Natural Attenuation (Parsons, 1997a)

(2) Feasibility Study (Parsons, 2001a)

(3) Supplemental Feasibility Study (Parsons, 2001b)

(4) *Long-Term Monitoring Optimization Technical Memorandum* (CH2M Hill, 2003)

[b] Source well selected based on proximity to inferred source area.

[c] Plume wells are located within the CAH plume but outside of the inferred source area.

[d] Sentry wells may be located downgradient, crossgradient, above, or below the current plume extents to monitor plume stability.

Notes: COC = contaminant of concern; TCE = trichloroethene; VC = vinyl chloride.

Table 4.9 Results of Previous Concentration-Based Plume Stability Analyses (continued)
Site LF-06, Columbus AFB, Mississippi

- CAH biodegradation is occurring, and the relatively stable magnitude of dissolved contaminant concentrations suggests that the CAH plume is stable.

- Conservative analytical model results suggest that the CAH plume will remain stable, even if the source levels persist that produced the highest observed concentrations for each of the modeled contaminants. During the modeling effort, steady-state contaminant plume lengths were predicted assuming that contaminant concentrations exceeding state groundwater standards would persist in the source area throughout time.

- CAH concentrations in source area groundwater beneath the landfill are relatively low, limiting the expansion potential of the CAH plume.

It should be noted that the analytical model for VC predicted that VC concentrations would exceed the state groundwater standard of 2 μg/L for approximately 1,000 feet downgradient from the simulated point source at well W-21. In contrast, the observed VC plume had migrated approximately 500 feet downgradient from W-21 as of 1996, when the modeling was performed. This information suggests the potential for expansion of the VC plume to the west; however, it contradicts a statement made elsewhere in the treatability study report, namely that the modeling results suggest that the contaminant plumes will remain stable.

The plume stability conclusions derived from the analytical modeling effort summarized above and in Table 4.8 were reiterated in the FS (Parsons, 2001a). The FS also noted that the model results indicate that the dissolved VOC plumes will not advance more than approximately 100 feet beyond the observed 1996 downgradient extent, suggesting that they were at or near steady-state equilibrium. The Supplemental FS (Parsons, 2001b) observed that natural infiltration and surface water recharge promote aerobic groundwater conditions that facilitate continued biodegradation of less-chlorinated VOCs such as VC. Temporal concentration plots for TCE and/or VC in four site wells were constructed, and an exponential linear regression (first-order) trend line was fit to the data for each well (See Appendix D for these figures). Temporal trends for TCE were decreasing in wells W-18 and W-21 and increasing in W-22. Trends for VC were decreasing in wells W-21, W-22, and W-81, and a very slight increasing trend was observed for W-18.

The Long-Term Monitoring Optimization (LTMO) Technical Memorandum prepared by CH2M Hill (2003) depicted time-series plots of TCE and VC using data collected during 12 sampling events performed from September 1996 to November 2002. Linear regression analyses were not performed, nor were best-fit trend lines fit to the data. Based on visual examination of these plots, CH2M Hill observed that concentrations of TCE at monitoring well W-21 (the only well containing TCE concentrations above the MCL) are decreasing. In addition, it was observed that the number of wells where VC was detected above the MDEQ standard of 2 μg/L decreased from four in December 2001 to one (W-18) in November 2002. Therefore, the overall concentration trend for VC at LF-06 was considered to be decreasing.

4.1.2.3 Results of Current Concentration-based Stability Analysis

Concentration-based stability analysis results obtained for the current project are summarized and compared to historical stability analysis results in Table 4.10, on Figure 4.9, and in the following paragraphs. Numerical results of the linear regression, MK, and Sen's Method analyses for individual wells are provided in Appendix C. For this study, statistical testing was performed on data sets using three different methods. However, the most rigorous approach to statistical analysis is to perform data distribution testing (including possible assessment of log-transformed data) prior to selecting a statistical test. The current version of MAROS does not offer the option of selecting a statistical test based on data distribution analyis or the existence of non-detect data, but rather provides the user with both linear regression and MK statistical results. Users of MAROS will be faced with the decision of having to select from the two test results, whether or not both results were desired. It is recommended that users of MAROS evaluate data distribution at locations where the parametric and nonparametric test results conflict to evaluate which statistical test result is most appropriate. Although data distribution analysis was performed for data sets used in this study, most of the results were inconclusive; an artifact of small data sets and large numbers of non-detect values. This indicates that the non-parametric MK approach is probably an appropriate, conservative choice in many cases.

Source Area

As described in Section 4.2.1.4, specific source areas for the contaminants detected in site groundwater have not been identified. Well W-21 was categorized as a source area well for purposes of this plume stability evaluation due to the fact it has historically contained relatively high concentrations of the parent solvent TCE. For purposes of this evaluation all other site wells have either been categorized as plume wells (within the CAH plume but outside of the source area) or sentry wells (installed exterior to the CAH plume in either the lateral or vertical dimension).

The linear regression and MK analyses identified the temporal trend for TCE at well W-21 as 'increasing' and 'probably increasing,' respectively. Both analyses assigned a 'no trend' designation to historical data for cis-1,2-DCE. The linear regression analysis also assigned a 'no trend' designation to historical VC data, but the MK analysis indicated that VC concentrations at W-21 were 'decreasing.' In contrast, statistical trend analysis results reported in Parsons (2001a.b) and summarized in Table 4.8 indicated decreasing trends for both TCE and VC at W-21, and visual examination of a time-series plot for TCE led CH2M Hill (2003) to conclude that TCE concentrations in W-21 were decreasing.

The differences in the current and historical statistical trend results for W-21 appear to be due to the fact that the various analyses were performed using different data sets. The current analysis used data obtained from 20 sampling events performed from April 1988 to May 2002. In contrast, the trend analysis performed by Parsons (2001b) used data collected during nine sampling events performed from approximately July 1995 to December 2000. As noted in Section 4.2.1.6, the analysis performed by CH2M Hill (2003) was based on data from 12 sampling events that occurred from September 1996 to November 2002.

Table 4.10 Comparison of Historical and Current Concentration-Based Plume Stability Analyses
Site LF-06, Columbus AFB, Mississippi

Evaluation Method	Data Used for Trend Assessment		Results of Trend Assessment	Plume Stability Conclusion	Related Conclusion(s) and Notes	Source [a/]	Comparison of Historical and Current Plume Stability Conclusions
	Monitoring Wells	Period of Sampling					
Temporal changes in source well concentrations [b/]							
Visual inspection of tabular data and data plotted on a site map	Multiple Site Wells	3/88 to 11/96	Concentrations have fluctuated over time with no clear overall trend apparent (i.e., some increase, some decrease, some are relatively constant)	Plume stable	Temporal trends in source area wells were not specifically assessed. However, an overall trend conclusion for site groundwater in general was presented	(1)	Historical qualitative and quantitative trend analysis results were interpreted to indicate the potential for a stable to receding plume. Current (quantitative) trend analysis results for well W-21 indicate an 'increasing' or 'probably increasing' trend for TCE, supporting the potential for CAH plume expansion. Differences in current and historical temporal trend analysis results appear to result primarily from use of data sets representing different time frames; data collected over the past 10 years indicates an overall decreasing trend. Therefore, sole reliance on statistical analysis results to understand plume dynamics can be misleading; the practitioner should ideally use a combination of statistical tests and visual analysis of tabular/graphical data to draw the most accurate conclusions.
Statistical analysis of primary COCs (i.e., TCE and VC) using the Mann-Kendall test	W-21	4/88 to 9/98	'Decreasing' trends for both TCE and VC	Plume stable to receding	--	(2)	
Statistical analysis of TCE and VC using linear regression and Mann-Kendall test	W-21	9/95 to 12/00	'Decreasing' trends for both TCE and VC using both tests	Not addressed	--	(3)	
Examination of time-series plots for TCE and VC	W-21	9/96 to 11/02	'Decreasing' trends for TCE and VC	Not addressed, although the inference is that the CAH plume is stable to receding	Best-fit trend lines were not fit to graphed data	(4)	
Statistical analysis of TCE, cis-1,2-DCE, and VC using linear regression	W-21	4/88 to 5/02	'Increasing for' TCE, 'no trend' for DCE and VC	Potential exists for expansion of TCE plume as a result of increasing CAH mass additions to groundwater; DCE and VC sources appear to be constant to diminishing, suggesting that related plumes are stable to receding	'Increasing' trends for TCE are based on analysis of the entire data set (21 sampling events over 14 years), and do not necessarily indicate continued plume expansion. TCE concentration trends over past 10 years are variable but decreasing overall	Appendix C of current study	
Statistical analysis of TCE, cis-1,2-DCE, and VC using Mann-Kendall test	W-21		'Probably increasing' for TCE, 'no trend' for DCE, and 'decreasing' for VC				
Statistical analysis of TCE, cis-1,2-DCE, and VC using Sen's slope	W-21		'No trend' for TCE and DCE, 'probably decreasing' for VC		--		
Temporal changes in plume well concentrations [c/]							
Visual inspection of tabular data and data plotted on a site map	Multiple Site Wells	3/88 to 11/96	Concentrations have fluctuated over time with no clear overall trend apparent (i.e., some increase, some decrease, some are relatively constant)	Plume stable	Temporal trends in plume wells were not specifically assessed; however, an overall trend conclusion for site groundwater in general was presented	(1)	Historical (qualitative and quantitative) trend analysis results have identified a mixture of increasing and decreasing trends, with an overall characterization of a stable plume. However, analytical model results derived using data collected in 1996 indicated the potential for VC plume expansion west of well W-21. Current (quantitative) analysis results for plume well W-22 support the modeling results by indicating prior expansion of the CAH plume that appears to be emanating from the vicinity of well W-21, but insufficient sentry well data are available to assess whether plume expansion continues to occur. Current
Statistical analysis of TCE and VC using linear regression and Mann- Kendall test	W-18, W-22, W-81	9/95 to 12/00	TCE concentrations are 'decreasing' at W18 and W81 and 'increasing' at W22. VC is 'decreasing' at W21, 'stable' (Mann-Kendall) to 'decreasing' (linear regression) at W81, and 'increasing' slightly at W18.	Not addressed	Except for VC at W-81, results of Mann-Kendall and linear regression analyses indicated similar trends	(3)	

Table 4.10 Comparison of Historical and Current Concentration-Based Plume Stability Analyses (continued)
Site LF-06, Columbus AFB, Mississippi

Evaluation Method	Data Used for Trend Assessment		Results of Trend Assessment	Plume Stability Conclusion	Related Conclusion(s) and Notes	Source [a/]	Comparison of Historical and Current Plume Stability Conclusions
	Monitoring Wells	Period of Sampling					
Statistical analysis of TCE, *cis*-1,2-DCE, and VC using linear regression	W-18, W-22, W-81	4/88 to 5/02	For TCE, 2 wells were 'no trend' and 1 well was 'increasing' For DCE, one well was 'no trend' and 2 wells were 'increasing' For VC, 2 wells were 'no trend' and 1 well was 'increasing'	Prior CAH plume expansion in vicinity of W-22; current plume dynamics unknown due to lack of additional sentry wells west of W-22. CAH plume further north appears to be stable	Data suggest that a 'slug' of CAH contamination previously migrated past W-22, with resulting plume expansion	Appendix C of current study	(quantitative) analysis results for plume wells located further north (W-18, W-81) indicate that other portions of the CAH plume further north are relatively stable.
Statistical analysis of TCE, *cis*-1,2-DCE, and VC using Mann-Kendall test	W-18, W-22, W-81	4/88 to 5/02	For TCE, 1 well was 'no trend', 1 well was 'decreasing,' and 1 well was 'increasing' For DCE, 2 wells were 'no trend' and one well was 'increasing' For VC, 1 well was 'no trend' and 2 wells were 'stable'	Prior CAH plume expansion in vicinity of W-22; current plume dynamics unknown due to lack of additional sentry wells west of W-22. CAH plume further north appears to be stable	Data suggest that a 'slug' of CAH contamination previously migrated past W-22, with resulting plume expansion	Appendix C of current study	
Statistical analysis of TCE, cis-1,2-DCE, and VC using Sen's slope	W-18, W-22, W-81	4/88 to 5/02	For TCE, 1 well was BD and 2 wells were 'no trend' For DCE, 3 wells were 'no trend' For VC, 2 wells were 'no trend' and 1 well was 'decreasing'	Predominance of 'no trend' results suggests plume stability	Sen's slope test may be less sensitive to low-magnitude temporal fluctuations in analyte concentrations than the linear regression and MK methods	Appendix C of current study	
Temporal changes in sentry well concentrations [d/]							
Historical analysis not performed	--	--	--	--	Limited sentry well data were available, but not specifically evaluated in sources (1), (2), or (3)	--	Although the current (quantitative) analysis results for sentry wells support a lack of significant plume expansion, these wells are not optimally positioned to monitor downgradient (i.e., westward) expansion in the southern portion of the site (i.e., west of plume well W-22). Therefore, results from these wells do not definitively indicate a lack of plume expansion. In addition, the downgradient extent of the VC plume west of plume well W-81 is not defined by the current monitoring well network. In several instances erroneous trends were derived via linear regression due to variation in sample-specific detection limits over time.
Statistical analysis of TCE, cis-1,2-DCE, and VC using linear regression	W-20, W-78, W-79, W-82, DW-92	4/88 to 11/02	For TCE and DCE: 1 well with 'no trend,' 3 wells were BD, and 1 well had insufficient data to support a trend analysis For VC: 1 well with 'no trend,' 4 wells were BD	Stable plume	Erroneous trends were derived for multiple non-detect wells due to variation in sample-specific detection limits over time. Sentry wells do not appear to be optimally located to evaluate plume dynamics	Appendix C of current study	
Statistical analysis of TCE, cis-1,2-DCE, and VC using Mann-Kendall test	W-20, W-78, W-79, W-82, DW-92	4/88 to 11/02	For TCE and DCE: 1 well with 'no trend,' 3 wells were BD, and 1 well had insufficient data to support a trend analysis For VC: 1 well with 'no trend,' 4 wells were BD	Stable plume	Sentry wells do not appear to be optimally located to evaluate plume dynamics	Appendix C of current study	
Statistical analysis of TCE, cis-1,2-DCE, and VC using Sen's slope	W-20, W-78, W-79, W-82, DW-92	4/88 to 11/02	For TCE and DCE: 1 well with 'no trend,' Sen's slopes could not be calculated for the remaining wells which were all BD For VC: Sen's slopes could not be calculated due to BD results	--	Sen's slope calculation requires at least four detected values	Appendix C of current study	

Table 4.10 Comparison of Historical and Current Concentration-Based Plume Stability Analyses (continued)
Site LF-06, Columbus AFB, Mississippi

Evaluation Method	Data Used for Trend Assessment		Results of Trend Assessment	Plume Stability Conclusion	Related Conclusion(s) and Notes	Source [a]	Comparison of Historical and Current Plume Stability Conclusions
	Monitoring Wells	Period of Sampling					
Numerical model simulation of contaminant transport							
Qualitative discussion of analytical model results	MPN, W-18, and MPK used for contaminant decay rate calculation; W21 used for source area concentrations	11/96	Not Applicable	Plume at or near steady-state equilibrium	The conclusion derived from the model results and presented in sources (1) and (2) was that the plume was stable or nearly stable. However, source (1) states that the VC model predicted that VC concentrations could exceed the state groundwater standard of 2 μg/L for approximately 1,000 feet downgradient from the point source well W21. The observed VC plume actually had migrated approximately 500 feet downgradient from W21, suggesting the potential for additional expansion. However, this possibility was not presented in either site report.	(1) and (2)	An 'increasing' trend identified for VC in plume well W-22 via linear regression supports plume expansion in this area and is consistent with the results of the analytical model for VC. Visual examination of tabular CAH data for W-22 indicates that a 'slug' of CAHs migrated through the W-22 area and the most recent concentrations are decreasing. Therefore, the increasing trend was not sustained. The MK and Sen's slope results for VC at W-22 indicated 'no trend'.

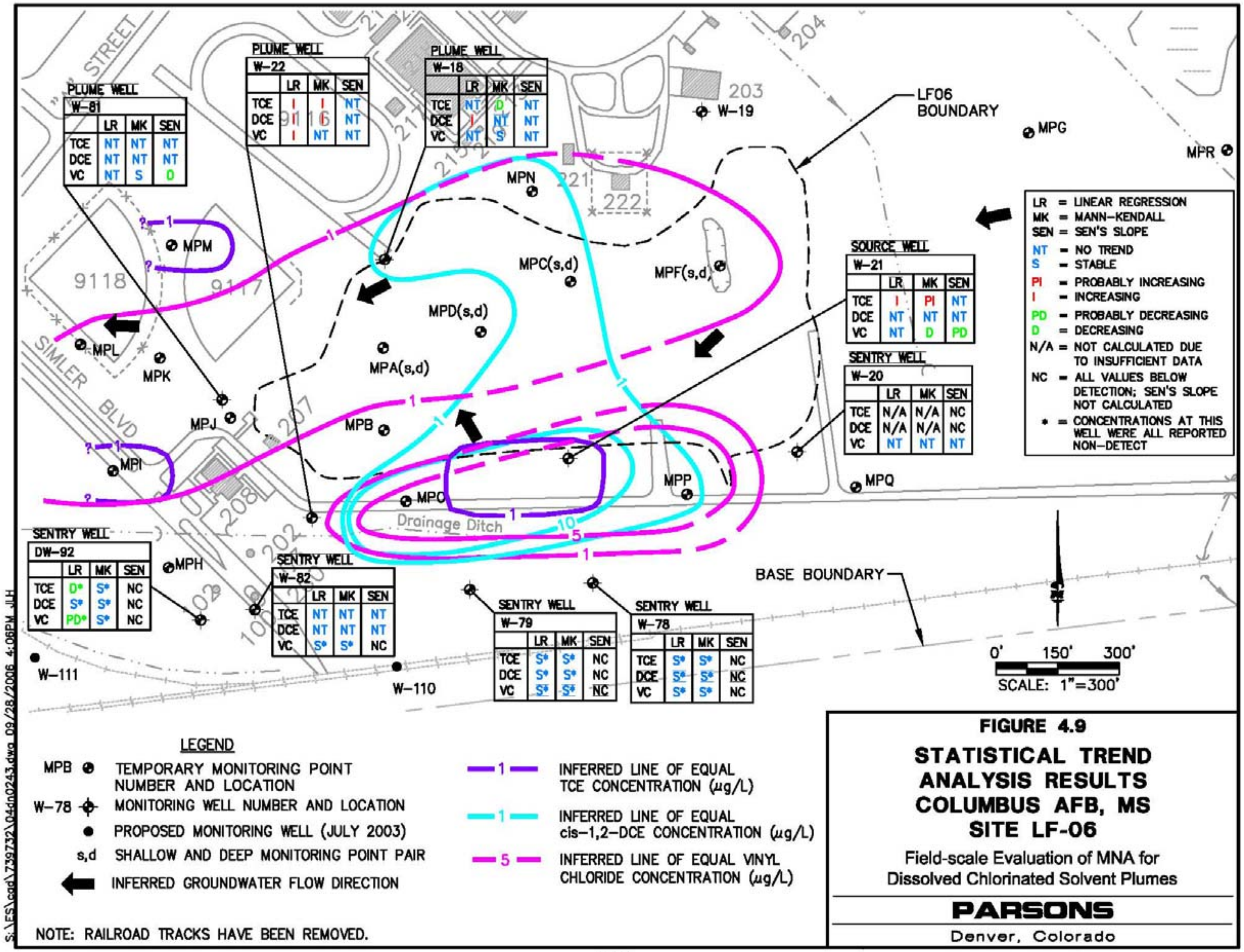
[a] Sources: (1) Treatability Study in Support of Remediation by Natural Attenuation (Parsons, 1997a)
(2) Feasibility Study (Parsons, 2001a)
(3) Supplemental Feasibility Study (Parsons, 2001b)
(4) Long-Term Monitoring Optimization Technical Memorandum (CH2M Hill, 2003)

[b] Source well selected based on proximity to inferred source area.

[c] Plume wells are located within the CAH plume but outside of the inferred source area.

[d] Sentry wells may be located downgradient, crossgradient, above, or below the current plume extents to monitor plume stability.

Notes: COC = contaminant of concern; TCE = trichloroethene; DCE = dichloroethene; VC = vinyl chloride; BD = below detection.



PLUME WELL

W-81	LR	MK	SEN
TCE	NT	NT	NT
DCE	NT	NT	NT
VC	NT	S	D

PLUME WELL

W-22	LR	MK	SEN
TCE	I	I	NT
DCE	I	I	NT
VC	I	NT	NT

PLUME WELL

W-18	LR	MK	SEN
TCE	NT	D	NT
DCE	I	NT	NT
VC	NT	S	NT

SOURCE WELL

W-21	LR	MK	SEN
TCE	I	PI	NT
DCE	NT	NT	NT
VC	NT	D	PD

SENTRY WELL

W-20	LR	MK	SEN
TCE	N/A	N/A	NC
DCE	N/A	N/A	NC
VC	NT	NT	NT

SENTRY WELL

DW-92	LR	MK	SEN
TCE	D*	S*	NC
DCE	S*	S*	NC
VC	PD*	S*	NC

SENTRY WELL

W-82	LR	MK	SEN
TCE	NT	NT	NT
DCE	NT	NT	NT
VC	S*	S*	NC

SENTRY WELL

W-79	LR	MK	SEN
TCE	S*	S*	NC
DCE	S*	S*	NC
VC	S*	S*	NC

SENTRY WELL

W-78	LR	MK	SEN
TCE	S*	S*	NC
DCE	S*	S*	NC
VC	S*	S*	NC

LR = LINEAR REGRESSION
MK = MANN-KENDALL
SEN = SEN'S SLOPE
NT = NO TREND
S = STABLE
PI = PROBABLY INCREASING
I = INCREASING
PD = PROBABLY DECREASING
D = DECREASING
N/A = NOT CALCULATED DUE TO INSUFFICIENT DATA
NC = ALL VALUES BELOW DETECTION; SEN'S SLOPE NOT CALCULATED
* = CONCENTRATIONS AT THIS WELL WERE ALL REPORTED NON-DETECT

LEGEND

MPB ⊕	TEMPORARY MONITORING POINT NUMBER AND LOCATION
W-78 ⊕	MONITORING WELL NUMBER AND LOCATION
●	PROPOSED MONITORING WELL (JULY 2003)
s,d	SHALLOW AND DEEP MONITORING POINT PAIR
⬅	INFERRED GROUNDWATER FLOW DIRECTION
—1—	INFERRED LINE OF EQUAL TCE CONCENTRATION (µg/L)
—1—	INFERRED LINE OF EQUAL cis-1,2-DCE CONCENTRATION (µg/L)
—5—	INFERRED LINE OF EQUAL VINYL CHLORIDE CONCENTRATION (µg/L)

NOTE: RAILROAD TRACKS HAVE BEEN REMOVED.

FIGURE 4.9

STATISTICAL TREND ANALYSIS RESULTS
COLUMBUS AFB, MS
SITE LF-06

Field-scale Evaluation of MNA for
Dissolved Chlorinated Solvent Plumes

PARSONS
Denver, Colorado

Figure 4.9 Statistical Trend Analysis Results, Columbus AFB, Mississippi, Site LF-06.

The ‘increasing’ trend for TCE at W-21 identified during the current analysis appears to be due to the fact that TCE was not detected during the first four sampling events (April 1988 to May 1989), and was detected at only a low concentration during the fifth event (December 1991). TCE concentrations increased to 26 μg/L by the sixth sampling event (November 1994), and have exhibited an erratic but overall decreasing trend since then. Therefore, the trend results which incorporate the 1988 through 1991 data do not accurately reflect the overall trend during the next 10 years, which may be more properly characterized as decreasing. This observation indicates that sole reliance on statistical analysis results to understand plume dynamics can be misleading. Contradictions between various types of analyses (statistical, qualitative, etc.) need to be thoroughly investigated to understand the root cause of conflicting conclusions. The practitioner should use a combination of statistical tests and visual analysis of tabular/graphical data to draw the most accurate conclusions. The variable magnitude of TCE concentrations at W-21 suggests that ‘slugs’ or ‘pulses’ of TCEcontaminated groundwater have migrated through the portion of the aquifer penetrated by this well.

As shown on Figure 4.9, the Sen’s slope results for well W-21 are not entirely consistent with the other statistical analysis results obtained for this well, but are more similar to the MK results than the linear regression results. The most significant discrepancy was for TCE; the Sen’s slope result for TCE indicated ‘no trend,’ while the linear regression and MK results indicated ‘increasing’ and ‘probably increasing’ concentrations, respectively. As described above, the ‘increasing’ trend is not representative of trends occurring within the last 10 years of the data series, and the Sen’s slope result for TCE appears to be more representative of the more recent concentration trend than are the linear regression and MK results. The take-away lesson is that any contradictions between the results of various types of statistical analyses need to be thoroughly investigated to understand the root cause of conflicting conclusions.

Plume Area

Statistical trend analyses were performed for three plume wells (W-18, W-22, and W-81), and results are plotted on Figure 4.9. The ‘plume area’ is defined as the area within the dissolved CAH plume (based on the most recent data) but outside of the inferred source area(s). The linear regression and MK analyses identified ‘increasing’ trends for TCE and DCE at well W-22, suggesting possible CAH plume expansion in this area. The statistical results for VC in well W-22 were not consistent between statistical tests, with the linear regression analysis and the MK test indicating an ‘increasing’ trend and ‘no trend,’ respectively. Further, the identification of ‘increasing’ trends for CAHs at plume well W-22 is not entirely consistent with historical characterizations of the CAH plumes at this site as largely stable. Again, contradictions between various types of analyses need to be thoroughly investigated to understand the root cause of conflicting conclusions. Visual examination of the data set used to perform the current statistical analyses indicates that the ‘increasing’ trends result from the migration of a ‘slug’ of groundwater containing slightly elevated concentrations of CAHs through the portion of the aquifer screened by well W-22 in late 2000 and 2001. CAH concentrations at W-22 prior to arrival of the ‘slug’ were mostly non-detect, and the most recent data indicate decreasing concentrations. As noted above for source area well W-21, reliance on statistical analysis results alone to understand plume dynamics may be misleading. Conflicting results indicate the need for a more detailed, comprehensive review of the data and possibly additional data collection to reduce uncertainty.

Statistical analysis results for plume wells W-18 and W-81 are more indicative of a stable CAH plume. Ten of 12 trend results obtained using linear regression or the MK test (i.e., two statistical tests for three CAHs at two wells) were ‘no trend’ or ‘stable.’ Note that ‘no trend’ does not necessarily mean stable, it simply means that no trend could be statistically discerned. ‘No trend’ conclusions have significantly more uncertainty with respect to their use in assessing plume stability than do other statistical finding offered in MAROS. Additional data collection and more rigorous analysis may be necessary to assess these trends. Visual examination of graphed DCE data for well W-18 does not suggest a significant increasing trend; the ‘increasing’ trend for cis-1,2-DCE identified for this well using linear regression is largely due to the fact that DCE was not detected during three sampling events in 1996 and 1998. Concentrations of cis-1,2-DCE detected during other events have been lowlevel and fairly stable (1.8 to 3.6 μg/L).

Temporal trends in CAH concentrations derived using Sen’s slope calculations were nearly all ‘no trend,’ and did not reflect the greater variety of trends identified using linear regression and the MK test. In that sense, they were more consistent with historical characterizations of the CAH plume at site LF-06 as largely stable. These results indicate that the Sen’s slope test may be less sensitive to low-magnitude temporal fluctuations in analyte concentrations than the linear regression and MK methods.

In summary, the statistical analysis results for plume wells indicates that some expansion of the CAH plume that appears to emanate from the general vicinity of well W-21 has occurred, but the degree to which expansion continues to occur can not be derived from the existing data due to the lack of sentry well data downgradient of W-22. This characterization of plume dynamics is not entirely consistent with the historical characterization of the CAH plume as largely stable. However, the linear regression result for VC at well W-22 (‘increasing’ trend) is consistent with the results of the analytical model described by Parsons (1997a), which indicated the potential for VC plume expansion in this area. Available information suggests that other portions of the CAH plume further north are relatively stable.

Plume Exterior

Statistical trend analyses were performed for a total of five sentry wells, as shown in Table 4.10. The results for these sentry wells are plotted on Figure 4.9. Four of the five sentry wells (W-82, W-79, W-78, and W-81) are screened in the surficial aquifer around the perimeter of the CAH plume. The fifth well, DW-92, is screened in a confined aquifer underlying the surficial aquifer, and was presumably installed to indicate the vertical extent of groundwater contamination in the surficial aquifer.

As shown on Figure 4.9 and the statistical summary tables in Appendix C, the linear regression and MK results for the five sentry wells were ‘no trend’ or ‘stable’ for all locations except for the linear regression results at DW-92. In two instances at DW-92, MAROS output indicated the presence of a ‘decreasing’ trend for TCE and a ‘probably decreasing’ trend for VC, even though all measurements of these two compounds were input as below detection limits. Because all measurements were below detection limits, these two trends are considered erroneous. Further investigation of the MAROS software indicated that that the linear regression algorithm in MAROS produced these erroneous results because of the way that the algorithm handles below-detection measurements. Specifically, MAROS assigns a numerical value of either the detection limit or a user-specified fraction of the detection limit to values reported as below detection, and then applies a linear-regression algorithm to these numerical values without consideration of whether the original data was reported as below detection or not. Because the method detection limit generally decreased over time for TCE and VC in samples collected from DW-92, MAROS erroneously interpreted the decreasing method detection limits as indicating a trend in CAH concentrations, when the reality is that CAHs have never been detected in this well. While MAROS will accept and perform statistical analysis for data series consisting entirely of "censored" or below-detection limit data, we do not recommend the practice.

While the calculated trends for sentry wells generally support the conclusion that the CAH plumes at this site are stable, the sentry wells at this site (as shown on Figure 4.9) are not optimally positioned to monitor downgradient (i.e., westward) expansion in the southern portion of the site. For example, there do not appear to be any sentry wells that are being sampled to define the downgradient extent of the CAH plume west of W-81. Therefore, while the statistical results from the available data suggest that the CAH plumes at this site are generally stable, the apparent absence of a monitored sentry well in the downgradient direction of groundwater flow limits the ability to definitively support a lack of plume expansion in that direction.

Summary

The results of the MK, linear regression, and Sen's slope analyses for Columbus AFB Site LF-06 are summarized for comparative purposes in Table 4.11. Comparison of the results of these three methods with each other and with historical trend analysis results yields the following observations:

Table 4.11 Summary of Statistical Analysis Results
Site LF-06, Columbus AFB, Mississippi

Statistical Analysis Method	Number of Instances Exhibiting the Indicated Trend [a]						
	Decreasing	Probably Decreasing	Stable	No Trend	Probably Increasing	Increasing	NC [b]
Linear Regression	0	0	0	10	0	5	2
MK	2	0	2	8	1	2	2
Sen's Slope	1	1	0	9	0	0	16

[a] Various trends from 12 additional data series, consisting entirely of non-detect values, were obtained using the MAROS linear regression and MK analyses, but are not reported in this table.

[b] NC = not calculated due to insufficient number of data points.

- Sole reliance on statistical analysis results to understand plume dynamics can be misleading; the practitioner should use a combination of statistical tests and visual analysis of tabular/graphical data to draw the most accurate conclusions.

- Erroneous trends due to temporal variations in the method detection limit are more likely to occur when using the linear regression method than when using the

MK method. Although the erroneous trends for this site were 'decreasing' and 'probably decreasing', it is equally possible that the erroneous trends could be 'increasing' or 'probably increasing' for data from other sites.

- The preponderance of 'stable' and 'no trend' results obtained using linear regression, the MK test, and Sen's slope method supports CAH plume stability, especially in the northern portion of the site. These findings are consistent with the results of historical stability analyses.

- 'Increasing' and 'probably increasing' trends were primarily associated with source area well W-21 and plume well W-22 in the southern portion of the site. These results suggest that at least limited CAH plume expansion in this portion of the site has occurred, contrary to historical characterizations of the CAH plume as primarily stable. However, the 'increasing' trends determined by the statistical analyses were caused by elevated CAH concentrations that were detected in these wells more than ten years ago. Importantly, concentration trends over the past ten years have been decreasing and may be more indicative of current conditions. The linear regression results indicated 'increasing' trends more often than the MK results, which were more often 'no trend'.

- Sen's method appears to be less sensitive to low-magnitude temporal fluctuations in analyte concentrations than the linear regression and MK methods. Due to this reduced sensitivity and the requirement to have at least four measurements above the detection limit, Sen's method was considered less useful than linear regression or the MK test at this site.

- The results of the plume stability analysis indicate that the revised LTMO plan (CH2MHill, 2003) may be overly conservative given the evidence that the plume is primarily stable to diminishing. Due to the fact that the Base boundary is hydraulically upgradient to cross-gradient of the landfill, less frequent (e.g., annual, every other year, every third year) monitoring of the boundary wells W-78, W-79, W-82, DW-92, W-110, and Q-111 should be considered.

4.1.2.4 Results of Current Mass-based Stability Analysis

A mass-based plume stability analysis was not developed for LF-06 because the seven shallow wells that were sampled do not provide sufficient spatial coverage to allow appropriate application of this method. Specifically, wells located east and north of the contaminant plumes that are hydraulically upgradient or crossgradient of the seven regularly sampled wells were not regularly sampled. Table 4.10 provides the names of the seven wells that were sampled more than three times, and Figure 4.9 depicts the spatial locations of these wells.

If future mass-based plume analyses were deemed important by stakeholders and decisionmakers for LF-06, infrequent but regular sampling (e.g., one sampling event every two or three years) of the seven regularly-sampled wells plus monitoring wells W-19, W-20, MPP, MPM, and MPC would be recommended to support future mass-based analysis. Note that monitoring of these additional wells would not provide support for concentration-based plume stability assessments or sentry well monitoring that is not already provided by the existing LTM plan. In addition, the low CAH concentrations measured across this site are likely to make mass-based stability analysis calculations less useful than at sites with higher concentrations because small variations in measured CAH concentrations at LF-06 may cause a large fluctuation in the mass calculations. Also note that some off-the-shelf software packages that perform dissolved plume mass calculations (e.g., MAROS) will provide numerical values for plume mass and centroid without consideration of the spatial extent of the monitoring well network used in the calculations. Therefore, the danger exists that the practioner could use erroneous mass calculations obtained by inappropriate use of a software package in a 'black-box' fashion. It is recommended that practitioners first review the spatial coverage of available data, relative to the size and shape of the contaminant plume, to determine if mass-based calculations based on the sampled monitoring wells would be representative of plume-wide characteristics.

4.1.2.5 Plume Stability Analysis Summary

The preponderance of 'stable' and 'no trend' results obtained using linear regression, the MK test, and Sen's slope method generally supports the conclusions of historic stability analyses (i.e., that the CAH plumes at LF-06 are stable). While 'increasing' and 'probably increasing' statistical trends were indicated for source area well W-21 and plume well W-22 in the southern portion of the site, further review of data from these points indicated that these increasing trends were caused by elevated CAH concentrations that were detected in these wells more than ten years ago. Importantly, concentration trends over the past ten years have been decreasing and may be more indicative of current conditions. These observations illustrate that sole reliance on statistical analysis results to understand plume dynamics can be misleading, and that the practitioner should use a combination of statistical tests and visual analysis of tabular/graphical data to draw the most accurate conclusions.

4.1.2.6 Recommendations

Due to the low concentrations and high number of below detection measurements at this site, use of the MK test is recommended over linear regression and Sen's method for current and future statistical analyses of trends at LF-06. This recommendation is based on the statistical characteristics of the MK test that make this test 1) less likely than linear regression to predict erroneous trends at monitoring wells with multiple below detection measurements and 2) more sensitive to trends and has less data frequency restrictions than Sen's method.

The results of the plume stability analysis indicate that the revised LTMO plan (CH2MHill, 2003) is more than is needed to provide statistical evidence that the CAH plumes at this site are primarily stable to diminishing. For example, less frequent (e.g., annual or every-other-year) monitoring of the five boundary wells that are south of the LF-06 CAH plumes should be sufficient to monitor for unexpected plume migration in this direction. Conversely, review of historical data and the current LTMO plan indicates that current and future data can not be used to appropriately support mass-based metrics for evaluating plume dynamics. While additional wells could be monitored on an infrequent (e.g., every-other year) basis to support mass-based calculations, the low CAH concentrations reported at this site suggest that the collection and analysis of samples from additional wells to support mass based calculations is unlikely to provide additional insight on plume stability that can not already be determined from visual and statistical analyses of concentration data.

4.1.3 Case Study: SS-45, England Air Force Base, Louisiana

4.1.3.1 Site Overview and Summary of Available Data

Site Description

England AFB is located approximately 5 miles west of the cities of Alexandria and Pineville, Louisiana. Site Spill Site 45 (SS-45) is entirely contained within England AFB and encompasses an area of approximately 240 acres. Due to the historical pattern of TCE use and disposal at most AFBs (i.e., small batches of TCE disposed in sanitary sewers), it has been difficult to isolate any concentrated source of TCE at SS-45. CAHs have been detected in the subsurface across the site near former maintenance facilities, oil/water separators, and sewer lines. Approximately 20 environmental restoration sites are located on the nearly 240 acres of land overlying the contaminated groundwater at SS-45. Low concentrations of VOCs were detected in the soil and/or shallow groundwater samples collected at five of these sites during previous investigations.

Plume Description

The current distribution of CAHs in the groundwater system beneath SS-45 is likely the result of a 30- to 40-year history of chemical releases from multiple widely dispersed historical sources. The groundwater contamination associated with SS-45 is primarily contained within the intermediate sand of the Red River Alluvial Aquifer, extending from depths of about 40 to 80 feet bgs. Groundwater contaminants also have been detected at lower concentrations in shallower (silt/clay) and deeper (sand) zones of the aquifer which extend from depths of about 5 to 20 feet bgs and 80 to more than 120 ft bgs, respectively. The groundwater contamination encountered within the shallow silt/clay stratum is heterogeneous and discontinuous in occurrence, becoming more homogeneous and dispersed with depth. The major COCs at SS-45 are TCE, cis-1,2-DCE, and VC.

The Focused Corrective Measures Study (CMS) for Groundwater at Site SS-45 (Parsons, 2000) stated the following conclusions regarding the nature, extent, and potential for transport of CAH contamination at SS-45:

- Two distinctive CAH plumes are apparent at SS-45 (Figures 4.10 through 4.12). For the purpose of this plume stability evaluation, the two plumes (referred to as the northwest [NW] and southeast [SE] plumes) will be evaluated separately.

- In general, DCE (but not VC) occurs in plume perimeter wells, indicating that the degradation of DCE to VC may be the rate-limiting step. However, there is significant evidence that VC is degrading to ethene based on the elevated ethene concentrations that occur in wells that also contain VC. (See Appendix D for ethene plume maps).

- The CAH compositions in the NW and SE plumes are noticeably different. Specifically, TCE is the principal component in goundwater the central portions of the NW Plume area. In contrast, DCE isomers and VC are the principal CAHs in groundwater within the intermediate sand in the SE Plume area. Possible explanations for the observed difference in CAH composition of these two plumes are that 1) TCE reached groundwater in the NW and SE Plume areas at different times and/or 2) differences in geochemical conditions by site location have caused differences in the rate of chemical degradation.

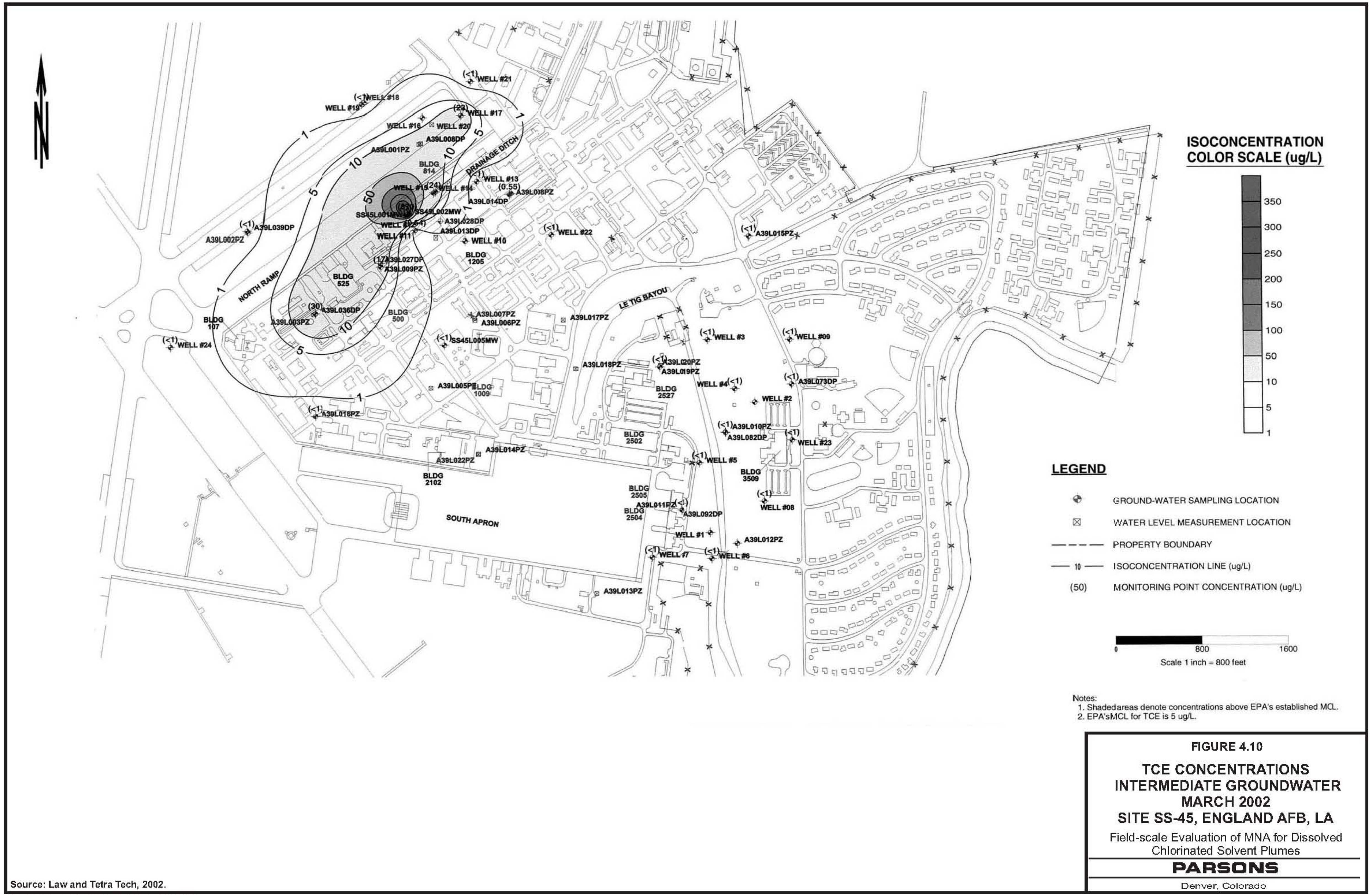
- Measured hydraulic conductivities in the intermediate sand range from 0.16 ft/day to 35 ft/day (geometric mean = 3.7 ft/day). There was no consistent hydraulic gradient across the site; flow direction is probably controlled by surface water features, particularly the Red River. In any round of sampling, the gradients can be significant (up to 0.001 ft/ft), and the calculated seepage velocities range up to 50 ft/yr. Groundwater flow directions can vary substantially from one sampling event to the next. While the groundwater is moving, it doesn't appear to move in a consistent direction. Therefore contaminants at SS-45 are unlikely to be transported away from the site via advection, but will be subject to significant "mixing" in the vicinity of the site through advective transport in changing directions.

Description of Engineered Remediation

No engineered remediation has occurred at SS-45 at England AFB.

Nature of Historical Data and Current LTM Program

The wells sampled for VOCs during previous groundwater monitoring events for the NW and SE Plumes at SS-45 from November 1996 to March 2002 are summarized in Tables 4.12 and 4.13, respectively. Between March 1999 and March 2002, a minimum of ten monitoring wells in the immediate sands of each site sampling were sampled during six events on a sampling interval that ranged from five to 14 months between events. During these six sampling events, nine deep wells were sampled for the NW Plume and one deep well was sampled for the SE



Notes:
1. Shaded areas denote concentrations above EPA's established MCL.
2. EPA's MCL for TCE is 5 ug/L.

FIGURE 4.10

TCE CONCENTRATIONS
INTERMEDIATE GROUNDWATER
MARCH 2002
SITE SS-45, ENGLAND AFB, LA

Field-scale Evaluation of MNA for Dissolved Chlorinated Solvent Plumes

PARSONS
Denver, Colorado

Source: Law and Tetra Tech, 2002.

Figure 4.10 TCE Concentrations Intermediate Groundwater, March 2002, Site SS-45, England AFB, Louisiana

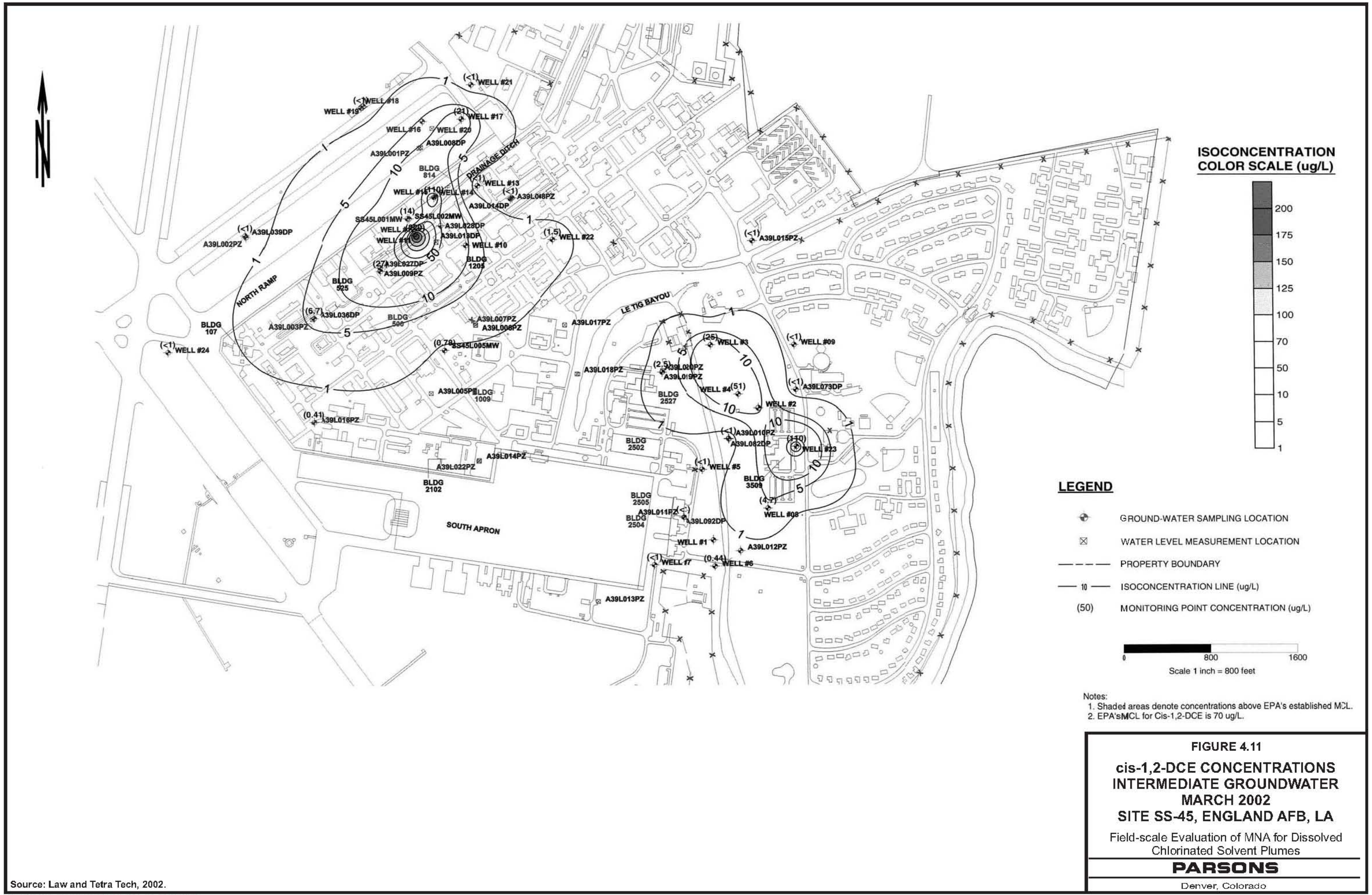
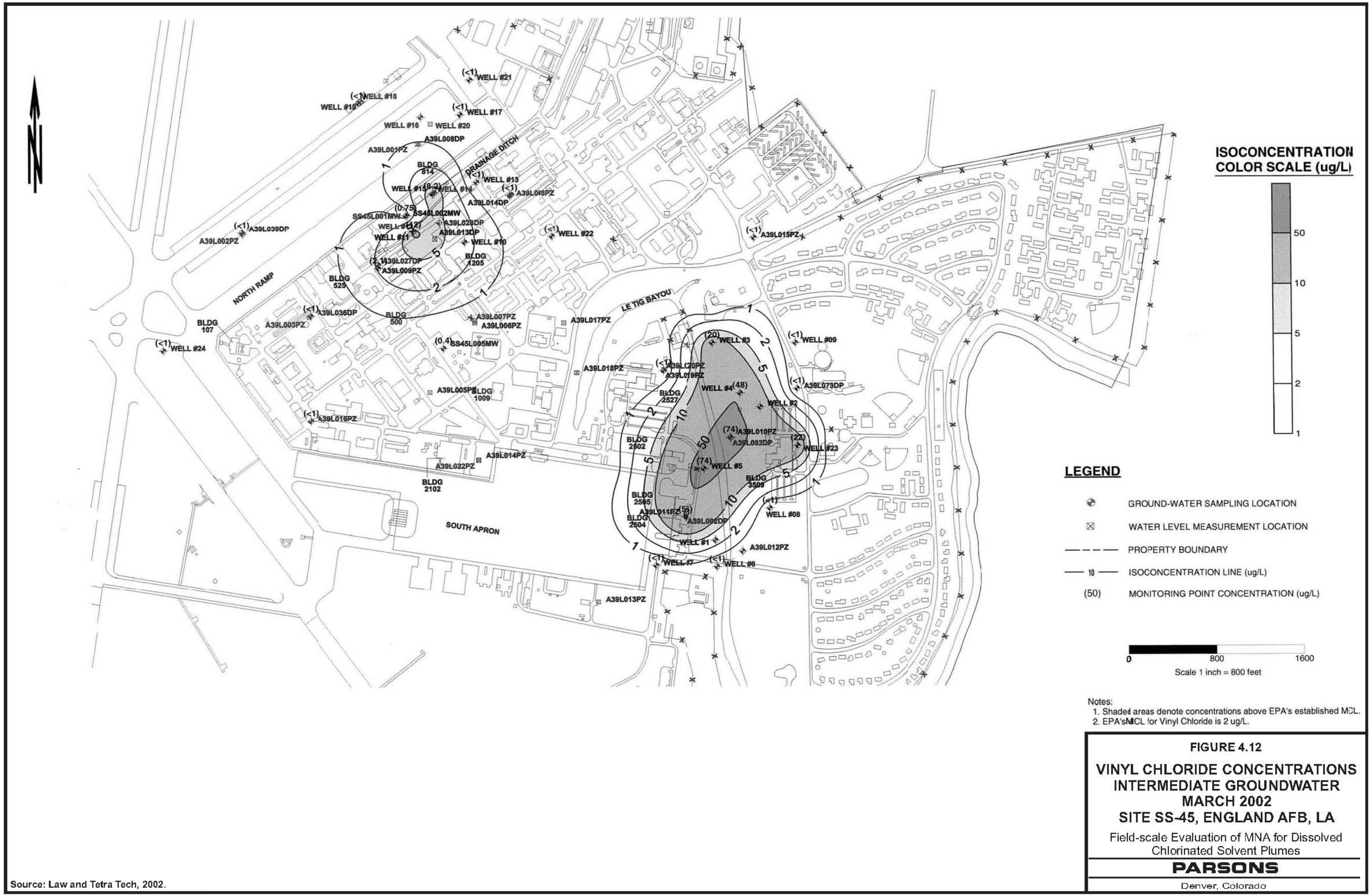


Figure 4.11 cis-1,2-DCE Concentrations Intermediate Groundwater, March 2002, Site SS-45, England AFB, Louisiana



Notes:
1. Shaded areas denote concentrations above EPA's established MCL.
2. EPA's MCL for Vinyl Chloride is 2 ug/L.

FIGURE 4.12

VINYL CHLORIDE CONCENTRATIONS
INTERMEDIATE GROUNDWATER
MARCH 2002
SITE SS-45, ENGLAND AFB, LA

Field-scale Evaluation of MNA for Dissolved
Chlorinated Solvent Plumes

PARSONS

Denver, Colorado

Source: Law and Tetra Tech, 2002.

Figure 4.12 Vinyl Chloride Concentrations, Intermediate Groundwater, March 2002, Site SS-45, England AFB, Louisiana

Table 4.12 Summary of Groundwater Monitoring Well Sampling for VOCs, Site SS-45 Northwest Plume, England AFB, Louisiana

Well	Completion Date	Hydrogeologic Unit	Plume Position	Used in Statistical Analyses?	Sampling Date for VOCs [a/]																		
					Nov-96	Jun-97	Sep-97	Dec-97	Sep-98	Feb-99	Mar-99	May-99	Jul-99	May-00	Aug-00	Oct-00	Dec-00	Mar-01	Jun-01	Sep-05	Dec-01	Feb-02	Mar-02
SS45LOO1MW	Unknown	Intermediate Sand	Source	Yes		X	X	X			X			X		X		X					X
WELL #15	Jan-99	Intermediate Sand	Plume	Yes						X	X			X	X	X		X					X
A39LOO9PZ	Unknown	Intermediate Sand	Plume	Yes		X	X	X			X			X		X		X					X
A39LO14DP	Unknown	Intermediate Sand	Plume	Yes				X						X	X	X		X					X
A39LO36DP	Unknown	Intermediate Sand	Plume	Yes		X	X	X						X		X	X	X					X
WELL #10	Aug-98	Intermediate Sand	Plume	No					X		X												
WELL #11	Jan-99	Intermediate Sand	Plume	Yes							X			X	X	X		X					X
WELL #13	Jan-99	Intermediate Sand	Plume	Yes						X	X			X	X	X		X					X
WELL #17	Jan-99	Intermediate Sand	Plume	Yes							X	X		X	X	X	X	X					X
WELL #22	Unknown	Intermediate Sand	Plume	Yes										X	X	X		X					X
SS45LOO5MW	Unknown	Intermediate Sand	Plume	Yes		X	X	X						X	X	X		X					X
A39LO28DP	Unknown	Deep Sand	Plume	Yes				X			X			X	X	X		X					X
SS45LOO2MW	Unknown	Deep Sand	Plume	Yes		X	X	X			X			X		X		X					X
Well #12	Unknown	Deep Sand	Plume	Yes							X			X	X	X		X					X
Well #14	Unknown	Deep Sand	Plume	Yes							X			X	X	X		X					X
Well #16	Unknown	Deep Sand	Plume	Yes							X			X	X	X		X					X
A39LO16PZ	Unknown	Intermediate Sand	Sentry	Yes															X	X	X		X
A39LO39DP	Unknown	Intermediate Sand	Sentry	Yes		X	X	X			X			X		X		X					X
WELL #19	Jan-99	Intermediate Sand	Sentry	Yes						X	X			X	X	X		X					X
WELL #21	Jul-99	Intermediate Sand	Sentry	Yes							X		X	X	X	X		X					X
WELL #24	Unknown	Intermediate Sand	Sentry	Yes															X	X	X		X
A39LOO2PZ	Unknown	Deep Sand	Sentry	Yes		X	X	X			X			X		X		X					X
A39LOO8PZ	Unknown	Deep Sand	Sentry	Yes				X			X			X	X	X		X					X
A39LO27DP	Unknown	Deep Sand	Sentry	Yes										X	X	X		X					X
Well #18	Unknown	Deep Sand	Sentry	Yes							X			X	X	X		X					X

[a/] VOCs - volatile organic compounds

Note: Highlighted cells indicate that the data were used in the mass-based analysis.

Table 4.13 Summary of Groundwater Monitoring Well Sampling for VOCs, Site SS-45 Southeast Plume, England AFB, Louisiana

					Sampling Date for VOCs [a/]																	
Well	Completion Date	Hydrogeological Unit	Plume Position	Used in Statistical Analyses?	Nov-96	Jun-97	Sep-97	Dec-97	Sep-98	Feb-99	Mar-99	May-99	Jul-99	May-00	Aug-00	Oct-00	Mar-01	Jun-01	Sep-01	Dec-01	Feb-02	Mar-02
A39LO10PZ	Unknown	Intermediate Sand	Plume	Yes		X	X	X			X			X		X	X					X
A39LO11PZ	Unknown	Intermediate Sand	Plume	Yes		X	X	X			X			X		X	X					X
A39LO12PZ	Unknown	Intermediate Sand	Plume	Yes				X			X			X	X	X	X					
A39LO18PZ	Unknown	Intermediate Sand	Plume	No							X											
A39LO19PZ	Unknown	Intermediate Sand	Plume	Yes							X			X	X	X	X					X
WELL #1	Feb-99	Intermediate Sand	Plume	No					X	X	X											
WELL #2	Feb-99	Intermediate Sand	Plume	No					X	X	X											
WELL #3	Feb-99	Intermediate Sand	Plume	Yes						X	X			X	X	X	X	X	X	X		X
WELL #4	Feb-99	Intermediate Sand	Plume	Yes							X	X		X	X	X	X					X
WELL #5	Feb-99	Intermediate Sand	Plume	Yes							X			X	X	X	X					X
WELL #8	Jul-99	Intermediate Sand	Plume	Yes							X		X	X	X	X	X					X
WELL #23	Unknown	Intermediate Sand	Plume	Yes										X	X	X	X					X
A39LO65DP	Nov-96	Intermediate Sand	Plume	No	X																	
A39LO84DP	Nov-96	Intermediate Sand	Plume	No	X																	
A39LO93DP	Sep-97	Intermediate Sand	Plume	No			X															
A39LO05PZ	Unknown	Intermediate Sand	Sentry	No			X															
A39LO13PZ	Unknown	Intermediate Sand	Sentry	No							X											
A39LO14PZ	Unknown	Intermediate Sand	Sentry	No			X															
A39LO15PZ	Unknown	Intermediate Sand	Sentry	No																	X	X
A39LO17PZ	Unknown	Intermediate Sand	Sentry	No			X															
A39LO73DP	Unknown	Intermediate Sand	Sentry	Yes				X						X	X	X	X					X
WELL #6	Feb-99	Intermediate Sand	Sentry	Yes						X	X			X	X	X	X					X
WELL #7	Feb-99	Intermediate Sand	Sentry	Yes							X			X	X	X	X					X
WELL #9	Unknown	Intermediate Sand	Sentry	Yes							X			X	X	X	X					X
A39LO75DP	Nov-96	Intermediate Sand	Sentry	No	X																	
A39LO78DP	Nov-96	Intermediate Sand	Sentry	No	X																	
A39LO86DP	Nov-96	Intermediate Sand	Sentry	No	X																	
A39LO95DP	Sep-97	Intermediate Sand	Sentry	No			X															
A39L082DP	Unknown	Deep Sand	Sentry	Yes							X			X	X	X	X					X

[a/] VOCs = volatile organic compounds.

Note: Highlighted cells indicate that the data were used in the mass-based analysis.

Plume. Monitoring events prior to March 1999 consisted of sampling between three and ten wells for each plume on a sampling interval that ranged from three to ten months.

Rationale for Selection as a Case Study

SS-45 was selected as a plume stability case study based on the following two considerations: 1) the site has had no active remedial activities occur since the CMS (Parsons, 2000) and 2) a considerable amount of consistent historical data is available.

4.1.3.2 Summary of Historic Plume Stability Assessments

The results of historical plume stability evaluations presented in the CMS (Parsons, 2000) and a subsequent LTM report (Law and Tetra Tech, 2002) are summarized in Table 4.14 (NW Plume) and Table 4.15 (SE Plume). The CMS indicated that the NW and SE plumes were likely stable. Specifically, the CMS presented the following conclusions regarding CAH plume stability at SS-45:

- The plumes may have stabilized based on 1) the low concentrations of TCE and its intermediate degradation products at the perimeter of the plumes, 2) the relatively low concentrations of CAHs in the general source areas, and 3) the high ratios of TCE breakdown products to TCE across much of the site. Although the timeframe for complete removal of CAHs from groundwater is uncertain, remediation by NA is expected to contain and gradually shrink the plumes at SS-45.

- 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.

- Based on the high levels of natural organic matter and anaerobic background conditions in the river-bottom sediments that comprise the impacted portion of the aquifer, there appears to be adequate supply of organic substrate to maintain geochemical conditions conducive to long-term reductive dechlorination.

In contrast, the subsequent LTM report prepared following the March 2002 groundwater sampling event (Law and Tetra Tech, 2002) stated that a review of analytical data did not indicate consistent trends in CAH concentrations in the intermediate sand in the NW plume, but that CAH concentrations in the intermediate sand in the SE plume generally increased. This LTM report also concluded that NA did not appear to be limiting migration of CAHs, as suggested by the presence of CAH concentrations greater than MCLs in sentry wells in both the NW and SE plumes. The report noted that total organic carbon (TOC) concentrations within the plume were consistently low over the previous three years, and that bioattenuation appeared to be limited and was not significantly reducing concentrations of CAHs in either plume.

Table 4.14 Results of Previous Concentration-Based Plume Stability Analyses
Site SS-45 Northwest Plume, England AFB, Louisiana

Evaluation Method	Data Used for Trend Assessment		Reported Results of Trend Assessment	Reported Plume Stability Conclusion	Related Conclusion(s) and Notes	Source[a/]
	Monitoring Wells	Period of Sampling				
Temporal changes in source well concentrations [b/]						
Visual inspection of isoconcentration contour maps	Not specified	11/96 to 3/99	CAH concentrations at both the edge and center of the plume are low	Plume may be stable	Given the low concentrations of CAHs at the edge and near the center of the plume, and the relatively long time period since the initial introduction of CAHs to groundwater, it is possible that chemical concentration gradients and/or net advective transport velocities are sufficiently low that advective-diffusive migration has ceased	(1)
Visual inspection of time-series graph for total chlorinated ethenes	SS45L001MW	4/96 to 3/99	TCE at SS45L001MW is decreasing slightly since mid-1997; concentrations of other VOCs have remained relatively constant	Due of the slow rate of contaminant transport at this site, a conclusive assessment of plume stability equilibrium cannot be made using the relatively short time period of available monitoring data.	SS45L001MW was identified as a 'source' well due to the high percentage of TCE in groundwater relative to degradation products and it's location in the approximate center of the NW Plume	(1)
Statistical trend analysis using Mann-Kendall test	SS45L001MW	4/96 to 3/99	'Stable' to 'no trend' results reported for SS45L001MW		The apparent absence of statistically-determined trends of decreasing concentrations through time is probably a result of the limited historical monitoring record	(1)
Visual inspection of tabular and graphed data	NW Plume wells in general, including SS45L001MW	6/97 to 3/02	No consistent trends in CAH concentrations, and no consistent accumulation of TCE degradation products.	None provided	Lack of build-up of DCE and VC suggests biodegradation may be limited and is not significantly reducing concentrations of CAHs	(2)

Table 4.14 Results of Previous Concentration-Based Plume Stability Analyses (continued)
Site SS-45 Northwest Plume, England AFB, Louisiana

Evaluation Method	Data Used for Trend Assessment		Reported Results of Trend Assessment	Reported Plume Stability Conclusion	Related Conclusion(s) and Notes	Source[a/]
	Monitoring Wells	Period of Sampling				
Temporal changes in plume well concentrations [c/]						
Visual inspection of isoconcentration contour maps	Not specified	11/96 to 3/99	CAH concentrations at both the edge and center of the plume are low	Plume may be stable	Given the low concentrations of CAHs at the edge and near the center of the plume, and the relatively long time period since the initial introduction of CAHs to groundwater, it is possible that chemical concentration gradients and/or net advective transport velocities are sufficiently low that advective-diffusive migration has ceased	(1)
Visual inspection of time-series graphs	A39L009PZ SS45L002MW	4/96 to 3/99	TCE and DCE concentrations in A39L009PZ are increasing and decreasing, respectively DCE concentrations at SS45L002MW have increased	Due to the slow rate of contaminant transport at this site, a conclusive assessment of plume stability equilibrium cannot be made using the relatively short time period of available monitoring data	SS45L002MW is a deep sand well adjacent to source well SS24L001MW, which is screened in the intermediate sand. The apparent absence of a greater number of statistically-determined trends of decreasing concentrations through time is probably a result of the limited historical monitoring record	(1)
Statistical trend analysis using Mann-Kendall test	A39L009PZ SS45L002MW	4/96 to 3/99	DCE and total molar VOCs are 'decreasing.' No other trend can be confirmed statistically			(1)
Visual inspection of tabular and graphed data	NW Plume wells in general	6/97 to 3/02	No consistent trends in CAH concentrations, and no consistent accumulation of TCE degradation products.	None provided	Lack of build-up of DCE and VC suggests biodegradation may be limited, and is not significantly reducing concentrations of CAHs	(2)

Table 4.14 Results of Previous Concentration-Based Plume Stability Analyses (continued)
Site SS-45 Northwest Plume, England AFB, Louisiana

Evaluation Method	Data Used for Trend Assessment		Reported Results of Trend Assessment	Reported Plume Stability Conclusion	Related Conclusion(s) and Notes	Source[a/]
	Monitoring Wells	Period of Sampling				
Temporal changes in sentry well concentrations [d/]						
Visual inspection of tabular and graphed data	Total of 15 sentry wells (defined by Law and Tetra Tech [2002] as wells where concentrations have generally not exceeded MCLs)	6/97 to 3/02	None provided	Natural attenuation does not appear to be limiting migration of CAHs, as suggested by the presence of CAH concentrations greater than MCLs in sentry wells	Law's (2002) plume stability conclusion for the NW plume does not appear to be substantiated by historical groundwater monitoring data. The only sentry wells in the NW plume that have historically had detections of CAHs greater than MCLs are deep sand Well #12 (in 5/2000) and Well A39L014DP (in 12/1997). There were several subsequent sampling events at these wells where CAH concentrations were less than MCLs	(2)

[a/] Sources: (1) Focused CMS (Parsons, 2000)
(2) IRP LTM Report (Law and Tetra Tech, 2002)

[b/] Source wells selected based on proximity to inferred source area.

[c/] Plume wells are located within the CAH plume but outside of the inferred source area. .

[d/] Sentry wells are located downgradient, crossgradient, above, or below the plume extents to monitor plume stability.

Notes: CAH = chlorinated aliphatic hydrocarbon; COC = contaminant of concern; TCE = trichloroethene; DCE = cis-1,2-dichloroethene; VC = vinyl chloride

Table 4.15 Results of Previous Concentration-Based Plume Stability Analyses
Site SS-45 Southeast Plume, England AFB, Louisiana

Evaluation Method	Data Used for Trend Assessment		Reported Results of Trend Assessment	Reported Plume Stability Conclusion	Related Conclusion(s) and Notes	Source[a/]
	Monitoring Wells	Period of Sampling				
Temporal changes in source well concentrations						
No source wells were identified in the southeast plume						
Temporal changes in plume well concentrations [b/]						
Visual inspection of isoconcentration contour maps	Not specified	11/96 to 3/99	CAH concentrations at both the edge and center of the plume are low	Plume may be stable	Given the low concentrations of CAHs at the edge and near the center of the plume, and the relatively long time period since the initial introduction of CAHs to ground water, it is possible that chemical concentration gradients and/or net advective transport velocities are sufficiently low that advective-diffusive migration has ceased	(1)
Visual inspection of time-series graphs and tabular data	A39LO10PZ A39LO11PZ	6/96 to 3/99	DCE isomers and VC have decreased through time at A39LO10PZ while ethene has increased. cis-DCE has decreased through time at A39LO11PZ while other VOCs have remained relatively constant	A full assessment regarding the degree to which the plume is at equilibrium cannot be made on the basis of the available data	The apparent absence of a greater number of statistically-demonstrable trends of decreasing concentrations through time is probably a result of the limited historical monitoring record	(1)
Statistical trend analysis using Mann-Kendall test	A39LO10PZ A39LO11PZ	6/96 to 3/99	*cis* and *trans*-DCE at A39LO10PZ have decreased; no other trend can be confirmed statistically • No statistical trend can be confirmed for A39LO11PZ	A full assessment regarding the degree to which the plume is at equilibrium cannot be made on the basis of the available data	The apparent absence of a greater number of statistically-demonstrable trends of decreasing concentrations through time is probably a result of the limited historical monitoring record	(1)

Table 4.14 Results of Previous Concentration-Based Plume Stability Analyses (continued)
Site SS-45 Northwest Plume, England AFB, Louisiana

Evaluation Method	Data Used for Trend Assessment		Reported Results of Trend Assessment	Reported Plume Stability Conclusion	Related Conclusion(s) and Notes	Source[a/]
	Monitoring Wells	Period of Sampling				
Visual inspection of tabular and graphed data	SE Plume interior wells in general	6/97 to 3/02	No consistent trends in CAH concentrations, and no consistent build-up of TCE intermediate degradation products	None provided	Lack of build-up of DCE and VC suggests biodegradation may be limited, and is not significantly reducing concentrations of CAHs	(2)
Temporal changes in sentry well concentrations [c/]						
Visual inspection of tabular and graphed data	Total of 10 sentry wells (defined by Law and Tetra Tech [2002] as wells where concentrations have generally not exceeded MCLs)	6/97 to 3/02	*cis*-DCE and VC detected in one sentry well at concentrations > MCLs for first time in 3/02	Plume expanding	--	(2)

[a/] Sources: (1) Focused CMS (Parsons, 2000)
(2) IRP LTM Report (Law and Tetra Tech, 2002)

[b/] Plume wells are located within the CAH plume but outside of an inferred source area.

[c/] Sentry wells at SS-45 are located in areas where dissolved contaminant concentrations have not historically exceeded US Environmental Protection Agency Maximum Contaminant Levels (MCLs).

Notes: CAH = chlorinated aliphatic hydrocarbon; COC = contaminant of concern; TCE = trichloroethene; DCE = cis-1,2-dichloroethene, VC = vinyl chloride

The conclusion that the NW plume was expanding (Law and Tetra Tech, 2002) does not appear to be substantiated by the historical groundwater monitoring data presented in the LTM Report. The only sentry wells in the NW plume that have historically contained CAH concentrations that exceeded MCLs are deep sand Wells #12 (TCE and cis-1,2-DCE in May 2000) and A39L014DP (VC in December 1997). In each of these instances, there were multiple subsequent sampling events when CAH concentrations did not exceed MCLs, suggesting that significant plume expansion is not occurring.

The conclusion that the SE plume was expanding in localized areas (Law and Tetra Tech, 2002) is substantiated by the fact that concentrations of both cis-1,2-DCE (110 µg/L) and VC (22 µg/L) in intermediate sand sentry Well #23 exceeded MCLs for the first time in March 2002. During subsequent confirmation sampling of Well #23, the cis-1,2-DCE concentration recorded as 60 µg/L was less than the MCL but still substantially higher than historicallydetected concentrations, but the VC concentration of 25 µg/L still exceeded the MCL. Well #23 is located near the inferred eastern edge of the DCE and VC plumes (Figures 4.11 and 4.12, respectively).

4.1.3.3 Results of Current Concentration-based Stability Analysis

Concentration-based stability analysis results obtained for the current project are summarized and compared to historical stability analysis results for the NW and SE plumes in the following two subsections. Numerical results of the linear regression and MK analyses for individual wells are provided in Appendix C. For this study, statistical testing was performed on data sets using two methods. However, the most rigorous approach to statistical analysis is to perform data distribution testing (including possible assessment of logtransformed data) prior to selecting a statistical test. The current version of MAROS does not offer the option of selecting a statistical test based on data distribution analyis or the existence of non-detect data, but rather provides the user with both linear regression and MK statistical results. Users of MAROS will be faced with the decision of having to select from the two test results, whether or not both results were desired. It is recommended that users of MAROS evaluate data distribution at locations where the parametric and nonparametric test results conflict to evaluate which statistical test result is most appropriate. Although data distribution analysis was performed for data sets used in this study, most of the results were inconclusive; an artifact of small data sets and large numbers of non-detect values. This indicates that the non-parametric MK approach is probably an appropriate, conservative choice in many cases.

As discussed in Section 4.1.3.1, available data indicate that there are multiple, poorlydefined, widely-dispersed historical sources at SS-45, and no single, significant TCE release or source area has been identified. Given the poorly-defined nature of the TCE sources, no SE Plume monitoring wells were classified as “source area” wells for this plume stability evaluation. However, one NW Plume well (SS45L001MW) screened in the intermediate sand was classified as a source area well due to 1) its location near the center of the plume (which is inferred to have expanded more or less radially via the changing direction of advective transport) and 2) the high TCE to intermediate degradation produce product ratio in groundwater from this well relative to the ratio detected in other NW Plume wells.

4.1.3.3.1 Concentration-based Analysis (NW Plume)

Concentration-based stability analysis results obtained for the NW Plume are summarized and compared to historical stability analysis results in Table 4.16, on Figure 4.13, and in the following paragraphs. Numerical results of the linear regression and MK analyses for individual wells are provided in Appendix C.

Source Area (NW Plume)

One source well was evaluated (SS45L001MW). All of the calculated trends were either 'stable' or 'no trend' except for the linear regression result for TCE ('probably decreasing') (Figure 4.13). The lack of a clear, consistent decreasing trend in TCE concentrations at this well suggests that a continuing TCE source is present in the vicinity of this well. Overall, the current trend analysis results for the source area well do not support significant plume recession, but may be indicative of either plume stability or potential expansion given the inferred presence of a continuing source.

Plume Area (NW Plume)

Statistical trend analyses were performed for the 14 plume wells listed in Table 4.12. Nine of the 14 plume wells are screened in the intermediate sand, and the remaining five wells are screened in the deep sand. Plume wells at this site are defined as those wells where the concentration of at least one CAH was measured as greater than 1 μg/L, but not identified as a source area well.

As shown on Figure 4.13, six of the 30 trend determinations made for the five plume wells screened in the deep sand (SS45L002MW, A39L028DP, #12, #14, and #16) were based entirely on non-detects. Therefore, these six trends (which ranged from 'stable' or 'no trend' to 'increasing') are considered spurious because they were derived using one-half of the detection limit as input into the calculation routines. While MAROS will accept and perform statistical analysis data series consisting entirely of "censored" or below-detection limit data, we do not recommend the practice. Twenty of the remaining 24 trend determinations (83 percent) made for these five wells were 'no trend'. 'Probably decreasing' and 'increasing' trends for TCE and VC, respectively, in deep sand Well #14 were indicated by linear regression, while the corresponding MK results were 'no trend'. 'Increasing' trends for cis-1,2-DCE in deep sand Well #16 were obtained using both linear regression and the MK test.

The 'increasing' trend for VC at deep sand Well #14 identified via linear regression appears to be based entirely on the most recent data point for VC used in the trend analysis (12 μg/L in March 2002). There was no discernable trend in VC concentrations at this well prior to this date, and the previous maximum-detected VC concentration was 6.3 μg/L. Although the March 2002 value may be indicative of an increasing trend, additional data should be collected and evaluated to validate this conclusion. Additional data also are recommended to validate the 'probably decreasing' trend derived for TCE at Well #14. The 'increasing' trend identified for cis-1,2-DCE in deep sand Well #16 via both linear regression and the MK test is consistent with visual inspection of the data. It is important to note that, although the trend is consistent

Table 4.16 Results of Historical and Current Concentration-Based Plume Stability Analyses
Site SS-45 Northwest Plume, England AFB, Louisiana

Evaluation Method	Data Used for Trend Assessment		Results of Trend Assessment	Plume Stability Conclusion	Related Conclusion(s) and Notes	Source [a/]	Comparison of Historical and Current Plume Stability Conclusions
	Monitoring Wells	**Period of Sampling**					
Temporal changes in source well concentrations [b/]							
Visual inspection of isoconcentration contour maps	Not specified	11/96 to 3/99	CAH concentrations at both the edge and center of the plume are low	Plume may be stable	Given the low concentrations of CAHs at the edge and near the center of the plume, and the relatively long time period since the initial introduction of CAHs to groundwater, it is possible that chemical concentration gradients and/or net advective transport velocities are sufficiently low that advective-diffusive migration has ceased	(1)	The current trend analysis results for the source area well do not support significant plume recession, but may be indicative of either plume stability or expansion given the inferred presence of a continuing source. This conclusion cannot be directly compared to historical plume stability conclusions given that conclusions were not previously derived from analysis of source area well data.
Visual inspection of time-series graph for total chlorinated ethenes	SS45L001MW	4/96 to 3/99	TCE at SS45L001MW is decreasing slightly since mid-1997; concentrations of other VOCs have remained relatively constant	A full assessment regarding the degree to which the plume is at equilibrium cannot be made on the basis of the available data	SS45L001MW was identified as a 'source' well due to the high percentage of TCE in groundwater relative to degradation products and it's location in the approximate center of the NW CAH plume	(1)	
Statistical trend analysis using Mann-Kendall test	SS45L001MW	4/96 to 3/99	'Stable' to 'no trend' results reported for SS45L001MW		The apparent absence of statistically-demonstrable trends of decreasing concentrations through time is probably a result of the limited historical monitoring record	(1)	
Visual inspection of tabular and graphed data	NW Plume wells, including SS45L001MW	6/97 to 3/02	No consistent trends in CAH concentrations and no consistent build-up of TCE intermediate degradation products.	None provided	Lack of build-up of DCE and VC suggests biodegradation may be limited and is not significantly reducing concentrations of CAHs	(2)	
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using linear regression and Mann-Kendall test	SS45L001MW	6/97 to 3/02	All calculated trends were 'stable' or 'no trend' except for the linear regression result for TCE ('probably decreasing')	Trend results suggest either plume stability or expansion	The lack of a clear, consistent decreasing trend in TCE concentrations at this well suggest the presence of a continuing TCE source	Appendix C of current study	
Temporal changes in plume well concentrations [c/]							
Visual inspection of isoconcentration contour maps	Not specified	11/96 to 3/99	CAH concentrations at both the edge and center of the plume are low	Plume may be stable	Given the low concentrations of CAHs at the edge and near the center of the plume, and the relatively long time period since the initial introduction of CAHs to groundwater, it is possible that chemical concentration gradients and/or net advective transport velocities are sufficiently low that advective-diffusive migration has ceased	(1)	The results of the current trend analysis for plume wells support the conclusion made by Parsons (2000) that a full assessment regarding the degree to which the plume is at equilibrium cannot be made on the basis of available data. Rates of change in plume size and shape in a diffusion-dominated system are very slow, and additional time-series data are required to more confidently discern plume dynamics. The localized 'increasing' trends identified by the current evaluation may indicate that natural attenuation rates are not sufficiently rapid to prevent plume expansion in localized areas, as postulated by Law and Tetra Tech (2002)
Visual inspection of time-series graphs	A39L009PZ SS45L002MW	4/96 to 3/99	TCE and DCE at A39L009PZ are increasing and decreasing, respectively DCE at SS45L002MW has increased	A full assessment regarding the degree to which the plume is at equilibrium cannot be made on the basis of the available data	SS45L002MW is a deep sand well adjacent to source well SS24L001MW, which is screened in the intermediate sand. The apparent absence of a greater number of statistically-demonstrable trends of decreasing concentrations through time is probably a result of the limited historical monitoring record.	(1)	

Table 4.16 Results of Historical and Current Concentration-Based Plume Stability Analyses (continued)
Site SS-45 Northwest Plume, England AFB, Louisiana

	Data Used for Trend Assessment						
Evaluation Method	**Monitoring Wells**	**Period of Sampling**	**Results of Trend Assessment**	**Plume Stability Conclusion**	**Related Conclusion(s) and Notes**	**Source [a/]**	**Comparison of Historical and Current Plume Stability Conclusions**
Statistical trend analysis using Mann-Kendall test	A39L009PZ SS45L002MW	4/96 to 3/99	DCE and total molar VOCs are 'decreasing.' No other trend can be confirmed statistically	A full assessment regarding the degree to which the plume is at equilibrium cannot be made on the basis of the available data	SS45L002MW is a deep sand well adjacent to source well SS24L001MW, which is screened in the intermediate sand. The apparent absence of a greater number of statistically-demonstrable trends of decreasing concentrations through time is probably a result of the limited historical monitoring record	(1)	See entry in column above on previous page.
Visual inspection of tabular and graphed data	NW Plume wells in general	6/97 to 3/02	No consistent trends in CAH concentrations, and no consistent build-up of TCE intermediate degradation products	None provided	Lack of build-up of DCE and VC suggests biodegradation may be limited, and is not significantly reducing concentrations of CAHs	(2)	
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using linear regression and Mann-Kendall test	14 plume wells listed in Table 4.12	6/97 to 3/02	20 of 24 trends for deep sand wells were 'no trend', 1 (TCE) was 'probably decreasing', and 3 (DCE and VC) were 'increasing.' 30 of 46 trends for intermediate sand wells were 'stable' or 'no trend,' 6 were 'decreasing,' and 10 were 'increasing'	The CAH plume is largely stable; however, increasing trends suggest the potential for localized plume expansion	The most substantial increasing trends identified for plume wells include TCE and DCE in intermediate sand wells A39L036DP and #17, respectively, and VC in deep sand well #14 and intermediate sand well #11	Appendix C of current study	
Temporal changes in sentry well concentrations [d/]							
Visual inspection of tabular and graphed data	15 sentry wells (defined by Law and Tetra Tech [2002] as wells where concentrations have generally not exceeded MCLs)	6/97 to 3/02	None provided	Natural attenuation does not appear to be limiting migration of CAHs, as suggested by the presence of CAH concentrations greater than MCLs in sentry wells	Law and Tetra Tech's (2002) plume stability conclusion for the NW plume does not appear to be substantiated by historical groundwater monitoring data. The only sentry wells in the NW plume that have historically had detections of CAHs greater than MCLs are deep sand Well #12 (in 5/2000) and Well A39L014DP (in 12/1997). There were several subsequent sampling events at these wells where CAH concentrations were less than MCLs.	(2)	The current trend analysis results support the observation made by Parsons (2000) that natural attenuation processes had likely stabilized the plume. In contrast, the current results do not support the contention made by Law and Tetra Tech (2002) that the NW plume was expanding. However, as described above for plume wells, the potential for future expansion cannot be ruled out due to the increasing trends exhibited for some plume wells.
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using linear regression and Mann-Kendall test	Nine sentry wells listed in Table 4.12 (defined as wells that contain less than 1 μg/L of each of the target VOCs)	6/97 to 3/02	Sentry wells were generally either all non-detect for CAHs, exhibited a 'stable' trend, or did not exhibit a definable trend. 'Increasing' trends identified for TCE (one intermediate well) and DCE (one deep well) do not appear to be indicative of plume expansion	Stable to decreasing plume	--	Appendix C of current study	

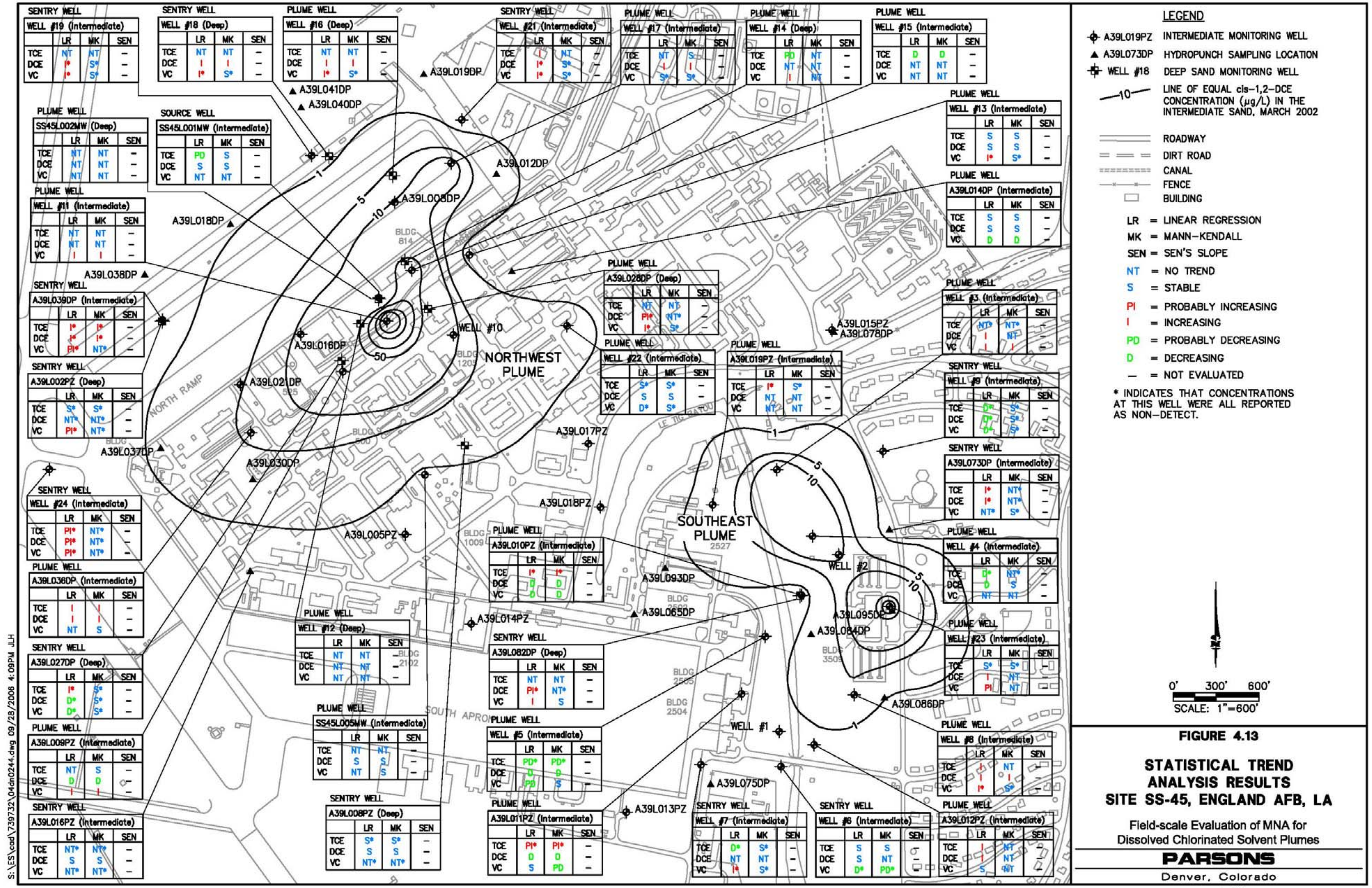
[a/] Sources: (1) Focused CMS (Parsons, 2000)
(2) IRP LTM Report (Law and Tetra Tech, 2002)

[b/] Source wells seelcted based on proximity to inferred source area.

[c/] Plume wells are located within the CAH plume but outside of the inferred source area.

[d/] Sentry wells at SS-45 are located in areas where dissolved contaminant concentrations have not historically exceeded US Environmental Protection Agency Maximum Contaminant Levels (MCLs).

Notes: CAH = chlorinated aliphatic hydrocarbon; COC = contaminant of concern; TCE = trichloroethene; DCE = cis-1,2-dichloroethene, VC = vinyl chloride



SENTRY WELL

WELL #19 (Intermediate)	LR	MK	SEN
TCE	NT	NT	–
DCE	I*	S*	–
VC	I*	S*	–

SENTRY WELL

WELL #18 (Deep)	LR	MK	SEN
TCE	NT	NT	–
DCE	I	I	–
VC	I*	S*	–

PLUME WELL

WELL #16 (Deep)	LR	MK	SEN
TCE	NT	NT	–
DCE	I	I	–
VC	I*	S*	–

SENTRY WELL

WELL #21 (Intermediate)	LR	MK	SEN
TCE	I	NT	–
DCE	I*	S*	–
VC	I*	S*	–

PLUME WELL

WELL #17 (Intermediate)	LR	MK	SEN
TCE	NT	S	–
DCE	I	I	–
VC	S*	S*	–

PLUME WELL

WELL #14 (Deep)	LR	MK	SEN
TCE	PD	NT	–
DCE	NT	NT	–
VC	I	NT	–

PLUME WELL

WELL #15 (Intermediate)	LR	MK	SEN
TCE	D	D	–
DCE	NT	NT	–
VC	NT	NT	–

PLUME WELL

SS45L002MW (Deep)	LR	MK	SEN
TCE	NT	NT	–
DCE	NT	NT	–
VC	NT	NT	–

SOURCE WELL

SS45L001MW (Intermediate)	LR	MK	SEN
TCE	PD	S	–
DCE	S	S	–
VC	NT	NT	–

PLUME WELL

WELL #13 (Intermediate)	LR	MK	SEN
TCE	S	S	–
DCE	S	S	–
VC	I*	S*	–

PLUME WELL

WELL #11 (Intermediate)	LR	MK	SEN
TCE	NT	NT	–
DCE	NT	NT	–
VC	I	I	–

PLUME WELL

A39L014DP (Intermediate)	LR	MK	SEN
TCE	S	S	–
DCE	S	S	–
VC	D	D	–

PLUME WELL

A39L028DP (Deep)	LR	MK	SEN
TCE	NT	NT	–
DCE	PI*	NT*	–
VC	I*	S*	–

SENTRY WELL

A39L039DP (Intermediate)	LR	MK	SEN
TCE	I*	I*	–
DCE	I*	I*	–
VC	PI*	NT*	–

PLUME WELL

WELL #3 (Intermediate)	LR	MK	SEN
TCE	NT*	NT*	–
DCE	I	NT	–
VC	I	I	–

PLUME WELL

WELL #22 (Intermediate)	LR	MK	SEN
TCE	S*	S*	–
DCE	S	S	–
VC	D*	S*	–

PLUME WELL

A39L019PZ (Intermediate)	LR	MK	SEN
TCE	I*	S*	–
DCE	NT	NT	–
VC	NT	NT	–

SENTRY WELL

A39L002PZ (Deep)	LR	MK	SEN
TCE	S*	S*	–
DCE	NT*	NT*	–
VC	PI*	NT*	–

SENTRY WELL

WELL #9 (Intermediate)	LR	MK	SEN
TCE	D*	S*	–
DCE	D*	S*	–
VC	D*	S*	–

SENTRY WELL

A39L073DP (Intermediate)	LR	MK	SEN
TCE	I*	NT*	–
DCE	I*	NT*	–
VC	NT*	S*	–

SENTRY WELL

WELL #24 (Intermediate)	LR	MK	SEN
TCE	PI*	NT*	–
DCE	PI*	NT*	–
VC	PI*	NT*	–

PLUME WELL

A39L010PZ (Intermediate)	LR	MK	SEN
TCE	I*	I*	–
DCE	D	D	–
VC	D	D	–

PLUME WELL

WELL #4 (Intermediate)	LR	MK	SEN
TCE	D*	NT*	–
DCE	D	S	–
VC	NT	NT	–

PLUME WELL

A39L036DP (Intermediate)	LR	MK	SEN
TCE	I	I	–
DCE	I	I	–
VC	NT	S	–

PLUME WELL

WELL #12 (Deep)	LR	MK	SEN
TCE	NT	NT	–
DCE	NT	NT	–
VC	NT	NT	–

SENTRY WELL

A39L082DP (Deep)	LR	MK	SEN
TCE	NT	NT	–
DCE	PI*	NT*	–
VC	I	S	–

PLUME WELL

WELL #23 (Intermediate)	LR	MK	SEN
TCE	S*	S*	–
DCE	I	NT	–
VC	PI	NT	–

SENTRY WELL

A39L027DP (Deep)	LR	MK	SEN
TCE	I*	S*	–
DCE	D*	S*	–
VC	D*	S*	–

PLUME WELL

SS45L005MW (Intermediate)	LR	MK	SEN
TCE	NT	NT	–
DCE	S	S	–
VC	NT	S	–

PLUME WELL

WELL #5 (Intermediate)	LR	MK	SEN
TCE	PD*	PD*	–
DCE	D	D	–
VC	PD	S	–

PLUME WELL

WELL #8 (Intermediate)	LR	MK	SEN
TCE	I	NT	–
DCE	I	I	–
VC	I*	S*	–

PLUME WELL

A39L009PZ (Intermediate)	LR	MK	SEN
TCE	NT	S	–
DCE	D	D	–
VC	I	I	–

SENTRY WELL

A39L016PZ (Intermediate)	LR	MK	SEN
TCE	NT*	NT*	–
DCE	S	S	–
VC	NT*	NT*	–

SENTRY WELL

A39L008PZ (Deep)	LR	MK	SEN
TCE	S*	S*	–
DCE	S	S	–
VC	NT*	NT*	–

PLUME WELL

A39L011PZ (Intermediate)	LR	MK	SEN
TCE	PI*	PI*	–
DCE	D	D	–
VC	S	PD	–

SENTRY WELL

WELL #7 (Intermediate)	LR	MK	SEN
TCE	D*	S*	–
DCE	NT	NT	–
VC	I*	S*	–

SENTRY WELL

WELL #6 (Intermediate)	LR	MK	SEN
TCE	S	S	–
DCE	S	NT	–
VC	D*	PD*	–

PLUME WELL

A39L012PZ (Intermediate)	LR	MK	SEN
TCE	I	NT	–
DCE	I	NT	–
VC	S	NT	–

Figure 4.13 Statistical Trend Analysis Results, Site SS-45, England AFB, Louisiana

from one sampling event to the next, the total magnitude of the concentration increase over a 3-year period is very slight (i.e., 0.8 µg/L), indicating that this trend is not indicative of significant plume expansion. In summary, the trend analysis results for the NW Plume wells screened in the deep sand unit indicate that significant plume expansion within the deep sand is not occurring.

Eight of the 48 trend determinations made for the nine NW Plume wells screened in the intermediate sand were based entirely on non-detects. As described above for the deep sand plume wells, these eight trends (which included 'stable,' 'increasing,' and 'decreasing' trends) are considered spurious. While MAROS will accept and perform statistical analysis for data series consisting entirely of "censored" or below-detection limit data, we do not recommend the practice. Thirty of the remaining 46 trend determinations (65 percent) made for these nine intermediate sand plume wells were either 'stable' or 'no trend', and six trend determinations (13 percent) were 'decreasing.' The remaining 10 trend determinations (22 percent) were 'increasing', and were consistently identified by both the linear regression and MK tests.

The only 'increasing' trends identified for TCE at plume wells screened in the intermediate sand were for A39L036DP (Figure 4.13). TCE concentrations at this well increased from 11 µg/L in June 1997 to a high of 34 µg/L in March 2001. The TCE concentration decreased slightly to 30 µg/L from March 2001 to March 2002. The increasing trend at this well is apparent upon visual inspection of the tabulated data, and is indicative of very slight increases in the concentration of dissolved TCE present in groundwater at this location over time.

'Increasing' trends for cis-1,2-DCE at plume wells screened in the intermediate sand were identified for wells A39L036DP and #17 (Figure 4.13). The most substantial increasing trend for cis-1,2-DCE appears to be associated with well #17, where concentrations increased from 1 µg/L in March 1999 to 23 µg/L in March 2001. From March 2001 to March 2002, the cis-1,2-DCE concentration decreased slightly from 23 to 21 µg/L. This well is located near the northern edge of the March 2002 cis-1,2-DCE plume delineated by Law and Tetra Tech (2002). The 'increasing' trend identified for cis-1,2-DCE in well A39L036DP appears to be relatively insignificant in that concentrations of cis-1,2-DCE at this well increased from 2.5 to 6.7 µg/L over a nearly 5-year period. Further monitoring of these wells is recommended to confirm the above observations. However, the data collected up to March 2002 suggest that the NW cis-1,2-DCE plume is relatively stable and the isolated 'increasing' trends are not indicative of substantial plume migration.

'Increasing' trends for VC in plume wells screened in the intermediate sand were identified for wells A39L009PZ and #11. The 'increasing' trend identified for A39L009PZ is based on very low-magnitude changes in VC concentrations, which increased from non-detect (less than 1 µg/L) in June 1997 to 2.1 µg/L in March 2002. There were corresponding decreases in cis-1,2-DCE concentrations at this well over the same period, suggesting gradual transformation of DCE to VC via reductive dechlorination. The measured decrease in cis-1,2-DCE concentrations was much higher in magnitude (69 µg/L) than the measured increase in VC concentrations (maximum of 2.1 µg/L), suggesting that much of the VC produced is also being degraded. VC concentrations at Well #11 increased from 1.4 µg/L in May 2000 to 12 µg/L in March 2002. This well is located near the inferred center of the NW VC plume; therefore, these increases do not indicate an increase in the footprint of the NW Plume. TCE and cis-1,2-DCE concentrations at

Well #11 do not exhibit a trend based on the results of the linear regression and MK tests (Figure 4.13).

In summary, the predominance of 'stable' to 'no trend' determinations for the plume wells screened in the intermediate and deep sands indicates that the CAH plume is largely stable. However, there are a few indications of localized increases in CAH concentrations that suggest the potential for localized plume expansion and therefore merit additional monitoring and trend analysis in the future. The most significant increases in CAH concentrations were noted for TCE in intermediate sand Well A39L036DP, cis-1,2-DCE in intermediate sand Well #17, and VC at deep sand Well #14 and intermediate sand Well #11.

Sentry Wells (NW Plume)

For purposes of this plume stability evaluation, sentry wells at this site are defined as those wells that contain concentrations of individual CAHs that are each less than 1 µg/L. For the NW Plume, sentry wells were regularly monitored in both the intermediate sand and deep sand units. CAH concentrations in both the intermediate sand and deep sand sentry wells were generally below detection limits. The intermediate sand sentry wells are located near the northern, western, and southern boundaries of the NW CAH plume (Figure 4.13). Overall, statistical analysis of results from the intermediate sentry wells suggest that lateral expansion of the CAH plume in the intermediate sand unit was not occurring during the time period assessed.

For intermediate sand sentry wells where one or more CAH concentrations were above the detection limit, results of statistical trend analysis were mostly either 'stable' or 'no trend.' The only exception was the finding of a single 'increasing' trend for TCE at Well #21 using linear regression analysis. The MK result for TCE trend analysis at Well #21 was 'no trend.' Inspection of the historical TCE data (see Appendix C) for this well indicates that the 'increasing' trend should be considered erroneous because the 'increasing' trend was based on a single trace measurement (0.13J µg/L in March 1999) followed by five below detection measurements that were assigned numerical values of 0.5 µg/L, or half the detection limit, in preparation for applying the linear regression trend analysis. While MAROS will accept and perform statistical analysis for data series consisting entirely of "censored" or below-detection limit data, we do not recommend the practice.

Trend analysis results for deep sand sentry wells suggest that lateral expansion of this plume was not occurring in this unit. For the limited cases in deep sand sentry wells where one or more CAH concentrations were above the detection limit, results of statistical trend analysis were mostly either 'stable' or 'no trend'. The only exceptions were 'increasing' trends identified for cis-1,2-DCE at deep sand Well #18 by both the linear regression and MK tests. Cis-1,2-DCE concentrations at this well ranged from below detection limits (less than 0.12 µg/L) to 0.57 µg/L over the three-year period from March 1999 to March 2002. These concentration values are all less than the reporting limit for this compound, so although the 'increasing' trend for cis-1,2-DCE in Well #21 should continue to be monitored, it does not appear to be a cause for concern (i.e., does not represent significant plume expansion) at the present time.

In summary, the trend analysis results for sentry wells in the intermediate and deep sand units indicate that the NW CAH plume in these units was either ‘stable’ or at least ‘no trend’ during the four-year period ending March 2002. The inferred lack of lateral expansion of the CAH plume in the deep sand suggests that significant vertical expansion of the intermediate sand plume into the deep sand also was not occurring. Due to the time-varying groundwater flow directions at this site, contaminant transport is characterized more as a mixing process than a uni-directional plume migration. Continued observation of temporal trends over a longer time period than was available for the current analysis will be necessary to determine if the contamination is truly stable. Nevertheless, the trend analyses performed in the current study using available data support the observation made in the CMS (Parsons, 2000) that NA processes had likely stabilized the plume. In contrast, the sentry well trend results do not appear to support the contention that the NW Plume was expanding, as indicated in a recent LTM report (Law and Tetra Tech, 2002).

Plume Stability Summary (NW Plume)

Table 4.17 lists a summary of the linear regression and MK trends for the NW Plume at SS-45. The linear regression and MK tests for trends in CAH concentrations over time at monitoring wells of the NW Plume generally produced similar results. The primary difference between the two sets of trend results is that the MK test yielded a greater number of ‘stable/no trend’ results while the linear regression test yielded a greater number of ‘decreasing/probably decreasing’ and ‘increasing/probably increasing’ results.

Overall, the current linear regression and MK trend analysis results for the source, plume, and sentry wells installed within and surrounding the NW CAH plume support a finding that this plume is stable. However, there are a few indications of localized increases in CAH concentrations that suggest the potential for localized plume expansion and that bear further analysis for trends as additional data are collected. The combination of a varying flow direction and the relatively short monitoring history at this site limits the ability to use available data to discern plume dynamics with greater certainty than is described above. Based on the preponderance of statistical trend analysis results that suggest that the NW plume is largely stable, continued monitoring of an MNA-based remedy to confirm this finding of plume stability is a scientifically-defensible approach for managing this plume.

Table 4.17 Summary of Current Statistical Analysis Results
Site SS-45 Northwest Plume, England AFB, Louisiana

Statistical Analysis Method	Number of Instances Exhibiting the Indicated Trend					
	Decreasing	Probably Decreasing	Stable	No Trend	Probably Increasing	Increasing
Linear Regression	3	2	9	21	0	9
MK	3	0	14	20	0	7
Data series with one or more detects						
Linear Regression	3	2	9	21	0	9
MK	3	0	14	20	0	7
Data series with all ND						
Linear Regression	3	0	4	4	6	11
MK	0	0	16	10	0	2

4.1.3.3.2 Concentration-based Analysis (SE Plume)

Concentration-based stability analyses obtained for the SE Plume are summarized and compared to historical stability analysis results in Table 4.18, on Figure 4.13, and in the following paragraphs. Numerical results of the linear regression and MK analyses for individual wells are provided in Appendix C.

Source Area (SE Plume)

As described in Section 4.1.3.3, no source area wells were identified for the SE Plume.

SE Plume Area (SE Plume)

Statistical trend analyses were performed for the nine intermediate sand plume wells listed in Table 4.12. Plume wells at this site are defined as those wells where the concentration of at least one CAH was measured as greater than 1 µg/L. As shown on Figure 4.13, 16 of the 54 trend determinations made for the nine plume wells are based entirely on non-detects. Therefore, these 16 trends, which included all six trend designations, are considered spurious. While MAROS will accept and perform statistical analysis for data series consisting entirely of “censored” or below-detection limit data, we do not recommend the practice. Seventeen of the remaining 38 trend determinations (45 percent) made for the nine SE Plume wells are ‘stable’ or ‘no trend,’ and 11 trends (29 percent) are ‘decreasing’ or ‘probably decreasing.’ The remaining 10 trends (26 percent) are either ‘increasing’ or ‘probably increasing.’ Note that while the 11 ‘decreasing’ and ‘probably decreasing’ trend conclusions returned by the linear regression and MK techniques were reasonably consistent with each other, eight of the 10 ‘increasing’ or ‘probably increasing’ trends were obtained via application of the linear regression technique. For two of these eight instances, ‘increasing’ trends identified by linear regression were supported by the MK results. In the other six instances when linear regression indicated an ‘increasing’ or ‘probably increasing’ trend, the MK results were ‘no trend’.

Table 4.18 Results of Historical and Current Concentration-Based Plume Stability Analyses
Site SS-45 Southeast Plume, England AFB, Louisiana

	Data Used for Trend Assessment						
Evaluation Method	**Monitoring Wells**	**Period of Sampling**	**Results of Trend Assessment**	**Plume Stability Conclusion**	**Related Conclusion(s) and Notes**	**Source [a/]**	**Comparison of Historical and Current Plume Stability Conclusions**
Temporal changes in source well concentrations							
No source wells were identified in the southeast plume							
Temporal changes in plume well concentrations [b/]							
Visual inspection of isoconcentration contour maps	Not specified	11/96 to 3/99	CAH concentrations at both the edge and center of the plume are low	Plume may be stable	Given the low concentrations of CAHs at the edge and near the center of the plume, and the relatively long time period since the initial introduction of CAHs to groundwater, it is possible that chemical concentration gradients and/or net advective transport velocities are sufficiently low that advective-diffusive migration has ceased	(1)	The results of the current trend analysis for plume wells support the conclusion made by Parsons (2000) that a full assessment regarding the degree to which the plume is at equilibrium cannot be made on the basis of available data. Rates of change in plume size and shape in a diffusion dominated system are very slow, and additional time-series data are required to more confidently discern plume dynamics. The localized increasing trends identified by the current evaluation may indicate that natural attenuation rates are not sufficiently rapid to prevent plume expansion in localized areas, as postulated by Law and Tetra Tech (2002). Plume expansion at well #23, highlighted by Law and Tetra Tech (2002), is supported by linear regression results for this well, but not by MK results.
Visual inspection of timeseries graphs and tabular data	A39LO10PZ A39LO11PZ	6/96 to 3/99	DCE isomers and VC have decreased through time at A39LO10PZ while ethane has increased DCE has decreased through time at A39LO11PZ while other VOCs have remained relatively constant	A full assessment regarding the degree to which the plume is at equilibrium cannot be made on the basis of the available data	The apparent absence of a greater number of statistically-demonstrable trends of decreasing concentrations through time is probably a result of the limited historical monitoring record	(1)	
Statistical trend analysis using the Mann-Kendall test	A39LO10PZ A39LO11PZ	6/96 to 3/99	*cis* and *trans*-DCE at A39LO10PZ have decreased; no other trend can be confirmed statistically No statistical trend can be confirmed for A39LO11PZ				
Visual inspection of tabular and graphed data	SE Plume interior wells in general	6/97 to 3/02	No consistent trends in CAH concentrations, and no consistent build-up of TCE intermediate degradation products	None provided	Lack of build-up of DCE and VC suggests biodegradation may be limited, and is not significantly reducing concentrations of CAHs	(2)	
Statistical analysis of primary COCs (TCE, DCE, and VC) using linear regression and Mann-Kendall test	9 intermediate sand plume wells listed in Table 4.13	6/97 to 3/02	17 of 38 trend determinations were 'stable' or 'no trend', 11 were 'decreasing' or 'probably decreasing', and 10 were 'increasing' or 'probably increasing'	Most of the CAH plume appears to be stable to decreasing. However, increasing trends identified for DCE and/or VC at 3 wells suggest the potential for localized plume expansion within the intermediate sand. Evidence for plume expansion in the intermediate sand is particularly compelling for well #23	A greater number of 'increasing' or 'probably increasing' trends were identified via linear regression, whereas the MK test yielded a greater number of 'stable' or 'no trend' results	Appendix C of current study	

Table 4.18 Results of Historical and Current Concentration-Based Plume Stability Analyses (continued)
Site SS-45 Southeast Plume, England AFB, Louisiana

	Data Used for Trend Assessment						
Evaluation Method	**Monitoring Wells**	**Period of Sampling**	**Results of Trend Assessment**	**Plume Stability Conclusion**	**Related Conclusion(s) and Notes**	**Source [a/]**	**Comparison of Historical and Current Plume Stability Conclusions**
Temporal changes in sentry well concentrations [c/]							
Visual inspection of tabular and graphed data	Total of 10 sentry wells (defined by Law and Tetra Tech [2002] as wells where concentrations have generally not exceeded MCLs)	6/97 to 3/02	DCE and VC detected in one sentry well (#23) at concentrations > MCLs for first time in 3/02	Plume expanding	--	(2)	Trend results for four intermediate sand sentry wells located south to southwest and east of the CAH plume do not indicate plume expansion. In cases where detections of TCE, DCE, and/or VC occurred, calculated trends were either 'decreasing,' 'probably decreasing', 'stable', or 'no trend'. These sentry well results do not support plume expansion, and therefore are not in full agreement with the conclusions presented by Law and Tetra Tech (2002).
Statistical analysis of primary COCs (TCE, DCE, and VC) using linear regression and Mann-Kendall test	5 sentry wells listed in Table 4.13 (defined as wells that contain less than 1 µg/L of each of the target VOCs)	6/97 to 3/02	One 'increasing' trend for VC in the only deep sand sentry well Trends calculated for intermediate sand sentry wells having target analyte detections were 'stable,' 'no trend' 'decreasing,' or 'probably decreasing'	Plume in intermediate sand is stable; expansion of plume into deep sand may be occurring	• 'Increasing' trend for VC in deep sand well A39L082DP due to detection of 1 µg/L of VC following several non-detects. Potential expansion of the VC plume in this area cannot be verified without additional time series data. • Plume expansion indicated at former intermediate sand sentry well #23 (now defined as a plume well) is discussed above under Plume Wells. • Only one deep sand sentry well is regularly sampled, and there are no sampled sentry wells near the current plume that are screened in the intermediate sand north, west, or southeast of the CAH plume. Therefore, trend analysis results for sentry wells are not definitive indicators of SE Plume dynamics.	Appendix C of current study	

[a/] Sources: (1) Focused CMS (Parsons, 2000)
(2) IRP LTM Report (Law and TetraTech, 2002)

[b/] Plume wells are located within the CAH plume but outside of an inferred source area.

[c/] Sentry wells at SS-45 are located in areas where dissolved contaminant concentrations have not historically exceeded US Environmental Protection Agency Maximum Contaminant Levels (MCLs).

Notes: CAH = chlorinated aliphatic hydrocarbon; COC = contaminant of concern; TCE = trichloroethene; DCE = cis-1,2- dichloroethene, VC = vinyl chloride.

Historical data for the ten instances where ‘increasing’ or ‘probably increasing’ trends were obtained were reviewed in more detail using the data in Table C.3D in Appendix C. Some of the ‘increasing’ or ‘probably increasing’ trends identified by linear regression, but not the MK test, do not appear to be an increasing trend based on a qualitative evaluation. For example, the data set for TCE at A39L012PZ consists of five non-detects with varying detection limits and one trace-level detection (0.35J µg/L). The ‘increasing’ trend identified via linear regression appears to be due primarily to the use of one-half the detection limit for instances where TCE was not detected. While MAROS will accept and perform statistical analysis for data series consisting entirely of “censored” or below-detection limit data, we do not recommend the practice. The data for cis-1,2-DCE in the same well indicate that concentrations increased from less than 0.5 µg/L in December 1997 to 16 µg/L in August 2000, remained stable through the October 2000 event, and then decreased to 2.8 µg/L in March 2001. From a qualitative standpoint, these data do not indicate a sustained increasing trend. Additional data are required to confirm the ‘probably increasing’ trend for VC in plume Well #4, given that the VC concentrations in this well have fluctuated up and down over time.

Instances where review of the historical analytical data supported the occurrence of actual increasing trends in plume wells include VC in Well #3, cis-1,2-DCE in Well #8, and VC and cis-1,2-DCE in Well #23. These three wells are scattered throughout the SE Plume. The first two instances (Well #3 and Well #8) were identified as ‘increasing’ trends by both linear regression and the MK test. In contrast, the MK result for both DCE and VC in Well #23 was ‘no trend’, despite relatively substantial increases in the concentrations of these analytes in March 2002. The statistical properties of the MK test cause the MK test to be less sensitive than linear regression to one-time increases or decreases in concentrations, even if the changes are substantial in magnitude. If sustained increases occur, the MK test will eventually indicate an increasing trend. In the case of cis-1,2-DCE and VC concentrations in Well #23, the linear regression results may be providing an ‘early warning’ of increasing trends that may be of concern.

In summary, despite the fact that 74 percent of the calculated trends for the SE Plume are ‘stable’, ‘no trend’, ‘probably decreasing’, or ‘decreasing’, the ‘increasing’ trends for cis-1,2-DCE and/or VC identified for three wells suggest the potential for localized CAH plume expansion within the intermediate sand. The evidence for plume expansion at Well #23 is particularly compelling, given that concentrations of cis-1,2-DCE and VC increased from below detection limits for both of these CAHs in May 2000 to 110 µg/L and 22 µg/L in March 2002, respectively. A greater number of ‘increasing’ or ‘probably increasing’ trends were identified via linear regression, whereas the MK test tended to yield a greater number of ‘stable’ or ‘no trend’ results.

Sentry Wells (SE Plume)

Sentry wells at this site are defined as those wells that contain concentrations of individual CAHs that are each less than 1 µg/L. CAH concentrations at four sentry wells screened in the intermediate sand unit and one sentry well screened in the deep sand unit (Table 4.13 and Figure 4.13) exhibited a variety of temporal trends. The intermediate sand sentry wells are located south, east, and west of the SE Plume, and the deep sand sentry well is screened beneath the center of the March 2002 VC plume.

Linear regression yielded an ‘increasing’ trend for VC in deep sand sentry well A39L082DP. Review of the historical analytical results for this well indicated five nondetects (less than 1.0 or 1.1 µg/L) followed by a detection of 1 µg/L. Although this may be the first indication of a longer-term increasing trend, potential expansion of the VC plume in the deep sand should be verified with additional time-series data. The MK test indicated a ‘stable’ trend for VC in this well.

Trend results for intermediate sand sentry Wells #6, #7, #9, and A39L073DP do not indicate expansion of the SE Plume. In cases where detections of TCE, cis-1,2-DCE, and/or VC occurred, calculated trends were ‘decreasing’, ‘probably decreasing’, ‘stable’, or ‘no trend’.

Stability Summary (SE Plume)

The results of the MK and linear regression analyses for the SE Plume at SS-45 are summarized in Table 4.19. The primary difference between the linear regression and MK results is that many of the ‘increasing’ or ‘probably increasing’ trends identified via linear regression were identified as ‘no trend’ by the MK test.

Table 4.19 Summary of Current Statistical Analysis Results
Site SS-45 Southeast Plume, England AFB, Louisiana

Statistical Analysis Method	Number of Instances Exhibiting the Indicated Trend [a/]					
	Decreasing	Probably Decreasing	Stable	No Trend	Probably Increasing	Increasing
Linear Regression	5	1	4	5	1	8
MK	4	1	4	13	0	2

[a/] Various trends from 18 additional data series, consisting entirely of non-detect values, were obtained using the MAROS linear regression and MK analyses, but are not reported in this table.

‘Increasing’ trends for cis-1,2-DCE and/or VC identified for three plume interior wells either suggest the potential for localized CAH plume expansion within the intermediate sand, or (in the case of Well #23) indicate that plume expansion has occurred. However, trend results for sentry wells do not indicate expansion of the plume footprint either vertically or laterally. Continued performance of statistical trend analyses as additional data is obtained is recommended to more clearly define temporal trends. It should be noted that only one deep sand sentry well is regularly sampled, and there are no sentry wells screened in the intermediate sand north, west, or southeast of the CAH plume. Therefore, trend analysis results for sentry wells are not definitive indicators of SE Plume dynamics.

4.1.3.4 Results of Current Mass-based Stability Analysis

Figure 4.14 shows the monitoring wells, model domain hull, and Theissen polygons used in the mass-based stability analyses for SS-45, England AFB. The monitoring wells used for the mass-based analyses were selected by reviewing the groundwater sampling history for VOCs summarized in Tables 4.12 and 4.13 and selecting the time periods that had the largest number of wells sampled in common. The common well set for the NW Plume consisted of 13 wells, as listed in table 4.12 and as shown on Figure 4.14. The common well set for the SE Plume consisted of 12 wells, as listed on Table 4.13 and as shown on Figure 4.14. All of the wells used in the mass-based analyses were screened in the intermediate sand unit. The wells in each of these common well sets were sampled four times during a 22-month period from May 2000 to March 2002.

Dissolved CAH Mass (NW Plume)

Figure 4.15 depicts the calculated CAH mass in the NW Plume (by individual species and total CAH as TCE) over time for each of the four sampling events and by analysis method (i.e., Theissen polygon or TIN grid). In general, the TIN grid method and Theissen polygon methods for estimating the dissolved mass of individual CAHs yielded similar estimates. Table 4.20 lists the molar mass of each compound as a percentage of the total molar CAH mass. As can be observed from Figure 4.15 and Table 4.20, the majority of dissolved mass in the NW Plume in May and October 2000 occurred as TCE, while the majority of CAH mass present in the 2001 was cis-1,2-DCE. In March 2002, the calculated dissolved masses of TCE and cis-1,2-DCE were nearly equal.

Table 4.20 Summary of CAH Distribution by Mass Percentage
Site SS-45 Northwest Plume, England AFB, Louisiana

	TCE		DCE		VC	
Sampling Date	**Kriging**	**Theissen**	**Kriging**	**Theissen**	**Kriging**	**Theissen**
May 2000	76.0%	69.0%	22.6%	29.4%	1.3%	1.6%
October 2000	67.1%	61.8%	31.4%	36.4%	1.5%	1.8%
March 2001	23.8%	23.7%	72.9%	73.1%	3.3%	3.2%
March 2002	45.9%	42.8%	49.7%	52.4%	4.5%	4.8%

Trend analyses for changes in the mass of CAH over time were performed using visual inspection of Figure 4.15 and application of the MK test for trends. The results of applying the MK test to the mass results are shown in the legend on the bottom of Figure 4.15. Visual inspection of Figure 4.15 suggests that the total CAH mass was relatively constant during the 22-month time period assessed. Application of the MK test confirmed this observation in that a ‘no trend’ result was indicated for the total CAH mass over time. The observation that total CAH mass was stable over the 22-month assessment period supports a finding that the plume is either stable or expanding. To determine whether the spatial extent of the CAH plume has stabilized, the concentration-based analyses (described above) and the center of mass calculations (described below) can be combined with the mass estimate to make a determination. This overall assessment for stability of the NW plume is described below in Section 4.1.3.5.

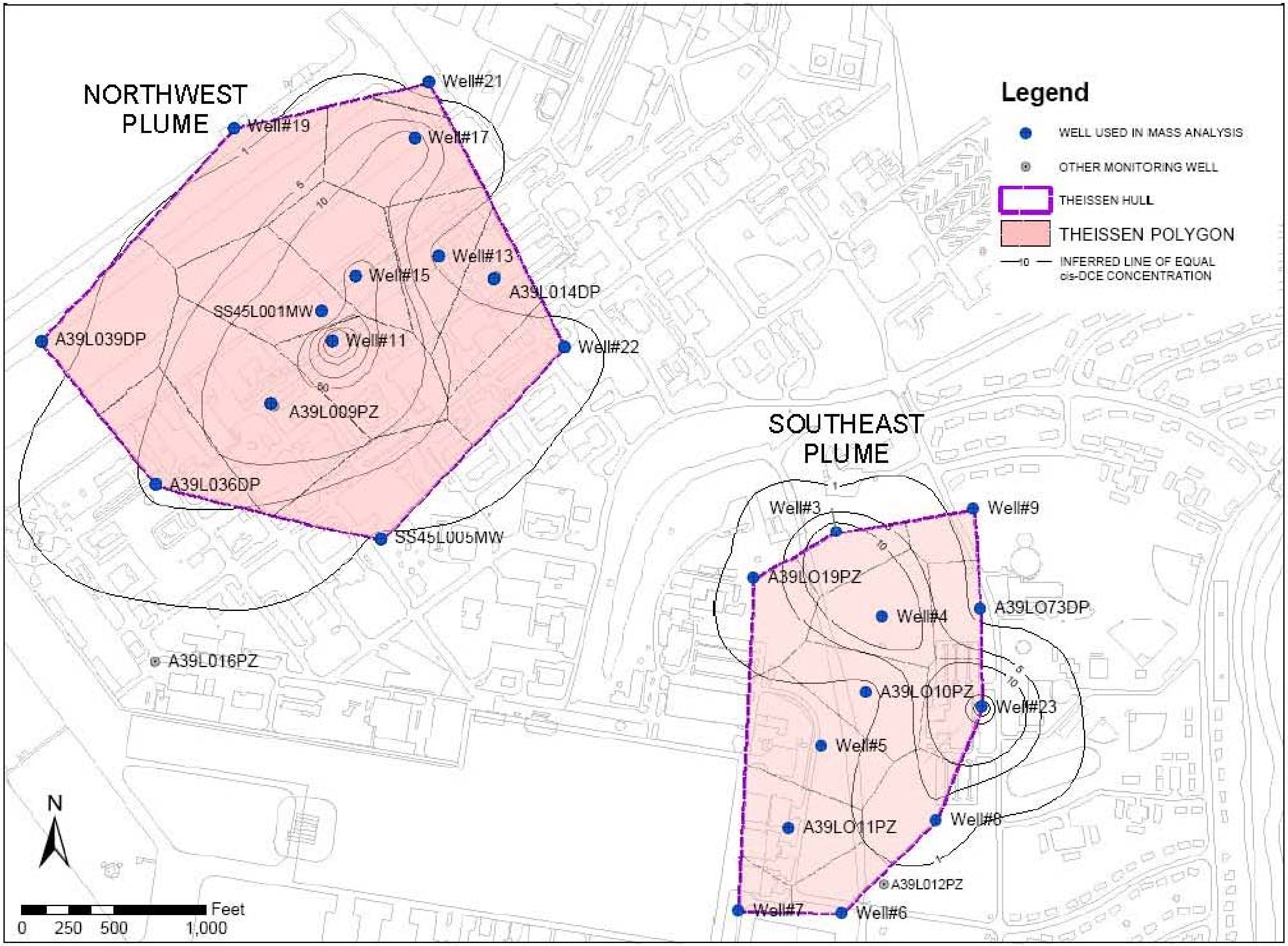


Figure 4.14 Model Domain and Common Wells for Mass-Based Calculations Site SS-45, England AFB, Louisiana

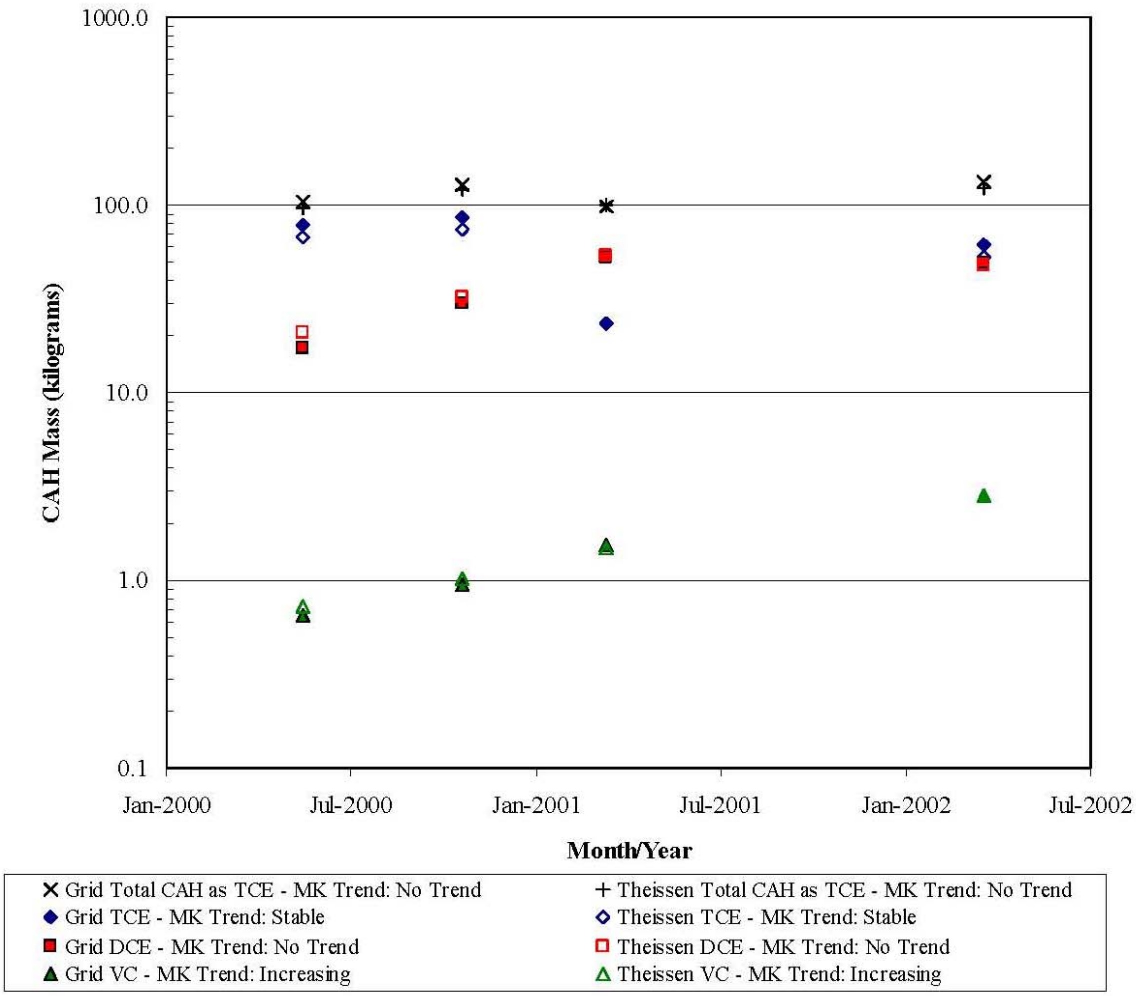


Figure 4.15 Estimated Dissolved Mass of CAH Compounds
Site SS-45 Northwest Plume, England AFB, Louisiana

Visual inspection of TCE mass over time indicates that the calculated TCE mass increased very slightly from May to October 2000, decreased substantially from October 2000 to March 2001, and then partially rebounded from March 2001 to March 2002. The MK test result for TCE mass over time was ‘stable’, which indicates that TCE mass did not decline in a statistically-significant manner over the 22 months of observation. The calculated cis-1,2-DCE mass increased from May 2000 to March 2001, then was relatively stable from March 2001 to March 2002. The MK result for cis-1,2-DCE was ‘no trend’, indicating that statistical testing of the increase in cis-1,2-DCE mass between May 2000 and March 2002 did not indicate a statistically significant trend for the available data. It is important to note that the properties of the MK test make it nearly impossible for this test to identify a trend other than ‘stable’ or ‘no trend’ if only four data points are used and there is a ‘fluctuation’ in the tend during one of these time periods. It is expected that the results of the MK trend and visual observation will converge if additional data is collected and used in future trend analyses. The calculated VC mass was observed to increase steadily throughout the 22-month assessment period. This trend was confirmed statistically by the identification of a statistically ‘increasing’ trend in the estimated VC mass over time. Further, since the total CAH mass is almost two orders-of-magnitude greater than the VC mass, it is reasonable that significant increases in VC are discernable while any corresponding decreases in TCE or cis-1,2-DCE are too small to be discerned as a trend.

Changes in the molar mass distribution over time, as reported in Table 4.20, were also reviewed as part of the current mass-based plume stability assessment. For example, the molar percentage of CAH mass found as TCE decreased from roughly 70 percent in 2000 to less than 50 percent in 2001 and 2002, with a corresponding increase in the mass percentage of cis-1,2-DCE and, to a lesser extent, VC. The combination of a decreasing TCE mass percentage with increases in the mass percentage of cis-1,2-DCE and VC mass suggests that NA through reductive dechlorination was more active in 2001 and 2002 than it was in 2000, and that the rate of TCE degradation in 2001 and 2002 was higher than the rate of TCE dissolution into groundwater during this time period.

These observations concerning contaminant mass changes over time should not be extrapolated into the future because the time period of available data is too short (i.e., 22 months) to support reliable predictions of plume mass dynamics. Continued monitoring of the thirteen intermediate sand wells indicated in Table 4.12 is recommended to support future mass-based calculations that can be used to confirm whether TCE has truly begun to decrease, or if the observed change is a temporary phenomena. Possible explanations why the TCE mass in the system may be changing include weathering of the contaminant source, ‘pulsed’ release of TCE from the contaminant source, yearly variations in precipitation recharge or other environmental factors, and natural variability in in situ degradation rates.

Center of Mass (NW Plume)

Figures 4.16 through 4.18 depict the locations of the centers of dissolved TCE, cis-1,2-DCE, and VC mass over time for each of the four sampling events and by analysis method (i.e., Theissen polygon or TIN grid) on a site base map. The center of mass for TCE in the NW Plume was calculated to be in a relatively constant location over time. In contrast, the center of mass calculations for cis-1,2-DCE and VC in the NW Plume suggest that the centers of mass for these compounds may be slowly migrating toward the east. Performance of center of mass calculations using more recent sampling data is recommended prior to drawing a final conclusion on this eastward trend because of the limited duration of appropriate data for performing this analysis.

Dissolved CAH Mass in the SE Plume

Figure 4.19 depicts the calculated CAH mass in the SE Plume (by individual species and total CAH as TCE) over time for each of the four sampling events and by analysis method (i.e., Theissen polygon or TIN grid). As was observed for the NW Plume, the TIN grid and Theissen polygon methods yielded similar estimates for the dissolved mass of both individual CAH and total CAH mass. Table 4.21 lists the molar mass of each compound as a percentage of the total molar CAH mass. As can be observed from Figure 4.19 and is shown on Table 4.21, the majority of dissolved mass in the SE Plume for the 22-month period between May 2000 and March 2002 was VC, with the remaining CAH mass found as cis-1,2-DCE. As listed in Table 4.21, TCE was less than 0.1 percent of the total CAH mass in the SE Plume for all four monitoring events. For this reason, the estimated masses of dissolved TCE mass were not shown on Figure 4.19.

Trend analyses for changes in the mass of CAH over time were performed using visual inspection of Figure 4.19 and application of the MK test for trends. The results of applying the MK test to the mass results are shown in the legend on the bottom of Figure 4.19. Visual inspection of Figure 4.19 for trends in CAH mass over time indicates that the total CAH mass decreased substantially from October 2000 to March 2002. Results of applying the MK test to the total CAH mass estimates were a ‘stable’ trend. This combination of observations on total CAH mass suggests that the SE Plume is stable to diminishing over time. As was noted above for the NW Plume, the reason that the MK test indicates a ‘stable’ trend when visual inspection suggests an overall decreasing trend may have been that there was a ‘fluctuation,’ rather than constant decline, in the mass estimate for the four data sets used in these calculations. The results of the MK trend and visual observation may be expected to converge if additional data is collected and used in future trend analyses.

Table 4.21 Summary of CAH Mass by Compound
Site SS-45 Southeast Plume, England AFB, Louisiana

	TCE		DCE		VC	
Sampling Date	**Kriging**	**Theissen**	**Kriging**	**Theissen**	**Kriging**	**Theissen**
May 2000	0.0%	0.0%	23.4%	20.5%	76.6%	79.5%
October 2000	0.0%	0.0%	18.5%	16.0%	81.5%	84.0%
March 2001	0.0%	0.0%	21.8%	19.4%	78.2%	80.6%
March 2002	0.0%	0.0%	25.1%	22.0%	74.9%	78.0%

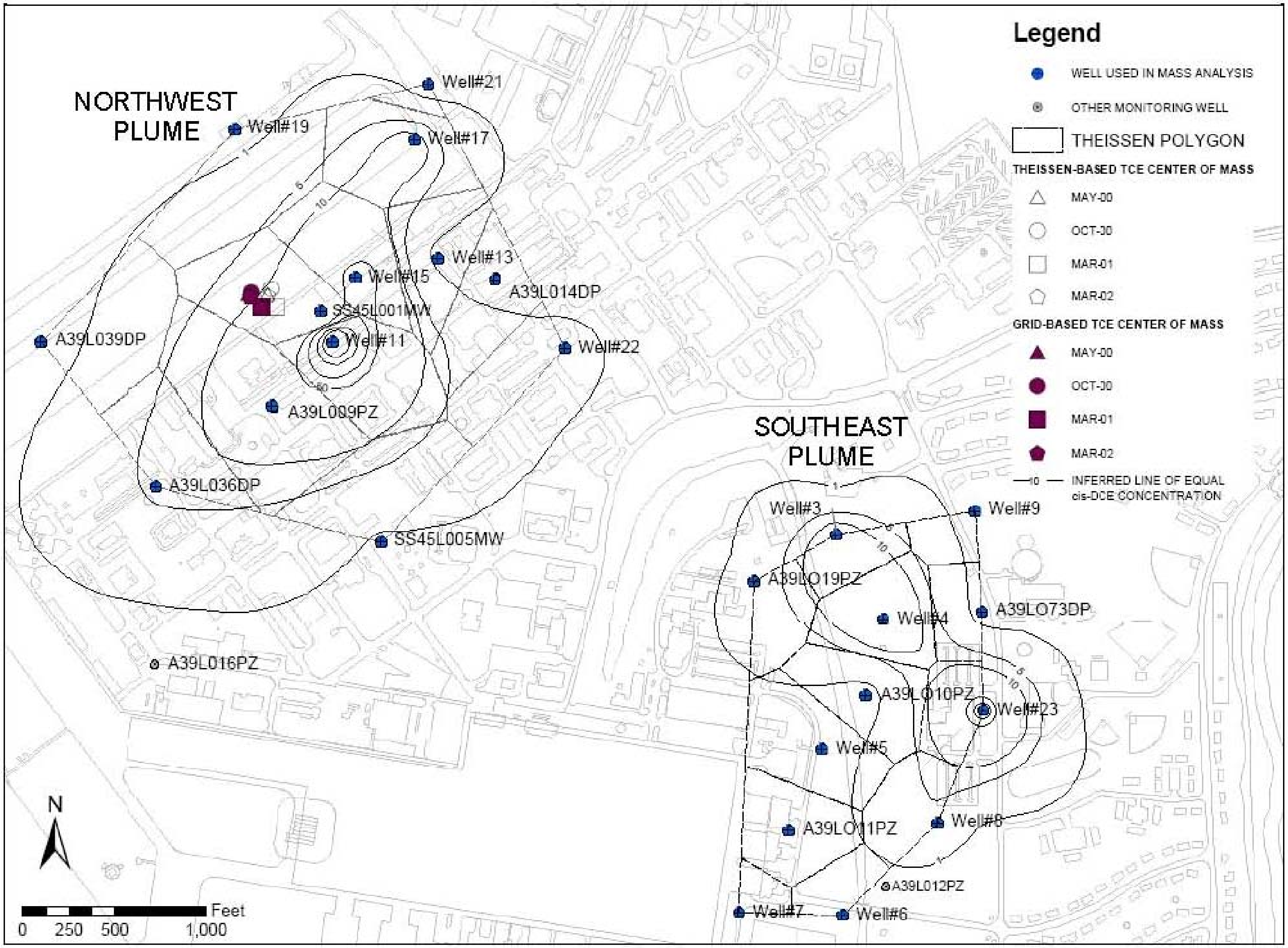


Figure 4.16 Location of Centers of Mass For TCE
Site SS-45, England AFB, Louisiana

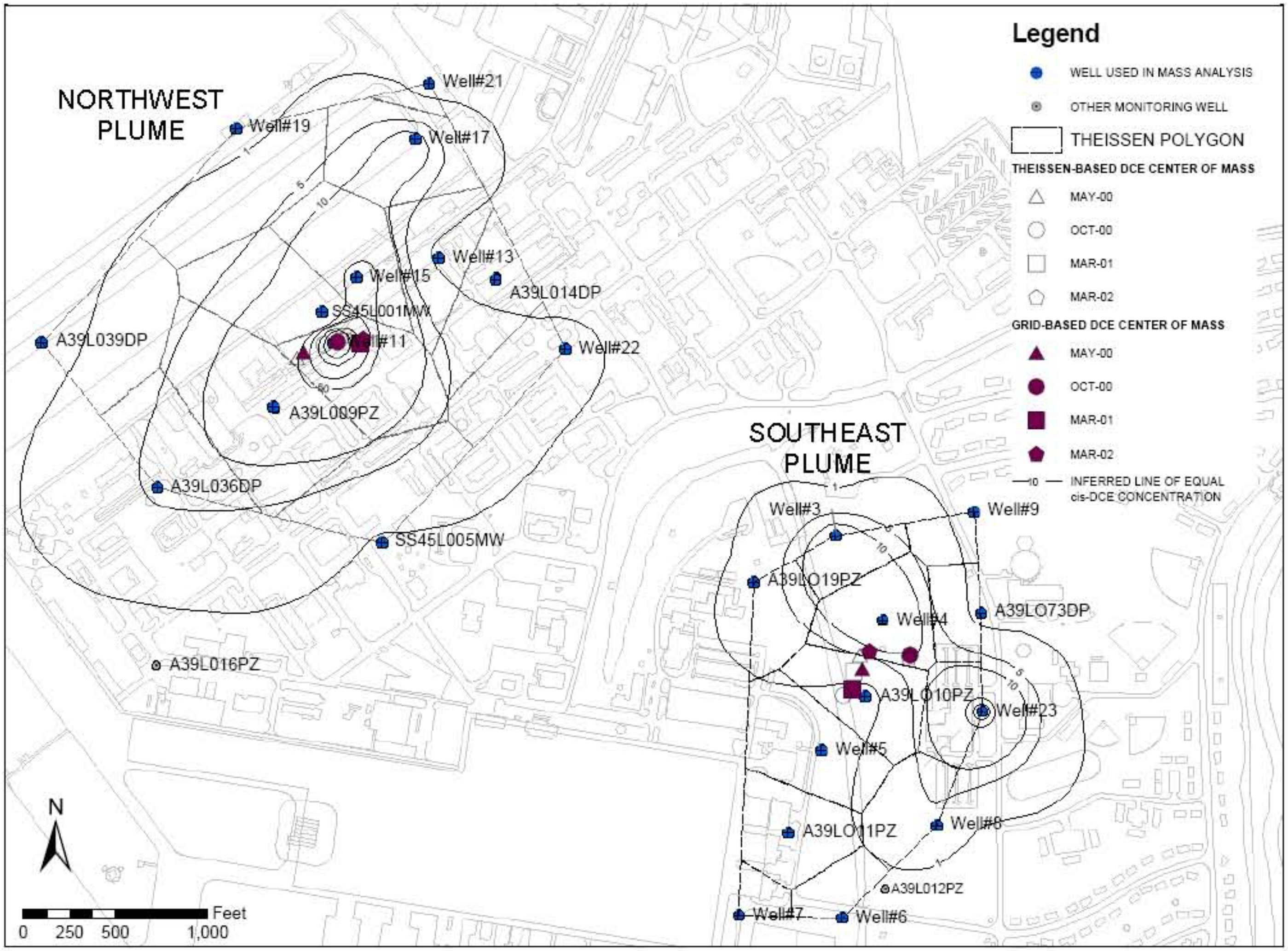


Figure 4.17 Location of Centers of Mass for cis-1,2-DCE
Site SS-45, England AFB, Louisiana

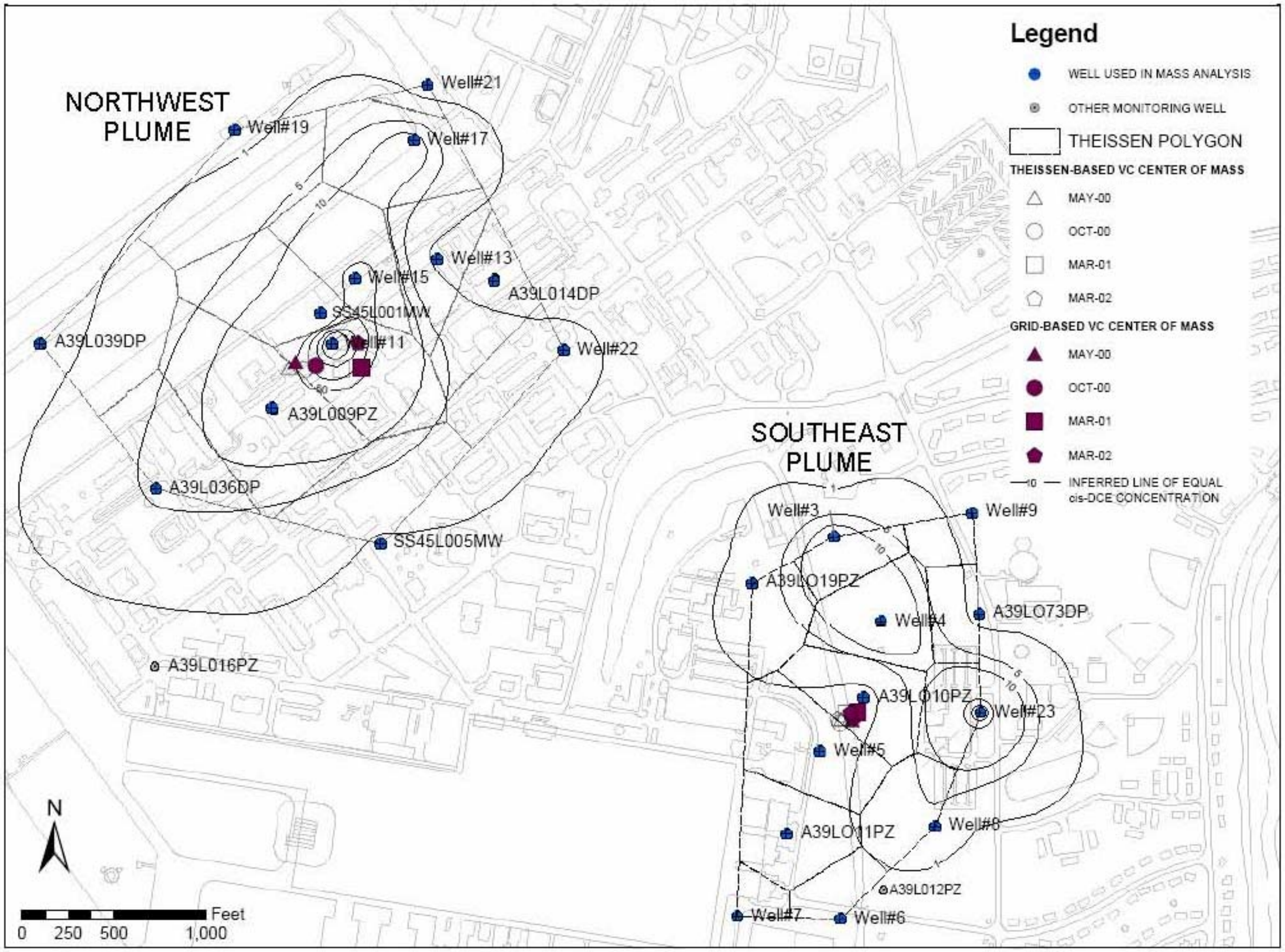


Figure 4.18 Location of Centers of Mass for VC
Site SS-45, England AFB, Louisiana

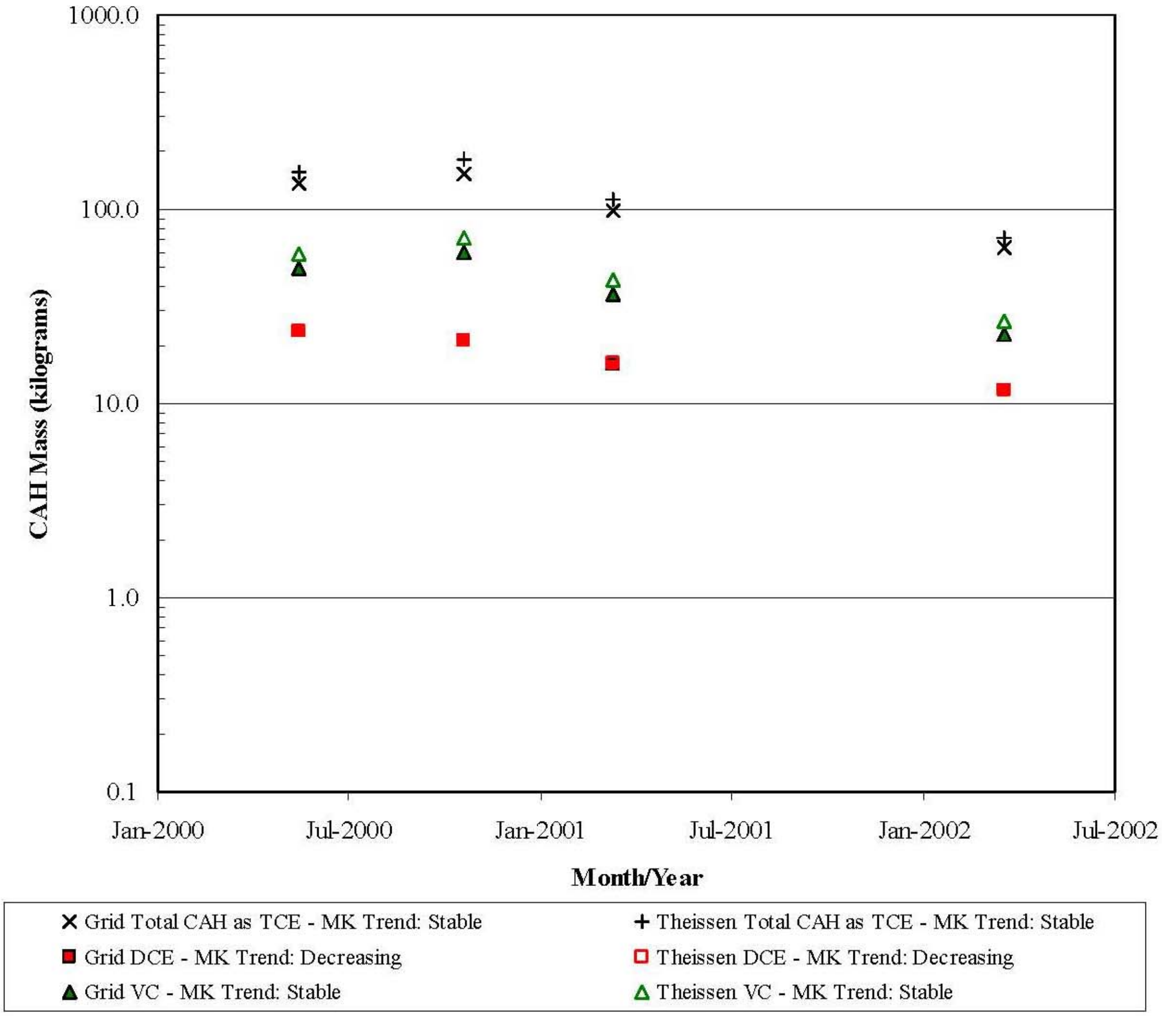


Figure 4.19 Estimated Dissolved Mass of CAH Compounds
Site SS-45 Southeast Plume, England AFB, Louisiana

Both visual observation and the MK analysis indicate a decreasing trend for cis-1,2-DCE mass over time, providing strong evidence that the cis-1,2-DCE plume is diminishing over time. Visual inspection of the estimated VC mass over time shows a slight increase in dissolved VC mass between May 2000 and October 2000, followed by a steady decrease in dissolved VC mass in sampling events during 2001 and 2002. MK analyses of the VC mass data indicates a 'stable' trend. It is interesting to note that the molar mass percentages of cis-1,2-DCE and VC remained relatively constant over the duration of the 22-month monitoring period. One explanation for this constant ratio of cis-1,2-DCE to VC is that the NA rate of these to compounds is equal. The combined observations of a statistical decrease in cis-1,2-DCE mass and an observed decrease in VC mass suggests that NA processes (i.e., reductive dechlorination and/or direct oxidation) are effective in degrading the remaining CAH contamination in the SE Plume at a rate faster than it is being released to groundwater. The absence of appreciable TCE mass suggests that the source of parent CAH compound to groundwater has been eliminated by natural processes. The absence of a significant CAH source adds further support to a conclusion from the mass-based results that the SE Plume is likely to continue to diminish in size and mass over time.

Center of Mass (SE Plume)

As introduced previously, Figures 4.17 and 4.18 depict the locations of the centers of mass for cis-1,2-DCE and VC over time for each of the four sampling events and by analysis method (i.e., Theissen polygon or TIN grid) on a site base map for SS-45. The location of the center of mass for TCE was not plotted on Figure 4.16 due to the very small mass of this contaminant. Visual inspection of Figure 4.17 indicates that the location of the center of mass for cis-1,2-DCE in the SE Plume moved over a larger distance than the other CAHs at SS-45, but generally was observed to remain in the west-central portion of the SE plume. By comparison, the center of mass for VC in the SE Plume was calculated to be in a nearly constant location over this timeframe. The absence of migration of the center of mass for cis-1,2-DCE and VC suggests that SE Plume is generally stable.

Summary of Mass-Based Analysis Results

Overall, the results of applying mass-based analyses to data from the NW and SE Plumes at SS-45 indicated the following:

- The SE Plume is clearly in a diminishing stage, whereas the NW Plume appears to be largely stable with localized areas of potential expansion. Evidence that the SE Plume is diminishing includes that 1) the majority of mass in the SE Plume is found as vinyl chloride, with almost no mass remaining as TCE, 2) the mass of total and individual CAHs in the SE Plume appears to be declining; 3) the locations of the center of mass in the SE Plume are relatively stable. Evidence that the NW Plume is either stable or potentially expanding includes that 1) significant dissolved contaminant mass is still found as TCE, 2) total and individual CAH mass appear to be stable or increasing over time, and 3) the center of mass for cis-1,2-DCE and VC was calculated as migrating in an easterly direction.

- Possible explanations for this difference in plume stability and condition include 1) the source mass of TCE released to the SE Plume was smaller than that released to the NW Plume and 2) the rate of contaminant degradation in the SE Plume was greater than in the NW Plume;

- The TIN grid and Theissen polygon methods of estimating dissolved CAH mass and centers of mass yielded similar results;

- The relatively short time period of available data (i.e., 22 months) makes it difficult to definitively identify trends, although available data does allow for identification of potential trends; and

- The limitation of having a common well set of only four wells confounds application of the MK test for statistically identifying increasing or decreasing trends results if one of the four data points causes a 'fluctuation' in the data trend.

4.1.3.5 Plume Stability Analysis Summary

Based on the available LTM data, the results of the concentration- and mass-based stability analyses indicate that the NW plume is stable or potentially expanding. This plume is large, with an estimated maximum length in March 2002 of approximately 3,300 feet, and is inferred to have expanded in a generally uniform radial direction due to a time-varying direction of groundwater flow and contaminant transport. The strongest evidence that the NW Plume is stable are the combined observations that 1) the total dissolved CAH mass is generally constant and 2) CAH concentration in NW Plume sentry wells have remained below detection. The strongest evidence that the plume has the potential for expansion includes the 1) identification of localized areas of statistically-significant increases in CAH concentrations within several plume wells, 2) observation of increasing mass of dissolved VC and probably cis-1,2-DCE, 3) observed eastward drift of the location of the center of mass for cis-1,2-DCE and VC, and 4) persistence of significant TCE mass in the aquifer.

The combined results of concentration-based and mass-based stability analyses suggest that the SE Plume is diminishing overall, with local areas where plume expansion may be occurring. The strongest evidence for a diminishing SE Plume is 1) the high percentage of VC mass, 2) the absence of a TCE source, and 3) the observed decrease in both total and individual CAH masses over time. The localized increases in CAH concentrations in the southern portion of the SE plume appear to indicate the potential for plume expansion in this area, and continued monitoring of existing wells, with the possible installation of additional monitoring wells to the south and east of this plume may be required to monitor localized contaminant migration towards potential receptors. Due to the weak strength of the contaminant source in the SE plume, it is reasonable to expect that CAH concentrations will begin to decrease in all monitoring wells due to NA effects.

4.1.3.6 Recommendations

As the length of the monitoring period and the number of data points for a given well increases, performance of statistical analyses will typically facilitate obtaining more definitive trend analysis results and increase the confidence in plume stability-related conclusions, especially in cases where temporal changes in monitoring well concentration or CAH mass are not obvious from visual inspection of data trend plots. While the above observations can be considered representative of current trends in CAH plume dynamics at SS-45, collection and analysis of additional monitoring data is recommended to further assess whether these observations are valid over the longer-term, particularly with respect to the potential of localized plume expansion. Specific examples of how the current data limits the quantitative assessment of plume dynamics include:

- The mass-based analysis was performed using data collected over a 22-month monitoring period. The concentration-based analysis was performed using data collected over a time period ranging from 22 months to nearly 5 years. Given the estimated slow rate of change in plume conditions at SS-45, analysis of data from a longer monitoring period is required to confidently discern plume dynamics;

- The results of the MK test for trend analysis of CAH mass over time would be more robust by the inclusion of additional monitoring data sets beyond the four currently available; and

- Only one deep sand sentry well is regularly sampled at the SE Plume, and there are no sentry wells screened in the intermediate sand north, west, or southeast of this plume. Therefore, trend analysis results for sentry wells may not be representative of SE Plume dynamics in these directions.

Available data for wells located within and around (both laterally and vertically) the NW and SE Plumes should continue to be assessed qualitatively using visual/graphical techniques to supplement statistical analysis results.

Periodic (e.g., once every 3 to 5 years) performance of quantitative analysis using concentration-based and/or mass-based statistical analyses can also be used to support future statistical analyses of CAH plume dynamics at SS-45. The minimum data needed to support further quantitative analysis would include periodic measurement of CAH concentrations in all of the ‘common’ wells listed in Tables 4.12 and 4.13. In addition, installation and sampling of an additional sentry well in the intermediate sand east of SE Plume Well #23 should be considered to assess potential continuing plume expansion in this area. The recommended location of this additional well, if installed, would between Well #23 and Bayou Rapides. In addition, the adequacy of the sentry well network in the intermediate sand unit north, west, and southeast of the SE plume and in the deep sand unit beneath the SE Plume should be assessed to ensure that it is adequate to meet site-specific data quality objectives for monitoring plume expansion and receptor exposure.

4.1.4 Facility 1381, Cape Canaveral Air Station, Florida

4.1.4.1 Site Overview and Summary of Available Data

Site Description

Cape Canaveral Air Force Station (CCAFS) is located on a barrier island off the east coast of Florida. The main complex occupies approximately 25 square miles of assembly and launch facilities for missiles and space vehicles. Facility 1381 is located in the center portion of the facility, just north of the CCAFS landfill. Several facilities are located within this site, including the support Facility Equipment Shed (AOC-517), the former Acid Neutralization Pit (AOC-518), and the Drainfield/Septic Tank (AOC-519). Ownership and operations of Facility 1381 have changed several times since 1958. The US Coast Guard has been operating the site as an Ordnance Support Facility since 1977.

CAH contamination at the site is suspected to have resulted from accidental releases during past metal cleaning operations. In the earliest available photograph of the site, taken in 1967, several drums were visible resting on the ground surface at various locations across the site. During site reconnaissance conducted as part of the 1998 RCRA Facility Investigation (RFI) report, several drums were discovered outside the fenced area southwest of Facility 1381 (Parsons, 1998a). It is suspected that drums containing CAHs were periodically stored at this location and contributed to soil and groundwater contamination. Solvents also were released at the site during the dumping of solvents from tanker trucks in wooded areas around the site. The duration of the disposal practices described above is unknown.

Plume Description

The conceptual site model for the Facility 1381 CAH plume incorporates three hydrogeologic units: shallow, intermediate and deep. Aquifer test results indicate that the shallow aquifer has a hydraulic conductivity ranging from 10 to nearly 90 ft/day. Estimated hydraulic conductivites in the intermediate and deep aquifers are lower (0.39 ft/day and 0.23 ft/day, respectively). Horizontal hydraulic gradients are variable in the shallow aquifer depending on nearby surface water features, with magnitudes ranging from 0.00011 to 0.00059 ft/ft. There is a groundwater divide near the source area, and a plume extending to the northeast in all three aquifers. Groundwater seepage velocities are estimated to be as high as 77 ft/yr in the shallow aquifer; this maximum value is consistent with the plume length given the estimated elapsed time since the contaminant release (Parsons, 1999c).

The primary COCs at Facility 1381 are TCE, cis-1,2-DCE, and VC. Groundwater analytical data collected in 1996 indicated that the TCE contamination was limited to an approximately 200-ft radius from Facility 1381, with the source of the plume located in the vicinity of well 1381MWS09 (Figure 4.20). TCE has been found in deep aquifer monitoring wells, indicating that TCE has penetrated to the full depth of the surficial aquifer in the source area.

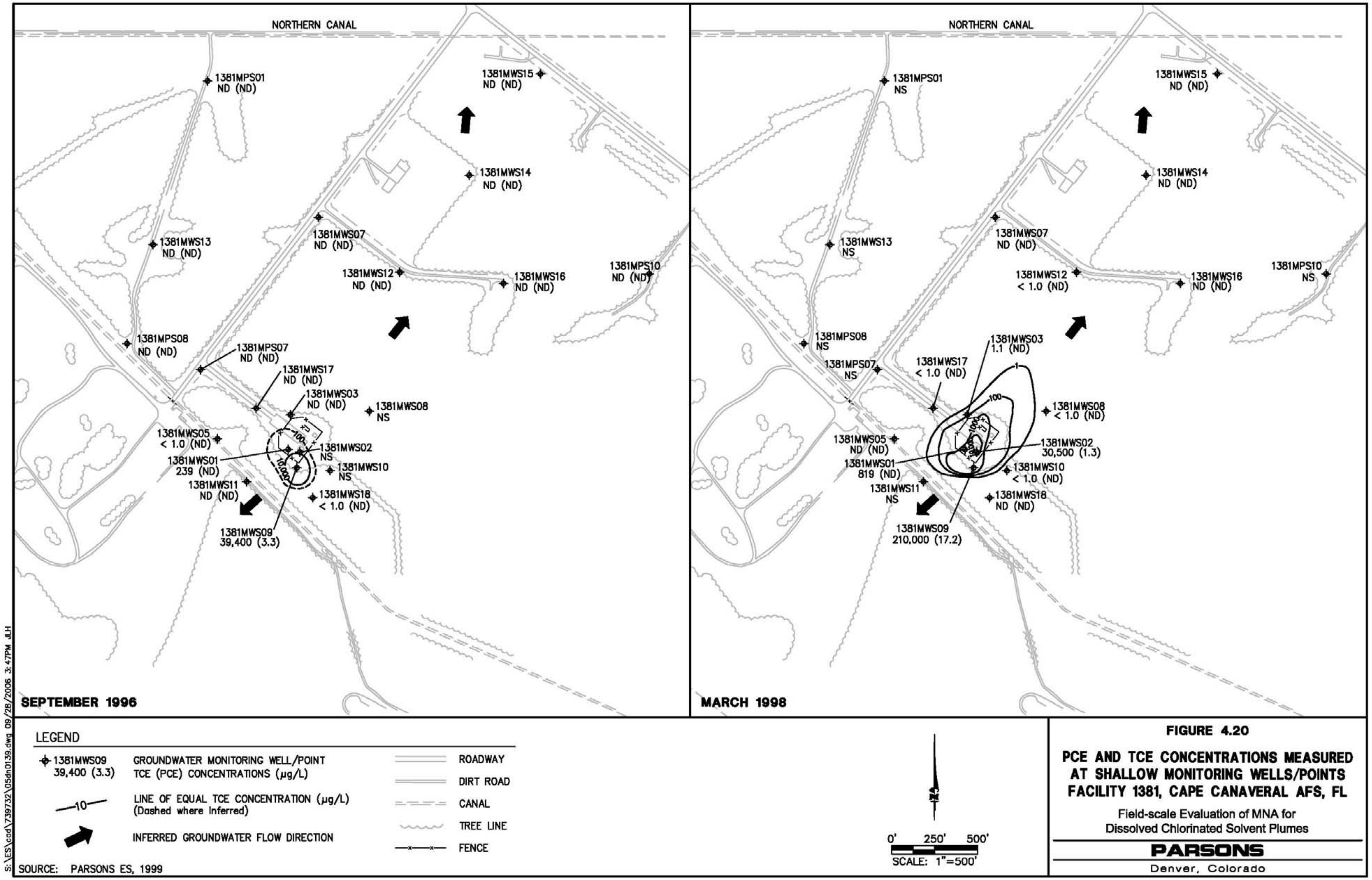


Figure 4.20 PCE and TCE Concentrations Measured at Shallow Monitoring Wells/Points, Facility 1381, Cape Canaveral AFS, Florida

As part of the RFI (Parsons, 1998a), cis-1,2-DCE was identified as the most widespread CAH detected in groundwater, comprising a plume measuring approximately 3,200 feet in length along a southwest/northeast axis (Figure 4.21). The cis-1,2-DCE data collected during a Remediation by Natural Attenuation Treatability Study (RNA TS; Parsons, 1999c) indicated that the general shape of the cis-1,2-DCE plume was remaining stable, but also that cis-1,2-DCE concentrations in most groundwater wells increased during the 17 months between sample collection for the RFI and the RNA TS.

VC is widespread in groundwater at Facility 1381, and was detected in the majority of groundwater samples collected as part of the RFI and RNA studies (Figure 4.22). The shape and extent of the VC plume is similar to the cis-1,2-DCE plume.

Historic site characterizations have revealed that hydrogeologic conditions at the site create both northward and southward contaminant migration due to the presence of a groundwater divide. Contaminated groundwater that discharges to the geographically closer southern drainage canal contains elevated concentrations of TCE and PCE.

Description of Engineered Remediation

Various innovative technologies have been tested to determine their effectiveness in treating dissolved contamination and/or DNAPL contamination at Facility 1381. All of the remedial actions have been applied to the southern portion of the plume, including a groundwater recirculation well, reductive anaerobic biological in-situ treatment, an air sparging pilot study, and a phytoremediation study. The innovative technology studies were conducted within the source area of the plume core and affected relatively small areas within the southern portion of the plume.

Nature of Historical Data and Current LTM Program

The current LTM program for Facility 1381 consists of monitoring groundwater and surface water every six months for VOCs. In addition, MNA parameters are collected annually to evaluate and track potential changes in dissolved VOC concentrations as a result of NA processes and to collect data for future actions required to protect human health and the environment (BEM, 2002). The scope of previous groundwater monitoring events for VOCs performed at Facility 1381 between December 1995 and November 2003 is summarized in Table 4.22.

Rationale for Selection for Case Study

Facility 1381 was selected as a case study for mass-based plume stability analysis based on the following two considerations:

1. Remedial actions performed at this site have been small-scale, innovative technology studies that have impacted a small portion of the plume near the source area. Because the affected area is small and within the southern portion

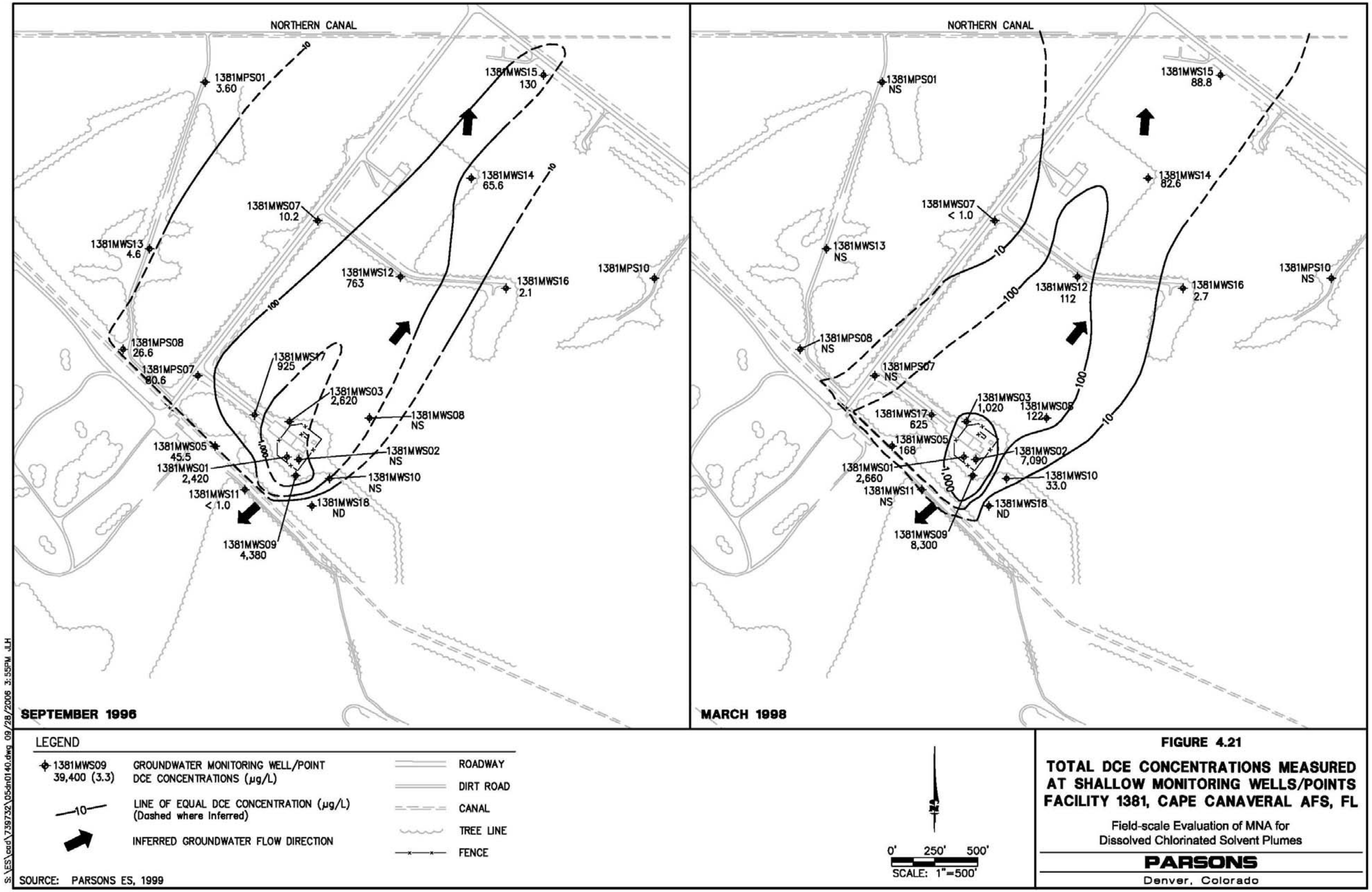


Figure 4.21 Total DCE Concentrations Measured at Shallow Monitoring Wells/Points, Facility 1381, Cape Canaveral AFS, Florida

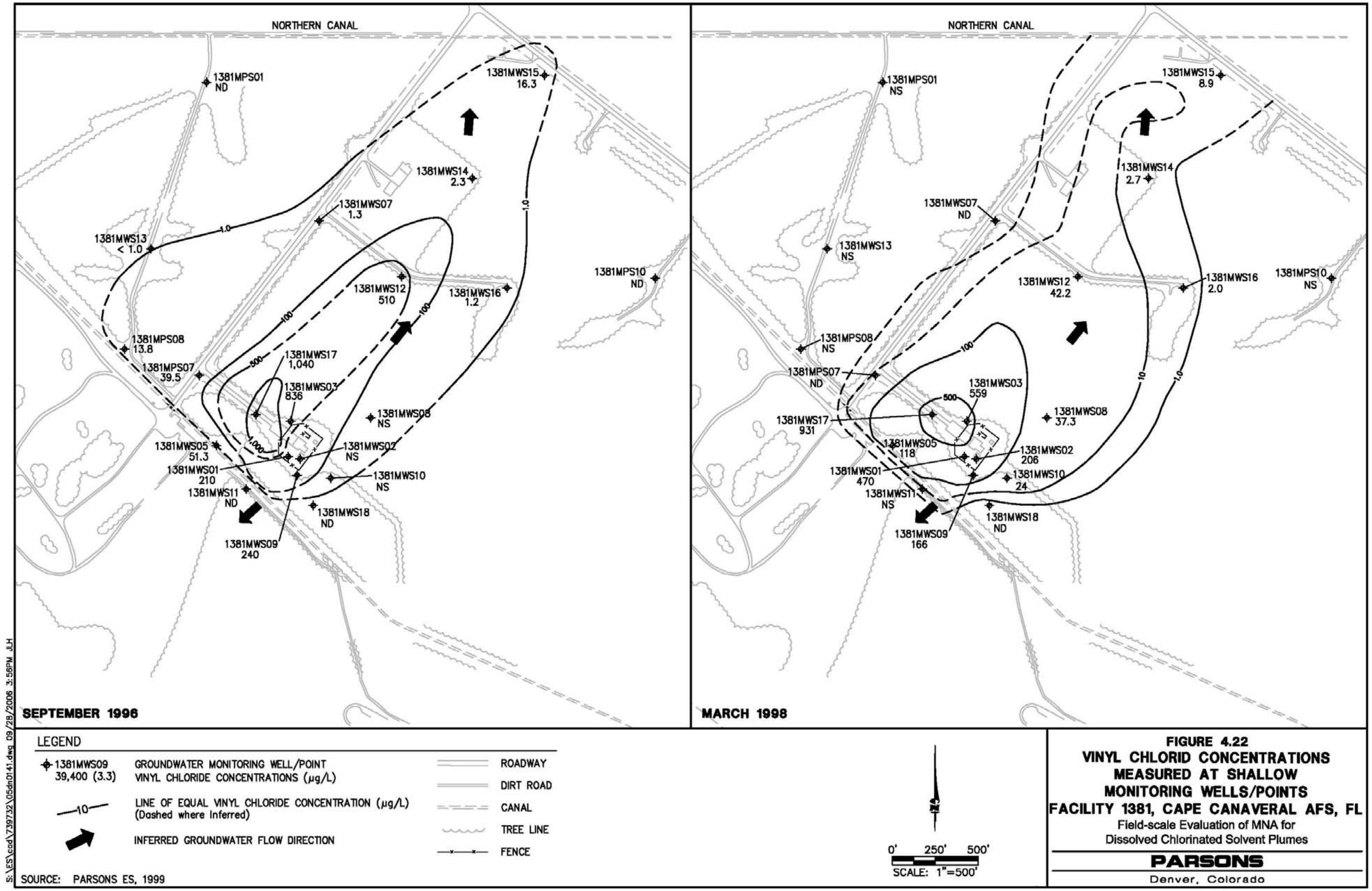


Figure 4.22 Vinyl Chloride Concentrations Measured at Shallow Monitoring Wells/Points, Facility 1381, Cape Canaveral AFS, Florida

Table 4.22 Summary of Groundwater Sampling for VOCs, Facility 1381, Cape Canaveral AFS, Florida Field-Scale Evaluation of MNA for Dissolved Chlorinated Solvent Plumes

Well	Completion Date	Position in Aquifer	Plume Position	Used in Statistical Analyses?	Sampling Date for VOCs [a/]										
					Dec-95	Mar-96	May-96	Sep-96	Mar-98	Mar/Apr-99	Jul/Aug-01	Mar-02	Nov/Dec-02	May/Jun-03	Oct/Nov-03
MWS02	Dec-93	Shallow	Source	No	X				X		X				
MWS09	Mar-96	Shallow	Source	Yes		X		X	X		X		X	X	X
PZ01	Unknown	Shallow	Source	No							X				
MWI09	Feb-96	Intermediate	Source	Yes				X	X		X		X	X	X
MWI19	Unknown	Intermediate	Source	Yes							X		X	X	X
MWI20	Unknown	Intermediate	Source	Yes							X		X	X	X
MPS01	Sep-96	Shallow	Plume	Yes				X			X		X	X	X
MPS04	Unknown	Shallow	Plume	No								X			
MPS07	Sep-96	Shallow	Plume	No				X			X				
MPS09	Unknown	Shallow	Plume	No								X		X	X
MWS01	Nov-93	Shallow	Plume	Yes	X			X	X		X				
MWS03	Dec-95	Shallow	Plume	Yes	X			X	X	X	X				
MWS05	Jan-96	Shallow	Plume	Yes		X		X	X	X	X				
MWS06	Jan-96	Shallow	Plume	No				X							
MWS07	Jan-96	Shallow	Plume	Yes				X	X	X	X		X	X	X
MWS08	Mar-96	Shallow	Plume	Yes		X			X	X	X		X	X	X
MWS10	Feb-96	Shallow	Plume	Yes		X			X	X	X		X	X	X
MWS12	Mar-96	Shallow	Plume	Yes		X		X	X	X	X				
MWS13	Mar-96	Shallow	Plume	Yes				X	X	X	X		X	X	X
MWS14	Mar-96	Shallow	Plume	Yes		X		X	X		X		X	X	X
MWS15	May-96	Shallow	Plume	Yes		X		X	X		X		X	X	X
MWS16	May-96	Shallow	Plume	Yes				X	X		X		X	X	X
MWS17	May-96	Shallow	Plume	Yes			X	X	X	X	X		X	X	X
MPI03	Sep-96	Intermediate	Plume	No				X			X				
MPI08	Sep-96	Intermediate	Plume	No				X			X				
MPI11	Sep-96	Intermediate	Plume	No				X			X				
MPI13	Sep-96	Intermediate	Plume	No				X			X				
MPI17	Sep-96	Intermediate	Plume	No				X			X				
MPI18	Sep-96	Intermediate	Plume	No				X	X		X				
MPI19	Sep-96	Intermediate	Plume	No				X			X				
MPI21	Sep-96	Intermediate	Plume	No				X			X				
MWI05	Jan-96	Intermediate	Plume	No					X		X				
MWD09	Mar-96	Deep	Plume	Yes				X	X		X		X	X	X
MWD10	Feb-96	Deep	Plume	Yes							X		X	X	X
MPS10	Sep-96	Shallow	Sentry	No				X			X				
MPS16	Unknown	Shallow	Sentry	No								X			
MWS11	Mar-96	Shallow	Sentry	Yes				X			X		X	X	X
MPI01	Sep-96	Intermediate	Sentry	Yes				X			X		X	X	X
MPI02	Sep-96	Intermediate	Sentry	Yes				X			X			X	X
MPI05	Sep-96	Intermediate	Sentry	Yes				X			X		X	X	X

Table 4.22 Summary of Groundwater Sampling for VOCs, Facility 1381, Cape Canaveral AFS, Florida (continued)

Well	Completion Date	Position in Aquifer	Plume Position	Used in Statistical Analyses?	Sampling Date for VOCs [a/]										
					Dec-95	Mar-96	May-96	Sep-96	Mar-98	Mar/Apr-99	Jul/Aug-01	Mar-02	Nov/Dec-02	May/Jun-03	Oct/Nov-03
MPI10	Sep-96	Intermediate	Sentry	No				X			X				
MPD04	Unknown	Deep	Sentry	No								X			
MPD10	Unknown	Deep	Sentry	No								X			
MPD16	Unknown	Deep	Sentry	No								X			
MPD21	Unknown	Deep	Sentry	No								X			
MPDD04	Unknown	Deep	Sentry	No								X			
MWD01	Nov-93	Deep	Sentry	No					X		X				
MWD02	Sep-95	Deep	Sentry	No							X				
MWD03	Jan-96	Deep	Sentry	No							X				
MWD04	Jan-96	Deep	Sentry	No							X				
MWD05	Jan-96	Deep	Sentry	No							X				
MWD08	May-96	Deep	Sentry	Yes							X		X	X	X
MWD11	Mar-96	Deep	Sentry	Yes							X		X	X	X
MWD12	Mar-96	Deep	Sentry	No				X			X				
MWD13	Mar-96	Deep	Sentry	No							X				
MWD17	May-96	Deep	Sentry	No							X				
MWD19	May-96	Deep	Sentry	No							X				
MWS18	May-96	Shallow	Upgradient Sentry	Yes				X	X		X		X	X	X

[a/] VOCs - volatile organic compounds.

Note: Highlighted cells indicate that the data were used in the mass-based analysis.

of the plume, this site offers a 'northern' portion of the contaminant plume that has been relatively unaffected by active remediation technologies over the 8-year monitoring period between 1995 and 2003. Given the relatively low groundwater flow velocity at this site, the effects of remedial actions performed in the source area is not expected to impact the northern portion of the plume for many years; and

2. A large amount of monitoring data has been collected relatively from relatively consistent locations and on a relatively consistent time interval over the 8-year monitoring period listed in Table 4.22.

4.1.4.2 Summary of Historic Plume Stability Assessments

The results of historical plume stability evaluations presented in the RNA TS (Parsons, 1999c) and RNA TS Addendum (Parsons, 1999d) reports are summarized in Table 4.23. In general, the results of plume stability assessments from both of these documents indicated that the CAH plume was expanding. In the RNA TS (Parsons, 1999c), the primary method of evaluating plume stability was groundwater fate and transport modeling because the available site monitoring data was limited to a six-month observation period. The numerical model analysis presented in the RNA TS for this site simulated migration and degradation of total CAHs, defined as the molar equivalent of TCE, cis-1,2-DCE, and VC. Note that the model predictions cannot be directly compared to the results of compound-specific temporal trend analyses because the total CAH concentrations, rather than concentrations of individual CAH compounds, were simulated.

In the RNA TS (Parsons, 1999c), the following three source conditions were simulated: 1) no source removal, with 4 percent decay per year, 2) instantaneous removal of 75 percent of the source, followed by 4 percent decay, and 3) instantaneous removal of 100 percent of the source. The results of these three model scenarios indicated that source removal would have no discernable effect on the overall CAH plume footprint within the next 30 years. In addition, the model predicted that concentrations of CAHs would remain above applicable groundwater standards (i.e., Florida Department of Environmental Protection [FDEP] Groundwater Cleanup Target Levels of 3 μg/L for TCE, 70 μg/L for cis-1,2-DCE, and 1 μg/L for VC) for more than 100 years unless significant remedial measures were implemented throughout the CAH plume.

Additional plume stability analysis completed as part of the update to the RNA TS (Parsons, 1999d) concluded that the overall extent of the CAH plume and distribution of parent and intermediate degradation compounds two years after the initial sampling event are similar in extent and concentration (Figures 4.20 through 4.22). However, migration to the northern drainage canals appeared to have been inhibited by temporary reversal of groundwater flow directions near the canal, most likely caused by increased flow and higher surface water levels in the canal. Overall, in 1998, TCE concentrations increased in the source area, indicating a residual source of TCE in the soils, and cis-1,2-DCE continued to be the most widespread contaminant in groundwater. However, the elapsed time between the RNA TS and the RNA TS update sampling events is insufficient to discern temporal trends.

Table 4.23 Results of Previous Concentration-Based Plume Stability Analyses
Facility 1381, Cape Canaveral AFS, Florida

Evaluation Method	Data Used for Trend Assessment		Reported Results of Trend Assessment	Reported Plume Stability Conclusion	Related Conclusion(s) and Notes	Source[a/]
	Monitoring Wells	Period of Sampling				
Temporal changes in source well concentrations [b/]						
Visual inspection of tabulated data for TCE	1381MWS01, 1381MWS02, 1381MWS09	11/95 to 5/96	TCE concentrations increasing over time	Period of observation (i.e., 6 months) was too short to develop defensible conclusions	Contamination generally limited to shallow groundwater	(1)
Visual comparison of isoconcentration contour maps and tabulated data for TCE over time		11/95 to 3/98	• TCE concentrations increasing over time in source area • Lateral extent of TCE plume stable and limited to a relatively small source area	Size of source area plume is stable	Indicates continuing contaminant source	(2)
Temporal changes in plume well concentrations [c/]						
Visual inspection of tabulated data and isoconcentration contour maps for individual chlorinated compounds	1381MWS03, 1381MWS07, 1381MWS08, 1381MWS10, 1381MWS12, 1381MWS13, 1381MWS14, 1381MWS15, 1381MWS16, 1381MWS17	11/95 to 5/96	• Plume footprint is stable • DCE concentrations increasing over time	Period of observation (i.e., 6 months) was too short to develop defensible conclusions	Increasing DCE to TCE ratio along plume centerline suggests active reductive dechlorination	(1)
Visual inspection of isoconcentration contour maps for total chlorinated ethenes		11/95 to 3/98	• CAH concentrations fluctuating over time • Plume footprint expanding • CAH concentrations decreasing over time	Plume expanding	Increasing DCE to TCE ratio along plume centerline suggests active reductive dechlorination is continuing	(2)
Count of number of wells where individual CAH concentrations increased between two monitoring events	Wells sampled during 3/96 and 9/96 d/	3/96 and 9/96	Individual CAH concentrations (e.g., DCE, VC) increasing over time in majority of wells	Plume expanding	--	(2)

Table 4.23 Results of Previous Concentration-Based Plume Stability Analyses (continued)
Facility 1381, Cape Canaveral AFS, Florida

	Data Used for Trend Assessment					
Evaluation Method	**Monitoring Wells**	**Period of Sampling**	**Reported Results of Trend Assessment**	**Reported Plume Stability Conclusion**	**Related Conclusion(s) and Notes**	**Source[a/]**
Temporal changes in sentry well concentrations [e/]						
Not performed due to absence of sufficient historical data						
Numerical model simulation of contaminant transport						
Visual inspection of model-generated graphs of CAH concentration (as DCE) over time at 4 monitoring wells	1381MWS09, 1381MWS12, 1381MWS14, 1381MWS15	1958 – 2098 [f/]	• CAH concentrations in source well (1381MWS09) modeled to decrease at 4 percent per year • CAH concentrations at downgradient locations predicted to increase and remain above standards for more than 100 years	Plume predicted to expand and enter bordering drainage canals	• Model assumed source decay rate of 4 percent per year • Additional modeling simulation of the effects of engineered remediation (assumed source concentration reduction of 50 percent per year) predicted that CAH concentrations at the selected downgradient monitoring wells would remain above standards for more than 100 years	(1)

[a/] Sources: (1) Remediation by Natural Attenuation Treatability Study (Parsons, 1999c)
(2) Remediation by Natural Attenuation Treatability Study Addendum (Parsons, 1999d)

[b/] Source wells selected based on proximity to observed source area.

[c/] Plume wells are located within the CAH plume but outside of the inferred source area.

[d/] See Table 4.22 for the complete list of wells sampled during the two monitoring events listed.

[e/] Sentry wells may be located downgradient, crossgradient, above, or below the current plume extents to monitor plume stability.

[f/] Period of sampling represents period of simulated contaminant transport.

Notes: CAH = chlorinated aliphatic hydrocarbon; COC = contaminant of concern; TCE = trichloroethene; DCE = cis-1,2-dichloroethene, VC = vinyl chloride.

4.1.4.3 Results of Current Concentration-based Stability Analysis

Concentration-based stability analysis results obtained for the current project are summarized and compared to historical stability analysis results in Table 4.24, on Figure 4.23, and in the following paragraphs. Numerical results of the linear regression, MK, and Sen's Method analyses for individual wells are provided in Appendix C. For this study, statistical testing was performed on data sets using three different methods. However, the most rigorous approach to statistical analysis is to perform data distribution testing (including possible assessment of log-transformed data) prior to selecting a statistical test. The current version of MAROS does not offer the option of selecting a statistical test based on data distribution analyis or the existence of non-detect data, but rather provides the user with both linear regression and MK statistical results. Users of MAROS will be faced with the decision of having to select from the two test results, whether or not both results were desired. It is recommended that users of MAROS evaluate data distribution at locations where the parametric and nonparametric test results conflict to evaluate which statistical test result is most appropriate. Although data distribution analysis was performed for data sets used in this study, most of the results were inconclusive; an artifact of small data sets and large numbers of non-detect values. This indicates that the non-parametric MK approach is probably an appropriate, conservative choice in many cases.

Source Area

The magnitude and statistical trends in CAH concentration of four source area wells screened at shallow (1381MWS09) and intermediate (1381MWI09, 1381MWI19, and 1381MWI20) depths were evaluated as part of the current plume stability analysis. The statistical tests applied to the source area wells were linear regression and the MK test.

In these source area wells at Facility 1381, TCE was the COC with the highest concentrations, which were generally an order of magnitude or more greater than cis-1,2-DCE concentrations. Although VC was detected in three of the four source area wells, with concentrations ranging up to 849 µg/L, VC concentrations were generally an order of magnitude or more lower than cis-1,2-DCE concentrations. It was also noted that the method detection limits in nearly half of the source well samples for VC were significantly greater (i.e., greater than 500 µg/L) than the MCL of 2 µg/L for VC. Because TCE concentrations were significantly higher than intermediate degradation product concentrations in the source area wells, temporal trends in TCE concentrations were considered to be the primary indicators of current and/or future source area dynamics in the absence of source area remediation.

The overall trend analysis results for source area wells suggest that the dissolved TCE mass in intermediate depth groundwater is increasing over time. Support for this conclusion is provided in that both statistical test methods indicated increasing TCE concentration in one source area well, and a 'probably increasing' trend for linear regression in a second well (see Table 4.24 and Figure 4.23). All remaining statistical test results for TCE in source area wells were 'stable' or 'no trend.' While the observation of cis-1,2-DCE and VC supports a finding that reductive dechlorination of TCE is occurring in the source area, the combined observations of 'increasing' TCE concentration trends in some locations with generally 'stable'

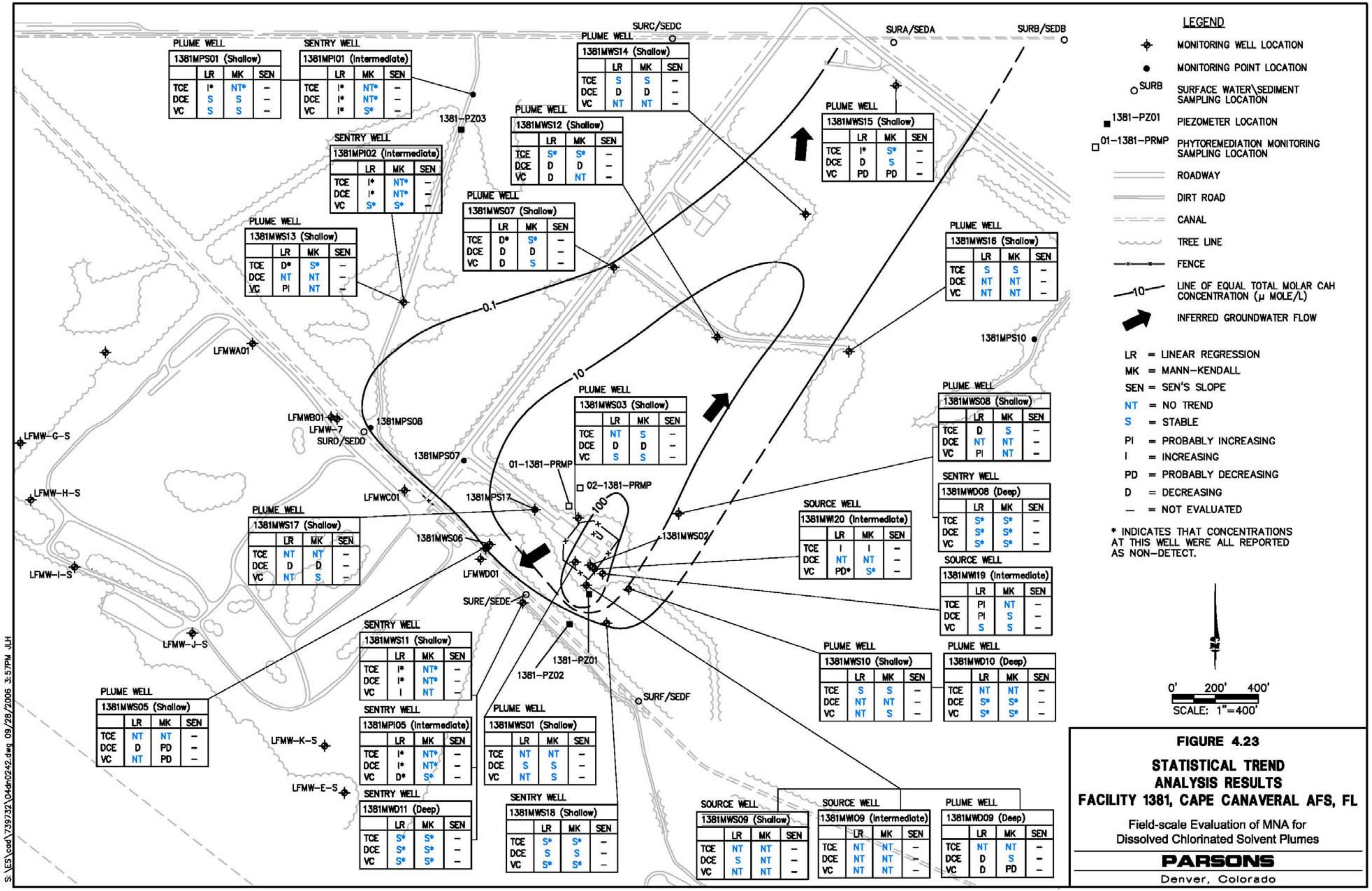
Table 4.24 Comparison of Historical and Current Concentration-Based Plume Stability Analyses, Facility 1381, Cape Canaveral AFS, Florida

Evaluation Method	Data Available at Time of Assessment		Results of Trend Assessment	Plume Stability Conclusion	Related Conclusion(s) and Notes	Source [a/]	Comparison of Historical and Current Plume Stability Conclusions
	Monitoring Wells	Period of Sampling					
Temporal changes in source well concentrations [b/]							
Visual inspection of tabulated data for TCE	1381MWS01, 1381MWS02, 1381MWS09	11/95 to 5/96	- TCE concentrations increasing over time	Period of observation (i.e., 6 months) was too short to develop defensible conclusions	- Contamination generally limited to shallow groundwater	(1)	Historical (qualitative) trend analysis results were interpreted as a stable CAH plume source. Current (quantitative) trend analysis results for shallow depth source area wells agree with the historical analysis, and suggest that the dissolved CAH source is stable or diminishing in this interval. Quantitative analysis of intermediate depth wells indicates that source mass flux to groundwater may be increasing, resulting in an increased potential for CAH plume expansion.
Visual comparison of isoconcentration contour maps and tabulated data for TCE over time		11/95 to 3/98	- TCE concentrations increasing over time in source area - Lateral extent of TCE plume stable and limited to a relatively small source area	Size of plume source area stable	- Indicates continuing contaminant source	(2)	
Statistical analysis of primary COCs (i.e., TCE, DCE, and VC) using linear regression	1381MWS09, 1381MWI09, 1381MWI19, 1381MWI20	12/95 to 11/03	- For TCE, 2 wells were 'increasing' or 'probably increasing,' and 2 wells were 'no trend' - For DCE, 1 well was 'probably increasing' and 3 wells were 'stable' or 'no trend' - For VC, 3 wells were 'no trend' or 'stable,' and 1 well was entirely BD for all analytes.	Plume likely to be stable or receding at shallow depths; Plume likely to be stable to expanding at intermediate depths	- Contaminant source strength at shallow depths appears to be weakening - Concentration data suggests contamination at intermediate depths is likely to act as a continuing source of contamination to groundwater	Appendix C of current study	
Statistical analysis of primary COCs (i.e., TCE, DCE, and VC) using the Mann-Kendall Test			- For TCE, 1 well was 'increasing' and 3 wells were 'no trend' - For DCE, all 4 wells were 'no trend' or 'stable' - For VC, 3 wells were 'no trend' or 'stable,' and 1 well had BD concentrations for all samples.	Plume likely to be stable or receding at shallow depths; Plume likely to be stable to expanding at intermediate depths	- Contaminant source strength at shallow depths appears to be stable or weakening - Contaminant source strength at intermediate depths appears to be stable and will likely be a long-term source of contamination to groundwater	Appendix C of current study	
Temporal changes in plume well concentrations [c/]							
Visual inspection of tabulated data and isoconcentration contour maps for individual chlorinated compounds	1381MWS03, 1381MWS07, 1381MWS08, 1381MWS10, 1381MWS12, 1381MWS13, 1381MWS14, 1381MWS15, 1381MWS16, 1381MWS17	11/95 to 5/96	- Plume footprint is stable - DCE concentrations increasing over time	Period of observation (i.e., 6 months) was too short to develop defensible conclusions	Increasing DCE to TCE ratio along plume centerline suggests active reductive dechlorination	(1)	Historical (qualitative) trend analysis results support increasing concentrations and suggested a stable or expanding dissolved plume. Current (quantitative) analysis results suggest that the contaminant plume is stable or receding at most locations. Statistical finding of 'stable' or 'decreasing' trends in DCE concentrations contrasts with initial observations of an expanding DCE plume. The increased number of locations and sampling events is deemed to provide sufficient evidence to show that the DCE plume has stabilized. Indication of a 'probably increasing' VC trends at two plume interior locations (1381MWS08 and 1381MWS13) suggests increased reductive dechlorination of DCE. However, visual inspection of the VC data indicates that the increasing trends ended in 2001 and VC concentrations decreased thereafter.
Visual inspection of isoconcentration contour maps for total chlorinated ethenes		11/95 to 3/98	- CAH concentrations fluctuating over time - Plume footprint expanding - CAH concentrations decreasing over time	Plume expanding	Increasing DCE to TCE ratio along plume centerline suggests active reductive dechlorination is continuing	(2)	
Count of number of wells where individual CAH concentrations increased between two monitoring events	Wells sampled during 3/96 and 9/96 c/	3/96 and 9/96	- Individual CAH concentrations (e.g., DCE, VC) increasing over time in majority of wells	Plume expanding	--	(2)	

Table 4.24 Comparison of Historical and Current Concentration-Based Plume Stability Analyses, Facility 1381, Cape Canaveral AFS, Florida (continued)

	Data Available at Time of Assessment						
Evaluation Method	**Monitoring Wells**	**Period of Sampling**	**Results of Trend Assessment**	**Plume Stability Conclusion**	**Related Conclusion(s) and Notes**	**Source a/**	**Comparison of Historical and Current Plume Stability Conclusions**
Temporal changes in plume well concentrations c/							
Statistical analysis of primary COCs (i.e., TCE, DCE, and VC) using linear regression	1381MWS01, 1381MWS03, 1381MWS05, 1381MWS07, 1381MWS08, 1381MWS10, 1381MWS12, 1381MWS13, 1381MWS14, 1381MWS15, 1381MWS16, 1381MWS17, 1381MWD09, 1381MWD10	12/95 to 11/03	• For TCE, trends in 9 wells were 'no trend' or 'stable', 1 well was 'decreasing', and 5 wells had BD concentrations in all samples • For DCE, trends in 6 wells were 'no trend' or 'stable', 8 wells were 'decreasing', and 1 well had BD concentrations in all samples • For VC, trends in 2 wells were 'probably increasing', 8 wells were 'no trend' or 'stable', 4 wells were 'decreasing' or 'probably decreasing', and 1 well had BD concentrations in all samples	Plume stable or receding	• Continued indication of significant degradation of TCE, DCE, and VC by reductive dechlorination • Well with 'increasing' VC trend is located within plume interior, relatively near to the source area	Appendix C of current study	See previous page for summary.
Statistical analysis of primary COCs (i.e., TCE, DCE, and VC) using the Mann-Kendall Test			• For TCE, trends in 10 wells were 'no trend' or 'stable' and 5 wells had BD concentrations in all samples • For DCE, trends in 8 wells were 'no trend' or 'stable', 6 wells were 'decreasing' or 'probably decreasing', and 1 well had BD concentrations in all samples • For VC, trends in 11 wells were 'no trend' or 'stable', 3 wells were 'probably decreasing', and 1 well had BD concentration in all samples	Plume stable or receding	• Continued indication of significant degradation of TCE, DCE, and VC by reductive dechlorination • Statistical test indicates concentration trends for all CAHS are 'stable,' 'no trend,' or 'probably decreasing' at all locations	Appendix C of current study	
Temporal changes in sentry well concentrations d/							
Historical trend assessment not performed due to absence of sufficient historical data							Unable to compare historical and current trend analysis results due to an absence of sufficient sentry monitoring history prior to performance of historical data assessment. Current statistical analysis of sentry wells supports a finding of a stable or receding plume.
Statistical analysis of primary COCs (i.e., TCE, DCE, and VC) using linear regression	1381MPS01, 1381MWS11, 1381MPI01, 1381MPI05, 1381MWD08, 1381MWD11	12/95 to 11/03	• TCE concentrations in all wells were BD for all samples • For DCE, the trend in 1 well was 'stable', and 6 wells had BD concentrations in all samples • For VC, the trend in 1 well was 'increasing', and 6 wells had BD concentrations in all samples	Plume stable or receding	• Sentry wells monitor potential plume expansion in both the lateral (S & I wells) and vertical (D wells) directions • 'Increasing' trend for VC in 1381MWS11 determined to be an artifact of the method for assigning quantities to trace and below detection measurements prior to performing statistical testing.	Appendix C of current study	
Statistical analysis of primary COCs (i.e., TCE, DCE, and VC) using the Mann-Kendall Test			• TCE concentrations in all wells were BD for all samples • For DCE, the trend in 1 well was 'stable,' and 6 wells had BD concentrations in all samples • For VC, the trend in 1 well was 'no trend,' and 6 wells had BD concentration in all samples	Plume stable or receding	• Sentry wells monitor potential plume expansion in both the lateral (S & I wells) and vertical (D wells) directions	Appendix C of current study	

a/ Sources: (1) Remediation by Natural Attenuation Treatability Study (Parsons, 1999c); (2) Remediation by Natural Attenuation Treatability Study Addendum (Parsons, 1999d).
b/ Source wells selected based on proximity to observed source area.
c/ Plume wells are located within the CAH plume but outside of the inferred source area.
d/ Sentry wells may be located downgradient, crossgradient, above, or below the current plume extents to monitor plume stability.
Notes: CAH = chlorinated aliphatic hydrocarbon; COC = contaminant of concern; TCE = trichloroethene; DCE = cis-1,2-dichloroethene; VC = vinyl chloride; BD = below detection



PLUME WELL

1381MPS01 (Shallow)	LR	MK	SEN
TCE	I*	NT*	—
DCE	S	S	—
VC	S	S	—

SENTRY WELL

1381MPI01 (Intermediate)	LR	MK	SEN
TCE	I*	NT*	—
DCE	I*	NT*	—
VC	I*	S*	—

SENTRY WELL

1381MPI02 (Intermediate)	LR	MK	SEN
TCE	I*	NT*	—
DCE	I*	NT*	—
VC	S*	S*	—

PLUME WELL

1381MWS13 (Shallow)	LR	MK	SEN
TCE	D*	S*	—
DCE	NT	NT	—
VC	PI	NT	—

PLUME WELL

1381MWS14 (Shallow)	LR	MK	SEN
TCE	S	S	—
DCE	D	D	—
VC	NT	NT	—

PLUME WELL

1381MWS12 (Shallow)	LR	MK	SEN
TCE	S*	S*	—
DCE	D	D	—
VC	D	NT	—

PLUME WELL

1381MWS07 (Shallow)	LR	MK	SEN
TCE	D*	S*	—
DCE	D	D	—
VC	D	S	—

PLUME WELL

1381MWS15 (Shallow)	LR	MK	SEN
TCE	I*	S*	—
DCE	D	S	—
VC	PD	PD	—

PLUME WELL

1381MWS16 (Shallow)	LR	MK	SEN
TCE	S	S	—
DCE	NT	NT	—
VC	NT	NT	—

PLUME WELL

1381MWS03 (Shallow)	LR	MK	SEN
TCE	NT	S	—
DCE	D	D	—
VC	S	S	—

PLUME WELL

1381MWS08 (Shallow)	LR	MK	SEN
TCE	D	S	—
DCE	NT	NT	—
VC	PI	NT	—

SENTRY WELL

1381MWD08 (Deep)	LR	MK	SEN
TCE	S*	S*	—
DCE	S*	S*	—
VC	S*	S*	—

SOURCE WELL

1381MWI20 (Intermediate)	LR	MK	SEN
TCE	I	I	—
DCE	NT	NT	—
VC	PD*	S*	—

SOURCE WELL

1381MWI19 (Intermediate)	LR	MK	SEN
TCE	PI	NT	—
DCE	PI	S	—
VC	S	S	—

PLUME WELL

1381MWS17 (Shallow)	LR	MK	SEN
TCE	NT	NT	—
DCE	D	D	—
VC	NT	S	—

SENTRY WELL

1381MWS11 (Shallow)	LR	MK	SEN
TCE	I*	NT*	—
DCE	I*	NT*	—
VC	I	NT	—

PLUME WELL

1381MWS05 (Shallow)	LR	MK	SEN
TCE	NT	NT	—
DCE	D	PD	—
VC	NT	PD	—

SENTRY WELL

1381MPI05 (Intermediate)	LR	MK	SEN
TCE	I*	NT*	—
DCE	I*	NT*	—
VC	D*	S*	—

PLUME WELL

1381MWS01 (Shallow)	LR	MK	SEN
TCE	NT	NT	—
DCE	S	S	—
VC	NT	S	—

PLUME WELL

1381MWS10 (Shallow)	LR	MK	SEN
TCE	S	S	—
DCE	NT	NT	—
VC	NT	S	—

PLUME WELL

1381MWD10 (Deep)	LR	MK	SEN
TCE	NT	NT	—
DCE	S*	S*	—
VC	S*	S*	—

SENTRY WELL

1381MWD11 (Deep)	LR	MK	SEN
TCE	S*	S*	—
DCE	S*	S*	—
VC	S*	S*	—

SENTRY WELL

1381MWS18 (Shallow)	LR	MK	SEN
TCE	S*	S*	—
DCE	S	S	—
VC	S*	S*	—

SOURCE WELL

1381MWS09 (Shallow)	LR	MK	SEN
TCE	NT	NT	—
DCE	S	NT	—
VC	NT	NT	—

SOURCE WELL

1381MWI09 (Intermediate)	LR	MK	SEN
TCE	NT	NT	—
DCE	NT	NT	—
VC	NT	NT	—

PLUME WELL

1381MWD09 (Deep)	LR	MK	SEN
TCE	NT	NT	—
DCE	D	S	—
VC	D	PD	—

Figure 4.23 Statistical Trend Analysis Results, Facility 1381, Cape Canaveral AFS, Florida

or ‘no trend’ results for cis-1,2-DCE and VC concentration trends suggests that the rate of TCE dissolution to groundwater is greater than the rate of TCE degradation in the source area.

Based on these observations, there appears to be a continuing source of TCE to intermediate groundwater at Facility 1381. The presence of a continuing TCE source implies that there is potential for plume expansion over time if the rate of NA in the dissolved plume is less than the rate of TCE release to source area groundwater.

Plume Area

Statistical trend analyses were performed for the 15 plume wells listed in Table 4.22. The majority (13) of plume wells were screened in the shallow portion of the aquifer, with the remaining two plume area wells identified as deep wells below the source area. No intermediate depth wells were identified as plume wells suitable for statistical analysis, based on the available information. Plume wells at this site are defined as those wells where at least one CAH was measured as greater than 1 μg/L, but not identified as a source area well.

As shown on Figure 4.23, 14 of the 90 trend determinations made for the 15 plume wells were based entirely on concentrations reported as below detection. These 14 trends (which included ‘increasing,’ ‘stable,’ ‘no trend,’ and ‘decreasing’) are considered spurious because they were developed using all below detection measurements, which are considered equivalent evidence of no contamination for a given CAH at a specific location. The reason that the statistical results yield ‘increasing’ or ‘decreasing’ trends at some locations is because MAROS assigns below detection measurements a numerical value equal to one-half of the detection limit, and the detection limit was observed to vary over time. While MAROS will accept and perform statistical analysis for data series consisting entirely of “censored” or below-detection limit data, we do not recommend the practice.

Of the remaining 68 trend determinations for shallow plume area well, 47 trends (69 percent) were ‘stable’ or ‘no trend’, two (three percent) were ‘increasing’ or ‘probably increasing’, and 19 (28 percent) were ‘decreasing’ or ‘probably decreasing’. Note that, in the two cases (i.e., 1381MWS08 and 1381MWS13) where a ‘probably increasing’ trend was identified when linear regression was applied to VC concentration data, the MK analysis for this same data yielded a ‘no trend’ result. On review of the actual data for these two locations (See Table C.5E of Appendix C), it appears that the difference in trend results between the two statistical methods was that there was an obvious increase in VC concentrations during the first three or four monitoring events (i.e., 1996 to 2001), followed by a decrease in VC concentrations in subsequent monitoring events between 2001 and 2003. Considering that the most recent data suggests that current VC concentrations appear to be decreasing at these two locations, the MK finding of ‘no trend’ is believed to be the more appropriate determination for trends at these two points. Periodic collection of additional data from these two data points is recommended to validate the ‘no trend’ conclusion for these two wells.

Of the 12 trend determinations for the two deep plume area wells, four trends were calculated when all measurements were below detection. While MAROS will accept and perform statistical analysis for data series consisting entirely of “censored” or below-detection limit data, we do not recommend the practice. Of the remaining eight trend determinations, five trends (52 percent) were ‘stable’ or ‘no trend’ and three (38 percent) were ‘decreasing’ or ‘probably decreasing’.

In summary, the observations that 1) more than three-quarters of the plume wells where CAHs were detected are ‘stable’ or ‘no trend’ and 2) nearly all of the remaining plume wells were either ‘decreasing’ or ‘probably decreasing’ support a finding that the individual dissolved CAH plumes are stable or receding at this site. In the two cases where VC concentration trends were identified as ‘probably increasing’ by linear regression, the MK test and a review of the actual data suggest that VC concentrations in these wells have stabilized or are decreasing during the most recent three years of monitoring. It is important to note, however, that the absence of sufficient data from monitoring wells screened at intermediate depths and categorized as plume wells makes it impossible to perform a statistical assessment of plume stability at intermediate depths using wells within the dissolved plume. The absence of intermediate data is of concern for this site because statistical results for source area wells screened at intermediate depths were ‘increasing’ and ‘probably increasing’ for TCE and DCE at two locations.

Sentry Wells

For the purpose of this plume stability evaluation, sentry wells at this site are defined as those wells that contain concentrations of individual CAHs that are below detection or found only at trace levels. A trace level is defined in this context as a concentration that is quantifiable, but a concentration that is below the analytical method detection limit. For Facility 1381, two shallow, three intermediate, and two deep wells meet the criterion for sentry wells.

Trace levels of CAH concentrations were measured for VC in shallow monitoring well 1381MWS11 and for cis-1,2-DCE in shallow monitoring well 1381MWS18. All other CAH concentrations in shallow sentry wells, and all CAH concentrations in intermediate and deep sentry wells were below detection. Of the trend analysis for the two wells where trace levels were reported, the ‘increasing’ trend identified by linear regression for VC in 1381MWS11 is of greatest potential concern because it suggests that the VC plume could be expanding in this direction. Further review of the actual data for VC at 1381MWS11 (see Tables C.5E Appendix C) indicates that the ‘increasing’ trend identified by linear regression is spurious in that a single trace measurement of 0.69 μg/L, measured in 2001, causes the MAROS algorithm to indicate an ‘increasing’ trend when all other measurements are below the method detection limit of 1 μg/L. Considering that the most recent data indicates that VC concentrations were below detection in the three most recent samples from 1381MWS11, the MK finding of ‘no trend’ is believed to be a more appropriate trend determination than the ‘increasing’ trend identified by linear regression.

Statistical testing for trend analysis is not recommended for locations where all measured concentrations for a particular COC are below detection. However, MAROS and possibly other ‘off-the-shelf’ software provide a trend evaluation without clearly indicating that the concentration data used to develop the trend were all below detection. The following text provides a discussion of the trends that were be observed when implementing MAROS for statistical trend analysis on data sets containing all below-detection measurements.

When reviewing the 32 trends in sentry wells where all measurements were reported as below detection, it is interesting to note that linear regression analysis results in identification of 'increasing' trend nine times, 'stable' trends nine times, and 'decreasing' trends once, whereas the MK test results in 'stable' or 'no trend' results for all 19 analyses. Upon further review of the data and the method that MAROS assigned numerical values to below detection measurements, the reason for 'increasing' trends being identified by linear regression for TCE and cis-1,2-DCE at four of the seven sentry wells (i.e., eight of the 'increasing' trends; locations shown on Figure 4.23) is that the method detection limit for both TCE and cis-1,2-DCE during the first sampling event for these four wells was 1 μg/L, and then increased to 2 μg/L for each of the subsequent monitoring events. Specifically, by selecting the option in MAROS that assigns a numerical value of one-half the detection limit for below detection measurements, the change in the reporting limit causes linear regression to predict an 'increasing' trend even though all data is reported as below detection. While the recommended practice is to avoid calculation of statistical trends when all data for a particular COC is below detection, it is interesting to note that the characteristics of the MK test help prevent false identification of trends when one or more below detection measurements are included in a data set, and in particular when the value of the method detection limit varies over time.

For the remaining 'increasing' trend (for VC at 1381MP0I01) and the single 'decreasing' trend (for VC at 1381MPI05), a review of input data indicated that there were below detection measurements and uniform quantification limits (i.e., 1 μg/L) for all samples. It is unclear as to why the MAROS linear regression trend analyses for these two points resulted in a trend determination other than 'stable', as the condition when all input parameters are equal in value resulted in a calculated zero slope and finding of a 'stable' trend in other cases where a similar data format was used as input. We do not recommend the practice of conducting statistical analysis on data series consisting of below detection and trace measurement values. In addition, based on the experiences with trend calculations using linear regression, as enabled in MAROS, for below detection and trace measurement values, it is recommended that practitioners carefully review the linear regression analysis results for sentry wells to verify that the calculated trends are representative and reasonable, relative to the available data.

In summary, statistical trend analyses of sentry wells supports a finding that none of the dissolved CAH plumes at this site are expanding. This data set further illustrates that assigning numerical values to below detection and trace measurements can cause spurious trend identification, especially if there are changes in the method detection limit over time or there are a mixture of trace and below detection measurements reported.

Summary

Table 4.25 lists a summary of the linear regression and MK trends for the CAH Plume at Facility 1381. The linear regression and MK tests for trends in CAH concentrations over time at monitoring wells of Facility 1381 generally produced similar results. The primary difference between the two sets of trend results is that the MK test yielded a greater number of 'stable/no trend' results while the linear regression test yielded a greater number of 'decreasing/probably decreasing' and 'increasing/probably increasing' results. Importantly, the linear regression test was observed to produce a relatively large number (i.e., 13 of 27 cases) of spurious trend results in data sets where all reported CAH concentrations were below detection, whereas the MK test correctly indicated that all 27 trends were ‘stable’ or ‘no trend’.

Table 4.25 Summary of Current Statistical Analysis Results
Facility 1381, Cape Canaveral AFS, Florida

Statistical Analysis Method	Number of Instances Exhibiting the Indicated Trend						BD [a]
	Decreasing	Probably Decreasing	Stable	No Trend	Probably Increasing	Increasing	
Linear Regression	12	1	10	22	4	2	27 [b]
MK	5	4	18	23	0	1	27 [c]

[a] BD = All reported concentrations below detection limits.

[b] Linear regression assigned 11 ‘increasing’, four ‘decreasing’ or ‘probably decreasing’, and 12 ‘no trend’ or ‘stable’ trends to data sets where all concentrations were reported as below detection.

[c] MK assigned ‘no trend’ or ‘stable’ trends to all data sets where all concentrations were reported as below detection.

Overall, the current linear regression and MK trend analysis results for the plume and sentry wells installed within and surrounding the Facility 1381 CAH plume support a finding that this plume is stable or receding. The primary evidence to support this conclusion is that in the dissolved plume and sentry wells. There are indications that the dissolved concentrations of TCE and possibly DCE are increasing in intermediate depth source area wells, which suggests a continued, persistent source of contamination to groundwater. The inferred strength of this source area implies that there is future potential for plume expansion if the rate of NA in the dissolved plume was to decline over time. Importantly, there generally appears to be sufficient intermediate-depth monitoring wells at sentry locations of this site to detect plume expansion outside the existing shallow plume footprint. However, the general absence of recent data at intermediate depths within the dissolved plume introduces uncertainty into whether the CAH plume(s) at this site are currently expanding at intermediate depths within the existing shallow plume footprint. The collection of additional samples from intermediate-depth monitoring wells would allow performance of statistical testing on plume wells that would improve the certainty of assessing current intermediate depth plume dynamics, while also providing advanced warning that the plume edges have the potential to expand. In addition, continued monitoring of deep wells below the source area is recommended to confirm that CAHs are not migrating to deeper depths over time.

4.1.4.4 Results of Current Mass-based Stability Analysis

Figure 4.24 shows the monitoring wells, model domain hull, and Theissen polygons used in the mass-based stability analyses for Facility 1381. The monitoring wells used for the mass-based analyses were selected by reviewing the groundwater sampling history for VOCs summarized in Table 4.22 and selecting the time periods that had the largest number of wells

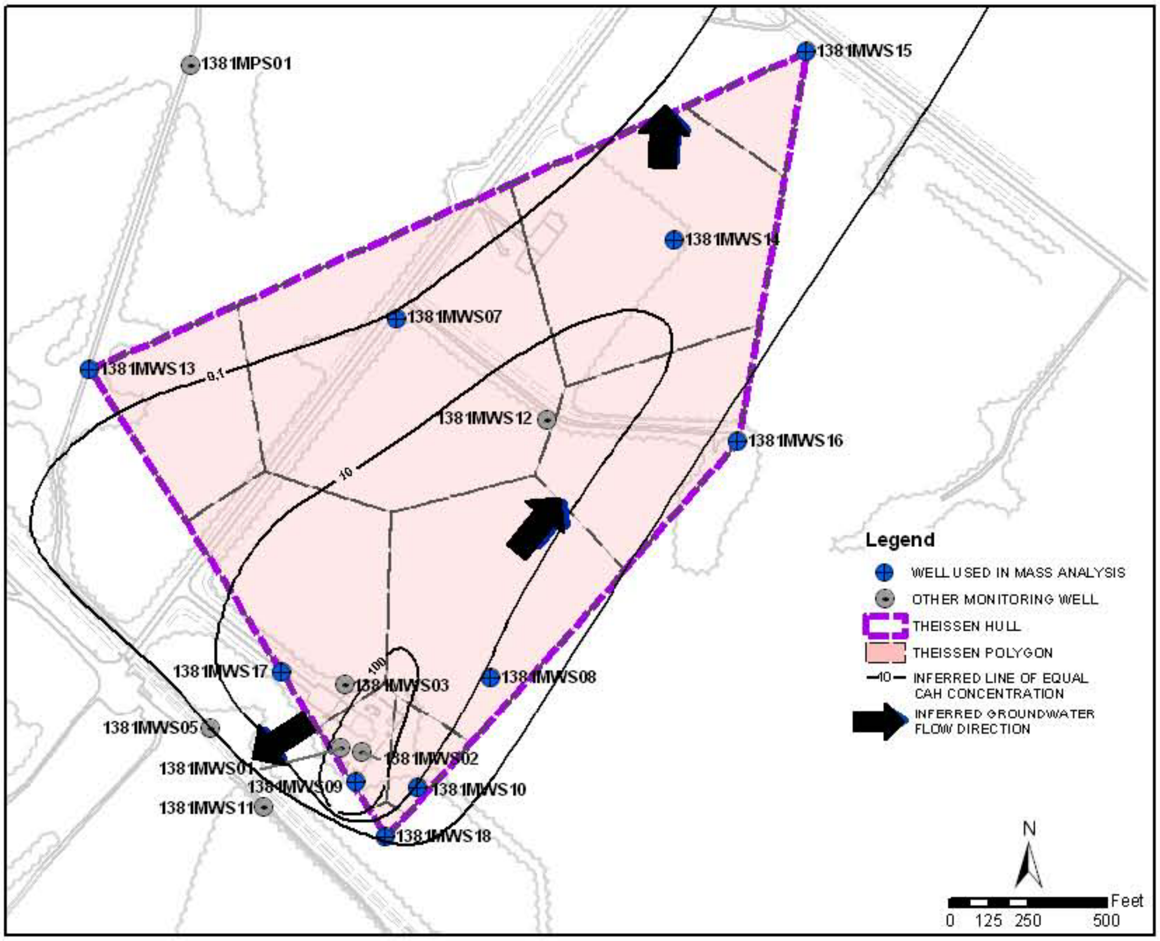


Figure 4.24 Model Domain and Common Wells for Mass-Based Calculations Facility 1381, Cape Canaveral AFS, Florida

sampled in common. The common well set for the Facility 1381 plume consisted of ten shallow wells, as listed in Table 4.22 and as shown on Figure 4.24. Note that one intermediate and one deep well were also sampled on the same schedule as the shallow common well set. These two deeper wells were not included in the mass-based calculations, however, because the absence of consistent sampling data from other wells at intermediate and deep depths makes it impossible to construct a Theissen polygon network for these depths. The wells in each of these common well sets were sampled five times during a 22-month period from March 1998 to October/November 2003.

Dissolved CAH Mass

Figure 4.25 depicts the calculated CAH mass in the Facility 1381 plume (by individual species and total CAH as TCE) over time for each of the five sampling events and by analysis method (i.e., Theissen polygon or TIN grid). As can be observed from Figure 4.25, the TIN grid method and Theissen polygon methods for estimating individual and total CAH mass yielded similar results. Table 4.26 lists the molar mass of each compound as a percentage of the total molar CAH mass. As can be observed from Figure 4.25 and Table 4.26, the majority of dissolved mass in groundwater at Facility 1381 was TCE during monitoring events in 1998 and 2003, cis-1,2-DCE during the 2001 monitoring event, and VC during the 2002 monitoring event.

Table 4.26 Summary of CAH Mass by Compound
Facility 1381, Cape Canaveral AFS, Florida

	TCE		DCE		VC	
Sampling Date	**Kriging**	**Theissen**	**Kriging**	**Theissen**	**Kriging**	**Theissen**
March 1998	87.1%	87.2%	7.7%	7.7%	5.2%	5.1%
August 2001	9.9%	9.5%	50.5%	52.1%	39.6%	38.4%
November 2002	0.0%	0.1%	17.1%	17.0%	82.9%	82.9%
May 2003	78.3%	78.6%	13.0%	12.9%	8.7%	8.5%
October 2003	51.6%	52.1%	17.6%	17.6%	30.8%	30.3%

Statistical trend analysis and visual observation were both used to access trends in dissolved mass over time for total and individual CAHs. The results of applying the MK test for trend analysis of estimate CAH mass are shown in the legend at the bottom of Figure 4.25. Visual inspection of Figure 4.25 suggests that the total CAH mass may be decreasing over time, but also that the fluctuation in the mass estimate, which is greater than an order of magnitude, is larger than the estimated mass change between the first and last measurement periods, which is less than an order of magnitude. Results of applying the MK test to the total and CAH dissolved mass estimates resulted in findings of ‘no trend’, indicating that the existing data does not statistically support a finding of decreasing total CAH mass.

Visual inspection of TCE mass over time yielded conclusions similar to those for total CAH mass in that TCE mass appears to be decreasing over time, but that the fluctuation in TCE mass estimates is much larger than the difference in mass between the first and last

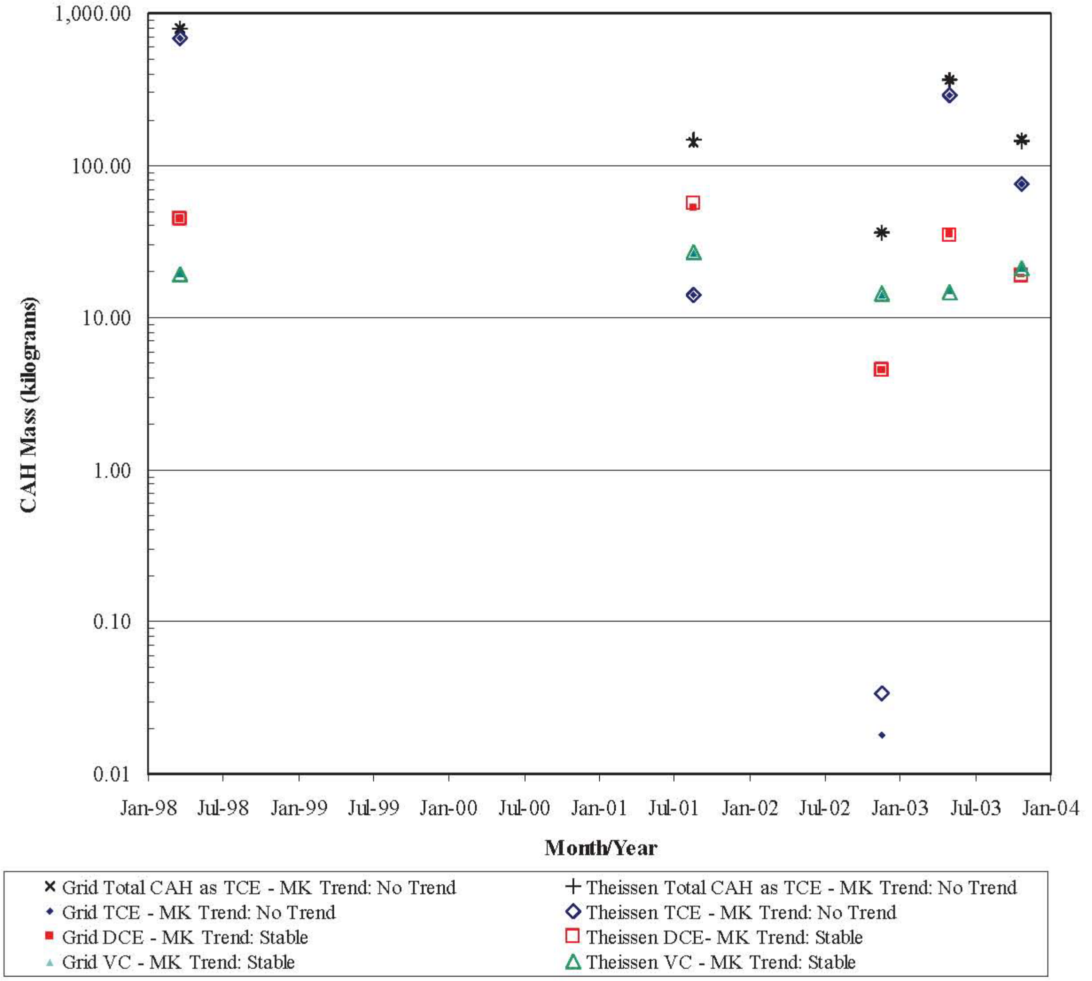


Figure 4.25 Estimated Dissolved Mass of CAH Compounds
Facility 1381, Cape Canaveral AFS, Florida

observation times. Upon review of input data used for these calculations, it is noted that very high concentrations of TCE (210,000 µg/L during the 1998 event, and 88,000 µg/L and 23,000 µg/L during the 2003 monitoring events) in a single monitoring well (1381MWS09) contribute nearly all of estimated TCE (and total CAH) contaminant mass estimated for the 1998 and 2003 monitoring events. During the 2001 and 2002 monitoring events, relatively low concentrations of TCE (i.e., 4290 µg/L and 1 µg/L, respectively) in this single monitoring well substantially reduced the estimated TCE mass and total CAH mass in shallow groundwater. For comparison purposes that illustrate the influence of TCE concentrations measured in 1381MW09 on TCE and total CAH mass estimates, the next highest TCE concentration (at 1381MWS08) was reported as 1.8 µg/L, while the highest reported cis-1,2-DCE and VC concentrations were 9,100 µg/L and 1050 µg/L, respectively.

The variation in estimated dissolved mass of cis-1,2-DCE and VC was much lower than was observed for TCE for the available data from Facility 1381. For example, the calculated cis-1,2-DCE mass was relatively constant for the 1998, 2001, and 2003 monitoring events (range: 19 kg to 57 kg), but was calculated as substantially smaller (4.6 kg) when data from the November 2002 sampling event was used to estimate dissolved cis-1,2-DCE mass. The MK result for cis-1,2-DCE was ‘no trend’, indicating that statistical testing of the variation in cis-1,2-DCE mass between March 1998 and October 2003 did not indicate a statistically significant trend for the available data. The calculated VC mass was observed to be the least variable CAH mass at Facility 1381 (range: 14 kg to 27 kg) over the four-and-a-half year assessment period. The MK result for VC was ‘no trend’, indicating that statistical testing of the variation in VC mass between March 1998 and October 2003 was not statistically significant.

Overall, the dissolved mass calculations support a conclusion that CAH mass is generally stable, with some evidence to suggest that the total dissolved CAH mass may be slowly decreasing over time. It is important to recognize that the high degree of variability of TCE, and to a lesser extent, cis-1,2-DCE, concentrations in a single source area well (i.e., 1381MW09) introduced a high degree of variability in the dissolved CAH plume mass estimates. The consequence of this large variation in estimated TCE mass, and the corresponding variation in total CAH mass, is that the ability to discern whether the possible slow decrease in CAH mass is a real trend or an artifact of natural variability in CAH concentrations over time. One possible strategy to improving the robustness of mass estimates at sites where one well has a large influence on mass calculations is to monitor and include data from additional existing or new wells that are spatially close to the most influential well in mass calculations. The purpose of this effort would be to provide a data set that is more spatially-refined in areas where concentrations may be rapidly changing over time and/or space.

Center of Dissolved CAH Mass

Figures 4.26 through 4.28 depict the locations of the centers of dissolved TCE, cis-1,2-DCE, and VC mass over time for each of the five sampling events and by analysis method (i.e., Theissen polygon or TIN grid) on a site base map. The center of mass for TCE in the

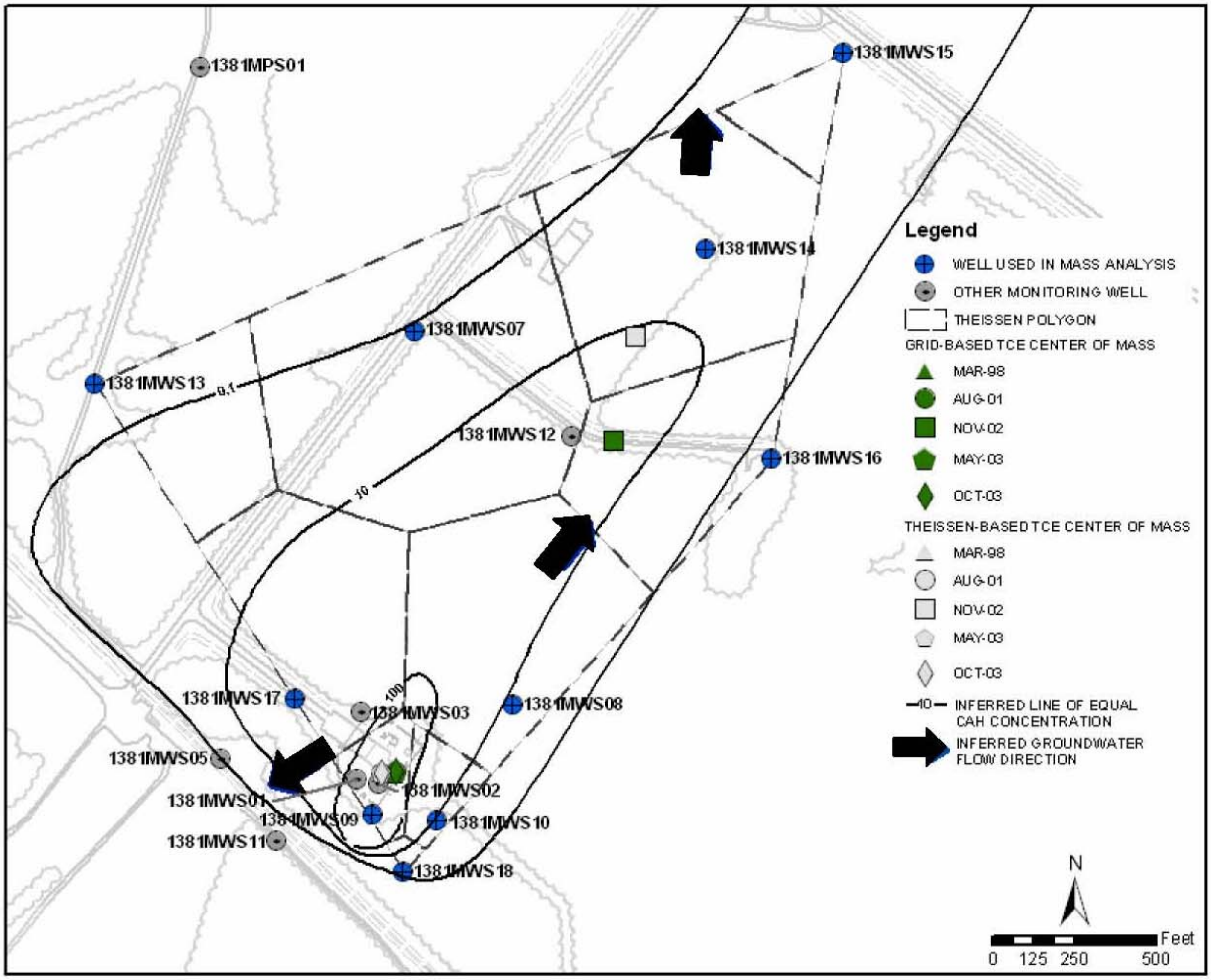


Figure 4.26 Location of Centers of Mass for TCE
Facility 1381, Cape Canaveral AFS, Florida

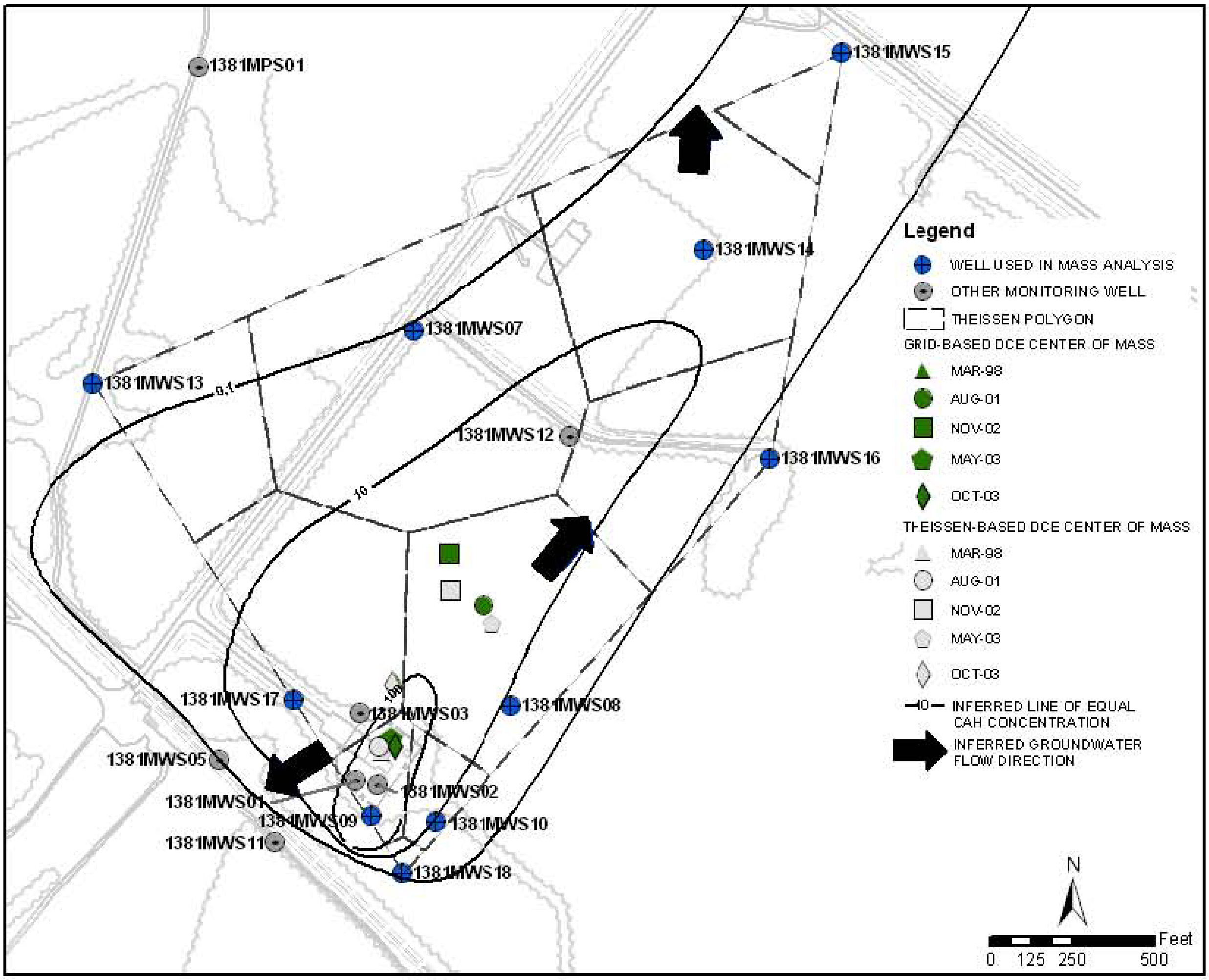


Figure 4.27 Location of Centers of Mass for cis-1,2-DCE
Facility 1381, Cape Canaveral AFS, Florida

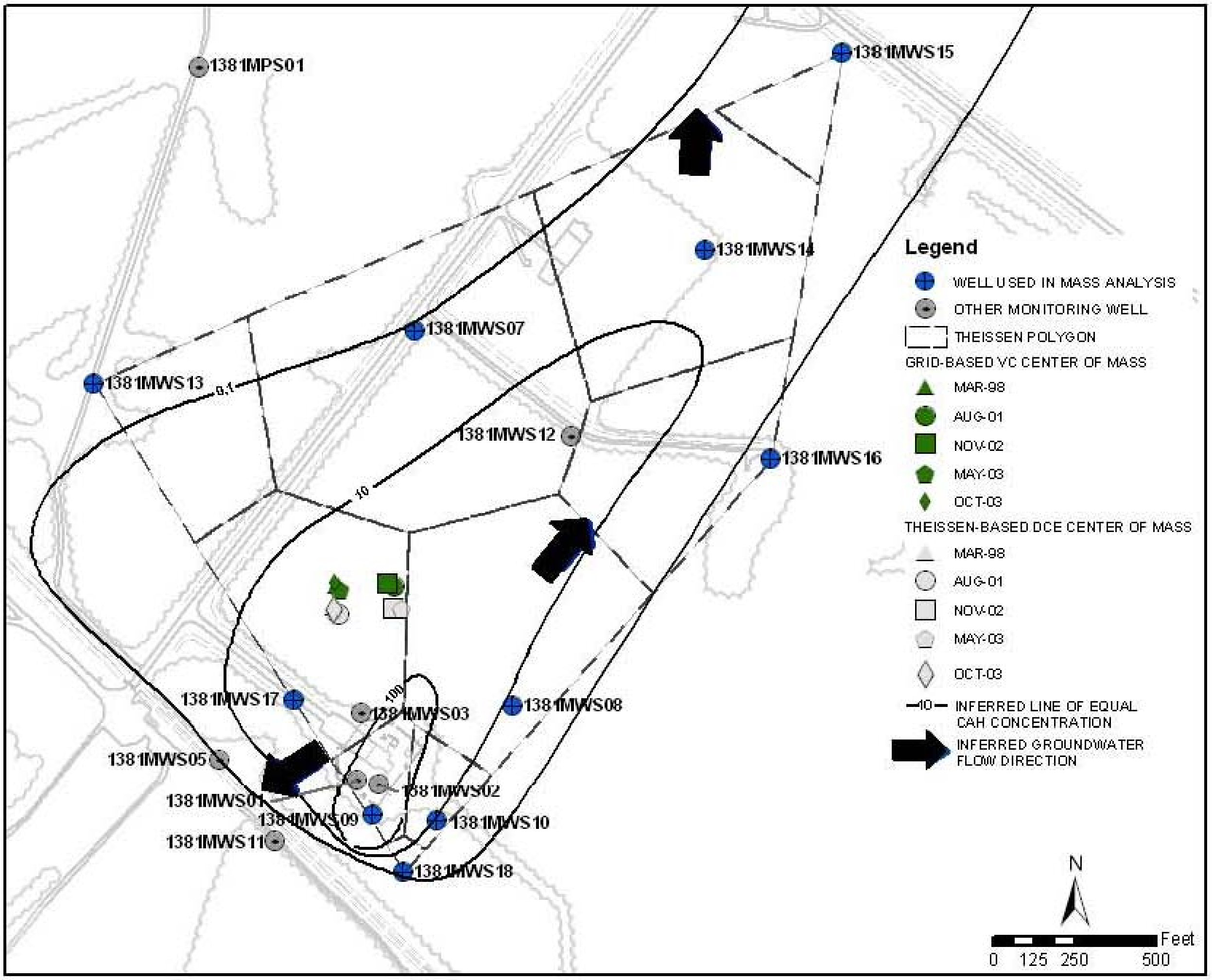


Figure 4.28 Location of the Centers of Mass for VC
Facility 1381, Cape Canaveral AFS, Florida

dissolved CAH plume at Facility 1381 was calculated to be in a relatively constant location over time for all sampling events other than the November 2002 event (see Figure 4.26). The reason for the large movement in the calculated TCE center of mass for the November 2002 event was the reported rapid decrease in the TCE concentration in 1381MW09, which caused this well to have very little impact on the center of mass calculation. In contrast, the center of mass calculations for cis-1,2-DCE indicate a much larger variation in location over time, and are generally further away and hydraulically downgradient from the source area than was the center of mass for TCE. The observation that the cis-1,2-DCE center of mass was calculated to move randomly within the center of the dissolved CAH plume (see Figure 4.27) suggests that the cis-1,2-DCE plume is generally not expanding, but also that there may be seasonal or other phenomena that are influencing the shape and size of this plume over time. As might be expected for a plume where reductive dechlorination is occurring, the location of the center of mass for VC was generally calculated as being the furthest downgradient (hydraulically) of the CAHs at this site. The observation that the center of mass for VC remaining in a relatively constant location, even though there was at least one occasion, in November 2002, when the cis-1,2-DCE center of mass was as far downgradient as the VC center of mass supports a conclusion that NA processes have prevented observable downgradient migration of the VC plume under a variety of source area and dissolved plume conditions.

4.1.4.5 Plume Stability Analysis Summary

Overall, the combined results of concentration-based statistical analysis and mass-based calculations suggest that the CAH plumes at Facility 1381 are stable. The primary observations that support this conclusion are that 1) nearly all CAH concentration trends are ‘stable/no trend’ or ‘decreasing/probably decreasing’ in the dissolved plume and at the sentry wells, 2) the estimated masses of total and individual CAHs are statistically stable and may be slowly decreasing, and 3) the locations of the center of mass for individual CAH plumes are generally stable and/or are not moving consistently downgradient over time. The combined plume stability analysis results do suggest that there is some potential for plume expansion in the future, as evidenced by the observations that 1) the CAH mass has remained relatively constant over time, 2) the majority of the CAH mass during the most recent two monitoring events was present as TCE, and 3) there are indications that the dissolved concentrations of TCE and possibly DCE are increasing in intermediate depth source area wells. The existence of a continuing source of contamination to groundwater implies that there is future potential for plume expansion if the rate of NA in the dissolved plume was to decline over time.

A review of the spatial coverage of monitoring wells indicates that there is sufficient monitoring data to perform plume stability analysis across the dissolved plume for shallow groundwater and at sentry locations for intermediate and deep groundwater. However, the available data indicates that there is a general absence of recent data at intermediate depths within the dissolved plume, which makes it impossible to use the methods described in the current study to discuss the plume dynamics in intermediate-depth groundwater. In addition, it was observed that TCE concentrations in a single shallow well dominate dissolved CAH mass calculations, and that large variations in the observed TCE, and to a lesser extent, cis-1,2-DCE, concentrations lead to considerable uncertainty in plume stability analysis using mass-based methods.

The results of applying the statistical analysis used in the current study to concentration data from Facility 1381 illustrate that the linear regression test can, under some conditions, produce a relatively large percentage of spurious trend results in data sets where all reported CAH concentrations were below detection. In contrast, the MK test was observed to correctly indicate 'stable' or 'no trend' in all cases. These results highlight the advantage of applying different statistical tests, each of which have different strengths and limitations, to an identical data set, and then investigating, understanding, and explaining why the application of different test methods produces different trend analysis results.

4.1.4.6 Recommendations

As with any site, increasing the number of data points for a given well through continued monitoring increases results in an approved ability to support plume stability analysis using statistical trend analysis and/or mass-based calculations. For Facility 1381, continuation of the existing monitoring program for shallow groundwater on an annual to every-other-year basis appears to be sufficient to support statistical analysis of concentration data for plume stability assessment. The ability to use mass-based metrics of plume dynamics of shallow groundwater could be improved by initiating regular sampling of monitoring wells (new or existing) in close spatial proximity to source well 1381MW09, as this well is by far the most dominant well in the common well set, in terms of impacting dissolved mass estimate calculations. The collection of additional samples from intermediate-depth monitoring wells between the source area and sentry wells would allow performance of statistical testing on plume wells that would improve the ability to assess current intermediate-depth plume dynamics. Sampling intermediate-depth plume wells would also help provide early warning should intermediate-depth plume have the potential to expand. In terms of deep groundwater, continued monitoring of existing deep wells below the source area is recommended to confirm the current finding that CAHs are not migrating to deeper depths over time.

4.1.5 Case Study: Site FPTA-2, Brooks City-Base, Texas

4.1.5.1 Site Overview and Summary of Available Data

Site Description

Fire Protection Training Area 2 (FPTA-2), located in the southwest corner of Brooks City-Base, was used for airplane crash fire training exercises from 1945 to 1960 (Parsons, 2002). The training involved igniting 50 to 100 gallons of waste oil, spent solvents, and contaminated fuels and putting the fire out with water. Drums of waste oils and solvents were often staged near FPTAs and mixed with fuels prior to ignition. Use of FPTA-2 ceased in 1960 when flight operations at Brooks City-Base were discontinued. The area around FPTA-2 is not currently in use.

Three operable units (OUs) have been defined at FPTA-2. OU1 consists of contaminated soils located on base, which have been further segregated into surface soils (defined as the soil interval from 0 to 2 feet bgs) and subsurface soils (defined as the soil interval greater than 2 feet bgs). Surface soils were approved for closure for non-residential use by the Texas Natural Resource Conservation Commission (TNRCC) in December 1999 and August 2000, and closure for subsurface soils will likely be sought for non-residential use as well. OU2 and OU3 consist of contaminated groundwater located on base and off base, respectively.

Site hydrogeologic conditions were observed to change significantly between on- and off-base locations. Prior to active remediation, measured hydraulic conductivities in the saturated zone on-base ranged from 0.62 to 4.35 ft/day (geometric mean = 1.90 ft/day), horizontal hydraulic gradient was about 0.012 ft/ft toward the southwest, and the groundwater seepage velocity averaged about 28 ft/yr. Off base, groundwater continued to flow toward the southwest, with measured hydraulic conductivities ranging from 243 ft/day (hydraulic gradient 0.028 ft/ft) near the base boundary decreasing to 19.2 ft/day (hydraulic gradient 0.005 ft/ft) nearer the San Antonio River. Based on these data, the groundwater seepage velocity in the off-base area near the base boundary was relatively high (8,300 ft/yr) compared to near the river (120 ft/yr) (Parsons, 2002).

Plume Description

Groundwater contamination at Site FPTA-2 primarily consists of CAHs and aromatic hydrocarbons (fuels). A dissolved CAH plume, consisting primarily of TCE and cis-1,2-DCE, was identified in the central and southern portions of FPTA-2 (Halliburton NUS [HNUS], 1996). In addition, lower concentrations of TCE and cis-1,2-DCE in groundwater have been detected in groundwater samples collected from off-base wells.

The distributions of TCE and cis-1,2-DCE in groundwater in December 1995 (prior to activation of soil vapor extraction (SVE) and groundwater extraction (GWE) systems described below), September 1998, and June 2001 are shown on Figures 4.29 and 4.30, respectively. In December 1995, the maximum concentrations of TCE and cis-1,2-DCE were detected at source area well MW-30, located within the North Burn Pit. In December 1995, TCE and cis-1,2-DCE were detected as far downgradient as DW-03, which is located approximately 2,000 feet downgradient from the North Burn Pit (Parsons, 2002).

TCE has historically been detected as far downgradient as well MW-42, a distance of approximately 2,500 feet from the suspected source area at the North Burn Pit and 1,800 feet from the Base boundary. MW-42 is located outside of the map window of Figures 4.29 and 4.30, but can be located on Figure 4.30 at a distance of approximately 600 feet southwest of well DW-03. As of June 2001, the only VOCs in groundwater at Site FPTA-2 that exceeded their respective MCLs were TCE, cis-1,2-DCE, and VC. VC was detected at a concentration above its MCL of 2 µg/L at three locations in June 2001. All three wells are located within the North Burn Pit source area, and the detection of VC is likely a result of the anaerobic degradation of cis-1,2-DCE (Parsons, 2002).

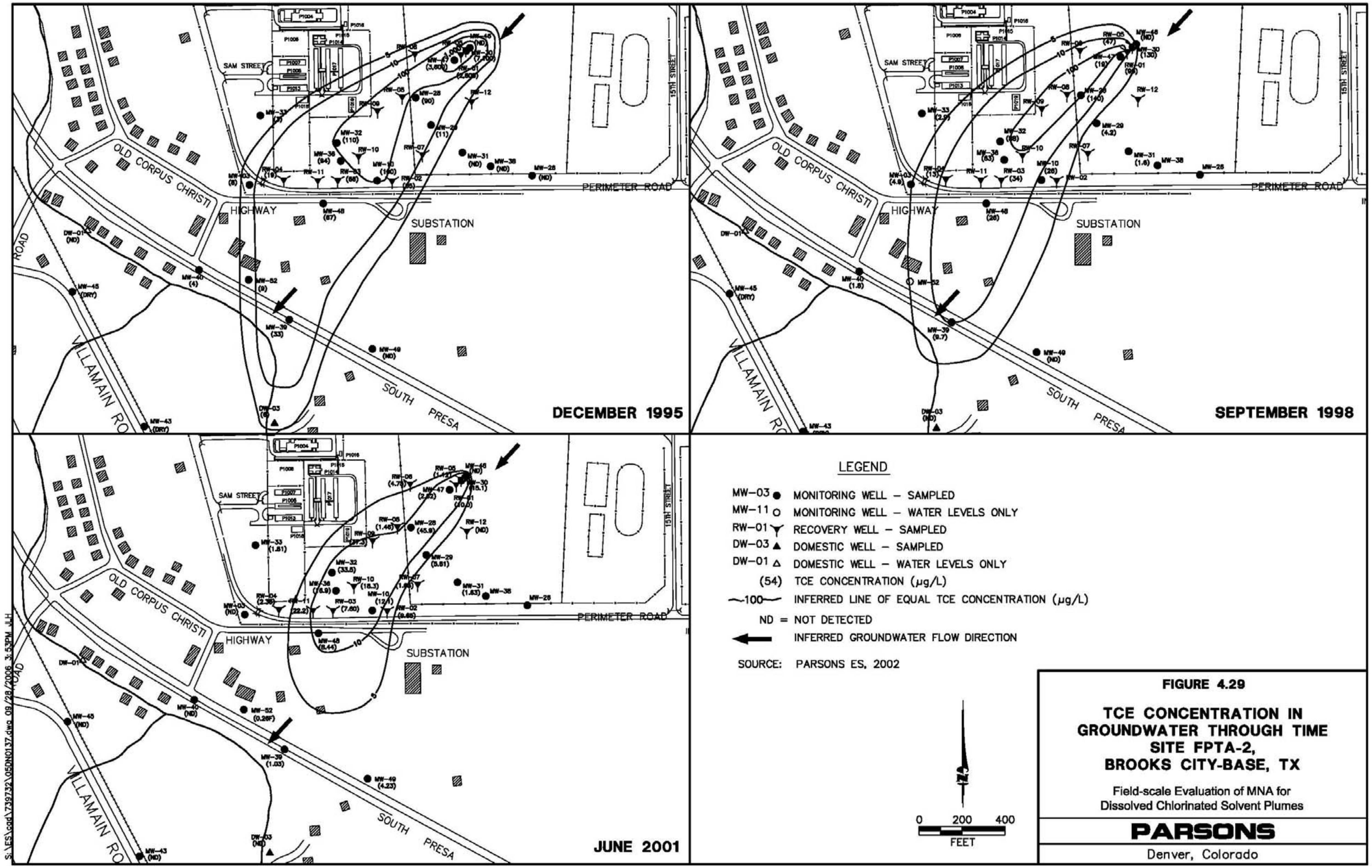


Figure 4.29 TCE Concentration in Groundwater through Time, Site FPTA-2, Brooks City-Base, Texas

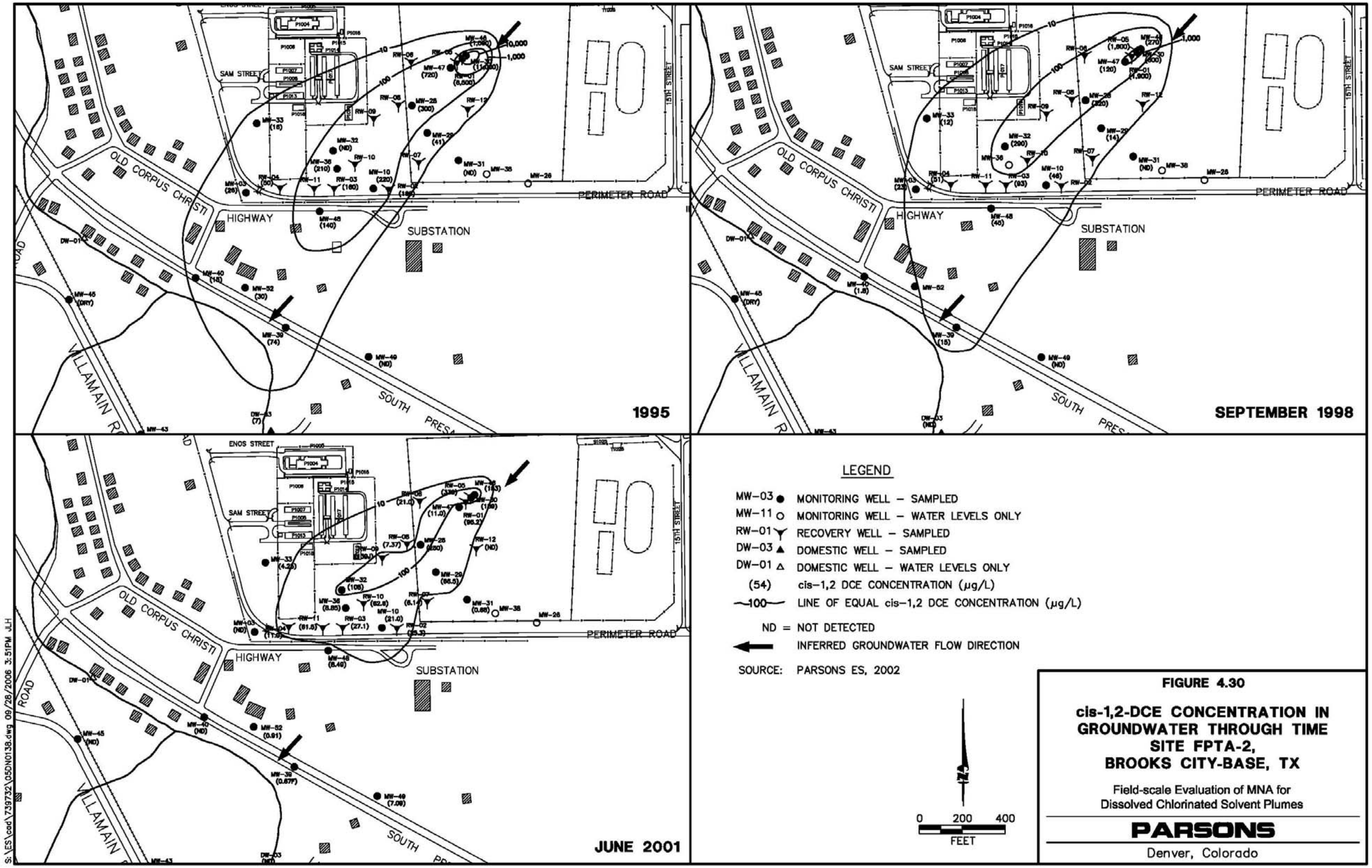


Figure 4.30 cis-1,2-DCE Concentration in Groundwater through Time, Site FPTA-2, Brooks City-Base, Texas

Description of Engineered Remediation

OU1 subsurface soils have been undergoing remediation via SVE since 1996, and OU2 is currently being remediated by a GWE system. OU3 (contaminated groundwater off-base) is being addressed using MNA. The cleanup levels in groundwater are based on State of Texas and Federal MCLs.

The initial SVE system installed in December 1995 was upgraded with additional extraction wells in 1999, and has been very effective for the remediation of TCE-impacted soils at depths ranging from approximately 10 to 40 feet bgs (Parsons, 2002). The SVE system is comprised of vapor extraction wells located within the North and South Burn Pit areas that physically remove VOCs from vadose zone soils.

The remedial process optimization (RPO) evaluation completed by Parsons (2002) concluded that "continued operation of the SVE system is not recommended as a soil remediation action, as the SVE system appeared to have addressed the majority of the contaminant mass it was designed for, and continued operation of the system may no longer be necessary to meet soil cleanup criteria. However, continued operation of the SVE system may be beneficial to continue to remove VOCs that volatilize from groundwater."

The GWE system at FPTA-2 consists of 12 recovery wells, installed in two phases. Wells RW-01 through RW-05 began operation in February 1996, and wells RW-06 through RW-12 began operation in December 1999. Operation of the GWE system has been moderately effective in reducing concentrations of VOCs in groundwater (Parsons, 2002). The GWE system includes recovery wells located 1) near the base boundary to prevent further off-base migration of VOCs and 2) in and immediately downgradient from the suspected source area. Extracted groundwater is treated ex situ and discharged to a wetland area located north and hydraulically upgradient of the site.

Nature of Historical Data and Current LTM Program

The scope of previous groundwater monitoring events for VOCs performed at FPTA-2 from June 1988 to June 2001 is summarized in Table 4.27. As shown in this table, between 25 and 34 wells have been sampled semi-annually for VOCs between December 1995 and June 2001.

Rationale for Selection for Case Study

This site was selected as a case study for two reasons:

1. A large number of monitoring wells was consistently sampled over a period of at least five years, facilitating the use of temporal trend analysis techniques, and

2. The presence of an active remediation system allowed demonstration of how the plume stability analysis techniques described in this study can be applied to remedies that are not solely-based on MNA.

Table 4.27 Summary of Groundwater Monitoring Well Sampling for VOCs
FPTA-2, Brooks City-Base, Texas

				Sampling Date for VOCs [c]																	
Well	**Completion Date**	**Plume**	**Used in Statistical Analyses?**	**Jun-88**	**Feb-90**	**Mar-91**	**Mar-94**	**Oct/Nov-94**	**Dec-95**	**Sep-96**	**Dec-96**	**Jun-97**	**Dec-97**	**Aug/Sept-98**	**Dec-98**	**Feb-99**	**Jun-99**	**Dec-99**	**Jun-00**	**Dec-00**	**Jun-01**
Monitoring Wells																					
MW-30	Jan-90	Source	Yes		X		X	X	X	X	X	X	X	X	X		X	X	X	X	X
MW-47	Jul-95	Source	Yes						X	X	X	X	X	X	X		X	X	X	X	X
MW-03	Feb-88	Plume	Yes						X	X	X	X	X	X	X		X	X	X	X	X
MW-10	Feb-88	Plume	Yes	X	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X
MW-28	Jan-90	Plume	Yes		X		X	X	X	X	X	X	X	X	X		X	X	X	X	X
MW-29	Jan-90	Plume	Yes					X	X	X	X	X	X	X	X		X	X	X	X	X
MW-32	Jan-90	Plume	Yes		X		X	X	X	X	X	X	X	X	X		X	X	X	X	X
MW-33	Jan-90	Plume	Yes						X	X	X	X	X	X	X		X	X	X	X	X
MW-36	Feb-90	Plume	Yes				X	X	X	X	X	X	X	X	X		X	X	X	X	X
MW-39	Feb-91	Plume	Yes			X	X	X	X	X	X	X	X	X	X		X	X	X	X	X
MW-46	Jul-95	Plume	Yes						X	X	X	X	X	X	X		X	X	X	X	X
MW-48	Jul-95	Plume	Yes						X	X	X	X	X	X	X		X	X	X	X	X
MW-52	Jul-95	Plume	Yes						X	X	X	X	X	X	X		X	X	X	X	X
MW-31	Jan-90	Sentry	Yes						X	X	X	X	X	X	X		X	X	X	X	X
MW-40	Feb-91	Sentry	Yes						X	X	X	X	X	X	X		X	X	X	X	X
MW-42 [a]	Mar-91	Sentry	No						X	X	X	X	X	X	X		X	X	X	X	X
MW-43 [a]	Mar-91	Sentry	No						X	X	X			X	X		X	X	X	X	X
MW-45 [a]	Oct-94	Sentry	No						X	X	X	X	X	X	X		X	X	X	X	X
MW-49	Jul-95	Sentry	Yes						X	X	X	X	X	X	X		X	X	X	X	X
MW-50 [a]	Jul-95	Sentry	No						X	X	X	X	X	X	X		X	X	X	X	X
MW-51 [a]	Aug-95	Sentry	No						X	X	X			X	X		X	X	X	X	X
Domestic and Recovery Wells [b]																					
DW-03	Unknown	Sentry	Yes						X	X	X	X	X	X	X		X	X	X	X	X
RW-1	Aug-95	Source	No						X	X	X	X	X	X			X	X	X	X	X
RW-5	Aug-95	Source	No						X	X	X	X	X	X	X		X	X	X	X	X
RW-2	Jul-95	Plume	No						X	X	X	X	X	X	X		X	X	X	X	X
RW-3	Jul-95	Plume	No						X	X	X	X	X	X	X		X	X	X	X	X
RW-4	Aug-95	Plume	No						X	X	X	X	X	X	X		X	X	X	X	X
RW-6	Jan-99	Plume	No													X	X	X	X	X	X
RW-7	Jan-99	Plume	No													X	X	X	X	X	X
RW-8	Jan-99	Plume	No													X	X	X	X	X	X
RW-9	Jan-99	Plume	No													X	X	X	X	X	X
RW-10	Jan-99	Plume	No													X	X	X	X	X	X
RW-11	Jan-99	Plume	No													X	X	X	X	X	X
RW-12	Jan-99	Sentry	No													X	X	X	X	X	X

[a] These wells were either dry or below detection limits for all sampling events. Statistical analysis was not completed for these wells.

[b] Recovery wells (RWs) were not included in the statistical trend analyses for the current evaluation.

[c] VOCs = volatile organic compounds.

Note: Highlighted cells indicate data that were used in mass-based analyses.

4.1.5.2 Summary of Historic Plume Stability Assessment

The results of historical plume stability evaluations are summarized in Table 4.28 and described in the paragraphs below.

Qualitative Evaluation of Historical Data and Plume Isopleth Maps

Historical data described in Parsons (2002) indicate that the TCE plume was naturally receding toward the source area prior to initiation of engineered remediation in July 1995. However, the available data are insufficient to estimate the rate of natural plume recession.

Since initiation of the SVE and GWE systems in 1996, concentrations of TCE and cis-1,2-DCE at MW-30 (North Burn Pit) have been significantly reduced. Off base, the TCE and cis-1,2-DCE plumes also appear to have attenuated, with the farthest downgradient detection of TCE and cis-1,2-DCE in September 1998 at well MW-39, a distance of approximately 1,500 feet from well MW-30. However, many of the downgradient, off-base monitoring wells were dry (including MW-42) in September 1998; as a result the actual extent of any residual TCE contamination in saturated zones off base could not be inferred with confidence (Parsons, 2002).

The distribution of TCE and cis-1,2-DCE in groundwater in June 2001 (the most recent data available, Figures 4.29 and 4.30, respectively) shows continued attenuation of TCE and cis-1,2-DCE in groundwater and suggests further shrinkage of the plume footprint. The farthest downgradient location where TCE and cis-1,2-DCE were detected during the June 2001 sampling event was at well MW-49 (Parsons, 2002).

The observation that TCE and cis-1,2-DCE concentrations measured in 2001 are generally lower than concentrations measured in 1998 supports the conclusion that the SVE and GWE systems have been effective in reducing CAH concentrations both on and off base. However, the measurement of elevated TCE and cis-1,2-DCE concentrations at locations in the source area and along the plume axis suggest that localized zones of elevated CAH contamination ingroundwater are still present on base as of June 2001 (Parsons, 2002). The observed distribution and persistence of CAHs in groundwater has led to a conclusion that aquifer heterogeneity, preferential flow paths, and/or localized bedrock lows with little or no flow (i.e., stagnation zones) are controlling the continued presence of significant CAH contamination on base (Parsons, 2002).

2002 RPO Linear Regression Results

A linear regression analysis was completed for the 2002 RPO report (Parsons, 2002). In the RPO report, contaminant concentrations were plotted as a function of time for selected wells, and trend lines were fit to the available data to develop the linear regression analysis. Although the trend of contaminant concentrations at each well was determined, the trend analysis results were not explicitly used to assess whether the contaminant plume was increasing, decreasing, or stable in extent. In addition to assessing the concentration trends,

Table 4.28 Results of Previous Concentration-Based Plume Stability Analyses
FPTA-2, Brooks City-Base, Texas

	Data Used for Trend Assessment					
Evaluation Method	**Monitoring Wells**	**Period of Sampling**	**Reported Results of Trend Assessment**	**Reported Plume Stability Conclusion**	**Related Conclusion(s) and Notes**	**Source**[a/]
Temporal changes in source well concentrations [b/]						
Visual inspection of isoconcentration contour maps for TCE and DCE	MW-30, MW-47	12/95 to 6/01	• Concentrations in the source area are steadily decreasing due to operation of SVE and GWE systems since 1996	None provided	--	(1)
Visual inspection of graphed molar fraction data for TCE, DCE, and VC	MW-30	3/94 to 6/01	• DCE fraction increasing faster than TCE fraction over time • Fraction of VC declined after start-up of GWE system in 1996	None provided	• Reductive dechlorination of TCE to DCE is proceeding • Either reductive dechlorination did not proceed past DCE or VC was degraded faster than it was generated	(1)
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using linear regression	MW-30, RW-01, RW-05	12/95 to 6/01	• TCE, DCE, and VC concentrations are ‘decreasing’	None provided	--	(1)
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using Mann-Kendall test	MW-30, MW-47, RW-01, RW-05	12/95 to 6/01	• TCE, DCE, and VC concentrations are ‘decreasing’ or ‘probably decreasing’	None provided	--	(1)
Temporal changes in plume well concentrations [c/]						
Visual inspection of graphed total CAH data	MW-10	3/94 to 6/01	• Molar ratios of DCE and TCE constant over time	None provided	• Molar ratio suggests that reductive dechlorination has not occurred to a significant extent at MW-10	(1)
Visual inspection of isoconcentration contour maps for CAH data	Plume wells listed in Table 4.27	12/95 to 6/01	• Concentrations throughout plume are steadily decreasing • The 1998 and 2001 plumes have similar extents, but concentrations are lower in 2001 plume	Plume receding	• Elevated concentrations along plume axis suggests presence of localized high concentrations zones, probably due to aquifer heterogeneity, preferential flow paths, and local bedrock depressions with little or no flow	(1)

Table 4.28 Results of Previous Concentration-Based Plume Stability Analyses
FPTA-2, Brooks City-Base, Texas

	Data Used for Trend Assessment					
Evaluation Method	**Monitoring Wells**	**Period of Sampling**	**Reported Results of Trend Assessment**	**Reported Plume Stability Conclusion**	**Related Conclusion(s) and Notes**	**Source[a/]**
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using linear regression	MW-10, MW-28, MW-29, MW-32, MW-36, MW-39, MW-46, MW-48, RW-02, RW-03, RW-06, RW-07, RW-09, RW-10, RW-11	10/94 to 6/01	• All TCE, DCE, and VC concentrations are 'decreasing' with the exception of DCE at MW-28 ('increasing') and TCE and DCE at MW-29 ('increasing')	None provided	• TCE and DCE concentrations at MW-29 and DCE concentrations at MW-28 were 'decreasing' prior to GWE system start-up • 'Increasing' trends at MW-28 and MW-29 after GWE system start-up attributed to GWE system pulling higher-concentration groundwater toward these locations	(1)
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using Mann-Kendall test	MW-03, MW-10, MW-28, MW-29, MW-32, MW-33, MW-36, MW-39, MW-46, MW-48, MW-52, and all Recovery Wells	10/94 to 6/01	• 46 of 52 trends were 'decreasing', 3 were 'stable', 1 was 'probably increasing' (DCE in MW-29), and 2 were 'no trend' (TCE in MW-28 and MW-29)	None provided	• Same as above	(1)
Temporal changes in sentry well concentrations d/						
Visual inspection of isoconcentration contour maps for CAHs	MW-42, MW-46, DW-03	12/95 to 06/01	• Farthest downgradient detections in 1995 and 2001 were 2500 ft and 2000 ft from source area, respectively	Plume receding	• Many off-Base, downgradient wells were dry in 9/98, making it difficult to confidently assess downgradient plume extent	(1)
Visual inspection of tabular concentration data for CAHs	DW-03, MW-42	Pre-1995 to 12/95	• Farthest downgradient detections re-1995 and in 12/95 were 2500 ft and 2000 ft from source area, respectively	Plume receding	• Same as above	(1)

[a/] Source: (1) RPO Report for FPTA-2 (Parsons, 2002)
[b/] Source wells selected based on proximity to inferred source area.
[c/] Plume wells are located within the CAH plume but outside of the inferred source area.
[d/] Sentry wells are located downgradient, crossgradient, above, or below the plume extents to monitor plume stability.
Notes: CAH = chlorinated aliphatic hydrocarbon; COC = contaminant of concern; TCE = trichloroethene; DCE = cis-1,2-dichloroethene, VC = vinyl chloride; GWE = groundwater extraction; SVE = soil vapor extraction.

the graphs were used to calculate an approximate length of time required to reach groundwater remediation goals under current conditions. Extrapolating the trend line at each location to the point where the concentration intersects the contaminant-specific remedial goal indicated an approximate length of time required to reach that goal.

The linear regression analysis concluded that all concentrations of TCE, cis-1,2-DCE, and VC were trending downward through time at all locations at FPTA-2, with the exception of wells MW-28 and MW-29. Assuming that the concentrations of TCE, cis-1,2-DCE, and VC continue to decrease through time, and the trends of decreasing concentrations continue to approximate first-order processes, it was projected that cleanup goals for OU2 would achieved for TCE at all monitoring locations (except MW-29) by the year 2023, giving a remediation timeframe of 22 years. Similarly, for on-base wells, it was projected that cleanup goals would be achieved for cis-1,2-DCE in the year 2006 at all locations (except MW-28 and MW-29), giving a remediation time-frame of 5 years. It was also projected that cleanup goals would be achieved for VC in the year 2003, giving a remediation time-frame of approximately 2 years. The RPO report states that, given the natural variation in contaminant concentrations measured at any given time, actual time to remediation will likely be longer than predicted by the linear regression analysis. In addition, the RPO report noted that the Rsquared statistics, a measure of the fit or variability of the data to the trend line, are low (less than 80 percent) in many cases, indicating that the concentration data may not be lognormally distributed and that confidence associated with these trends and associated remediation timeframe estimates is low.

Cleanup dates could not be estimated for TCE at well MW-29 and for cis-1,2-DCE at wells MW-28 and MW-29 because concentration data for these wells either exhibited ‘no trend’ or an ‘increasing’ trend. These two wells are downgradient of the suspected source area, and the increasing trends were thought to be a result of more highly-contaminated groundwater being pulled through the location of the monitoring wells by nearby groundwater extraction wells.

2002 RPO Mann-Kendall Results

A MK analysis was also performed as part of the RPO evaluation (Parsons, 2002). The MK analyses for TCE, cis-1,2-DCE, and VC indicate concentration trends that are ‘decreasing’, ‘probably decreasing’, or ‘stable’ with three exceptions. The exceptions for TCE are a determination of ‘no trend’ at wells MW-28 and MW-29. For cis-1,2-DCE, the exception is a determination of a ‘probably increasing’ trend at well MW-29. Therefore, it was concluded that contaminants at these monitoring locations have not been affected by the operation of the GWE and SVE systems.

4.1.5.3 Results of Concentration-Based Stability Analysis

Concentration-based stability analysis results obtained for the current project are summarized and compared to historical stability analysis results in Table 4.29 and in the following paragraphs. Trend analysis results for TCE concentrations over time at selected wells along the plume axis are provided as Figure 4.31. Note that each statistical test was applied to develop two statistical trend analyses for each data set. The first trend analysis was for the period from December 1995 to December 1998, while and the second trend analysis was

Table 4.29 Comparison of Historical and Current Concentration-Based Plume Stability Analyses
FPTA-2, Brooks City-Base, Texas

	Data Available at Time of Assessment						
Evaluation Method	**Monitoring Wells**	**Period of Sampling**	**Results of Trend Assessment**	**Plume Stability Conclusion**	**Related Conclusion(s) and Notes**	**Source** [a]	**Comparison of Historical and Current Plume Stability Conclusions**
Temporal changes in source well concentrations [b]							
Visual inspection of isoconcentration contour maps for TCE and DCE	MW-30, MW-47	12/95 to 6/01	• Concentrations in the source area are steadily decreasing due to operation of SVE and GWE systems since 1996	None provided	--	(1)	Current (quantitative) trend analysis results for source area wells agree with the historical trend analysis results, and indicate the effectiveness of the GWE and SVE systems at reducing dissolved CAH levels in the source area. Unless significant rebound occurs when the GWE/SVE systems are shut off, the diminished source area CAH concentrations should result in a decreased potential for CAH plume expansion. Calculation of statistical trends for multiple discrete time periods as opposed to one trend for the entire sampling history provides statistical confirmation of changing trends as CAH concentrations approach asymptotic levels.
Visual inspection of graphed molar fraction data for TCE, DCE, and VC	MW-30	3/94 to 6/01	• DCE fraction increasing faster than TCE fraction over time • Fraction of VC declined after start-up of GWE system in 1996	None provided	• Reductive dechlorination of TCE to DCE is proceeding • Either reductive dechlorination did not proceed past DCE or VC was degraded faster than it was generated	(1)	
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using linear regression	MW-30, RW-01, RW-05	12/95 to 6/01	• TCE, DCE, and VC concentrations are 'decreasing'	None provided	--	(1)	
Statistical analysis of primary COCs (i.e., TCE and DCE) using the Mann-Kendall test	MW-30, MW-47, RW-01, RW-05	12/95 to 6/01	• TCE, DCE, and VC concentrations are 'decreasing' or 'probably decreasing'	None provided	--	(1)	
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using linear regression and the Mann-Kendall test	MW-30, MW-47	10/94 to 6/01	Both statistical analysis methods indicated: • 'Decreasing' trends for all COCs from 12/95 to 12/98 or 6/99. • Trends ranged from 'decreasing' to 'no trend' from 6/99 to 6/01	Diminished potential for future plume expansion assuming lack of significant rebound when GWE and SVE systems are shut off	• The Phase 1 GWE and SVE systems resulted in rapid reduction of CAH concentrations in the source area; in recent years, the rate of decrease has slowed substantially as concentrations approach asymptotic levels.	Appendix C of current study	
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using Sen's slope	MW-47	12/95 to 6/01	• 'Probably decreasing' to 'no trend' from 12/95 to 12/98, • 'No trend' from 12/98 to 6/01	Sen's slope does not indicate a diminished potential for plume expansion as strongly as linear regression and MK tests	• In some instances, Sen's slope test was relatively insensitive to temporal trends that are visually apparent on time-series graphs	Appendix C of current study	
Temporal changes in plume well concentrations [c]							
Visual inspection of graphed total CAH data	MW-10	3/94 to 6/01	• Molar ratio of DCE and TCE constant over time	None provided	• Molar ratio suggests that reductive dechlorination has not occurred to a significant extent at MW-10	(1)	Historical trend data were not used to derive conclusions related to plume stability; therefore, comparison of historical and current plume stability conclusions is not possible. However, historical (qualitative and quantitative) and current (quantitative) trend analysis results both support the potential for CAH plume recession based on the overall trend of decreasing TCE and DCE concentrations throughout much of the plume. Quantitative analysis provides statistical confidence in the accuracy of this assessment.
Visual inspection of isoconcentration contour maps for CAH data	Plume wells listed in Table 4.27	12/95 to 6/01	• Concentrations throughout plume are steadily decreasing • The 1998 and 2001 plumes are of similar extents, but concentrations are lower in 2001 plume	Plume receding	• Elevated concentrations along plume axis suggests presence of localized high concentrations zones, probably due to aquifer heterogeneity, preferential flow paths, and local bedrock depressions with little or no flow	(1)	
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using linear regression	MW-10, MW-28, MW-29, MW-32, MW-36, MW-39, MW-46, MW-48, RW-02, RW-03, RW-06, RW-07, RW-09, RW-10, RW-11	10/94 to 6/01	• All TCE, DCE, and VC concentrations are 'decreasing' with the exception of DCE at MW-28 ('increasing') and TCE and DCE at MW-29 ('increasing')	None provided	• TCE and DCE concentrations at MW-29 and DCE concentrations at MW-28 were decreasing prior to GWE system start-up • 'Increasing' trends at MW-28 and MW-29 after GWE system start-up attributed to GWE system pulling higher-concentration groundwater toward these locations	(1)	

Table 4.29 Comparison of Historical and Current Concentration-Based Plume Stability Analyses (continued)
FPTA-2, Brooks City-Base, Texas

	Data Available at Time of Assessment						
Evaluation Method	**Monitoring Wells**	**Period of Sampling**	**Results of Trend Assessment**	**Plume Stability Conclusion**	**Related Conclusion(s) and Notes**	**Source a/**	**Comparison of Historical and Current Plume Stability Conclusions**
Temporal changes in plume well concentrations $^{c/}$ (Concluded)							
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using the Mann-Kendall test	MW-03, MW-10, MW-28, MW-29, MW-32, MW-33, MW-36, MW-39, MW-46, MW-48, MW-52, and all Recovery Wells	10/94 to 6/01	• 46 of 52 trends were 'decreasing,' 3 were 'stable,' 1 was 'probably increasing' (DCE in MW-29), and 2 were 'no trend' (TCE in MW-28 and MW-29)	None provided	• Individual CAH concentrations in MW-28 and MW-29 have increased since start-up of the GWE system	(1)	Variation between quantitative trend results reported in the RPO report (Parsons, 2002) and results obtained for the current study using the same methods is due to the fact that at least a portion of the historical results were obtained by analyzing the entire dataset for each well, whereas the current study assessed trends for discrete portions of the monitoring history to identify the effects of 1) the installation of recovery wells RW1-RW5 in July 1995 and 2) the installation of RW6-RW12 in January 1999. This approach allowed temporal variations in trends to be identified (e.g., decreasing during the early portion of the groundwater extraction period, transitioning to stable as asymptotic levels were attained). In this way, the effects of the GWE system could be better quantified.
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using linear regression	Plume monitoring wells listed on Table 4.27 (excluding recovery wells)	6/88 to 6/01	• From 12/95 to 12/98, 8 of 20 trends for TCE/DCE were 'probably decreasing' or 'decreasing,' 9 were 'no trend' or 'stable,' and 3 were 'probably increasing' • From 12/98 to 6/01, 16 of 21 trends were 'probably decreasing' or 'decreasing', 4 were 'stable', and 1 was 'increasing'	Decreasing trends for TCE and DCE in downgradient plume axis wells MW-39 and MW-48 strongly support plume recession from 12/95 to 12/98. Linear regression results for 12/98 to 6/01 provide strong evidence for plume recession and eventual collapse	• Statistical trend analysis results indicate that the GWE system operation has either caused or increased the rate of plume recession, and that the impact of the GWE system was substantially increased by the addition of recovery wells RW-6 through RW-12	Appendix C of current study	
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using the Mann-Kendall test		12/95 to 06/01	• From 12/95 to 12/98, 6 of 20 trends for TCE/DCE were 'probably decreasing' or 'decreasing', and 14 were "no trend" or 'stable.' No 'increasing' or 'probably increasing' trends were identified • From 12/98 to 6/01, 13 of 21 trends were 'probably decreasing' or 'decreasing', 7 were 'stable', and one was 'increasing'	Decreasing trends for TCE and DCE in downgradient plume axis well MW-39 support plume recession from 12/95 to 12/98. MK results for 12/98 to 6/01 also show evidence for plume recession. However, MK results do not indicate plume recession as clearly as linear regression results do due to the greater number of 'stable' trends.	• The MK trend result for DCE in downgradient well MW-39 ('stable') from 12/98 to 6/01 does not support plume recession during that time period. However, visual inspection of the DCE time series plot (Appendix C) shows decreasing concentrations from 5/00 to 6/01, indicating the potential for	Appendix C of current study	
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using Sen's slope	MW-3, MW-10, MW-47, MW-52	12/95 to 06/01	• From 12/95 to 12/98, 4 of 6 calculated trends for TCE/DCE were 'no trend', and 2 were 'decreasing' • From 12/98 to 6/01, 2 of 6 trends were 'no trend' and 4 were 'probably decreasing' to 'decreasing'	Based on limited data, the CAH plume was stable to diminishing from 12/95 to 12/98. From 12/98 to 6/01, there was an increased potential for plume recession as indicated by the greater number of decreasing trends (vs. 'no trend')	• The Sen's slope test tended to correctly identify strong, unambiguous trends. The Sen's test was less sensitive to plume recession more subtle trends that were identified by the linear regression and MK methods, and to less ambiguous trends that are visually apparent on time-series plots, but that are not entirely consistent (i.e., there were significant fluctuations in concentrations over time). This reduced sensitivity resulted in a greater number of 'no trend' designations	Appendix C of current study	

Table 4.29 Comparison of Historical and Current Concentration-Based Plume Stability Analyses (continued)
FPTA-2, Brooks City-Base, Texas

	Data Available at Time of Assessment						
Evaluation Method	**Monitoring Wells**	**Period of Sampling**	**Results of Trend Assessment**	**Plume Stability Conclusion**	**Related Conclusion(s) and Notes**	**Source a/**	**Comparison of Historical and Current Plume Stability Conclusions**
Temporal changes in sentry well concentrations [d]							
Visual inspection of isoconcentration contour maps for CAHs	MW-42, MW-46, DW-03	12/95 to 06/01	• Farthest downgradient detections in 1995 and 2001 were 2500 ft and 2000 ft from source area, respectively	Plume receding	• Many off-Base, downgradient wells were dry in 9/98, making it difficult to confidently assess downgradient plume extent	(1)	Both historical (qualitative) and current (quantitative) trend analysis results for sentry wells support CAH plume recession toward the source area. Quantitative analysis provides statistical confidence in the accuracy of this assessment. Sentry well MW-49 was not included in historical trend analyses; identification of slight increasing or probably increasing trends at this well using linear regression bears further scrutiny as additional data are collected to ensure that these trends are not indicative of significant plume expansion
Visual inspection of tabular concentration data for CAHs	DW-03, MW-42	Pre-1995 to 12/95	• Farthest downgradient detections pre1995 and in 12/95 were 2500 ft and 2000 ft from source area, respectively	Plume receding		(1)	
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using linear regression	Sentry wells listed in Table 4.27	12/95 to 06/01	• TCE and DCE concentrations for entire period of sampling were 'decreasing' at DW-03, 'stable' to 'no trend' at MW-31 (mostly non-detect), 'stable' (12/95 to 12/98) to 'decreasing' (12/98 to 6/01) at MW-40, and 'no trend' to 'probably increasing' at MW-49 (12/95 to 6/01). Linear regression results for the sampling period subsets 12/95 to 12/98 and 12/98 to 6/01 were all 'no trend'	'Decreasing trends' at DW-03 and MW-40 support plume recession. However, 'probably increasing' trends for TCE and DCE at MW-49, although slight, bear further scrutiny as more data are collected	--	Appendix C of current study	
Statistical analysis of primary COCs (i.e., TCE, DCE, VC) using the Mann-Kendall test		12/95 to 06/01	• TCE and DCE concentrations are 'decreasing' at DW-03, 'no trend' at MW-31, 'stable' (12/95 to 12/98) to 'probably decreasing' (12/98 to 6/01) at MW-40, and 'no trend' to 'increasing' at MW-49. The sole 'increasing' trend was only for DCE from 12/95 to 12/98	'Decreasing' to 'probably decreasing' trends at DW-03 and MW-40 support plume recession. In contrast to linear regression results, MK results for MW-49 do not indicate potential plume expansion		Appendix C of current study	

[a] Source: (1) RPO Report for FPTA-2 (Parsons, 2002).
[b] Source wells selected based on proximity to inferred source area.
[c] Plume wells are located within the CAH plume but outside of the inferred source area.
[d] Sentry wells are located downgradient, crossgradient, above, or below the plume extents to monitor plume stability.
Notes: CAH = chlorinated aliphatic hydrocarbon; COC = contaminant of concern; TCE = trichloroethene; DCE = cis-1,2-dichloroethene; VC = vinyl chloride; BD = below detection; GWE = groundwater extraction; SVE = soil vapor extraction.

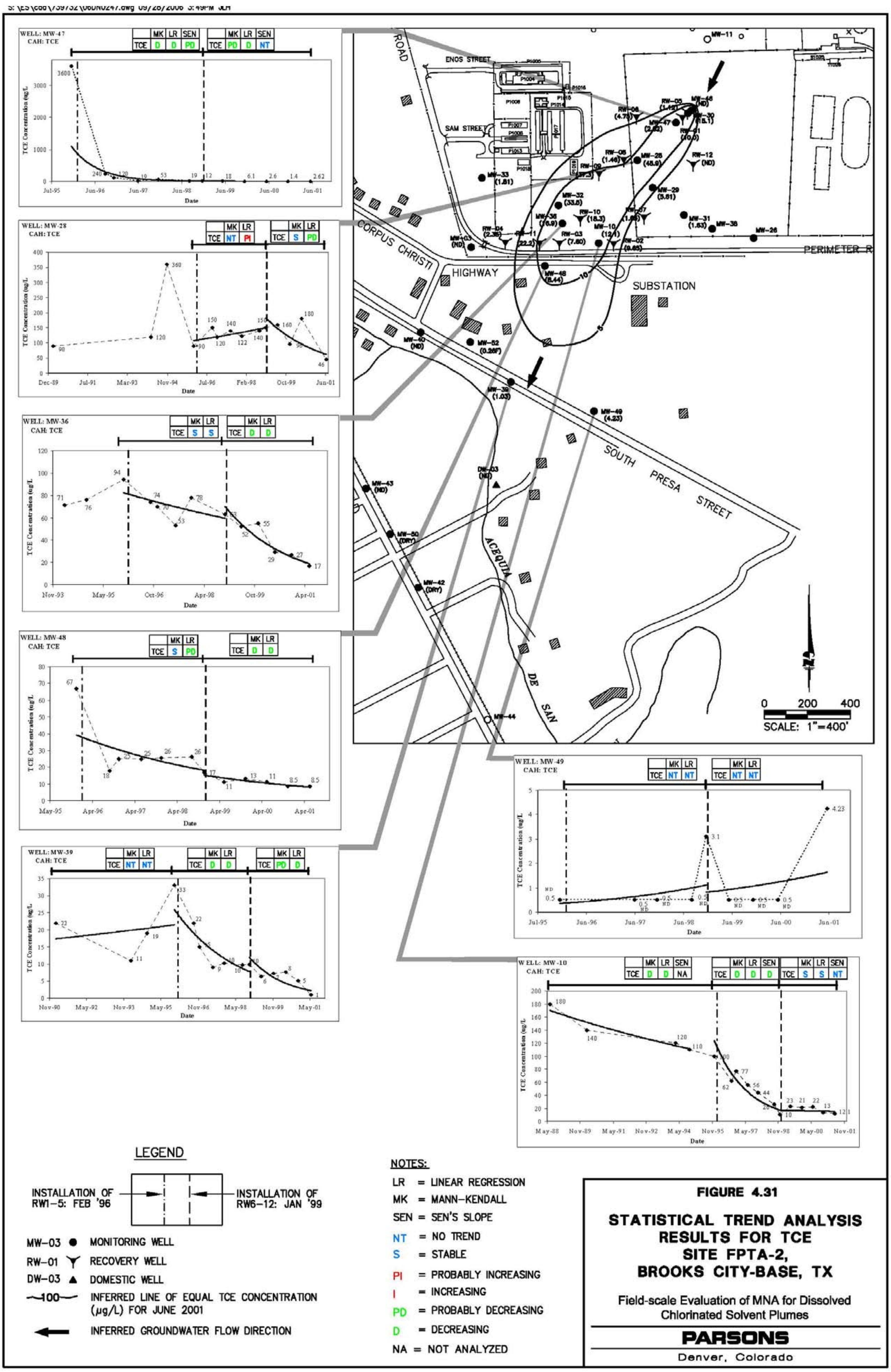


Figure 4.31 Statistical Trend Analysis Results for TCE Site FPTA-2, Brooks City-Base, Texas.

applied to data from December 1998 to June 2001. The first time period was used to evaluate early system performance, with the start data corresponding to just before GWE system start-up of the initial five recovery wells in February 1996 and the end data corresponding to the period just before start-up of the seven additional recovery wells in January 1999. The second time period was used to evaluate longer-term system performance, with the specific goal of observing whether the current study methods were capable of quantifying changes between initial and long-term GWE/SVE system performance. Detailed results of linear regression, MK and Sen's slope analyses for all compounds are contained in Appendix C. For this study, statistical testing was performed on data sets using three different methods. However, the most rigorous approach to statistical analysis is to perform data distribution testing (including possible assessment of log-transformed data) prior to selecting a statistical test. The current version of MAROS does not offer the option of selecting a statistical test based on data distribution analyis or the existence of non-detect data, but rather provides the user with both linear regression and MK statistical results. Users of MAROS will be faced with the decision of having to select from the two test results, whether or not both results were desired. It is recommended that users of MAROS evaluate data distribution at locations where the parametric and nonparametric test results conflict to evaluate which statistical test result is most appropriate. Although data distribution analysis was performed for data sets used in this study, most of the results were inconclusive; an artifact of small data sets and large numbers of non-detect values. This indicates that the non-parametric MK approach is probably an appropriate, conservative choice in many cases.

Source Area

Statistical trend analysis was performed on two source wells (MW-30 and MW-47) as part of the current study. Results of applying the linear regression and MK tests to early system operation data (i.e., data from December 1995 through December 1998) uniformly identified 'decreasing' trends for TCE, cis-1,2-DCE, and VC at both wells. When the same statistical methods were applied to the second analysis period (i.e., December 1998 to June 2001), the linear regression analysis of TCE concentrations at MW-47 was the only statistical trend result that was still found to be 'decreasing'. For the other compounds analyzed over the second analysis period, trends in MW-47 for TCE were 'probably decreasing' when using the MK test, while cis-1,2-DCE and VC in MW-47 were identified as 'probably decreasing' when using linear regression and 'no trend' and 'stable' when using the MK test. At MW-30, statistical trends for all CAHs during the second analysis period were 'no trend' with using either linear regression or the MK test. The identification of 'probably decreasing', 'stable', and 'no trend' results in the second timeframe was caused by a substantial slowing in the rate of concentration decrease because concentrations appear to be approaching relatively low, asymptotic levels during 1999 to 2002 time period. For example, concentrations of TCE, cis- 1,2-DCE, and VC at MW-47 had decreased to concentrations all below their respective MCLs by June 2000. A graph of TCE concentration versus time for MW-47, as shown in the upper left corner of Figure 4.31, provides a visual example of this observed condition. Concentration trends for MW-47 also were evaluated using the Sen's Slope method. As shown on Figure 4.31, this method gave 'no trend' results for TCE for both early (i.e., 1995 to 1998) and late (i.e., 1998 to 2001) data sets, despite the observations that 1) decreasing trends were visually apparent on the time-series graph and 2) the other two statistical methods identified 'decreasing' and 'probably decreasing' trends for TCE from this well.

The decreasing trends identified in the current analysis are generally consistent with trends identified during the RPO report (Parsons, 2002). Both current and historical trend analysis results indicate that 1) the GWE and SVE systems have been reasonably effective at reducing concentrations of CAHs and 2) CAH plume recession has occurred and is likely to continue to recede until eventual elimination of detectable dissolved CAH contamination. Results of performing statistical tests on both early time and later data indicates that 1) linear regression and the MK test are sensitive enough to be useful for identifying changes in system performance over time, 2) the rate of change in CAH concentrations after 1998 is moving toward stability from clearly 'decreasing' trends observed from 1995 to 1998, and 3) the installation of the additional recovery wells had little or no impact on CAH concentrations in source area wells. Application of various statistical tests to the same data set provide examples that 1) linear regression was more apt to interpret that a trend exists than the MK method and 2) Sen's method was relatively insensitive to trends that are apparent from visual observation and the application of other statistical tests. Based on this latter result, Sen's Method is not recommended for use as a sole indicator of trends because this method is too insensitive to changes in contaminant concentration.

Plume Area

Statistical trend analyses were performed for the 11 plume wells listed in Table 4.27; trend analysis results for five of these wells (MW-28, MW-36, MW-48, MW-39, and MW-10) are shown on Figure 4.31. Overall, the results of the current statistical analyses are indicative of a receding plume. Specific evidence that supports a conclusion of a receding plume includes 1) the majority of plume well trend results were 'decreasing' or 'probably decreasing', with all but four of the remaining trend results identified as 'stable' or 'no trend' and 2) trends in off base wells (i.e., MW-39, MW-48, MW-52) located in the historical toe of the plume are 'decreasing' or 'probably decreasing' in all cases except for a 'stable' trend for cis-1,2-DCE at well MW-39. When comparing trend analysis results by analysis method, the MK test resulted in a larger number of 'stable' trend results than the linear regression test. Based on this observation, the linear regression method is interpreted to be a more sensitive indicator of plume recession than the the MK test (at least in this case).

Review of changes in trend identification over time provides insight on how operation of the remedial systems at this site has affected both overall and localized plume dynamics. For example, a comparison of CAH concentration trends during early GWE system operation (i.e., 1995 to 1998) with trends during expanded GWE system operation (i.e., 1999 to 2001) shows that the majority of CAH trends in plume wells either stayed the same or have gone from 'no trend' or 'stable' to 'decreasing', with only a few trends going from 'decreasing' to 'stable'. In terms of overall plume dynamics, this observation provides statistical support that operation of additional GWE wells generally has caused the CAH plumes to further recede. The two wells where CAH concentration trends were identified as 'increasing' or 'probably increasing' during GWE system operation (i.e., MW-28 and MW-29) provide examples of how trend analysis can also help identify localized changes in plume dynamics. At MW-28, the first three years of SVE/GWE system operation appears to have resulted in increases in TCE and cis-1,2-DCE concentrations which linear regression identified as 'probably increasing' trends. Statistical analysis of TCE and cis-1,2-DCE data from the next three years of operation (i.e., following installation of additional GWE wells, one of which is very close to MW-28) resulted in identification of ‘probably decreasing’ trends for TCE and cis-1,2-DCE concentrations. In terms of interpreting local plume dynamics, one possible interpretation of these observations is that operation of the initial five recovery wells may have caused more highly-contaminated groundwater to be pulled toward MW-28, but also that the installation of additional recovery wells is now preventing this more highly-contaminated groundwater from reaching MW-28 (i.e., by altering the groundwater flow direction and/or removing the more highly-contaminated groundwater from the ground). In contrast, the first three years of SVE/GWE operation appears to have had little or no effect on TCE and cis-1,2-DCE concentrations at MW-29, with trends for these compounds identified as ‘stable’ by both linear regression and the MK test. Statistical analysis of TCE and cis-1,2-DCE data from the next three years of operation (i.e., following installation of additional GWE wells) resulted in identification of an ‘increasing’ trend for cis-1,2-DCE concentrations, while having no effect on the TCE concentration trend. Upon review of these trends results and a visual inspection of concentration versus time data for cis-1,2-DCE (see Appendix C), it appears that operation of the additional GWE wells has caused more highly-contaminated groundwater to be pulled toward MW-29, creating a potential for localized plume expansion east of MW-29.

Concentration trends for four plume wells (MW-3, MW-10, MW-47, and MW-52) also were evaluated using the Sen’s Slope method. While the Sen’s results correctly identified relatively strong, unambiguous trends (e.g., see graph for MW-10 on Figure 4.31), it was less sensitive to more subtle trends that were identified by the linear regression and MK methods, and to less ambiguous trends that are visually apparent on time-series plots, but that are not entirely consistent over time (i.e., significant up or down fluctuations in concentrations occurred over time). For example, Sen’s method gave ‘no trend’ results for both early (1995 to 1998) and late (1998 to 2001) TCE at MW-47 despite the fact that decreasing trends were visually apparent on the time-series graph (see Figure 4.31). Based on these and similar observations for other wells, Sen’s method was considered too insensitive to trends that were occurring, leading to a recommendation that this method should not be used as a sole indicator of trend because it has significant potential to inaccurately inform plume stability conclusions.

In summary, the findings of the current study agree with historical interpretations of isoconcentration plume maps and statistical trend analyses presented in a previous RPO assessment (Parsons, 2002) that concluded that the overall trend within the CAH plumes at FPTA-2 is decreasing, resulting in overall plume recession. Findings from the current study also agree with historical trend analysis from the RPO report (Parsons, 2002) that cis-1,2-DCE concentrations are increasing CAH concentrations at MW-29. However, results from using discrete time sets as part of the current study offer a finer interpretation of plume dynamics near MW-28. Specifically, results from the current study suggest that operation of the initial GWE system appears to have caused an increase in TCE and cis-1,2-DCE concentrations, which agrees with the findings of the RPO report that CAH concentrations increased after GWE system start-up, but also that operation of the expanded groundwater extraction system has reversed this trend between 1998 and 2001. As with source area wells, results of performing statistical tests on both early time and later data indicates that linear regression and the MK test are sensitive enough to be useful for identifying changes in system performance over time., but that Sen's method was not sensitive enough to trends that appeared obvious visually and were identified by the other statistical tests. Unlike the source area wells, operation of the expanded GWE system appears to have increased the rate of CAH concentration reduction, presumably resulting in the CAH plume receding faster than occurred under the influence of the initial five recovery wells.

Sentry Wells

Statistical trend analyses were performed during the current study for the four sentry wells listed in Table 4.27 (MW-31, MW-40, MW-49, and DW-03). As noted on Table 4.27, statistical analysis was not performed on the remaining sentry wells because these wells were either dry or below detection for all monitoring events. Trend analysis results for TCE at sentry well MW-49 are shown on Figure 4.31.

Statistical analysis (linear regression and MK) results for cross-gradient sentry well MW-31 are 'stable' to 'no trend' due to the fact that TCE and cis-1,2-DCE have generally not been detected in this well. These results support the conclusion that the CAH plume is not expanding in an easterly (i.e., cross-gradient) direction. Statistically 'decreasing' or 'probably decreasing' trends for downgradient sentry wells MW-40 and DW-03 offer strong support for plume recession. This is especially true for DW-03, which appears to be located along the approximate longitudinal axis of the CAH plume (Figure 4.31). Statistical analysis for downgradient sentry well MW-49 resulted in identification of 'no trend' for TCE and cis-1,2-DCE concentrations. Upon review of the data for this well, it was noted that, while the majority of measurements for CAHs in this well have been below detection, TCE and cis-1,2-DCE were detected at concentrations of 4.2 μg/L and 7.1 μg/L, respectively, during the June 2001 monitoring event. While these recent measurements did not result in a statistical finding of 'increasing' or 'probably increasing' trends for these compounds and the detected concentrations were less than MCLs, it is particularly important to continue monitoring to demonstrate that concentrations are not increasing at this well.

Although temporal concentration trends for these wells were not quantitatively evaluated during the RPO assessment report (Parsons, 2002), the observation in the RPO report that historical sampling data for downgradient, off-Base wells supported plume recession is in agreement with the statistical findings of the current study.

Summary

The results of the MK, linear regression, and Sen's slope analyses for Brooks City-Base Site FPTA-2 are summarized in Table 4.30. Summaries for two time periods (12/95 to 12/99 and 12/99 to 6/01) are provided for comparison. Recovery wells RW-1 through RW-5 were active during the majority of the earlier time period, and RW-6 through RW-12 were activated near the start of the later period. Comparison of the results of these three methods with each other and with historical trend analysis results yields the following observations:

Table 4.30 Summary of Statistical Analysis Results
FPTA-2, Brooks City-Base, Texas

Statistical Analysis Method	Number of Instances Exhibiting the Indicated Trend					
	Decreasing	Probably Decreasing	Stable	No Trend	Probably Increasing	Increasing
December 1995 to December 1998						
Linear Regression	14	2	9	4	3	0
MK	10	4	13	4	0	1
Sen’s Slope	2	1	0	6	0	0
December 1998 to June 2001						
Linear Regression	16	5	4	6	0	1
MK	12	4	8	7	0	1
Sen’s Slope	3	1	0	5	0	0

- The relative abundance of ‘decreasing’ and ‘probably decreasing’ trends within each time period supports plume recession and eventual collapse. The rapid rate of concentration decrease indicates that the operation of the GWE system is generally having the intended effect;

- As shown in Table 4.30, the number of ‘decreasing’ and ‘probably decreasing’ trends obtained for the later time period (12/99 to 6/01) was greater than during the earlier time period (12/95 to 12/99), indicating that the activation of recovery wells RW-6 through RW-12 generally caused CAH concentrations within a larger portion of the CAH plume to decrease. There was a concurrent decrease in the number of ‘stable’ to ‘no trend’ results from the earlier to the later time period, indicating that some previously stable portions of the plume were positively impacted by the GWE system. From a spatial perspective, the wells where trends went from ‘stable’ toward ‘decreasing’ were in the dissolved plume, whereas trends tended to go from ‘decreasing’ toward ‘stable’ in the source area. This observation suggests that there is a diminishing effect of continued GWE system operation on source area concentrations;

- The statistical analysis results support historical observations that the GWE system is not significantly impacting the eastern portion of the CAH plume, in vicinity of wells MW-28 and MW-29. In addition, the recent detection of CAH concentrations at MW-49 (located hydraulically downgradient of MW-28 and MW-29) should be monitored to confirm that the CAH plume is not temporarily expanding in this area;

- Application of the MK method was more likely to result in ‘stable’ trends than linear regression, which was more likely to indicate an ‘increasing’ or ‘decreasing’ trend. However, for this site similar conclusions would have been derived from the application of either method.

- The Sen’s slope method, which was only performed using data for four wells, was more likely to yield a ‘no trend’ result than both the MK and linear regression methods, which more readily (and correctly) indicated ‘increasing’ or ‘decreasing’ trends. The Sen’s slope method is relatively insensitive to trends that are not strong and unambiguous. The insensitivity of Sen’s method to trends leads to a recommendation that Sen’s method not be used as a sole indicator of trend.

- For this site, a similar conclusion regarding plume stability would likely have been reached regardless of which method (preparation of isopleth maps or statistical trend analysis) had been employed. In this case the isopleth maps visually depict the temporal trends in a convincing and compelling manner. However, the statistical analysis results add value in that they indicate the potential for additional plume recession in the future, as evidenced by the ‘decreasing’ trends for downgradient plume interior wells such as MW-48. Therefore, in this case the construction of isopleth maps combined with the performance of temporal trend analyses provides the most information regarding past and potential future plume dynamics.

4.1.5.4 Results of Current Mass-based Stability Analysis

Figure 4.32 shows the monitoring wells, model domain hull, and Theissen polygons used in the mass-based stability analyses for FPTA-2, Brooks City-Base. The monitoring wells used for the mass-based analyses were selected by reviewing the groundwater sampling history for VOCs summarized in Table 4.27 and selecting the time periods that had the largest number of wells sampled in common. The common well set for the CAH plume at FPTA-2 consisted of 16 wells, as listed in Table 4.27 and as shown on Figure 4.32. Note that five additional wells were scheduled for sampling on the same schedule as the 16 common wells. These five additional wells were not included in the mass-based calculations because each of these wells was dry for at least one monitoring event. Mass-based calculations were performed using data from ten sampling events where each of the common wells were sampled, starting in December 1995 and ending five-and-a-half-years later in June 2001.

Dissolved CAH Mass

Figure 4.33 depicts the calculated CAH mass in the FPTA-2 CAH plumes (by individual species and total CAH as TCE) over time for each of the ten sampling events and by analysis method (i.e., Theissen polygon or TIN grid). In general, the TIN grid method and Theissen polygon methods for estimating the dissolved mass of individual CAHs yielded similar estimates. Table 4.31 lists the molar mass of each compound as a percentage of the total molar CAH mass. As can be observed from Figure 4.33 and Table 4.31, the dissolved mass in

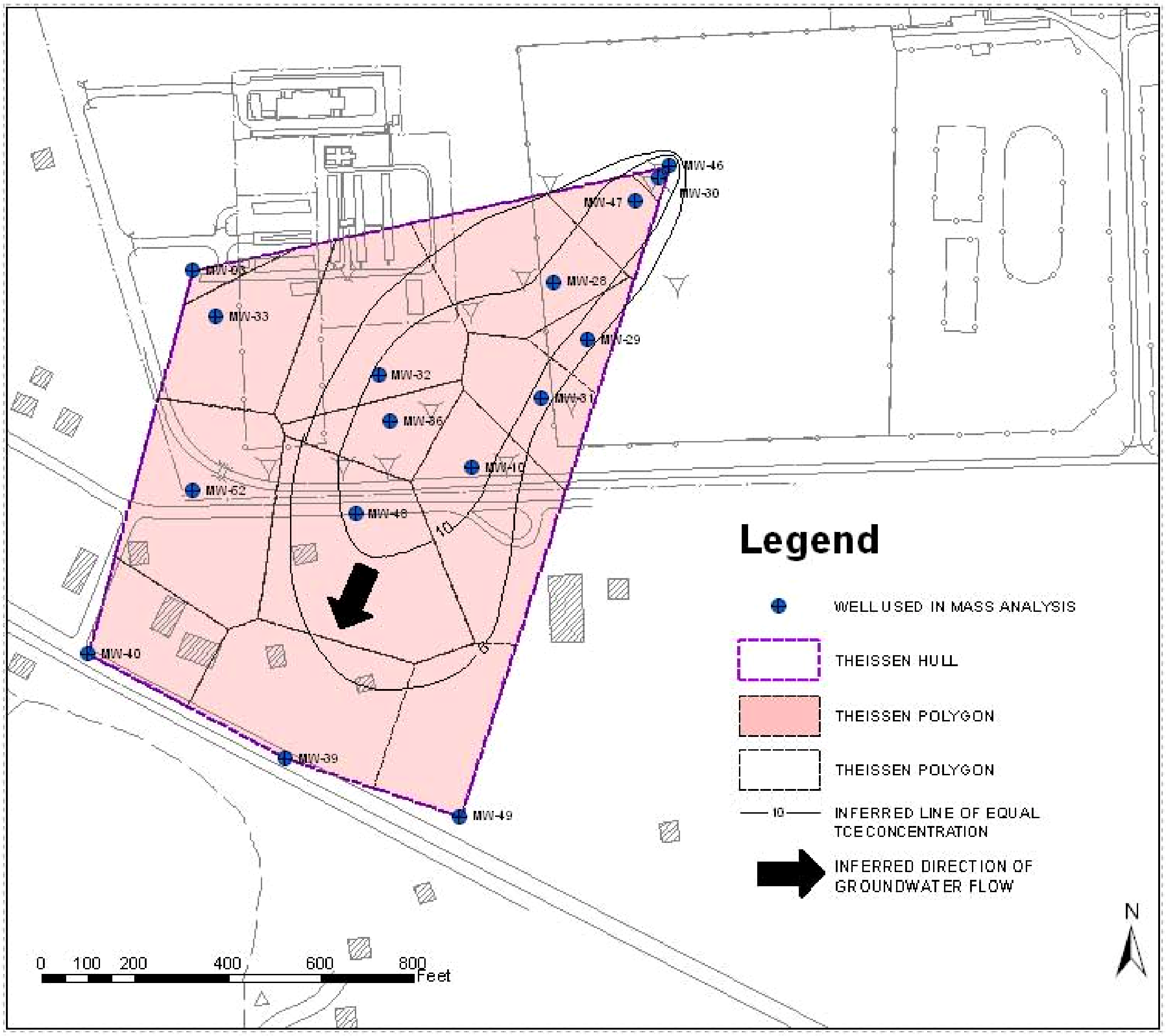


Figure 4.32 Model Domain and Common Wells for Mass-Based Calculations FPTA-2, Brooks City-Base, Texas

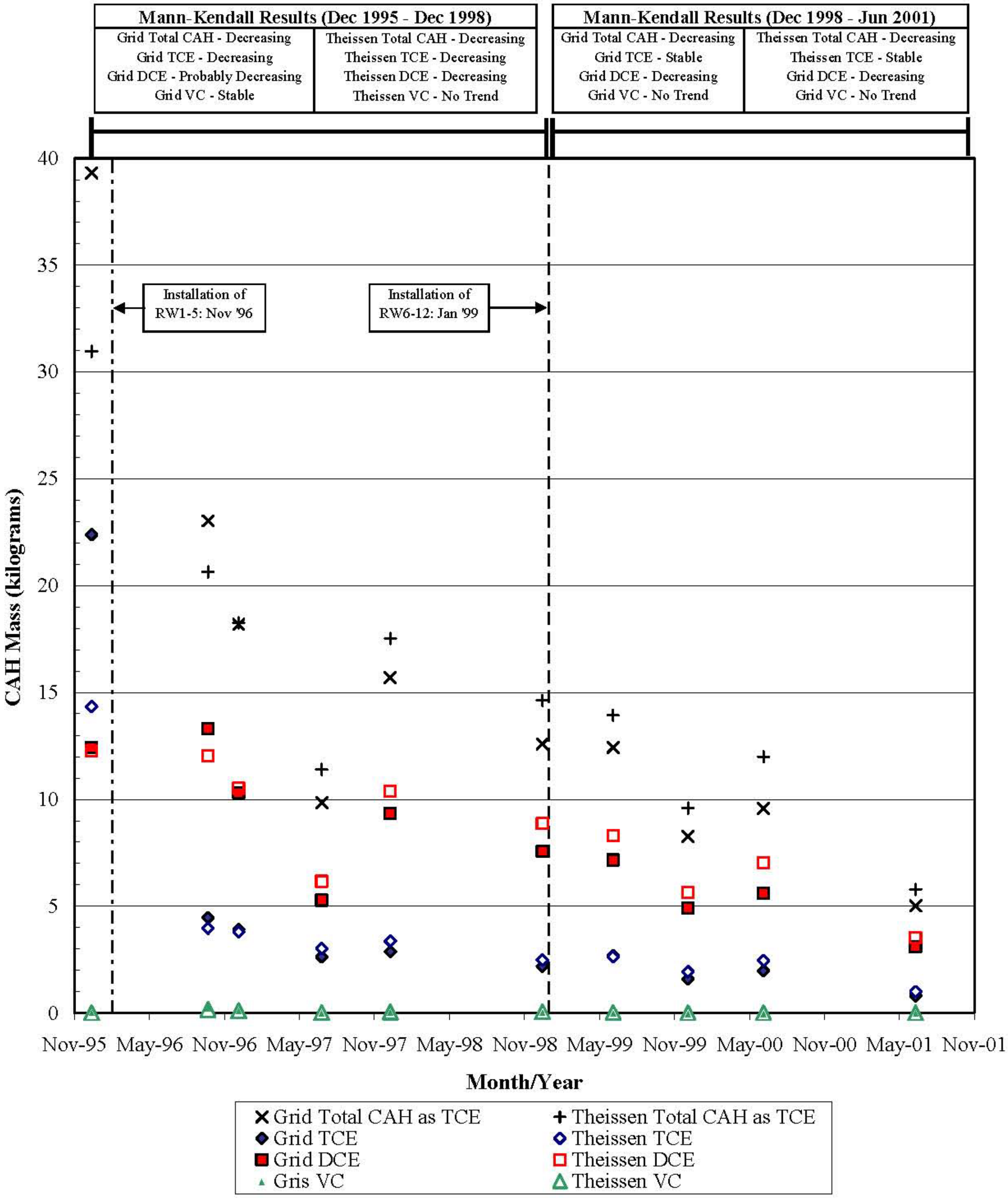


Figure 4.33 Estimated Dissolved Mass of CAH Compounds FPTA-2, Brooks City-Base, Texas

Table 4.31 Summary of CAH Mass by Compound FPTA-2, Brooks City-Base, Texas

Sampling Date	TCE		DCE		VC	
	Kriging	Theissen	Kriging	Theissen	Kriging	Theissen
12/13/1995	57%	46%	43%	54%	0.26%	<0.01%
9/22/1996	19%	19%	78%	79%	2.4%	1.7%
12/6/1996	21%	21%	77%	78%	1.7%	1.15%
6/26/1997	27%	26%	73%	73%	0.66%	0.31%
12/11/1997	18%	19%	81%	80%	1.14%	0.63%
12/17/1998	17%	17%	82%	82%	1.04%	0.94%
6/7/1999	22%	19%	78%	81%	0.39%	0.30%
12/7/1999	19%	20%	81%	80%	0.11%	<0.01%
6/8/2000	21%	21%	79%	79%	0.08%	<0.01%
6/14/2001	16%	17%	84%	83%	0.27%	0.08%

the FPTA-2 plume in December 1995 (i.e., prior to start-up of the SVE and GWE systems) was split equally between TCE and cis-1,2-DCE, with less than 1 percent of the mass found as VC. For all subsequent events, the majority of CAH mass was found as cis-1,2-DCE (range: 73 percent to 84 percent), followed by TCE (range: 17 to 27 percent) and very low percentages of vinyl chloride (less than 2.4 percent in all cases).

Trend analyses for changes in the mass of CAH over time were performed using visual inspection of Figure 4.33 and application of the MK test for trends. The results of applying the MK test to the mass results are shown in the legend at the top of Figure 4.33 for the periods from December 1995 to December 1998 and December 1998 to June 2001. Visual inspection of Figure 4.33 suggests that the total CAH mass has slowly declined over the 66¬month time period assessed. Application of the MK test confirmed this observation in that a ‘decreasing’ result was indicated for the total CAH mass for both time intervals. The observation that total CAH mass was ‘decreasing’ supports a finding that the combined operation of the SVE and GWE systems are removing quantifiable amounts of mass from groundwater and that the plume is likely to be receding.

Visual inspection of TCE mass over time indicates that the calculated TCE mass decreased most rapidly between December 1995 and September 1996, with a slower but noticeable decrease over the remaining monitoring events. The MK test result for TCE mass over time was ‘decreasing’ over the first time interval and ‘stable over the second time interval. The MK test findings are in agreement with visual observation and the concentration-based analyses that indicated a rapid decrease in TCE concentrations (and therefore dissolved mass) immediately following system start-up, followed by a slower decline or stability in TCE concentrations over time, suggesting that the GWE system may have reached an asymptotic condition in terms of removing contaminant mass from the source area. The observed trend for cis-1,2-DCE is a continued slow decrease in mass over time for both intervals, which is confirmed by the MK statistical results of ‘probably decreasing’ to ‘decreasing’ cis-1,2-DCE mass over time. The finding of a ‘decreasing’ trends in cis-1,2-DCE but ‘stable’ trends for TCE during the second monitoring period is in agreement with concentration-based analyses that indicated the dissolved plume was impacted more by continued operation of the GWE system than the source area was impacted. The calculated VC mass appeared to noticeably decrease over the assessment period, although it is important to note that the maximum estimated dissolved VC mass was less than 0.5 kilograms. Statistical testing for trends resulted in ‘stable’ or ‘no trend’ findings for VC mass over time.

Center of Dissolved CAH Mass

The calculated center of dissolved mass for TCE, cis-1,2-DCE, and VC for nine sampling events are presented on a site base map as Figures 4.34, 4.35, and 4.36, respectively. Because of the large number of observation periods, the center of mass results for only one method (i.e., Theissen polygons) were plotted on these figures. As shown on Figure 4.34, the center of mass for TCE was observed to shift several hundred feet down the plume axis between December 1995 and September 1996, and then to remain in a relatively constant location through June 2001. This movement in the TCE center of mass can be explained by looking at the operational history of the SVE/GWE system. Specifically, the initial center of mass calculation (i.e., December 1995) placed the TCE center of mass relatively close to the source area because TCE concentrations in the source area were much greater than the rest of the plume. Following system start-up, however, TCE concentrations declined more rapidly in the source area than in the dissolved plume, causing the calculated center of mass to move downgradient and then remain in the same general location.

Interestingly, the same phenomenon is not observed for the center of mass for cis-1,2-DCE, which generally remained in the same location over time (see Figure 4.35). The combined observation of a decreasing cis-1,2-DCE mass with no consistent trend in movement of the cis-1,2-DCE center of mass implies that operation of the SVE/GWE system reduced the areal extent of the the cis-1,2-DCE plume by removing mass from the subsurface, but did not significant impact the relative concentration distribution of cis-1,2-DCE across the site. The reason that the SVE/GWE system did not cause a noticeable downgradient “jump” in the center of mass for cis-1,2-DCE was that the initial mass of cis-1,2-DCE was more uniformly distributed across the entire CAH plume than was the case for TCE. This relatively uniform distribution of cis-1,2-DCE resulted in the SVE/GWE system extracting significant cis-1,2-DCE mass from both the source area and the downgradient dissolved CAH plume during SVE/GWE system startup. In contrast, and as described above, the spatial distribution of TCE prior to SVE/GWE system start up resulted in the system removing more TCE mass from the source area than was removed from the downgradient dissolved plume, thereby causing the initial downgradient “jump” in the location of the TCE center of mass.

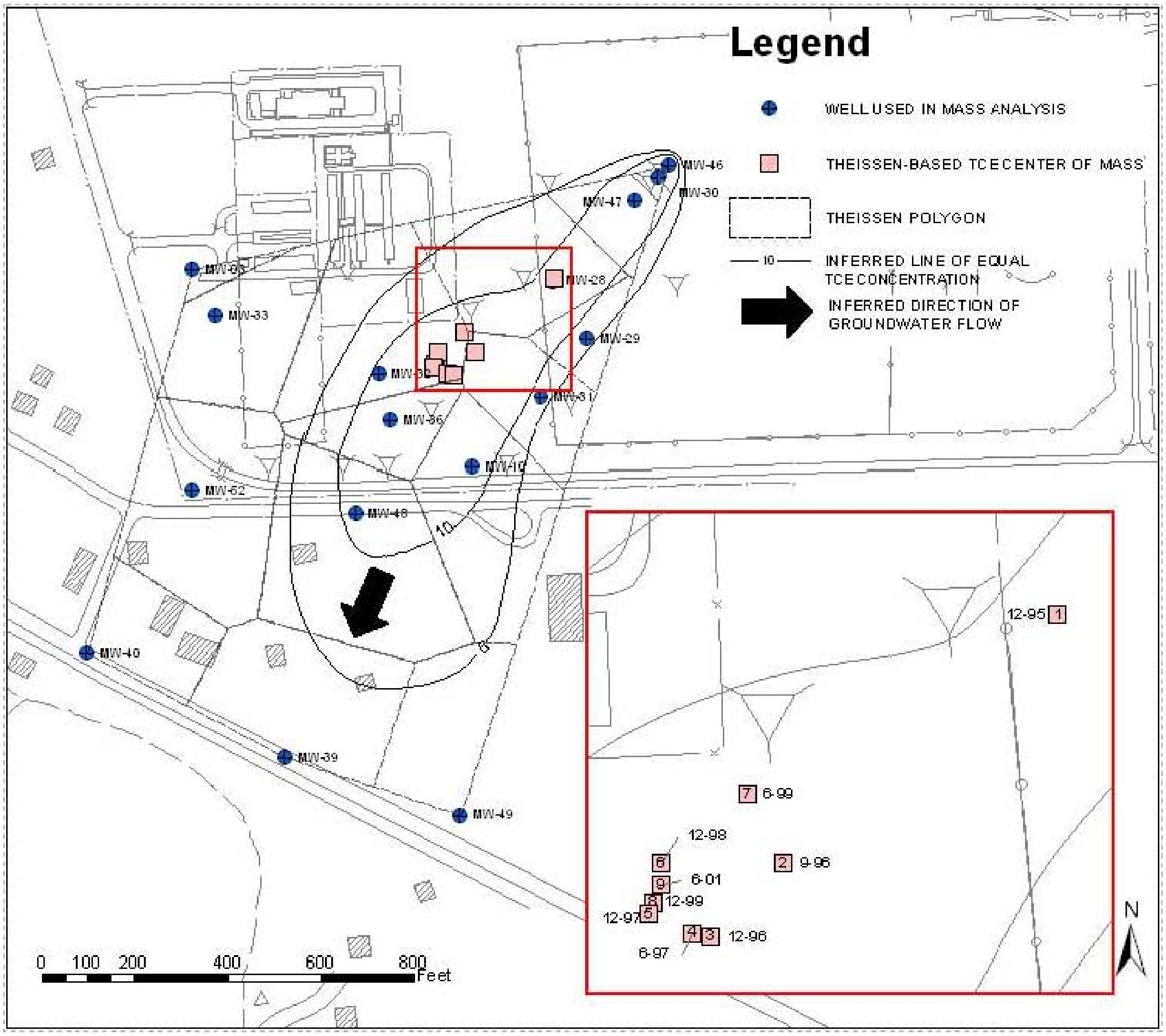


Figure 4.34 Location of Centers of Mass for TCE
FPTA-2, Brooks City-Base, Texas

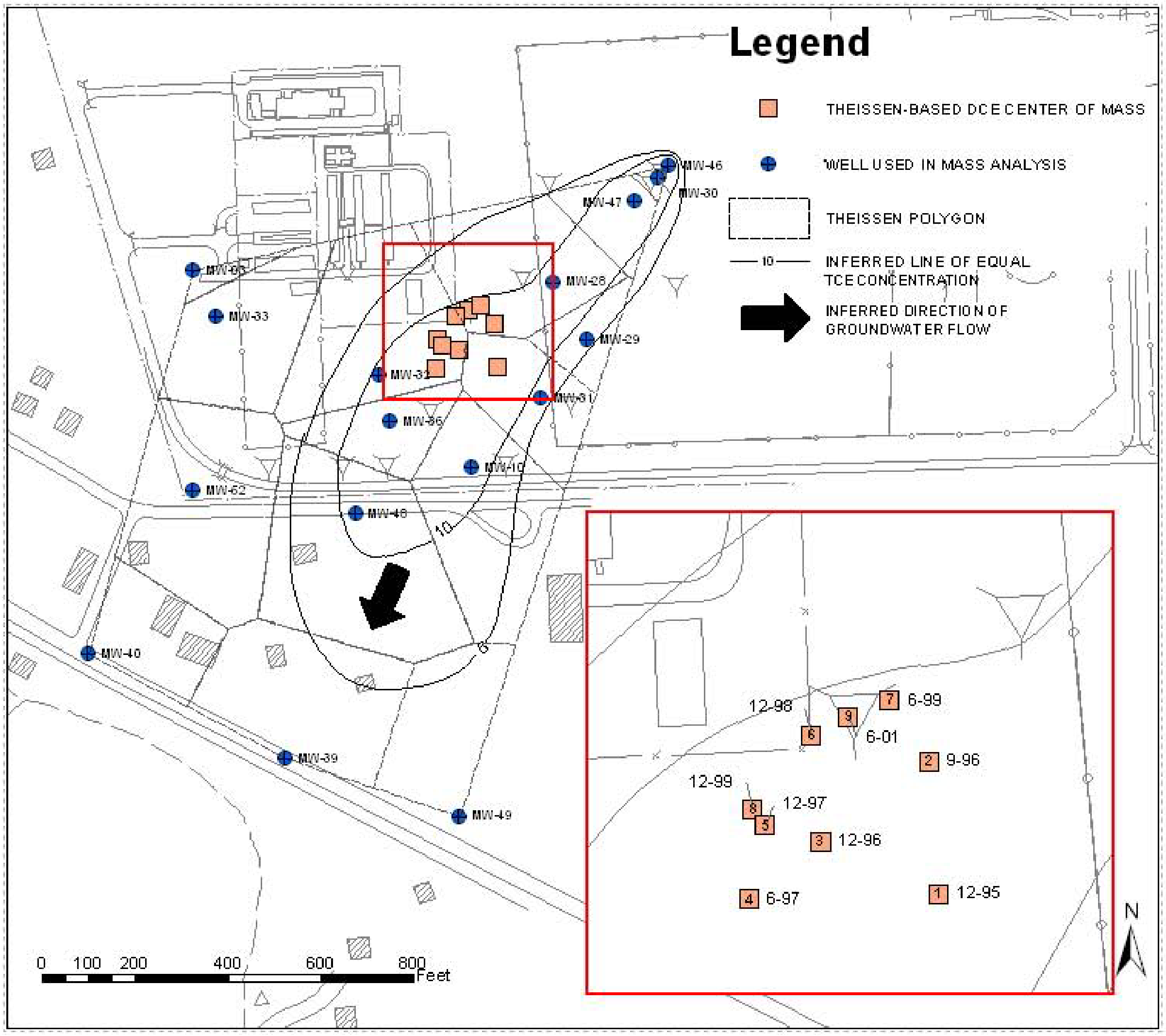


Figure 4.35 Location of Centers of Mass for Cis-1,2-DCE
FPTA-2, Brooks City-Base, Texas

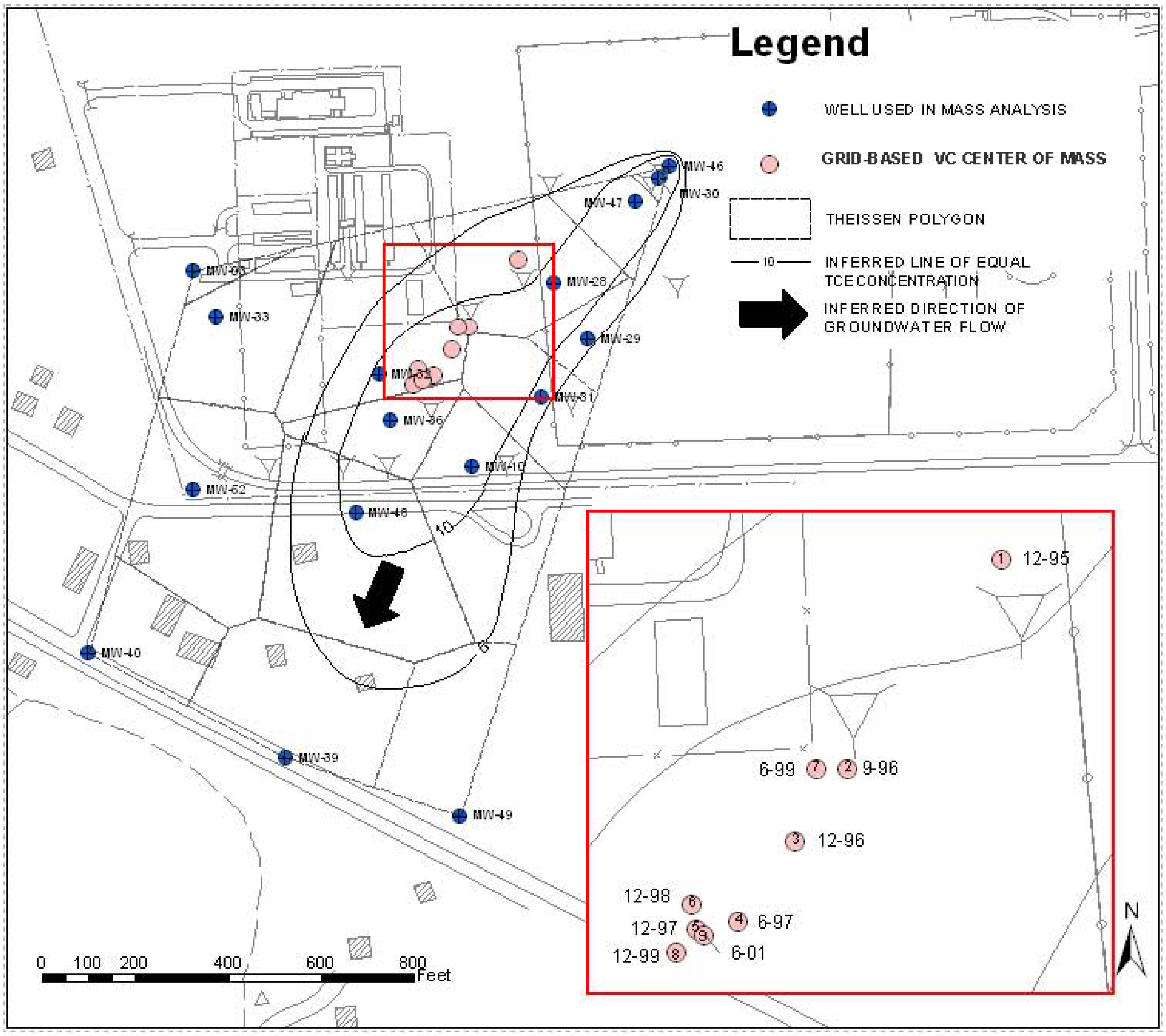


Figure 4.36 Location of Centers of Mass for VC FPTA-2, Brooks City-Base, Texas

Summary of Mass-Based Analysis Results

Overall, the results of applying mass-based analyses to data from CAH plumes at FPTA-2 indicated the following:

- The total CAH mass and mass of cis-1,2-DCE have continued to decrease over time. It is expected that trends for total CAH mass and cis-1,2-DCE would be similar because cis-1,2-DCE has been the major contributor to total CAH mass for all monitoring events after SVE/GWE system start-up. While it is obvious that total CAH mass and the mass of cis-1,2-DCE continued to decline following the installation and operation of additional recovery wells, it is not obvious from the available data that the installation of these additional wells increased the rate of CAH removal from groundwater;

- The mass of TCE decreased significantly during early operation of the SVE/GWE system, but appears to have stabilized over longer-term operation. The most likely explanation for this pattern is that early system operation rapidly removed contaminants from the source area, where TCE concentrations were highest, and that continued pumping from the source area has resulted in an asymptotic condition where the groundwater extraction rate is not the limiting factor on the removal rate of the TCE source;

- The center of mass results for TCE and VC showed an initial downgradient shift along the plume axis, followed by stabilization of the plume center of mass during later monitoring events. Unlike TCE and VC, the cis-1,2-DCE center of mass was predicted to have stayed in the same general location for all monitoring events. The explanation for this observed phenomena is that the SVE/GWE system start-up caused concentrations of TCE and VC to initially decline in the source area, where concentrations of these two compounds were highest, whereas cis-1,2-DCE concentrations were more uniformly impacted across the entire extent of the CAH plume;

- For most compounds and sampling events, the TIN grid and Theissen polygon methods yielded similar estimates for dissolved CAH mass.

4.1.5.5 Plume Stability Analysis Summary

Overall, the combined results of concentration-based statistical analysis and mass-based calculations suggest that the CAH plumes at FPTA-2 are receding. The primary observations that support this conclusion are that 1) ‘decreasing’ and ‘probably decreasing’ trends are abundantly found across the CAH plume; 2) the estimated dissolved mass of total CAHs and cis-1,2-DCE are statistically ‘decreasing’, with the dissolved masses of TCE and VC ranging from ‘decreasing’ to ‘stable’; and 3) the locations of the center of mass for individual CAH plumes have generally stabilized following an initial downgradient movement immediately following start-up of the SVE/GWE system. The combined plume stability analysis results also suggest that the rate of depletion of the TCE source of contamination to groundwater has slowed over time, which provides an indication that TCE depletion rates are reaching an asymptotic condition where contaminant diffusion/dissolution, rather than groundwater extraction, will control the remediation timeframe. In addition, while it is obvious that total CAH mass and the mass of cis-1,2-DCE continued to decline following the installation and operation of additional recovery wells, it is not obvious from the available data that the installation of these additional wells increased the rate of CAH removal from groundwater.

A review of the spatial coverage of monitoring wells indicates that there is sufficient monitoring data to perform plume stability analysis across the dissolved plume. In addition, the results of this study illustrate that the uniform collection of spatial data from common wells on a regular time schedule increases the value of results from the concentration-based and mass-based analyses presented in the current study.

The results of applying the statistical analysis used in the current study to concentration data from FPTA-2 illustrate that the MK method was more likely to result in ‘stable’ trends than linear regression, which was more likely to indicate an ‘increasing’ or ‘decreasing’ trend. However, the results of applying either method to data from FPTA-2 would lead to similar conclusions on plume stability. The Sen’s slope method, which was only performed using data for four wells, was more likely to yield a ‘no trend’ result than both the MK and linear regression methods, which more readily (and correctly) idenified ‘increasing’ or ‘decreasing’ trends that were obvious from visual inspection of the data. Based on results from this case study, it appears that Sen’s slope method is too insensitive for use as a sole indicator of trend, and is therefore not recommended for use in developing plume stability conclusions. It is also interesting to note that a similar conclusion regarding plume stability would likely have been reached regardless of which method (preparation of isopleth maps or statistical trend analysis) had been employed. Specifically, the isopleth maps for FPTA-2 visually depict the temporal trends in a convincing and compelling manner. However, the statistical analysis results add value in that they indicate the potential for additional plume recession in the future, as evidenced by the ‘decreasing’ trends for downgradient plume interior wells such as MW-48. Therefore, in this case the construction of isopleth maps combined with the performance of temporal trend analyses provides the most information regarding past and potential future plume dynamics.

4.1.5.6 <u>Recommendations</u>

For FPTA-2, continuation of the existing monitoring program for shallow groundwater on an annual to every-other-year basis appears to be sufficient to support statistical analysis of concentration data for plume stability assessment, as it is anticipated that current trends indicating that the CAH plumes are receding will continue. During future monitoring, it is also recommended that particular attention be given to CAH concentrations measured in monitoring wells in the source area and along the eastern portion of the plume. The purposes of giving specific attention to these two locations are 1) to determine whether operating the GWE system is providing a significant benefit in reduction in CAH concentrations in the source area and 2) to confirm that the indications of increasing trends at MW-28 and MW-29 were a temporary condition produced by changes in groundwater flow directions that were caused by operation of recovery wells.

4.2 ESTIMATES OF REMEDIATION TIMEFRAME

As discussed in Section 3.2, the source area modeling review performed as part of the current study concluded that the best available tools for estimating source duration (and, therefore, remediation timeframe) at CAH-impacted sites are empirical source decay models that are ‘fitted’ to available source area well data. Section 4.2.1 reviews empirical modeling efforts that were used in the late 1990s to simulate CAH fate and transport at 10 USAF sites. Section 4.2.2 compares the predictions from the models at three of these sites to data that were collected after the initial modeling effort. Section 4.2.2 also provides recommendations and examples of how the estimate of source duration could be improved through both data analysis and future LTM activities.

4.2.1 Review of Source Models Used in Previous Modeling Efforts

Between 1997 and 1999, Parsons used the numerical models MT3D or MT3D96 for simulation of CAH fate and transport at 10 sites where MNA-based remedies were being evaluated. The names and locations of the 10 sites are indicated by an ‘X’ in Table 4.1.

As described in Section B.3 of Appendix B, MT3D or MT3D96 are software packages that do not have built-in mechanistic (implicit) models for simulating NAPL source terms. Therefore, the NAPL source term was modeled for these ten sites by specifying either a concentration or a flux boundary condition, as described in Section 3.2.2.2. According to the modeling reports, the modeling approach used at each site assumed that the simulated constituent (i.e., total CAH, TCE, or DCE) entered groundwater through contact between groundwater and mobile or residual NAPL at or below the water table. The partitioning between NAPL and aqueous phases was simulated by defining source area recharge concentrations or source area flux (depending on the modeler’s choice) at a given number of model cells in the vicinity of the NAPL body. The decision to use this modeling approach for source terms was based on experience gained with modeling contaminated sites as part of the AFCEE Natural Attenuation Initiative. Specifically, the modeling efforts associated with this AFCEE initiative led to a recommendation that this modeling approach was the best available method for reproducing observed plumes using contaminant fate and transport models.

Table 4.32 provides a summary of the simulated boundary condition, number of source wells, and contaminant source history for each of the 10 models reviewed as part of the current study. The two basic categories of input parameters required for defining the source models at each of these 10 sites were 1) the spatial extent of the source area and 2) the value for the specified concentration or flux into the model domain over time. The spatial extent of the source area was defined by the modeler as a number of ‘source’ cells located in the area of the model domain that represented the NAPL body. In some cases, multiple source areas were used to simulate contaminant loadings from multiple NAPL bodies.

Table 4.32 Summary of Simulated Source Conditions during Previous Evaluations of MNA for Dissolved CAH Plumes

Site Identification	Boundary Condition	Number of Source Wells	Source Introduction and Duration	Software Used	Source Weathering Rate	Simulated Boundary Condition	Notes
OU-1 Altus AFB	Flux	4	• Introduced in 1956	MT3D96	• 5.5% per year from 1956 to 2021 • 2% per year from 2022 to 2056.	• The source input was a predetermined specified flux • No discussion was identified in the report how the flux was determined	• The concentrations were initially spiked to simulate the dissolution of pure product into the system. Source concentrations were subsequently decreased geometrically during calibration.
Building 1381 Cape Canaveral AFS	Flux	Undetermined in report.	• Constant source from 1958 to 1996	MT3D96	• 4% per year.	• The source input was a predetermined specified flux • No discussion was identified in the report how the flux was determined	
FT-17 Cape Canaveral AFS	Concentration	9	• Introduced in 1985	MT3D	• 8.7% per year from 1985 to 1997 • 90% removal rate in 1997 and 1998 • 10.5% per year from 1999 to 2066	• The source input was a predetermined specified concentration • No discussion was identified in the report regarding how the concentration was determined.	• BTEX and CAH comingled
LF03 F.E. Warren AFB	Flux	Undetermined in report.	• Constant source from 1960 to 1999	MT3D96	• 7.3% per year.	• The source input was a predetermined specified flux	• Weathering rate was adjusted during calibration until simulated concentrations were consistent with measured concentrations in downgradient and near-source wells
OU1 Hill AFB	Flux	43	• Constant source duration from 1940 to 1980	MT3D	• 2% per year.	• The source input was a predetermined specified flux • No discussion was identified in the report how the flux was determined	• Select pumping was occurring at this site at seeps on the hill during the modeling effort
OU5 Hill AFB	Flux	8	• Constant source duration from 1949 to 1964 • Second constant source introduced in 1988	MT3D	• Undetermined in report.	• The source input was a predetermined specified flux • No discussion was identified in the report how the flux was determined	
Building 301 Offutt AFB	Flux	4	• Constant source from 1942 to 1997	MT3D96	• None	• The source input was a predetermined specified flux • No discussion was identified in the report how the flux was determined	• End date of constant source was the year the model was completed
OU4 Shaw AFB	Flux	15	• Undetermined in report	MT3D96	• Undetermined in report.	• The source input was a predetermined specified flux • No discussion was identified in the report how the flux was determined	
Area A Tinker AFB	Concentration	42	• Constant source introduced in 1942 • Source concentrations assumed to have increased from 1977 to 1992	MT3D	• 3% per year	• The source input was a predetermined specified concentration • No discussion was identified in the report regarding how the concentration was determined	• BTEX and CAHs
FTA-2 Tinker AFB	Concentration	4	• Source introduced in 1962 • Source decay by 5-year step function from 1962 to 1997 • Constant source decay after 1997	MT3D96	• 2% per year.	• The source input was a predetermined specified concentration • No discussion was identified in the report regarding how the concentration was determined	• Source was simulated as four cells, with one 'primary' source cell. Other source cells were varied to match dissolved plume shape and size.

Specified concentration boundary conditions were used at three sites and specified-flux boundary conditions were used at the remaining seven sites. According to the modeling reports, it was generally assumed that source concentration or flux was constant for some period of time, and then the source would begin to weather (i.e., lose mass) due to processes such as volatilization, dissolution, and biodegradation. The assumption of a weathering source implies that the mass of contaminants entering groundwater will decline over time. Past experience with the AFCEE Natural Attenuation Initiative suggested that the residual NAPL sources can weather at rates as rapid as 10 percent per year. Table 4.32 lists the specific source weathering rates used at each site. To be conservative and because there was significant uncertainty in the history of the contaminant sources, it was assumed that the CAH sources at nine of these 10 sites would weather at rates ranging from two to 10 percent per year. At the tenth site (Building 301, Offutt AFB), the source was simulated as being constant over time. In some cases, such as LF03, F.E. Warren AFB, the weathering rate was estimated as part of the model calibration process. The calibration process used in this case was to adjust the weathering rate until concentrations simulated in the model were consistent with downgradient and near-source historical concentrations. In other cases, the basis for selecting a source weathering rate was not evident from the modeling report text.

4.2.2 Comparison of Predicted and Measured Source Area Concentrations

The base contact for each of the ten sites reviewed above was contacted to see if there was recent site data available to support an evaluation of the effectiveness and appropriateness of using empirical models to predict source duration under natural weathering conditions. Additional data beyond the original Parsons modeling reports were available from eight of the sites. The two sites (OU5, Hill AFB and Building 501, Offutt AFB) where additional data could not be obtained were removed from further consideration. At five sites, extensive active remediation and source removal has occurred since the original modeling effort. Because of this active remediation, these five sites were also removed from further consideration because the more-recently collected monitoring data from these five sites was not representative of groundwater conditions under pure NA conditions. As discussed below, further analysis was performed using data from the remaining three sites (OU1, Altus AFB; Facility 1381, Cape Canaveral AFS; and FTA-2, Tinker AFB).

4.2.2.1 Case Study: Operable Unit 1, Altus AFB, Oklahoma

OU1, Altus AFB was previously a base landfill in use from 1956 to 1983. The landfill was closed in 1983 and partially excavated in early 1993. Additional remediation at the site has been limited to a pilot study bark mulch biowall installed in July 2002 approximately 30 feet downgradient of source area monitoring well OU1-01. The decay rate of TCE concentrations at OU1-01 was used to estimate the remediation timeframe for this site.

Figure 4.37 presents a series of curves that show the predicted decrease in TCE concentrations for three source decay scenarios. Each of these three scenarios assumed that TCE concentrations in the source area would decrease by a constant percentage each year over the life of the source area. The assumption that source area will, on average, decay by a constant

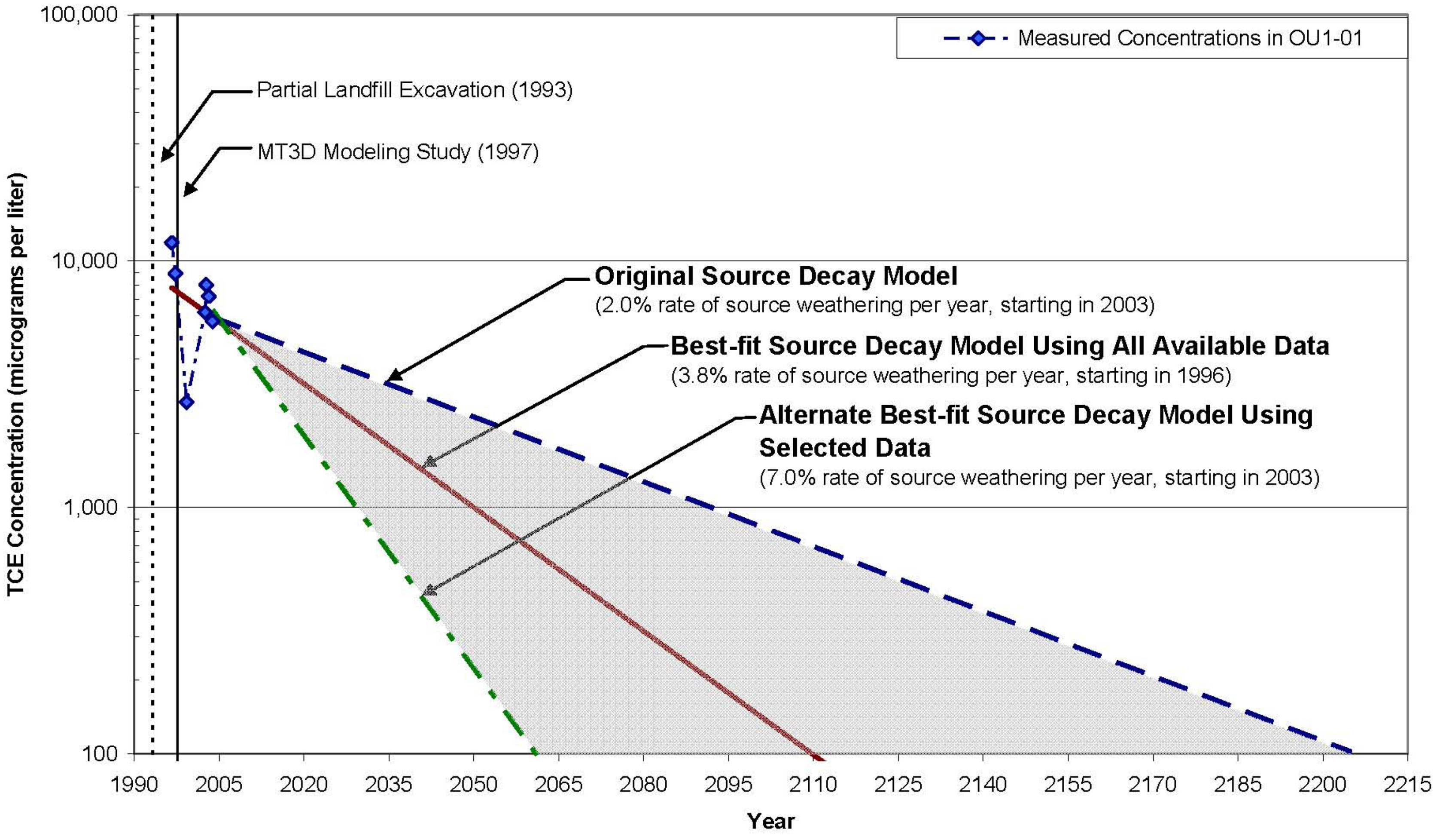


Figure 4.37 Measured and Predicted TCE Concentrations Over Time
OU1, Altus AFB, Oklahoma

percentage each year implies that the source will weather following a first-order (i.e., exponential) decay function, as described in Section 3.2.2.2. The first scenario was developed using a decay rate published as part of a previous modeling effort (Parsons, 1999e), where TCE concentrations in the source area were assumed to decay, or weather, at a constant rate of 2 percent per year following initial release to groundwater in 1956. As stated in the modeling report, an assumed source condition was used in this study because there were insufficient historical records and environmental monitoring data (i.e., only two data points) available for the source area to allow interpretation of actual source conditions. The second source decay scenario was developed using a decay rate of 3.8 percent per year, which was determined as the 'best-fit', first-order decay constant for TCE concentration data collected from monitoring well OU1-01 between September 1996 and November 2003. In the third scenario, a second 'best-fit' trend line was developed by excluding one of the data points (2,680 µg/L in April 1999) during the decay-rate estimation process. Exclusion of this data point was based on the observation that the TCE concentration in this sample was substantially lower than all of the other TCE concentrations measured before and after April 1999. When the April 1999 data point was excluded from consideration, the best-fit decay constant interpreted from this 'alternate' source decay scenario was 7.0 percent.

Based on the seven years of monitoring data that were available for source area monitoring well OU1-01, it appears that the original assumption of a 2.0 percent annual weathering rate was more conservative than the actual site conditions at OU1. Table 4.33 summarizes the weathering rates, R-squared values, and the year when TCE concentrations in the source area are predicted to reach 100 µg/L for each of the three source decay scenarios described above. The 90 percent confidence interval for the estimate of the year when TCE concentrations in the source area are predicted to reach 100 µg/L is also provided for each of the two projections estimated in this study. The purpose of providing an estimate of when each scenario is predicted to achieve a concentration of 100 µg/L in source area groundwater is to illustrate how empirical first-order decay rates can be used to estimate remediation timeframes for achieving a particular target concentration. As shown on Figure 4.37 and Table 4.33, the conservative (2 percent) scenario predicts that it will take between 100 and 150 years longer to reach a source area target concentration than is predicted by scenarios that use currently available data to estimate the 'best-fit' rate of source decay. However, the estimates based on the currently available data have very high uncertainty, as illustrated both by the differences in the estimates and the 90 percent confidence intervals associated with each of the estimates.

Table 4.33 Weathering Rates, R-Squared Values, and Timeframe Estimates for Various Source Decay Scenarios, OU1, Altus AFB, Oklahoma

Source Decay Scenario	First-order Weathering Rate (percent per year)	R-squared Value	Year when TCE Concentration is Predicted to Reach 100 µg/L (90% confidence intervals)
Original Source Decay Rate	2.0	N/C [a/]	2206
Best-fit Rate (All Data)	3.8	0.06	2108 (2017 - ∞) [b/]
Best-fit Rate (Selected Data)	7.0	0.76	2061 (2034 – 2164)

[a/] N/C = Not calculated.

[b/] ∞ = infinity.

This example further illustrates that there is considerable uncertainty in this estimate. Perhaps the greatest underlying source of this uncertainty is in the presumption that a short time period of monitoring data (i.e., seven years) is appropriate for predicting data trends that will occur over the distant future (i.e., the next 50 to 150 years). The elements that contribute to this uncertainty include 1) variability in sampling and analysis and 2) uncertainty of whether a first-order model appropriately captures the long-term effects of the dominant phenomena or a change in the dominant process controlling CAH source concentrations. The uncertainty associated with measurement variability for this site is discussed below. A discussion of the uncertainty associated with a potential future rate change is provided in the closing paragraph of Section 3.2.2.2, and will not be repeated here.

Using the data from OU1-01 as an example of the influence of sampling and analytical variability on the uncertainty of future predictions, TCE concentrations have ranged from 2,680 to 11,900 µg/L, or 0.65 orders of magnitude, over the past seven years. Over this same seven-year period, the ‘best-fit’ source decay scenario (i.e., 3.8 percent decay) predicts an average change of 0.12 orders of magnitude. The observation that the range in sampling variability is larger than the predicted change by the ‘best-fit’ scenario over the period of measurement implies that there is significant uncertainty in whether the interpolated source decay trend is reliable. Stated another way, the best-fit source decay scenario predicted that it would take nearly 39 years for the average source area concentration to decrease by 0.65 orders of magnitude. This uncertainty is also reflected in the low R-squared value for the best-fit scenario to all data (i.e., 0.06, where an R-squared of 1.0 represents a perfect correlation and zero represents no correlation). Assuming that the source at OU1 really is decaying over time, the certainty of the interpreted source decay rate is likely to be improved as additional monitoring occurs. However, it will take several years to several decades of monitoring at this site to confirm the actual rate of source decay and an associated remediation timeframe estimate.

4.2.2.2 Case Study: Facility 1381, Cape Canaveral AFS, Florida

Since construction in 1958, Facility 1381, Cape Canaveral AFS has been used for research and testing, equipment cleaning, and operations support. An acid neutralization pit, acid dip tank, and solvents tanks were housed in the building and used at various times. Chlorinated solvent contamination at the site is suspected to have resulted from accidental releases during past metal cleaning operations. Chlorinated solvents were also dumped on the ground from tanker trucks in wooded areas of the site. The primary COCs at this site are TCE and its regulated intermediate degradation products.

Several in situ treatment technologies have been pilot-tested at this site. The pilot-tested technologies included air sparging (October 1996 to February 1997), phytoremediation (June to September 1997), reductive anaerobic biological in-situ treatment technology (RABITT; 1998), and groundwater recirculation wells (May 2000). Although the pilot tests were located throughout the site, including in the source area, these tests were small-scale and believed to have had little or no effect on source area monitoring well 1381MWS09. CAH concentrations measured in 1381MWS09 were therefore be used in this study to estimate the remediation timeframe for this site.

TCE concentrations at the source well (1381MWS09) have ranged between 0.73 µg/L and 210,000 µg/L, or 5.5 orders of magnitude, during the seven-year monitoring period. Much of this variation is associated with one very low measurement in November 2002. If the November 2002 data point is not included in this data range assessment, TCE concentrations in 1381MWS09 were observed to range over 1.7 orders of magnitude.

Figure 4.38 presents a series of curves that show the predicted decrease in TCE concentrations for three source decay scenarios. Each of the three source decay scenarios applied to data from Facility 1381 used the same assumptions as were used for OU1, Altus AFB (i.e., constant exponential decay). The first scenario was developed using a 4.0 percent decay rate for TCE concentrations, as published in a previous modeling effort (Parsons, 1999c). Similar to OU1, Altus AFB, the Parsons (1999c) model for Facility 1381 used an assumed source decay rate because there were insufficient historical records and environmental monitoring data (i.e., only two data points) available for the source area to allow interpolation of actual monitoring data. Also note that the Parsons (1999c) model simulated total CAHs, rather than TCE as a single species. Because the current study is focused on source decay, concentrations of the primary parent compound, TCE, were used in the empirical models discussed in this section. Upon review of collected CAH concentration data, it was noted that TCE represented more than 75 percent of the total CAH mass present in each sample except for the sample collected in November 2002, when all CAHs were found at concentrations that were several orders of magnitude lower than were observed for all other monitoring events. The second scenario was developed using an exponential decay rate of 43.6 percent per year, which was determined as the 'best-fit', first-order decay constant for TCE concentration data collected from monitoring well 1381MWS09 between September 1996 and October 2003. In the third scenario, a second 'best-fit' source decay rate was estimated by excluding one of the data points (0.73 µg/L in November 2002) during the rate fitting process. The exclusion of the November 2002 data point was based on the observation that both the TCE and DCE concentrations in this sample were substantially lower than all of the other TCE concentrations measured before and after November 2002. When the November 2002 data point was excluded from consideration, the best-fit decay constant interpreted from this 'alternate' source scenario was 13.5 percent.

Based on the seven years of monitoring data that were available for source area monitoring well 1381MWS09, it appears that the original assumption of a 4.0 percent annual weathering rate was more conservative than the actual site conditions. Table 4.34 summarizes the weathering rates, R-squared values, and the year when TCE concentrations in the source area are predicted to reach 100 µg/L for each of the three source decay scenarios described above. The 90 percent confidence interval for the estimate of the year when TCE concentrations in the source area are predicted to reach 100 µg/L is also provided for each of the two projections estimated in this study. As described in Section 4.2.2.1, the purpose of providing an estimate of when each scenario is predicted to achieve a concentration of 100 µg/L in source area groundwater is to illustrate how empirical models can be used to estimate remediation timeframes for achieving a particular target concentration. As shown on Figure 4.38 and Table 4.34, the conservative (i.e., 4.0 percent per year) source-decay scenario predicts that it will take up to 124 years longer to reach 100 µg/L than is predicted by the scenario that uses currently available data to estimate the rate of source decay by 'best-fit' to selected data (i.e., 13.5 percent per year). For Facility 1381,

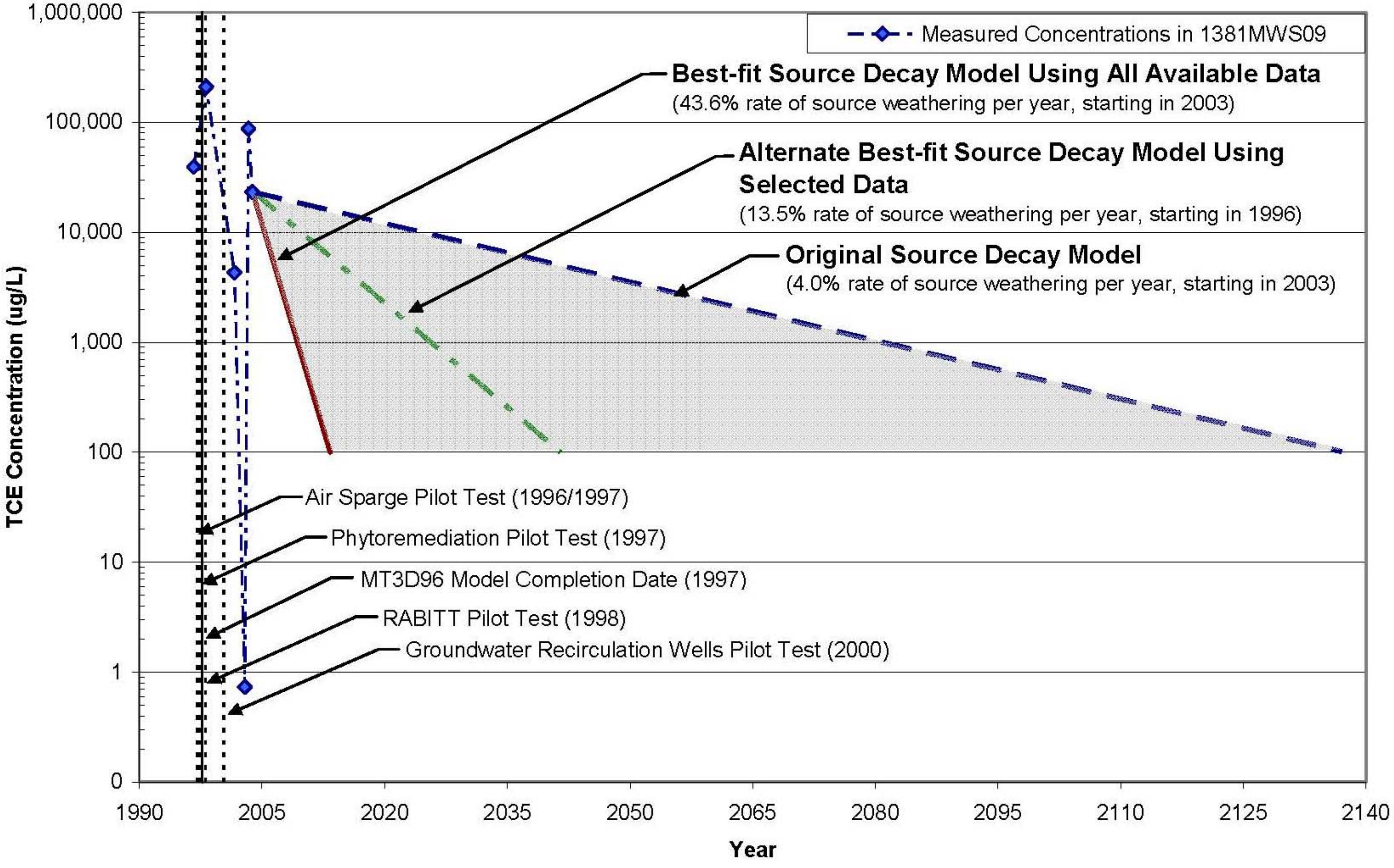


Figure 4.38 Measured and Predicted TCE Concentrations Over Time
Facility 1381, Cape Canaveral AFS, Florida

Table 4.34 Weathering Rates, R-Squared Values, and Timeframe Estimates for Various Source Decay Scenarios
Facility 1381, Cape Canaveral AFS, Florida

Source Decay Scenario	First-Order Weathering Rate (percent per year)	R-squared Value	Year when TCE Concentration is Predicted to Reach 100 µg/L (90% confidence intervals)
Original Source Decay Rate	4.0	N/C [a/]	2137
Best-fit Rate (All Data)	43.6	0.14	2013 (1996 - ∞) [b/]
Best-fit Rate (Selected Data)	13.5	0.10	2041 (2001 - ∞)

[a/] N/C = Not calculated.

[b/] ∞ = infinity.

the decay rate interpolated from all data except the November 2002 measurement was assumed to be a better estimate than the best-fit rate for all data because 1) the November 2002 measurements of both TCE and DCE, relative to the other measurement periods, were unexpectedly low and 2) the interpreted decay rate of 43.5 percent per year seems unreasonably high, based on historical data from this and other sites with TCE sources. Both estimates based on the currently available data have very high uncertainty, as illustrated by the very wide 90 percent confidence intervals associated with each of the estimates.

Similar to source decay observations at OU1, Altus AFB, the variability in observed TCE concentrations introduces significant uncertainty in the reliability of future predictions of source area concentrations using 'best-fit' empirical models. For example, the 'best-fit' source decay rate for selected data (i.e., 13.5 percent decay per year) predicts an average change in TCE concentrations of 0.44 orders of magnitude over a seven-year period. The 0.44 orders of magnitude change predicted by this scenario over seven years is substantially smaller than both the 5.5 orders of magnitude observation for all data and the 1.7 orders of magnitude observation for selected data. The 13.5 percent decay rate scenario predicts that it will take nearly 87 years for the average source area concentration to decrease by 5.5 orders of magnitude and 39 years for the average source area concentration to decrease by 1.7 orders of magnitude, which further suggests that the observation period is short relative to the expected duration of measurable contamination in well 1381MWS09. The uncertainty of predicting future source concentrations for this site is also reflected in the low R-squared value for the two best-fit scenarios (i.e., 0.14 and 0.10). Assuming that the source at Facility 1381 really is decaying over time, the certainty of the interpreted source decay rate is likely to be improved as additional monitoring occurs. However, it will take several years to several decades of monitoring to confirm the actual rate of source decay, and associated remediation timeframe estimate, for this site.

4.2.2.3 Case Study: Site FTA-2, Tinker AFB, Oklahoma

Site FTA-2, Tinker AFB was originally a temporary, unlined pit used for fire training exercises from 1962 to 1966. Fuels and solvents were placed in the pit, mixed with water, ignited, and extinguished. The residuals were left in the pit to evaporate or infiltrate the soil until the next training exercise. No active remediation has occurred at FTA-2. The remedy for the site has been MNA with LTM since December 1993. TCE concentrations at source area monitoring well 2-62B were used to estimate the remediation timeframe for this site.

As with other sites in this portion of the study, three source-decay scenarios were developed using the assumption that TCE concentrations in the source area will vary by a constant percentage each year over the life of the source area. The assumption that source area will, on average, vary by a constant percentage each year implies that the source will weather following a first-order (i.e., exponential) decay function described in Section 3.2.2.2. Figure 4.39 presents the decay curves for the first and third source decay scenarios examined in the current study. The first scenario was developed using the source conditions published as part of a previous modeling effort (Parsons, 1999b). In this study, the primary source cell was specified as starting with an assumed TCE source concentration of 75,000 µg/L in 1962, with a step function (in 5-year intervals) that reduced the TCE source concentration to 20,000 µg/L for the interval from 1993-1997. After 1997, the source cells were assumed to start with a concentration of 9500 µg/L and then weather at a constant rate of 2 percent per year from 1997 through the end of the simulation. As stated in the modeling report (Parsons, 1999b), selection of a source area decay rate of 2 percent per year was assumed to be a conservative assumption for the actual decay rate, based on experience gained during the AFCEE Natural Attenuation Initiative. When the development of a second source decay scenario was attempted using all available data collected from monitoring well 2-62B between December 1993 and May 2004, the 'best-fit', first-order rate was +1.5 percent per year. A positive firstorder rate implies that contaminant concentrations in the source area were, on average, increasing over the duration of available data for this well. A decay curve for the second scenario is not shown on Figure 4.39 because the best-fit exponential rate for the second scenario resulted in positive rate (i.e., prediction of an increase in source area concentration over time). In the third scenario, a second 'best-fit' trend line was developed by excluding the most recent TCE concentration measurement (9,330 µg/L in May 2004) during the decay rate estimation process. The decision to exclude this most recent data point from the decay rate estimate was to support the discussion below on how additional data points can significantly impact remediation timeframe estimates, particularly if the data set duration is short (e.g., several years) to the time anticipated for natural source weathering (e.g., several decades). When the May 2004 data point was excluded from consideration, the best-fit decay constant interpreted from this 'alternate' source decay scenario was 4.3 percent.

Table 4.35 summarizes the weathering rates, R-squared values, and the year when TCE concentrations in the source area are predicted to reach 100 µg/L for the three source weathering scenarios described above. The 90 percent confidence interval for the estimate of the year when TCE concentrations in the source area are predicted to reach 100 µg/L is also provided for the "selected data" projection estimated in this study. As shown on Figure 4.39 and Table 4.35, the conservative (2 percent) scenario predicts that it will take about 120 years longer to reach a source area target concentration than is predicted by the scenario that excludes the 2004 data point from the estimated source decay rate. It is important to note that use of all available data for source area monitoring well 2-62B results in essentially an infinite remediation timeframe estimate because the source concentrations are interpreted to be increasing over time. In reality, the source of contamination to groundwater is not infinite, which means that TCE concentrations in the source area will be observed to decrease at some point in the future when the mass flux of TCE contamination from the source to groundwater weathers to a rate that is less than the mass flux of TCE flowing out of the source area in groundwater.

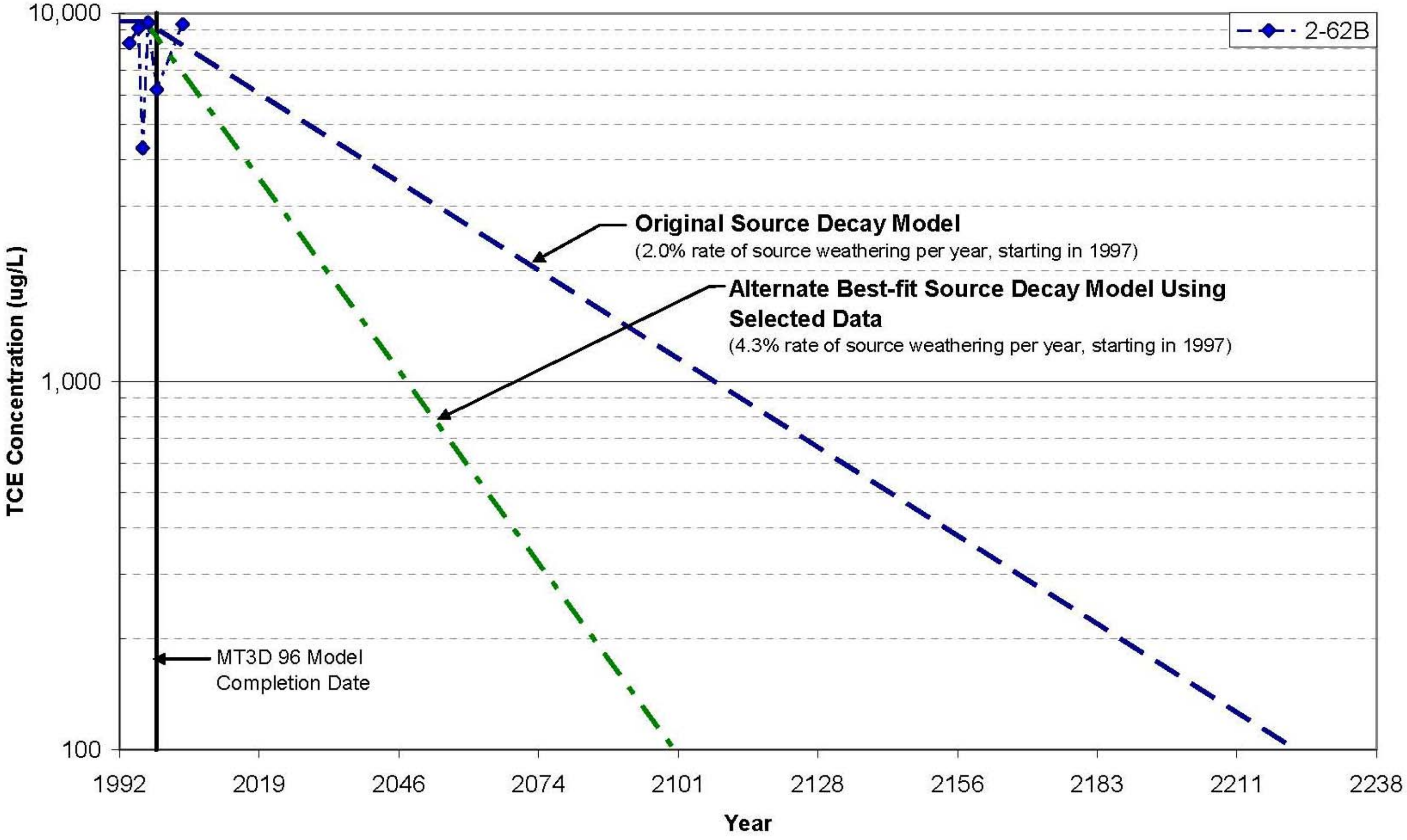


Figure 4.39 **Measured and Predicted TCE Concentrations Over Time**
Site FTA-2, Tinker AFB, Oklahoma

Table 4.35 Weathering Rates, R-Squared Values, and Timeframe Estimates for Various Source Decay Scenarios
Site FTA-2, Tinker AFB, Oklahoma

Source Decay Scenario	First-order Weathering Rate (percent per year)	R-squared Value	Year when TCE Concentration is Predicted to Reach 100 µg/L (90% confidence intervals)
Original Source Decay Model	-2.0	N/C [a/]	2222
Best-fit Model (All Data)	+1.5	0.03	N/C
Best-fit Model (Selected Data)	-4.3	0.07	2097 (2015 - ∞) [b/]

[a/] N/C = Not calculated.

[b/] ∞ = infinity.

Importantly, it is impossible to estimate when this quantifiable decay will begin to occur at this site, which suggests that the remediation timeframe for this site will most likely be longer than the estimates developed for the original and third source decay scenarios (i.e., longer than 100 years). The estimate based on the currently available data has very high uncertainty, as illustrated by the very wide 90 percent confidence interval associated with the estimate.

At FTA-2, there is relatively little fluctuation in the actual data compared to the other two case study sites. The actual site data ranges from 8,300 µg/L to 9,330 µg/L (only 0.05 orders of magnitude) over the period from December 1993 to May 2004. By comparison, the original weathering rate of 2.0 percent results in an expected decrease in TCE concentration of about 0.06 orders of magnitude, which is very close to the range of observed data variation. Considering that the range of fluctuation in measurements is nearly equal to the range of fluctuation predicted by the original model, it may be possible to determine with more certainty if the observed fluctuation is ‘noise’ or if the observed fluctuation is real source decay within the next decade or two of monitoring if the rate of predicted decay remains on the same magnitude as the rate of observed change in measured concentrations.

The combined observations that 1) the estimated weathering rates ranged from +1.5 percent to -4.3 percent, 2) the R-squared coefficients for weathering rate estimates were very low (i.e., R-squared < 0.07), and 3) that the range of observed data variability was on the same order of magnitude as the predicted change suggest that there is significant uncertainty in whether any of the interpolated or assumed source decay trends are reliable. In this case, the most appropriate conclusion for evaluation of source area weathering and associated remediation timeframe estimates is the qualitative statement that source concentrations greater than 100 µg/L weathering are likely to persist for a very long period of time (i.e., more than 100 years, and probably longer) under natural weathering conditions.

4.2.2.4 Summary of Remediation Timeframe Case Study Results

Table 4.36 summarizes weathering rates, available site data, and the range of estimated remediation timeframes for each scenario of the three sites evaluated in this section. At two of the sites, OU1, Altus AFB and Facility 1381, Cape Canaveral AFS, the weathering rate estimated using best-fit first-order decay models was greater than the rate used in previous numerical modeling studies at this site. From a remediation timeframe estimate standpoint, to provide context on how long it could take to confidently observe decreasing trends for various source weathering rates, calculations were performed on how long it will take for various first-order decay rates to produce order of magnitude decreases in source area concentrations. The results of these calculations are summarized in Table 4.37 for decreases in concentration of 1, 2, and 3 order of magnitude, corresponding to 90 percent, 99 percent, and 99.9 percent reductions, respectively, if the first-order decay rate is 2, 5, or 10 percent per year. Figure 4.40 provides a visual representation of these same calculations applied to a hypothetical source area that has a starting TCE concentration of 5000 µg/L and a target concentration of 5 µg/L. As can be observed from Table 4.37 and Figure 4.40, it could take decades to more than a century to observe an order of magnitude decrease in concentration.

Table 4.36 Summary of Case Study Weathering Rates, Site Data, and Remediation Timeframe Estimates

Parameter	OU1 Altus AFB	Facility 1381 Cape Canaveral AFS	FTA-2 Tinker AFB
Weathering Rate in Original Model	-2.0%	-4.0%	0% to 2%
Best-fit Estimate of Weathering Rate (All Data) [R-squared Value]	-3.8% [0.06]	-43.6 [0.14]	+1.5% [0.03]
Best-fit Estimate of Weathering Rate (Selected Data) [R-squared Value]	-7.0% [0.76]	-13.5% [0.10]	-4.3% [0.07]
Number of Data Points	7	6	6
Time Period of Available Data	Sep-96 – Nov-03 (7.2 years)	Sep-96 – Oct-03 (7.2 years)	Dec-93 – May-04 (11.4 years)
Data Range (orders of magnitude)	0.65	3.5	0.05
Range of Estimated Remediation Timeframes	56 to 201 years	8 to 132 years	96 to 217+ years

Table 4.37 Timeframes Required for Order of Magnitude Concentration Reductions at Varying First-Order Weathering Rates

Weathering Rate	Time Required to Reduce Concentrations by:		
	90 percent	99 percent	99.9 percent
2 percent/year	114 years	228 years	342 years
5 percent/year	45 years	90 years	135 years
10 percent/year	22 years	44 years	66 years

In summary, a source area well will need to span a ‘sufficient’ period to support a reliable source decay estimate based on observed changes in concentrations, with the duration of the ‘sufficient’ period becoming shorter as the weathering rate increases. In most cases, there will be fluctuations in the data due to natural heterogeneity, seasonal variation, and normal variability in sampling and analysis procedures. For sites where the fluctuation in the data is large, more data over a longer period is necessary to separate the overall trend from noise, relative to a site with a similar decay rate but less data fluctuation.

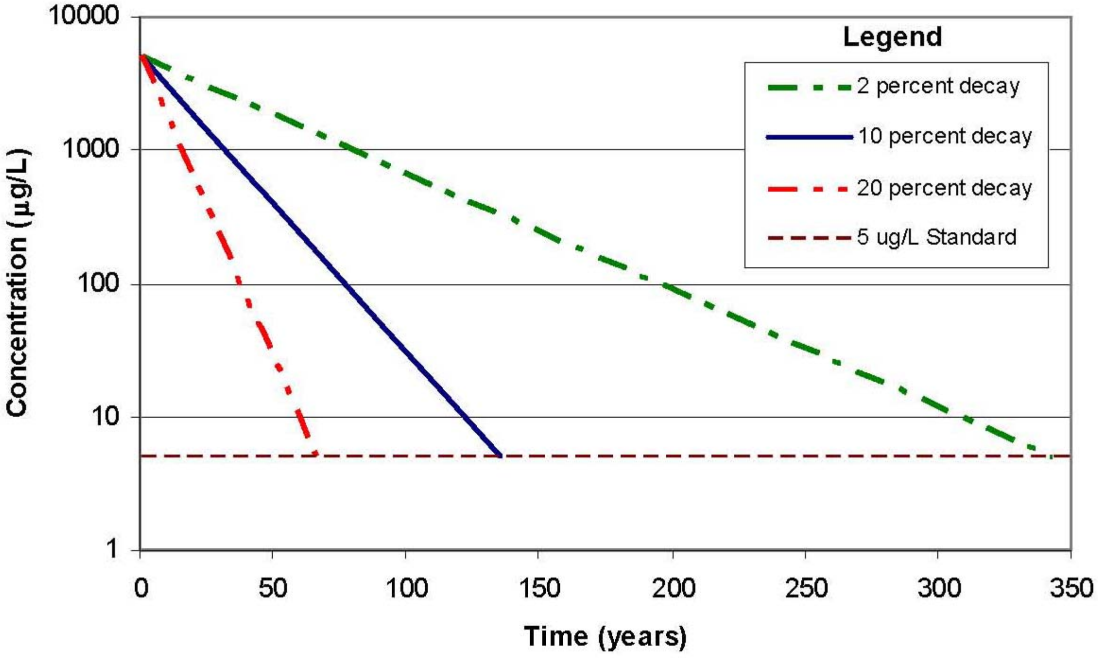


Figure 4.40 Temporal Changes in CAH Concentration for Varying First-Order Weathering Rates

In summary and based on the three sites examined, it can be concluded that not enough time has passed since the modeling efforts were completed to confidently interpolate the actual weathering rates. Two of the three sites had seven years of data available and one site had 11 years of data available. Although two of the sites appear to show weathering rates that are greater than those used for the modeling efforts, the wide scatter in data reduces confidence in these estimates. To increase confidence in these estimates, data will need to be collected over a longer period of time so that weathering trends can be distinguished from data 'noise'. Importantly, the frequency of measurement at sites where several years of data exist is probably less important than collecting data during the same season and with the same methods, with the goal of reducing 'noise' while extending the duration of measurement. Given the current state-of-science, the most reliable method for determining if the exponential weathering models applied in the current study are appropriate for CAH source areas will be to collect additional data over time and revisit the calculations presented above.

This page left blank intentionally.

5.0 SUMMARY AND RECOMMENDATIONS

This report presents a strategy and framework for assessing the sustainability of MNA-based remedies for groundwater at CAH-impacted sites. The three principal components of this framework are 1) analysis of plume stability, 2) estimation of remediation timeframes, and 3) estimation of the longevity of specific CAH degradation processes. Recommended methods that advance the state-of-practice in each of these three principal framework components are also presented, with multiple case study examples provided for the plume stability and remediation timeframe estimation portions of the MNA sustainability framework. Key observations and recommendations are provided for each framework component in the subsections below.

5.1 PLUME STABILITY ASSESSMENTS

One of the main purposes of evaluating various techniques for assessing plume stability was to advance the state-of-practice toward quantitative, rather than purely qualitative, metrics of plume stability. As part of the current effort, both concentration-based and mass-based metrics of plume dynamics were evaluated. The findings of the current study indicate that concentration-based and mass-based analyses of plume dynamics provide complementary information that can not readily be quantified by one method. For example, trend analysis of compliance well concentrations will continue to be important for documenting protectiveness of downgradient receptors. Similarly, trend analysis of source area well concentrations will continue to be important for estimates of remediation timeframe (for summary, see Section 5.2). In this context, the main advantage of mass-based metrics over concentration trend analysis appears to be in the interpretation of overall plume strength through the quantification of plume-wide changes in individual and total CAH mass. It is important to note, however, that mass-based analyses for plume stability are limited by the fact that 1) regulatory standards are enforced as concentrations, not as masses, and 2) data input requirements for the mass-based methods are much more restrictive than the concentration-based methods. Specific findings for concentration-based and mass-based plume stability assessments are described below.

For concentration-based metrics, the following items were noted as significant findings:

- ***Observation 1:*** Care must be taken when implementing statistical trend analysis for wells where all data is reported as below detection. Specifically, MAROS and perhaps other off-the-shelf statistical packages assign numerical values equal to a percentage of the MDL (e.g., one-half of the MDL) to below detection limit results. In cases where the MDL varies over time, erroneous trends may be identified by the statistical packages that are artifacts of this approach, with the potential to lead to invalid conclusions about plume dynamics. Trend analysis programs that allow end-users to produce tables of trend results from direct-input of electronic databases without a requisite 'reality check' (e.g., visual inspection of data or trend lines) should be used with particular care, especially if the end-user is not intimately familiar with site conditions and historical trends.

  Recommendation 1: To mitigate this concern, it is recommended that 1) the method of assigning numerical values to below detection results be understood and accounted for prior to performing data analysis and 2) any visual or tabular representations of trends for wells that have all below detection measurements be given a unique identifier that denotes that all measurements were below detection, and 3) statistical analysis not be performed for data series consisting entirely of below-detection-limit data.

- ***Observation 2:*** Similar to the previous observation, trend results that are based on very low concentrations (e.g., less than 10 μg/L) or a combination of low concentrations and below detection measurements can also result in a statistical finding of increasing or decreasing trends that are not important or are misleading.

  Recommendation 2: For locations where contaminant concentrations are very low and/or below detection, trend analysis results that are 'increasing' or 'decreasing' should be reviewed in the context of the actual data to qualitatively assess the accuracy of the trend result. For example, a dataset of three below detection measurements (with a detection limit of 1 μg/L) followed by a measurement of 0.8 μg/L may be identified as an increasing trend by statistical analysis. In the context of potential plume expansion, identification of this increasing trend may not be significant. However, if the last measurement was 8 μg/L, for example, the well may be providing an early indication of an expanding plume. In this latter case, data from the next several monitoring events should be closely reviewed to confirm that plume concentrations are or are not increasing in this area. When statistical analysis is needed for data sets that contain some data below the detection limit, non-parametric tests (such as MK analysis) are recommended. However, if a parametric test, such as linear regression, is applied to a data set with below detection measurements, elimination of below detection measurements prior to applying the parametric test should be considered as a method of conservatively estimating a rate constant for contaminant concentration decay.

- ***Observation 3:*** It is often difficult to develop a meaningful assessment of plume stability using tabulated statistical trend analyses of well-by-well data because the spatial distribution of trends cannot be readily discerned.

  Recommendation 3: Plotting color-coded statistical trends by statistical method and COC on a base map showing important surface features, the direction of groundwater flow, and the interpreted extent of contamination (i.e., isoconcentration contour maps) can be a helpful method of identifying whether increasing, decreasing, or stable trends are spatially clustered and meaningful. For example, a map showing stable concentrations within the source area and dissolved plume and decreasing trends along the plume edges provides visual evidence of a plume that is stable or receding. Importantly, visual evidence presented in this manner is based on statistical results that are quantifiable, reproducible, and objective.

- ***Observation 4:*** Linear regression and the MK test have important differences that influence how early and often concentration trends are identified. Specifically, 1) linear regression is more sensitive to changes in the magnitude of contaminant concentration than the MK test and 2) the MK test is able to provide trend analysis results by directly handling non-numerical values (i.e., below detection measurements) rather than converting these non-numerical values to concentration measurements, as is required for linear regression, prior to analysis.

Recommendation 4: The most rigorous approach to statistical analysis is to perform data distribution testing (including possible assessment of log-transformed data) prior to selecting a statistical test. The current version of MAROS does not offer the option of selecting a statistical test based on data distribution analyis or the existence of non-detect data, but rather provides the user with both statistical results. Users of MAROS will be faced with the decision of having to select from the two test results, whether or not both results were desired. It is recommended that users of MAROS evaluate data distribution at locations where the parametric and nonparametric test results conflict to evaluate which statistical test result is most appropriate. Although data distribution analysis was performed for data sets used in this study, most of the results were inconclusive; an artifact of small data sets and large numbers of non-detect values. This indicates that the non-parametric MK approach is probably an appropriate, conservative choice in many cases. Although not stastically appropriate in all cases, application of both linear regression and MK tests for identifying contaminant concentration trends provides insight into plume stability assessments that is beyond what can be provided by either test individually. For example, a finding of the same trend by both methods generally indicates that the indicated trend is real. Conversely, the end user should have less confidence in an assigned trend when the results of the linear regression and MK test are different. When working with low concentration and below detection data, linear regression is more likely to identify a trend (i.e., ‘increasing’ or ‘decreasing’) than the MK test. While the increased sensitivity of the linear regression test offers a potential benefit of identifying locations where concentrations have recently changed, experience gained during the current study suggests that the MK test is more likely to 1) accurately identify a trend in low concentration and below detection data that is consistent with the overall assessment of plume stability and 2) result in fewer ‘false alarms’ of a change in trend. If, for some reason, only one statistical test will be applied for trend analysis of groundwater contaminant concentration data, the MK test is recommended over linear regression because of it’s robustness for handling a wide range of contaminant concentration data of unknown data distribution (i.e., a non-parametric test).

- ***Observation 5:*** Trends that appear obvious upon visual inspection of a plotted best-fit linear regression trend line through available data may not correlate to a statistical finding of a significant trend for linear regression analysis. For example, there were several instances when a visual inspection of the best-fit trend line to data from FPTA¬2, Brooks City-Base appeared to be increasing or decreasing, even though the statistical finding using linear regression was ‘stable’ or ‘no trend’.

Recommendation 5: It is important to choose the decision rules for identifying a trend, and then to consistently apply these rules across all locations of the site and during each subsequent monitoring event. For example, if statistical analysis for trend is used as the basis for confirming the presence of trends in an objective manner, then the most important data to report will be the findings of these statistical trends, even if the visual appearance of the best-fit trend line appears to ‘subjectively’ indicate a different trend. If the trend indicated by visual examination of a best-fit trend line conflicts with a statistically-defined trend for the same data, it is recommended that the statistical evaluation be revisited for accuracy and/or to explain why a difference in visually-observed and statistically-determined trends exists. Resolution of these cases may require additional data collection.

- ***Observation 6:*** Sen's Method of trend analysis was less sensitive to detecting trends than linear regression or the MK test. In addition, Sen's method is most appropriate for data sets that are collected at a constant time interval (e.g., every six months) that is not common in historical groundwater monitoring records. Linear regression and the MK test are better-suited and more appropriate for identification of concentration trends than Sen's method, particularly if the sampling interval between monitoring events varies over time. Furthermore, Sen's method is much less sensitive to the impacts of sudden increases in concentration than linear regression and the MK test. This experience indicates that sole reliance on Sen's method for trend identification is likely to inappropriately delay identification of contaminant concentration changes that indicate a change in plume dynamics.

  Recommendation 6: Sen's Method is not recommended for use in evaluating trends in groundwater contaminant concentration data.

- ***Observation 7:*** As with any analysis method, both the accuracy and an understanding of the contents of the site database are necessary to develop meaningful and accurate findings.

  Recommendation 7: It is important to review the data input for 1) accuracy of contaminant names, numerical values, and data qualifier flags, 2) compatibility of data format with input requirements of analysis software, 3) understanding of designations for QA/QC samples and data qualification flags, and 4) confirmation that the spatial location and coordinates for each sampling point are known. Performing this level of data review prior to performing data analysis for any of the methods discussed in this report is particularly important if the data analyst is unfamiliar with the site. One method used in the current study for organizing available data was to create a data table that identifies 1) well designations, 2) the site-specific hydrogeologic stratum that the well is screened, 3) the location of the well relative to the contaminant plume(s), and 4) sample collection dates for each monitoring well prior to performing data analysis. Compiling this table was found to be an important first step in 1) deciding which wells could be included for each analysis method examined in the current study and 2) confirming that the physical location of each well in the database was known.

- ***Observation 8:*** To the extent possible, ensure that the assumptions inherent to the linear regression test are not violated by the data set properties (e.g., linear regression assumes data is normally distributed) before placing weight on the linear regression results.

  Recommendation 8: The most rigorous approach to statistical analysis is to perform data distribution testing (including possible assessment of log-transformed data) prior to selecting a statistical test. The current version of MAROS does not offer the option of selecting a statistical test based on data distribution analyis or the existence of non-detect data, but rather provides the user with both statistical results. Users of MAROS will be faced with the decision of having to select from the two test results, whether or not both results were desired. It is recommended that users of MAROS evaluate data distribution at locations where the parametric and nonparametric test results conflict to evaluate which statistical test result is most appropriate. If normality testing is not feasible for a small number of data points, the linear regression test should not be relied upon as the sole indicator of trend in a plume dynamics analysis. As indicated above, use of the MK test in addition or in lieu of the linear regression test is recommended.

For mass-based metrics, the following items were noted as significant findings:

- ***Observation 9:*** The findings of the current study indicate that sampling the same set of wells (i.e., a "common well set") at periodic intervals was critical to being able to perform the mass-based analyses described in this report. The common well sets that were most useful were comprised of data from at least eight wells screened in the same hydrogeologic unit, with 1) at least one well in each 'zone' of the plume (i.e., source area, dissolved plume, and plume edges) and 2) a domain hull that covered the majority of the dissolved plume's spatial extent. The primary advantage of using a common well set is to eliminate the portion of variability in the mass-based calculations that is due to changes in volume (i.e., the 'noise') so that trends in plume mass due to changes in concentration (i.e., the 'signal') are easier to observe.

  Recommendation 9: Creation of the data table described above under Recommendation 7 is recommended as an efficient method for evaluating 1) whether sufficient historical data are available to support mass-based calculations and 2) how to design future LTM programs for supporting mass-based calculations. Historical data can be quickly evaluated by visual inspection to determine how well a particular dissolved plume is covered by a particular common well set. In the event that one or more of the common well sets provides sufficient coverage of the dissolved plume, mass-based calculations can be implemented using one or both of the algorithms described in the current study.

- ***Observation 10:*** During site data reviews, there were multiple occasions when the absence of data from one or two wells during one or more monitoring events caused a reduction in the number of wells in the common well set and/or the number of events when the mass-based plume stability method described in this report could be used. Some of this absence of data was unavoidable because wells were installed in different years as part of the progression from the RI stage to remedy implementation. In other cases, it was not obvious why one or more existing wells were not sampled during a particular monitoring event, but it was obvious that the absence of this data limited the spatial or temporal application of mass-based analyses. In summary, the historical sampling record dictated which wells and sampling events could be included in mass-based plume stability calculations.

  Recommendation 10: At sites where mass-based analyses of plume dynamics will be used in the future to assess remedy performance, LTM programs should be reviewed to ensure the data from these programs will support mass-based calculations. Specifically, the LTM program should specify that all wells in the common well set are schedule for sampling during the same sampling events. The creation of the data table and visual representation of the 'best' current common well set described under Recommendation 9 is a useful aide in selecting the wells that will need to be sampled in future LTM events. In the event that none of the common well sets identified from historical data provide sufficient dissolved plume coverage, wells that have not been sampled regularly for other reasons would need to be added to future common well sampling events. In most cases where MNA is a significant contributor to the remedy, sampling of the common well set either annually or once every two years will be sufficient to 'see' relevant trends because the rate of mass-removal due to natural processes is unlikely to be discernable over shorter time periods. In addition, sampling the common wells the same season of the year is a recommended method for reducing data 'noise' related to seasonal variation. Finally, it is valuable to review data calculations to determine what percentage of a particular mass-metric is estimated as coming from each well for each CAH species. The value in performing this evaluation is that it provides a quantitative understanding of whether one or two wells are controlling the observed mass trends. If one or two wells are found to be controlling an important plume mass metric (e.g., total estimated CAH plume mass), adding additional wells in higher concentration areas to the common well set for future LTM should be considered as a method of making the mass-based metrics more representative of overall plume conditions.

- ***Observation 11:*** The mass-based plume metrics described in this report provide a method of collapsing a large amount of data into single data points in time for dissolved contaminant mass (described here) and the location of the center of dissolved mass (described Observation 12). When plotted over time, the dissolved plume mass estimates can be used to categorize a plume as strengthening (dissolved mass increasing), sustaining (dissolved mass stable), or weakening (dissolved mass decreasing). The analysis of these trends can be performed visually or statistically, assuming that data from at least four events is available to support the statistical analysis. In addition, plotting or tabulating temporal changes in dissolved mass percentage (by CAH species) provides an indication of plume strength and dynamics.

  Recommendation 11: In cases where the dissolved plume is weakening, estimates for the expected rate of contaminant mass loss can be developed and used as a performance metric to document if a remedy (MNA-based or otherwise) is performing better, the same, or worse than previous data predicts. In cases where the total dissolved plume is strengthening or sustaining, it will not be possible to estimate how long the total dissolved plume will persist using mass-based metrics. Note that different CAH plumes at the same site may behave differently in terms of mass metrics over time, particularly if the degradation kinetics of an intermediate degradation product are slower than those of the parent product. A common example may be observed at sites where cis-1,2-DCE degrades more slowly than TCE, causing the cis-1,2-DCE mass to increase while TCE mass is declining. In this case, analyzing the change in total CAH mass (expressed in moles or mass as equivalent TCE) provides one method of documenting whether the overall dissolved CAH mass is increasing, decreasing, or staying the same over time. Furthermore, tabulating and/or plotting the CAH mass distribution by CAH species can provide a quantitative indicator of when degradation of intermediate degradation products becomes as important (or more important) than degradation of the parent compound.

- ***Observation 12:*** Plotting the location of the center of dissolved mass for each monitoring event on a site base map was found to be a useful way to determine if the center of mass was moving with respect to the source area and direction of groundwater flow. However, interpretation of what this movement means, and whether the center of mass is useful for understanding plume dynamics, was not as straight-forward as was originally anticipated. For example, rapid reduction in source concentrations due to the installation of a pump-and-treat system in the source area at FPTA-2, Brooks City-Base caused the center of mass for chlorinated solvents to 'jump' downgradient prior to restabilizing in a new location. This result was different than what had been expected because it was incorrectly assumed that a receding, weakening plume (as indicated by concentration-based and dissolved mass analyses, respectively, for this site) would have caused the calculated center of mass to move back toward the source area. In hindsight, it was recognized that the center of mass is highly dependent on the distribution of mass across the plume. Based on this experience, there does not appear to be a straightforward relationship between changes in the location of the center of mass and interpretation of plume dynamics. However, plotting the results of center of mass calculations on a site base map did draw attention to monitoring events where there were significant changes in concentration distribution, either through implementation of an active remedy (e.g., pump and treat at FPTA-2, Brooks City-Base) or a temporary drop in source area concentrations that was attributed to sampling variability (e.g., LTM sampling at Facility 1381, Cape Canaveral AFS).

  Recommendation 12: Because there does not appear to be a readily-understandable relationship between changes in the location of the center of dissolved plume mass and the assessment of plume stability using other methods, center of mass calculations are not recommended as a performance metric for interpreting plume stability. However, center of mass calculations and data plotting are relatively easy to implement if total dissolved mass is being calculated for a series of time events, so plotting center of mass calculations on site base maps may be a relatively inexpensive method of directing attention to monitoring events where there has been a rapid change in the distribution of contaminant concentrations.

- ***Observation 13:*** It is important to understand how mass-based calculations handle below detection measurements because large changes in the method detection limit over time can complicate the application and interpretation of mass-based metrics. Specifically, sample dilution that is required for measuring high CAH concentrations can cause concentrations of other CAHs of interest to be reported as below detection at concentrations higher than what have been observed during other monitoring events. At many CAH-impacted sites, TCE concentrations tend to be high when a strong source is present, causing cis-1,2-DCE and/or VC concentrations to be reported as below detection when these compounds may be present at concentrations of the hundreds or thousands of µg/L. Over time, continued TCE degradation to cis-1,2-DCE and VC tends to cause concentrations of these CAHs to be detected at locations that were previously reported as below detection. In this case, TCE mass may be accurately estimated for the entire time period, whereas accurate estimates for cis-1,2-DCE and VC mass may only be obtained for later monitoring events.

Recommendation 13: The range of reported concentrations for individual CAHs should be compared with the range of method detection limits to ascertain how much these ranges overlap for wells in the common well set. In cases where there is significant overlap, individual data values for the common wells should be reviewed in the context of the mass-metric calculation algorithm to determine which time events have data that will allow calculation of a representative mass-metric. As part of an evaluation of the algorithm method, it is appropriate to run several test cases (see Appendix A for examples) to ensure that the analyst understands the impact of decisions on how to handle below detection measurements. Evaluation of the mass calculation algorithm is particularly important if the user is unfamiliar with how calculations are performed and data are handled in an off-the-shelf program.

- ***Observation 14:*** The Theissen polygon and TIN grid methods applied in the current study produced similar results for dissolved CAH mass and the location of the center of mass. Note that these two methods were specifically chosen because they do not rely on subjective interpretation of data for estimation of plume mass metrics. Based on the findings on this study, it appears that results from mass-metric trend analysis using the Theissen polygon and TIN grid methods are functionally equivalent.

  Recommendation 14: While the Theissen polygon and TIN grid methods appear to provide identical interpretation of mass-metric trends, it is recommended that this finding be confirmed using data from additional sites to gain confidence that this functional equivalence is maintained for a wider variety and larger number of sites. Upon confirmation that these two methods are functionally equivalent for a given site, implementation costs for mass-based metrics could be reduced by relying solely on one method for data interpretation. In the event that a proponent of mass-based metrics chooses to use a different method of converting monitoring well concentrations into mass-based metrics than is presented in the current study, performance of algorithm testing with test cases and comparison to results of the current study is recommended.

5.2 REMEDIATION TIMEFRAME ESTIMATES

Reliable estimates of remediation timeframe are important for 1) evaluating whether an MNA-based remedy is capable of achieving an acceptable remediation endpoint in a timeframe that is reasonable when compared to other alternatives, 2) calculating life-cycle costs of LTM for an MNA-based remedy, and 3) providing a target timeframe that can be used to evaluate whether current and future NA processes are likely to be sustained over the duration of contamination in the subsurface. The following observations and recommendations provide a summary of lessons learned about estimating remediation timeframes using existing LTM data and the current state-of-practice for source area modeling.

- ***Observation 15:*** At CAH-impacted sites where natural weathering of the source area is relied upon as part of the overall remediation strategy, the duration of the remediation timeframe will most often be defined as the time required for CAH concentrations in the source area to reach site-specific regulatory targets. The source area modeling review performed as part of the current study concluded that the best available tools for estimating source duration (and, therefore, remediation timeframe) at CAH-impacted sites are empirical, first-order (exponential) decay models that are 'fitted' to available source area well data. Some of the important advantages of empirical models over mechanistic models for estimating CAH source duration are that these models typically 1) require a small number of input parameters and 2) are not explicitly dependent on an estimate of the contaminant mass in the system at any point in time. The primary practical limitation of mechanistic models for simulating source decay is the current inability to measure necessary input parameters that result in a 'singular' solution for source area decay.

Recommendation 15: Given the current state-of-practice of modeling and parameter estimation, first-order source decay models that are fitted to available source area well concentration data are recommended as the best available method for estimating remediation timeframes. As part of this recommendation, it is acknowledged that 1) refinements in mechanistic models, 2) development of parameter measurement techniques, and/or 3) continued collection of LTM data may one day offer a method of simulating CAH release to groundwater that is more accurate than the results that empirical models currently offer.

- ***Observation 16:*** Based on observations from three case study sites, it can be concluded that even a decade of regular source area monitoring is too short to accurately estimate site-specific weathering rates. The basis of this conclusion is that the variability in source well monitoring data was larger than what would be expected for a typical range of source area degradation rates (e.g., 2 to 10 percent per year).

Recommendation 16: To increase confidence in estimated remediation timeframes, additional data will need to be collected in the future so that actual source weathering can be distinguished from normal data variability. During this period of additional monitoring, sampling and analysis of compliance monitoring wells should be used to demonstrate protectiveness of site-specific receptors. In lieu of having additional time available for making an assessment of remediation timeframe, experience gained during the current study indicates that analyzing source area well data sets using 1) all data and 2) selected data (if obvious outliers appear to exist) is one way to develop a range of remediation timeframe estimates. This range of remediation timeframe estimates could then be used to evaluate 1) the degree of confidence that can be placed on a given estimate and 2) how frequently source area monitoring wells need to be sampled to improve the trend estimate. As an example of this latter point, a remediation timeframe estimate that is on the order of decades would provide support for sampling source area wells on an annual or an every-other-year basis because less-frequent sampling (e.g., semi-annual) is unlikely to result in a significantly improved estimate of the remediation timeframe.

- ***Observation 17:*** In the two case studies where the source area concentrations appear to be decreasing over time due to natural source weathering, the assumed weathering rate during previous modeling studies of 2 percent per year appears to be overly conservative. Results from these two sites suggest that a lower bound on the natural source area weathering rate of between 4 and 7 percent per year may be appropriate for these sites. Note that each doubling of the first-order decay rate results in a reduction in the remediation timeframe estimate to reach a particular regulatory concentration by 50 percent, which will have a major impact on life-cycle cost estimates for MNA-based remedies. It is interesting to note that data from the third case study site does not conclusively indicate a decrease in source area concentrations. In this case, the current state-of-practice does not support a scientifically-defendable estimate for the remediation timeframe because 1) a first-order decay rate cannot be reliably estimated to support use of an empirical model and 2) there is no reliable estimate for the mass of contaminant in the subsurface to support estimation with a mechanistic model.

  Recommendation 17: While use of 'conservative' source area model decay rates may be acceptable practice for predicting whether simulated contaminants are likely to reach compliance monitoring locations and/or downgradient receptors, conservative source decay estimates can result in projected plume durations that are decades or even centuries longer than will occur in reality. As such, the impact of using a 'conservative' estimate of source decay should be accounted for in 1) the evaluation of life-cycle costs of MNA-based remedies and 2) the determination of whether the remediation timeframe for an MNA-based remedy is reasonable relative to other feasible alternatives. For sites where source area concentrations do not exhibit measurable decay, efforts during the current study support a conclusion that the current state-of-practice does not allow development of scientifically-defensible estimates for remediation timeframes.

5.3 EVAULATION AND PREDICTION OF MNA SUSTAINABILITY

At the outset of this project, the envisioned approach for advancing the state-of-practice for long-term sustainability assessments of MNA was to evaluate whether existing LTM data sets could be used to predict how long biodegradation processes could be counted on to maintain plume stability. Of particular interest was the development and demonstration of a procedure that would help move the state-of-practice beyond the 20-mg/L 'rule-of-thumb' described in USEPA (1998a) as the threshold below which dissolved organic carbon concentrations are likely to limit the beneficial effects of biodegradation. Unfortunately, a review of available data from 35 candidate sites did not yield any sites with existing data sets that contained all of the data required to perform the type of analysis that is believed to be needed to make a quantitative assessment of MNA sustainability where biodegradation is a significant contributor to contaminant mass degradation and protection of site-specific receptors. Based on the review of available site information and knowledge of efforts to evaluate the long-term sustainability of enhanced anaerobic bioremediation remedies, the following observation and recommendation are provided on a process and sampling program that is needed to advance the state-of-practice for assessing the long-term sustainability of MNA processes.

- ***Observation 18:*** One process that could be used to estimate the sustainability of biodegradation processes for containment of dissolved CAH plumes is to 1) observe whether organic carbon is being consumed faster than it is being replaced by natural processes, 2) estimate the rate of organic carbon consumption or accumulation, 3) estimate the minimum, site-specific threshold organic carbon concentration that is required to sustain sufficient biodegradation to maintain plume stability, 4) calculate the estimated time until organic carbon concentrations can no longer sustain existing biodegradation processes, and 5) compare this estimated duration of sustaining existing biodegradation processes with estimates for remediation timeframe to quantitatively indicate the likelihood that biodegradation processes are sustainable.

Recommendation 18: To provide sufficient data to support the calculations described above, the full suite of natural attenuation parameters described in the Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater (USEPA, 1998a) should be collected once every two years during the same season of the year for a minimum of 4 events from a common well set that includes source area wells and wells along a plume axis for at least three, and preferably 5 or more sites with known hydrogeologic conditions. A process for estimating the threshold organic carbon requirements, based on measured concentrations of native (inorganic) electron acceptors and reaction endproducts, can then be applied to these data using procedures similar to those described for electron donor demand in the Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater (AFCEE, 1995) and Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents (AFCEE et al., 2004). While the outcome of the sampling and analysis program described above is not certain, following this sampling program at multiple sites where MNA is the primary remedy would allow the current state-of-practice to be tested to prove whether existing knowledge and analytical procedures are sufficient to evaluate whether it is possible to quantify the sustainability of biologically-based MNA processes.

This page left blank intentionally.

6.0 REFERENCES

Abriola, L.M., 1996. Organic liquid contaminant entrapment and persistence in the subsurface: Interphase mass transfer limitation and implications for remediation. 1996 Darcy Lecture. National Ground Water Association, presented at Colorado School of Mines. 25 October.

AFCEE. 1995. Technical Protocol for Implementing Intrinsic Remediation with Long-TermMonitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater.Brooks City-Base, Texas.

AFCEE. 2000a. Aqueous and Mineral Intrinsic Bioremediation Assessment (AMIBA) Protocol. Brooks City-Base, Texas. (http://www.afcee.brooks.af.mil/products/techtrans/monitorednaturalattenuation/protocols.asp)

AFCEE. 2002. Monitoring and Remediation Optimization System (MAROS): Software Version 2.0 User's Guide. Brooks City-Base, Texas. (http://www.gsi-net.com/software/MAROS.htm)

AFCEE. 2003. Aqueous and Mineral Intrinsic Bioremediation Analysis (AMIBA) of the Pine Bark Mulch Permeable Barrier at Altus Air Force Base SWU-7 (OU-1). Brooks City-Base, Texas.

AFCEE, NFESC, and SERDP. 2004. Principles and Practices of Enhanced Anaerobic Bioremediation of Chlorinated Solvents. (http://www.afcee.brooks.af.mil/products/techtrans/Bioremediation/downloads/PrinciplesandPractices.pdf)

Brauner, J.S. 1997. Nonparametric Estimation of Slope: Sen's Method in Environmental Pollution. In: Environmental Sampling and Monitoring Primer (D. Gallagher, Ed.).Virginia Tech, Blacksburg, VA. (http://ewr.cee.vt.edu/environmental/teach/smprimer/sen/sen.html)

BEM Systems, Inc. (BEM). 2002. Corrective Measures Study Report, Revision 1. Facility 1381, Solid Waste Management Unit C021, Cape Canaveral Air Station, Florida. Prepared for U.S. Air Force Space Command and AFCEE. December.

CH2M Hill. 2003. Long Term Monitoring Optimization Technical Memorandum with Proposed LF-06 Monitoring Plan. July.

Chapelle, F.H., M.A. Widdowson, J.S. Brauner, E. Mendez, and C.C. Casey. 2003. Methodology For Estimating Times Of Remediation Associated With Monitored Natural Attenuation. USGS Water-Resources Investigations Report 03-4057. September. (http://toxics.usgs.gov/pubs/wri03-4057/index.html)

Chow, V.T., D.R. Maidment, and L.W. Mays. 1988. Applied Hydrology. McGraw Hill Book Co., New York.

Columbus Air Force Base. 2001. Installation Restoration Program, LF-06, Old Landfill #6 Technical Data. Copy of presentation provided by Mr. Troy Stewart, Columbus AFB. 1 November.

ESRI. 2001. Geostatistical Analyst™ Statistical Software. (http://www.esri.com/)

Ferry, M.L., R.T. Wilkin, R.G. Ford, and J.T. Wilson. 2004. Nonbiological removal of cis¬dichloroethylene and 1,1-dichloroethylene in aquifer sediment containing magnetite. Environmental Science and Technology 38(6):1746-1752

Flynn, S., F. Löffler, and J. Tiedje. 2000. Microbial community changes associated with a shift from reductive dechlorination of PCE to reductive dechlorination of cis-DCE and VC. Environmental Science and Technology 34(6):1056-1061

Gilbert, R.O. 1987. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold Co., New York. 320pp.

Halliburton NUS Corporation (HNUS). 1996. Remedial Investigation Report, Fire Protection Training Area No. 2, Brooks Air Force Base, Texas. Vol. 1&2. June.

Hendrickson, E.R., J.A. Payne, R.M. Young, M.G. Starr, M.P. Perry, S. Fahnestock. D.E. Ellis, and R.C. Ebersole. 2002. Molecular analysis of Dehalococcoides 16S ribosomalDNA from chloroethene-contaminated sites throughout North America and Europe. Applied and Environmental Microbiology 68(2):485-495

Kendall, M.G. 1975. Rank Correlation Methods. 4th Edition. Charles Griffin, London.

Kennedy, L.G., J.W. Everret, and J. Gonzales. 2003. Biogeochemical treatment for the engineered and natural attenuation of chlorinated solvents. In: In Situ and On-Site Bioremediation - 2003. Proceedings of the Seventh International In Situ and On-Site Bioremediation Symposium (Orlando, Florida; June), V.S. Magar and M.E. Kelley, Eds.Battelle Press, Columbus, Ohio. Paper H-16.

Law Engineering and Environmental Services, Inc. (Law) and Tetra Tech. 2002. Installation Restoration Program Long term Monitoring Report, March 2002 Groundwater Sampling Event, SS-45 – Remedial Action Operations, Project GAMH 20027030, England Air Force Base, Louisiana. Prepared for AFCEE. August.

Mann, H.B. 1945. Non-Parametric Tests against Trend. Econometrica 13:245-259

Maymo-Gatell, X., V. Tandoi, J.M. Gossett, and S.H. Zinder. 1995. Characterization of an H2-utilizing enrichment culture that reductively dechlorinates tetrachlorethene to vinyl chloride in the absence of methanogenesis acetogenesis. Applied and EnvironmentalMicrobiology 61(11):3928-3933

McNab, W.W. Jr., D.W. Rice, J. Bear, R. Ragaini, C. Tuckfield, and C. Oldenburg. 1999. Historical Case Analysis of Chlorinated Volatile Organic Compound Plumes. Lawrence Livermore National Laboratory (LLNL). March.

NRC. 2000. Natural Attenuation for Groundwater Remediation. Prepared by the Commission on Geosciences, Environment and Resources. National Academy Press, Washington, DC. 274pp.

Parsons. 1997a. Draft Treatability Study in Support of Remediation by Natural Attenuation for Groundwater at Site LF-06, Columbus Air Force Base, Mississippi. Prepared for AFCEE Technology Transfer Division and Columbus Air Force Base. August.

Parsons. 1998a. RCRA Facility Investigation Report for Facility 1381 (SWMU 21), CapeCanaveral Air Station, Florida. Revision 1. Volumes I & II. Prepared for U.S. Air ForceSpace Command, AFCEE, and Air Mobility Command. January.

Parsons. 1999a. Demonstration of Remediation by Natural Attenuation for Groundwater at Site FTA-2, Tinker AFB, Oklahoma.

Parsons. 1999b. Demonstration of Remediation by Natural Attenuation for Groundwater at Site FTA-2, Addendum, Tinker AFB, Oklahoma.

Parsons. 1999c. Final Remediation by Natural Attentuation Treatability Study for Facility 1381 (SWMU 21), Cape Canaveral Air Station, Florida. Prepared for AFCEE and 45th Space Wing Facilities. December.

Parsons 1999d. Final Remediation by Natural Attentuation Treatability Study Addendum for Facility 1381 (SWMU 21), Cape Canaveral Air Station, Florida. Prepared for AFCEE and 45th Space Wing Facilities. December.

Parsons. 1999e. Final Remediation by Natural Attenuation, Treatability Study for Operable Unit 1, Altus Air Force Base, Oklahoma. Prepared for Air Force Center for Environmental Excellence Technology Transfer Division and 97 CES/CEVR Altus Air Force Base. December.

Parsons. 2000. Final Focused Corrective Measures Study for Groundwater at Site SS-45 at England Air Force Base, Louisiana. Prepared for AFCEE Technology Transfer Division and England Air Force Base Conversion Agency. February.

Parsons. 2001a. Final Feasibility Study for IRP Site LF-06, Columbus Air Force Base,Mississippi. Prepared for Air Force Mobility Command, AFCEE, and Columbus Air Force Base. January.

Parsons. 2001b. Supplemental Feasibility Study Evaluation for IRP Site LF-06, Columbus Air Force Base, Mississippi. Prepared for Air Force Mobility Command, AFCEE and Columbus Air Force Base. June.

Parsons. 2002. Demonstration of Remedial Actions Operating Properly and Successfully for Fire Protection Training Area 2 Brook Air Force Base, Texas, Revision 2.1, Final. Prepared for AFCEE Consultant Operations Division (AFCEE/ERC), Brooks City-Base, Texas and 311 HSW/EM Brooks City-Base, Texas. January.

Ritalahti, K.M., J. He, R. Krajmalnik-Brown, Y. Sung, F.E. Löffler, and S.S. Koenigsberg. 2003. Complete reductive dechlorination of chlorinated ethenes: Characterization of thekey players and implications for their specific detection and enumeration. Presentation at the Seventh International Symposium of In Situ and On-Site Bioremediation, Orlando, Florida, June 2-5.

Sen, P. 1968. Estimates of the Regression Coefficient Based on Kendall's Tau. Journal of American Statistical Association 67:1379-1389

USEPA. 1988a. Preamble to the 1988 Proposed NCP (National Oil and Hazardous Substances Pollution Contingency Plan; Proposed Rules). Federal Register. 53(245):51434

USEPA. 1988b. Guidance on Remedial Actions for Contaminated Ground Water at Superfund Site. OSWER Directive 9282.1-2. December.

USEPA. 1998a. Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater. EPA/600/R-98/128. Office of Research and Development. Washington, DC. September.

USEPA. 1998b. Monitoring and Assessment of in-situ Biocontainment of Petroleum Contaminated Ground-water Plumes. EPA/600/SR-98/020. National Exposure Research Laboratory, Research Triangle Park, North Carolina. July.

USEPA. 1999. Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. OSWER Directive 9200.4-17P (Final). April 21.

USEPA. 2001. Monitored Natural Attenuation: USEPA Research Program – An EPA Science Advisory Board Review. Review by the Environmental Engineering Committee (EEC) ofthe EPA Science Advisory Board (SAB), EPA-SAB-EEC-01-004. May.

Widdowson, M.A., F.H. Chapelle, J.T. Novak, and J.C. Parker. 2004. Integrated Protocol forAssessment of Long-Term Sustainability of Monitored Natural Attenuation of Chlorinated Solvent Plumes. SERDP Research Project CU-1349. (http://www.serdp.org/research/CU/CU-1349.pdf)

Wilson, J.T., C. Lebron, and P. Evans. 2003. Measurement of bioavailable iron at two hazardous waste sites (abstract). Presentation at the Seventh International Symposium of In Situ and On-Site Bioremediation, Orlando, Florida, June 2-5.

APPENDIX A

MATHEMATICAL DESCRIPTION OF METHODS FOR EVALUATING THE STABILITY OF CONTAMINANT PLUMES DISSOLVED IN GROUNDWATER

APPENDIX A

TABLE OF CONTENTS

Page

A.0 INTRODUCTION

This appendix provides a detailed description of both the methods and the steps used to implement the plume stability assessments presented in Section 4 of the report text. Section A.1 describes concentration-based analysis methods and Section A.2 describes mass-based analysis methods.

A.1 CONCENTRATION-BASED ANALYSIS METHODS

The objective of the concentration-based evaluations of dissolved chlorinated aliphatic hydrocarbon (CAH) plume stability was to evaluate advantages, disadvantages, and data input requirements for three statistical trend analysis methods. The three statistical methods implemented as part of the current study were the Mann-Kendall (MK) test for trends (Mann, 1945; Kendall, 1975; Gilbert, 1987), linear regression analysis, and Sen's Estimater of Slope (Sen, 1968; Gilbert, 1987) calculations to evaluate temporal trends in CAH concentrations. Descriptions of these methods are provided in Section A.1.2 and Section A.1.3.

The general approach for completing statistical trend analyses of CAH concentration data was a three-step procedure that consisted of 1) data preparation, 2) performance of statistical analyses, and 3) presentation of results. The steps within each of these procedures are outlined and described below.

A.1.1 Data Preparation

The following steps where use to compile and prepare data for review and analysis:

1. Data was gathered from various historical reports, including Parsons-generated reports, reports supplied by the individual bases covering the time period from the Parsons report until the present, Air Force Base site internet searches, and data provided by the USEPA Robert S. Kerr Laboratory located in Ada, Oklahoma.

2. A list was compiled summarizing volatile organic compound (VOC) data, sampling periods, and monitoring points available.

3. A chart was created depicting the VOC data available per well over all of the sampling events (See "Summary of Groundwater Sampling" tables in Section 4 for examples of these charts.) This chart was used to determine what wells at each site could be used in the statistical analyses.

4. A Microsoft® Excel database was compiled for each site including well name, coordinates (if available), constituents, sampling date, VOC analytical results, units, detection limits, and any flags assigned to the results. (See Appendix C for examples of these tables.) The structure of the Microsoft® Excel database was set-up to be easily imported into Monitoring and Remediation Optimization Software (MAROS).

5. Monitoring well position within the plume was determined based on historical and present isoconcentration contour maps. Wells were designated as "source", "plume", or "sentry" wells based on their horizontal and vertical location relative to the dissolved CAH plume(s) and the source area. The well designations are included on

"Summary of Groundwater Sampling" charts in Section 4. Use of these charts was helpful in selecting the wells to include in each type of data analysis.

A.1.2 Use of MAROS for Linear Regression and MK Test Analyses

MAROS estimates statistical trends for both linear regression analysis and MK test analyses from an imported database. The ***MK test*** (Mann, 1945; Kendall, 1975; Gilbert, 1987) is well-suited for environmental data because it can be used on small sample sizes (i.e., $n \geq 4$) and does not assume any underlying distribution for the data (i.e., it is nonparametric). The null hypothesis of this test is that no trend exists in the data. Hypothesis testing to assess the presence of a trend can only be performed for data sets consisting of four or more data points. The output of the MK test is the S statistic. Positive and negative S statistics are indicators of increasing and decreasing concentration trends, respectively. If desired, a statistical confidence can be assigned to MK test results (e.g., trichloroethene [TCE] concentrations are decreasing over time at well A, and there is a 95-percent confidence level associated with this conclusion). In summary, the MK test provides a quantitative method of determining whether chemical concentrations are decreasing or increasing with time.

To differentiate whether a trend finding from the S-statistic is statistically significant, MAROS uses a decision matrix based on the S-statistic, the confidence in the trend, and the coefficient of variation (COV). The confidence in trend is determined using a Kendall probability table. The COV is defined as the standard deviation of the sample set divided by the average of the sample set. Based on the results of calculating these three statistics, the concentration trend indicated by the S-statistic is determined to be increasing (I), probably increasing (PI), no trend (NT), stable (S), probably decreasing (PD), or decreasing (D) using the MAROS decision matrix presented in **Table A-1**. As indicated in Table A-1, trends indicated as 'I' or 'D' represent trends with greater than 95 percent confidence, trends indicated as 'PI' or 'PD' represent trends with between 90 and 95 percent confidence, and trends indicated as 'NT' or 'S' indicate less than 90 percent confidence in the S-statistic result. Note that a 95 percent confidence level corresponds to five percent chance of incorrectly accepting the null hypothesis (no trend is present) when a trend actually is present.

TABLE A-1

MANN-KENDALL ANALYSIS DECISION MATRIX USING MAROS

Mann-Kendall Statistic	Confidence in Trend	Statistical Trend
$S > 0$	> 95%	Increasing
$S > 0$	90 - 95%	Probably Increasing
$S > 0$	< 90%	No Trend
$S \leq 0$	< 90% and COV ≥ 1	No Trend
$S \leq 0$	< 90% and COV < 1	Stable
$S < 0$	90 - 95%	Probably Decreasing
$S < 0$	95%	Decreasing

Note: COV = coefficient of variation (standard deviation divided by the average)
Reference: AFCEE (2002).

Care should be taken in interpretation of "no trend" and "stable" statistical trends. In it's purest statistical form, being unable to reject the null hypothesis means that a trend cannot be ascertained. The MAROS decision logic extends this level of analysis to interpret a "stable" trend when $S \leq 0$ and $COV < 1$. It is important to remember that conclusions that involve "no trend" and even "stable" trends have inherently more uncertainty than do conclusions regarding increasing or decreasing trends. Generally, additional data collection and/or more rigorous statistical testing than that offered by MAROS should be performed if statistical evaluation of plume dynamics is being used as a key component of remedy assessment at sites where a significant portion of the statistical findings from MAROS are "no trend."

The statistical criteria used in MAROS and this study represent only one approach to trend analysis. Different or additional statistical criteria, such as confidence intervals, should be considered as part of the process for identifying increasing, decreasing, or stable trends from contaminant concentration data.

Linear regression analysis is a parametric statistical method that also is used by MAROS to identify trends in concentration over time. Unlike the non-parametric MK test, this approach assumes that the data are either normally or log-normally distributed about the mean of the data set. The objectives of linear regression analysis are 1) to find the trend in the data through the estimation of the log slope and 2) place confidence limits on the log slope of the trend. Positive and negative values of the log slope of concentration-versus-time data sets indicate increasing and decreasing constituent concentrations over time, respectively, and MAROS uses a similar decision matrix as described for Mann-Kendall analysis in Table A-1 to assign statistical significance to trends. Unlike the MK test, the results of linear regression analyses can be substantially affected by data outliers.

The coefficient of variation (COV) of residuals (i.e., the difference between the predicted value and the observed value) is a statistical measure of how the residuals vary about the mean value. Values near 1.00 indicate that the values form a relatively close group about the mean value, and that the linear regression statistics can be relied upon more strongly. Values either larger or smaller then 1.00 indicate that the data exhibit a greater degree of scatter about the mean, and therefore the MK analysis will tend to provide a more reliable quantitative evaluation of slope (AFCEE, 2002).

Prior to importing into MAROS, wells that do not have numerical data (e.g., dry wells were eliminated from the Microsoft® Excel database because MAROS does not have the ability to recognize and ignore dry well data. Also, estimated values (usually a reported using either a "J" or "F" data qualification flag) need to be denoted with a "TR" flag so that MAROS would treat these entries as a "trace" values in the software algorithms.

To import easily into MAROS, a specific Microsoft® Excel template must be followed, including specific naming conventions, fonts, and data type. MAROS comes with a template Microsoft® Excel file that has the guidelines for database format. If the template is not used, the data can be entered directly into MAROS, data point by data point.

After the database has been imported into MAROS, the user interface guides that the user through a five-step data analysis and reporting process. The first three steps are needed to complete the MK and linear regression analyses of concentrations and the Spatial Moment Analysis. The fourth step is an optional Sampling Optimization step. Note that the user can avoid going through the Statistical Trend Analysis portion of Step 3 by printing out the MK and linear regression result forms after completion of the statistical analysis of concentrations and then exiting the program.

In summary, the MAROS steps used in the current study were:

Step 1 – Data Management: MAROS allows the import of Microsoft® Excel, Microsoft® Access, ERPIMS Access, and ERPIMS text files. The databases in the current study were compiled in Microsoft® Excel.

Step 2 – Site Details: Input requirements included location, state, seepage velocity, main constituents, plume width, plume length, and the presence of groundwater fluctuation. Source information regarding free-phase NAPL presence and current source treatments were entered. Finally, downgradient information is entered included distance from the source to downgradient receptors and property lines and distance from the tail of the plume to downgradient receptors and property lines. All information for this section was determined using historical reports, primarily the Parsons-generated reports.

Step 3 – Plume Analysis: The four parts of Step 3 are Data Consolidation, Statistical Trend Analysis, Spatial Moment Analysis, and External Plume Information.

Step 5 – MAROS Output: Allows program results to be viewed and printed.

In the current study, the following options were selected when running MAROS:

Data Consolidation

Data Consolidation allows the user to group the data into discrete time periods or chose "Auto Event" which assigns each sampling date it's own event time. The "Auto Event" option was used on all of the studied sites.

Statistical Trend Analysis

A. *Source/Tail Zone Selection*. Each well in the database was designated as either a source well or tail well. This designation was made using the source, plume, or sentry well designations made during the preparation step. Plume and sentry wells were designated as tail wells.

B. *Data Reduction*. In this step, a specified time period can be chosen to analyze. For all sites other than Site FPTA-1, Brooks AFB, no data reduction was done. Time periods were specified for Site FPTA-2, Brooks AFB to assess the effects of the upgrade to the pump and treat system. At FPTA-2, six pump and treat wells were installed at two different times (July 1995 and January 1999) within the period of historical sampling data (June 1988 to June 2001). To account for the effects of the treatment system, the linear regression and MK analyses were completed in distinct time intervals to illustrate the time periods pre-installation of the treatment system (i.e., June 1988 to July 1995), between installations of recovery wells (i.e., July 1995 to January 1999, and post-installation of the complete system (i.e., January 1999 to June 2001). For some wells, the complete set of data was also analyzed to provide a comparison to results from the analysis of distinct time periods.

C. *Data Consolidation*. Data can be consolidated within the specified time period as quarterly, yearly, a specified interval, or no consolidation. No data consolidation was chosen for data in the current study.

D. *Non-detect Treatment*. The value to be modeled for non-detect results has to be determined at this step. Four mathematical choices are available: ½ the detection limit, detection limit, specified fraction of the detection limit, or a uniform detection limit specified per constituent. One-half of the detection limit was used for all of the studied sites.

E. *Duplicate Treatment*. In cases where duplicate measurements exist in site data, the user has three mathematical choices: average all values, use the maximum value, or use the first result. For the current study, the average all values option was selected. Note that this choice was unnecessary as all duplicates were removed from the original database prior to importing the database into MAROS.

F. *Trace Treatment*. The value to be modeled for trace, or estimated, results has to be determined at this step. Estimated results are generally indicated by "F" or "J" data qualifier flags in the historical reports. Before import into the MAROS database, the "F" and "J" flags were changed to TR to indicate a trace value to the model. Four mathematical choices are available: actual, ½ the detection limit, detection limit, specified fraction of the actual value. The actual trace value was specified for all of the studied sites. During the current study, the results of importing and consolidating the complete database for Facility 1381, Cape Canaveral AS was performed to confirm that the actual TR value was being assigned by MAROS. The results of this investigation suggest that the the current version of MAROS (version 2beta) assigns a value of the ½ the trace value even if "actual" is chosen.

Statistical Plume Analysis Results

This component of MAROS presents the results of the MK and linear regression analyses. Data plots are available for each monitoring well and constituent for both the MK and linear regression analyses. The individual plots can be printed at this point in the software. MK and linear regression summary tables for all of the wells and constituents are also available at this step and can be printed.

Note that on multiple occasions, proceeding to the Spatial Moment Analysis portion of the data algorithm caused MAROS to display an error and crash. (See Section A.2.2 for additional information) When MAROS crashed, it was impossible to get to the final MAROS output step where reports are available. Therefore, MK and linear regression plots and summary tables were printed at the end of Step 3, the Statistical Trend Analysis, and the program closed to avoid 'crashing' the user's computer.

Spatial Moment Analysis

This section does not contribute to the statistical analysis of the database and therefore is not essential if the statistical analysis results are printed at the end of step 3. However, the steps required to complete this part of the program are described here for completeness in the event that the end user wishes to use the MAROS Spatial Moment Analysis algorithm and/or the data summary report information (Step 5) in a future update of MAROS. The primary input requirements under Spatial Moment Analysis are hydrogeologic information and source area coordinates. This information can be readily be compiled from historical feasibility study reports and/or available survey information.

Results of Previous Analyses

MAROS also allows the user to enter plume assessment information previously determined by other models or empirical results. This option was not used in the current study. The final options in Step 3 allows the user to weight the importance (low to high) of the MK results, linear regression results, historical modeling, and empirical modeling. The weights for each of the studies sites were left as medium for MK and linear regression results and low for the historical modeling and empirical results.

MAROS Output

The final MAROS output step allows the user to produce a variety of summary reports as well as individual data plots for the MK and linear regression analyses. For each of the site studied, three reports were produced if the program allowed the user to get to the MAROS Output screen: COC Assessment Report, MK Statistical Report, and Linear Regression Statistical Report.

A.1.3 Sen's Slope

Sen's Method is a simple, non-parametric procedure developed by Sen (1968) and described by Gilbert (1987). If a linear trend is present, the true slope (concentration change per unit of time) of the time-series graph for a sampling location may be estimated using Sens' Method. Unlike the true slope obtained by computing the least-squares estimate of the slope by linear regression methods, Sen's method is not greatly affected by gross data errors or outliers, and the slope can be computed when data are missing. However, Sen's slope analysis results are most accurate when data are collected at a regular frequency (e.g., quarterly, semiannual, annual). If the data are not approximately equally spaced in time, then use of the resulting slope may lead to erroneous conclusions regarding temporal concentration trends and plume stability.

Sen's method is closely related to the MK test, and the resulting slope can be used to assess the relative magnitudes of temporal trends. Similar to the S statistic (discussed above for the MK test), positive and negative slopes indicate increasing and decreasing trends, respectively. The magnitude of the slope is an indicator of the rate at which dissolved contaminant concentrations are changing (e.g., a slope of -1,000 indicates more rapid decreases than a slope of -500).

Data Preparation

To complete the Sen's Slope test, the "Summary of Groundwater Sampling" charts described above were used to determine what sites had evenly-spaced data available. To perform Sen's slope analysis, the data must be evenly spaced and at least four data points must be available. Two sites were determined to have sufficient data, Site FPTA-2, Brooks AFB and LF-03, Columbus AFB. LF-03 has evenly spaced data available from November 1996 to November 2001 with sampling events occurring in the spring and autumn. Site FPTA-2 has evenly spaced data available from November 1994 to June 2001 with sampling events occurring in the winter and summer. At the Site FPTA-2, additional data was available that did not fit into the evenly spaced time periods (i.e., September 1996),and was therefore not used in the Sen's Slope analysis of the current study.

Calculations

The data was then entered into a modified Microsoft® Excel spreadsheet developed and described by Brauner (1997). The spreadsheet calculates the slope as a change in measurement per change in time and the median slope. If the median slope is negative, the trend is decreasing; if the slope is positive, the trend is increasing. To determine whether the median slope is statistically different from zero, a confidence interval is developed by 1) estimating the rank for the upper and lower confidence interval and 2) using the slopes corresponding to these ranks to define the actual confidence interval for the median slope. The median slope is considered statistically different from zero (for the selected confidence interval) if zero does not lie between the upper and lower confidence limits. A summary worksheet of the spreadsheet presents the median slope, trend, and whether or not the trend is statistically different from zero is provided as Tables C.6B (LF-03) and C9F (Site FPTA-2).

The spreadsheet was modified from the original form to run calculations for two confidence intervals: 90th percentile and 95th percentile. The two confidence intervals were used to differentiate definite trends from probable trends (e.g., differentiating 'decreasing' from 'probably decreasing' trends). The following rules were used to determine a probable trend from a definite trend for Sen's Method:

1. If the median slope was statistically different than zero for both the 90th and 95th confidence interval, the trend was considered definite ('increasing' [I] or 'decreasing' [D]);

2. If the median slope was statistically different than zero for the 90th confidence interval, but the same as zero for the 95th confidence interval, the trend was considered probable ('probably increasing' [PI] or 'probably decreasing' [PD]);

3. If the median slope was the same as zero for both the 90th and 95th confidence interval, the result was considered 'no trend' (NT).

An additional result of NC was reported at locations and/or analytes where Sen's method was not calculated. NC results were reported when all of data at a monitoring well was reported as non-detect (ND). In this case, a trend could not be calculated and NC is presented in the results summary table to differentiate this finding from NT.

Note that Sen's Method was completed in the same distinct time intervals described above for Site FPTA-2 to account for the effects of a groundwater treatment system installed within the plume during the complete monitoring period.

A.1.4 Data Presentation

The following is a list of tables and figures presented within the text and appendices to present the results of the MK, linear regression, and Sen's method analyses.

Tables

Summary of Groundwater Monitoring Well Sampling for VOCs tables are presented in Section 4 for each case study site. These tables present a summary of the monitoring wells and sampling events for all VOC data available to Parsons as of the writing of this report. Also included in this table are well completion dates, hydrological units, screen depth within the aquifer, well position within the plume, and whether or not the well was used in the statistical analysis.

MAROS Linear Regression Statistical Summary tables are presented for each site in Appendix C. These tables present the results of the linear regression analysis for each well and each constituent assessed. Appendix C also contains *MAROS Mann-Kendall Statistical Summary* tables that present the results of the MK analysis for each well and each constituent assessed. For LF-03, Columbus AFB and FPTA-2, Brooks AFB, *Sen's Slope Statistical Summary* tables are included in Appendix C for each well and each constituent assessed.

Figures

Figures depicting *Statistical Trend Analysis Results* are presented throughout Section 4 as a means of providing a spatial component to the tabular results presented in the Statistical Summary Tables described above and presented in Appendix C. Note that these figures have been placed on base maps that have the most recent available isoconcentration contours for the CAH compound shown. This method of presenting statistical results was particularly useful to the authors of the current study when developing the narrative assessment of what statistical results meant in terms of plume stability. Note that the *Statistical Trend Analysis Results* figure for FPTA-2, Brooks AFB presents only select wells. Because the statistical analyses were conducted at various time periods and multiple trend results were produced for each well, all of the well results could not be represented on a single figure. Therefore, the Brooks AFB FPTA-2 figure shows the isocontour map, concentration over time graphs, and statistical analysis results for select wells along the centerline of the plume. The results for the remainder of the wells are presented in graphs described below and presented in Appendix C under the heading "*Case Study Data for Site FPTA-2, Brooks Air Force Base, Texas*".

Graphs

As mentioned above, *CAH Concentrations over Time and MAROS Statistical Trend Results* were compiled only for Brooks AFB FPTA-2. This site was modeled in a series of time periods to illustrate the effect of a pump and treat system installed within the plume. The MK, linear regression, and Sen's method were run at several different time periods to model the effects of the groundwater treatment system. These figures were created to best illustrate the data available, the data periods modeled, and the results of the linear regression, MK, and Sen's method analyses.

A.2 MASS-BASED ANALYSIS METHODS

Calculation and reporting of temporal changes in the total mass and centroid location of dissolved contaminant plumes can be accomplished by using the method of moments to translate monitoring well concentration measurements to mass-based metrics. Section A.2.1 describes the method of moments approach for converting contaminant concentrations to dissolved contaminant plume mass and center of mass estimates. A preliminary step to applying the method of moments to environmental data is to allocate concentrations measured in a monitoring well to a representative volume of aquifer. Sections A.2.2 and A.2.3 describe two methods for allocating contaminant concentrations to representative aquifer volumes. Included in Sections A.2.2 and A.2.3 are the results of using each mass estimation method on theoretical test cases to 1) demonstrate that the algorithms are correctly coded and 2) illustrate that the approach and assumptions used to allocate contaminant concentrations to aquifer volumes can affect calculation results under some scenarios. Section A.2.4 presents a discussion of recommended approaches for using monitoring data collected as part of typical site investigation and LTM activities to assign numerical values to the parameters in the method of moments.

A.2.1 Method of Moments Analysis

The method of moments is one general approach for calculating the total mass and center of mass for dissolved contaminant plumes using monitoring well concentration data. The zeroeth order moment (M_{000}) corresponds to the total dissolved plume mass. Mathematically, M_{000} is applied to environmental monitoring data using:

$$Mass = M_{000} = \iiint_{x,y,z} \left[C(x,y,z) * \theta(x,y,z) \right] dxdydz \qquad \text{(Equation A-1)}$$

where: $C(x,y,z)$ = spatial distribution of contaminant concentration in groundwater [M/L^3];

$\theta(x,y,z)$ = spatial distribution of aquifer porosity in the saturated medium [L^3/L^3];

dx = distance in the longitudinal direction that an assigned concentration and porosity can be assumed to represent [L];

dy = distance in the lateral direction that an assigned concentration and porosity can be assumed to represent [L]; and

dz = distance in the vertical direction that an assigned concentration and porosity can be assumed to represent [L].

Similarly, environmental monitoring data can be substituted into the equation for calculating the first order moment to estimate the location of the center of mass for dissolved contaminant plumes. For example, the location of the center of contaminant plume mass in the longitudinal direction ($\bar{x}_c$) is the first order moment in the x-direction (M_{100}) divided by the total plume mass, given mathematically by:

$$\begin{matrix} Location\ of\ Center\ of\ Mass \\ (x - direction) \end{matrix} = \bar{x}_c = \frac{\iiint_{x,y,z} x * C(x,y,z) * \theta(x,y,z) dxdydz}{M_{000}} \qquad \text{(Equation A-2)}$$

where: x = is the longitudinal location of the concentration value [L].

The centroid of mass in the lateral ($\overline{y}_c$) and vertical ($\overline{z}_c$) directions can be calculated in an analogous manner to the way $\overline{x}_c$ is calculated in Equation A-2.

By the nature of the expressions used to express equations A-1 and A-2, knowledge of a continuous function that represents the exact change in concentration and porosity over space would be required to calculate an exact numerical value for the dissolved contaminant plume mass and associated centroid location. In reality, it is impossible to measure environmental data as a continuous function. The two ways to overcome this limitation are to 1) assume that the concentration measurement at each well can be used to represent the average concentration of an aquifer volume around that well or 2) use data interpolation methods to infer a continuous function for concentration distribution from discrete measurements in space. Mathematically, discrete concentration measurements can be used to estimate contaminant plume mass (M^*) and spatial coordinates of the centroid location (x_c, y_c) of the contaminant plume mass using Equations A-3, A-4, and A-5, respectively:

$$M_{000} \cong M^* = \sum_{\mathrm{i=1}}^{\text{all wells}} C_i * A_i * t_i * \theta_i * 2.83\text{x}10^{-5} \qquad \text{(Equation A-3)}$$

$$M_{100} \cong x_c = \frac{\sum_{\mathrm{i=1}}^{\text{all wells}} x_i * C_i * A_i * t_i * \theta_i * 2.83\text{x}10^{-5}}{M^*} \qquad \text{(Equation A-4)}$$

$$M_{010} \cong y_c = \frac{\sum_{\mathrm{i=1}}^{\text{all wells}} y_i * C_i * A_i * t_i * \theta_i * 2.83\text{x}10^{-5}}{M^*} \qquad \text{(Equation A-5)}$$

where: C_i = representative contaminant concentration for some volume of aquifer [µg/L];

A_i = lateral area assumed to be represented by C_i [ft^2];

t_i = average thickness of A_i [ft];

θ_i = average porosity of the aquifer in the volume represented by C_i [unitless];

x_i = coordinate of spatial centroid of the A_i in the x-direction [ft]; and

y_i = coordinate of spatial centroid of the A_i in the y-direction [ft].

The conversion factor (i.e., $2.83\text{x}10^{-5}$) shown in Equations A-3 through A-5 is used to estimate contaminant mass in kilograms (kg) using contaminant concentrations measured in µg/L and well spatial coordinates reported in feet.

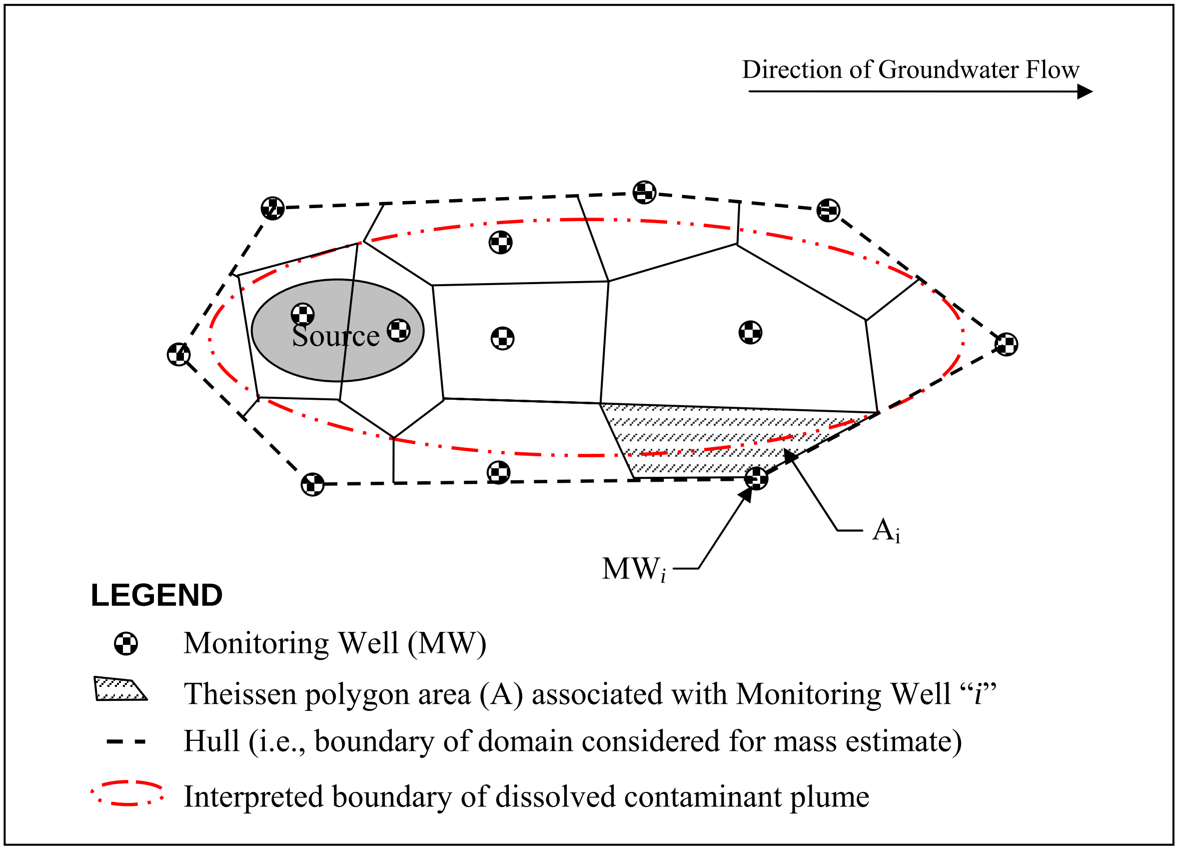
The two methods used in the current study for converting concentration data to dissolved mass and centroid locations using Equations A-3 through A-5 are discussed in Sections A.2.2 and A.2.3.

A.2.2 Theissen Polygon Method

The Theissen polygon method described in Chow *et al.* (1988), USEPA (1998), and AFCEE (2002) is one method for using groundwater contaminant concentration data to estimate dissolved contaminant plume mass metrics. **Figure A.1** depicts a schematic representation of the Theissen polygons associated with a hypothetical network of 13 monitoring wells. The specific steps used to apply the Theissen polygon method to environmental monitoring data include:

- Calculation of the Theissen polygon (A_i)area associated with each monitoring well for which contaminant concentration data are available;
- Assignment of an average aquifer porosity and depth for each Theissen polygon;
- Calculation of the dissolved plume mass (zeroeth order moment) using Equation A-3, where the Theissen polygon area for each monitoring well is substituted for Ai and the contaminant concentration measured at each monitoring well is substituted for *Ci*; and

FIGURE A.1
SCHEMATIC OF THE THEISSEN POLYGON APPROACH FOR ESTIMATING CONTAMINANT MASS USING DISCRETE MONITORING POINT CONCENTRATION DATA.



- Calculation of the spatial location of the dissolved center of mass (first order moment) using Equations A-4 and A-5, where the Theissen polygon area is substituted for Ai, the contaminant concentration measured at each monitoring well is substituted for C_i, and the spatial coordinates (eastings and northings) of the spatial centroid of each Theissen polygon are substituted for x_i and y_i, respectively.

For the current study, a geographic information system(GIS)-based algorithm was used to automate application of the Theissen polygon approach to the method of moments analysis for contaminant plume mass metrics. The data input required to support the Theissen polygon calculations are the monitoring well name, monitoring well coordinates, sampling date, contaminant name, contaminant concentration, data qualifier flag, and method detection limit (if one or more measurements were reported as below detection). When available, an electronic representation of site features that could be tied to real-world coordinates was used as a base map for illustrating the extent of the domain hull and changes in the spatial location of the dissolved contaminant plume center of mass. Information on options for selecting a hull for a given monitoring well network is provided in Section A.2.4.

The procedures described above for applying the method of moments using a Theissen polygon approach were implemented by applying the following steps:

- Application of an existing ArcView extension available from the ESRI website (http://arcscripts.esri.com/details.asp?dbid=10107) that was designed for creating Theissen polygons from user-specified coordinate data (i.e., monitoring well survey data) and a user-specified hull. A convex hull that encompasses the outermost points of the well network (see example shown in Figure A.1) is created by selecting the option of a “buffered point area” of zero while applying the Theissen polygon extension. This extension creates both a visual representation of the Theissen polygons and an associated attribute table that lists the area for each Theissen polygon and the percentage of the total hull area contributed by each well’s Theissen polygon area.
- Calculation of the contaminant mass contained within each Theissen polygon by substituting user-specified values for the contaminant concentration, porosity and thickness of each polygon, and the polygon area obtained from the ArcView script, into the right side of Equation A-3. The total contaminant mass was calculated subsequently by summing the mass estimates from each individual polygon. Equation A-3 was coded into a Microsoft® Excel spreadsheet, verified by hand calculations, and the verified spreadsheet used for all test cases and case study examples.
- Application of an existing ArcView extension available from the ESRI website (http://arcscripts.esri.com/details.asp?dbid=10185) to calculate the coordinates of the centroids of each Theissen polygon. The x and y locations of each Theissen polygon centroid were substituted for x_i and y_i in Equations A-4 and A-5 to calculate the location of the center of mass for the entire dissolved plume. Equations A-4 and A-5 were calculated using an ArcView script written for that purpose; these equations could also be calculated using a spreadsheet. Note that x_i and y_i are identical to the coordinates of the corresponding monitoring well only if none of the sides of the Theissen polygon for that well are part of the domain hull.

The Theissen polygon method employed in this study is designed to produce results that are identical to the method of moments analysis package that is included in the Monitoring and Remediation Optimization System (MAROS) software package (AFCEE, 2002). MAROS is a public domain, Microsoft® Access database application developed to assist users with groundwater data trend analysis and LTM optimization at contaminated groundwater sites (AFCEE, 2002). During an initial test of the algorithms produced by the method of moments package of MAROS, Parsons identified and documented the presence of calculation errors in the method of moments component of MAROS. Parsons has communicated the observed errors in the MAROS mass calculations to Groundwater Services, Inc. (GSI), the developer of MAROS, and AFCEE, the development sponsor for MAROS. GSI informed AFCEE and Parsons that these errors will be corrected, but that the updated version of MAROS will not be available until fall 2004 at the earliest. Based on this input from GSI, Parsons developed the ArcGIS-enabled Theissen polygon/method of moments analysis algorithm described above. It is recommended the MAROS users that intend to use the method of moments mass calculation component verify that they have the corrected version of MAROS prior to using the mass-based plume metrics algorithm for site data. As part of this verification process, users may wish to enter one or more of the test case scenarios described in Sections A.2.2 and A.2.3 to confirm the accuracy of MAROS method of moments results. Note that Parsons is unaware of any errors in the concentration-based analysis portion of the MAROS software.

Parsons developed multiple theoretical test cases to verify the accuracy of the procedure and associated ArcView scripts listed for performing method of moments calculations using the Theissen polygon method. The results of three hand calculations (performed using a Microsoft® Excel spreadsheet) are compared with ArcGIS results in **Figures A.2, A.3,** and **A.4**. For tests cases A and B (Figures A.2 and A.3, respectively), the theoretical monitoring well network was laid out on a grid pattern that resulted in rectangular Theissen polygons areas that were easy to calculate by hand and subsequently substitute into the method of moments formulae. As can be seen from these initial two test cases, the results of the GIS-enabled method of moments calculations using Theissen polygons were exactly equal to values produced by hand calculation. For test case C (Figure A.4), an irregularly-spaced theoretical monitoring well network with a non-symmetrical concentration distribution was constructed. The purpose of test case C was to verify that the simple geometry (i.e., rectangular polygons) and contaminant concentration distributions of the first two test cases did not hide calculation errors in the ArcView scripts. Prior to performing hand calculations of the method of moments for the irregular polygons of test case C, methods for determining the vertices, area, and spatial centroid location of the test case C Theissen polygons were needed. Briefly, the x and y coordinates of the vertices that defined the Theissen polygon for each well were calculated by using geometry to find the intersection of perpendicular bisectors of the connectors between a given well and it's nearest neighboring wells. **Figure A.5** provides a schematic representation of the process for identifying locations of "connectors" and "bisectors".) Next, the (x, y) coordinates of the Theissen polygon vertices were substituted into the "surveyor's formula". The "surveyor's formula calculates the area

Finally, the spatial location of the centroid for each Theissen polygons was calculated by partitioning each polygon into triangles and computing the weighted sum of the centroids for these triangles. (See http://www.saltspring.com/brochmann/math /centroid/centroid.html for a more detailed description of this method.) As can be observed from results presented in Figure A.4, there were very small differences (less than 0.1 percent) between the area, mass,

FIGURE A.2
TEST CASE A: METHOD OF MOMENTS CALCULATIONS USING THESISSEN POLYGONS

Input Data

Porosity, θ = 0.3 (Assumed uniform)
Contaminant Thickness, t = 1 ft (Assumed uniform)

Well Designation	Well Coordinates x (ft)	y (ft)	Contaminant Concentration C_i (µg/L)
MW-1	0	0	5000
MW-2	0	100	5000
MW-3	100	100	1000
MW-4	100	0	1000
MW-5	200	100	100
MW-6	200	0	100

Thiessen Polygon Information

Thiessen Polygon Name	Thiessen Polygon Area, A_i (ft2) Hand Calculated	GIS Calculated	Location of Spatial Centroid of Thiessen Polygon Hand Calculated x_i (ft)	y_i (ft)	GIS Calculated x_i (ft)	y_i (ft)
TP1	2500	2500	25	25	25	25
TP2	2500	2500	25	75	25	75
TP3	5000	5000	100	75	100	75
TP4	5000	5000	100	25	100	25
TP5	2500	2500	175	75	175	75
TP6	2500	2500	175	25	175	25
Total Area	**20,000**	**20,000**				

Method of Moments Calculations

Thiessen Polygon Name	Contaminant Mass Estimate M_i = Ci*Ai*t*θ (kg) Hand Calculated	Excel Calculated	Locating the Center of Mass for the Contaminant Plume Excel Calculated x_i*Mi (kg*ft)	y_i*Mi (kg*ft)	GIS Calculated x_i*Mi (kg*ft)	y_i*Mi (kg*ft)
TP1	106.2	106.2	2655	2655	2655	2655
TP2	106.2	106.2	2655	7965	2655	7965
TP3	42.48	42.48	4248	3186	4248	3186
TP4	42.48	42.48	4248	1062	4248	1062
TP5	2.124	2.124	371.7	159.3	371.7	159.3
TP6	2.124	2.124	371.7	53.1	371.7	53.1
	Total Mass	**Total Mass**	**Mass Centroid Locations**		**Mass Centroid Locations**	
	$M^* = \sum M_i$	$M^* = \sum M_i$	$x_c = \sum x_i{*}M_i/M^*$	$y_c = \sum y_i{*}M_i/M^*$	$x_c = \sum x_i{*}M_i/M^*$	$y_c = \sum y_i{*}M_i/M^*$
	301.6	**301.6**	**48.2**	**50**	**48.2**	**50**

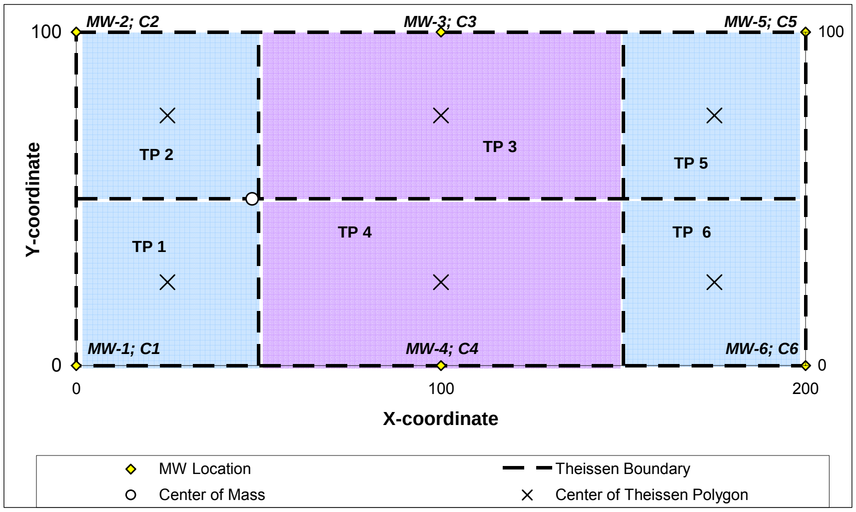


FIGURE A.3
TEST CASE B: METHOD OF MOMENTS CALCULATIONS USING THESISSEN POLYGONS

Input Data

Porosity, θ = 0.3 (Assumed uniform)
Contaminant Thickness, t = 1 ft (Assumed uniform)

Well Designation	Well Coordinates x (ft)	 y (ft)	Contaminant Concentration C_i (μg/L)
MW-1	0	0	2
MW-2	0	100	50
MW-3	100	100	1000
MW-4	100	0	250
MW-5	200	100	500
MW-6	200	0	100

Thiessen Polygon Information

Thiessen Polygon Name	Thiessen Polygon Area, A_i (ft2)		Location of Spatial Centroid of Thiessen Polygon			
			Hand Calculated		GIS Calculated	
	Hand Calculated	GIS Calculated	x_i (ft)	y_i (ft)	x_i (ft)	y_i (ft)
TP1	2500	2500	25	25	25	25
TP2	2500	2500	25	75	25	75
TP3	5000	5000	100	75	100	75
TP4	5000	5000	100	25	100	25
TP5	2500	2500	175	75	175	75
TP6	2500	2500	175	25	175	25
Total Area	**20,000**	**20,000**				

Method of Moments Calculations

Thiessen Polygon Name	Contaminant Mass Estimate M_i = Ci*Ai*t*θ (kg)		Locating the Center of Mass for the Contaminant Plume			
			Excel Calculated		GIS Calculated	
	Hand Calculated	Excel Calculated	x_i*Mi (kg*ft)	y_i*Mi (kg*ft)	x_i*Mi (kg*ft)	y_i*Mi (kg*ft)
TP1	0.04248	0.04248	1.062	1.062	1.062	1.062
TP2	1.062	1.062	26.55	79.65	26.55	79.65
TP3	42.48	42.48	4248	3186	4248	3186
TP4	10.62	10.62	1062	265.5	1062	265.5
TP5	10.62	10.62	1858.5	796.5	1858.5	796.5
TP6	2.124	2.124	371.7	53.1	371.7	53.1
	Total Mass	**Total Mass**	**Mass Centroid Locations**		**Mass Centroid Locations**	
	$M^* = \sum M_i$	$M^* = \sum M_i$	$x_c = \sum x_i{*}M_i/M^*$	$y_c = \sum y_i{*}M_i/M^*$	$x_c = \sum x_i{*}M_i/M^*$	$y_c = \sum y_i{*}M_i/M^*$
	66.9	**66.9**	**113.04**	**65.45**	**113.04**	**65.45**

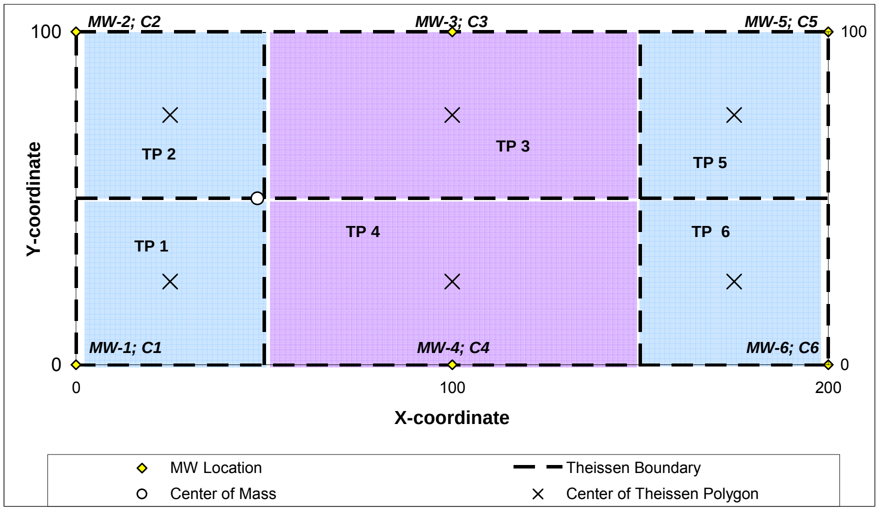


FIGURE A.4
TEST CASE C: METHOD OF MOMENTS CALCULATIONS USING THESISSEN POLYGONS

Input Data

Porosity, θ = 0.3 (Assumed uniform)
Contaminant Thickness, t = 1 ft (Assumed uniform)

Well Designation	Well Coordinates x (ft)	 y (ft)	Contaminant Concentration C_i (μg/L)
MW-1	0	0	2
MW-2	0	100	0.5
MW-3	100	100	950
MW-4	100	0	50
MW-5	200	100	650
MW-6	200	0	40
MW-7	50	150	750
MW-8	70	60	3500

Thiessen Polygon Information

Thiessen Polygon Name	Thiessen Polygon Area, A_i (ft2)		Location of Spatial Centroid of Thiessen Polygon			
			Excel Calculated		GIS Calculated	
	Excel Calculated	GIS Calculated	x_i (ft)	y_i (ft)	x_i (ft)	y_i (ft)
TP1	1898.1	1897.3	20.47	21.04	20.46	21.03
TP2	2228.1	2228.1	19.28	86.97	19.28	86.97
TP3	5295.6	5297.6	111.26	95.06	111.24	95.05
TP4	3593.8	3593.8	109.78	20.11	109.78	20.11
TP5	2917.5	2916.7	173.81	79.37	173.81	79.37
TP6	2500.0	2500.0	175.00	25.00	175	25
TP7	1554.2	1554.4	54.19	127.64	54.19	127.63
TP8	5013.3	5012.2	64.33	56.17	64.31	56.15
Total Area	**25,000.6**	**25,000.0**				

Method of Moments Calculations

Thiessen Polygon Name	Contaminant Mass Estimate M_i = Ci*Ai*t*θ (kg)		Locating the Center of Mass for the Contaminant Plume			
			Excel Calculated		GIS Calculated	
	Hand Calculated	Excel Calculated	x_i*Mi (kg*ft)	y_i*Mi (kg*ft)	x_i*Mi (kg*ft)	y_i*Mi (kg*ft)
TP1	0.03	0.03	0.66	0.68	0.66	0.68
TP2	0.01	0.01	0.18	0.82	0.18	0.82
TP3	42.74	42.76	4755.27	4062.87	4754.63	4062.63
TP4	1.53	1.53	167.60	30.70	167.59	30.70
TP5	16.11	16.11	2800.32	1278.84	2800.36	1278.78
TP6	0.85	0.85	148.68	21.24	148.68	21.24
TP7	9.90	9.90	536.64	1264.04	536.67	1263.98
TP8	149.08	149.04	9589.46	8373.93	9587.08	8370.62
	Total Mass	**Total Mass**	**Mass Centroid Locations**		**Mass Centroid Locations**	
	$M^* = \sum M_i$	$M^* = \sum M_i$	$x_c = \sum x_i{*}M_i/M^*$	$y_c = \sum y_i{*}M_i/M^*$	$x_c = \sum x_i{*}M_i/M^*$	$y_c = \sum y_i{*}M_i/M^*$
	220.3	**220.2**	**81.72**	**68.25**	**81.71**	**68.24**

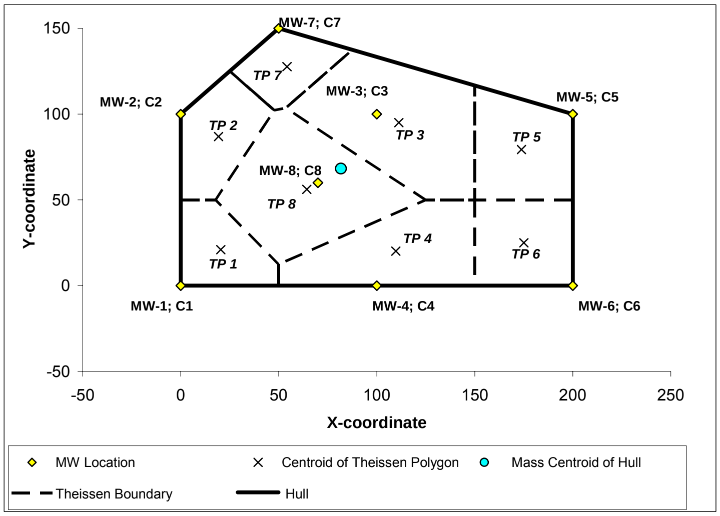
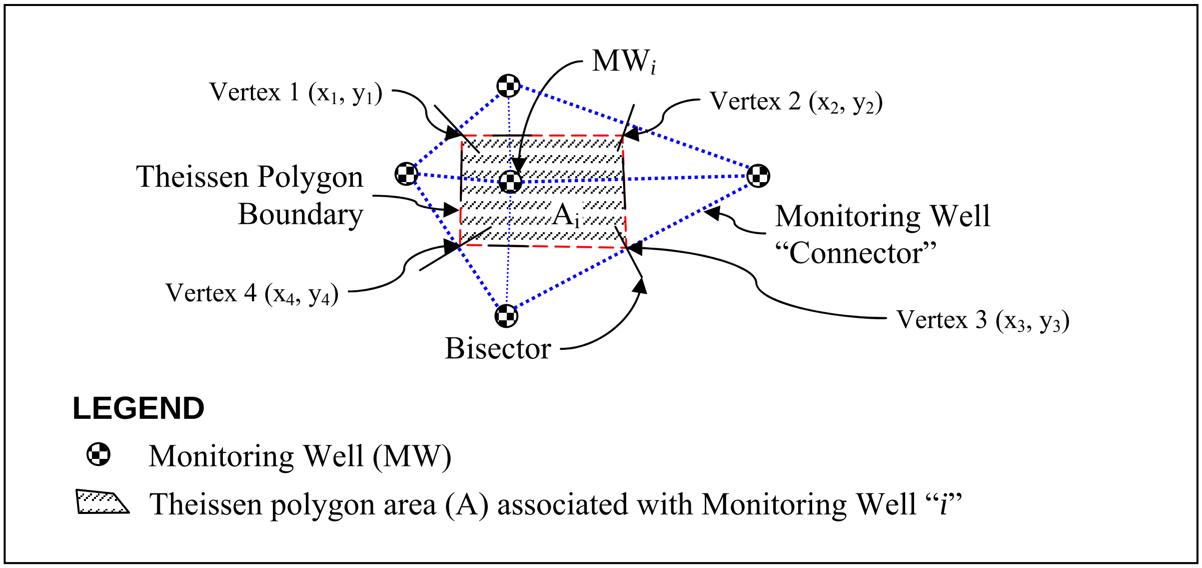


FIGURE A.5
SCHEMATIC OF APPROACH USED TO FIND VERTICES OF A THEISSEN POLYGON FOR AN IRREGULAR WELL SPACING.



and centroid location results of ArcView scripts and the results obtained from the complex hand calculations that were coded and calculated in Microsoft® Excel for test case C.

(A) of a polygon with 'n' vertices as follows:

$$A = \frac{1}{2}\left[\begin{vmatrix} x_1 & y_1 \\ x_2 & y_2 \end{vmatrix} + \begin{vmatrix} x_2 & y_2 \\ x_3 & y_3 \end{vmatrix} + \begin{vmatrix} x_3 & y_3 \\ x_4 & y_4 \end{vmatrix} + \cdots + \begin{vmatrix} x_n & y_n \\ x_1 & y_1 \end{vmatrix} \right] \qquad \text{(Equation A-6)}$$

where: $\begin{vmatrix} x_1 & y_1 \\ x_2 & y_2 \end{vmatrix}$ = Determinant (x_1, y_1, x_2, y_2) = ($x_1 * y_2 - x_2 * y_1$)

Based on the agreement of hand calculations with the GIS results for these three test cases, the ArcView scripts were judged to be correct and were subsequently applied to actual monitoring data in the case study examples described in Section 4.

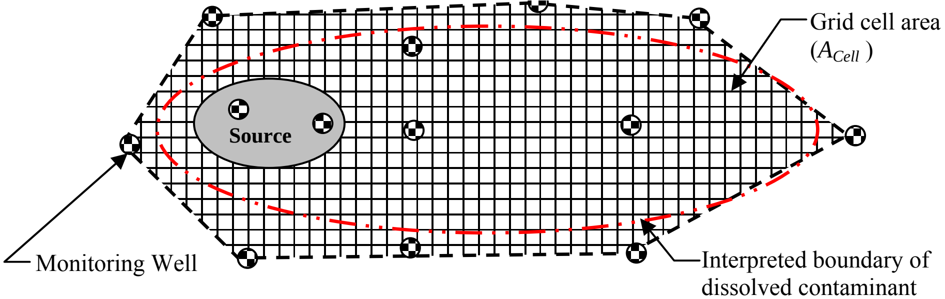
A.2.3 Triangular Irregular Network Method of Calculating Plume Metrics

Figure A.6 is a schematic representation of an approach for using data interpolation to convert monitoring wells contaminant concentrations into plume mass metrics. In the TIN method, a GIS-enable TIN algorithm is applied as the data interpolation method. The steps used to apply the TIN method to environmental data include:

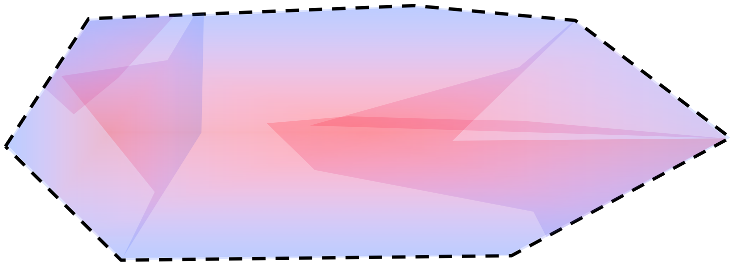
- Selection of monitoring wells to form a convex hull for available monitoring well data, and creation of a square grid of discretized cells that cover the convex hull;

FIGURE A.6
SCHEMATIC OF A KRIGING APPROACH FOR ESTIMATING CONTAMINANT MASS FROM DISCRETE MONITORING POINT CONCENTRATION DATA

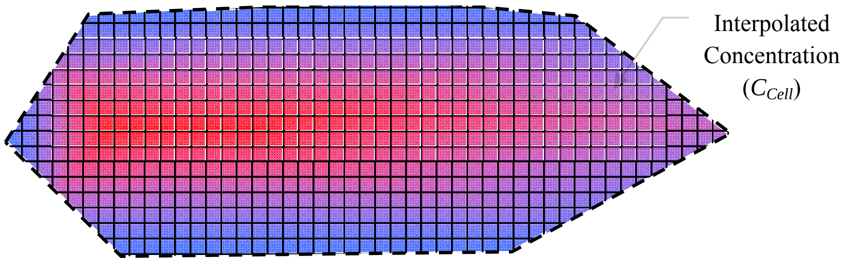
a) Grid overlay covering domain hull



b) Interpolated concentration distribution using kriging within domain hull



c) Grid overlay on concentration distribution



d) Calculate plume mass (M^*) and centroid location (x_c, y_c)

$$M^* = \sum^{All\ Cells} C_{Cell} * A_{Cell} * t_{Cell} * \theta_{Cell}$$

$$x_c = \frac{\sum_{i=1}^{\text{all wells}} x_i * C_i * A_i * t_i * \theta_i}{M^*}; \quad y_c = \frac{\sum_{i=1}^{\text{all wells}} y_i * C_i * A_i * t_i * \theta_i}{M^*}$$

where t_i = contaminated aquifer thickness of grid cell i; and
θ_I = porosity for grid cell i.

- Application of a TIN data interpolation algorithm that converts discrete contaminant concentration data from monitoring wells into a continuous spatial distribution of contaminant concentrations;

- Assignment of aquifer porosity and thickness for each grid cell;
- Calculation of the dissolved plume mass (zeroth order moment) using Equation A-3, where the grid cell area is substituted for A_i and the TIN-interpolated contaminant concentration at the spatial center of each grid cell is substituted for C_i;
- Calculation of the spatial location of the dissolved center of mass (first order moment) using Equations A-4 and A-5, where the grid area is substituted for A_i, the contaminant concentration assigned to each grid cell is substituted for C_i, and the spatial coordinates (eastings and northings) of the center of each grid cell are assigned to x_i and y_i.

The TIN data interpolation approach was selected for use in this study because this approach does not require the user to specify kriging input parameters, and therefore eliminates the use of subjective judgment for parameter selection. Note that the TIN approach described here is only one of many data interpolation approaches that could have been applied to contaminant concentration data. Note that kriging approaches to data interpolation often require the user to specify one or more input parameters prior to kriging application, and that these input parameters may be based on user judgment (i.e., a subjective approach), statistical interpretation (i.e., semi-variograms or other data interpretation approaches), or a combination of these approaches. Kanevski and Maignan (2004) is one of many resources that provide a summary of the advantages and limitations of applying various kriging algorithms to environmental data.

A GIS-based algorithm was used to implement the TIN approach to estimating contaminant plume mass metrics. The data input required to support the TIN calculations are the same as those required for the Theissen polygon method (See Section A.2.2). The procedures for applying the method of moments using a TIN approach were implemented using the following steps:

- The ArcView 3-D Geostatistical Analyst Statistical Software (ESRI, 2001) extension was applied to create a TIN from the monitoring well point concentrations;
- The Geostatistical Spatial Analyst extension was applied to convert the TIN to a grid for a user-defined grid spacing and extent. The extent was specified by the user as the convex hull of the available monitoring wells. Based on the results of a sensitivity analysis of variation in grid size, a 1-foot by 1-foot square grid was chosen as an appropriate grid spacing for the test cases and subsequent case study applications performed in this study. A description of the procedure for selecting an appropriate grid spacing is described in Section A.2.4;
- The total contaminant mass was calculated by summing the mass estimate for each grid cell across all of the grids in the area of interest using Equation A-3. In the current study, Equation A-3 was calculated using the “Map Calculator” and “Summarize Zones” features of the Geostatistical Spatial Analyst extension. This process was automated by development of a customized ArcView script; and
- Calculations for the center of dissolved contaminant mass were performed using a customized ArcView script. This ArcView script 1) determines the coordinates of the center points of each grid cell, 2) determines the interpolated contaminant concentration of at the center of each grid cell, 3) substitutes the grid cell center point coordinates into x_i and y_i of Equations 4 and 5, respectively, 4) substitutes the grid cell concentration for C_i, the grid cell area for A_i , the user-specified cell thickness for t_i,

and the user-specified porosity for θ_i into Equations 4 and 5, and 5) sums the results to calculate the location of the center of mass for the entire dissolved plume.

The TIN algorithm was applied to the three theoretical test cases described above, with the results compared with calculations for the Theissen polygon method to evaluate similarities and differences between methods of implementing method of moments calculations. **Figures A.7, A.8, and A.9** present the results of applying the Theissen polygon and TIN-based methods to test cases A, B and C, respectively. As can be observed from the data presented in Figure A-7, application of both methods to test case A yielded an equivalent estimation of total area, total mass, and the y-coordinate of the mass centroid. The difference in the estimated x-coordinate for the mass centroid was just over 11 percent for the two methods. For test case B (Figure A-8), the two methods yield area estimates that were equivalent, whereas the variability in results for dissolved mass and centroid location varied between 4 and 9 percent. For the irregularly shaped model domain hull of test case C (Figure A-9), dissolved estimate mass varied by 13 percent between methods, with less variation (i.e., between 4 and 5 percent) in the estimated center of mass calculations. As with other case studies, the area calculations were virtually identical between methods. Based on the results of these test cases, it is reasonable to expect that there may be up to a 15 percent variation in mass estimate and/or centroid location estimate due to a difference between methods

It is important to note that the aforementioned test case comparisons do not imply that one method is ‘correct’ and the other is ‘wrong.’ Rather, these results simply show that different concentration allocation methods result in different *estimates* for dissolved mass and centroid location. In cases where concentrations are distributed symmetrically (i.e., concentration and well distribution in the y-direction in Test Case A), the mass and center of mass algorithms of each method produce virtually identical results. However, non-symmetrical concentration distributions and well spacing can yield the different concentration distributions shown by method at the bottom of Figures A.7 through A.9. These differences in concentration distribution cause the observed differences in mass allocation and center of mass calculations described above.

This section presents a discussion of recommended approaches for using monitoring data collected as part of typical site investigation and LTM activities to assign numerical values to the parameters in method of moments. These recommendations were developed from the combined experience gained from the test case studies (described in Sections A.2.2 and A.2.3) and site applications to actual environmental monitoring data (described in Section 4.1).

A.2.4 Data Input Considerations

As described in Section 3.1.2, the first step in performing mass-based plume metrics is to choose a common well set of at least 8 wells. These eight wells should be distributed between the source area, dissolved plume, and plume edges and produce a model domain hull the covers the majority of the extent of the largest dissolved CAH plume. During initial stages of the current study, use of all available wells for a given monitoring event was compared with the results of using the common well data set approach. The results of this investigation indicated that using different sets of wells for each event introduced variations in dissolved plume estimates that varied over an order of magnitude or more. Importantly, use of different well sets for each event appear to ‘mask’ trend results that appeared to be ‘real’ when evaluating mass estimates using the common well set.

FIGURE A.7
TEST CASE A: COMPARISON OF THESISSEN POLYGON AND TIN METHODS

Input Data

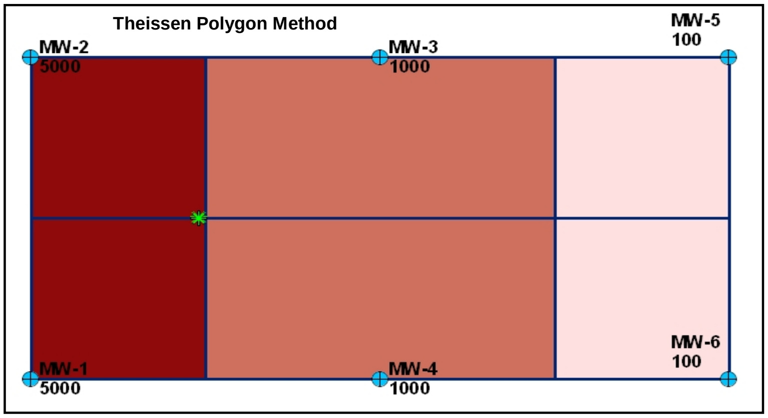
Porosity, θ = 0.3 (Assumed uniform)
Contaminant Thickness, t = 1 ft (Assumed uniform)

Well Designation	Well Coordinates x (ft)	Well Coordinates y (ft)	Contaminant Concentration C_i (µg/L)
MW-1	0	0	5000
MW-2	0	100	5000
MW-3	100	100	1000
MW-4	100	0	1000
MW-5	200	100	100
MW-6	200	0	100

Results

	Total Mass (kg)	Centroid x	Centroid y	Area (ft^2)
Theissen Polygon	301.6	48.2	50	20,000
TIN	301.6	53.99	50	20,000
Average % Diff.	*0.0%*	*11.3%*	*0.0%*	*0.0%*

Concentration Distribution



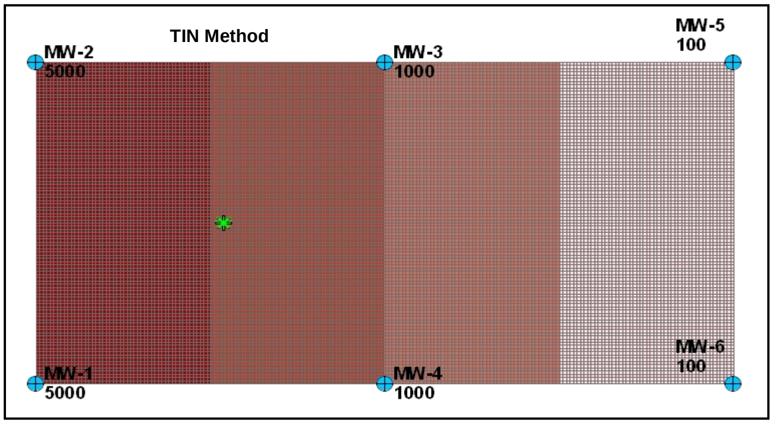


FIGURE A.8
TEST CASE B: COMPARISON OF THESISSEN POLYGON AND TIN METHODS

Input Data

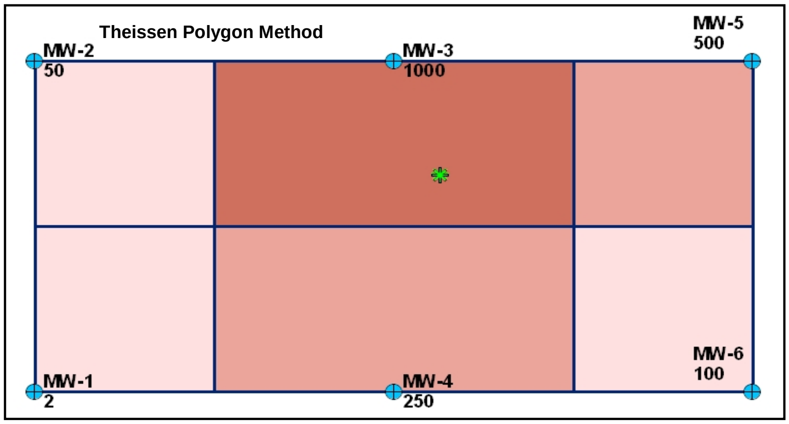
Porosity, θ = 0.3 (Assumed uniform)
Contaminant Thickness, t = 1 ft (Assumed uniform)

Well Designation	Well Coordinates x (ft)	 y (ft)	Contaminant Concentration C_i (μg/L)
MW-1	0	0	2
MW-2	0	100	50
MW-3	100	100	1000
MW-4	100	0	250
MW-5	200	100	500
MW-6	200	0	100

Results

	Total Mass (kg)	Centroid x	 y	Area (ft^2)
Theissen Polygon	66.95	113.04	65.45	20,000
TIN	69.4	105.81	59.93	20,000
Average % Diff.	*3.6%*	*6.6%*	*8.8%*	*0.0%*

Concentration Distribution



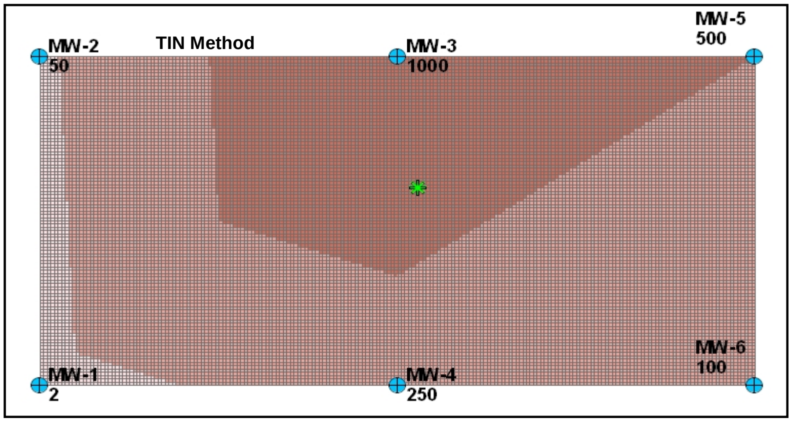


FIGURE A.9
TEST CASE C: COMPARISON OF THESISSEN POLYGON AND TIN METHODS

Input Data

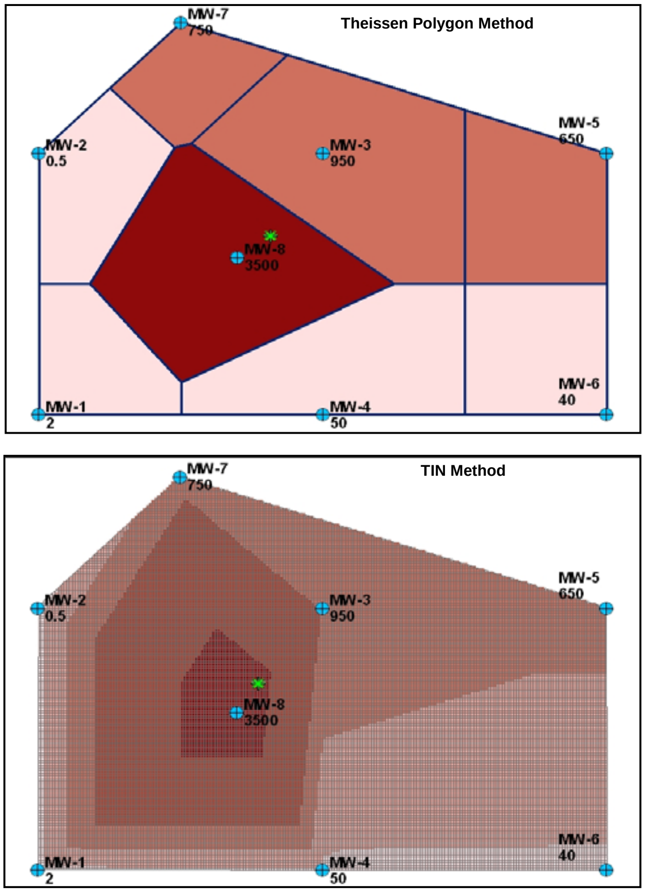
Porosity, θ = 0.3 (Assumed uniform)
Contaminant Thickness, t = 1 ft (Assumed uniform)

Well Designation	Well Coordinates x (ft)	 y (ft)	Contaminant Concentration C_i (μg/L)
MW-1	0	0	2
MW-2	0	100	0.5
MW-3	100	100	950
MW-4	100	0	50
MW-5	200	100	650
MW-6	200	0	40
MW-7	50	150	750
MW-8	70	60	3500

Results

	Total Mass (kg)	Centroid x	 y	Area (ft^2)
Theissen Polygon	220.23	81.7	68.24	25,000
TIN	193.6	77.59	71.27	25,050
Average % Diff.	*13%*	*5.2%*	*4.3%*	*0.2%*

Concentration Distribution



- Calculations of dissolved mass and center of mass using the common well set(s) described above should be reviewed to determine if one or two wells represent the majority of the total mass estimate for one or more constituents. If one or two wells are identified as controlling overall mass metric trends, future LTM plans should consider adding additional wells in higher concentration areas to reduce the dependence of results on measurements from one or two monitoring locations.
- In the current study, input values for aquifer porosity and aquifer thickness were assumed to be constant across the entire model domain hull. The rationale for the use of uniform values is that 1) all wells used in case study calculations were screened in the same hydrogeologic unit for each site and 2) measurements of changes in porosity and contaminated aquifer thickness were not readily apparent in available data. In cases where it is reasonable to assume uniform porosity and contaminated aquifer thickness, these values will affect the magnitude, but have no effect on the trends, observed from plotting estimate mass and center of mass locations over time.
- Note that there the data analyst does not need to make any decisions on data handling for the Theissen polygon method after the common well set, aquifer porosity, and aquifer thickness are selected. For the TIN method, the data analyst must choose a grid spacing prior to implementing the calculation algorithm described in Section A.2.3. In the current study, use of a 1-foot square grid was found to provide a reasonable balance between computer processing ability, time for data analysis, and desire to use small grid sizes to minimize the excess area included in this method along model domain edges. In the current study, the process used to confirm that a 1-foot square grid size was appropriate for available data sets was to repeatedly implement that TIN algorithm using larger (e.g., 2-foot, 5-foot, 100-foot) and smaller (e.g., 0.5-foot, 0.1 foot) square grids to calculate mass metrics. The results of these calculations were plotted on graphs of grid space versus mass estimate to observe at what point changes in the grid size had little or no effect (by percent change) on mass estimates.

A.3 REFERENCES

AFCEE. 2002. *Monitoring and Remediation Optimization System (MAROS): Software Version 2.0 User's Guide*. Brooks City-Base, Texas. (http://www.gsi-net.com/software/MAROS.htm)

Brauner, J.S. 1997. Nonparametric Estimation of Slope: Sen's Method in Environmental Pollution. In: *Environmental Sampling and Monitoring Primer* (D. Gallagher, Ed.). Virginia Tech, Blacksburg, VA. (http://ewr.cee.vt.edu/environmental/teach/smprimer/sen/sen.html)

Chow, V.T., D.R. Maidment, and L.W. Mays. 1988. *Applied Hydrology*. McGraw Hill Book Co., New York.

ESRI. 2001. *Geostatistical Analyst™ Statistical Software*. (http://www.esri.com/)

Gilbert, R.O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold Co., New York. 320pp.

Kendall, M.G. 1975. *Rank Correlation Methods. 4th Edition*. Charles Griffin, London.

Mann, H.B. 1945. Non-Parametric Tests against Trend. *Econometrica* 13:245-259

Kanevski, M. and. M. Maignan. 2004. *Analysis and Modeling of Spatial Environmental Data*. EPFL Press, Lausanne, Switzerland. 228pp.

Sen, P. 1968. Estimates of the Regression Coefficient Based on Kendall's Tau. *Journal of American Statistical Association* 67:1379-1389

USEPA. 1998. *Monitoring and Assessment of in-situ Biocontainment of Petroleum Contaminated Ground-water Plumes.* EPA/600/SR-98/020. National Exposure Research Laboratory, Research Triangle Park, North Carolina. July.

APPENDIX B

REVIEW OF CAH SOURCE DEPLETION PROCESSES
AND
SOURCE DECAY MODELS OFFERED IN SELECTED SOFTWARE PACKAGES

APPENDIX B

TABLE OF CONTENTS

Page

B.0 INTRODUCTION

This appendix provides a 1) description of the major physiochemical processes that control contaminant sources at CAH-impacted sites, 2) discussion of various methods of modeling CAH sources in groundwater fate and transport models, and 3) a summary of source simulation options currently offered in selected software.

B.1 DESCRIPTION OF PROCESSES CONTROLLING CONTAMINANT SOURCE DECAY AT CAH-IMPACTED SITES

The following two subsections provide a basic description of the two processes that control CAH release to groundwater at most sites: 1) DNAPL dissolution (Section B.1.1) and 2) desorption/diffusion from low permeability zones (Section B.1.2).

B.1.1 Primary CAH Contaminant Source: DNAPL Dissolution

The two primary morphologies for DNAPL in porous media are 1) immobile residual saturation (also variously referred to as DNAPL “ganglia” or “fingers”) and 2) mobile DNAPL (commonly referred to as DNAPL “pools”). DNAPL residual saturation is predominantly a vertical feature that consists of CAH droplets or ganglia that are caught in the aquifer matrix during downward migration following DNAPL release to the subsurface and subsequent penetration of the water table. This morphology is characterized by a high surface area between the DNAPL and mobile groundwater. The high surface areas of residual DNAPLs are conducive to a relatively high rate of DNAPL dissolution to groundwater. Mobile DNAPL is typically a horizontal feature that occurs when DNAPL has accumulated due to inhibition of vertical migration. Mobile DNAPL is generally encountered at the interface of a change in local stratigraphy. Mobile DNAPL tends to dissolve into groundwater at a slower rate than residual saturation features because mobile DNAPL 1) occupies a higher percentage of the pore space, leading to less groundwater migration through the DNAPL, and 2) has a much lower surface area between DNAPL and mobile groundwater for phase transfer to occur. Based on this information, mobile DNAPL, when present, is expected to last longer than residual saturation because mobile DNAPL is expected to 1) contain the majority of contaminant mass and 2) have a slower dissolution rate. In support of this statement, research by Anderson *et al.* (1992) and Johnson and Pankow (1992) suggests that diffusion from mobile DNAPL to mobile groundwater is the primary process limiting mass transfer, and therefore the primary long-term factor driving CAH-dissolution.

B.1.2 Secondary CAH Contaminant Sources: Diffusion/Sorption Zones

A secondary source of CAH dissolution into groundwater was described by Illangasekare *et al.* (2002) and Illangasekare and Sale (2004) when they refined the Anderson *et al.* (1992) and Johnson and Pankow (1992) models to include diffusion and sorption/desorption of dissolved-phase CAHs into and out of non-advective zones (e.g., clay layers). Specifically, these researchers found that the low permeability layers can be important secondary CAH source(s) because these zones can act initially as a contaminant “sink” (by accumulating CAH mass when concentrations are high), but subsequently as a CAH “source” (by releasing the accumulated CAH mass to more permeable zones when dissolved concentrations are lower). From a remediation timeframe perspective, these secondary sources have the potential to extend the duration of CAH release to groundwater because the relatively slow rate of CAH desorption and diffusive transport from low permeability zones may impact groundwater for a time period that is significantly longer than the groundwater impact from the relatively high rate of CAH release from DNAPL-impacted zones where advective transport dominates. Note that this secondary source of CAH contamination to groundwater is likely to have a similar effect on the remediation timeframe for both passive (i.e., MNA-based) and active (e.g., pump and treat, partial source removal/treatment) remedies because contaminant transport to groundwater will be controlled by diffusion and desorption, rather than by advection, under this condition.

B.2 MECHANISTIC MODELING OF CAH SOURCES

Common features shared by most mechanistic models of CAH sources are 1) conservation of mass, 2) an assumed model of the NAPL dissolution process, 3) an assumed model for sorption and desorption processes, and 4) assumptions on process kinetics. The following bullet list provides a brief discussion of each of these mechanistic model features:

- Conservation of Mass: Nearly all mechanistic models track the amount of mass in the NAPL phase and account for contaminant mass as it transfers to other phases (i.e., groundwater, soil, air). The mass conservation principle means that the mass of contaminant as NAPL will become depleted at some point in the future due to transfer to other phases.

- NAPL Dissolution: Chemical equilibrium between contaminant concentrations in the NAPL and the interfacing groundwater drives NAPL dissolution. For NAPLs that are composed of a single contaminant (e.g., pure TCE), the equilibrium concentration in the groundwater phase is the aqueous solubility of the contaminant. For NAPLs that are composed of several contaminants (e.g., multiple chlorinated solvents or a mixture of solvents and petroleum hydrocarbons), the equilibrium partition coefficient for each NAPL constituent can be derived from Raoult's Law:

$$K_{n/w} = \left(\overline{\upsilon}_n \frac{C^0_{i(w)}}{MW_i} \right)^{-1}$$

  where: $K_{n/w}$ = NAPL/water partition coefficient for contaminant *i*,

  $\overline{\upsilon}_n$ = average molar volume of NAPL,

  $C^0_{i(w)}$ = aqueous solubility of contaminant *i*, and

  MW_i = molecular weight of contaminant *i*.

  Note that the NAPL/water partition coefficient calculated by Raoult's Law is a function of the average molar volume of the NAPL. If the average molar volume of NAPL changes appreciably over time as more soluble components are depleted through dissolution, the partition coefficient changes. Not all programs account for this change; some always assume a constant NAPL/water partition coefficient.

- Sorption/Desorption: Chemical equilibrium behavior between aqueous and sorbed contaminant concentrations is most commonly described by isothermic relationships based on equivalent concentrations. Most models use isotherms that are singular (i.e., the same for sorption and desorption) and reversible (i.e., everything that sorbs can desorb), as is the case when retardation factors are used with contaminant transport. More complex models of sorption/desorption processes use nonlinear isotherms that can account field for observations of irreversible sorption (e.g., oxidative coupling reactions) or differences in the rate of sorption and desorption that depend on which phase direction contaminants are being driven. Additional information on modeling sorption is provided below.

- Kinetics: Source modeling in mechanistic models may use instantaneous reactions (i.e., no kinetic limitation on achieving equilibrium) or kinetic-limited phase transfer. In addition, a mechanistic model that simulates multiple phase-transfer processes may use an instantaneous reaction for one process (e.g., sorption) and kinetics-limited reactions for a different process (e.g., NAPL dissolution).

As described above and in Section 3.2 of the current study, the ability to accurately predict remediation timeframes may depend on models of the sorption and/or diffusion from low-permeability formations to high permeability zones after the NAPL has been depleted. Sorption is the process of a chemical associating with a solid surface (adsorption) or diffusing into the particle (absorption). Organic contaminants (including CAHs) transfer between the solid (particularly natural organic carbon) and aqueous phases. An effective result of sorption is that the transport of the contaminant is slowed or retarded relative to groundwater flow velocities. Sorption processes are driven by chemical equilibrium that may be rate-limited by mass transfer processes (usually diffusion).

The equilibrium behavior between the aqueous and sorbed concentration can be described using an isotherm. The most common methods for modeling sorption are linear equilibrium, nonlinear equilibrium, and using first-order kinetics. Linear isotherms are described by a linear equilibrium relationship between the sorbed and aqueous phase contaminant concentrations.

$$S\big|_{equilibrium} = K_d C \quad or \quad S\big|_{equilibrium} = K_p C$$

where: S = Sorbed concentration,

C = Aqueous concentration,

K_d = Distribution coefficient, and

K_p = Partition coefficient.

The partition coefficient assumes that the sorption process is partitioning, which is a reasonable assumption for CAHs. The distribution coefficient does not presume a sorption process. In the case of a CAH exhibiting a linear isotherm, these two coefficients are functionally equivalent. For CAHs, values for K_p can be reliably estimated from a contaminant's organic carbon partition coefficient (K_{oc}) and the fraction of organic carbon (f_{oc}) of the porous media. Note that K_{oc} can be estimated from the octanol-water partition coefficient (K_{ow}).

Nonlinear isotherms are most commonly modeled by either the Freundlich or Langmuir isotherms. Langmuir isotherms assume a finite capacity for the sorbing chemical, and are therefore not appropriate for CAH sorption. Freundlich isotherms are defined by the equation:

$$S\Big|_{equilibrium} = K_F C^n$$

where: K_F = Freundlich coefficient, and

n = nonlinear coefficient (usually < 1 for CAH contaminants).

Research by Huang *et al.* (1997) and others demonstrates that isotherms for organic chemicals tend to linear only if isotherms are calculated for a limited range of concentrations or experiments are conducted for short times. Field sorption behavior of CAHs is expected to be nonlinear. However, because site-specific isotherms are rarely established, linear isotherms based on K_{ow} and f_{oc} are usually the only approaches available.

Retardation factors that assume linear, instantaneous, and reversible phase transfer between groundwater and soil have been shown to work well for contaminants in portions of porous media dominated by advection. Retardation factors can be calculated using:

$$R = 1 + \frac{\rho_b K_d}{\theta_w} \quad or \quad 1 + \frac{\rho_b K_p}{\theta_w} \quad or \quad 1 + \frac{\rho_b K_F C^{n-1}}{\theta_w}$$

where: R = retardation factor,

ρ_b = solids bulk density, and

θ_w = water content of porous media.

Researchers have also developed a number of sophisticated models for grain-scale sorption kinetics that include retarded inter-particle diffusion and multi-site first-order models. Contaminant transport codes rarely incorporate sorption kinetics, and when they do, it is generally limited to simple first-order models:

$$\frac{dS}{dt} = k_2 (K_d C - S)$$

where: k_2 = mass transfer rate coefficient (desorption rate coefficient).

Grain-scale equilibrium is believed to occur on the order of days or weeks. For field-scale simulations on time scales of years or decades, grain scale sorption mass transfer is not likely to be a significant issue.

Sorption is conceptualized to be an important secondary source of contamination when it is associated with non-advective zones (e.g., clay layers). While the application of retardation factors described above works well for contaminants in portions of porous media dominated by advection, a key process often ignored by modelers is diffusion or diffusion and sorption into low-permeability strata (e.g., clay layers). Specifically, macro-scale mass-transfer between advective and non-advective zones is likely to be the cause of secondary contaminant sources and “rebound.” While mass transfer limitations exist and incorporating mass transfer between advective and non-advective zones into models gives the potential for greater accuracy, choosing an appropriate value for the mass transfer rate coefficient is difficult because the mass transfer process depends on the scale of the model. In addition, modeling diffusion and sorption processes in low-permeability layers is problematic because the numerical methods used to simulate advection-dominated contaminant transport produce numerical errors when applied to contaminant transport in diffusion-dominated zones. Although extensive research is underway in this area by various researchers, the authors of this study are unaware of any publicly-available models that currently offer a suitable method of mechanistically modeling diffusion and sorption processes in low-permeability formations.

B.3 SUMMARY OF CAH SOURCE MODELS AVAILABLE IN CURRENT SOFTWARE PACKAGES

The source modeling approaches offered in ten software programs that are appropriate for modeling CAH fate and transport were reviewed as part of the current study. **Table B.1** provides a list of the programs considered and selected for further review. Eight of the selected software programs were identified from the list of modeling programs that are available as freeware from either the AFCEE technology transfer website (http://www.afcee.brooks.af.mil/products/techtrans/models.asp) or the USEPA Groundwater and Ecosystems Restoration Research website (http://www.epa.gov/ada/csmos/models.html). Source modeling approaches offered in two additional groundwater fate and transport models, RT3D (Clement *et al.*, 1998) and SEAM3D (Waddill and Widdowson, 1997), were included in this review because these two programs 1) offer options for simulating CAH sources that are not offered by the other eight packages and 2) are available free-of-charge to DoD, DOE, and USEPA personnel as optional components of the United States Army Engineering Research and Development Center's Groundwater Modeling System (GMS) package (http://chl.erdc.usace.army.mil/).

Mechanistic modeling of CAH sources is available as part of fate and transport modeling in nine of the ten software packages of reviewed in the current study. The tenth software package, SourceDK (AFCEE, 2004), is different from the other packages in that SourceDK was specifically designed for interpreting dissolved contaminant concentrations in the source area, and does explicitly simulate contaminant fate and transport in groundwater. A brief description of the modeling options for these software packages is provided in Table B.1.

Four of the nine software fate and transport packages have built-in capabilities for explicitly simulating DNAPL as a CAH source. The four packages are MOFAT (Imhoff *et al.*, 1992), NAPL Simulator (UESPA, 1997a), SEAM3D (Waddill and Widdowson, 1997), and UTCHEM (Clement *et al.*, 1998). While all four of these software packages use conservation of mass as the basic principle for tracking NAPL mass, the method of for simulating the rate of NAPL dissolution varies by code. NAPL Simulator uses rate-limited first-order transfer kinetics to simulate dissolution of a single NAPL component. UTCHEM can be used to simulate dissolution of a multiple NAPL components using either linear or first-order mass transfer kinetics. SEAM3D can also be used to simulate dissolution of multiple NAPL components with the added benefit that the partition coefficient can change over time with changes in NAPL composition. SEAM3D only offers first-order kinetics for simulating the rate of NAPL dissolution. MOFAT offers the most complex array of NAPL source options by explicitly simulating transfer of multiple constituents between four different phases: NAPL, vapor (air), aqueous, and sorbed. It is important to recognize that an increase in the complexity of NAPL dissolution model options corresponds to an increase in the number of input parameters that must be measured or estimated. If attempting to explicitly simulating DNAPL dissolution of CAHs at a particular site, it is important to consider how

TABLE B.1
GROUNDWATER FATE AND TRANSPORT MODELS AVAILABLE FOR DOWNLODAD ON AFCEE AND US EPA WEBSITES
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Model	Description	Further Considered
2DFATMIC [a/]	2D subsurface flow, fate and transport of microbes and chemicals.	Yes
3DFATMIC [a/]	3D subsurface flow, fate and transport of microbes and chemicals.	Yes
BIOCHLOR [a/, b/]	Simulates remediation by natural attenuation of dissolved solutes at chlorinated solvent release sites. Simulates transport without decay and solute transport with biodegradation modeled as a sequential 1st order process within 1 or 2 reaction zones.	Yes
BIOPLUME II [a/]	Specific to fuel hydrocarbons (BTEX).	No
BIOPLUME III [a/]	Specific to fuel hydrocarbons (BTEX).	No
BIOSCREEN [a/, b/]	Specific to fuel hydrocarbons (BTEX).	No
CHEMFLO-2000 [a/]	1D for chemical movement.	No
CZAEM [a/]	Well-head protection model.	No
GEOEAS [a/]	Statistics package.	No
GEOPACK [a/]	Statistics package.	No
HSSM [a/]	Hydrocarbon Spill Screening Model for use with LNAPLS only.	No
MODFLOW [a/]	Groundwater flow package.	No
MOFAT [a/]	2D model for groundwater, NAPL, and gas.	Yes
MT3D [a/]	3D contaminant transport in the saturated zone.	Yes
NAPL Simulator [a/]	3D, 3-phase simulator for NAPLs in near surface granular soils.	Yes
OWL [a/]	Evaluates existing well networks.	No
PESTAN [a/]	Specific to pesticides.	No
RETC [a/]	Estimates soil-water retention curves, hydraulic conductivity, or soil model parameters.	No
RITZ [a/]	Specific to oily wastes.	No
RT3D [c/]	3D contaminant transport in the saturated zone.	Yes
SEAM3D [c/]	3D solute transport coupled with sequential electron acceptor-based biological reactions.	Yes
Source DK [b/]	Specific to fuel hydrocarbons (BTEX and naphthalene). [d/]	Yes
STF [a/]	Database on soil parameters.	No
UTCHEM [a/]	3D model, general purpose NAPL simulator.	Yes
Virulo [a/]	Probabilistic model for predicting leaching of viruses in unsaturated soils.	No
VLEACH [a/]	1D water and chemical movement in vadose zone.	No
WhAEM 2000 [a/]	Delineates capture zones and isochrones of groundwater residence time for "wellhead protection".	No
WHPA [a/]	Simulates capture zones for pumping wells.	No

[a/] Model available from USEPA CSMoS website. (http://www.epa.gov/ada/csmos/models.html)

[b/] Available from the AFCEE Technology Transfer website. (http://www.afcee.brooks.af.mil/products/techtrans/models.asp)

[c/] Available from the GMS portion of the US Army Engineering Research and Development Center website. (http://chl.erdc.usace.army.mil/)

[d/] SourceDK model input can be modified for application to CAH compounds.

reliably various site-specific input parameters can be estimated as part of overall model selection process.

All nine of the fate and transport packages offer an ability to simulate desorption as a CAH source. Five of the nine fate and transport software packages model sorption as a linear equilibrium process. These five packages are 2DFATMIC (USEPA, 1997b), 3DFATMIC (USEPA, 1997c), BIOCHLOR (USEPA, 2000; AFCEE, 2002), NAPL Simulator, and UTCHEM. In the modeling codes based on MT3D (i.e., MT3D96, MT3DMS, RT3D, and

SEAM3D), the user has the option of three types of sorption isotherms: linear, Freundlich, and Langmuir. MOFAT and RT3D offer a first-order, rate limited mass sorption algorithm. Note that the first-order sorption mass-transfer option offered in RT3D and MOFAT is not well-suited for simulating desorption/diffusion of CAHs from low permeability layers because first-order mass transfer processes cannot adequately simulate long-term tailing that is observed by diffusion-dominated process.

In addition to general solute transport models, there is at least one specific model application involving similar implicit approaches to simulate NAPL dissolution by defining boundary conditions. BIOCHLOR is a modeling tool designed to evaluate natural attenuation of chlorinated solvents. BIOCHLOR defines the NAPL source as an area of specified length and width, and further specifies a constant contaminant concentration in groundwater in this source zone. The constant concentration boundary remains constant for the simulation. BIOCHLOR offers the advantage of only requiring minimal data input (i.e., existing concentration data and a minimal number of curve-fitting parameters) and does not require mass estimate at any point in time. It is important to note, however, that the best-fit curve-fitting parameters in BIOCHLOR do not simulate any specific phenomenon. Because the BIOCHLOR curve-fitting parameters do not simulate specific phenomena, there is significant uncertainty when (if) the current best-fit parameters for existing data will change in the future, particularly there is a change in the dominant phenomena contributing to the CAH source,. For example, the best-fit model for DNAPL dissolution may be different from the best-fit model for diffusion/desorption from a low-permeability layer.

SourceDK is a simple, empirical spreadsheet approach to estimating time until NAPL sources are depleted and dissolved contaminants in groundwater meet regulatory clean-up levels. This planning model was developed for LNAPLs (fuels), but can be manipulated to model CAH contamination. SourceDK has three levels of analysis. Tier 1 is extrapolation of groundwater contaminant concentrations in the source zone, and assumes that concentrations will decrease according to an exponential function. Section 3.2.2.2 of the current study provides additional discussion of empirical models of CAH sources. Tier 2 analysis treats the source zone as a mixed reactor. Tier 2 calculations require input of groundwater flow through the source zone, the volume of the source zone, the total mass of contaminant, and the initial concentration of contaminant in groundwater at the source zone. Biological decay rates can also be incorporated into Tier 2 calculations. The Tier 2 approach also results in exponentially decaying source concentrations. Tier 3 calculations are based on one-dimensional flow through a column containing NAPL residual saturation. While the configuration of the Tier 3 model is appropriate for estimates of CAH sources from residual DNAPL, Tier 3 calculations should not be used when the CAH source is mobile DNAPL.

B.4 REFERENCES

AFCEE. 2002. *BIOCHLOR Natural Attenuation Decision Support System Version 2.2. User's Manual Addendum.* Prepared for AFCEE Technology Transfer Division, Brooks City-Base, Texas. March

AFCEE. 2004. *Sourcedk: Remediation Timeframe Decision Support System. Version 1.0.* AFCEE Technology Transfer Division, Brooks City-Base, Texas. (http://www.gsi-net.com/Software/SourceDK.htm)

Anderson, M.R., R.L. Johnson, and J.F. Pankow. 1992. Dissolution of dense chlorinated solvents into groundwater: 3. Modeling contaminant plumes from fingers and pools of solvents. *Environmental Science and Technology* 26(5):901-908

Clement, T.P., Y. Sun, B.S. Hooker, and J.N. Petersen. 1998. Modeling multispecies reactive transport in groundwater. *Groundwater Monitoring and Review* 18(2):79-92

Huang, W., T.M. Young, M.A. Schlautman, H. Yu., and W.J. Weber, Jr. 1997. A distributed reactivity model for sorption by soils and sediments. 9. General isotherm nonlinearity and applicability of the dual reactive domain model. *Environmental Science and Technology* 31(6):1703-1710

Illangasekare, T.H., S. Saenton, D. Dai, and Q. Moore. 2002. Modeling for determination of pre- and post- remediation prediction of dissolved contaminant concentration downstream of NAPL. In: *Development in Water Science*, 47 Volume 1 (S.M. Hassanizadeh, R.J. Schotting, W.G. Gray and G.F. Pinder, Eds.) Elsevier Science and Technology, San Diego, CA. p. 843-850

Illangasekare, T.H. and T. Sale. 2004. *Technical Protocol for Evaluating Effects of Source Zone Remediation on Groundwater Quality and Source Longevity*. Center for Experimental Study of Subsurface Environmental Processes, Colorado School of Mines. (http://cesep.mines.edu/projects/AFCEE.htm)

Imhoff, P.T., P.R. Jaffe, and G.F. Pinder. 1992. An experimental study of the dissolution of trichloroethene in saturated porous media. *Princeton University Water Resources Program Report: WR-92-1.*

Johnson, R.L., and J.F. Pankow.1992. Dissolution of dense chlorinated solvents into groundwater: 2. Source functions for pools of solvent. *Environmental Science and Technology* 26(5):896-901

USEPA. 1997a. *NAPL: Simulator Documentation.* National Risk Management Research Laboratory, Ada, Oklahoma. EPA/600/R-97/102. October. (http://www.epa.gov/ada/csmos/models/napl.html)

USEPA. 1997b. *Three-Dimensional Subsurface Flow, Fate and Transport of Microbes and Chemicals Model. User's Manual Version 1.0.* Office of Research and Development, Washington, DC. EPA/600/R-97/052. August. (http://www.epa.gov/ada/csmos/models/2dfatmic.html)

USEPA. 1997c. *Three-Dimensional Subsurface Flow, Fate and Transport of Microbes and Chemicals Model. User's Manual Version 1.0.* Office of Research and Development, Washington, DC. EPA/600/R-97/053. August. (http://www.epa.gov/ada/csmos/models/3dfatmic.html)

USEPA. 2000. *BIOCHLOR Natural Attenuation Decision Support System User's Manual Version 1.0.* Office of Research and Development, Washington, DC. EPA/600/R-00/008. January. (http://www.epa.gov/ada/csmos/models/biochlor.html)

Waddill, D.W. and M.A. Widdowson. 1998. Three-dimensional model for subsurface transport and biodegradation. *ASCE Journal of Environmental Engineering* 124(4):336-344

APPENDIX C

CASE STUDY DATA AND STATISTICAL ANALYSIS RESULTS

APPENDIX C

TABLE OF CONTENTS

Case Study Data for Site FTA-2, Tinker Air Force Base, Oklahoma

Case Study Data for LF-06, Columbus Air Force Base, Mississippi

Case Study Data for Northwest Plume, SS-45, England Air Force Base, Louisiana

Case Study Data for Southeast Plume, SS-45, England Air Force Base, Louisiana

Case Study Data for Facility 1381, Cape Canaveral Air Station, Florida

Case Study Data for Site FPTA-2, Brooks Air Force Base, Texas

Case Study Data for Site FTA-2, Tinker Air Force Base, Oklahoma

TABLE C.1A
MAROS LINEAR REGRESSION STATISTICS SUMMARY
SITE FTA-2, TINKER AFB, OKLAHOMA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Average Conc (mg/L) [a/]	Median Conc (mg/L)	Standard Deviation	All Samples ND? [b/]	LN Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend [c/]	Designation for Current Analysis
Teterachloroethene (PCE)										
2-62B	S	2.4E-02	4.9E-03	5.0E-02	No	2.3E-03	2.10	88.9%	NT	Source
2-63B	S	1.6E-03	1.4E-03	1.8E-03	No	1.9E-03	1.15	92.0%	PI	Source
2-64B	S	2.5E-03	6.5E-04	4.9E-03	No	1.8E-03	1.95	88.6%	NT	Source
2-272B	T	3.3E-04	2.0E-04	4.2E-04	No	1.0E-03	1.29	67.3%	NT	Plume
2-65B	T	5.4E-02	4.4E-02	5.9E-02	No	4.9E-03	1.09	96.5%	I	Plume
2-274B	T	1.6E-04	3.5E-05	2.7E-04	No	1.4E-03	1.69	79.0%	NT	Plume
Trichloroethene (TCE)										
2-62B	S	7.8E+00	8.7E+00	2.1E+00	No	3.4E-05	0.27	58.8%	NT	Source
2-63B	S	1.7E-01	5.0E-02	3.0E-01	No	9.9E-04	1.78	98.3%	I	Source
2-64B	S	9.3E-01	6.9E-01	8.6E-01	No	1.1E-03	0.93	99.2%	I	Source
2-272B	T	3.9E-01	2.4E-01	5.0E-01	No	2.3E-03	1.27	96.6%	I	Plume
2-65B	T	1.1E-01	9.0E-02	7.9E-02	No	4.7E-04	0.70	85.0%	NT	Plume
2-274B	T	5.8E-01	5.6E-01	2.8E-01	No	3.4E-04	0.48	79.2%	NT	Plume
cis-1,2-Dichloroethene (cis-1,2-DCE)										
2-62B	S	1.1E+00	1.0E+00	3.1E-01	No	-1.7E-04	0.29	90.2%	PD	Source
2-63B	S	1.3E-01	1.4E-01	6.7E-02	No	4.5E-04	0.52	95.3%	I	Source
2-64B	S	1.7E-01	1.7E-01	1.2E-01	No	7.4E-04	0.71	97.7%	I	Source
2-272B	T	3.8E-01	1.9E-02	5.3E-02	No	2.5E-03	1.40	97.4%	I	Plume
2-65B	T	5.1E-02	3.3E-02	5.4E-02	No	9.8E-04	1.70	95.5%	I	Plume
2-274B	T	6.5E-02	5.8E-02	2.4E-02	No	1.8E-04	0.36	74.3%	NT	Plume
Vinyl Chloride (VC)										
2-62B	S	1.4E-03	1.0E-03	7.7E-04	No	3.2E-04	0.54	96.6%	I	Source
2-63B	S	3.6E-03	4.3E-03	3.0E-03	No	2.5E-03	0.83	95.0%	I	Source
2-64B	S	2.1E-03	5.0E-06	5.1E-03	Yes	3.5E-04	2.43	58.9%	NT * [d/]	Source
2-272B	T	1.5E-04	4.3E-05	2.4E-04	Yes	-2.1E-04	1.61	54.2%	NT *	Plume
2-65B	T	1.7E-03	1.3E-03	2.1E-03	No	4.1E-03	1.25	97.1%	I	Plume
2-274B	T	2.1E-03	4.3E-05	4.2E-03	Yes	-1.2E-03	1.97	65.3%	NT *	Plume

[a/] mg/L = milligrams per liter.

[b/] ND = non-detect.

[c/] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[d/] * indicates that the concentrations at this well were reported as non detect (ND) for every sampling event available.

TABLE C.2A
MAROS MANN-KENDALL STATISTICS SUMMARY
SITE FTA-2, TINKER AFB, OKLAHOMA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples ND? [a]	Concentration Trend [b]	Designation for Current Analysis
Teterachloroethene (PCE)									
2-62B	S	6	3	2.10	6	81.5%	No	NT	Source
2-63B	S	6	3	1.15	4	70.3%	No	NT	Source
2-64B	S	6	2	1.95	6	81.5%	No	NT	Source
2-272B	T	4	1	1.29	1	50.0%	No	NT	Plume
2-65B	T	5	4	1.09	10	99.2%	No	I	Plume
2-274B	T	4	1	1.69	1	50.0%	No	NT	Plume
Trichloroethene (TCE)									
2-62B	S	6	6	0.27	3	64.0%	No	NT	Source
2-63B	S	6	6	1.78	9	93.2%	No	PI	Source
2-64B	S	6	6	0.93	13	99.2%	No	I	Source
2-272B	T	4	4	1.27	6	95.8%	No	I	Plume
2-65B	T	5	5	0.70	2	59.2%	No	NT	Plume
2-274B	T	4	4	0.48	4	83.3%	No	NT	Plume
cis-1,2-Dichloroethene (cis-1,2-DCE)									
2-62B	S	6	6	0.29	-7	86.4%	No	S	Source
2-63B	S	6	6	0.52	9	93.2%	No	PI	Source
2-64B	S	6	6	0.71	9	93.2%	No	PI	Source
2-272B	T	4	4	1.40	6	95.8%	No	I	Plume
2-65B	T	5	5	1.07	8	95.8%	No	I	Plume
2-274B	T	4	4	0.36	4	83.3%	Yes	NT	Plume
Vinyl Chloride (VC)									
2-62B	S	6	6	0.54	7	86.4%	No	NT	Source
2-63B	S	6	3	0.83	8	89.8%	No	NT	Source
2-64B	S	6	0	2.43	3	64.0%	Yes	NT * [c]	Source
2-272B	T	4	0	1.61	-1	50.0%	Yes	NT *	Plume
2-65B	T	5	3	1.25	7	92.1%	No	PI	Plume
2-274B	T	4	0	1.97	-1	50.0%	Yes	NT *	Plume

[a] ND = non-detect.

[b] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[c] * indicates that the concentrations at this well were reported as non detect (ND) for every sampling event available.

TABLE C.3A
ANALYTICAL DATA - TETRACHLOROETHENE (PCE)
SITE FTA-2, TINKER AFB, OKLAHOMA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a]	DetLim	Flags [b]
2-62B	2182140.56	150444.52	TETRACHLOROETHENE(PCE)	12/10/1993		ug/L	0.01	ND
2-62B	2182140.56	150444.52	TETRACHLOROETHENE(PCE)	9/13/1995		ug/L	0.01	ND
2-62B	2182140.56	150444.52	TETRACHLOROETHENE(PCE)	7/24/1996		ug/L	250	ND
2-62B	2182140.56	150444.52	TETRACHLOROETHENE(PCE)	7/31/1997	6.1	ug/L	0.01	
2-62B	2182140.56	150444.52	TETRACHLOROETHENE(PCE)	4/8/1999	3.7	ug/L	0.01	
2-62B	2182140.56	150444.52	TETRACHLOROETHENE(PCE)	5/1/2002	7.46	ug/L	0.01	
2-63B	2182035.36	150386.11	TETRACHLOROETHENE(PCE)	12/10/1993		ug/L	0.01	ND
2-63B	2182035.36	150386.11	TETRACHLOROETHENE(PCE)	9/13/1995		ug/L	0.01	ND
2-63B	2182035.36	150386.11	TETRACHLOROETHENE(PCE)	7/24/1996		ug/L	10	ND
2-63B	2182035.36	150386.11	TETRACHLOROETHENE(PCE)	7/31/1997	1.9	ug/L	0.01	
2-63B	2182035.36	150386.11	TETRACHLOROETHENE(PCE)	4/8/1999	1	ug/L	0.01	
2-63B	2182035.36	150386.11	TETRACHLOROETHENE(PCE)	5/1/2002	1.7	ug/L	0.01	
2-64B	2181967.76	150467.40	TETRACHLOROETHENE(PCE)	12/10/1993		ug/L	0.01	ND
2-64B	2181967.76	150467.40	TETRACHLOROETHENE(PCE)	9/13/1995		ug/L	0.01	ND
2-64B	2181967.76	150467.40	TETRACHLOROETHENE(PCE)	7/24/1996		ug/L	25	ND
2-64B	2181967.76	150467.40	TETRACHLOROETHENE(PCE)	7/31/1997		ug/L	0.01	ND
2-64B	2181967.76	150467.40	TETRACHLOROETHENE(PCE)	4/8/1999	1.3	ug/L	0.01	
2-64B	2181967.76	150467.40	TETRACHLOROETHENE(PCE)	5/1/2002	1.33	ug/L	0.01	
2-272B	2181581.74	150784.70	TETRACHLOROETHENE(PCE)	8/22/1996		ug/L	0.8	ND
2-272B	2181581.74	150784.70	TETRACHLOROETHENE(PCE)	8/1/1997		ug/L	0.01	ND
2-272B	2181581.74	150784.70	TETRACHLOROETHENE(PCE)	4/8/1999		ug/L	0.01	ND
2-272B	2181581.74	150784.70	TETRACHLOROETHENE(PCE)	5/1/2002	0.89	ug/L	0.01	
B97-43s	2181770.08	150861.52	TETRACHLOROETHENE(PCE)	5/1/2002	0.5	ug/L	0.01	
B97-43s	2181770.08	150861.52	TETRACHLOROETHENE(PCE)	7/31/1997		ug/L	0.01	ND
B97-43s	2181770.08	150861.52	TETRACHLOROETHENE(PCE)	4/8/1999		ug/L	0.01	ND
2-65B	2182183.20	150712.88	TETRACHLOROETHENE(PCE)	12/10/1993		ug/L	0.01	ND
2-65B	2182183.20	150712.88	TETRACHLOROETHENE(PCE)	9/13/1995	22	ug/L	0.01	
2-65B	2182183.20	150712.88	TETRACHLOROETHENE(PCE)	7/24/1996	44	ug/L	0.01	
2-65B	2182183.20	150712.88	TETRACHLOROETHENE(PCE)	7/31/1997	52	ug/L	0.01	
2-65B	2182183.20	150712.88	TETRACHLOROETHENE(PCE)	4/8/1999	154	ug/L	0.01	
2-274B	2181625.92	151126.23	TETRACHLOROETHENE(PCE)	8/22/1996		ug/L	0.13	ND
2-274B	2181625.92	151126.23	TETRACHLOROETHENE(PCE)	8/3/1997		ug/L	0.01	ND
2-274B	2181625.92	151126.23	TETRACHLOROETHENE(PCE)	4/8/1999		ug/L	0.01	ND
2-274B	2181625.92	151126.23	TETRACHLOROETHENE(PCE)	5/1/2002	0.56	ug/L	0.01	
2-355B	2181400.66	151233.46	TETRACHLOROETHENE(PCE)	8/3/1997		ug/L	0.01	ND
2-355B	2181400.66	151233.46	TETRACHLOROETHENE(PCE)	4/8/1999		ug/L	0.01	ND
2-355B	2181400.66	151233.46	TETRACHLOROETHENE(PCE)	5/1/2002	0.29	ug/L	0.01	
2-393B	2181280.87	151434.08	TETRACHLOROETHENE(PCE)	8/1/1997		ug/L	0.01	ND
2-393B	2181280.87	151434.08	TETRACHLOROETHENE(PCE)	4/8/1999		ug/L	0.01	ND
2-393B	2181280.87	151434.08	TETRACHLOROETHENE(PCE)	5/1/2002	0.28	ug/L	0.01	
2-167B	2182408.35	150539.81	TETRACHLOROETHENE(PCE)	7/24/1996		ug/L	1	ND
2-167B	2182408.35	150539.81	TETRACHLOROETHENE(PCE)	8/1/1997		ug/L	0.01	ND
2-168B	2181976.69	150249.00	TETRACHLOROETHENE(PCE)	7/24/1996		ug/L	5	ND
2-168B	2181976.69	150249.00	TETRACHLOROETHENE(PCE)	7/31/1997		ug/L	0.01	ND
2-168B	2181976.69	150249.00	TETRACHLOROETHENE(PCE)	4/1/1999		ug/L	0.01	ND
2-142B	2180907.60	151507.21	TETRACHLOROETHENE(PCE)	9/13/1995		ug/L	0.01	ND
2-142B	2180907.60	151507.21	TETRACHLOROETHENE(PCE)	8/2/1997		ug/L	0.01	ND
2-273B	2181576.36	150351.11	TETRACHLOROETHENE(PCE)	8/9/1996		ug/L	0.8	ND
2-273B	2181576.36	150351.11	TETRACHLOROETHENE(PCE)	8/1/1997		ug/L	0.01	ND
2-301B	2182586.00	149701.00	TETRACHLOROETHENE(PCE)	7/16/1996		ug/L	0.8	ND
2-301B	2182586.00	149701.00	TETRACHLOROETHENE(PCE)	5/1/2002	0.33	ug/L	0.01	

[a] ug/L = micrograms per liter.

[b] ND = non detect, J = estimated value, F = estimated value.

TABLE C.4A
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE FTA-2, TINKER AFB, OKLAHOMA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
2-62B	2182140.56	150444.52	TRICHLOROETHENE (TCE)	12/10/1993	8300	ug/L	0.01	
2-62B	2182140.56	150444.52	TRICHLOROETHENE (TCE)	9/13/1995	9100	ug/L	0.01	
2-62B	2182140.56	150444.52	TRICHLOROETHENE (TCE)	7/24/1996	4300	ug/L	0.01	
2-62B	2182140.56	150444.52	TRICHLOROETHENE (TCE)	7/31/1997	9440	ug/L	0.01	
2-62B	2182140.56	150444.52	TRICHLOROETHENE (TCE)	4/8/1999	6200	ug/L	0.01	
2-62B	2182140.56	150444.52	TRICHLOROETHENE (TCE)	5/1/2002	9330	ug/L	0.01	
2-63B	2182035.36	150386.11	TRICHLOROETHENE (TCE)	12/10/1993	33	ug/L	0.01	
2-63B	2182035.36	150386.11	TRICHLOROETHENE (TCE)	9/13/1995	47	ug/L	0.01	
2-63B	2182035.36	150386.11	TRICHLOROETHENE (TCE)	7/24/1996	22	ug/L	0.01	
2-63B	2182035.36	150386.11	TRICHLOROETHENE (TCE)	7/31/1997	75.4	ug/L	0.01	
2-63B	2182035.36	150386.11	TRICHLOROETHENE (TCE)	4/8/1999	53.7	ug/L	0.01	
2-63B	2182035.36	150386.11	TRICHLOROETHENE (TCE)	5/1/2002	775	ug/L	0.01	
2-64B	2181967.76	150467.40	TRICHLOROETHENE (TCE)	12/10/1993	96	ug/L	0.01	
2-64B	2181967.76	150467.40	TRICHLOROETHENE (TCE)	9/13/1995	160	ug/L	0.01	
2-64B	2181967.76	150467.40	TRICHLOROETHENE (TCE)	7/24/1996	470	ug/L	0.01	
2-64B	2181967.76	150467.40	TRICHLOROETHENE (TCE)	7/31/1997	914	ug/L	0.01	
2-64B	2181967.76	150467.40	TRICHLOROETHENE (TCE)	4/8/1999	2130	ug/L	0.01	
2-64B	2181967.76	150467.40	TRICHLOROETHENE (TCE)	5/1/2002	1810	ug/L	0.01	
2-272B	2181581.74	150784.70	TRICHLOROETHENE (TCE)	8/22/1996	9	ug/L	0.01	
2-272B	2181581.74	150784.70	TRICHLOROETHENE (TCE)	8/1/1997	28.1	ug/L	0.01	
2-272B	2181581.74	150784.70	TRICHLOROETHENE (TCE)	4/8/1999	455	ug/L	0.01	
2-272B	2181581.74	150784.70	TRICHLOROETHENE (TCE)	5/1/2002	1070	ug/L	0.01	
B97-43s	2181770.08	150861.52	TRICHLOROETHENE (TCE)	5/1/2002	570	ug/L	0.01	
B97-43s	2181770.08	150861.52	TRICHLOROETHENE (TCE)	7/31/1997	1490	ug/L	0.01	
B97-43s	2181770.08	150861.52	TRICHLOROETHENE (TCE)	4/8/1999	751	ug/L	0.01	
2-65B	2182183.20	150712.88	TRICHLOROETHENE (TCE)	12/10/1993	99	ug/L	0.01	
2-65B	2182183.20	150712.88	TRICHLOROETHENE (TCE)	9/13/1995	68	ug/L	0.01	
2-65B	2182183.20	150712.88	TRICHLOROETHENE (TCE)	7/24/1996	55	ug/L	0.01	
2-65B	2182183.20	150712.88	TRICHLOROETHENE (TCE)	7/31/1997	90	ug/L	0.01	
2-65B	2182183.20	150712.88	TRICHLOROETHENE (TCE)	4/8/1999	250	ug/L	0.01	
2-274B	2181625.92	151126.23	TRICHLOROETHENE (TCE)	8/22/1996	260	ug/L	0.01	
2-274B	2181625.92	151126.23	TRICHLOROETHENE (TCE)	8/3/1997	518	ug/L	0.01	
2-274B	2181625.92	151126.23	TRICHLOROETHENE (TCE)	4/8/1999	942	ug/L	0.01	
2-274B	2181625.92	151126.23	TRICHLOROETHENE (TCE)	5/1/2002	609	ug/L	0.01	
2-355B	2181400.66	151233.46	TRICHLOROETHENE (TCE)	8/3/1997	344	ug/L	0.01	
2-355B	2181400.66	151233.46	TRICHLOROETHENE (TCE)	4/8/1999	186	ug/L	0.01	
2-355B	2181400.66	151233.46	TRICHLOROETHENE (TCE)	5/1/2002	99.1	ug/L	0.01	
2-393B	2181280.87	151434.08	TRICHLOROETHENE (TCE)	8/1/1997	406	ug/L	0.01	
2-393B	2181280.87	151434.08	TRICHLOROETHENE (TCE)	4/8/1999	114	ug/L	0.01	
2-393B	2181280.87	151434.08	TRICHLOROETHENE (TCE)	5/1/2002	10.3	ug/L	0.01	
2-167B	2182408.35	150539.81	TRICHLOROETHENE (TCE)	7/24/1996		ug/L	1	ND
2-167B	2182408.35	150539.81	TRICHLOROETHENE (TCE)	8/1/1997		ug/L	0.01	ND
2-168B	2181976.69	150249.00	TRICHLOROETHENE (TCE)	7/24/1996		ug/L	5	ND
2-168B	2181976.69	150249.00	TRICHLOROETHENE (TCE)	7/31/1997	1.4	ug/L	0.01	
2-168B	2181976.69	150249.00	TRICHLOROETHENE (TCE)	4/1/1999	1	ug/L		
2-142B	2180907.60	151507.21	TRICHLOROETHENE (TCE)	9/13/1995	2	ug/L	0.01	
2-142B	2180907.60	151507.21	TRICHLOROETHENE (TCE)	8/2/1997		ug/L	0.01	ND
2-273B	2181576.36	150351.11	TRICHLOROETHENE (TCE)	8/9/1996		ug/L	0.8	ND
2-273B	2181576.36	150351.11	TRICHLOROETHENE (TCE)	8/1/1997		ug/L	0.01	ND
2-301B	2182586.00	149701.00	TRICHLOROETHENE (TCE)	7/16/1996		ug/L	0.8	ND
2-301B	2182586.00	149701.00	TRICHLOROETHENE (TCE)	5/1/2002	15.4	ug/L	0.01	

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, J = estimated value, F = estimated value.

TABLE C.5A
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE FTA-2, TINKER AFB, OKLAHOMA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
2-62B	2182140.56	150444.52	cis-1,2-DICHLOROETHENE	12/10/1993	1600	ug/L	0.01	
2-62B	2182140.56	150444.52	cis-1,2-DICHLOROETHENE	9/13/1995	1100	ug/L	0.01	
2-62B	2182140.56	150444.52	cis-1,2-DICHLOROETHENE	7/24/1996	960	ug/L	0.01	
2-62B	2182140.56	150444.52	cis-1,2-DICHLOROETHENE	7/31/1997	1200	ug/L	0.01	
2-62B	2182140.56	150444.52	cis-1,2-DICHLOROETHENE	4/8/1999	650	ug/L	0.01	
2-62B	2182140.56	150444.52	cis-1,2-DICHLOROETHENE	5/1/2002	977	ug/L	0.01	
2-63B	2182035.36	150386.11	cis-1,2-DICHLOROETHENE	12/10/1993	45	ug/L	0.01	
2-63B	2182035.36	150386.11	cis-1,2-DICHLOROETHENE	9/13/1995	53	ug/L	0.01	
2-63B	2182035.36	150386.11	cis-1,2-DICHLOROETHENE	7/24/1996	190	ug/L	0.01	
2-63B	2182035.36	150386.11	cis-1,2-DICHLOROETHENE	7/31/1997	161	ug/L	0.01	
2-63B	2182035.36	150386.11	cis-1,2-DICHLOROETHENE	4/8/1999	126	ug/L	0.01	
2-63B	2182035.36	150386.11	cis-1,2-DICHLOROETHENE	5/1/2002	197	ug/L	0.01	
2-64B	2181967.76	150467.40	cis-1,2-DICHLOROETHENE	12/10/1993	39	ug/L	0.01	
2-64B	2181967.76	150467.40	cis-1,2-DICHLOROETHENE	9/13/1995	35	ug/L	0.01	
2-64B	2181967.76	150467.40	cis-1,2-DICHLOROETHENE	7/24/1996	180	ug/L	0.01	
2-64B	2181967.76	150467.40	cis-1,2-DICHLOROETHENE	7/31/1997	154	ug/L	0.01	
2-64B	2181967.76	150467.40	cis-1,2-DICHLOROETHENE	4/8/1999	328	ug/L	0.01	
2-64B	2181967.76	150467.40	cis-1,2-DICHLOROETHENE	5/1/2002	280	ug/L	0.01	
2-272B	2181581.74	150784.70	cis-1,2-DICHLOROETHENE	8/22/1996	0.6	ug/L	0.01	
2-272B	2181581.74	150784.70	cis-1,2-DICHLOROETHENE	8/1/1997	2.1	ug/L	0.01	
2-272B	2181581.74	150784.70	cis-1,2-DICHLOROETHENE	4/8/1999	34.9	ug/L	0.01	
2-272B	2181581.74	150784.70	cis-1,2-DICHLOROETHENE	5/1/2002	113	ug/L	0.01	
B97-43s	2181770.08	150861.52	cis-1,2-DICHLOROETHENE	5/1/2002	67.8	ug/L	0.01	
B97-43s	2181770.08	150861.52	cis-1,2-DICHLOROETHENE	7/31/1997	183	ug/L	0.01	
B97-43s	2181770.08	150861.52	cis-1,2-DICHLOROETHENE	4/8/1999	98.6	ug/L	0.01	
2-65B	2182183.20	150712.88	cis-1,2-DICHLOROETHENE	12/10/1993	24	ug/L	0.01	
2-65B	2182183.20	150712.88	cis-1,2-DICHLOROETHENE	9/13/1995	14	ug/L	0.01	
2-65B	2182183.20	150712.88	cis-1,2-DICHLOROETHENE	7/24/1996	33	ug/L	0.01	
2-65B	2182183.20	150712.88	cis-1,2-DICHLOROETHENE	7/31/1997	37	ug/L	0.01	
2-65B	2182183.20	150712.88	cis-1,2-DICHLOROETHENE	4/8/1999	147	ug/L	0.01	
2-274B	2181625.92	151126.23	cis-1,2-DICHLOROETHENE	8/22/1996	46	ug/L	0.01	
2-274B	2181625.92	151126.23	cis-1,2-DICHLOROETHENE	8/3/1997	51.7	ug/L	0.01	
2-274B	2181625.92	151126.23	cis-1,2-DICHLOROETHENE	4/8/1999	99.2	ug/L	0.01	
2-274B	2181625.92	151126.23	cis-1,2-DICHLOROETHENE	5/1/2002	64.8	ug/L	0.01	
2-355B	2181400.66	151233.46	cis-1,2-DICHLOROETHENE	8/3/1997	50	ug/L	0.01	
2-355B	2181400.66	151233.46	cis-1,2-DICHLOROETHENE	4/8/1999	28.5	ug/L	0.01	
2-355B	2181400.66	151233.46	cis-1,2-DICHLOROETHENE	5/1/2002	13.9	ug/L	0.01	
2-393B	2181280.87	151434.08	cis-1,2-DICHLOROETHENE	8/1/1997	54.3	ug/L	0.01	
2-393B	2181280.87	151434.08	cis-1,2-DICHLOROETHENE	4/8/1999	13.3	ug/L	0.01	
2-393B	2181280.87	151434.08	cis-1,2-DICHLOROETHENE	5/1/2002	0.73	ug/L	0.01	
2-167B	2182408.35	150539.81	cis-1,2-DICHLOROETHENE	7/24/1996		ug/L	1	ND
2-167B	2182408.35	150539.81	cis-1,2-DICHLOROETHENE	8/1/1997		ug/L	0.01	ND
2-168B	2181976.69	150249.00	cis-1,2-DICHLOROETHENE	7/24/1996	19	ug/L	0.01	
2-168B	2181976.69	150249.00	cis-1,2-DICHLOROETHENE	7/31/1997	27.6	ug/L	0.01	
2-168B	2181976.69	150249.00	cis-1,2-DICHLOROETHENE	4/1/1999	6.3	ug/L		
2-142B	2180907.60	151507.21	cis-1,2-DICHLOROETHENE	9/13/1995		ug/L	0.01	ND
2-142B	2180907.60	151507.21	cis-1,2-DICHLOROETHENE	8/2/1997		ug/L	0.01	ND
2-273B	2181576.36	150351.11	cis-1,2-DICHLOROETHENE	8/9/1996		ug/L	0.5	ND
2-273B	2181576.36	150351.11	cis-1,2-DICHLOROETHENE	8/1/1997		ug/L	0.01	ND
2-301B	2182586.00	149701.00	cis-1,2-DICHLOROETHENE	7/16/1996		ug/L	0.5	ND
2-301B	2182586.00	149701.00	cis-1,2-DICHLOROETHENE	5/1/2002	1.3	ug/L	0.01	

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, J = estimated value, F = estimated value.

TABLE C.6A
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE FTA-2, TINKER AFB, OKLAHOMA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
2-62B	2182140.56	150444.52	VINYL CHLORIDE	12/10/1993	1	ug/L	0.01	
2-62B	2182140.56	150444.52	VINYL CHLORIDE	9/13/1995	1	ug/L	0.01	
2-62B	2182140.56	150444.52	VINYL CHLORIDE	7/24/1996	1	ug/L	0.01	
2-62B	2182140.56	150444.52	VINYL CHLORIDE	7/31/1997	1.7	ug/L	0.01	
2-62B	2182140.56	150444.52	VINYL CHLORIDE	4/8/1999	1	ug/L	0.01	
2-62B	2182140.56	150444.52	VINYL CHLORIDE	5/1/2002	2.91	ug/L	0.01	
2-63B	2182035.36	150386.11	VINYL CHLORIDE	12/10/1993		ug/L	0.01	ND
2-63B	2182035.36	150386.11	VINYL CHLORIDE	9/13/1995		ug/L	0.01	ND
2-63B	2182035.36	150386.11	VINYL CHLORIDE	7/24/1996		ug/L	10	ND
2-63B	2182035.36	150386.11	VINYL CHLORIDE	7/31/1997	6.6	ug/L	0.01	
2-63B	2182035.36	150386.11	VINYL CHLORIDE	4/8/1999	3.6	ug/L	0.01	
2-63B	2182035.36	150386.11	VINYL CHLORIDE	5/1/2002	6.47	ug/L	0.01	
2-64B	2181967.76	150467.40	VINYL CHLORIDE	12/10/1993		ug/L	0.01	ND
2-64B	2181967.76	150467.40	VINYL CHLORIDE	9/13/1995		ug/L	0.01	ND
2-64B	2181967.76	150467.40	VINYL CHLORIDE	7/24/1996		ug/L	25	ND
2-64B	2181967.76	150467.40	VINYL CHLORIDE	7/31/1997		ug/L	0.01	ND
2-64B	2181967.76	150467.40	VINYL CHLORIDE	4/8/1999		ug/L	0.01	ND
2-64B	2181967.76	150467.40	VINYL CHLORIDE	5/1/2002		ug/L	0.16	ND
2-272B	2181581.74	150784.70	VINYL CHLORIDE	8/22/1996		ug/L	1	ND
2-272B	2181581.74	150784.70	VINYL CHLORIDE	8/1/1997		ug/L	0.01	ND
2-272B	2181581.74	150784.70	VINYL CHLORIDE	4/8/1999		ug/L	0.01	ND
2-272B	2181581.74	150784.70	VINYL CHLORIDE	5/1/2002		ug/L	0.16	ND
B97-43s	2181770.08	150861.52	VINYL CHLORIDE	5/1/2002		ug/L	0.16	ND
B97-43s	2181770.08	150861.52	VINYL CHLORIDE	7/31/1997		ug/L	0.01	ND
B97-43s	2181770.08	150861.52	VINYL CHLORIDE	4/8/1999		ug/L	0.01	ND
B97-43s	2181770.08	150861.52	VINYL CHLORIDE	4/8/1999		ug/L	0.01	ND
2-65B	2182183.20	150712.88	VINYL CHLORIDE	12/10/1993		ug/L	0.01	ND
2-65B	2182183.20	150712.88	VINYL CHLORIDE	9/13/1995		ug/L	0.01	ND
2-65B	2182183.20	150712.88	VINYL CHLORIDE	7/24/1996	2	ug/L	0.01	
2-65B	2182183.20	150712.88	VINYL CHLORIDE	7/31/1997	1.3	ug/L	0.01	
2-65B	2182183.20	150712.88	VINYL CHLORIDE	4/8/1999	5.1	ug/L	0.01	
2-274B	2181625.92	151126.23	VINYL CHLORIDE	8/22/1996		ug/L	17	ND
2-274B	2181625.92	151126.23	VINYL CHLORIDE	8/3/1997		ug/L	0.01	ND
2-274B	2181625.92	151126.23	VINYL CHLORIDE	4/8/1999		ug/L	0.01	ND
2-274B	2181625.92	151126.23	VINYL CHLORIDE	5/1/2002		ug/L	0.16	ND
2-355B	2181400.66	151233.46	VINYL CHLORIDE	8/3/1997		ug/L	0.01	ND
2-355B	2181400.66	151233.46	VINYL CHLORIDE	4/8/1999		ug/L	0.01	ND
2-355B	2181400.66	151233.46	VINYL CHLORIDE	5/1/2002		ug/L	0.16	ND
2-393B	2181280.87	151434.08	VINYL CHLORIDE	8/1/1997		ug/L	0.01	ND
2-393B	2181280.87	151434.08	VINYL CHLORIDE	4/8/1999		ug/L	0.01	ND
2-393B	2181280.87	151434.08	VINYL CHLORIDE	5/1/2002		ug/L	0.16	ND
2-167B	2182408.35	150539.81	VINYL CHLORIDE	7/24/1996		ug/L	1	ND
2-167B	2182408.35	150539.81	VINYL CHLORIDE	8/1/1997		ug/L	0.01	ND
2-168B	2181976.69	150249.00	VINYL CHLORIDE	7/24/1996		ug/L	5	ND
2-168B	2181976.69	150249.00	VINYL CHLORIDE	7/31/1997		ug/L	0.01	ND
2-168B	2181976.69	150249.00	VINYL CHLORIDE	4/1/1999		ug/L	0.01	ND
2-142B	2180907.60	151507.21	VINYL CHLORIDE	9/13/1995		ug/L	0.01	ND
2-142B	2180907.60	151507.21	VINYL CHLORIDE	8/2/1997		ug/L	0.01	ND
2-273B	2181576.36	150351.11	VINYL CHLORIDE	8/9/1996		ug/L	1	ND
2-273B	2181576.36	150351.11	VINYL CHLORIDE	8/1/1997		ug/L	0.01	ND
2-301B	2182586.00	149701.00	VINYL CHLORIDE	7/16/1996		ug/L	1	ND
2-301B	2182586.00	149701.00	VINYL CHLORIDE	5/1/2002		ug/L	0.16	ND

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, J = estimated value, F = estimated value.

TABLE C.7A
INPUT PARAMETERS FOR MASS-BASED CALCULATIONS
SITE FTA-2, TINKER AFB, OKLAHOMA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	Theissen Polygon Area (square feet)
2-272B	28,537
2-274B	38,815
2-355B	24,557
2-393B	2,873
2-62B	5,107
2-63B	4,071
2-64B	41,334
B97-43s	57,770
Total	203,065

Parameter	Value
Porosity (percentage)	20
Thickness of Contaminated Aquifer (feet)	25

TABLE C.8A
RESULTS OF DISSOLVED MASS ESTIMATION
SITE FTA-2, TINKER AFB, OKLAHOMA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

	Mass in kilograms									
	Trichloroethene (TCE)		Dichloroethene (DCE)		Vinyl Chloride (VC)		Tetrachloroethene (PCE)		Total CAHs	
Date	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass
8/1/1997	42.41	28.73	5.53	3.85	0.008	0.03961	0.02	0.01	49.93	34.04
4/1/1999	38.23	30.83	4.58	4.06	0.005	0.02165	0.02	0.02	44.45	36.40
5/1/2002	46.33	30.47	5.36	3.88	0.011	0.03955	0.04	0.05	53.65	35.84

	Percentage of Total CAH Mass							
	Trichloroethene (TCE)		Dichloroethene (DCE)		Tetrachloroethene (PCE)		Vinyl Chloride (VC)	
Date	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass
8/1/1997	84.9%	84.4%	15.0%	15.3%	0.03%	0.24%	0.03%	0.03%
4/1/1999	86.0%	84.7%	14.0%	15.1%	0.02%	0.13%	0.03%	0.04%
5/1/2002	86.4%	85.0%	13.5%	14.7%	0.04%	0.23%	0.06%	0.10%

TABLE C.9A
RESULTS OF GIS MASS-BASED CALCULATIONS FOR CENTER OF MASS LOCATION
SITE FTA-2, TINKER AFB, OKLAHOMA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

	Trichloroethene (TCE)				Dichloroethene (DCE)				Vinyl Chloride (VC)				Tetrachloroethene (PCE)			
	Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass	
Date	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate
1997	2181842.40	150725.20	2181892.40	150682.30	2181856.90	150704.40	2181896.50	150673.20	2182055.1	150436.5	2181987	150531	2182081	150461	2181984.2	150587.8
1999	2181836.50	150713.30	2181859.30	150700.50	2181852.70	150692.70	2181863.50	150689.20	2182055.8	150437.2	2181996	150523	2181984	150536	2181956.2	150586.9
2002	2181857.80	150679.10	2181877.50	150677.90	2181869.00	150664.00	2181877.50	150671.80	2182060.6	150441.7	218985	150552	2181839	150703	2181858.3	150702.3

Case Study Data for LF-06, Columbus Air Force Base, Mississippi

TABLE C.1B
MAROS LINEAR REGRESSION STATISTICS SUMMARY
SITE LF-06, COLUMBUS AFB, MISSISSIPPI
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Average Conc (mg/L) [a/]	Median Conc (mg/L)	Standard Deviation	All Samples ND? [b/]	LN Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend [c/]	Designation for Current Analysis
Trichloroethene (TCE)										
W21	S	8.0E-03	5.8E-03	9.3E-03	No	1.8E-03	1.15	100.0%	I	Source
W18	T	1.0E-04	5.0E-07	1.2E-04	No	-1.6E-03	1.17	86.4%	NT	Plume
W22	T	1.2E-03	5.0E-07	3.1E-03	No	1.2E-03	2.66	99.1%	I	Plume
W81	T	1.1E-04	5.0E-07	3.1E-04	No	1.3E-04	2.82	53.2%	NT	Plume
W20	T	5.0E-07	5.0E-07	0.0E+00	Yes	0.0E+00	0.00	0.0%	N/A * [d/]	Sentry
W78	T	5.0E-07	5.0E-07	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
W79	T	5.0E-07	5.0E-07	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
W82	T	2.7E-05	5.0E-07	7.4E-05	No	-2.1E-04	2.78	56.5%	NT	Sentry
DW92	T	6.3E-05	6.3E-05	4.9E-05	Yes	-4.0E-03	0.79	95.6%	D *	Sentry
cis-1,2-Dichloroethene (cis-1,2-DCE)										
W21	S	1.1E-02	1.2E-02	7.7E-03	No	1.2E-03	0.69	79.3%	NT	Source
W18	T	1.9E-03	2.2E-03	1.2E-03	No	2.6E-03	0.62	97.6%	I	Plume
W22	T	4.1E-03	1.6E-03	5.7E-03	No	5.2E-03	1.38	100.0%	I	Plume
W81	T	2.9E-04	2.9E-04	2.7E-04	No	1.0E-03	0.91	79.6%	NT	Plume
W20	T	5.0E-07	5.0E-07	0.0E+00	Yes	0.0E+00	0.00	0.0%	N/A *	Sentry
W78	T	5.0E-07	5.0E-07	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
W79	T	5.0E-07	5.0E-07	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
W82	T	4.6E-04	5.0E-07	1.3E-03	No	1.5E-04	2.83	53.2%	NT	Sentry
DW92	T	6.8E-05	6.3E-05	6.0E-05	Yes	-3.9E-03	0.88	87.0%	S *	Sentry
Vinyl Chloride (VC)										
W21	S	1.2E-02	1.0E-02	7.9E-03	No	2.4E-04	0.64	78.9%	NT	Source
W18	T	6.7E-03	6.1E-03	4.0E-03	No	5.1E-03	0.61	88.8%	NT	Plume
W22	T	2.0E-03	1.1E-03	2.8E-03	No	4.3E-03	1.39	98.9%	I	Plume
W81	T	4.4E-03	4.8E-03	2.3E-03	No	4.8E-04	0.52	76.1%	NT	Plume
W20	T	1.5E-03	5.0E-07	3.7E-03	No	-6.3E-04	2.53	68.5%	NT	Sentry
W78	T	5.0E-07	5.0E-07	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
W79	T	5.0E-07	5.0E-07	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
W82	T	5.0E-07	5.0E-07	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
DW92	T	9.4E-05	9.4E-05	7.3E-05	Yes	-3.5E-03	0.77	92.6%	PD *	Sentry

[a/] mg/L = milligrams per liter.

[b/] ND = non-detect.

[c/] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[d/] * indicates that the concentrations at this well were reported as non detect (ND) for every sampling event available.

TABLE C.2B
MAROS MANN-KENDALL STATISTICS SUMMARY
SITE LF-06, COLUMBUS AFB, MISSISSIPPI
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples ND? [a/]	Concentration Trend [b/]	Designation for Current Analysis
Trichloroethene (TCE)									
W21	S	21	17	1.15	50	93.0%	No	PI	Source
W18	T	11	5	1.17	-23	95.7%	No	D	Plume
W81	T	8	1	2.82	-1	50.0%	No	NT	Plume
W20	T	1	0	0	0	0.0%	Yes	N/A * [c/]	Plume
W22	T	21	8	2.66	70	98.2%	No	I	Sentry
W78	T	5	0	0.00	0	40.8%	Yes	S *	Sentry
W79	T	5	0	0.00	0	40.8%	Yes	S *	Sentry
W82	T	8	1	2.78	-3	59.4%	No	NT	Sentry
DW92	T	4	0	0.79	-4	83.3%	Yes	S *	Sentry
cis-1,2-Dichloroethene (cis-1,2-DCE)									
W21	S	13	11	0.69	6	61.7%	No	NT	Source
W18	T	13	10	0.62	4	57.1%	No	NT	Plume
W81	T	12	9	0.91	5	60.6%	No	NT	Plume
W20	T	1	0	0	0	0.0%	Yes	N/A *	Plume
W22	T	12	7	1.38	26	95.7%	No	I	Sentry
W78	T	5	0	0.00	0	40.8%	Yes	S *	Sentry
W79	T	5	0	0.00	0	40.8%	Yes	S *	Sentry
W82	T	8	1	2.83	-1	50.0%	No	NT	Sentry
DW92	T	4	0	0.88	-4	83.3%	Yes	S *	Sentry
Vinyl Chloride (VC)									
W21	S	21	10	0.64	-99	99.9%	No	D	Source
W18	T	20	18	0.61	-23	76.0%	No	S	Plume
W81	T	16	15	0.52	-19	78.8%	No	S	Plume
W20	T	7	2	2.53	-3	61.4%	No	NT	Plume
W22	T	8	6	1.39	5	68.3%	No	NT	Sentry
W78	T	5	0	0.00	0	40.8%	Yes	S *	Sentry
W79	T	5	0	0.00	0	40.8%	Yes	S *	Sentry
W82	T	5	0	0.00	0	40.8%	Yes	S *	Sentry
DW92	T	4	0	0.77	-2	62.5%	Yes	S *	Sentry

[a/] ND = non-detect.

[b/] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[c/] * indicates that the concentrations at this well were reported as non detect (ND) for every sampling event available.

TABLE C.3B
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE LF-06, COLUMBUS AFB, MISSISSIPPI
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MPO	621222.08	1439452.86	TRICHLOROETHENE (TCE)	11/15/96	0.68	ug/L	0.001	J
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	04/01/88		ug/L	0.001	ND
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	07/01/88		ug/L	0.001	ND
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	12/01/88		ug/L	0.001	ND
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	05/01/89		ug/L	0.001	ND
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	11/01/91	4	ug/L	0.001	J
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	11/01/94	26	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	09/01/95	26	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	11/01/96	7.4	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	11/15/96	7.4	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	08/01/96	29.9	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	04/01/97	5.8	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	12/01/97	3.1	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	03/01/98	1.4	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	09/01/98	0.78	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	04/01/99	0.67	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	06/01/00	1.61	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	12/01/00	13	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	11/18/02	9.28	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	05/06/02	7.2	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	12/03/01	16	ug/L	0.001	
W21	621616.88	1439564.86	TRICHLOROETHENE (TCE)	05/30/01	9.2	ug/L	0.001	
MPAS	621166.02	1439839.59	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPAD	621166.02	1439839.59	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPCS	621620.45	1440002.24	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPCD	621620.45	1440002.24	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPDD	621404.39	1439880.21	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPFS	621987.11	1440040.79	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPFD	621987.11	1440040.79	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPI	620508.39	1439541.56	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPJ	620792.41	1439669.53	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPK	620620.25	1439815.82	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPL	620429.65	1439848.22	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPN	621528.63	1440221.40	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPP	621894.23	1439472.55	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
W18	621169.72	1440056.04	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
W18	620810.93	1439807.23	TRICHLOROETHENE (TCE)	12/01/97	0.29	ug/L	0.001	
W18	620810.93	1439807.23	TRICHLOROETHENE (TCE)	03/01/98	0.24	ug/L	0.001	
W18	620810.93	1439807.23	TRICHLOROETHENE (TCE)	09/01/98		ug/L	0.001	ND
W18	620810.93	1439807.23	TRICHLOROETHENE (TCE)	04/01/99	0.21	ug/L	0.001	
W18	620810.93	1439807.23	TRICHLOROETHENE (TCE)	06/01/00	0.2	ug/L	0.001	
W18	620810.93	1439807.23	TRICHLOROETHENE (TCE)	12/01/00	0.2	ug/L	0.001	
W18	620810.93	1439807.23	TRICHLOROETHENE (TCE)	12/03/01		ug/L	0.001	ND
W18	620810.93	1439807.23	TRICHLOROETHENE (TCE)	05/30/01		ug/L	0.001	ND
W18	620810.93	1439807.23	TRICHLOROETHENE (TCE)	11/18/02		ug/L	0.001	ND
W18	620810.93	1439807.23	TRICHLOROETHENE (TCE)	05/06/02		ug/L	0.001	ND
W81	620830.78	1439155.87	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
W81	620830.78	1439155.87	TRICHLOROETHENE (TCE)	04/01/99		ug/L	0.001	ND
W81	620830.78	1439155.87	TRICHLOROETHENE (TCE)	06/01/00		ug/L	0.001	ND
W81	620830.78	1439155.87	TRICHLOROETHENE (TCE)	12/01/00	0.87	ug/L	0.001	
W81	620830.78	1439155.87	TRICHLOROETHENE (TCE)	12/03/01		ug/L	0.001	ND
W81	620830.78	1439155.87	TRICHLOROETHENE (TCE)	05/30/01		ug/L	0.001	ND
W81	620830.78	1439155.87	TRICHLOROETHENE (TCE)	11/18/02		ug/L	0.001	ND
W81	620830.78	1439155.87	TRICHLOROETHENE (TCE)	05/06/02		ug/L	0.001	ND
MPB	621168.37	1439643.05	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPG	622741.12	1440365.41	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPH	620642.97	1439306.16	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPM	620650.44	1440089.86	TRICHLOROETHENE (TCE)	11/15/96	1.1	ug/L	0.001	
MPQ	622302.94	1439501.90	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
MPR	623216.88	1440344.40	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
W19	621948.89	1440413.50	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
W20	622175.29	1439588.35	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	04/01/88		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	07/01/88		ug/L	0.001	ND

TABLE C.3B
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE LF-06, COLUMBUS AFB, MISSISSIPPI
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	12/01/88		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	05/01/89		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	11/01/91	14	ug/L	0.001	
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	11/01/94		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	09/01/95		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	11/01/96		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	08/01/96		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	04/01/97		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	12/01/97	0.008	ug/L	0.001	
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	03/01/98		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	09/01/98		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	04/01/99		ug/L	0.001	ND
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	06/01/00	1.55	ug/L	0.001	
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	12/01/00	3.2	ug/L	0.001	
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	12/03/01	3.1	ug/L	0.001	
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	05/30/01	1	ug/L	0.001	
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	11/18/02	0.71	ug/L	0.001	F
W22	620992.47	1439427.13	TRICHLOROETHENE (TCE)	05/06/02	0.93	ug/L	0.001	F
W78	621658.51	1439168.24	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
W78	621658.51	1439168.24	TRICHLOROETHENE (TCE)	12/03/01		ug/L	0.001	ND
W78	621658.51	1439168.24	TRICHLOROETHENE (TCE)	05/30/01		ug/L	0.001	ND
W78	621658.51	1439168.24	TRICHLOROETHENE (TCE)	11/18/02		ug/L	0.001	ND
W78	621658.51	1439168.24	TRICHLOROETHENE (TCE)	05/06/02		ug/L	0.001	ND
W79	621310.63	1439177.54	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
W79	621310.63	1439177.54	TRICHLOROETHENE (TCE)	12/03/01		ug/L	0.001	ND
W79	621310.63	1439177.54	TRICHLOROETHENE (TCE)	05/30/01		ug/L	0.001	ND
W79	621310.63	1439177.54	TRICHLOROETHENE (TCE)	11/18/02		ug/L	0.001	ND
W79	621310.63	1439177.54	TRICHLOROETHENE (TCE)	05/06/02		ug/L	0.001	ND
W82	620810.93	1439807.23	TRICHLOROETHENE (TCE)	11/15/96		ug/L	0.001	ND
W82	620810.93	1439807.23	TRICHLOROETHENE (TCE)	04/01/99		ug/L	0.001	ND
W82	620810.93	1439807.23	TRICHLOROETHENE (TCE)	06/01/00	0.21	ug/L	0.001	
W82	620810.93	1439807.23	TRICHLOROETHENE (TCE)	12/01/00		ug/L	0.001	ND
W82	620810.93	1439807.23	TRICHLOROETHENE (TCE)	12/03/01		ug/L	0.001	ND
W82	620810.93	1439807.23	TRICHLOROETHENE (TCE)	05/30/01		ug/L	0.001	ND
W82	620810.93	1439807.23	TRICHLOROETHENE (TCE)	11/18/02		ug/L	0.001	ND
W82	620810.93	1439807.23	TRICHLOROETHENE (TCE)	05/06/02		ug/L	0.001	ND
DW89	620890.00	1439887.00	TRICHLOROETHENE (TCE)	05/30/01		ug/L	0.200	ND
DW89	620890.00	1439887.00	TRICHLOROETHENE (TCE)	12/04/01		ug/L	0.220	ND
DW89	620890.00	1439887.00	TRICHLOROETHENE (TCE)	05/01/02		ug/L	0.050	ND
DW89	620890.00	1439887.00	TRICHLOROETHENE (TCE)	11/19/02		ug/L	0.030	ND
DW92	620900.00	1439897.00	TRICHLOROETHENE (TCE)	05/30/01		ug/L	0.200	ND
DW92	620900.00	1439897.00	TRICHLOROETHENE (TCE)	12/04/01		ug/L	0.220	ND
DW92	620900.00	1439897.00	TRICHLOROETHENE (TCE)	05/01/02		ug/L	0.050	ND
DW92	620900.00	1439897.00	TRICHLOROETHENE (TCE)	11/19/02		ug/L	0.030	ND

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, J = estimated value, F = estimated value.

TABLE C.4B
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE LF-06, COLUMBUS AFB, MISSISSIPPI
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MPO	621222.08	1439452.86	cis-1,2-DICHLOROETHENE	11/15/96	15	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	11/15/96	14	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	08/01/96	19.3	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	04/01/97	11	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	12/01/97	9.7	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	03/01/98		ug/L	0.001	ND
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	09/01/98		ug/L	0.001	ND
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	04/01/99	3.42	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	06/01/00	3.42	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	12/01/00	18.4	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	12/03/01	25	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	05/30/01	16	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	11/18/02	13.3	ug/L	0.001	
W21	621616.88	1439564.86	cis-1,2-DICHLOROETHENE	05/06/02	12.1	ug/L	0.001	
MPAS	621166.02	1439839.59	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPAD	621166.02	1439839.59	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPCS	621620.45	1440002.24	cis-1,2-DICHLOROETHENE	11/15/96	0.78	ug/L	0.001	J
MPCD	621620.45	1440002.24	cis-1,2-DICHLOROETHENE	11/15/96	2.3	ug/L	0.001	
MPDD	621404.39	1439880.21	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPFS	621987.11	1440040.79	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPFD	621987.11	1440040.79	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPI	620508.39	1439541.56	cis-1,2-DICHLOROETHENE	11/15/96	1.8	ug/L	0.001	
MPJ	620792.41	1439669.53	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPK	620620.25	1439815.82	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPL	620429.65	1439848.22	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPN	621528.63	1440221.40	cis-1,2-DICHLOROETHENE	11/15/96	7.2	ug/L	0.001	
MPP	621894.23	1439472.55	cis-1,2-DICHLOROETHENE	11/15/96	7.5	ug/L	0.001	
W18	621169.72	1440056.04	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	08/01/96		ug/L	0.001	ND
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	04/01/97	2.3	ug/L	0.001	
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	12/01/97	3.6	ug/L	0.001	
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	03/01/98	2.1	ug/L	0.001	
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	09/01/98		ug/L	0.001	ND
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	04/01/99	2.85	ug/L	0.001	
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	06/01/00	2.19	ug/L	0.001	
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	12/01/00	2.8	ug/L	0.001	
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	12/03/01	2.3	ug/L	0.001	
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	05/30/01	2.7	ug/L	0.001	
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	11/18/02	1.85	ug/L	0.001	
W18	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	05/06/02	1.96	ug/L	0.001	
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	04/01/97	0.4	ug/L	0.001	J
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	12/01/97	0.32	ug/L	0.001	
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	03/01/98		ug/L	0.001	ND
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	09/01/98	0.22	ug/L	0.001	
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	04/01/99	0.49	ug/L	0.001	
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	06/01/00	0.41	ug/L	0.001	
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	12/01/00	0.95	ug/L	0.001	
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	12/03/01	0.25	ug/L	0.001	F
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	05/30/01		ug/L	0.001	ND
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	11/18/02	0.15	ug/L	0.001	F
W81	620830.78	1439155.87	cis-1,2-DICHLOROETHENE	05/06/02	0.34	ug/L	0.001	F
MPB	621168.37	1439643.05	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPG	622741.12	1440365.41	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPH	620642.97	1439306.16	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPM	620650.44	1440089.86	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPQ	622302.94	1439501.90	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
MPR	623216.88	1440344.40	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
W19	621948.89	1440413.50	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
W20	622175.29	1439588.35	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	04/01/97		ug/L	0.001	ND

TABLE C.4B
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE LF-06, COLUMBUS AFB, MISSISSIPPI
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	12/01/97	0.2	ug/L	0.001	
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	03/01/98		ug/L	0.001	ND
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	09/01/98		ug/L	0.001	ND
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	04/01/99		ug/L	0.001	ND
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	06/01/00	5.8	ug/L	0.001	
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	12/01/00	15.4	ug/L	0.001	
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	12/03/01	15	ug/L	0.001	
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	05/30/01	5.5	ug/L	0.001	
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	11/18/02	2.95	ug/L	0.001	
W22	620992.47	1439427.13	cis-1,2-DICHLOROETHENE	05/06/02	4.48	ug/L	0.001	
W78	621658.51	1439168.24	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
W78	621658.51	1439168.24	cis-1,2-DICHLOROETHENE	12/03/01		ug/L	0.001	ND
W78	621658.51	1439168.24	cis-1,2-DICHLOROETHENE	05/30/01		ug/L	0.001	ND
W78	621658.51	1439168.24	cis-1,2-DICHLOROETHENE	11/18/02		ug/L	0.001	ND
W78	621658.51	1439168.24	cis-1,2-DICHLOROETHENE	05/06/02		ug/L	0.001	ND
W79	621310.63	1439177.54	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
W79	621310.63	1439177.54	cis-1,2-DICHLOROETHENE	12/03/01		ug/L	0.001	ND
W79	621310.63	1439177.54	cis-1,2-DICHLOROETHENE	05/30/01		ug/L	0.001	ND
W79	621310.63	1439177.54	cis-1,2-DICHLOROETHENE	11/18/02		ug/L	0.001	ND
W79	621310.63	1439177.54	cis-1,2-DICHLOROETHENE	05/06/02		ug/L	0.001	ND
W82	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	11/15/96		ug/L	0.001	ND
W82	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	04/01/99		ug/L	0.001	ND
W82	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	06/01/00		ug/L	0.001	ND
W82	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	12/01/00	3.65	ug/L	0.001	
W82	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	12/03/01		ug/L	0.001	ND
W82	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	05/30/01		ug/L	0.001	ND
W82	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	11/18/02		ug/L	0.001	ND
W82	620810.93	1439807.23	cis-1,2-DICHLOROETHENE	05/06/02		ug/L	0.001	ND
DW89	620890.00	1439887.00	cis-1,2-DICHLOROETHENE	05/30/01		ug/L	0.270	ND
DW89	620890.00	1439887.00	cis-1,2-DICHLOROETHENE	12/04/01		ug/L	0.200	ND
DW89	620890.00	1439887.00	cis-1,2-DICHLOROETHENE	05/01/02		ug/L	0.020	ND
DW89	620890.00	1439887.00	cis-1,2-DICHLOROETHENE	11/19/02		ug/L	0.051	ND
DW92	620900.00	1439897.00	cis-1,2-DICHLOROETHENE	05/30/01		ug/L	0.270	ND
DW92	620900.00	1439897.00	cis-1,2-DICHLOROETHENE	12/04/01		ug/L	0.200	ND
DW92	620900.00	1439897.00	cis-1,2-DICHLOROETHENE	05/01/02		ug/L	0.020	ND
DW92	620900.00	1439897.00	cis-1,2-DICHLOROETHENE	11/19/02		ug/L	0.051	ND

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, J = estimated value, F = estimated value.

TABLE C.5B
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE LF-06, COLUMBUS AFB, MISSISSIPPI
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MPO	621222.08	1439452.86	VINYL CHLORIDE	11/15/96	8	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	04/01/88	26	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	07/01/88		ug/L	0.001	ND
W21	621616.88	1439564.86	VINYL CHLORIDE	12/01/88	21	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	05/01/89	22	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	11/01/91	10	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	11/01/94	33	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	09/01/95	16	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	11/01/96	10	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	11/15/96	10	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	08/01/96	18.9	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	04/01/97	9.4	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	12/01/97	11	ug/L	0.001	J
W21	621616.88	1439564.86	VINYL CHLORIDE	03/01/98	11	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	09/01/98	12.5	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	04/01/99	11.2	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	06/01/00	7.84	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	12/01/00	9.04	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	12/03/01	10	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	05/30/01	7.6	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	11/18/02	1.48	ug/L	0.001	
W21	621616.88	1439564.86	VINYL CHLORIDE	05/06/02	4.34	ug/L	0.001	
MPAS	621166.02	1439839.59	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
MPAD	621166.02	1439839.59	VINYL CHLORIDE	11/15/96	6.6	ug/L	0.001	
MPCS	621620.45	1440002.24	VINYL CHLORIDE	11/15/96	2	ug/L	0.001	J
MPCD	621620.45	1440002.24	VINYL CHLORIDE	11/15/96	3	ug/L	0.001	
MPDD	621404.39	1439880.21	VINYL CHLORIDE	11/15/96	4.2	ug/L	0.001	
MPFS	621987.11	1440040.79	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
MPFD	621987.11	1440040.79	VINYL CHLORIDE	11/15/96	1.7	ug/L	0.001	J
MPI	620508.39	1439541.56	VINYL CHLORIDE	11/15/96	3.4	ug/L	0.001	
MPJ	620792.41	1439669.53	VINYL CHLORIDE	11/15/96	2.1	ug/L	0.001	J
MPK	620620.25	1439815.82	VINYL CHLORIDE	11/15/96	3	ug/L	0.001	
MPL	620429.65	1439848.22	VINYL CHLORIDE	11/15/96	2.1	ug/L	0.001	J
MPN	621528.63	1440221.40	VINYL CHLORIDE	11/15/96	2.4	ug/L	0.001	J
MPP	621894.23	1439472.55	VINYL CHLORIDE	11/15/96	9	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	04/01/88	15	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	07/01/88		ug/L	0.001	ND
W18	620810.93	1439807.23	VINYL CHLORIDE	05/01/89	15	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	11/01/91	6	ug/L	0.001	J
W18	620810.93	1439807.23	VINYL CHLORIDE	11/01/94	8	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	09/01/95		ug/L	0.001	ND
W18	620810.93	1439807.23	VINYL CHLORIDE	11/01/96	4.9	ug/L	0.001	
W18	621169.72	1440056.04	VINYL CHLORIDE	11/15/96	4.9	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	08/01/96	5.57	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	04/01/97	6.7	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	12/01/97	7.6	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	03/01/98	6.6	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	09/01/98	8.54	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	04/01/99	12.6	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	06/01/00	8.17	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	12/01/00	6.19	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	12/03/01	5.6	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	05/30/01	6.1	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	11/18/02	3	ug/L	0.001	
W18	620810.93	1439807.23	VINYL CHLORIDE	05/06/02	2.76	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	11/01/94	6	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	09/01/95		ug/L	0.001	ND
W81	620830.78	1439155.87	VINYL CHLORIDE	11/01/96	4.8	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	11/15/96	4.8	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	08/01/96	3.66	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	04/01/97	7.4	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	12/01/97	3.8	ug/L	0.001	

TABLE C.5B
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE LF-06, COLUMBUS AFB, MISSISSIPPI
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
W81	620830.78	1439155.87	VINYL CHLORIDE	03/01/98	5.6	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	09/01/98	5.44	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	04/01/99	8.85	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	06/01/00	6.15	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	12/01/00	4.92	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	12/03/01	2.4	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	05/30/01	4.2	ug/L	0.001	
W81	620830.78	1439155.87	VINYL CHLORIDE	11/18/02	0.85	ug/L	0.001	F
W81	620830.78	1439155.87	VINYL CHLORIDE	05/06/02	2.02	ug/L	0.001	
MPB	621168.37	1439643.05	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
MPG	622741.12	1440365.41	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
MPH	620642.97	1439306.16	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
MPM	620650.44	1440089.86	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
MPQ	622302.94	1439501.90	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
MPR	623216.88	1440344.40	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
W19	621948.89	1440413.50	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
W20	622175.29	1439588.35	VINYL CHLORIDE	04/01/88		ug/L	0.001	ND
W20	622175.29	1439588.35	VINYL CHLORIDE	07/01/88		ug/L	0.001	ND
W20	622175.29	1439588.35	VINYL CHLORIDE	05/01/89	9.8	ug/L	0.001	
W20	622175.29	1439588.35	VINYL CHLORIDE	11/01/94	0.4	ug/L	0.001	J
W20	622175.29	1439588.35	VINYL CHLORIDE	09/01/95		ug/L	0.001	ND
W20	622175.29	1439588.35	VINYL CHLORIDE	11/01/96		ug/L	0.001	ND
W20	622175.29	1439588.35	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
W22	620992.47	1439427.13	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
W22	620992.47	1439427.13	VINYL CHLORIDE	04/01/99		ug/L	0.001	ND
W22	620992.47	1439427.13	VINYL CHLORIDE	06/01/00	1.45	ug/L	0.001	
W22	620992.47	1439427.13	VINYL CHLORIDE	12/01/00	3.87	ug/L	0.001	
W22	620992.47	1439427.13	VINYL CHLORIDE	12/03/01	8.1	ug/L	0.001	
W22	620992.47	1439427.13	VINYL CHLORIDE	05/30/01	1.2	ug/L	0.001	
W22	620992.47	1439427.13	VINYL CHLORIDE	11/18/02	0.3	ug/L	0.001	F
W22	620992.47	1439427.13	VINYL CHLORIDE	05/06/02	0.99	ug/L	0.001	F
W78	621658.51	1439168.24	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
W78	621658.51	1439168.24	VINYL CHLORIDE	12/03/01		ug/L	0.001	ND
W78	621658.51	1439168.24	VINYL CHLORIDE	05/30/01		ug/L	0.001	ND
W78	621658.51	1439168.24	VINYL CHLORIDE	11/18/02		ug/L	0.001	ND
W78	621658.51	1439168.24	VINYL CHLORIDE	05/06/02		ug/L	0.001	ND
W79	621310.63	1439177.54	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
W79	621310.63	1439177.54	VINYL CHLORIDE	12/03/01		ug/L	0.001	ND
W79	621310.63	1439177.54	VINYL CHLORIDE	05/30/01		ug/L	0.001	ND
W79	621310.63	1439177.54	VINYL CHLORIDE	11/18/02		ug/L	0.001	ND
W79	621310.63	1439177.54	VINYL CHLORIDE	05/06/02		ug/L	0.001	ND
W80	620830.00	1439156.00	VINYL CHLORIDE	05/30/01		ug/L	0.310	ND
W82	620810.93	1439807.23	VINYL CHLORIDE	11/15/96		ug/L	0.001	ND
W82	620810.93	1439807.23	VINYL CHLORIDE	12/03/01		ug/L	0.001	ND
W82	620810.93	1439807.23	VINYL CHLORIDE	05/30/01		ug/L	0.001	ND
W82	620810.93	1439807.23	VINYL CHLORIDE	11/18/02		ug/L	0.001	ND
W82	620810.93	1439807.23	VINYL CHLORIDE	05/06/02		ug/L	0.001	ND
DW89	620890.00	1439887.00	VINYL CHLORIDE	05/30/01		ug/L	0.310	ND
DW89	620890.00	1439887.00	VINYL CHLORIDE	12/04/01		ug/L	0.320	ND
DW89	620890.00	1439887.00	VINYL CHLORIDE	05/01/02		ug/L	0.060	ND
DW89	620890.00	1439887.00	VINYL CHLORIDE	11/19/02		ug/L	0.065	ND
DW92	620900.00	1439897.00	VINYL CHLORIDE	05/30/01		ug/L	0.310	ND
DW92	620900.00	1439897.00	VINYL CHLORIDE	12/04/01		ug/L	0.320	ND
DW92	620900.00	1439897.00	VINYL CHLORIDE	05/01/02		ug/L	0.060	ND
DW92	620900.00	1439897.00	VINYL CHLORIDE	11/19/02		ug/L	0.065	ND

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, J = estimated value, F = estimated value.

Case Study Data for Northwest Plume, SS-45, England Air Force Base, Louisiana

TABLE C.1C
MAROS LINEAR REGRESSION STATISTICS SUMMARY
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Average Conc (mg/L) [a/]	Median Conc (mg/L)	Standard Deviation	All Samples ND? [b/]	LN Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend [c/]	Designation for Current Analysis
Trichloroethene (TCE)										
SS45LO01MW	S	5.3E-01	5.4E-01	1.0E-01	No	-1.9E-04	0.20	92.9%	PD	Source
A39LO09PZ	T	2.1E-02	1.9E-02	1.1E-02	No	1.6E-04	0.51	66.9%	NT	Plume
A39LO14DP	T	2.6E-04	2.1E-04	2.0E-04	No	-6.9E-04	0.75	79.3%	S	Plume
A39LO28DP	T	4.3E-04	5.0E-04	1.7E-04	No	1.2E-04	0.40	54.3%	NT	Plume
A39LO36DP	T	2.3E-02	2.6E-02	9.2E-03	No	6.0E-04	0.41	100.0%	I	Plume
SS45LO02MW	T	6.9E-03	2.5E-04	1.7E-02	No	2.8E-04	2.52	58.3%	NT	Plume
SS45LO05MW	T	3.3E-04	2.5E-04	7.0E+00	No	2.7E-04	0.52	72.0%	NT	Plume
Well #11	T	9.6E-04	4.1E-04	1.1E-03	No	-1.2E-03	1.09	75.9%	NT	Plume
Well #12	T	1.7E-03	5.0E-04	2.9E-03	No	-5.4E-04	1.71	63.2%	NT	Plume
Well #13	T	2.9E-04	2.3E-04	1.7E-04	No	-9.1E-05	0.57	54.3%	S	Plume
Well #14	T	1.2E-02	8.8E-03	1.2E-02	No	-3.2E-03	1.03	92.6%	PD	Plume
Well #15	T	4.7E-02	3.9E-02	3.2E-02	No	-1.4E-03	0.67	99.8%	D	Plume
Well #16	T	1.7E-03	1.7E-03	5.9E-04	No	5.6E-04	0.36	84.6%	NT	Plume
Well #22	T	5.0E-04	5.0E-04	0.0E+00	Yes	0.0E+00	0.00	100.0%	S * [d/]	Plume
A39LO02PZ	T	5.0E-04	5.0E-04	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
A39LO08PZ	T	5.0E-04	5.0E-04	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
A39LO16PZ	T	4.4E-04	5.0E-04	1.3E-04	Yes	2.1E-03	0.29	87.8%	NT *	Sentry
A39LO27DP	T	5.0E-04	5.0E-04	0.0E+00	Yes	7.3E-34	0.00	100.0%	I *	Sentry
A39LO39DP	T	3.5E-04	5.0E-04	2.3E-04	Yes	2.4E-03	0.66	98.5%	I *	Sentry
Well #18	T	4.4E-04	5.0E-04	1.6E-04	No	9.1E-05	0.36	54.3%	NT	Sentry
Well #19	T	4.3E-04	5.0E-04	1.7E-04	No	1.0E-04	0.39	53.9%	NT	Sentry
Well #21	T	4.3E-04	5.0E-04	1.8E-04	No	1.7E-03	0.42	96.2%	I	Sentry
Well #24	T	4.4E-04	5.0E-04	1.3E-04	Yes	2.3E-03	0.29	90.9%	PI *	Sentry
cis-1,2-Dichloroethene (cis-1,2-DCE)										
SS45LO01MW	S	9.9E-03	1.1E-02	5.5E-03	No	-1.4E-04	0.55	61.3%	S	Source
A39LO09PZ	T	6.1E-02	5.5E-02	2.2E-02	No	-5.6E-04	0.36	100.0%	D	Plume
A39LO14DP	T	3.6E-04	3.0E-04	3.1E-04	No	-7.9E-04	0.85	77.6%	S	Plume
A39LO28DP	T	5.0E-04	6.0E-04	2.0E-04	Yes	1.3E-03	0.39	93.8%	PI *	Plume
A39LO36DP	T	4.1E-03	4.1E-03	1.4E-03	No	4.6E-04	0.33	100.0%	I	Plume
SS45LO02MW	T	1.5E-01	1.7E-01	6.4E-02	No	1.3E-03	0.43	82.5%	NT	Plume
SS45LO05MW	T	3.9E-04	3.9E-04	1.1E-04	No	-5.3E-05	0.23	61.4%	S	Plume
Well #11	T	1.3E-01	1.2E-01	7.8E-02	No	9.4E-04	0.58	81.4%	NT	Plume
Well #12	T	2.0E-02	5.5E-03	3.6E-02	No	4.1E-04	1.78	57.2%	NT	Plume
Well #13	T	3.9E-04	5.0E-04	2.5E-04	No	-4.7E-04	0.64	62.1%	S	Plume
Well #14	T	2.1E-01	2.1E-01	1.7E-01	No	6.8E-04	0.79	68.0%	NT	Plume
Well #15	S	9.0E-02	9.8E-02	2.8E-02	No	2.0E-04	0.31	65.2%	NT	Plume
Well #16	T	9.1E-04	9.0E-04	5.4E-04	No	1.6E-03	0.59	98.4%	I	Plume
Well #17	T	9.4E-03	3.4E-03	9.7E-03	No	3.4E-03	1.03	98.2%	I	Plume
Well #22	T	1.5E-03	1.5E-03	4.5E-05	No	-3.5E-05	0.03	70.3%	S	Plume
A39LO02PZ	T	5.1E-04	5.0E-04	1.1E-04	Yes	2.2E-04	0.23	89.6%	NT *	Sentry
A39LO08PZ	T	3.4E-04	5.0E-04	2.3E-04	No	-6.5E-04	0.69	78.4%	S	Sentry
A39LO16PZ	T	2.1E-04	2.0E-04	2.2E-05	No	-5.1E-04	0.10	82.0%	S	Sentry
A39LO27DP	T	5.8E-04	6.0E-04	4.5E-05	Yes	-2.8E-04	0.08	98.3%	D *	Sentry
A39LO39DP	T	4.4E-04	5.0E-04	1.7E-04	Yes	5.6E-04	0.37	99.8%	I *	Sentry
Well #18	T	1.4E-04	1.5E-04	8.2E-05	No	1.4E-03	0.57	99.1%	I	Sentry
Well #19	T	5.7E-04	6.0E-04	5.2E-05	Yes	7.7E-06	0.09	100.0%	I *	Sentry
Well #21	T	5.7E-04	6.0E-04	5.2E-05	Yes	7.7E-06	0.09	100.0%	I *	Sentry
Well #24	T	4.4E-04	5.0E-04	1.3E-04	Yes	2.3E-03	0.29	90.9%	PI *	Sentry
Vinyl Chloride (VC)										
SS45LO01MW	S	1.6E-03	4.6E-04	3.4E-03	No	9.7E-04	2.16	77.3%	NT	Source
A39LO09PZ	T	1.1E-03	1.1E-03	5.6E-04	No	5.9E-04	0.50	97.9%	I	Plume
A39LO14DP	T	8.1E-04	5.5E-04	8.9E-04	No	-1.4E-03	1.10	95.3%	D	Plume
A39LO28DP	T	5.3E-04	5.5E-04	2.6E-05	Yes	3.9E-06	0.05	100.0%	I *	Plume
A39LO36DP	T	2.6E-04	1.5E-04	2.1E-04	No	5.1E-04	0.81	70.6%	NT	Plume
SS45LO02MW	T	9.1E-03	2.9E-03	1.9E-02	No	6.7E-04	2.03	79.3%	NT	Plume
SS45LO05MW	T	2.8E-04	2.1E-04	2.0E-04	No	4.7E-04	0.72	68.8%	NT	Plume
Well #11	T	3.6E-03	2.7E-03	2.6E-03	No	1.7E-03	0.73	98.4%	I	Plume
Well #12	T	6.7E-04	5.0E-04	7.2E-04	No	-2.3E-04	1.08	56.7%	NT	Plume
Well #13	T	5.3E-04	5.5E-04	2.6E-05	Yes	4.0E-06	0.05	100.0%	I *	Plume
Well #14	T	4.1E-03	4.6E-03	2.4E-03	No	2.2E-03	0.59	97.0%	I	Plume
Well #15	S	1.7E-03	1.4E-03	1.3E-03	No	9.5E-04	0.75	85.3%	NT	Plume
Well #16	T	5.3E-04	5.5E-04	2.6E-05	Yes	3.7E-06	0.05	100.0%	I *	Plume
Well #17	T	4.9E-04	5.5E-04	1.1E-04	Yes	-6.3E-05	0.22	56.1%	S *	Plume
Well #22	T	5.4E-04	5.5E-04	2.2E-05	Yes	-1.5E-04	0.04	98.4%	D *	Plume

TABLE C.1C
MAROS LINEAR REGRESSION STATISTICS SUMMARY
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Average Conc (mg/L) [a]	Median Conc (mg/L)	Standard Deviation	All Samples ND? [b]	LN Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend [c]	Designation for Current Analysis
A39LO02PZ	T	5.2E-04	5.0E-04	2.6E-05	Yes	4.1E-05	0.05	91.9%	PI *	Sentry
A39LO08PZ	T	5.3E-04	5.5E-04	2.7E-05	Yes	3.7E-05	0.05	79.6%	NT *	Sentry
A39LO16PZ	T	4.4E-04	5.0E-04	1.3E-04	Yes	2.1E-03	0.29	87.8%	NT *	Sentry
A39LO27DP	T	5.4E-04	5.5E-04	2.2E-05	Yes	-1.5E-04	0.04	98.3%	D *	Sentry
A39LO39DP	T	5.2E-04	5.0E-04	2.6E-05	Yes	4.1E-05	0.05	92.0%	PI *	Sentry
Well #18	T	5.3E-04	5.5E-04	2.6E-05	Yes	3.8E-06	0.05	100.0%	I *	Sentry
Well #19	T	5.3E-04	5.5E-04	2.6E-05	Yes	4.0E-06	0.05	100.0%	I *	Sentry
Well #21	T	5.3E-04	5.5E-04	2.6E-05	Yes	4.0E-06	0.05	100.0%	I *	Sentry
Well #24	T	4.4E-04	5.0E-04	1.3E-04	Yes	2.3E-03	0.29	90.9%	PI *	Sentry

[a] mg/L = milligrams per liter.

[b] ND = non-detect.

[c] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[d] * indicates that the concentrations at this well were reported as non detect (ND) for every sampling event available.

TABLE C.2C
MAROS MANN-KENDALL STATISTICS SUMMARY
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples ND? [a/]	Concentration Trend [b/]	Designation for Current Analysis
Trichloroethene (TCE)									
SS45LO01MW	S	7	7	0.20	-9	88.1%	No	S	Source
A39LO09PZ	T	8	8	0.51	-5	68.3%	No	S	Plume
A39LO14DP	T	6	4	0.75	-4	7.0E-01	No	S	Plume
A39LO28DP	T	6	1	0.40	1	5.0E-01	No	NT	Plume
A39LO36DP	T	7	7	0.41	19	99.9%	No	I	Plume
SS45LO02MW	T	8	4	2.52	-7	7.6E-01	No	NT	Plume
SS45LO05MW	T	7	1	0.52	9	88.1%	No	NT	Plume
Well #11	S	6	3	1.09	-3	64.0%	No	NT	Plume
Well #12	T	6	1	1.71	-3	6.4E-01	No	NT	Plume
Well #13	T	6	4	0.57	-2	57.0%	No	S	Plume
Well #14	T	6	6	1.03	-7	8.6E-01	No	NT	Plume
Well #15	S	6	6	0.67	-14	99.6%	No	D	Plume
Well #16	T	6	6	0.36	7	8.6E-01	No	NT	Plume
Well #17	T	6	6	0.42	-1	50.0%	No	S	Plume
Well #22	T	5	0	0.00	0	40.8%	Yes	S * [c/]	Plume
A39LO02PZ	T	8	0	0.00	0	4.5E-01	Yes	S *	Sentry
A39LO08PZ	T	7	0	0.00	0	4.4E-01	Yes	S *	Sentry
A39LO16PZ	T	4	0	0.29	3	7.3E-01	Yes	NT *	Sentry
A39LO27DP	T	5	0	0.00	0	4.1E-01	Yes	S *	Sentry
A39LO39DP	T	8	0	0.66	17	97.7%	Yes	I *	Sentry
Well #18	T	6	1	0.36	1	5.0E-01	No	NT	Sentry
Well #19	T	6	1	0.39	1	50.0%	No	NT	Sentry
Well #21	T	6	1	0.42	5	76.5%	No	NT	Sentry
Well #24	T	4	0	0.29	3	72.9%	Yes	NT *	Sentry
cis-1,2-Dichloroethene (cis-1,2-DCE)									
SS45LOO1MW	S	8	8	0.55	0	45.2%	No	S	Source
A39LO09PZ	T	8	8	0.36	-24	99.9%	No	D	Plume
A39LO14DP	T	6	4	0.85	-4	7.0E-01	No	S	Plume
A39LO28DP	T	6	0	0.39	1	5.0E-01	Yes	NT *	Plume
A39LO36DP	T	8	8	0.33	20	99.3%	No	I	Plume
SS45LO02MW	T	8	7	0.43	5	6.8E-01	No	NT	Plume
SS45LO05MW	T	8	8	0.29	-2	54.8%	No	S	Plume
Well #11	S	6	6	0.58	5	76.5%	No	NT	Plume
Well #12	T	6	6	1.78	-1	5.0E-01	No	NT	Plume
Well #13	T	6	2	0.64	-3	64.0%	No	S	Plume
Well #14	T	6	6	0.79	7	8.6E-01	No	NT	Plume
Well #15	S	6	6	0.31	6	81.5%	No	NT	Plume
Well #16	T	6	6	0.59	15	1.0E+00	No	I	Plume
Well #17	T	7	6	1.03	17	99.5%	No	I	Plume
Well #22	T	5	5	0.03	-2	59.2%	No	S	Plume
A39LO02PZ	T	8	0	0.23	9	8.3E-01	Yes	NT *	Sentry
A39LO08PZ	T	7	3	0.69	-5	7.2E-01	No	S	Sentry
A39LO16PZ	T	4	4	0.10	-2	6.3E-01	No	S	Sentry
A39LO27DP	T	5	0	0.08	-4	7.6E-01	Yes	S *	Sentry
A39LO39DP	T	8	0	0.37	15	95.8%	Yes	I *	Sentry
Well #18	T	6	4	0.57	12	9.8E-01	No	I	Sentry
Well #19	T	6	0	0.09	0	42.3%	Yes	S *	Sentry
Well #21	T	6	0	0.09	0	42.3%	Yes	S *	Sentry
Well #24	T	4	0	0.29	3	72.9%	Yes	NT *	Sentry
Vinyl Chloride (VC)									
SS45LOO1MW	S	8	4	2.16	6	72.6%	No	NT	Source
A39LO09PZ	T	8	6	0.50	15	95.8%	No	I	Plume
A39LO14DP	T	6	2	1.10	-10	95.2%	No	D	Plume
A39LO28DP	T	6	0	0.05	0	42.3%	Yes	S *	Plume
A39LO36DP	T	8	4	0.81	-1	50.0%	No	S	Plume
SS45LO02MW	T	8	6	2.03	4	64.0%	No	NT	Plume
SS45LO05MW	T	8	4	0.72	-1	50.0%	No	S	Plume
Well #11	S	6	6	0.73	11	97.0%	No	I	Plume
Well #12	T	6	3	1.08	0	0.4%	No	NT	Plume
Well #13	T	6	0	0.05	0	42.3%	Yes	S *	Plume

TABLE C.2C
MAROS MANN-KENDALL STATISTICS SUMMARY
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples ND? [a/]	Concentration Trend [b/]	Designation for Current Analysis
Well #14	T	6	6	0.59	3	64.0%	No	NT	Plume
Well #15	S	6	6	0.75	5	76.5%	No	NT	Plume
Well #16	T	6	0	0.05	0	42.3%	Yes	S *	Plume
Well #17	T	7	0	0.22	-2	55.7%	Yes	S *	Plume
Well #22	T	5	0	0.04	-4	75.8%	Yes	S *	Plume
A39LO02PZ	T	8	0	0.05	9	83.2%	Yes	NT *	Sentry
A39LO08PZ	T	7	0	0.05	4	66.7%	Yes	NT *	Sentry
A39LO16PZ	T	4	0	0.29	3	72.9%	Yes	NT *	Sentry
A39LO27DP	T	5	0	0.04	-4	75.8%	Yes	S *	Sentry
A39LO39DP	T	8	0	0.05	9	83.2%	Yes	NT *	Sentry
Well #18	T	6	0	0.05	0	42.3%	Yes	S *	Sentry
Well #19	T	6	0	0.05	0	42.3%	Yes	S *	Sentry
Well #21	T	6	0	0.05	0	42.3%	Yes	S *	Sentry
Well #24	T	4	0	0.29	3	72.9%	Yes	NT *	Sentry

[a/] ND = non-detect.

[b/] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[c/] * indicates that the concentrations at this well were reported as non detect (ND) for every sampling event available.

TABLE C.3C
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
SS45LOO1MW	1988025.86	240183.74	TRICHLOROETHENE (TCE)	06/01/97	451	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	TRICHLOROETHENE (TCE)	09/01/97	697	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	TRICHLOROETHENE (TCE)	12/01/97	598	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	TRICHLOROETHENE (TCE)	03/01/99	560	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	TRICHLOROETHENE (TCE)	05/15/00	510	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	TRICHLOROETHENE (TCE)	10/20/00	540	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	TRICHLOROETHENE (TCE)	03/20/02	370	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	TRICHLOROETHENE (TCE)	06/01/97	35.8	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	TRICHLOROETHENE (TCE)	09/01/97	9	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	TRICHLOROETHENE (TCE)	12/01/97	6.93	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	TRICHLOROETHENE (TCE)	03/01/99	34	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	TRICHLOROETHENE (TCE)	05/15/00	25	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	TRICHLOROETHENE (TCE)	10/20/00	17	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	TRICHLOROETHENE (TCE)	03/12/01	20	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	TRICHLOROETHENE (TCE)	03/20/02	17	ug/l	0.01	
A39LO14DP	1988962.30	240367.69	TRICHLOROETHENE (TCE)	12/1/1997		ug/l	1	ND
A39LO14DP	1988962.30	240367.69	TRICHLOROETHENE (TCE)	5/11/2000		ug/l	1	ND
A39LO14DP	1988962.30	240367.69	TRICHLOROETHENE (TCE)	8/14/2000	0.16	ug/l	1	TR
A39LO14DP	1988962.30	240367.69	TRICHLOROETHENE (TCE)	10/24/2000	0.14	ug/l	1	TR
A39LO14DP	1988962.30	240367.69	TRICHLOROETHENE (TCE)	3/13/2001	0.3	ug/l	1	TR
A39LO14DP	1988962.30	240367.69	TRICHLOROETHENE (TCE)	3/20/2002	0.55	ug/l	1	TR
A39LO36DP	1987131.17	239247.70	TRICHLOROETHENE (TCE)	06/01/97	11	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	TRICHLOROETHENE (TCE)	09/01/97	12.9	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	TRICHLOROETHENE (TCE)	12/01/97	15.8	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	TRICHLOROETHENE (TCE)	10/20/00	26	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	TRICHLOROETHENE (TCE)	12/01/00	29	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	TRICHLOROETHENE (TCE)	03/12/01	34	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	TRICHLOROETHENE (TCE)	03/20/02	30	ug/l	0.01	
Well#11	1988082.96	240028.65	TRICHLOROETHENE (TCE)	03/01/99		ug/l	4.2	ND
Well#11	1988082.96	240028.65	TRICHLOROETHENE (TCE)	05/15/00		ug/l	1	ND
Well#11	1988082.96	240028.65	TRICHLOROETHENE (TCE)	08/15/00	0.47	ug/l	0.01	TR
Well#11	1988082.96	240028.65	TRICHLOROETHENE (TCE)	10/20/00	0.25	ug/l	0.01	TR
Well#11	1988082.96	240028.65	TRICHLOROETHENE (TCE)	03/12/01		ug/l	5	ND
Well#11	1988082.96	240028.65	TRICHLOROETHENE (TCE)	03/20/02	0.64	ug/l	0.01	TR
Well#13	1988661.28	240491.55	TRICHLOROETHENE (TCE)	03/01/99		ug/l	1	ND
Well#13	1988661.28	240491.55	TRICHLOROETHENE (TCE)	05/15/00	0.5	ug/l	0.01	TR
Well#13	1988661.28	240491.55	TRICHLOROETHENE (TCE)	08/15/00	0.36	ug/l	0.01	TR
Well#13	1988661.28	240491.55	TRICHLOROETHENE (TCE)	10/20/00	0.24	ug/l	0.01	TR
Well#13	1988661.28	240491.55	TRICHLOROETHENE (TCE)	03/12/01	0.41	ug/l	0.01	TR
Well#13	1988661.28	240491.55	TRICHLOROETHENE (TCE)	03/20/02		ug/l	1	ND
Well#15	1988258.48	240384.17	TRICHLOROETHENE (TCE)	03/01/99	110	ug/l	0.01	
Well#15	1988258.48	240384.17	TRICHLOROETHENE (TCE)	05/15/00	46	ug/l	0.01	
Well#15	1988258.48	240384.17	TRICHLOROETHENE (TCE)	08/15/00	39	ug/l	0.01	
Well#15	1988258.48	240384.17	TRICHLOROETHENE (TCE)	10/20/00	39	ug/l	0.01	
Well#15	1988258.48	240384.17	TRICHLOROETHENE (TCE)	03/12/01	26	ug/l	0.01	
Well#15	1988258.48	240384.17	TRICHLOROETHENE (TCE)	03/20/02	24	ug/l	0.01	
Well#17	1988517.55	241116.22	TRICHLOROETHENE (TCE)	03/01/99	9.8	ug/l	0.01	
Well#17	1988517.55	241116.22	TRICHLOROETHENE (TCE)	08/15/00	38	ug/l	0.01	
Well#17	1988517.55	241116.22	TRICHLOROETHENE (TCE)	10/20/00	37	ug/l	0.01	
Well#17	1988517.55	241116.22	TRICHLOROETHENE (TCE)	12/01/00	20	ug/l	0.01	
Well#17	1988517.55	241116.22	TRICHLOROETHENE (TCE)	03/12/01	26	ug/l	0.01	
Well#17	1988517.55	241116.22	TRICHLOROETHENE (TCE)	03/20/02	23	ug/l	0.01	
Well#22	1989357.77	239983.11	TRICHLOROETHENE (TCE)	05/15/00		ug/l	1	ND
Well#22	1989357.77	239983.11	TRICHLOROETHENE (TCE)	08/15/00		ug/l	1	ND
Well#22	1989357.77	239983.11	TRICHLOROETHENE (TCE)	10/20/00		ug/l	1	ND
Well#22	1989357.77	239983.11	TRICHLOROETHENE (TCE)	03/12/01		ug/l	1	ND
Well#22	1989357.77	239983.11	TRICHLOROETHENE (TCE)	03/20/02		ug/l	1	ND
SS45LOO5MW	1988349.09	238944.02	TRICHLOROETHENE (TCE)	06/01/97		ug/l	0.5	ND
SS45LOO5MW	1988349.09	238944.02	TRICHLOROETHENE (TCE)	09/01/97		ug/l	0.5	ND
SS45LOO5MW	1988349.09	238944.02	TRICHLOROETHENE (TCE)	12/01/97		ug/l	0.5	ND
SS45LOO5MW	1988349.09	238944.02	TRICHLOROETHENE (TCE)	08/15/00	0.13	ug/l	0.01	TR

TABLE C.3C
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
SS45LOO5MW	1988349.09	238944.02	TRICHLOROETHENE (TCE)	10/20/00		ug/l	1	ND
SS45LOO5MW	1988349.09	238944.02	TRICHLOROETHENE (TCE)	03/12/01		ug/l	1	ND
SS45LOO5MW	1988349.09	238944.02	TRICHLOROETHENE (TCE)	03/20/02		ug/l	1	ND
A39LO28DP	1988324.68	240122.50	TRICHLOROETHENE (TCE)	3/1/1999		ug/l	1	ND
A39LO28DP	1988324.68	240122.50	TRICHLOROETHENE (TCE)	5/15/2000		ug/l	1	ND
A39LO28DP	1988324.68	240122.50	TRICHLOROETHENE (TCE)	8/10/2000	0.16	ug/l	1	TR
A39LO28DP	1988324.68	240122.50	TRICHLOROETHENE (TCE)	10/18/2000		ug/l	1	ND
A39LO28DP	1988324.68	240122.50	TRICHLOROETHENE (TCE)	3/14/2001		ug/l	1	ND
A39LO28DP	1988324.68	240122.50	TRICHLOROETHENE (TCE)	3/19/2002		ug/l	1	ND
SS45LOO2MW	1988088.69	240181.59	TRICHLOROETHENE (TCE)	06/01/97		ug/l	0.5	ND
SS45LOO2MW	1988088.69	240181.59	TRICHLOROETHENE (TCE)	09/01/97	0.37	ug/l	0.5	TR
SS45LOO2MW	1988088.69	240181.59	TRICHLOROETHENE (TCE)	12/01/97		ug/l	0.5	ND
SS45LOO2MW	1988088.69	240181.59	TRICHLOROETHENE (TCE)	03/01/99		ug/l	8.3	ND
SS45LOO2MW	1988088.69	240181.59	TRICHLOROETHENE (TCE)	05/15/00		ug/l	100	ND
SS45LOO2MW	1988088.69	240181.59	TRICHLOROETHENE (TCE)	10/19/00	0.48	ug/l	0.5	TR
SS45LOO2MW	1988088.69	240181.59	TRICHLOROETHENE (TCE)	03/12/01	0.47	ug/l	0.5	TR
SS45LOO2MW	1988088.69	240181.59	TRICHLOROETHENE (TCE)	03/20/02	0.34	ug/l	0.5	TR
Well #12	1988071.39	240018.02	TRICHLOROETHENE (TCE)	3/1/1999		ug/l	1	ND
Well #12	1988071.39	240018.02	TRICHLOROETHENE (TCE)	5/11/2000	7.5	ug/l	1	
Well #12	1988071.39	240018.02	TRICHLOROETHENE (TCE)	8/8/2000		ug/l	1	ND
Well #12	1988071.39	240018.02	TRICHLOROETHENE (TCE)	10/24/2000		ug/l	1	ND
Well #12	1988071.39	240018.02	TRICHLOROETHENE (TCE)	3/9/2001		ug/l	1	ND
Well #12	1988071.39	240018.02	TRICHLOROETHENE (TCE)	3/21/2002		ug/l	1	ND
Well #14	1988276.49	240390.50	TRICHLOROETHENE (TCE)	3/1/1999	15	ug/l	1	
Well #14	1988276.49	240390.50	TRICHLOROETHENE (TCE)	5/15/2000	30	ug/l	1	
Well #14	1988276.49	240390.50	TRICHLOROETHENE (TCE)	8/14/2000	2.5	ug/l	1	
Well #14	1988276.49	240390.50	TRICHLOROETHENE (TCE)	10/20/2000	4.1	ug/l	1	TR
Well #14	1988276.49	240390.50	TRICHLOROETHENE (TCE)	3/12/2001	20	ug/l	1	
Well #14	1988276.49	240390.50	TRICHLOROETHENE (TCE)	3/21/2002	0.6	ug/l	1	TR
Well #16	1988154.58	241090.04	TRICHLOROETHENE (TCE)	3/1/1999	1.4	ug/l	1	
Well #16	1988154.58	241090.04	TRICHLOROETHENE (TCE)	5/16/2000	1.3	ug/l	1	
Well #16	1988154.58	241090.04	TRICHLOROETHENE (TCE)	8/11/2000	1.6	ug/l	1	TR
Well #16	1988154.58	241090.04	TRICHLOROETHENE (TCE)	10/18/2000	2	ug/l	1	
Well #16	1988154.58	241090.04	TRICHLOROETHENE (TCE)	3/13/2001	2.3	ug/l	1	
Well #16	1988154.58	241090.04	TRICHLOROETHENE (TCE)	3/21/2002	2.2	ug/l	1	
A39LO16PZ	1987126.39	238276.09	TRICHLOROETHENE (TCE)	6/1/2001		ug/l	0.5	ND
A39LO16PZ	1987126.39	238276.09	TRICHLOROETHENE (TCE)	9/1/2001		ug/l	1	ND
A39LO16PZ	1987126.39	238276.09	TRICHLOROETHENE (TCE)	12/1/2001		ug/l	1	ND
A39LO16PZ	1987126.39	238276.09	TRICHLOROETHENE (TCE)	3/21/2002		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	TRICHLOROETHENE (TCE)	06/01/97		ug/l	0.01	ND
A39LO39DP	1986510.40	240027.24	TRICHLOROETHENE (TCE)	09/01/97		ug/l	0.01	ND
A39LO39DP	1986510.40	240027.24	TRICHLOROETHENE (TCE)	12/01/97		ug/l	0.5	ND
A39LO39DP	1986510.40	240027.24	TRICHLOROETHENE (TCE)	03/01/99		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	TRICHLOROETHENE (TCE)	05/15/00		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	TRICHLOROETHENE (TCE)	10/20/00		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	TRICHLOROETHENE (TCE)	03/12/01		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	TRICHLOROETHENE (TCE)	03/20/02		ug/l	1	ND
Well#19	1987589.51	241223.83	TRICHLOROETHENE (TCE)	03/01/99		ug/l	1	ND
Well#19	1987589.51	241223.83	TRICHLOROETHENE (TCE)	05/15/00		ug/l	1	ND
Well#19	1987589.51	241223.83	TRICHLOROETHENE (TCE)	08/15/00	0.17	ug/l	0.01	TR
Well#19	1987589.51	241223.83	TRICHLOROETHENE (TCE)	10/20/00		ug/l	1	ND
Well#19	1987589.51	241223.83	TRICHLOROETHENE (TCE)	03/12/01		ug/l	1	ND
Well#19	1987589.51	241223.83	TRICHLOROETHENE (TCE)	03/20/02		ug/l	1	ND
Well#21	1988608.26	241437.57	TRICHLOROETHENE (TCE)	03/01/99	0.13	ug/l	0.01	TR
Well#21	1988608.26	241437.57	TRICHLOROETHENE (TCE)	05/15/00		ug/l	1	ND
Well#21	1988608.26	241437.57	TRICHLOROETHENE (TCE)	08/15/00		ug/l	1	ND
Well#21	1988608.26	241437.57	TRICHLOROETHENE (TCE)	10/20/00		ug/l	1	ND
Well#21	1988608.26	241437.57	TRICHLOROETHENE (TCE)	03/12/01		ug/l	1	ND
Well#21	1988608.26	241437.57	TRICHLOROETHENE (TCE)	03/20/02		ug/l	1	ND
Well #24	1989357.77	239983.11	TRICHLOROETHENE (TCE)	6/1/2001		ug/l	0.5	ND
Well #24	1989357.77	239983.11	TRICHLOROETHENE (TCE)	10/1/2001		ug/l	1	ND

TABLE C.3C
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
Well #24	1989357.77	239983.11	TRICHLOROETHENE (TCE)	12/1/2001		ug/l	1	ND
Well #24	1989357.77	239983.11	TRICHLOROETHENE (TCE)	3/19/2002		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	TRICHLOROETHENE (TCE)	6/1/1997		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	TRICHLOROETHENE (TCE)	9/1/1997		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	TRICHLOROETHENE (TCE)	12/1/1997		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	TRICHLOROETHENE (TCE)	3/1/1999		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	TRICHLOROETHENE (TCE)	5/10/2000		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	TRICHLOROETHENE (TCE)	10/19/2000		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	TRICHLOROETHENE (TCE)	3/13/2001		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	TRICHLOROETHENE (TCE)	3/20/2002		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	TRICHLOROETHENE (TCE)	12/1/1997		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	TRICHLOROETHENE (TCE)	3/1/1999		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	TRICHLOROETHENE (TCE)	5/11/2000		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	TRICHLOROETHENE (TCE)	8/14/2000		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	TRICHLOROETHENE (TCE)	10/24/2000		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	TRICHLOROETHENE (TCE)	3/13/2001		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	TRICHLOROETHENE (TCE)	3/20/2002		ug/l	1	ND
A39LO27DP	1987750.95	239697.83	TRICHLOROETHENE (TCE)	5/15/2000		ug/l	1	ND
A39LO27DP	1987750.95	239697.83	TRICHLOROETHENE (TCE)	8/15/2000		ug/l	1	ND
A39LO27DP	1987750.95	239697.83	TRICHLOROETHENE (TCE)	10/23/2000		ug/l	1	ND
A39LO27DP	1987750.95	239697.83	TRICHLOROETHENE (TCE)	3/14/2001		ug/l	1	ND
A39LO27DP	1987750.95	239697.83	TRICHLOROETHENE (TCE)	3/19/2002		ug/l	1	ND
Well #18	1987611.24	241236.21	TRICHLOROETHENE (TCE)	3/1/1999		ug/l	1	ND
Well #18	1987611.24	241236.21	TRICHLOROETHENE (TCE)	5/12/2000		ug/l	1	ND
Well #18	1987611.24	241236.21	TRICHLOROETHENE (TCE)	8/10/2000	0.24	ug/l	1	TR
Well #18	1987611.24	241236.21	TRICHLOROETHENE (TCE)	10/23/2000		ug/l	1	ND
Well #18	1987611.24	241236.21	TRICHLOROETHENE (TCE)	3/12/2001		ug/l	1	ND
Well #18	1987611.24	241236.21	TRICHLOROETHENE (TCE)	3/20/2002		ug/l	1	ND

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, TR = trace or estimated value.

TABLE C.4C
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units[a/]	DetLim	Flags[b/]
SS45LOO1MW	1988025.86	240183.74	cis-1,2-DICHLOROETHENE	06/01/97	4.31	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	cis-1,2-DICHLOROETHENE	09/01/97	14.7	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	cis-1,2-DICHLOROETHENE	12/01/97	16.8	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	cis-1,2-DICHLOROETHENE	03/01/99	12	ug/l	0.01	TR
SS45LOO1MW	1988025.86	240183.74	cis-1,2-DICHLOROETHENE	05/15/00	8.9	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	cis-1,2-DICHLOROETHENE	10/20/00	13	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	cis-1,2-DICHLOROETHENE	03/12/01	1.8	ug/l	0.01	
SS45LOO1MW	1988025.86	240183.74	cis-1,2-DICHLOROETHENE	03/20/02	14	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	cis-1,2-DICHLOROETHENE	06/01/97	80.3	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	cis-1,2-DICHLOROETHENE	09/01/97	95.7	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	cis-1,2-DICHLOROETHENE	12/01/97	79.8	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	cis-1,2-DICHLOROETHENE	03/01/99	57	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	cis-1,2-DICHLOROETHENE	05/15/00	53	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	cis-1,2-DICHLOROETHENE	10/20/00	47	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	cis-1,2-DICHLOROETHENE	03/12/01	51	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	cis-1,2-DICHLOROETHENE	03/20/02	27	ug/l	0.01	
A39LO14DP	1988962.30	240367.69	cis-1,2-DICHLOROETHENE	12/1/1997	0.772	ug/l	1	
A39LO14DP	1988962.30	240367.69	cis-1,2-DICHLOROETHENE	5/11/2000		ug/l	1.2	ND
A39LO14DP	1988962.30	240367.69	cis-1,2-DICHLOROETHENE	8/14/2000	0.16	ug/l	1	TR
A39LO14DP	1988962.30	240367.69	cis-1,2-DICHLOROETHENE	10/24/2000	0.19	ug/l	1	TR
A39LO14DP	1988962.30	240367.69	cis-1,2-DICHLOROETHENE	3/13/2001	0.19	ug/l	1	TR
A39LO14DP	1988962.30	240367.69	cis-1,2-DICHLOROETHENE	3/20/2002		ug/l	1	ND
A39LO36DP	1987131.17	239247.70	cis-1,2-DICHLOROETHENE	06/01/97	2.53	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	cis-1,2-DICHLOROETHENE	09/01/97	2.95	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	cis-1,2-DICHLOROETHENE	12/01/97	2.87	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	cis-1,2-DICHLOROETHENE	05/15/00	4.6	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	cis-1,2-DICHLOROETHENE	10/20/00	4.2	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	cis-1,2-DICHLOROETHENE	12/01/00	4	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	cis-1,2-DICHLOROETHENE	03/12/01	4.9	ug/l	0.01	
A39LO36DP	1987131.17	239247.70	cis-1,2-DICHLOROETHENE	03/20/02	6.7	ug/l	0.01	
Well#11	1988082.96	240028.65	cis-1,2-DICHLOROETHENE	03/01/99	120	ug/l	0.01	
Well#11	1988082.96	240028.65	cis-1,2-DICHLOROETHENE	05/15/00	28	ug/l	0.01	
Well#11	1988082.96	240028.65	cis-1,2-DICHLOROETHENE	08/15/00	110	ug/l	0.01	
Well#11	1988082.96	240028.65	cis-1,2-DICHLOROETHENE	10/20/00	96	ug/l	0.01	
Well#11	1988082.96	240028.65	cis-1,2-DICHLOROETHENE	03/12/01	230	ug/l	0.01	
Well#11	1988082.96	240028.65	cis-1,2-DICHLOROETHENE	03/20/02	220	ug/l	0.01	
Well#13	1988661.28	240491.55	cis-1,2-DICHLOROETHENE	03/01/99		ug/l	1	ND
Well#13	1988661.28	240491.55	cis-1,2-DICHLOROETHENE	05/15/00		ug/l	1.2	ND
Well#13	1988661.28	240491.55	cis-1,2-DICHLOROETHENE	08/15/00	0.18	ug/l	0.01	TR
Well#13	1988661.28	240491.55	cis-1,2-DICHLOROETHENE	10/20/00		ug/l	1.2	ND
Well#13	1988661.28	240491.55	cis-1,2-DICHLOROETHENE	03/12/01	0.12	ug/l	0.01	TR
Well#13	1988661.28	240491.55	cis-1,2-DICHLOROETHENE	03/20/02		ug/l	1	ND
Well#15	1988258.48	240384.17	cis-1,2-DICHLOROETHENE	03/01/99	110	ug/l	0.01	
Well#15	1988258.48	240384.17	cis-1,2-DICHLOROETHENE	05/15/00	50	ug/l	0.01	
Well#15	1988258.48	240384.17	cis-1,2-DICHLOROETHENE	08/15/00	64	ug/l	0.01	
Well#15	1988258.48	240384.17	cis-1,2-DICHLOROETHENE	10/20/00	86	ug/l	0.01	
Well#15	1988258.48	240384.17	cis-1,2-DICHLOROETHENE	03/12/01	120	ug/l	0.01	
Well#15	1988258.48	240384.17	cis-1,2-DICHLOROETHENE	03/20/02	110	ug/l	0.01	
Well#17	1988517.55	241116.22	cis-1,2-DICHLOROETHENE	03/01/99	1	ug/l	0.01	
Well#17	1988517.55	241116.22	cis-1,2-DICHLOROETHENE	05/15/00		ug/l	1.2	ND
Well#17	1988517.55	241116.22	cis-1,2-DICHLOROETHENE	08/15/00	3.1	ug/l	0.01	
Well#17	1988517.55	241116.22	cis-1,2-DICHLOROETHENE	10/20/00	3.4	ug/l	0.01	
Well#17	1988517.55	241116.22	cis-1,2-DICHLOROETHENE	12/01/00	14	ug/l	0.01	
Well#17	1988517.55	241116.22	cis-1,2-DICHLOROETHENE	03/12/01	23	ug/l	0.01	
Well#17	1988517.55	241116.22	cis-1,2-DICHLOROETHENE	03/20/02	21	ug/l	0.01	
Well#22	1989357.77	239983.11	cis-1,2-DICHLOROETHENE	05/15/00	1.5	ug/l	0.01	
Well#22	1989357.77	239983.11	cis-1,2-DICHLOROETHENE	08/15/00	1.6	ug/l	0.01	
Well#22	1989357.77	239983.11	cis-1,2-DICHLOROETHENE	10/20/00	1.5	ug/l	0.01	
Well#22	1989357.77	239983.11	cis-1,2-DICHLOROETHENE	03/12/01	1.5	ug/l	0.01	
Well#22	1989357.77	239983.11	cis-1,2-DICHLOROETHENE	03/20/02	1.5	ug/l	0.01	
SS45LOO5MW	1988349.09	238944.02	cis-1,2-DICHLOROETHENE	06/01/97	0.472	ug/l	0.01	TR

TABLE C.4C
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
SS45LOO5MW	1988349.09	238944.02	cis-1,2-DICHLOROETHENE	09/01/97	0.602	ug/l	0.01	
SS45LOO5MW	1988349.09	238944.02	cis-1,2-DICHLOROETHENE	12/01/97	0.472	ug/l	0.01	
SS45LOO5MW	1988349.09	238944.02	cis-1,2-DICHLOROETHENE	05/15/00	0.42	ug/l	0.01	
SS45LOO5MW	1988349.09	238944.02	cis-1,2-DICHLOROETHENE	08/15/00	0.6	ug/l	0.01	TR
SS45LOO5MW	1988349.09	238944.02	cis-1,2-DICHLOROETHENE	10/20/00	0.66	ug/l	0.01	TR
SS45LOO5MW	1988349.09	238944.02	cis-1,2-DICHLOROETHENE	03/12/01	0.77	ug/l	0.01	TR
SS45LOO5MW	1988349.09	238944.02	cis-1,2-DICHLOROETHENE	03/20/02	0.78	ug/l	0.01	TR
A39LO28DP	1988324.68	240122.50	cis-1,2-DICHLOROETHENE	3/1/1999		ug/l	0.22	ND
A39LO28DP	1988324.68	240122.50	cis-1,2-DICHLOROETHENE	5/15/2000		ug/l	1.2	ND
A39LO28DP	1988324.68	240122.50	cis-1,2-DICHLOROETHENE	8/10/2000		ug/l	1.2	ND
A39LO28DP	1988324.68	240122.50	cis-1,2-DICHLOROETHENE	10/18/2000		ug/l	1.2	ND
A39LO28DP	1988324.68	240122.50	cis-1,2-DICHLOROETHENE	3/14/2001		ug/l	1.2	ND
A39LO28DP	1988324.68	240122.50	cis-1,2-DICHLOROETHENE	3/19/2002		ug/l	1	ND
SS45LOO2MW	1988088.69	240181.59	cis-1,2-DICHLOROETHENE	06/01/97	128	ug/l	0.5	
SS45LOO2MW	1988088.69	240181.59	cis-1,2-DICHLOROETHENE	09/01/97	186	ug/l	0.5	
SS45LOO2MW	1988088.69	240181.59	cis-1,2-DICHLOROETHENE	12/01/97		ug/l	0.5	ND
SS45LOO2MW	1988088.69	240181.59	cis-1,2-DICHLOROETHENE	03/01/99	210	ug/l	0.5	
SS45LOO2MW	1988088.69	240181.59	cis-1,2-DICHLOROETHENE	05/15/00	150	ug/l	0.5	
SS45LOO2MW	1988088.69	240181.59	cis-1,2-DICHLOROETHENE	10/19/00	170	ug/l	0.5	
SS45LOO2MW	1988088.69	240181.59	cis-1,2-DICHLOROETHENE	03/12/01	170	ug/l	0.5	
SS45LOO2MW	1988088.69	240181.59	cis-1,2-DICHLOROETHENE	03/20/02	170	ug/l	0.5	
Well #12	1988071.39	240018.02	cis-1,2-DICHLOROETHENE	3/1/1999	1	ug/l	1	
Well #12	1988071.39	240018.02	cis-1,2-DICHLOROETHENE	5/11/2000	92	ug/l	1	
Well #12	1988071.39	240018.02	cis-1,2-DICHLOROETHENE	8/8/2000	7.4	ug/l	1	
Well #12	1988071.39	240018.02	cis-1,2-DICHLOROETHENE	10/24/2000	13	ug/l	1	
Well #12	1988071.39	240018.02	cis-1,2-DICHLOROETHENE	3/9/2001	2.9	ug/l	1	
Well #12	1988071.39	240018.02	cis-1,2-DICHLOROETHENE	3/21/2002	3.6	ug/l	1	
Well #14	1988276.49	240390.50	cis-1,2-DICHLOROETHENE	3/1/1999	44	ug/l	1	
Well #14	1988276.49	240390.50	cis-1,2-DICHLOROETHENE	5/15/2000	340	ug/l	1	
Well #14	1988276.49	240390.50	cis-1,2-DICHLOROETHENE	8/14/2000	120	ug/l	1	TR
Well #14	1988276.49	240390.50	cis-1,2-DICHLOROETHENE	10/20/2000	350	ug/l	1	
Well #14	1988276.49	240390.50	cis-1,2-DICHLOROETHENE	3/12/2001	390	ug/l	1	
Well #14	1988276.49	240390.50	cis-1,2-DICHLOROETHENE	3/21/2002	77	ug/l	1	
Well #16	1988154.58	241090.04	cis-1,2-DICHLOROETHENE	3/1/1999	0.67	ug/l	1	TR
Well #16	1988154.58	241090.04	cis-1,2-DICHLOROETHENE	5/16/2000	0.9	ug/l	1	TR
Well #16	1988154.58	241090.04	cis-1,2-DICHLOROETHENE	8/11/2000	1	ug/l	1	TR
Well #16	1988154.58	241090.04	cis-1,2-DICHLOROETHENE	10/18/2000	1.3	ug/l	1	
Well #16	1988154.58	241090.04	cis-1,2-DICHLOROETHENE	3/13/2001	1.4	ug/l	1	
Well #16	1988154.58	241090.04	cis-1,2-DICHLOROETHENE	3/21/2002	1.5	ug/l	1	
A39LO16PZ	1987126.39	238276.09	cis-1,2-DICHLOROETHENE	6/1/2001	0.48	ug/l	0.5	TR
A39LO16PZ	1987126.39	238276.09	cis-1,2-DICHLOROETHENE	9/1/2001	0.4	ug/l	0.5	TR
A39LO16PZ	1987126.39	238276.09	cis-1,2-DICHLOROETHENE	12/1/2001	0.38	ug/l	0.5	TR
A39LO16PZ	1987126.39	238276.09	cis-1,2-DICHLOROETHENE	3/21/2002	0.41	ug/l	0.5	TR
A39LO39DP	1986510.40	240027.24	cis-1,2-DICHLOROETHENE	06/01/97		ug/l	0.5	ND
A39LO39DP	1986510.40	240027.24	cis-1,2-DICHLOROETHENE	09/01/97		ug/l	0.5	ND
A39LO39DP	1986510.40	240027.24	cis-1,2-DICHLOROETHENE	12/01/97		ug/l	0.5	ND
A39LO39DP	1986510.40	240027.24	cis-1,2-DICHLOROETHENE	03/01/99		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	cis-1,2-DICHLOROETHENE	05/15/00		ug/l	1.2	ND
A39LO39DP	1986510.40	240027.24	cis-1,2-DICHLOROETHENE	10/20/00		ug/l	1.2	ND
A39LO39DP	1986510.40	240027.24	cis-1,2-DICHLOROETHENE	03/12/01		ug/l	1.2	ND
A39LO39DP	1986510.40	240027.24	cis-1,2-DICHLOROETHENE	03/20/02		ug/l	1	ND
Well#19	1987589.51	241223.83	cis-1,2-DICHLOROETHENE	03/01/99		ug/l	1	ND
Well#19	1987589.51	241223.83	cis-1,2-DICHLOROETHENE	05/15/00		ug/l	1.2	ND
Well#19	1987589.51	241223.83	cis-1,2-DICHLOROETHENE	08/15/00		ug/l	1.2	ND
Well#19	1987589.51	241223.83	cis-1,2-DICHLOROETHENE	10/20/00		ug/l	1.2	ND
Well#19	1987589.51	241223.83	cis-1,2-DICHLOROETHENE	03/12/01		ug/l	1.2	ND
Well#19	1987589.51	241223.83	cis-1,2-DICHLOROETHENE	03/20/02		ug/l	1	ND
Well#21	1988608.26	241437.57	cis-1,2-DICHLOROETHENE	03/01/99		ug/l	1	ND
Well#21	1988608.26	241437.57	cis-1,2-DICHLOROETHENE	05/15/00		ug/l	1.2	ND
Well#21	1988608.26	241437.57	cis-1,2-DICHLOROETHENE	08/15/00		ug/l	1.2	ND
Well#21	1988608.26	241437.57	cis-1,2-DICHLOROETHENE	10/20/00		ug/l	1.2	ND

TABLE C.4C
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
Well#21	1988608.26	241437.57	cis-1,2-DICHLOROETHENE	03/12/01		ug/l	1.2	ND
Well#21	1988608.26	241437.57	cis-1,2-DICHLOROETHENE	03/20/02		ug/l	1	ND
Well #24	1989357.77	239983.11	cis-1,2-DICHLOROETHENE	6/1/2001		ug/l	0.5	ND
Well #24	1989357.77	239983.11	cis-1,2-DICHLOROETHENE	10/1/2001		ug/l	1	ND
Well #24	1989357.77	239983.11	cis-1,2-DICHLOROETHENE	12/1/2001		ug/l	1	ND
Well #24	1989357.77	239983.11	cis-1,2-DICHLOROETHENE	3/19/2002		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	cis-1,2-DICHLOROETHENE	6/1/1997		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	cis-1,2-DICHLOROETHENE	9/1/1997		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	cis-1,2-DICHLOROETHENE	12/1/1997		ug/l	0.5	ND
A39LOO2PZ	1986520.49	240011.13	cis-1,2-DICHLOROETHENE	3/1/1999		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	cis-1,2-DICHLOROETHENE	5/10/2000		ug/l	1.2	ND
A39LOO2PZ	1986520.49	240011.13	cis-1,2-DICHLOROETHENE	10/19/2000		ug/l	1.2	ND
A39LOO2PZ	1986520.49	240011.13	cis-1,2-DICHLOROETHENE	3/13/2001		ug/l	1.2	ND
A39LOO2PZ	1986520.49	240011.13	cis-1,2-DICHLOROETHENE	3/20/2002		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	cis-1,2-DICHLOROETHENE	12/1/1997		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	cis-1,2-DICHLOROETHENE	3/1/1999		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	cis-1,2-DICHLOROETHENE	5/11/2000		ug/l	1.2	ND
A39LOO8PZ	1988976.57	240376.58	cis-1,2-DICHLOROETHENE	8/14/2000	0.17	ug/l	1	TR
A39LOO8PZ	1988976.57	240376.58	cis-1,2-DICHLOROETHENE	10/24/2000	0.21	ug/l	1	TR
A39LOO8PZ	1988976.57	240376.58	cis-1,2-DICHLOROETHENE	3/13/2001	0.17	ug/l	1	TR
A39LOO8PZ	1988976.57	240376.58	cis-1,2-DICHLOROETHENE	3/20/2002		ug/l	1	ND
A39LO27DP	1987750.95	239697.83	cis-1,2-DICHLOROETHENE	5/15/2000		ug/l	1.2	ND
A39LO27DP	1987750.95	239697.83	cis-1,2-DICHLOROETHENE	8/15/2000		ug/l	1.2	ND
A39LO27DP	1987750.95	239697.83	cis-1,2-DICHLOROETHENE	10/23/2000		ug/l	1.2	ND
A39LO27DP	1987750.95	239697.83	cis-1,2-DICHLOROETHENE	3/14/2001		ug/l	1.2	ND
A39LO27DP	1987750.95	239697.83	cis-1,2-DICHLOROETHENE	3/19/2002		ug/l	1	ND
Well #18	1987611.24	241236.21	cis-1,2-DICHLOROETHENE	3/1/1999		ug/l	0.13	ND
Well #18	1987611.24	241236.21	cis-1,2-DICHLOROETHENE	5/12/2000		ug/l	0.12	ND
Well #18	1987611.24	241236.21	cis-1,2-DICHLOROETHENE	8/10/2000	0.27	ug/l	1	TR
Well #18	1987611.24	241236.21	cis-1,2-DICHLOROETHENE	10/23/2000	0.31	ug/l	1	TR
Well #18	1987611.24	241236.21	cis-1,2-DICHLOROETHENE	3/12/2001	0.31	ug/l	1	TR
Well #18	1987611.24	241236.21	cis-1,2-DICHLOROETHENE	3/20/2002	0.57	ug/l	1	TR

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, TR = trace or estimated value.

TABLE C.5C
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
SS45LOO1MW	1988025.86	240183.74	VINYL CHLORIDE	06/01/97	0.548	ug/l	0.01	TR
SS45LOO1MW	1988025.86	240183.74	VINYL CHLORIDE	09/01/97		ug/l	0.01	ND
SS45LOO1MW	1988025.86	240183.74	VINYL CHLORIDE	12/01/97		ug/l	1	ND
SS45LOO1MW	1988025.86	240183.74	VINYL CHLORIDE	03/01/99		ug/l	20	ND
SS45LOO1MW	1988025.86	240183.74	VINYL CHLORIDE	05/15/00	0.9	ug/l	0.01	TR
SS45LOO1MW	1988025.86	240183.74	VINYL CHLORIDE	10/20/00	0.93	ug/l	0.01	TR
SS45LOO1MW	1988025.86	240183.74	VINYL CHLORIDE	03/12/01		ug/l	1.1	ND
SS45LOO1MW	1988025.86	240183.74	VINYL CHLORIDE	03/20/02	0.75	ug/l	0.01	TR
A39LOO9PZ	1987757.70	239690.06	VINYL CHLORIDE	06/01/97		ug/l	1	ND
A39LOO9PZ	1987757.70	239690.06	VINYL CHLORIDE	09/01/97		ug/l	1	ND
A39LOO9PZ	1987757.70	239690.06	VINYL CHLORIDE	12/01/97	1.05	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	VINYL CHLORIDE	03/01/99	1.4	ug/l	0.01	TR
A39LOO9PZ	1987757.70	239690.06	VINYL CHLORIDE	05/15/00	1.7	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	VINYL CHLORIDE	10/20/00	2	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	VINYL CHLORIDE	03/12/01	1.5	ug/l	0.01	
A39LOO9PZ	1987757.70	239690.06	VINYL CHLORIDE	03/20/02	2.1	ug/l	0.01	TR
A39LO14DP	1988962.30	240367.69	VINYL CHLORIDE	12/1/1997	2.58	ug/l	1	
A39LO14DP	1988962.30	240367.69	VINYL CHLORIDE	5/11/2000		ug/l	1.1	ND
A39LO14DP	1988962.30	240367.69	VINYL CHLORIDE	8/14/2000		ug/l	1.1	ND
A39LO14DP	1988962.30	240367.69	VINYL CHLORIDE	10/24/2000		ug/l	1.1	ND
A39LO14DP	1988962.30	240367.69	VINYL CHLORIDE	3/13/2001	0.22	ug/l	1	TR
A39LO14DP	1988962.30	240367.69	VINYL CHLORIDE	3/20/2002		ug/l	1	ND
A39LO36DP	1987131.17	239247.70	VINYL CHLORIDE	06/01/97		ug/l	1	ND
A39LO36DP	1987131.17	239247.70	VINYL CHLORIDE	09/01/97		ug/l	0.01	ND
A39LO36DP	1987131.17	239247.70	VINYL CHLORIDE	12/01/97		ug/l	1	ND
A39LO36DP	1987131.17	239247.70	VINYL CHLORIDE	05/15/00	0.3	ug/l	0.01	TR
A39LO36DP	1987131.17	239247.70	VINYL CHLORIDE	10/20/00	0.27	ug/l	0.01	TR
A39LO36DP	1987131.17	239247.70	VINYL CHLORIDE	12/01/00	0.22	ug/l	0.01	TR
A39LO36DP	1987131.17	239247.70	VINYL CHLORIDE	03/12/01	0.28	ug/l	0.01	TR
A39LO36DP	1987131.17	239247.70	VINYL CHLORIDE	03/20/02		ug/l	1	ND
Well#11	1988082.96	240028.65	VINYL CHLORIDE	03/01/99	2.4	ug/l	0.01	TR
Well#11	1988082.96	240028.65	VINYL CHLORIDE	05/15/00	1.4	ug/l	0.01	
Well#11	1988082.96	240028.65	VINYL CHLORIDE	08/15/00	2.7	ug/l	0.01	
Well#11	1988082.96	240028.65	VINYL CHLORIDE	10/20/00	2.6	ug/l	0.01	
Well#11	1988082.96	240028.65	VINYL CHLORIDE	03/12/01	7.6	ug/l	0.01	
Well#11	1988082.96	240028.65	VINYL CHLORIDE	03/20/02	12	ug/l	0.01	TR
Well#13	1988661.28	240491.55	VINYL CHLORIDE	03/01/99		ug/l	1	ND
Well#13	1988661.28	240491.55	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND
Well#13	1988661.28	240491.55	VINYL CHLORIDE	08/15/00		ug/l	1.1	ND
Well#13	1988661.28	240491.55	VINYL CHLORIDE	10/20/00		ug/l	1.1	ND
Well#13	1988661.28	240491.55	VINYL CHLORIDE	03/12/01		ug/l	1.1	ND
Well#13	1988661.28	240491.55	VINYL CHLORIDE	03/20/02		ug/l	1	ND
Well#15	1988258.48	240384.17	VINYL CHLORIDE	03/01/99	3.1	ug/l	0.01	TR
Well#15	1988258.48	240384.17	VINYL CHLORIDE	05/15/00	0.8	ug/l	0.01	
Well#15	1988258.48	240384.17	VINYL CHLORIDE	08/15/00	1.2	ug/l	0.01	
Well#15	1988258.48	240384.17	VINYL CHLORIDE	10/20/00	1.25	ug/l	0.01	TR
Well#15	1988258.48	240384.17	VINYL CHLORIDE	03/12/01	1.9	ug/l	0.01	
Well#15	1988258.48	240384.17	VINYL CHLORIDE	03/20/02	8.2	ug/l	0.01	TR
Well#17	1988517.55	241116.22	VINYL CHLORIDE	03/01/99		ug/l	1	ND
Well#17	1988517.55	241116.22	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND
Well#17	1988517.55	241116.22	VINYL CHLORIDE	08/15/00		ug/l	1.1	ND
Well#17	1988517.55	241116.22	VINYL CHLORIDE	10/20/00		ug/l	1.1	ND
Well#17	1988517.55	241116.22	VINYL CHLORIDE	12/01/00		ug/l	0.5	ND
Well#17	1988517.55	241116.22	VINYL CHLORIDE	03/12/01		ug/l	1.1	ND
Well#17	1988517.55	241116.22	VINYL CHLORIDE	03/20/02		ug/l	1	ND
Well#22	1989357.77	239983.11	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND
Well#22	1989357.77	239983.11	VINYL CHLORIDE	08/15/00		ug/l	1.1	ND

TABLE C.5C
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
Well#22	1989357.77	239983.11	VINYL CHLORIDE	10/20/00		ug/l	1.1	ND
Well#22	1989357.77	239983.11	VINYL CHLORIDE	03/12/01		ug/l	1.1	ND
Well#22	1989357.77	239983.11	VINYL CHLORIDE	03/20/02		ug/l	1	ND
SS45LOO5MW	1988349.09	238944.02	VINYL CHLORIDE	06/01/97		ug/l	1	ND
SS45LOO5MW	1988349.09	238944.02	VINYL CHLORIDE	09/01/97		ug/l	0.01	ND
SS45LOO5MW	1988349.09	238944.02	VINYL CHLORIDE	12/01/97		ug/l	1	ND
SS45LOO5MW	1988349.09	238944.02	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND
SS45LOO5MW	1988349.09	238944.02	VINYL CHLORIDE	08/15/00	0.24	ug/l	0.01	TR
SS45LOO5MW	1988349.09	238944.02	VINYL CHLORIDE	10/20/00	0.36	ug/l	0.01	TR
SS45LOO5MW	1988349.09	238944.02	VINYL CHLORIDE	03/12/01	0.42	ug/l	0.01	TR
SS45LOO5MW	1988349.09	238944.02	VINYL CHLORIDE	03/20/02	0.4	ug/l	0.01	TR
A39LO28DP	1988324.68	240122.50	VINYL CHLORIDE	3/1/1999		ug/l	1	ND
A39LO28DP	1988324.68	240122.50	VINYL CHLORIDE	5/15/2000		ug/l	1.1	ND
A39LO28DP	1988324.68	240122.50	VINYL CHLORIDE	8/10/2000		ug/l	1.1	ND
A39LO28DP	1988324.68	240122.50	VINYL CHLORIDE	10/18/2000		ug/l	1.1	ND
A39LO28DP	1988324.68	240122.50	VINYL CHLORIDE	3/14/2001		ug/l	1.1	ND
A39LO28DP	1988324.68	240122.50	VINYL CHLORIDE	3/19/2002		ug/l	1	ND
SS45LOO2MW	1988088.69	240181.59	VINYL CHLORIDE	06/01/97	2.5	ug/l	0.5	
SS45LOO2MW	1988088.69	240181.59	VINYL CHLORIDE	09/01/97	3.35	ug/l	0.5	
SS45LOO2MW	1988088.69	240181.59	VINYL CHLORIDE	12/01/97		ug/l	1	ND
SS45LOO2MW	1988088.69	240181.59	VINYL CHLORIDE	03/01/99	3.6	ug/l	0.5	TR
SS45LOO2MW	1988088.69	240181.59	VINYL CHLORIDE	05/15/00		ug/l	110	ND
SS45LOO2MW	1988088.69	240181.59	VINYL CHLORIDE	10/19/00	4.2	ug/l	0.5	
SS45LOO2MW	1988088.69	240181.59	VINYL CHLORIDE	03/12/01	3.5	ug/l	0.5	
SS45LOO2MW	1988088.69	240181.59	VINYL CHLORIDE	03/20/02	4.6	ug/l	0.5	TR
Well #12	1988071.39	240018.02	VINYL CHLORIDE	3/1/1999		ug/l	1	ND
Well #12	1988071.39	240018.02	VINYL CHLORIDE	5/11/2000	2.1	ug/l	1	
Well #12	1988071.39	240018.02	VINYL CHLORIDE	8/8/2000	0.3	ug/l	1	TR
Well #12	1988071.39	240018.02	VINYL CHLORIDE	10/24/2000	0.4	ug/l	1	TR
Well #12	1988071.39	240018.02	VINYL CHLORIDE	3/9/2001		ug/l	1.1	ND
Well #12	1988071.39	240018.02	VINYL CHLORIDE	3/21/2002		ug/l	1	ND
Well #14	1988276.49	240390.50	VINYL CHLORIDE	3/1/1999	0.91	ug/l	1	TR
Well #14	1988276.49	240390.50	VINYL CHLORIDE	5/15/2000	6.3	ug/l	1	
Well #14	1988276.49	240390.50	VINYL CHLORIDE	8/14/2000	3.2	ug/l	1	
Well #14	1988276.49	240390.50	VINYL CHLORIDE	10/20/2000	5	ug/l	1	TR
Well #14	1988276.49	240390.50	VINYL CHLORIDE	3/12/2001	6.2	ug/l	1	
Well #14	1988276.49	240390.50	VINYL CHLORIDE	3/21/2002	12	ug/l	1	TR
Well #16	1988154.58	241090.04	VINYL CHLORIDE	3/1/1999		ug/l	1	ND
Well #16	1988154.58	241090.04	VINYL CHLORIDE	5/16/2000		ug/l	1.1	ND
Well #16	1988154.58	241090.04	VINYL CHLORIDE	8/11/2000		ug/l	1.1	ND
Well #16	1988154.58	241090.04	VINYL CHLORIDE	10/18/2000		ug/l	1.1	ND
Well #16	1988154.58	241090.04	VINYL CHLORIDE	3/13/2001		ug/l	1.1	ND
Well #16	1988154.58	241090.04	VINYL CHLORIDE	3/21/2002		ug/l	1	ND
A39LO16PZ	1987126.39	238276.09	VINYL CHLORIDE	6/1/2001		ug/l	0.5	ND
A39LO16PZ	1987126.39	238276.09	VINYL CHLORIDE	9/1/2001		ug/l	1	ND
A39LO16PZ	1987126.39	238276.09	VINYL CHLORIDE	12/1/2001		ug/l	1	ND
A39LO16PZ	1987126.39	238276.09	VINYL CHLORIDE	3/21/2002		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	VINYL CHLORIDE	06/01/97		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	VINYL CHLORIDE	09/01/97		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	VINYL CHLORIDE	12/01/97		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	VINYL CHLORIDE	03/01/99		ug/l	1	ND
A39LO39DP	1986510.40	240027.24	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND
A39LO39DP	1986510.40	240027.24	VINYL CHLORIDE	10/20/00		ug/l	1.1	ND
A39LO39DP	1986510.40	240027.24	VINYL CHLORIDE	03/12/01		ug/l	1.1	ND
A39LO39DP	1986510.40	240027.24	VINYL CHLORIDE	03/20/02		ug/l	1	ND
Well#19	1987589.51	241223.83	VINYL CHLORIDE	03/01/99		ug/l	1	ND
Well#19	1987589.51	241223.83	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND

TABLE C.5C
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE SS-45 NORTHWEST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
Well#19	1987589.51	241223.83	VINYL CHLORIDE	08/15/00		ug/l	1.1	ND
Well#19	1987589.51	241223.83	VINYL CHLORIDE	10/20/00		ug/l	1.1	ND
Well#19	1987589.51	241223.83	VINYL CHLORIDE	03/12/01		ug/l	1.1	ND
Well#19	1987589.51	241223.83	VINYL CHLORIDE	03/20/02		ug/l	1	ND
Well#21	1988608.26	241437.57	VINYL CHLORIDE	03/01/99		ug/l	1	ND
Well#21	1988608.26	241437.57	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND
Well#21	1988608.26	241437.57	VINYL CHLORIDE	08/15/00		ug/l	1.1	ND
Well#21	1988608.26	241437.57	VINYL CHLORIDE	10/20/00		ug/l	1.1	ND
Well#21	1988608.26	241437.57	VINYL CHLORIDE	03/12/01		ug/l	1.1	ND
Well#21	1988608.26	241437.57	VINYL CHLORIDE	03/20/02		ug/l	1	ND
Well #24	1989357.77	239983.11	VINYL CHLORIDE	6/1/2001		ug/l	0.5	ND
Well #24	1989357.77	239983.11	VINYL CHLORIDE	10/1/2001		ug/l	1	ND
Well #24	1989357.77	239983.11	VINYL CHLORIDE	12/1/2001		ug/l	1	ND
Well #24	1989357.77	239983.11	VINYL CHLORIDE	3/19/2002		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	VINYL CHLORIDE	6/1/1997		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	VINYL CHLORIDE	9/1/1997		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	VINYL CHLORIDE	12/1/1997		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	VINYL CHLORIDE	3/1/1999		ug/l	1	ND
A39LOO2PZ	1986520.49	240011.13	VINYL CHLORIDE	5/10/2000		ug/l	1.1	ND
A39LOO2PZ	1986520.49	240011.13	VINYL CHLORIDE	10/19/2000		ug/l	1.1	ND
A39LOO2PZ	1986520.49	240011.13	VINYL CHLORIDE	3/13/2001		ug/l	1.1	ND
A39LOO2PZ	1986520.49	240011.13	VINYL CHLORIDE	3/20/2002		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	VINYL CHLORIDE	12/1/1997		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	VINYL CHLORIDE	3/1/1999		ug/l	1	ND
A39LOO8PZ	1988976.57	240376.58	VINYL CHLORIDE	5/11/2000		ug/l	1.1	ND
A39LOO8PZ	1988976.57	240376.58	VINYL CHLORIDE	8/14/2000		ug/l	1.1	ND
A39LOO8PZ	1988976.57	240376.58	VINYL CHLORIDE	10/24/2000		ug/l	1.1	ND
A39LOO8PZ	1988976.57	240376.58	VINYL CHLORIDE	3/13/2001		ug/l	1.1	ND
A39LOO8PZ	1988976.57	240376.58	VINYL CHLORIDE	3/20/2002		ug/l	1	ND
A39LO27DP	1987750.95	239697.83	VINYL CHLORIDE	5/15/2000		ug/l	1.1	ND
A39LO27DP	1987750.95	239697.83	VINYL CHLORIDE	8/15/2000		ug/l	1.1	ND
A39LO27DP	1987750.95	239697.83	VINYL CHLORIDE	10/23/2000		ug/l	1.1	ND
A39LO27DP	1987750.95	239697.83	VINYL CHLORIDE	3/14/2001		ug/l	1.1	ND
A39LO27DP	1987750.95	239697.83	VINYL CHLORIDE	3/19/2002		ug/l	1	ND
Well #18	1987611.24	241236.21	VINYL CHLORIDE	3/1/1999		ug/l	1	ND
Well #18	1987611.24	241236.21	VINYL CHLORIDE	5/12/2000		ug/l	1.1	ND
Well #18	1987611.24	241236.21	VINYL CHLORIDE	8/10/2000		ug/l	1.1	ND
Well #18	1987611.24	241236.21	VINYL CHLORIDE	10/23/2000		ug/l	1.1	ND
Well #18	1987611.24	241236.21	VINYL CHLORIDE	3/12/2001		ug/l	1.1	ND
Well #18	1987611.24	241236.21	VINYL CHLORIDE	3/20/2002		ug/l	1	ND

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, TR = trace or estimated value.

TABLE C.6C
INPUT PARAMETERS FOR MASS-BASED CALCULATIONS
NORTHWEST PLUME, SS-45, ENGLAND AIR FORCE BASE, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	Theissen Polygon Area (square feet)
A39LO14DP	278,368
A39LO36DP	288,069
A39LO39DP	393,012
A39LOO9PZ	662,826
SS45L001MW	357,128
SS45LOO5MW	349,733
Well#11	378,104
Well#13	294,659
Well#15	330,481
Well#17	371,070
Well#19	454,159
Well#21	34,568
Well#22	206,002
Total	694,729

Parameter	Value
Porosity (percentage)	27.6
Thickness of Contaminated Aquifer (feet)	40

TABLE C.7C
RESULTS OF DISSOLVED MASS ESTIMATION
NORTHWEST PLUME, SS-45, ENGLAND AIR FORCE BASE, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

	Mass in kilograms							
	Trichloroethene (TCE)		Dichloroethene (DCE)		Vinyl Chloride (VC)		Total CAHs	
Date	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass
5/15/2000	78.65	66.93	17.28	21.01	0.65	0.73	103.44	96.93
10/20/2000	86.53	74.55	29.84	32.38	0.95	1.02	128.97	120.58
3/12/2001	23.21	23.58	52.42	53.68	1.54	1.50	97.50	99.48
3/20/2002	60.66	52.81	48.46	47.75	2.81	2.83	132.25	123.48

	Percentage of Total CAH Mass					
	Trichloroethene (TCE)		Dichloroethene (DCE)		Vinyl Chloride (VC)	
Date	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass
5/15/2000	76.0%	69.0%	22.6%	29.4%	1.3%	1.6%
10/20/2000	67.1%	61.8%	31.4%	36.4%	1.6%	1.8%
3/12/2001	23.8%	23.7%	72.9%	73.1%	3.3%	3.2%
3/20/2002	45.9%	42.8%	49.7%	52.4%	4.5%	4.8%

TABLE C.8C
RESULTS OF GIS MASS-BASED CALCULATIONS FOR CENTER OF MASS LOCATION
NORTHWEST PLUME, SS-45, ENGLAND AIR FORCE BASE, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

	Trichloroethene (TCE)				Dichloroethene (DCE)				Vinyl Chloride (VC)			
	Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass	
Date	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate
5/15/2000	1,987,737.40	240,282.14	1,987,632.90	240,282.49	1,987,889.80	239,938.96	1,987,924.90	239,968.69	1,987,855.70	239,893.69	1,987,890.30	239,923.30
10/20/2000	1,987,756.30	240,313.82	1,987,650.70	240,295.04	1,988,036.80	240,013.68	1,988,110.60	240,026.56	1,987,939.90	239,881.79	1,988,000.60	239,905.24
3/12/2001	1,987,782.60	240,213.78	1,987,706.30	240,214.26	1,988,139.30	240,030.43	1,988,235.30	240,019.84	1,988,140.00	239,884.14	1,988,248.20	239,893.67
3/20/2002	1,987,738.90	240,277.53	1,987,642.50	240,269.29	1,988,166.90	240,062.15	1,988,250.80	240,044.69	1,988,144.40	240,031.09	1,988,230.60	240,030.11

Case Study Data for Southeast Plume, SS-45, England Air Force Base, Louisiana

TABLE C.1D
MAROS LINEAR REGRESSION STATISTICS SUMMARY
SITE SS-45 SOUTHEAST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Average Conc (mg/L) [a]	Median Conc (mg/L)	Standard Deviation	All Samples ND? [b]	LN Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend [c]	Designation for Current Analysis
Trichloroethene (TCE)										
A39LO10PZ	T	9.1E-04	5.0E-04	1.7E-03	Yes	2.6E-03	1.84	97.6%	I * [d]	Plume
A39LO11PZ	T	5.0E-04	5.0E-04	3.5E-04	Yes	1.6E-03	0.70	94.3%	PI *	Plume
A39LO12PZ	T	3.6E-04	5.0E-04	2.2E-04	No	3.2E-03	0.60	97.0%	I	Plume
A39LO19PZ	T	5.0E-04	5.0E-04	0.0E+00	Yes	6.0E-34	0.00	100.0%	I *	Plume
Well #3	T	5.8E-04	5.0E-04	2.5E-04	Yes	3.1E-04	0.43	74.5%	NT *	Plume
Well #4	T	1.4E-03	5.0E-04	2.2E-03	Yes	-2.1E-03	1.58	96.1%	D *	Plume
Well #5	T	3.0E-03	3.0E-03	2.6E-03	Yes	-2.3E-03	0.86	93.9%	PD *	Plume
Well #8	T	4.5E-04	5.0E-04	1.6E-04	No	1.4E-03	0.38	96.1%	I	Plume
Well #23	T	5.0E-04	5.0E-04	0.0E+00	Yes	0.00E+00	0.00	100.0%	S *	Plume
A39LO73DP	T	4.2E-04	5.0E-04	2.0E-04	Yes	3.2E-03	0.48	99.1%	I *	Sentry
Well #6	T	4.3E-04	5.0E-04	1.7E-04	No	-7.2E-05	0.40	52.6%	S	Sentry
Well #7	T	5.0E-04	5.0E-04	0.0E+00	Yes	-6.0E-34	0.00	100.0%	D *	Sentry
Well #9	T	5.0E-04	5.0E-04	0.0E+00	Yes	-7.10E-34	0.00	100.0%	D *	Sentry
A39LO82DP	T	4.3E-04	5.0E-04	1.7E-04	No	1.2E-04	0.40	54.3%	NT	Sentry
cis-1,2-Dichloroethene (cis-1,2-DCE)										
A39LO10PZ	T	4.7E-03	3.7E-03	4.3E-03	No	-1.3E-03	0.90	97.3%	D	Plume
A39LO11PZ	T	8.0E-02	5.0E-02	7.0E-02	No	-2.1E-03	0.87	98.5%	D	Plume
A39LO12PZ	T	7.1E-03	4.6E-03	7.2E-03	No	3.1E-03	1.02	98.5%	I	Plume
A39LO19PZ	T	8.1E-04	4.0E-04	8.9E-04	No	6.5E-03	1.10	67.9%	NT	Plume
Well #3	T	3.8E-02	4.1E-02	1.7E-02	No	3.1E-03	0.44	98.4%	I	Plume
Well #4	T	1.1E-01	1.3E-01	3.8E-02	No	-9.2E-04	0.33	97.6%	D	Plume
Well #5	T	7.8E-03	1.8E-03	1.5E-02	No	-3.9E-03	1.96	99.7%	D	Plume
Well #8	T	1.6E-03	8.0E-04	1.9E-03	No	3.8E-03	1.15	99.8%	I	Plume
Well #23	T	2.5E-02	6.0E-04	4.8E-02	No	9.8E-03	1.92	98.1%	I	Plume
A39LO73DP	T	4.8E-04	6.0E-04	2.4E-04	Yes	3.2E-03	0.49	98.9%	I *	Sentry
Well #6	T	2.9E-04	1.9E-04	2.1E-04	No	-3.4E-04	0.71	63.8%	S	Sentry
Well #7	T	5.4E-04	6.0E-04	1.1E-04	No	3.5E-04	0.20	86.6%	NT	Sentry
Well #9	T	5.8E-04	6.0E-04	4.5E-05	Yes	-2.8E-04	0.08	98.4%	D *	Sentry
A39LO82DP	T	5.0E-04	6.0E-04	2.0E-04	Yes	1.3E-03	0.39	93.8%	PI*	Sentry
Vinyl Chloride (VC)										
A39LO10PZ	T	4.3E-01	4.5E-01	1.9E-01	No	-1.0E-03	0.44	51.7%	D	Plume
A39LO11PZ	T	5.1E-02	4.9E-02	2.4E-02	No	-3.0E-04	0.47	83.4%	S	Plume
A39LO12PZ	T	4.6E-04	5.3E-04	1.7E-04	No	-5.9E-04	0.38	79.0%	S	Plume
A39LO19PZ	T	4.0E-04	5.0E-04	2.0E-04	No	4.0E-05	0.50	51.7%	NT	Plume
Well #3	T	4.8E-03	3.6E-03	4.2E-03	No	3.0E-03	0.88	100.0%	I	Plume
Well #4	T	1.6E-02	1.7E-02	8.7E-03	No	8.9E-04	0.54	84.3%	NT	Plume
Well #5	T	1.3E-01	1.3E-01	7.0E-02	No	-1.1E-03	0.52	90.2%	PD	Plume
Well #8	T	5.3E-04	5.5E-04	2.6E-05	Yes	3.4E-06	0.05	100.0%	I *	Plume
Well #23	T	2.6E-03	5.5E-04	4.7E-03	No	4.4E-03	1.84	93.3%	PI	Plume
A39LO73DP	T	5.3E-04	5.5E-04	2.6E-05	Yes	2.3E-05	0.05	67.8%	NT *	Sentry
Well #6	T	6.2E-04	5.5E-04	1.9E-04	Yes	-5.8E-04	0.31	98.2%	D *	Sentry
Well #7	T	5.3E-04	5.5E-04	2.6E-05	Yes	3.3E-06	0.05	100.0%	I *	Sentry
Well #9	T	5.4E-04	5.5E-04	2.2E-05	Yes	-1.5E-04	0.04	98.4%	D *	Sentry
A39LO82DP	T	5.3E-04	5.5E-04	2.6E-05	No	3.9E-06	0.05	100.0%	I	Sentry

[a] mg/L = milligrams per liter.

[b] ND = non-detect.

[c] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[d] * indicates that the concentrations at this well were reported as non detect (ND) for every sampling event available.

TABLE C.2D
MAROS MANN-KENDALL STATISTICS SUMMARY
SITE SS-45 SOUTHEAST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples ND? [a]	Concentration Trend [b]	Designation for Current Analysis
Trichloroethene (TCE)									
A39LO10PZ	T	8	0	1.84	15	95.8%	Yes	I * [c]	Plume
A39LO11PZ	T	8	0	0.70	13	92.9%	Yes	PI *	Plume
A39LO12PZ	T	6	1	0.60	5	76.5%	No	NT	Plume
A39LO19PZ	T	6	0	0.00	0	42.3%	Yes	S *	Plume
Well #3	T	9	0	0.43	6	69.4%	Yes	NT *	Plume
Well #4	T	6	0	1.58	-5	76.5%	Yes	NT *	Plume
Well #5	T	6	0	0.86	-9	93.2%	Yes	PD *	Plume
Well #8	T	6	1	0.38	5	76.5%	No	NT	Plume
Well #23	T	5	0	0.00	0	40.8%	Yes	S *	Plume
A39LO73DP	T	6	0	0.48	5	76.5%	Yes	NT *	Sentry
Well #6	T	6	1	0.40	-1	50.0%	No	S	Sentry
Well #7	T	6	0	0.00	0	42.3%	Yes	S *	Sentry
Well #9	T	5	0	0.00	0	40.8%	Yes	S *	Sentry
A39LO82DP	T	6	1	0.40	1	50.0%	No	NT	Sentry
cis-1,2-Dichloroethene (cis-1,2-DCE)									
A39LO10PZ	T	8	7	0.9	-16	96.9%	No	D	Plume
A39LO11PZ	T	8	7	0.87	-18	98.4%	No	D	Plume
A39LO12PZ	T	6	5	1.02	8	89.8%	No	NT	Plume
A39LO19PZ	T	6	6	1.10	1	50.0%	No	NT	Plume
Well #3	T	9	8	0.44	4	61.9%	No	NT	Plume
Well #4	T	6	6	0.33	-8	89.8%	No	S	Plume
Well #5	T	6	5	1.96	-13	99.2%	No	D	Plume
Well #8	T	6	6	1.15	15	99.9%	No	I	Plume
Well #23	T	5	4	1.92	6	88.3%	No	NT	Plume
A39LO73DP	T	6	0	0.49	1	50.0%	Yes	NT *	Sentry
Well #6	T	6	4	0.71	1	50.0%	No	NT	Sentry
Well #7	T	6	1	0.20	1	50.0%	No	NT	Sentry
Well #9	T	5	0	0.08	-4	75.8%	Yes	S *	Sentry
A39LO82DP	T	6	0	0.39	1	50.0%	Yes	NT *	Sentry
Vinyl Chloride (VC)									
A39LO10PZ	T	8	8	0.44	-18	98.4%	No	D	Plume
A39LO11PZ	T	8	8	0.47	-12	91.1%	No	PD	Plume
A39LO12PZ	T	6	1	0.38	1	50.0%	No	NT	Plume
A39LO19PZ	T	6	2	0.50	1	50.0%	No	NT	Plume
Well #3	T	9	8	0.88	29	100.0%	No	I	Plume
Well #4	T	6	5	0.54	5	76.5%	No	NT	Plume
Well #5	T	6	6	0.52	-5	76.5%	No	S	Plume
Well #8	T	6	0	0.05	0	42.3%	Yes	S *	Plume
Well #23	T	5	2	1.84	1	50.0%	No	NT	Plume
A39LO73DP	T	6	0	0.05	0	42.3%	Yes	S *	Sentry
Well #6	T	6	0	0.31	-9	93.2%	Yes	PD *	Sentry
Well #7	T	6	0	0.05	0	42.3%	Yes	S *	Sentry
Well #9	T	5	0	0.04	-4	75.8%	Yes	S *	Sentry
A39LO82DP	T	6	1	0.05	-1	50.0%	No	S	Sentry

[a] ND = non-detect.

[b] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[c] * indicates that the concentrations at this well were reported as non detect (ND) for every sampling event available.

TABLE C.3D
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE SS-45 SOUTHEAST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
A39LO10PZ	1990975.23	238111.74	TRICHLOROETHENE (TCE)	06/01/97		ug/l	0.01	ND
A39LO10PZ	1990975.23	238111.74	TRICHLOROETHENE (TCE)	09/01/97		ug/l	0.01	ND
A39LO10PZ	1990975.23	238111.74	TRICHLOROETHENE (TCE)	12/01/97		ug/l	0.5	ND
A39LO10PZ	1990975.23	238111.74	TRICHLOROETHENE (TCE)	03/01/99		ug/l	1	ND
A39LO10PZ	1990975.23	238111.74	TRICHLOROETHENE (TCE)	05/10/00		ug/l	10	ND
A39LO10PZ	1990975.23	238111.74	TRICHLOROETHENE (TCE)	10/18/00		ug/l	1	ND
A39LO10PZ	1990975.23	238111.74	TRICHLOROETHENE (TCE)	03/14/01		ug/l	1	ND
A39LO10PZ	1990975.23	238111.74	TRICHLOROETHENE (TCE)	03/20/02		ug/l	1	ND
A39LO11PZ	1990555.68	237371.80	TRICHLOROETHENE (TCE)	06/01/97		ug/l	0.01	ND
A39LO11PZ	1990555.68	237371.80	TRICHLOROETHENE (TCE)	09/01/97		ug/l	0.5	ND
A39LO11PZ	1990555.68	237371.80	TRICHLOROETHENE (TCE)	12/01/97		ug/l	0.5	ND
A39LO11PZ	1990555.68	237371.80	TRICHLOROETHENE (TCE)	03/01/99		ug/l	2	ND
A39LO11PZ	1990555.68	237371.80	TRICHLOROETHENE (TCE)	05/09/00		ug/l	1	ND
A39LO11PZ	1990555.68	237371.80	TRICHLOROETHENE (TCE)	10/20/00		ug/l	2	ND
A39LO11PZ	1990555.68	237371.80	TRICHLOROETHENE (TCE)	03/12/01		ug/l	1	ND
A39LO11PZ	1990555.68	237371.80	TRICHLOROETHENE (TCE)	03/19/02		ug/l	1	ND
A39LO12PZ	1991877.01	237603.80	TRICHLOROETHENE (TCE)	12/01/97		ug/l	0.01	ND
A39LO12PZ	1991877.01	237603.80	TRICHLOROETHENE (TCE)	03/01/99		ug/l	1	ND
A39LO12PZ	1991877.01	237603.80	TRICHLOROETHENE (TCE)	05/15/00		ug/l	1	ND
A39LO12PZ	1991877.01	237603.80	TRICHLOROETHENE (TCE)	08/10/00	0.35	ug/l	0.01	TR
A39LO12PZ	1991877.01	237603.80	TRICHLOROETHENE (TCE)	10/16/00		ug/l	1	ND
A39LO12PZ	1991877.01	237603.80	TRICHLOROETHENE (TCE)	03/09/01		ug/l	1	ND
A39LO19PZ	1990363.94	238733.96	TRICHLOROETHENE (TCE)	03/01/99		ug/l	1	ND
A39LO19PZ	1990363.94	238733.96	TRICHLOROETHENE (TCE)	05/16/00		ug/l	1	ND
A39LO19PZ	1990363.94	238733.96	TRICHLOROETHENE (TCE)	08/11/00		ug/l	1	ND
A39LO19PZ	1990363.94	238733.96	TRICHLOROETHENE (TCE)	10/23/00		ug/l	1	ND
A39LO19PZ	1990363.94	238733.96	TRICHLOROETHENE (TCE)	03/12/01		ug/l	1	ND
A39LO19PZ	1990363.94	238733.96	TRICHLOROETHENE (TCE)	03/21/02		ug/l	1	ND
Well#3	1990815.35	238988.97	TRICHLOROETHENE (TCE)	03/01/99		ug/l	1	ND
Well#3	1990815.35	238988.97	TRICHLOROETHENE (TCE)	05/12/00		ug/l	1	ND
Well#3	1990815.35	238988.97	TRICHLOROETHENE (TCE)	08/07/00		ug/l	1	ND
Well#3	1990815.35	238988.97	TRICHLOROETHENE (TCE)	10/17/00		ug/l	1	ND
Well#3	1990815.35	238988.97	TRICHLOROETHENE (TCE)	03/09/01		ug/l	1	ND
Well#3	1990815.35	238988.97	TRICHLOROETHENE (TCE)	06/01/01		ug/l	0.5	ND
Well#3	1990815.35	238988.97	TRICHLOROETHENE (TCE)	09/01/01		ug/l	2	ND
Well#3	1990815.35	238988.97	TRICHLOROETHENE (TCE)	12/01/01		ug/l	2	ND
Well#3	1990815.35	238988.97	TRICHLOROETHENE (TCE)	03/21/02		ug/l	1	ND
Well#4	1991064.89	238523.71	TRICHLOROETHENE (TCE)	03/01/99		ug/l	12	ND
Well#4	1991064.89	238523.71	TRICHLOROETHENE (TCE)	05/17/00		ug/l	1	ND
Well#4	1991064.89	238523.71	TRICHLOROETHENE (TCE)	08/09/00		ug/l	1	ND
Well#4	1991064.89	238523.71	TRICHLOROETHENE (TCE)	10/19/00		ug/l	1	ND
Well#4	1991064.89	238523.71	TRICHLOROETHENE (TCE)	03/14/01		ug/l	1	ND
Well#4	1991064.89	238523.71	TRICHLOROETHENE (TCE)	03/22/02		ug/l	1	ND
Well#5	1990733.85	237820.99	TRICHLOROETHENE (TCE)	03/01/99		ug/l	12	ND
Well#5	1990733.85	237820.99	TRICHLOROETHENE (TCE)	05/12/00		ug/l	10	ND
Well#5	1990733.85	237820.99	TRICHLOROETHENE (TCE)	08/08/00		ug/l	1	ND
Well#5	1990733.85	237820.99	TRICHLOROETHENE (TCE)	10/20/00		ug/l	10	ND
Well#5	1990733.85	237820.99	TRICHLOROETHENE (TCE)	03/12/01		ug/l	2	ND
Well#5	1990733.85	237820.99	TRICHLOROETHENE (TCE)	03/20/02		ug/l	1	ND
Well#8	1991332.48	237454.33	TRICHLOROETHENE (TCE)	03/01/99	0.2	ug/l	0.01	TR
Well#8	1991332.48	237454.33	TRICHLOROETHENE (TCE)	05/15/00		ug/l	1	ND
Well#8	1991332.48	237454.33	TRICHLOROETHENE (TCE)	08/08/00		ug/l	1	ND
Well#8	1991332.48	237454.33	TRICHLOROETHENE (TCE)	10/16/00		ug/l	1	ND
Well#8	1991332.48	237454.33	TRICHLOROETHENE (TCE)	03/14/01		ug/l	1	ND
Well#8	1991332.48	237454.33	TRICHLOROETHENE (TCE)	03/22/02		ug/l	1	ND
Well#23	1991599.90	238033.31	TRICHLOROETHENE (TCE)	05/18/00		ug/l	1	ND
Well#23	1991599.90	238033.31	TRICHLOROETHENE (TCE)	08/08/00		ug/l	1	ND
Well#23	1991599.90	238033.31	TRICHLOROETHENE (TCE)	10/17/00		ug/l	1	ND
Well#23	1991599.90	238033.31	TRICHLOROETHENE (TCE)	03/13/01		ug/l	1	ND
Well#23	1991599.90	238033.31	TRICHLOROETHENE (TCE)	03/21/02		ug/l	1	ND

TABLE C.3D
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE SS-45 SOUTHEAST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
A39LO73DP	1991596.95	238565.66	TRICHLOROETHENE (TCE)	12/01/97		ug/l	0.01	ND
A39LO73DP	1991596.95	238565.66	TRICHLOROETHENE (TCE)	05/10/00		ug/l	1	ND
A39LO73DP	1991596.95	238565.66	TRICHLOROETHENE (TCE)	08/09/00		ug/l	1	ND
A39LO73DP	1991596.95	238565.66	TRICHLOROETHENE (TCE)	10/17/00		ug/l	1	ND
A39LO73DP	1991596.95	238565.66	TRICHLOROETHENE (TCE)	03/13/01		ug/l	1	ND
A39LO73DP	1991596.95	238565.66	TRICHLOROETHENE (TCE)	03/21/02		ug/l	1	ND
Well#6	1990843.94	236910.91	TRICHLOROETHENE (TCE)	03/01/99		ug/l	1	ND
Well#6	1990843.94	236910.91	TRICHLOROETHENE (TCE)	05/12/00		ug/l	1	ND
Well#6	1990843.94	236910.91	TRICHLOROETHENE (TCE)	08/07/00		ug/l	1	ND
Well#6	1990843.94	236910.91	TRICHLOROETHENE (TCE)	10/16/00	0.15	ug/l	0.01	TR
Well#6	1990843.94	236910.91	TRICHLOROETHENE (TCE)	03/15/01		ug/l	1	ND
Well#6	1990843.94	236910.91	TRICHLOROETHENE (TCE)	03/19/02		ug/l	1	ND
Well#7	1990282.67	236924.25	TRICHLOROETHENE (TCE)	03/01/99		ug/l	1	ND
Well#7	1990282.67	236924.25	TRICHLOROETHENE (TCE)	05/11/00		ug/l	1	ND
Well#7	1990282.67	236924.25	TRICHLOROETHENE (TCE)	08/08/00		ug/l	1	ND
Well#7	1990282.67	236924.25	TRICHLOROETHENE (TCE)	10/17/00		ug/l	1	ND
Well#7	1990282.67	236924.25	TRICHLOROETHENE (TCE)	03/09/01		ug/l	1	ND
Well#7	1990282.67	236924.25	TRICHLOROETHENE (TCE)	03/19/02		ug/l	1	ND
Well#9	1991582.85	238988.96	TRICHLOROETHENE (TCE)	05/15/00		ug/l	1	ND
Well#9	1991582.85	238988.96	TRICHLOROETHENE (TCE)	08/09/00		ug/l	1	ND
Well#9	1991582.85	238988.96	TRICHLOROETHENE (TCE)	10/17/00		ug/l	1	ND
Well#9	1991582.85	238988.96	TRICHLOROETHENE (TCE)	03/15/01		ug/l	1	ND
Well#9	1991582.85	238988.96	TRICHLOROETHENE (TCE)	03/22/02		ug/l	1	ND
A39LO82DP	1990977.93	238106.35	TRICHLOROETHENE (TCE)	03/01/99		ug/l	1	ND
A39LO82DP	1990977.93	238106.35	TRICHLOROETHENE (TCE)	05/15/00		ug/l	1	ND
A39LO82DP	1990977.93	238106.35	TRICHLOROETHENE (TCE)	08/10/00	0.16	ug/l	1	TR
A39LO82DP	1990977.93	238106.35	TRICHLOROETHENE (TCE)	10/18/00		ug/l	1	ND
A39LO82DP	1990977.93	238106.35	TRICHLOROETHENE (TCE)	03/14/01		ug/l	1	ND
A39LO82DP	1990977.93	238106.35	TRICHLOROETHENE (TCE)	03/19/02		ug/l	1	ND

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, TR = trace or estimated.

TABLE C.4D
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE SS-45 SOUTHEAST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
A39LO10PZ	1990975.23	238111.74	cis-1,2-DICHLOROETHENE	06/01/97	9.46	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	cis-1,2-DICHLOROETHENE	09/01/97	4.52	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	cis-1,2-DICHLOROETHENE	12/01/97	6.7	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	cis-1,2-DICHLOROETHENE	03/01/99	2.8	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	cis-1,2-DICHLOROETHENE	05/10/00	3	ug/l	0.01	TR
A39LO10PZ	1990975.23	238111.74	cis-1,2-DICHLOROETHENE	10/18/00	12	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	cis-1,2-DICHLOROETHENE	03/14/01	1.01	ug/l	0.01	TR
A39LO10PZ	1990975.23	238111.74	cis-1,2-DICHLOROETHENE	03/20/02		ug/l	1	ND
A39LO11PZ	1990555.68	237371.80	cis-1,2-DICHLOROETHENE	06/01/97	77.2	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	cis-1,2-DICHLOROETHENE	09/01/97	189	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	cis-1,2-DICHLOROETHENE	12/01/97	186	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	cis-1,2-DICHLOROETHENE	03/01/99	44	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	cis-1,2-DICHLOROETHENE	05/09/00	100	ug/l	0.01	TR
A39LO11PZ	1990555.68	237371.80	cis-1,2-DICHLOROETHENE	10/20/00	43	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	cis-1,2-DICHLOROETHENE	03/12/01	49	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	cis-1,2-DICHLOROETHENE	03/19/02		ug/l	1	ND
A39LO12PZ	1991877.01	237603.80	cis-1,2-DICHLOROETHENE	12/01/97		ug/l	0.5	ND
A39LO12PZ	1991877.01	237603.80	cis-1,2-DICHLOROETHENE	03/01/99	1	ug/l	0.01	
A39LO12PZ	1991877.01	237603.80	cis-1,2-DICHLOROETHENE	05/15/00	6.4	ug/l	0.01	
A39LO12PZ	1991877.01	237603.80	cis-1,2-DICHLOROETHENE	08/10/00	16	ug/l	0.01	
A39LO12PZ	1991877.01	237603.80	cis-1,2-DICHLOROETHENE	10/16/00	16	ug/l	0.01	
A39LO12PZ	1991877.01	237603.80	cis-1,2-DICHLOROETHENE	03/09/01	2.8	ug/l	0.01	
A39LO19PZ	1990363.94	238733.96	cis-1,2-DICHLOROETHENE	03/01/99	1.1	ug/l	0.01	
A39LO19PZ	1990363.94	238733.96	cis-1,2-DICHLOROETHENE	05/16/00	0.7	ug/l	0.01	TR
A39LO19PZ	1990363.94	238733.96	cis-1,2-DICHLOROETHENE	08/11/00	0.6	ug/l	0.01	TR
A39LO19PZ	1990363.94	238733.96	cis-1,2-DICHLOROETHENE	10/23/00	0.33	ug/l	0.01	TR
A39LO19PZ	1990363.94	238733.96	cis-1,2-DICHLOROETHENE	03/12/01	0.88	ug/l	0.01	TR
A39LO19PZ	1990363.94	238733.96	cis-1,2-DICHLOROETHENE	03/21/02	2.5	ug/l	0.01	
Well#3	1990815.35	238988.97	cis-1,2-DICHLOROETHENE	03/01/99		ug/l	1	ND
Well#3	1990815.35	238988.97	cis-1,2-DICHLOROETHENE	05/12/00	41	ug/l	0.01	
Well#3	1990815.35	238988.97	cis-1,2-DICHLOROETHENE	08/07/00	39	ug/l	0.01	
Well#3	1990815.35	238988.97	cis-1,2-DICHLOROETHENE	10/17/00	43	ug/l	0.01	
Well#3	1990815.35	238988.97	cis-1,2-DICHLOROETHENE	03/09/01	58	ug/l	0.01	
Well#3	1990815.35	238988.97	cis-1,2-DICHLOROETHENE	06/01/01	49	ug/l	0.01	
Well#3	1990815.35	238988.97	cis-1,2-DICHLOROETHENE	09/01/01	47	ug/l	0.01	
Well#3	1990815.35	238988.97	cis-1,2-DICHLOROETHENE	12/01/01	40	ug/l	0.01	
Well#3	1990815.35	238988.97	cis-1,2-DICHLOROETHENE	03/21/02	25	ug/l	0.01	
Well#4	1991064.89	238523.71	cis-1,2-DICHLOROETHENE	03/01/99	140	ug/l	0.01	
Well#4	1991064.89	238523.71	cis-1,2-DICHLOROETHENE	05/17/00	130	ug/l	0.01	
Well#4	1991064.89	238523.71	cis-1,2-DICHLOROETHENE	08/09/00	130	ug/l	0.01	
Well#4	1991064.89	238523.71	cis-1,2-DICHLOROETHENE	10/19/00	150	ug/l	0.01	
Well#4	1991064.89	238523.71	cis-1,2-DICHLOROETHENE	03/14/01	87	ug/l	0.01	
Well#4	1991064.89	238523.71	cis-1,2-DICHLOROETHENE	03/22/02	51	ug/l	0.01	
Well#5	1990733.85	237820.99	cis-1,2-DICHLOROETHENE	03/01/99	39	ug/l	0.01	
Well#5	1990733.85	237820.99	cis-1,2-DICHLOROETHENE	05/12/00	4	ug/l	0.01	TR
Well#5	1990733.85	237820.99	cis-1,2-DICHLOROETHENE	08/08/00	2.8	ug/l	0.01	
Well#5	1990733.85	237820.99	cis-1,2-DICHLOROETHENE	10/20/00	3.1	ug/l	0.01	TR
Well#5	1990733.85	237820.99	cis-1,2-DICHLOROETHENE	03/12/01	1.8	ug/l	0.01	TR
Well#5	1990733.85	237820.99	cis-1,2-DICHLOROETHENE	03/20/02		ug/l	1	ND
Well#8	1991332.48	237454.33	cis-1,2-DICHLOROETHENE	03/01/99	0.19	ug/l	0.01	TR
Well#8	1991332.48	237454.33	cis-1,2-DICHLOROETHENE	05/15/00	0.6	ug/l	0.01	TR
Well#8	1991332.48	237454.33	cis-1,2-DICHLOROETHENE	08/08/00	0.8	ug/l	0.01	TR
Well#8	1991332.48	237454.33	cis-1,2-DICHLOROETHENE	10/16/00	1.2	ug/l	0.01	
Well#8	1991332.48	237454.33	cis-1,2-DICHLOROETHENE	03/14/01	3	ug/l	0.01	
Well#8	1991332.48	237454.33	cis-1,2-DICHLOROETHENE	03/22/02	4.7	ug/l	0.01	
Well#23	1991599.90	238033.31	cis-1,2-DICHLOROETHENE	05/18/00		ug/l	1.2	ND
Well#23	1991599.90	238033.31	cis-1,2-DICHLOROETHENE	08/08/00	0.3	ug/l	0.01	TR

TABLE C.4D
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE SS-45 SOUTHEAST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units[a/]	DetLim	Flags[b/]
Well#23	1991599.90	238033.31	cis-1,2-DICHLOROETHENE	10/17/00	0.41	ug/l	0.01	TR
Well#23	1991599.90	238033.31	cis-1,2-DICHLOROETHENE	03/13/01	14	ug/l	0.01	
Well#23	1991599.90	238033.31	cis-1,2-DICHLOROETHENE	03/21/02	110	ug/l	0.01	
A39LO73DP	1991596.95	238565.66	cis-1,2-DICHLOROETHENE	12/01/97		ug/l	0.01	ND
A39LO73DP	1991596.95	238565.66	cis-1,2-DICHLOROETHENE	05/10/00		ug/l	1.2	ND
A39LO73DP	1991596.95	238565.66	cis-1,2-DICHLOROETHENE	08/09/00		ug/l	1.2	ND
A39LO73DP	1991596.95	238565.66	cis-1,2-DICHLOROETHENE	10/17/00		ug/l	1.2	ND
A39LO73DP	1991596.95	238565.66	cis-1,2-DICHLOROETHENE	03/13/01		ug/l	1.2	ND
A39LO73DP	1991596.95	238565.66	cis-1,2-DICHLOROETHENE	03/21/02		ug/l	1	ND
Well#6	1990843.94	236910.91	cis-1,2-DICHLOROETHENE	03/01/99		ug/l	1	ND
Well#6	1990843.94	236910.91	cis-1,2-DICHLOROETHENE	05/12/00	0.3	ug/l	0.01	TR
Well#6	1990843.94	236910.91	cis-1,2-DICHLOROETHENE	08/07/00	0.26	ug/l	0.01	TR
Well#6	1990843.94	236910.91	cis-1,2-DICHLOROETHENE	10/16/00	0.28	ug/l	0.01	TR
Well#6	1990843.94	236910.91	cis-1,2-DICHLOROETHENE	03/15/01		ug/l	1.2	ND
Well#6	1990843.94	236910.91	cis-1,2-DICHLOROETHENE	03/19/02	0.44	ug/l	0.01	TR
Well#7	1990282.67	236924.25	cis-1,2-DICHLOROETHENE	03/01/99	0.67	ug/l	0.01	TR
Well#7	1990282.67	236924.25	cis-1,2-DICHLOROETHENE	05/11/00		ug/l	1.2	ND
Well#7	1990282.67	236924.25	cis-1,2-DICHLOROETHENE	08/08/00		ug/l	1.2	ND
Well#7	1990282.67	236924.25	cis-1,2-DICHLOROETHENE	10/17/00		ug/l	1.2	ND
Well#7	1990282.67	236924.25	cis-1,2-DICHLOROETHENE	03/09/01		ug/l	1.2	ND
Well#7	1990282.67	236924.25	cis-1,2-DICHLOROETHENE	03/19/02		ug/l	1	ND
Well#9	1991582.85	238988.96	cis-1,2-DICHLOROETHENE	05/15/00		ug/l	1.2	ND
Well#9	1991582.85	238988.96	cis-1,2-DICHLOROETHENE	08/09/00		ug/l	1.2	ND
Well#9	1991582.85	238988.96	cis-1,2-DICHLOROETHENE	10/17/00		ug/l	1.2	ND
Well#9	1991582.85	238988.96	cis-1,2-DICHLOROETHENE	03/15/01		ug/l	1.2	ND
Well#9	1991582.85	238988.96	cis-1,2-DICHLOROETHENE	03/22/02		ug/l	1	ND
A39LO82DP	1990977.93	238106.35	cis-1,2-DICHLOROETHENE	03/01/99		ug/l	0.22	ND
A39LO82DP	1990977.93	238106.35	cis-1,2-DICHLOROETHENE	05/15/00		ug/l	1.2	ND
A39LO82DP	1990977.93	238106.35	cis-1,2-DICHLOROETHENE	08/10/00		ug/l	1.2	ND
A39LO82DP	1990977.93	238106.35	cis-1,2-DICHLOROETHENE	10/18/00		ug/l	1.2	ND
A39LO82DP	1990977.93	238106.35	cis-1,2-DICHLOROETHENE	03/14/01		ug/l	1.2	ND
A39LO82DP	1990977.93	238106.35	cis-1,2-DICHLOROETHENE	03/19/02		ug/l	1	ND

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, TR = trace or estimated.

TABLE C.5D
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE SS-45 SOUTHEAST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
A39LO10PZ	1990975.23	238111.74	VINYL CHLORIDE	06/01/97	549	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	VINYL CHLORIDE	09/01/97	605	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	VINYL CHLORIDE	12/01/97	619	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	VINYL CHLORIDE	03/01/99	420	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	VINYL CHLORIDE	05/10/00	380	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	VINYL CHLORIDE	10/18/00	470	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	VINYL CHLORIDE	03/14/01	330	ug/l	0.01	
A39LO10PZ	1990975.23	238111.74	VINYL CHLORIDE	03/20/02	74	ug/l	0.01	TR
A39LO11PZ	1990555.68	237371.80	VINYL CHLORIDE	06/01/97	85.3	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	VINYL CHLORIDE	09/01/97	59.2	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	VINYL CHLORIDE	12/01/97	22.7	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	VINYL CHLORIDE	03/01/99	80	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	VINYL CHLORIDE	05/09/00	78	ug/l	0.01	TR
A39LO11PZ	1990555.68	237371.80	VINYL CHLORIDE	10/20/00	63	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	VINYL CHLORIDE	03/12/01	32	ug/l	0.01	
A39LO11PZ	1990555.68	237371.80	VINYL CHLORIDE	03/19/02	56	ug/l	0.01	TR
A39LO12PZ	1991877.01	237603.80	VINYL CHLORIDE	12/01/97		ug/l	1	ND
A39LO12PZ	1991877.01	237603.80	VINYL CHLORIDE	03/01/99		ug/l	1	ND
A39LO12PZ	1991877.01	237603.80	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND
A39LO12PZ	1991877.01	237603.80	VINYL CHLORIDE	08/10/00		ug/l	1.1	ND
A39LO12PZ	1991877.01	237603.80	VINYL CHLORIDE	10/16/00		ug/l	1.1	ND
A39LO12PZ	1991877.01	237603.80	VINYL CHLORIDE	03/09/01	0.22	ug/l	0.01	TR
A39LO19PZ	1990363.94	238733.96	VINYL CHLORIDE	03/01/99		ug/l	1	ND
A39LO19PZ	1990363.94	238733.96	VINYL CHLORIDE	05/16/00		ug/l	1.1	ND
A39LO19PZ	1990363.94	238733.96	VINYL CHLORIDE	08/11/00	0.26	ug/l	0.01	TR
A39LO19PZ	1990363.94	238733.96	VINYL CHLORIDE	10/23/00	0.32	ug/l	0.01	TR
A39LO19PZ	1990363.94	238733.96	VINYL CHLORIDE	03/12/01		ug/l	1.1	ND
A39LO19PZ	1990363.94	238733.96	VINYL CHLORIDE	03/21/02		ug/l	1	ND
Well#3	1990815.35	238988.97	VINYL CHLORIDE	03/01/99		ug/l	1	ND
Well#3	1990815.35	238988.97	VINYL CHLORIDE	05/12/00	1.3	ug/l	0.01	
Well#3	1990815.35	238988.97	VINYL CHLORIDE	08/07/00	1.3	ug/l	0.01	
Well#3	1990815.35	238988.97	VINYL CHLORIDE	10/17/00	1.5	ug/l	0.01	
Well#3	1990815.35	238988.97	VINYL CHLORIDE	03/09/01	5.5	ug/l	0.01	
Well#3	1990815.35	238988.97	VINYL CHLORIDE	06/01/01	7.6	ug/l	0.01	
Well#3	1990815.35	238988.97	VINYL CHLORIDE	09/01/01	3.6	ug/l	0.01	
Well#3	1990815.35	238988.97	VINYL CHLORIDE	12/01/01	12	ug/l	0.01	
Well#3	1990815.35	238988.97	VINYL CHLORIDE	03/21/02	20	ug/l	0.01	TR
Well#4	1991064.89	238523.71	VINYL CHLORIDE	03/01/99		ug/l	12	ND
Well#4	1991064.89	238523.71	VINYL CHLORIDE	05/17/00	16	ug/l	0.01	
Well#4	1991064.89	238523.71	VINYL CHLORIDE	08/09/00	27	ug/l	0.01	
Well#4	1991064.89	238523.71	VINYL CHLORIDE	10/19/00	18	ug/l	0.01	
Well#4	1991064.89	238523.71	VINYL CHLORIDE	03/14/01	6.3	ug/l	0.01	
Well#4	1991064.89	238523.71	VINYL CHLORIDE	03/22/02	48	ug/l	0.01	TR
Well#5	1990733.85	237820.99	VINYL CHLORIDE	03/01/99	120	ug/l	0.01	
Well#5	1990733.85	237820.99	VINYL CHLORIDE	05/12/00	140	ug/l	0.01	
Well#5	1990733.85	237820.99	VINYL CHLORIDE	08/08/00	230	ug/l	0.01	
Well#5	1990733.85	237820.99	VINYL CHLORIDE	10/20/00	190	ug/l	0.01	
Well#5	1990733.85	237820.99	VINYL CHLORIDE	03/12/01	84	ug/l	0.01	
Well#5	1990733.85	237820.99	VINYL CHLORIDE	03/20/02	74	ug/l	0.01	TR
Well#8	1991332.48	237454.33	VINYL CHLORIDE	03/01/99		ug/l	1	ND
Well#8	1991332.48	237454.33	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND
Well#8	1991332.48	237454.33	VINYL CHLORIDE	08/08/00		ug/l	1.1	ND
Well#8	1991332.48	237454.33	VINYL CHLORIDE	10/16/00		ug/l	1.1	ND
Well#8	1991332.48	237454.33	VINYL CHLORIDE	03/14/01		ug/l	1.1	ND
Well#8	1991332.48	237454.33	VINYL CHLORIDE	03/22/02		ug/l	1	ND
Well#23	1991599.90	238033.31	VINYL CHLORIDE	05/18/00		ug/l	1.1	ND
Well#23	1991599.90	238033.31	VINYL CHLORIDE	08/08/00		ug/l	1.1	ND

TABLE C.5D
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE SS-45 SOUTHEAST PLUME, ENGLAND AFB, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
Well#23	1991599.90	238033.31	VINYL CHLORIDE	10/17/00		ug/l	1.1	ND
Well#23	1991599.90	238033.31	VINYL CHLORIDE	03/13/01	0.39	ug/l	0.01	TR
Well#23	1991599.90	238033.31	VINYL CHLORIDE	03/21/02	22	ug/l	0.01	TR
A39LO73DP	1991596.95	238565.66	VINYL CHLORIDE	12/01/97		ug/l	1	ND
A39LO73DP	1991596.95	238565.66	VINYL CHLORIDE	05/10/00		ug/l	1.1	ND
A39LO73DP	1991596.95	238565.66	VINYL CHLORIDE	08/09/00		ug/l	1.1	ND
A39LO73DP	1991596.95	238565.66	VINYL CHLORIDE	10/17/00		ug/l	1.1	ND
A39LO73DP	1991596.95	238565.66	VINYL CHLORIDE	03/13/01		ug/l	1.1	ND
A39LO73DP	1991596.95	238565.66	VINYL CHLORIDE	03/21/02		ug/l	1	ND
Well#6	1990843.94	236910.91	VINYL CHLORIDE	03/01/99		ug/l	2	ND
Well#6	1990843.94	236910.91	VINYL CHLORIDE	05/12/00		ug/l	1.1	ND
Well#6	1990843.94	236910.91	VINYL CHLORIDE	08/07/00		ug/l	1.1	ND
Well#6	1990843.94	236910.91	VINYL CHLORIDE	10/16/00		ug/l	1.1	ND
Well#6	1990843.94	236910.91	VINYL CHLORIDE	03/15/01		ug/l	1.1	ND
Well#6	1990843.94	236910.91	VINYL CHLORIDE	03/19/02		ug/l	1	ND
Well#7	1990282.67	236924.25	VINYL CHLORIDE	03/01/99		ug/l	1	ND
Well#7	1990282.67	236924.25	VINYL CHLORIDE	05/11/00		ug/l	1.1	ND
Well#7	1990282.67	236924.25	VINYL CHLORIDE	08/08/00		ug/l	1.1	ND
Well#7	1990282.67	236924.25	VINYL CHLORIDE	10/17/00		ug/l	1.1	ND
Well#7	1990282.67	236924.25	VINYL CHLORIDE	03/09/01		ug/l	1.1	ND
Well#7	1990282.67	236924.25	VINYL CHLORIDE	03/19/02		ug/l	1	ND
Well#9	1991582.85	238988.96	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND
Well#9	1991582.85	238988.96	VINYL CHLORIDE	08/09/00		ug/l	1.1	ND
Well#9	1991582.85	238988.96	VINYL CHLORIDE	10/17/00		ug/l	1.1	ND
Well#9	1991582.85	238988.96	VINYL CHLORIDE	03/15/01		ug/l	1.1	ND
Well#9	1991582.85	238988.96	VINYL CHLORIDE	03/22/02		ug/l	1	ND
A39LO82DP	1990977.93	238106.35	VINYL CHLORIDE	03/01/99		ug/l	1	ND
A39LO82DP	1990977.93	238106.35	VINYL CHLORIDE	05/15/00		ug/l	1.1	ND
A39LO82DP	1990977.93	238106.35	VINYL CHLORIDE	08/10/00		ug/l	1.1	ND
A39LO82DP	1990977.93	238106.35	VINYL CHLORIDE	10/18/00		ug/l	1.1	ND
A39LO82DP	1990977.93	238106.35	VINYL CHLORIDE	03/14/01		ug/l	1.1	ND
A39LO82DP	1990977.93	238106.35	VINYL CHLORIDE	03/19/02	1	ug/l	1	TR

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, TR = trace or estimated.

TABLE C.6D
INPUT PARAMETERS FOR MASS-BASED CALCULATIONS
SOUTHEAST PLUME, SS-45, ENGLAND AIR FORCE BASE, LOUISIANA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	Theissen Polygon Area (square feet)
MW-03	0.05
MW-10	0.66
MW-28	0.56
MW-29	0.16
MW-30	0.02
MW-31	0.34
MW-32	0.71
MW-33	0.50
MW-36	0.26
MW-39	0.68
MW-40	0.33
MW-46	0.00
MW-47	0.17
MW-48	0.92
MW-49	0.42
MW-52	0.80
Total	2.64

Parameter	Value
Porosity (percentage)	30
Thickness of Contaminated Aquifer (feet)	10

TABLE C.7D

RESULTS OF DISSOLVED MASS ESTIMATION

SOUTHEAST PLUME, SS-45, ENGLAND AIR FORCE BASE, LOUISIANA

FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

	Mass in kilograms							
	Trichloroethene (TCE)		Dichloroethene (DCE)		Vinyl Chloride (VC)		Total CAHs	
Date	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass
5/15/2000	0.000	0.000	23.51	23.51	49.67	58.90	136.28	155.69
10/20/2000	0.005	0.006	20.90	21.14	59.33	71.60	153.05	179.17
3/12/2001	0.000	0.000	15.89	16.11	36.76	43.27	98.82	112.80
3/20/2002	0.000	0.000	11.74	11.54	22.58	26.39	63.38	71.13

	Percentage of Total CAH Mass					
	Trichloroethene (TCE)		Dichloroethene (DCE)		Vinyl Chloride (VC)	
Date	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass
5/15/2000	0.000%	0.000%	23.4%	20.5%	76.6%	79.5%
10/20/2000	0.003%	0.003%	18.5%	16.0%	81.5%	84.0%
3/12/2001	0.000%	0.000%	21.8%	19.4%	78.2%	80.6%
3/20/2002	0.000%	0.000%	25.1%	22.0%	74.9%	78.0%

TABLE C.8D

RESULTS OF GIS MASS-BASED CALCULATIONS FOR CENTER OF MASS LOCATION

SOUTHEAST PLUME, SS-45, ENGLAND AIR FORCE BASE, LOUISIANA

FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

	Trichloroethene (TCE)				Dichloroethene (DCE)				Vinyl Chloride (VC)			
	Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass	
Date	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate
5/1/2000	NC	NC	NC	NC	1990855.61	238110.88	1990904.70	238144.12	1990847.34	237968.20	1990910.70	237979.91
10/1/2000	1990822.10	237080.25	NC	NC	1990945.09	238327.41	1990997.40	238349.14	1990852.94	237988.13	1990921.70	238001.98
3/1/2001	NC	NC	NC	NC	1990913.58	238237.92	1990958.50	238252.49	1990881.31	238017.56	1990942.00	238024.75
3/1/2002	NC	NC	NC	NC	1991212.22	238314.28	1991217.80	238329.36	1990833.23	237986.67	1990905.60	238022.75

NC = Not Calculated.

Case Study Data for Facility 1381, Cape Canaveral Air Station, Florida

TABLE C.1E
MAROS LINEAR REGRESSION STATISTICS SUMMARY
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Average Conc (mg/L) [a/]	Median Conc (mg/L)	Standard Deviation	All Samples ND? [b/]	LN Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend [c/]	Designation for Current Analysis
Trichloroethene (TCE)										
1381MWS09	S	5.7E+01	3.5E+01	7.3E+01	No	-1.4E-03	1.29	80.5%	NT	Source
1381MWI09	S	3.4E+00	1.4E-02	8.2E+00	No	-8.3E-04	2.41	66.3%	NT	Source
1381MWI19	S	8.5E+02	8.8E+02	8.1E+01	No	2.4E-04	0.10	94.4%	PI	Source
1381MWI20	S	8.0E+02	8.6E+02	2.5E+02	No	1.0E-03	0.32	99.5%	I	Source
1381MWS01	T	3.3E-01	2.1E-01	3.3E-01	No	-5.0E-04	1.01	73.5%	NT	Plume
1381MWS03	T	9.1E-04	1.0E-03	2.0E-04	No	1.2E-05	0.22	52.3%	NT	Plume
1381MWS05	T	1.0E-03	1.0E-03	0.0E+00	Yes	0.0E+00	0.00	100.0%	S * [d/]	Plume
1381MWS07	T	1.0E-03	1.0E-03	0.0E+00	Yes	-6.5E-35	0.00	100.0%	D *	Plume
1381MWS08	T	9.9E-04	1.0E-03	3.8E-05	No	-5.0E-06	0.04	100.0%	D	Plume
1381MWS10	T	9.3E-04	1.0E-03	1.9E-04	No	-8.3E-05	0.21	76.0%	S	Plume
1381MWS12	T	1.0E-03	1.0E-03	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Plume
1381MWS13	T	1.0E-03	1.0E-03	0.0E+00	Yes	-9.8E-35	0.00	100.0%	D *	Plume
1381MWS14	T	9.3E-04	1.0E-03	2.0E-04	No	-7.8E-05	0.21	76.8%	S	Plume
1381MWS15	T	1.0E-03	1.0E-03	0.0E+00	Yes	4.7E-35	0.00	100.0%	I *	Plume
1381MWS16	T	9.0E-04	1.0E-03	2.5E-04	No	-1.3E-04	0.28	76.6%	S	Plume
1381MWS17	T	4.2E-03	1.0E-03	6.6E-03	No	4.5E-04	1.56	86.1%	NT	Plume
1381MWD09	T	8.1E-03	2.7E-03	1.3E-02	No	-3.1E-04	1.67	64.8%	NT	Plume
1381MWD10	T	9.3E-03	1.0E-03	1.7E-02	No	3.4E-03	1.83	78.0%	NT	Plume
1381MPS01	T	9.0E-04	1.0E-03	2.2E-04	Yes	2.8E-04	0.25	99.5%	I *	Plume
1381MWS11	T	9.0E-04	1.0E-03	2.2E-04	Yes	2.8E-04	0.25	99.5%	I *	Sentry
1381MPI01	T	9.0E-04	1.0E-03	2.2E-04	Yes	2.8E-04	0.25	99.5%	I *	Sentry
1381MPI02	T	8.8E-04	1.0E-03	2.5E-04	Yes	2.8E+01	0.29	97.8%	I *	Sentry
1381MPI05	T	9.0E-04	1.0E-03	2.2E-04	Yes	2.8E-04	0.25	99.5%	I *	Sentry
1381MWD08	T	1.0E-03	1.0E-03	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
1381MWD11	T	1.0E-03	1.0E-03	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
1381MWS18	T	1.0E-03	1.0E-03	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Upgradient Sentry
Dichloroethenes (DCE)										
1381MWS09	S	4.4E+00	4.4E+00	3.4E+00	No	-6.3E-04	0.78	74.4%	S	Source
1381MWI09	S	1.0E+00	1.8E-02	2.0E+00	No	-1.0E-03	1.87	75.5%	NT	Source
1381MWI19	S	1.5E+01	1.7E+01	7.2E+00	No	1.8E-03	0.49	93.5%	PI	Source
1381MWI20	S	1.6E+01	1.6E+01	8.9E+00	No	1.1E-03	0.55	81.7%	NT	Source
1381MWS01	T	4.0E+00	2.5E+00	3.2E+00	No	-4.5E-04	0.80	82.1%	S	Plume
1381MWS03	T	1.3E+00	1.0E+00	1.2E+00	No	-1.5E-03	0.91	98.7%	D	Plume
1381MWS05	T	1.3E-01	4.6E-02	1.8E-01	No	-3.0E-03	1.41	96.2%	D	Plume
1381MWS07	T	2.9E-03	1.0E-03	3.8E-03	No	-9.6E-04	1.31	98.0%	D	Plume
1381MWS08	T	3.4E-01	2.8E-02	7.8E-01	No	2.8E-04	2.28	62.7%	NT	Plume
1381MWS10	T	1.9E-02	1.4E-02	2.1E-02	No	5.1E-04	1.08	73.3%	NT	Plume
1381MWS12	T	3.0E-01	1.1E-01	3.6E-01	No	-3.4E-03	1.19	99.9%	D	Plume
1381MWS13	T	8.3E-03	7.5E-03	5.7E-03	No	1.9E-04	0.69	74.3%	NT	Plume
1381MWS14	T	5.7E-02	2.2E-02	7.5E-02	No	-1.3E-03	1.32	100.0%	D	Plume
1381MWS15	T	5.2E-02	3.0E-02	4.4E-02	No	-6.4E-04	0.86	98.5%	D	Plume
1381MWS16	T	5.3E-03	2.1E-03	8.9E-03	No	-2.7E-04	1.68	66.0%	NT	Plume
1381MWS17	T	3.9E-01	1.7E-01	4.1E-01	No	-8.1E-04	1.05	97.5%	D	Plume
1381MWD09	T	1.4E-03	1.0E-03	1.2E-03	No	-5.9E-04	0.82	95.5%	D	Plume
1381MWD10	T	1.0E-03	1.0E-03	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Plume
1381MPS01	T	3.3E-03	3.4E-03	7.4E-04	No	-3.7E-05	0.22	60.7%	S	Plume
1381MWS11	T	9.0E-04	1.0E-03	2.2E-04	Yes	2.8E-04	0.25	99.5%	I *	Sentry
1381MPI01	T	9.0E-04	1.0E-03	2.2E-04	Yes	2.8E-04	0.25	99.5%	I *	Sentry
1381MPI02	T	8.8E-04	1.0E-03	2.5E-04	Yes	2.8E-04	0.29	97.8%	I *	Sentry
1381MPI05	T	9.0E-04	1.0E-03	2.2E-04	Yes	2.8E-04	0.25	99.5%	I *	Sentry
1381MWD08	T	1.0E-03	1.0E-03	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
1381MWD11	T	1.0E-03	1.0E-03	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
1381MWS18	T	9.1E-04	1.0E-03	2.1E-04	No	-1.0E-04	0.23	76.5%	S	Upgradient Sentry
Vinyl Chloride (VC)										
1381MWS09	S	1.3E-01	1.7E-01	1.1E-01	No	5.1E-04	0.86	69.4%	NT	Source
1381MWI09	S	1.8E-01	1.4E-02	3.2E-01	No	-9.9E-04	1.75	82.8%	NT	Source
1381MWI19	S	5.2E+00	5.0E+00	3.7E+00	No	-7.0E-04	0.72	62.2%	S	Source
1381MWI20	S	2.8E+00	2.8E+00	2.6E+00	Yes	-3.0E-03	0.94	90.1%	PD *	Source
1381MWS01	T	6.8E-01	6.1E-01	4.7E-01	No	7.5E-05	0.69	54.5%	NT	Plume
1381MWS03	T	4.7E-01	4.6E-01	2.5E-01	No	-1.4E-04	0.52	62.9%	S	Plume
1381MWS05	T	9.2E-02	5.1E-02	1.2E-01	No	-3.3E-03	1.31	96.8%	D	Plume
1381MWS07	T	7.0E-04	5.0E-04	3.5E-04	No	-3.1E-04	0.49	96.8%	D	Plume
1381MWS08	T	1.2E-01	4.0E-02	1.6E-01	No	6.8E-04	1.36	91.5%	PI	Plume
1381MWS10	T	1.2E-02	1.2E-02	9.3E-03	No	5.7E-04	0.79	78.6%	NT	Plume
1381MWS12	T	1.6E-01	9.8E-02	2.0E-01	No	-2.9E-03	1.31	97.7%	D	Plume
1381MWS13	T	2.4E-03	1.9E-03	1.9E-03	No	5.4E-04	0.80	91.4%	PI	Plume
1381MWS14	T	7.8E-03	2.7E-03	1.1E-02	No	-3.4E-04	1.39	82.2%	NT	Plume
1381MWS15	T	7.8E-03	7.3E-03	4.0E-03	No	-2.6E-04	0.52	94.1%	PD	Plume
1381MWS16	T	3.9E-03	1.9E+01	5.7E-03	No	2.6E-05	1.48	51.9%	NT	Plume
1381MWS17	T	7.4E-01	8.7E-01	3.5E-01	No	1.0E-04	0.47	56.4%	NT	Plume
1381MWD09	T	8.5E-04	5.0E-04	5.4E-04	No	-5.2E-04	0.64	99.9%	D	Plume
1381MWD10	T	5.0E-04	5.0E-04	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Plume

TABLE C.1E
MAROS LINEAR REGRESSION STATISTICS SUMMARY
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Average Conc (mg/L) [a]	Median Conc (mg/L)	Standard Deviation	All Samples ND? [b]	LN Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend [c]	Designation for Current Analysis
1381MPS01	T	4.3E-04	5.0E-04	1.0E-04	No	-1.3E-04	0.24	81.7%	S	Plume
1381MWS11	T	4.7E-04	5.0E-04	6.9E-05	No	1.5E-06	0.15	100.0%	I	Sentry
1381MPI01	T	5.0E-04	5.0E-04	0.0E+00	Yes	9.1E-35	0.00	100.0%	I *	Sentry
1381MPI02	T	5.0E-04	5.0E-04	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
1381MPI05	T	5.0E-04	5.0E-04	0.0E+00	Yes	-4.5E-35	0.00	100.0%	D *	Sentry
1381MWD08	T	5.0E-04	5.0E-04	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
1381MWD11	T	5.0E-04	5.0E-04	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Sentry
1381MWS18	T	5.0E-04	5.0E-04	0.0E+00	Yes	0.0E+00	0.00	100.0%	S *	Upgradient Sentry

[a] mg/L = milligrams per liter.

[b] ND = non-detect.

[c] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[d] * indicates that the concentrations at this well were reported as non detect (ND) for every sampling event available.

TABLE C.2E
MAROS MANN-KENDALL STATISTICS SUMMARY
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples ND? $^{a/}$	Concentration Trend $^{b/}$	Designation for Current Analysis
Trichloroethene (TCE)									
1381MWS09	S	7	7	1.29	-3	614.0%	No	NT	Source
1381MWI09	S	6	4	2.41	-6	81.5%	No	NT	Source
1381MWI19	S	4	4	0.10	4	83.3%	No	NT	Source
1381MWI20	S	4	4	0.32	6	95.8%	No	I	Source
1381MWS01	T	4	4	1.01	0	37.5%	No	NT	Plume
1381MWS03	T	5	1	0.22	0	40.8%	No	S	Plume
1381MWS05	T	5	0	0.00	0	40.8%	Yes	S * $^{c/}$	Plume
1381MWS07	T	7	0	0.00	0	43.7%	Yes	S *	Plume
1381MWS08	T	7	1	0.04	0	43.7%	No	S	Plume
1381MWS10	T	7	1	0.21	-2	55.7%	No	S	Plume
1381MWS12	T	5	0	0.00	0	40.8%	Yes	S *	Plume
1381MWS13	T	7	0	0.00	0	43.7%	Yes	S *	Plume
1381MWS14	T	7	1	0.21	-2	55.7%	No	S	Plume
1381MWS15	T	7	0	0.00	0	43.7%	Yes	S *	Plume
1381MWS16	T	6	1	0.28	-3	64.0%	No	S	Plume
1381MWS17	T	8	1	1.56	8	80.1%	No	NT	Plume
1381MWD09	T	6	4	1.67	-2	57.0%	No	NT	Plume
1381MWD10	T	4	2	1.83	3	72.9%	No	NT	Plume
1381MPS01	T	5	0	0.25	4	75.8%	Yes	NT *	Plume
1381MWS11	T	5	0	0.25	4	75.8%	Yes	NT *	Sentry
1381MPI01	T	5	0	0.25	4	75.8%	Yes	NT *	Sentry
1381MPI02	T	4	0	0.29	3	72.9%	Yes	NT *	Sentry
1381MPI05	T	5	0	0.25	4	75.8%	Yes	NT *	Sentry
1381MWD08	T	4	0	0.00	0	37.5%	Yes	S *	Sentry
1381MWD11	T	4	0	0.00	0	37.5%	Yes	S *	Sentry
1381MWS18	T	6	0	0.00	0	42.3%	Yes	S *	Upgradient Sentry
Dichloroethenes (DCE)									
1381MWS09	S	7	7	0.78	3	61.4%	No	NT	Source
1381MWI09	S	6	6	1.87	-7	86.4%	No	NT	Source
1381MWI19	S	4	3	0.49	0	37.5%	No	S	Source
1381MWI20	S	4	3	0.55	2	62.5%	No	NT	Source
1381MWS01	T	4	4	0.80	-4	83.3%	No	S	Plume
1381MWS03	T	5	5	0.91	-8	95.8%	No	D	Plume
1381MWS05	T	5	3	1.41	-7	92.1%	No	PD	Plume
1381MWS07	T	7	5	1.31	-13	96.5%	No	D	Plume
1381MWS08	T	7	7	2.28	-3	61.4%	No	NT	Plume
1381MWS10	T	7	6	1.08	3	61.4%	No	NT	Plume
1381MWS12	T	5	4	1.19	-8	95.8%	No	D	Plume
1381MWS13	T	7	7	0.69	4	66.7%	No	NT	Plume
1381MWS14	T	7	7	1.32	-19	99.9%	No	D	Plume
1381MWS15	T	7	7	0.86	-9	88.1%	No	S	Plume
1381MWS16	T	6	6	1.68	-5	76.5%	No	NT	Plume
1381MWS17	T	8	8	1.05	-16	96.9%	No	D	Plume
1381MWD09	T	6	3	0.82	-8	89.8%	No	S	Plume
1381MWD10	T	4	0	0	0	37.5%	Yes	S *	Plume
1381MPS01	T	5	5	0.22	0	40.8%	No	S	Plume
1381MWS11	T	5	0	0.25	4	75.8%	Yes	NT *	Sentry
1381MPI01	T	5	0	0.25	4	75.8%	Yes	NT *	Sentry
1381MPI02	T	4	0	0.29	3	72.9%	Yes	NT *	Sentry
1381MPI05	T	5	0	0.25	4	75.8%	Yes	NT *	Sentry
1381MWD08	T	4	0	0	0	37.5%	Yes	S *	Sentry
1381MWD11	T	4	0	0	0	37.5%	Yes	S *	Sentry
1381MWS18	T	6	1	0.23	-3	64.0%	No	S	Upgradient Sentry
Vinyl Chloride (VC)									
1381MWS09	S	7	5	0.86	7	80.9%	No	NT	Source
1381MWI09	S	6	5	1.75	-5	76.5%	No	NT	Source
1381MWI19	S	4	1	0.72	-1	50.0%	No	S	Source

TABLE C.2E
MAROS MANN-KENDALL STATISTICS SUMMARY
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples ND? [a]	Concentration Trend [b]	Designation for Current Analysis
1381MWI20	S	4	0	0.94	-4	83.3%	Yes	S *	Source
1381MWS01	T	4	4	0.69	0	37.5%	No	S	Plume
1381MWS03	T	5	5	0.52	-2	59.2%	No	S	Plume
1381MWS05	T	5	3	1.31	-7	92.1%	No	PD	Plume
1381MWS07	T	7	2	0.49	-9	88.1%	No	S	Plume
1381MWS08	T	7	7	1.36	9	88.1%	No	NT	Plume
1381MWS10	T	7	5	0.79	0	43.7%	No	S	Plume
1381MWS12	T	5	4	1.31	-6	88.3%	No	NT	Plume
1381MWS13	T	7	5	0.80	6	76.4%	No	NT	Plume
1381MWS14	T	7	7	1.39	-8	84.5%	No	NT	Plume
1381MWS15	T	8	8	0.52	-14	94.6%	No	PD	Plume
1381MWS16	T	6	5	1.48	1	50.0%	No	NT	Plume
1381MWS17	T	8	8	0.47	-2	54.8%	No	S	Plume
1381MWD09	T	6	2	0.64	-9	93.2%	No	PD	Plume
1381MWD10	T	4	0	0.00	0	37.5%	Yes	S *	Plume
1381MPS01	T	5	2	0.24	-5	82.1%	No	S	Plume
1381MWS11	T	5	1	0.15	2	59.2%	No	NT	Sentry
1381MPI01	T	5	0	0.00	0	40.8%	Yes	S *	Sentry
1381MPI02	T	4	0	0.00	0	37.5%	Yes	S *	Sentry
1381MPI05	T	5	0	0.00	0	40.8%	Yes	S *	Sentry
1381MWD08	T	4	0	0.00	0	37.5%	Yes	S *	Sentry
1381MWD11	T	4	0	0.00	0	37.5%	Yes	S *	Sentry
1381MWS18	T	6	0	0.00	0	42.3%	Yes	S *	Upgradient Sentry

[a] ND = non-detect.

[b] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[c] * indicates that the concentrations at this well were reported as non detect (ND) for every sampling event available.

TABLE C.3E
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
1381MWS02	1504368.77	797491.99	TRICHLOROETHENE (TCE)	12/15/1995	4300	ug/L	2	
1381MWS02	1504368.77	797491.99	TRICHLOROETHENE (TCE)	3/19/1998	30500	ug/L	2	
1381MWS02	1504368.77	797491.99	TRICHLOROETHENE (TCE)	8/28/2001	9340	ug/L	2	
1381MWS09	1504278.21	797469.30	TRICHLOROETHENE (TCE)	3/6/1996	35000	ug/L	2	
1381MWS09	1504278.21	797469.30	TRICHLOROETHENE (TCE)	9/19/1996	39400	ug/L	2	
1381MWS09	1504278.21	797469.30	TRICHLOROETHENE (TCE)	3/19/1998	210000	ug/L	2	
1381MWS09	1504278.21	797469.30	TRICHLOROETHENE (TCE)	8/24/2001	4290	ug/L	2	
1381MWS09	1504278.21	797469.30	TRICHLOROETHENE (TCE)	11/22/2002	0.73	ug/L	2	
1381MWS09	1504275.71	797474.19	TRICHLOROETHENE (TCE)	5/7/2003	88000	ug/L	2	
1381MWS09	1504275.71	797474.19	TRICHLOROETHENE (TCE)	10/28/2003	23200	ug/L	2	
1381MWI09	1504272.57	797478.96	TRICHLOROETHENE (TCE)	9/19/1996	27	ug/L	1	
1381MWI09	1504272.57	797478.96	TRICHLOROETHENE (TCE)	3/19/1998	251	ug/L	1	
1381MWI09	1504272.57	797478.96	TRICHLOROETHENE (TCE)	8/24/2001		ug/L	2	ND
1381MWI09	1504272.57	797478.96	TRICHLOROETHENE (TCE)	11/22/2002	20100	ug/L	2	
1381MWI09	1504272.57	797478.96	TRICHLOROETHENE (TCE)	5/7/2003		ug/L	2	ND
1381MWI09	1504272.57	797478.96	TRICHLOROETHENE (TCE)	10/28/2003	1.7	ug/L	2	TR
1381MWI19	1504325.50	797542.45	TRICHLOROETHENE (TCE)	7/24/2001	733000	ug/L	20000	
1381MWI19	1504325.50	797542.45	TRICHLOROETHENE (TCE)	11/22/2002	903000	ug/L	20000	
1381MWI19	1504325.50	797542.45	TRICHLOROETHENE (TCE)	5/8/2003	852000	ug/L	20000	
1381MWI19	1504325.50	797542.45	TRICHLOROETHENE (TCE)	11/28/2003	908000	ug/L	20000	
1381MWI20	1504358.27	797503.46	TRICHLOROETHENE (TCE)	7/24/2001	448000	ug/L	20000	
1381MWI20	1504358.27	797503.46	TRICHLOROETHENE (TCE)	11/27/2002	793000	ug/L	20000	
1381MWI20	1504358.27	797503.46	TRICHLOROETHENE (TCE)	5/8/2003	936000	ug/L	20000	
1381MWI20	1504358.27	797503.46	TRICHLOROETHENE (TCE)	11/4/2003	1020000	ug/L	20000	
1381MWS01	1504383.31	797422.99	TRICHLOROETHENE (TCE)	12/15/1995	190	ug/L	2	
1381MWS01	1504383.31	797422.99	TRICHLOROETHENE (TCE)	9/19/1996	239	ug/L	2	
1381MWS01	1504383.31	797422.99	TRICHLOROETHENE (TCE)	3/19/1998	819	ug/L	2	
1381MWS01	1504383.31	797422.99	TRICHLOROETHENE (TCE)	8/28/2001	74	ug/L	2	
1381MWS03	1504588.46	797436.66	TRICHLOROETHENE (TCE)	12/15/1995		ug/L	2	ND
1381MWS03	1504588.46	797436.66	TRICHLOROETHENE (TCE)	9/20/1996		ug/L	2	ND
1381MWS03	1504588.46	797436.66	TRICHLOROETHENE (TCE)	3/19/1998	1.1	ug/L	2	TR
1381MWS03	1504588.46	797436.66	TRICHLOROETHENE (TCE)	3/30/1999		ug/L	2	ND
1381MWS03	1504588.46	797436.66	TRICHLOROETHENE (TCE)	8/23/2001		ug/L	2	ND
1381MWS05	1504447.00	797005.30	TRICHLOROETHENE (TCE)	3/6/1996		ug/L	2	ND
1381MWS05	1504447.00	797005.30	TRICHLOROETHENE (TCE)	9/20/1996		ug/L	2	ND
1381MWS05	1504447.00	797005.30	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS05	1504447.00	797005.30	TRICHLOROETHENE (TCE)	4/1/1999		ug/L	2	ND
1381MWS05	1504447.00	797005.30	TRICHLOROETHENE (TCE)	8/22/2001		ug/L	2	ND
1381MWS07	1505755.00	797602.10	TRICHLOROETHENE (TCE)	9/20/1996		ug/L	2	ND
1381MWS07	1505755.00	797602.10	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS07	1505755.00	797602.10	TRICHLOROETHENE (TCE)	3/30/1999		ug/L	2	ND
1381MWS07	1505755.00	797602.10	TRICHLOROETHENE (TCE)	8/22/2001		ug/L	2	ND
1381MWS07	1505755.00	797602.10	TRICHLOROETHENE (TCE)	11/21/2002		ug/L	2	ND
1381MWS07	1505755.00	797602.10	TRICHLOROETHENE (TCE)	5/8/2003		ug/L	2	ND
1381MWS07	1505755.00	797602.10	TRICHLOROETHENE (TCE)	11/3/2003		ug/L	2	ND
1381MWS08	1504609.52	797903.21	TRICHLOROETHENE (TCE)	3/6/1996		ug/L	2	ND
1381MWS08	1504609.52	797903.21	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS08	1504609.52	797903.21	TRICHLOROETHENE (TCE)	3/31/1999		ug/L	2	ND
1381MWS08	1504609.52	797903.21	TRICHLOROETHENE (TCE)	8/28/2001	1.8	ug/L	2	TR
1381MWS08	1504609.52	797903.21	TRICHLOROETHENE (TCE)	11/27/2002		ug/L	2	ND
1381MWS08	1504609.52	797903.21	TRICHLOROETHENE (TCE)	5/6/2003		ug/L	2	ND
1381MWS08	1504609.52	797903.21	TRICHLOROETHENE (TCE)	11/4/2003		ug/L	2	ND
1381MWS10	1504258.18	797671.13	TRICHLOROETHENE (TCE)	3/5/1996		ug/L	2	ND
1381MWS10	1504258.18	797671.13	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS10	1504258.18	797671.13	TRICHLOROETHENE (TCE)	3/31/1999		ug/L	2	ND
1381MWS10	1504258.18	797671.13	TRICHLOROETHENE (TCE)	8/24/2001		ug/L	2	ND
1381MWS10	1504258.18	797671.13	TRICHLOROETHENE (TCE)	11/27/2002	1.0	ug/L	2	TR
1381MWS10	1504258.18	797671.13	TRICHLOROETHENE (TCE)	5/6/2003		ug/L	2	ND
1381MWS10	1504258.18	797671.13	TRICHLOROETHENE (TCE)	10/29/2003		ug/L	2	ND
1381MWS12	1505429.89	798083.35	TRICHLOROETHENE (TCE)	3/6/1996		ug/L	2	ND

TABLE C.3E
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
1381MWS12	1505429.89	798083.35	TRICHLOROETHENE (TCE)	9/21/1996		ug/L	2	ND
1381MWS12	1505429.89	798083.35	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS12	1505429.89	798083.35	TRICHLOROETHENE (TCE)	3/31/1999		ug/L	2	ND
1381MWS12	1505429.89	798083.35	TRICHLOROETHENE (TCE)	8/21/2001		ug/L	2	ND
1381MWS13	1505592.71	796624.10	TRICHLOROETHENE (TCE)	9/21/1996		ug/L	2	ND
1381MWS13	1505592.71	796624.10	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS13	1505592.71	796624.10	TRICHLOROETHENE (TCE)	3/31/1999		ug/L	2	ND
1381MWS13	1505592.71	796624.10	TRICHLOROETHENE (TCE)	8/14/2001		ug/L	2	ND
1381MWS13	1505592.71	796624.10	TRICHLOROETHENE (TCE)	11/21/2002		ug/L	2	ND
1381MWS13	1505592.71	796624.10	TRICHLOROETHENE (TCE)	5/7/2003		ug/L	2	ND
1381MWS13	1505592.71	796624.10	TRICHLOROETHENE (TCE)	10/28/2003		ug/L	2	ND
1381MWS14	1506002.99	798494.39	TRICHLOROETHENE (TCE)	3/6/1996		ug/L	2	ND
1381MWS14	1506002.99	798494.39	TRICHLOROETHENE (TCE)	9/21/1996		ug/L	2	ND
1381MWS14	1506002.99	798494.39	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS14	1506002.99	798494.39	TRICHLOROETHENE (TCE)	8/21/2001		ug/L	2	ND
1381MWS14	1506002.99	798494.39	TRICHLOROETHENE (TCE)	11/22/2002	1.0	ug/L	2	TR
1381MWS14	1506002.99	798494.39	TRICHLOROETHENE (TCE)	5/8/2003		ug/L	2	ND
1381MWS14	1506002.99	798494.39	TRICHLOROETHENE (TCE)	11/4/2003		ug/L	2	ND
1381MWS15	1506601.74	798915.22	TRICHLOROETHENE (TCE)	3/22/1996		ug/L	2	ND
1381MWS15	1506601.74	798915.22	TRICHLOROETHENE (TCE)	9/20/1996		ug/L	2	ND
1381MWS15	1506601.74	798915.22	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS15	1506601.74	798915.22	TRICHLOROETHENE (TCE)	8/22/2001		ug/L	2	ND
1381MWS15	1506601.74	798915.22	TRICHLOROETHENE (TCE)	11/21/2002		ug/L	2	ND
1381MWS15	1506601.74	798915.22	TRICHLOROETHENE (TCE)	5/21/2003		ug/L	2	ND
1381MWS15	1506601.74	798915.22	TRICHLOROETHENE (TCE)	10/29/2003		ug/L	2	ND
1381MWS16	1505363.75	798696.50	TRICHLOROETHENE (TCE)	9/21/1996		ug/L	2	ND
1381MWS16	1505363.75	798696.50	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS16	1505363.75	798696.50	TRICHLOROETHENE (TCE)	8/20/2001		ug/L	2	ND
1381MWS16	1505363.75	798696.50	TRICHLOROETHENE (TCE)	11/21/2002		ug/L	2	ND
1381MWS16	1505363.75	798696.50	TRICHLOROETHENE (TCE)	5/8/2003	0.8	ug/L	2	TR
1381MWS16	1505363.75	798696.50	TRICHLOROETHENE (TCE)	11/3/2003		ug/L	2	ND
1381MWS17	1504627.62	797234.30	TRICHLOROETHENE (TCE)	5/22/1996	3.7	ug/L	2	
1381MWS17	1504627.62	797234.30	TRICHLOROETHENE (TCE)	9/20/1996		ug/L	2	ND
1381MWS17	1504627.62	797234.30	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS17	1504627.62	797234.30	TRICHLOROETHENE (TCE)	3/30/1999		ug/L	2	ND
1381MWS17	1504627.62	797234.30	TRICHLOROETHENE (TCE)	8/23/2001		ug/L	2	ND
1381MWS17	1504627.62	797234.30	TRICHLOROETHENE (TCE)	11/27/2002		ug/L	2	ND
1381MWS17	1504627.62	797234.30	TRICHLOROETHENE (TCE)	5/8/2003		ug/L	10	ND
1381MWS17	1504627.62	797234.30	TRICHLOROETHENE (TCE)	11/4/2003		ug/L	40	ND
1381MWD09	1504275.71	797474.19	TRICHLOROETHENE (TCE)	9/19/1996	6.6	ug/L	1	
1381MWD09	1504275.71	797474.19	TRICHLOROETHENE (TCE)	3/19/1998	4.4	ug/L	1	
1381MWD09	1504275.71	797474.19	TRICHLOROETHENE (TCE)	8/24/2001		ug/L	2	ND
1381MWD09	1504275.71	797474.19	TRICHLOROETHENE (TCE)	11/22/2002	0.6	ug/L	2	TR
1381MWD09	1504275.71	797474.19	TRICHLOROETHENE (TCE)	5/7/2003		ug/L	2	ND
1381MWD09	1504275.71	797474.19	TRICHLOROETHENE (TCE)	10/28/2003	35.00	ug/L	2	
1381MWD10	1504188.81	797182.42	TRICHLOROETHENE (TCE)	8/24/2001		ug/L	2	ND
1381MWD10	1504188.81	797182.42	TRICHLOROETHENE (TCE)	11/27/2002	0.64	ug/L	2	TR
1381MWD10	1504188.81	797182.42	TRICHLOROETHENE (TCE)	5/6/2003		ug/L	2	ND
1381MWD10	1504188.81	797182.42	TRICHLOROETHENE (TCE)	10/28/2003	35.00	ug/L	2	
1381MPS01	1506560.30	796946.63	TRICHLOROETHENE (TCE)	9/19/1996		ug/L	1	ND
1381MPS01	1506560.30	796946.63	TRICHLOROETHENE (TCE)	8/20/2001		ug/L	2	ND
1381MPS01	1506560.30	796946.63	TRICHLOROETHENE (TCE)	11/21/2002		ug/L	2	ND
1381MPS01	1506560.30	796946.63	TRICHLOROETHENE (TCE)	6/7/2003		ug/L	2	ND
1381MPS01	1506560.30	796946.63	TRICHLOROETHENE (TCE)	10/28/2003		ug/L	2	ND
1381MWS11	1504193.92	797178.06	TRICHLOROETHENE (TCE)	9/20/1996		ug/L	1	ND
1381MWS11	1504193.92	797178.06	TRICHLOROETHENE (TCE)	8/22/2001		ug/L	2	ND
1381MWS11	1504193.92	797178.06	TRICHLOROETHENE (TCE)	12/2/2002		ug/L	2	ND
1381MWS11	1504193.92	797178.06	TRICHLOROETHENE (TCE)	5/6/2003		ug/L	2	ND
1381MWS11	1504193.92	797178.06	TRICHLOROETHENE (TCE)	10/31/2003		ug/L	2	ND
1381MPI01	1506558.32	796945.88	TRICHLOROETHENE (TCE)	9/21/1996		ug/L	1	ND
1381MPI01	1506558.32	796945.88	TRICHLOROETHENE (TCE)	8/20/2001		ug/L	2	ND

TABLE C.3E
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a]	DetLim	Flags [b]
1381MPI01	1506558.32	796945.88	TRICHLOROETHENE (TCE)	11/21/2002		ug/L	2	ND
1381MPI01	1506558.32	796945.88	TRICHLOROETHENE (TCE)	5/7/2003		ug/L	2	ND
1381MPI01	1506558.32	796945.88	TRICHLOROETHENE (TCE)	10/28/2003		ug/L	2	ND
1381MPI02	150400.00	797000.00	TRICHLOROETHENE (TCE)	9/21/1996		ug/L	1	ND
1381MPI02	150400.00	797000.00	TRICHLOROETHENE (TCE)	8/20/2001		ug/L	2	ND
1381MPI02	150400.00	797000.00	TRICHLOROETHENE (TCE)	5/7/2003		ug/L	2	ND
1381MPI02	150400.00	797000.00	TRICHLOROETHENE (TCE)	11/3/2003		ug/L	2	ND
1381MPI05	1504201.84	797183.59	TRICHLOROETHENE (TCE)	9/24/1996		ug/L	1	ND
1381MPI05	1504201.84	797183.59	TRICHLOROETHENE (TCE)	8/22/2001		ug/L	2	ND
1381MPI05	1504201.84	797183.59	TRICHLOROETHENE (TCE)	11/20/2002		ug/L	2	ND
1381MPI05	1504201.84	797183.59	TRICHLOROETHENE (TCE)	5/8/2003		ug/L	2	ND
1381MPI05	1504201.84	797183.59	TRICHLOROETHENE (TCE)	10/31/2003		ug/L	2	ND
1381MWD08	1504603.00	797900.19	TRICHLOROETHENE (TCE)	8/24/2001		ug/L	2	ND
1381MWD08	1504603.00	797900.19	TRICHLOROETHENE (TCE)	11/27/2002		ug/L	2	ND
1381MWD08	1504603.00	797900.19	TRICHLOROETHENE (TCE)	5/6/2003		ug/L	2	ND
1381MWD08	1504603.00	797900.19	TRICHLOROETHENE (TCE)	11/4/2003		ug/L	2	ND
1381MWD11	1504188.81	797182.42	TRICHLOROETHENE (TCE)	8/22/2001		ug/L	2	ND
1381MWD11	1504188.81	797182.42	TRICHLOROETHENE (TCE)	11/20/2002		ug/L	2	ND
1381MWD11	1504188.81	797182.42	TRICHLOROETHENE (TCE)	5/6/2003		ug/L	2	ND
1381MWD11	1504188.81	797182.42	TRICHLOROETHENE (TCE)	10/31/2003		ug/L	2	ND
1381MWS18	1504099.04	797568.54	TRICHLOROETHENE (TCE)	9/19/1996		ug/L	2	ND
1381MWS18	1504099.04	797568.54	TRICHLOROETHENE (TCE)	3/19/1998		ug/L	2	ND
1381MWS18	1504099.04	797568.54	TRICHLOROETHENE (TCE)	8/28/2001		ug/L	2	ND
1381MWS18	1504099.04	797568.54	TRICHLOROETHENE (TCE)	12/2/2002		ug/L	2	ND
1381MWS18	1504099.04	797568.54	TRICHLOROETHENE (TCE)	5/8/2003		ug/L	2	ND
1381MWS18	1504099.04	797568.54	TRICHLOROETHENE (TCE)	11/4/2003		ug/L	2	ND

[a] ug/L = micrograms per liter.

[b] ND = non detect, TR = trace value

TABLE C.4E
ANALYTICAL DATA - DICHLOROETHENES (DCE)
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
1381MWS02	1504368.77	797491.99	DICHLOROETHENES	12/15/1995	3000	ug/L	2	
1381MWS02	1504368.77	797491.99	DICHLOROETHENES	3/19/1998	7086	ug/L	2	
1381MWS02	1504368.77	797491.99	DICHLOROETHENES	8/28/2001	2839	ug/L	2	
1381MWS09	1504278.21	797469.30	DICHLOROETHENES	3/6/1996	3000	ug/L	2	
1381MWS09	1504278.21	797469.30	DICHLOROETHENES	9/19/1996	4383	ug/L	2	
1381MWS09	1504278.21	797469.30	DICHLOROETHENES	3/19/1998	8295	ug/L	2	
1381MWS09	1504278.21	797469.30	DICHLOROETHENES	8/24/2001	993	ug/L	2	
1381MWS09	1504278.21	797469.30	DICHLOROETHENES	11/22/2002	7.5	ug/L	2	
1381MWS09	1504275.71	797474.19	DICHLOROETHENES	5/7/2003	9103	ug/L	2	
1381MWS09	1504275.71	797474.19	DICHLOROETHENES	10/28/2003	5200	ug/L	2	
1381MWI09	1504272.57	797478.96	DICHLOROETHENES	9/19/1996	1361	ug/L	1	
1381MWI09	1504272.57	797478.96	DICHLOROETHENES	3/19/1998	24.2	ug/L	1	
1381MWI09	1504272.57	797478.96	DICHLOROETHENES	8/24/2001	4.5	ug/L	2	
1381MWI09	1504272.57	797478.96	DICHLOROETHENES	11/22/2002	4880	ug/L	2	
1381MWI09	1504272.57	797478.96	DICHLOROETHENES	5/7/2003	10.9	ug/L	2	
1381MWI09	1504272.57	797478.96	DICHLOROETHENES	10/28/2003	3.6	ug/L	2	
1381MWI19	1504325.50	797542.45	DICHLOROETHENES	7/24/2001	8210	ug/L	20000	TR
1381MWI19	1504325.50	797542.45	DICHLOROETHENES	11/22/2002		ug/L	40000	ND
1381MWI19	1504325.50	797542.45	DICHLOROETHENES	5/8/2003	17930	ug/L	2000	
1381MWI19	1504325.50	797542.45	DICHLOROETHENES	11/28/2003	16980	ug/L	20000	
1381MWI20	1504358.27	797503.46	DICHLOROETHENES	7/24/2001		ug/L	20000	ND
1381MWI20	1504358.27	797503.46	DICHLOROETHENES	11/27/2002	6950	ug/L	20000	
1381MWI20	1504358.27	797503.46	DICHLOROETHENES	5/8/2003	24580	ug/L	20000	
1381MWI20	1504358.27	797503.46	DICHLOROETHENES	11/4/2003	22830	ug/L	20000	
1381MWS01	1504383.31	797422.99	DICHLOROETHENES	12/15/1995	8800	ug/L	2	
1381MWS01	1504383.31	797422.99	DICHLOROETHENES	9/19/1996	2424	ug/L	2	
1381MWS01	1504383.31	797422.99	DICHLOROETHENES	3/19/1998	2660	ug/L	2	
1381MWS01	1504383.31	797422.99	DICHLOROETHENES	8/28/2001	2184	ug/L	2	
1381MWS03	1504588.46	797436.66	DICHLOROETHENES	12/15/1995	2500	ug/L	2	
1381MWS03	1504588.46	797436.66	DICHLOROETHENES	9/20/1996	2618	ug/L	2	
1381MWS03	1504588.46	797436.66	DICHLOROETHENES	3/19/1998	1021	ug/L	2	
1381MWS03	1504588.46	797436.66	DICHLOROETHENES	3/30/1999	210	ug/L	2	
1381MWS03	1504588.46	797436.66	DICHLOROETHENES	8/23/2001	189	ug/L	2	
1381MWS05	1504447.00	797005.30	DICHLOROETHENES	3/6/1996	436	ug/L	2	
1381MWS05	1504447.00	797005.30	DICHLOROETHENES	9/20/1996	45.5	ug/L	2	
1381MWS05	1504447.00	797005.30	DICHLOROETHENES	3/19/1998	168	ug/L	2	
1381MWS05	1504447.00	797005.30	DICHLOROETHENES	4/1/1999		ug/L	2	ND
1381MWS05	1504447.00	797005.30	DICHLOROETHENES	8/22/2001		ug/L	2	ND
1381MWS07	1505755.00	797602.10	DICHLOROETHENES	9/20/1996	10.2	ug/L	2	
1381MWS07	1505755.00	797602.10	DICHLOROETHENES	3/19/1998		ug/L	2	ND
1381MWS07	1505755.00	797602.10	DICHLOROETHENES	3/30/1999	6.2	ug/L	2	
1381MWS07	1505755.00	797602.10	DICHLOROETHENES	8/22/2001	1.7	ug/L	2	TR
1381MWS07	1505755.00	797602.10	DICHLOROETHENES	11/21/2002		ug/L	2	ND
1381MWS07	1505755.00	797602.10	DICHLOROETHENES	5/8/2003	0.55	ug/L	2	TR
1381MWS07	1505755.00	797602.10	DICHLOROETHENES	11/3/2003	1.7	ug/L	2	TR
1381MWS08	1504609.52	797903.21	DICHLOROETHENES	3/6/1996	14	ug/L	2	
1381MWS08	1504609.52	797903.21	DICHLOROETHENES	3/19/1998	122	ug/L	2	
1381MWS08	1504609.52	797903.21	DICHLOROETHENES	3/31/1999	7	ug/L	2	
1381MWS08	1504609.52	797903.21	DICHLOROETHENES	8/28/2001	2115	ug/L	2	
1381MWS08	1504609.52	797903.21	DICHLOROETHENES	11/27/2002	102	ug/L	2	
1381MWS08	1504609.52	797903.21	DICHLOROETHENES	5/6/2003	27.8	ug/L	2	
1381MWS08	1504609.52	797903.21	DICHLOROETHENES	11/4/2003	11	ug/L	2	
1381MWS10	1504258.18	797671.13	DICHLOROETHENES	3/5/1996		ug/L	2	ND
1381MWS10	1504258.18	797671.13	DICHLOROETHENES	3/19/1998	33	ug/L	2	

TABLE C.4E
ANALYTICAL DATA - DICHLOROETHENES (DCE)
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
1381MWS10	1504258.18	797671.13	DICHLOROETHENES	3/31/1999	14	ug/L	2	
1381MWS10	1504258.18	797671.13	DICHLOROETHENES	8/24/2001	0.63	ug/L	2	TR
1381MWS10	1504258.18	797671.13	DICHLOROETHENES	11/27/2002	60	ug/L	2	
1381MWS10	1504258.18	797671.13	DICHLOROETHENES	5/6/2003	10.4	ug/L	2	
1381MWS10	1504258.18	797671.13	DICHLOROETHENES	10/29/2003	17.3	ug/L	2	
1381MWS12	1505429.89	798083.35	DICHLOROETHENES	3/6/1996	606	ug/L	2	
1381MWS12	1505429.89	798083.35	DICHLOROETHENES	9/21/1996	763	ug/L	2	
1381MWS12	1505429.89	798083.35	DICHLOROETHENES	3/19/1998	112	ug/L	2	
1381MWS12	1505429.89	798083.35	DICHLOROETHENES	3/31/1999	18	ug/L	2	
1381MWS12	1505429.89	798083.35	DICHLOROETHENES	8/21/2001		ug/L	2	ND
1381MWS13	1505592.71	796624.10	DICHLOROETHENES	9/21/1996	4.6	ug/L	2	
1381MWS13	1505592.71	796624.10	DICHLOROETHENES	3/19/1998	2.6	ug/L	2	
1381MWS13	1505592.71	796624.10	DICHLOROETHENES	3/31/1999	20.0	ug/L	2	
1381MWS13	1505592.71	796624.10	DICHLOROETHENES	8/14/2001	7.5	ug/L	2	
1381MWS13	1505592.71	796624.10	DICHLOROETHENES	11/21/2002	7.5	ug/L	2	
1381MWS13	1505592.71	796624.10	DICHLOROETHENES	5/7/2003	10.6	ug/L	2	
1381MWS13	1505592.71	796624.10	DICHLOROETHENES	10/28/2003	5.6	ug/L	2	
1381MWS14	1506002.99	798494.39	DICHLOROETHENES	3/6/1996	211	ug/L	2	
1381MWS14	1506002.99	798494.39	DICHLOROETHENES	9/21/1996	65.6	ug/L	2	
1381MWS14	1506002.99	798494.39	DICHLOROETHENES	3/19/1998	82.6	ug/L	2	
1381MWS14	1506002.99	798494.39	DICHLOROETHENES	8/21/2001	21.6	ug/L	2	
1381MWS14	1506002.99	798494.39	DICHLOROETHENES	11/22/2002	7.0	ug/L	2	
1381MWS14	1506002.99	798494.39	DICHLOROETHENES	5/8/2003	5.4	ug/L	2	
1381MWS14	1506002.99	798494.39	DICHLOROETHENES	11/4/2003	3.4	ug/L	2	
1381MWS15	1506601.74	798915.22	DICHLOROETHENES	3/22/1996	63	ug/L	2	
1381MWS15	1506601.74	798915.22	DICHLOROETHENES	9/20/1996	130.0	ug/L	2	
1381MWS15	1506601.74	798915.22	DICHLOROETHENES	3/19/1998	88.8	ug/L	2	
1381MWS15	1506601.74	798915.22	DICHLOROETHENES	8/22/2001	9.6	ug/L	2	
1381MWS15	1506601.74	798915.22	DICHLOROETHENES	11/21/2002	26.9	ug/L	2	
1381MWS15	1506601.74	798915.22	DICHLOROETHENES	5/21/2003	30.2	ug/L	2	
1381MWS15	1506601.74	798915.22	DICHLOROETHENES	10/29/2003	14.8	ug/L	2	
1381MWS16	1505363.75	798696.50	DICHLOROETHENES	9/21/1996	2.1	ug/L	2	
1381MWS16	1505363.75	798696.50	DICHLOROETHENES	3/19/1998	2.7	ug/L	2	
1381MWS16	1505363.75	798696.50	DICHLOROETHENES	8/20/2001	23.4	ug/L	2	
1381MWS16	1505363.75	798696.50	DICHLOROETHENES	11/21/2002	1.2	ug/L	2	
1381MWS16	1505363.75	798696.50	DICHLOROETHENES	5/8/2003	0.8	ug/L	2	TR
1381MWS16	1505363.75	798696.50	DICHLOROETHENES	11/3/2003	2	ug/L	2	
1381MWS17	1504627.62	797234.30	DICHLOROETHENES	5/22/1996	1045.0	ug/L	2	
1381MWS17	1504627.62	797234.30	DICHLOROETHENES	9/20/1996	924.5	ug/L	2	
1381MWS17	1504627.62	797234.30	DICHLOROETHENES	3/19/1998	624.6	ug/L	2	
1381MWS17	1504627.62	797234.30	DICHLOROETHENES	3/30/1999	37	ug/L	2	
1381MWS17	1504627.62	797234.30	DICHLOROETHENES	8/23/2001	133	ug/L	2	
1381MWS17	1504627.62	797234.30	DICHLOROETHENES	11/27/2002	82	ug/L	2	
1381MWS17	1504627.62	797234.30	DICHLOROETHENES	5/8/2003	215.0	ug/L	10	
1381MWS17	1504627.62	797234.30	DICHLOROETHENES	11/4/2003	69	ug/L	40	
1381MWD09	1504275.71	797474.19	DICHLOROETHENES	9/19/1996	3.6	ug/L	1	
1381MWD09	1504275.71	797474.19	DICHLOROETHENES	3/19/1998	1.6	ug/L	1	
1381MWD09	1504275.71	797474.19	DICHLOROETHENES	8/24/2001		ug/L	2	ND
1381MWD09	1504275.71	797474.19	DICHLOROETHENES	11/22/2002	0.52	ug/L	2	TR
1381MWD09	1504275.71	797474.19	DICHLOROETHENES	5/7/2003		ug/L	2	ND
1381MWD09	1504275.71	797474.19	DICHLOROETHENES	10/28/2003		ug/L	2	ND
1381MWD10	1504188.81	797182.42	DICHLOROETHENES	8/24/2001		ug/L	2	ND
1381MWD10	1504188.81	797182.42	DICHLOROETHENES	11/27/2002		ug/L	2	ND
1381MWD10	1504188.81	797182.42	DICHLOROETHENES	5/6/2003		ug/L	2	ND
1381MWD10	1504188.81	797182.42	DICHLOROETHENES	10/28/2003		ug/L	2	ND

TABLE C.4E
ANALYTICAL DATA - DICHLOROETHENES (DCE)
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
1381MPS01	1506560.30	796946.63	DICHLOROETHENES	9/19/1996	3.6	ug/L	1	
1381MPS01	1506560.30	796946.63	DICHLOROETHENES	8/20/2001	3.0	ug/L	2	
1381MPS01	1506560.30	796946.63	DICHLOROETHENES	11/21/2002	3.4	ug/L	2	
1381MPS01	1506560.30	796946.63	DICHLOROETHENES	6/7/2003	2.3	ug/L	2	
1381MPS01	1506560.30	796946.63	DICHLOROETHENES	10/28/2003	4.3	ug/L	2	
1381MWS11	1504193.92	797178.06	DICHLOROETHENES	9/20/1996		ug/L	1	ND
1381MWS11	1504193.92	797178.06	DICHLOROETHENES	8/22/2001		ug/L	2	ND
1381MWS11	1504193.92	797178.06	DICHLOROETHENES	12/2/2002		ug/L	2	ND
1381MWS11	1504193.92	797178.06	DICHLOROETHENES	5/6/2003		ug/L	2	ND
1381MWS11	1504193.92	797178.06	DICHLOROETHENES	10/31/2003		ug/L	2	ND
1381MPI01	1506558.32	796945.88	DICHLOROETHENES	9/21/1996		ug/L	1	ND
1381MPI01	1506558.32	796945.88	DICHLOROETHENES	8/20/2001		ug/L	2	ND
1381MPI01	1506558.32	796945.88	DICHLOROETHENES	11/21/2002		ug/L	2	ND
1381MPI01	1506558.32	796945.88	DICHLOROETHENES	5/7/2003		ug/L	2	ND
1381MPI01	1506558.32	796945.88	DICHLOROETHENES	10/28/2003		ug/L	2	ND
1381MPI02	150400.00	797000.00	DICHLOROETHENES	9/21/1996		ug/L	1	ND
1381MPI02	150400.00	797000.00	DICHLOROETHENES	8/20/2001		ug/L	2	ND
1381MPI02	150400.00	797000.00	DICHLOROETHENES	5/7/2003		ug/L	2	ND
1381MPI02	150400.00	797000.00	DICHLOROETHENES	11/3/2003		ug/L	2	ND
1381MPI05	1504201.84	797183.59	DICHLOROETHENES	9/24/1996		ug/L	1	ND
1381MPI05	1504201.84	797183.59	DICHLOROETHENES	8/22/2001		ug/L	2	ND
1381MPI05	1504201.84	797183.59	DICHLOROETHENES	11/20/2002		ug/L	2	ND
1381MPI05	1504201.84	797183.59	DICHLOROETHENES	5/8/2003		ug/L	2	ND
1381MPI05	1504201.84	797183.59	DICHLOROETHENES	10/31/2003		ug/L	2	ND
1381MWD08	1504603.00	797900.19	DICHLOROETHENES	8/24/2001		ug/L	2	ND
1381MWD08	1504603.00	797900.19	DICHLOROETHENES	11/27/2002		ug/L	2	ND
1381MWD08	1504603.00	797900.19	DICHLOROETHENES	5/6/2003		ug/L	2	ND
1381MWD08	1504603.00	797900.19	DICHLOROETHENES	11/4/2003		ug/L	2	ND
1381MWD11	1504188.81	797182.42	DICHLOROETHENES	8/22/2001		ug/L	2	ND
1381MWD11	1504188.81	797182.42	DICHLOROETHENES	11/20/2002		ug/L	2	ND
1381MWD11	1504188.81	797182.42	DICHLOROETHENES	5/6/2003		ug/L	2	ND
1381MWD11	1504188.81	797182.42	DICHLOROETHENES	10/31/2003		ug/L	2	ND
1381MWS18	1504099.04	797568.54	DICHLOROETHENES	9/19/1996		ug/L	2	ND
1381MWS18	1504099.04	797568.54	DICHLOROETHENES	3/19/1998		ug/L	2	ND
1381MWS18	1504099.04	797568.54	DICHLOROETHENES	8/28/2001		ug/L	2	ND
1381MWS18	1504099.04	797568.54	DICHLOROETHENES	12/2/2002		ug/L	2	ND
1381MWS18	1504099.04	797568.54	DICHLOROETHENES	5/8/2003	0.97	ug/L	2	TR
1381MWS18	1504099.04	797568.54	DICHLOROETHENES	11/4/2003		ug/L	2	ND

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, TR = trace value

TABLE C.5E
ANALYTICAL DATA - VINYL CHLORIDE (VC)
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
1381MWS02	1504368.77	797491.99	VINYL CHLORIDE	12/15/1995	100	ug/L	1	
1381MWS02	1504368.77	797491.99	VINYL CHLORIDE	3/19/1998	206	ug/L	1	
1381MWS02	1504368.77	797491.99	VINYL CHLORIDE	8/28/2001	533	ug/L	1	
1381MWS09	1504278.21	797469.30	VINYL CHLORIDE	3/6/1996		ug/L	1	ND
1381MWS09	1504278.21	797469.30	VINYL CHLORIDE	9/19/1996	240	ug/L	1	
1381MWS09	1504278.21	797469.30	VINYL CHLORIDE	3/19/1998	166	ug/L	1	
1381MWS09	1504278.21	797469.30	VINYL CHLORIDE	8/24/2001	42	ug/L	1	
1381MWS09	1504278.21	797469.30	VINYL CHLORIDE	11/22/2002	1.7	ug/L	1	
1381MWS09	1504275.71	797474.19	VINYL CHLORIDE	5/7/2003	197	ug/L	1	
1381MWS09	1504275.71	797474.19	VINYL CHLORIDE	10/28/2003		ug/L	500	ND
1381MWI09	1504272.57	797478.96	VINYL CHLORIDE	9/19/1996	795	ug/L	1	
1381MWI09	1504272.57	797478.96	VINYL CHLORIDE	3/19/1998	12	ug/L	1	
1381MWI09	1504272.57	797478.96	VINYL CHLORIDE	8/24/2001	3.3	ug/L	2	
1381MWI09	1504272.57	797478.96	VINYL CHLORIDE	11/22/2002		ug/L	500	ND
1381MWI09	1504272.57	797478.96	VINYL CHLORIDE	5/7/2003	17	ug/L	2	
1381MWI09	1504272.57	797478.96	VINYL CHLORIDE	10/28/2003	4.1	ug/L	2	
1381MWI19	1504325.50	797542.45	VINYL CHLORIDE	7/24/2001		ug/L	10000	ND
1381MWI19	1504325.50	797542.45	VINYL CHLORIDE	11/22/2002		ug/L	20000	ND
1381MWI19	1504325.50	797542.45	VINYL CHLORIDE	5/8/2003	849	ug/L	20000	
1381MWI19	1504325.50	797542.45	VINYL CHLORIDE	11/28/2003		ug/L	10000	ND
1381MWI20	1504358.27	797503.46	VINYL CHLORIDE	7/24/2001		ug/L	10000	ND
1381MWI20	1504358.27	797503.46	VINYL CHLORIDE	11/27/2002		ug/L	10000	ND
1381MWI20	1504358.27	797503.46	VINYL CHLORIDE	5/8/2003		ug/L	1000	ND
1381MWI20	1504358.27	797503.46	VINYL CHLORIDE	11/4/2003		ug/L	1000	ND
1381MWS01	1504383.31	797422.99	VINYL CHLORIDE	12/15/1995	1300	ug/L	1	
1381MWS01	1504383.31	797422.99	VINYL CHLORIDE	9/19/1996	210	ug/L	1	
1381MWS01	1504383.31	797422.99	VINYL CHLORIDE	3/19/1998	470	ug/L	1	
1381MWS01	1504383.31	797422.99	VINYL CHLORIDE	8/28/2001	741	ug/L	1	
1381MWS03	1504588.46	797436.66	VINYL CHLORIDE	12/15/1995	330	ug/L	1	
1381MWS03	1504588.46	797436.66	VINYL CHLORIDE	9/20/1996	836	ug/L	1	
1381MWS03	1504588.46	797436.66	VINYL CHLORIDE	3/19/1998	559	ug/L	1	
1381MWS03	1504588.46	797436.66	VINYL CHLORIDE	3/30/1999	180	ug/L	1	
1381MWS03	1504588.46	797436.66	VINYL CHLORIDE	8/23/2001	458	ug/L	1	
1381MWS05	1504447.00	797005.30	VINYL CHLORIDE	3/6/1996	290	ug/L	1	
1381MWS05	1504447.00	797005.30	VINYL CHLORIDE	9/20/1996	51	ug/L	1	
1381MWS05	1504447.00	797005.30	VINYL CHLORIDE	3/19/1998	118	ug/L	1	
1381MWS05	1504447.00	797005.30	VINYL CHLORIDE	4/1/1999		ug/L	1	ND
1381MWS05	1504447.00	797005.30	VINYL CHLORIDE	8/22/2001		ug/L	1	ND
1381MWS07	1505755.00	797602.10	VINYL CHLORIDE	9/20/1996	1.3	ug/L	1	
1381MWS07	1505755.00	797602.10	VINYL CHLORIDE	3/19/1998		ug/L	1	ND
1381MWS07	1505755.00	797602.10	VINYL CHLORIDE	3/30/1999	1.1	ug/L	1	
1381MWS07	1505755.00	797602.10	VINYL CHLORIDE	8/22/2001		ug/L	1	ND
1381MWS07	1505755.00	797602.10	VINYL CHLORIDE	11/21/2002		ug/L	1	ND
1381MWS07	1505755.00	797602.10	VINYL CHLORIDE	5/8/2003		ug/L	1	ND
1381MWS07	1505755.00	797602.10	VINYL CHLORIDE	11/3/2003		ug/L	1	ND
1381MWS08	1504609.52	797903.21	VINYL CHLORIDE	3/6/1996	12	ug/L	1	
1381MWS08	1504609.52	797903.21	VINYL CHLORIDE	3/19/1998	37	ug/L	1	
1381MWS08	1504609.52	797903.21	VINYL CHLORIDE	3/31/1999	27	ug/L	1	
1381MWS08	1504609.52	797903.21	VINYL CHLORIDE	8/28/2001	448	ug/L	1	
1381MWS08	1504609.52	797903.21	VINYL CHLORIDE	11/27/2002	215	ug/L	1	
1381MWS08	1504609.52	797903.21	VINYL CHLORIDE	5/6/2003	40	ug/L	1	
1381MWS08	1504609.52	797903.21	VINYL CHLORIDE	11/4/2003	51	ug/L	1	
1381MWS10	1504258.18	797671.13	VINYL CHLORIDE	3/5/1996		ug/L	1	ND
1381MWS10	1504258.18	797671.13	VINYL CHLORIDE	3/19/1998	24	ug/L	1	
1381MWS10	1504258.18	797671.13	VINYL CHLORIDE	3/31/1999	12	ug/L	1	
1381MWS10	1504258.18	797671.13	VINYL CHLORIDE	8/24/2001		ug/L	1	ND
1381MWS10	1504258.18	797671.13	VINYL CHLORIDE	11/27/2002	20	ug/L	1	

TABLE C.5E
ANALYTICAL DATA - VINYL CHLORIDE (VC)
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
1381MWS10	1504258.18	797671.13	VINYL CHLORIDE	5/6/2003	18	ug/L	1	
1381MWS10	1504258.18	797671.13	VINYL CHLORIDE	10/29/2003	7.7	ug/L	1	
1381MWS12	1505429.89	798083.35	VINYL CHLORIDE	3/6/1996	130	ug/L	1	
1381MWS12	1505429.89	798083.35	VINYL CHLORIDE	9/21/1996	510	ug/L	1	
1381MWS12	1505429.89	798083.35	VINYL CHLORIDE	3/19/1998	42	ug/L	1	
1381MWS12	1505429.89	798083.35	VINYL CHLORIDE	3/31/1999	98	ug/L	1	
1381MWS12	1505429.89	798083.35	VINYL CHLORIDE	8/21/2001		ug/L	1	ND
1381MWS13	1505592.71	796624.10	VINYL CHLORIDE	9/21/1996		ug/L	1	ND
1381MWS13	1505592.71	796624.10	VINYL CHLORIDE	3/19/1998		ug/L	1	ND
1381MWS13	1505592.71	796624.10	VINYL CHLORIDE	3/31/1999	6.0	ug/L	1	
1381MWS13	1505592.71	796624.10	VINYL CHLORIDE	8/14/2001	1.9	ug/L	1	
1381MWS13	1505592.71	796624.10	VINYL CHLORIDE	11/21/2002	2.8	ug/L	1	
1381MWS13	1505592.71	796624.10	VINYL CHLORIDE	5/7/2003	3.5	ug/L	1	
1381MWS13	1505592.71	796624.10	VINYL CHLORIDE	10/28/2003	1.7	ug/L	1	
1381MWS14	1506002.99	798494.39	VINYL CHLORIDE	3/6/1996	32	ug/L	1	
1381MWS14	1506002.99	798494.39	VINYL CHLORIDE	9/21/1996	2.3	ug/L	1	
1381MWS14	1506002.99	798494.39	VINYL CHLORIDE	3/19/1998	2.7	ug/L	1	
1381MWS14	1506002.99	798494.39	VINYL CHLORIDE	8/21/2001	7.9	ug/L	1	
1381MWS14	1506002.99	798494.39	VINYL CHLORIDE	11/22/2002	5.1	ug/L	1	
1381MWS14	1506002.99	798494.39	VINYL CHLORIDE	5/8/2003	2.3	ug/L	1	
1381MWS14	1506002.99	798494.39	VINYL CHLORIDE	11/4/2003	2.3	ug/L	1	
1381MWS15	1506601.74	798915.22	VINYL CHLORIDE	3/31/1999		ug/L	2	ND
1381MWS15	1506601.74	798915.22	VINYL CHLORIDE	3/31/1999	9.0	ug/L	2	
1381MWS15	1506601.74	798915.22	VINYL CHLORIDE	3/22/1996	5.9	ug/L	1	
1381MWS15	1506601.74	798915.22	VINYL CHLORIDE	9/20/1996	16	ug/L	1	
1381MWS15	1506601.74	798915.22	VINYL CHLORIDE	3/19/1998	8.9	ug/L	1	
1381MWS15	1506601.74	798915.22	VINYL CHLORIDE	3/31/1999	10	ug/L	1	
1381MWS15	1506601.74	798915.22	VINYL CHLORIDE	8/22/2001	4.4	ug/L	1	
1381MWS15	1506601.74	798915.22	VINYL CHLORIDE	11/21/2002	8.7	ug/L	1	
1381MWS15	1506601.74	798915.22	VINYL CHLORIDE	5/21/2003	5.8	ug/L	1	
1381MWS15	1506601.74	798915.22	VINYL CHLORIDE	10/29/2003	3.5	ug/L	1	
1381MWS16	1505363.75	798696.50	VINYL CHLORIDE	9/21/1996	1.2	ug/L	1	
1381MWS16	1505363.75	798696.50	VINYL CHLORIDE	3/19/1998	2.0	ug/L	1	
1381MWS16	1505363.75	798696.50	VINYL CHLORIDE	8/20/2001	16	ug/L	1	
1381MWS16	1505363.75	798696.50	VINYL CHLORIDE	11/21/2002	1.7	ug/L	1	
1381MWS16	1505363.75	798696.50	VINYL CHLORIDE	5/8/2003		ug/L	1	ND
1381MWS16	1505363.75	798696.50	VINYL CHLORIDE	11/3/2003	2.4	ug/L	1	
1381MWS17	1504627.62	797234.30	VINYL CHLORIDE	5/22/1996	890	ug/L	1	
1381MWS17	1504627.62	797234.30	VINYL CHLORIDE	9/20/1996	1040	ug/L	1	
1381MWS17	1504627.62	797234.30	VINYL CHLORIDE	3/19/1998	931	ug/L	1	
1381MWS17	1504627.62	797234.30	VINYL CHLORIDE	3/30/1999	8.7	ug/L	1	
1381MWS17	1504627.62	797234.30	VINYL CHLORIDE	8/23/2001	848	ug/L	1	
1381MWS17	1504627.62	797234.30	VINYL CHLORIDE	11/27/2002	481	ug/L	1	
1381MWS17	1504627.62	797234.30	VINYL CHLORIDE	5/8/2003	697	ug/L	1	
1381MWS17	1504627.62	797234.30	VINYL CHLORIDE	11/4/2003	1050	ug/L	1	
1381MWD09	1504275.71	797474.19	VINYL CHLORIDE	9/19/1996	1.6	ug/L	1	
1381MWD09	1504275.71	797474.19	VINYL CHLORIDE	3/19/1998	1.5	ug/L	1	
1381MWD09	1504275.71	797474.19	VINYL CHLORIDE	8/24/2001		ug/L	1	ND
1381MWD09	1504275.71	797474.19	VINYL CHLORIDE	11/22/2002		ug/L	1	ND
1381MWD09	1504275.71	797474.19	VINYL CHLORIDE	5/7/2003		ug/L	1	ND
1381MWD09	1504275.71	797474.19	VINYL CHLORIDE	10/28/2003		ug/L	1	ND
1381MWD10	1504188.81	797182.42	VINYL CHLORIDE	8/24/2001		ug/L	1	ND
1381MWD10	1504188.81	797182.42	VINYL CHLORIDE	11/27/2002		ug/L	1	ND
1381MWD10	1504188.81	797182.42	VINYL CHLORIDE	5/6/2003		ug/L	1	ND
1381MWD10	1504188.81	797182.42	VINYL CHLORIDE	10/28/2003		ug/L	1	ND
1381MPS01	1506560.30	796946.63	VINYL CHLORIDE	9/19/1996		ug/L	1	ND
1381MPS01	1506560.30	796946.63	VINYL CHLORIDE	8/20/2001		ug/L	1	ND

TABLE C.5E
ANALYTICAL DATA - VINYL CHLORIDE (VC)
FACILITY 1381, CAPE CANAVERAL AS, FLORIDA
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
1381MPS01	1506560.30	796946.63	VINYL CHLORIDE	11/21/2002	0.63	ug/L	1	TR
1381MPS01	1506560.30	796946.63	VINYL CHLORIDE	6/7/2003		ug/L	1	ND
1381MPS01	1506560.30	796946.63	VINYL CHLORIDE	10/28/2003	0.62	ug/L	1	TR
1381MWS11	1504193.92	797178.06	VINYL CHLORIDE	9/20/1996		ug/L	1	ND
1381MWS11	1504193.92	797178.06	VINYL CHLORIDE	8/22/2001	0.69	ug/L	1	TR
1381MWS11	1504193.92	797178.06	VINYL CHLORIDE	12/2/2002		ug/L	1	ND
1381MWS11	1504193.92	797178.06	VINYL CHLORIDE	5/6/2003		ug/L	1	ND
1381MWS11	1504193.92	797178.06	VINYL CHLORIDE	10/31/2003		ug/L	1	ND
1381MPI01	1506558.32	796945.88	VINYL CHLORIDE	9/21/1996		ug/L	1	ND
1381MPI01	1506558.32	796945.88	VINYL CHLORIDE	8/20/2001		ug/L	1	ND
1381MPI01	1506558.32	796945.88	VINYL CHLORIDE	11/21/2002		ug/L	1	ND
1381MPI01	1506558.32	796945.88	VINYL CHLORIDE	5/7/2003		ug/L	1	ND
1381MPI01	1506558.32	796945.88	VINYL CHLORIDE	10/28/2003		ug/L	1	ND
1381MPI02	150400.00	797000.00	VINYL CHLORIDE	9/21/1996		ug/L	1	ND
1381MPI02	150400.00	797000.00	VINYL CHLORIDE	8/20/2001		ug/L	1	ND
1381MPI02	150400.00	797000.00	VINYL CHLORIDE	5/7/2003		ug/L	1	ND
1381MPI02	150400.00	797000.00	VINYL CHLORIDE	11/3/2003		ug/L	1	ND
1381MPI05	1504201.84	797183.59	VINYL CHLORIDE	9/24/1996		ug/L	1	ND
1381MPI05	1504201.84	797183.59	VINYL CHLORIDE	8/22/2001		ug/L	1	ND
1381MPI05	1504201.84	797183.59	VINYL CHLORIDE	11/20/2002		ug/L	1	ND
1381MPI05	1504201.84	797183.59	VINYL CHLORIDE	5/8/2003		ug/L	1	ND
1381MPI05	1504201.84	797183.59	VINYL CHLORIDE	10/31/2003		ug/L	1	ND
1381MWD08	1504603.00	797900.19	VINYL CHLORIDE	8/24/2001		ug/L	1	ND
1381MWD08	1504603.00	797900.19	VINYL CHLORIDE	11/27/2002		ug/L	1	ND
1381MWD08	1504603.00	797900.19	VINYL CHLORIDE	5/6/2003		ug/L	1	ND
1381MWD08	1504603.00	797900.19	VINYL CHLORIDE	11/4/2003		ug/L	1	ND
1381MWD11	1504188.81	797182.42	VINYL CHLORIDE	8/22/2001		ug/L	1	ND
1381MWD11	1504188.81	797182.42	VINYL CHLORIDE	11/20/2002		ug/L	1	ND
1381MWD11	1504188.81	797182.42	VINYL CHLORIDE	5/6/2003		ug/L	1	ND
1381MWD11	1504188.81	797182.42	VINYL CHLORIDE	10/31/2003		ug/L	1	ND
1381MWS18	1504099.04	797568.54	VINYL CHLORIDE	9/19/1996		ug/L	1	ND
1381MWS18	1504099.04	797568.54	VINYL CHLORIDE	3/19/1998		ug/L	1	ND
1381MWS18	1504099.04	797568.54	VINYL CHLORIDE	8/28/2001		ug/L	1	ND
1381MWS18	1504099.04	797568.54	VINYL CHLORIDE	12/2/2002		ug/L	1	ND
1381MWS18	1504099.04	797568.54	VINYL CHLORIDE	5/8/2003		ug/L	1	ND
1381MWS18	1504099.04	797568.54	VINYL CHLORIDE	11/4/2003		ug/L	1	ND

[a/] ug/L = micrograms per liter.

[b/] ND = non detect, TR = trace value

TABLE C.6E
INPUT PARAMETERS FOR MASS-BASED CALCULATIONS
FACILITY 1381, CAPE CANAVERAL AIR STATION, FLORIDA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	Theissen Polygon Area (square feet)
1381MWS07	757,524
1381MWS08	416,011
1381MWS09	57,556
1381MWS10	55,482
1381MWS13	217,955
1381MWS14	524,627
1381MWS15	71,770
1381MWS16	310,862
1381MWS17	329,056
1381MWS18	6,638
Total	2,747,482

Parameter	Value
Porosity (percentage)	20
Thickness of Contaminated Aquifer (feet)	10

TABLE C.7E
RESULTS OF DISSOLVED MASS ESTIMATION
FACILITY 1381, CAPE CANAVERAL AIR STATION, FLORIDA
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

	Mass in kilograms							
	Trichloroethene (TCE)		Dichloroethene (DCE)		Vinyl Chloride (VC)		Total CAHs	
Date	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass
3/19/98	687.18	684.61	44.63	44.77	19.67	19.07	789.03	785.39
8/20/01	14.08	14.03	52.95	56.80	26.75	27.02	142.07	147.83
11/21/02	0.02	0.03	4.57	4.57	14.28	14.35	36.23	36.39
5/6/03	287.98	286.90	35.26	34.82	15.17	14.76	367.66	365.13
10/28/03	75.92	75.63	19.08	18.89	21.54	20.93	147.05	145.24

	Percentage of Total CAH Mass					
	Trichloroethene (TCE)		Dichloroethene (DCE)		Vinyl Chloride (VC)	
Date	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass
3/19/1998	87.1%	87.2%	7.7%	7.7%	5.2%	5.1%
8/20/2001	9.9%	9.5%	50.5%	52.1%	39.6%	38.4%
11/21/2002	0.05%	0.09%	17.1%	17.0%	82.9%	82.9%
5/6/2003	78.3%	78.6%	13.0%	12.9%	8.7%	8.5%
10/28/2003	51.6%	52.1%	17.6%	17.6%	30.8%	30.3%

TABLE C.8E

RESULTS OF GIS MASS-BASED CALCULATIONS FOR CENTER OF MASS LOCATION

FACILITY 1381, CAPE CANAVERAL AIR STATION, FLORIDA

FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

	Trichloroethene (TCE)				Dichloroethene (DCE)				Vinyl Chloride (VC)			
	Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass	
Date	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate
3/19/1998	797500.35	1504400.40	797544.78	1504403.20	797535.55	1504672.93	797547.39	1504687.80	797356.96	1504900.39	797365.50	1504979.10
8/20/2001	797501.51	1504401.81	797545.46	1504404.10	797846.37	1504862.21	797819.76	1504916.70	797560.64	1504905.03	797540.38	1504975.10
11/21/2002	798281.03	1505736.57	798211.51	1505417.90	797712.92	1504960.51	797708.96	1505071.30	797535.02	1504908.93	797517.99	1504983.40
5/6/2003	797500.39	1504400.45	797544.78	1504403.20	797493.58	1504487.27	797534.71	1504511.40	797368.06	1504890.73	797374.27	1504967.00
10/28/2003	797500.35	1504400.40	797544.78	1504403.20	797502.65	1504466.66	797545.49	1504484.80	797355.34	1504911.52	797359.80	1504988.80

Case Study Data for Site FPTA-2, Brooks Air Force Base, Texas

TABLE C.1F
MAROS LINEAR REGRESSION STATISTICS SUMMARY
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Model Time Period	Average Conc (mg/L) [a/]	Median Conc (mg/L)	Standard Deviation	All Samples ND? [b/]	LN Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend [c/]	Designation for Current Analysis
Trichloroethene (TCE)											
MW-30	S	12/1/95-6/30/01	8.7E-01	1.4E-01	2.0E+00	No	-2.9E-03	2.30	100.0%	D	Source
		12/1/95-12/30/98	1.4E+00	2.6E-01	2.6E+00	No	-3.7E-03	1.84	100.0%	D	
		12/1/98-6/30/01	1.3E-01	4.3E-02	2.3E-01	No	-3.1E-03	1.75	88.3%	NT	
MW-47	S	12/1/95-12/30/98	5.8E-01	5.3E-02	1.3E+00	No	-4.5E-03	2.30	99.7%	D	Source
		12/1/98-6/30/01	7.1E-03	4.4E-03	6.6E-03	No	-2.5E-03	0.92	98.8%	D	
MW-03	T	12/1/95-12/30/98	5.6E-03	5.0E-03	2.0E-03	No	-5.3E-07	0.36	100.0%	D	Plume
		12/1/98-6/30/01	3.6E-03	3.2E-03	2.9E-03	No	-4.2E-03	0.81	98.0%	D	
MW-10	T	6/1/88-12/1/94	1.4E-01	1.3E-01	3.1E-02	No	-1.8E-04	0.23	98.0%	D	Plume
		12/1/95-12/31/98	5.4E-02	5.6E-02	3.0E-02	No	-1.8E-03	0.57	99.8%	D	
		12/1/98-6/30/01	1.7E-02	1.7E-02	5.8E-03	No	-1.2E-04	0.34	58.7%	S	
MW-28	T	6/1/88-12/31/98	1.5E-01	1.3E-01	7.7E-02	No	7.5E-05	0.52	69.5%	NT	Plume
		12/1/95-12/31/98	1.3E-01	1.4E-01	2.1E-02	No	3.0E-04	0.16	94.6%	PI	
		12/1/98-6/30/01	1.3E-01	1.5E-01	5.5E-02	No	-1.2E-03	0.43	92.2%	PD	
MW-29	T	6/1/88-12/31/98	7.4E-03	5.8E-03	3.9E-03	No	-5.8E-04	0.52	94.8%	PD	Plume
		12/1/95-12/31/98	6.3E-03	5.6E-03	2.5E-03	No	-2.5E-04	0.40	72.0%	S	
		12/1/98-6/30/01	8.6E-03	8.8E-03	2.3E-03	No	-1.5E-04	0.27	63.0%	S	
MW-32	T	6/1/88-12/31/98	8.8E-02	9.0E-02	2.1E-02	No	-9.0E-05	0.24	82.2%	S	Plume
		12/1/95-12/31/98	8.6E-02	8.8E-02	2.4E-02	No	-3.0E-04	0.28	82.0%	S	
		12/1/98-6/30/01	4.9E-01	5.0E-02	9.3E-03	No	-5.1E-04	0.19	98.3%	D	
MW-33	T	12/1/95-12/30/98	2.9E-03	3.0E-03	1.4E-03	No	1.5E-04	0.47	59.6%	NT	Plume
		12/1/98-6/30/01	2.8E-03	2.2E-03	1.4E-03	No	-1.0E-03	0.51	97.4%	D	
MW-36	T	6/1/88-12/31/98	7.2E-02	7.3E-02	1.2E-02	No	-1.1E-04	0.16	82.9%	S	Plume
		12/1/95-12/31/98	7.2E-02	7.2E-02	1.4E-02	No	-2.9E-04	0.19	88.5%	S	
		12/1/98-6/30/01	4.0E-02	4.1E-02	1.9E-02	No	-1.4E-03	0.46	99.9%	D	
MW-39	T	3/1/91-6/30/01	1.3E-02	9.8E-03	8.3E-03	No	-5.8E-04	0.66	99.9%	D	Plume
		3/1/91-12/30/95	2.1E-02	2.1E-02	9.1E-03	No	1.2E-04	0.43	60.0%	NT	
		12/1/95-12/31/98	1.6E-02	1.0E-02	9.0E-03	No	-1.1E-03	0.58	99.4%	D	
		12/1/98-6/30/01	6.2E-03	6.8E-03	3.0E-03	No	-1.9E-03	0.48	96.7%	D	
MW-46	T	10/30/95-6/30/01	2.6E-03	5.0E-04	7.1E-03	No	-1.8E-03	2.77	99.9%	D	Plume
MW-48	T	12/1/95-12/31/98	2.9E-02	2.5E-02	1.7E-02	No	-7.0E-04	0.59	92.9%	PD	Plume
		12/1/98-6/30/01	1.1E-02	1.1E-02	3.2E-03	No	-6.9E-04	0.28	99.1%	D	
MW-52	T	12/1/95-6/30/01	4.1E-03	2.9E-03	3.2E-03	No	-1.9E-03	0.80	100.0%	D	Plume
		12/1/95-12/30/98	6.0E-03	6.7E-03	2.6E-03	No	-6.4E-04	0.43	83.0%	S	
		12/1/98-6/30/01	2.2E-03	1.8E-03	2.5E-03	No	-4.3E-03	1.14	100.0%	D	
MW-31	T	12/1/95-6/30/01	6.7E-04	5.0E-04	4.5E-04	No	1.9E-04	0.66	78.1%	NT	Sentry
MW-40	T	12/1/95-12/30/98	2.5E-03	2.0E-03	2.3E-03	No	-9.9E-04	0.92	75.5%	S	Sentry
		12/1/98-6/30/01	1.4E-03	5.0E-04	2.4E-03	No	-3.5E-03	1.74	98.2%	D	
MW-49	T	12/1/95-6/30/01	1.2E-03	5.0E-04	1.4E-03	No	6.9E-04	1.18	90.1%	PI	Sentry
		12/1/95-12/30/98	1.0E-03	5.0E-04	1.2E-03	No	1.0E-03	1.14	82.9%	NT	
		12/1/98-6/30/01	1.8E-03	5.0E-04	1.8E-03	No	-1.4E-03	1.01	65.5%	NT	
DW-03	T	12/1/95 - 6/30/01	1.6E-03	5.0E-04	2.5E-03	No	-2.1E-03	1.53	99.9%	D	Sentry
cis-1,2-Dichloroethene (cis-1,2-DCE)											
MW-30	S	12/1/95-6/30/01	2.1E+00	5.0E-01	3.2E+00	No	-1.4E-03	1.54	98.1%	D	Source
		12/1/95-12/30/98	2.5E+00	6.0E-01	3.9E+00	No	-3.4E-03	1.54	99.7%	D	
		12/1/98-6/30/01	1.2E+00	1.9E-01	1.9E+00	No	-1.3E-03	1.59	70.8%	NT	
MW-47	S	12/1/95-12/30/98	5.3E-01	4.2E-01	5.6E-01	No	-3.2E-03	1.05	98.7%	D	Source
		12/1/98-6/30/01	2.5E-02	1.4E-02	3.1E-02	No	-1.8E-03	1.25	90.6%	PD	
MW-03	T	12/1/95-12/30/98	2.3E-02	2.4E-02	4.7E-03	No	2.5E-05	0.20	53.8%	NT	Plume
		12/1/98-6/30/01	1.4E-02	1.4E-02	1.0E-02	No	-5.4E-03	0.73	97.0%	D	
MW-10	T	12/1/95-12/31/98	1.1E-01	1.1E-01	6.7E-02	No	-1.8E-03	0.59	100.0%	D	Plume
		12/1/98-6/30/01	3.7E-02	3.9E-02	1.2E-02	No	-2.0E-04	0.32	64.3%	S	
MW-28	T	6/1/88-12/31/98	3.8E-01	3.1E-01	1.7E-01	No	2.8E-05	0.44	53.4%	NT	Plume
		12/1/95-12/31/98	3.5E-01	3.0E-01	1.6E-01	No	5.7E-04	0.45	92.9%	PI	
		12/1/98-6/30/01	4.4E-01	4.6E-01	1.8E-01	No	-9.2E-04	0.41	93.7%	PD	
MW-29	T	6/1/88-12/31/98	2.6E-02	2.1E-02	1.5E-02	No	-6.8E-04	0.56	96.9%	D	Plume
		12/1/95-12/31/98	2.2E-02	2.0E-02	9.6E-03	No	-3.8E-04	0.43	80.7%	S	
		12/1/98-6/30/01	4.6E-02	4.8E-02	1.4E-02	No	7.9E-04	0.30	98.2%	I	
MW-32	T	12/1/95-12/31/98	2.4E-01	2.3E-01	1.2E-01	No	2.1E-03	0.51	93.9%	PI	Plume
		12/1/98-6/30/01	1.7E-01	1.9E-01	6.1E-02	No	-1.1E-03	0.36	98.6%	D	
MW-33	T	12/1/95-12/30/98	1.2E-02	1.2E-02	4.2E-03	No	-7.0E-05	0.35	55.7%	S	Plume
		12/1/98-6/30/01	8.6E-03	7.3E-03	4.8E-03	No	-1.3E-03	0.56	99.4%	D	
MW-36	T	12/1/95-12/30/97 [d/]	1.5E-01	1.4E-01	4.6E-02	No	-4.9E-04	0.32	76.0%	S	Plume
		6/1/99-6/30/01 [d/]	6.6E-02	5.5E-02	4.8E-02	No	-3.4E-03	0.72	99.2%	D	
MW-39	T	12/1/95-6/30/01	2.1E-02	1.6E-02	2.0E-02	No	-1.5E-03	0.94	99.7%	D	Plume
		12/1/95-12/31/98	2.9E-02	1.7E-02	2.3E-02	No	-1.4E-03	0.77	98.4%	D	
		12/1/98-6/30/01	1.1E-02	1.2E-02	6.1E-03	No	-3.1E-03	0.56	93.9%	PD	
MW-46	T	10/30/95-6/30/01	2.7E-01	2.0E-01	2.4E-01	No	-7.0E-04	0.90	99.8%	D	Plume
		12/1/95-12/30/98	3.5E-01	2.4E-01	2.9E-01	No	-1.2E-03	0.83	97.5%	D	
		12/1/98-6/30/01	1.6E-01	1.7E-01	4.2E-02	No	-1.6E-04	0.27	64.1%	S	
MW-48	T	12/1/95-12/31/98	5.8E-02	4.5E-02	3.7E-02	No	-8.2E-04	0.64	95.5%	D	Plume
		12/1/98-6/30/01	1.7E-02	1.6E-02	9.1E-03	No	-1.5E-03	0.54	99.9%	D	
MW-52	T	12/1/95-6/30/01	1.5E-02	1.3E-02	1.1E-02	No	-1.6E-03	0.74	100.0%	D	Plume
		12/1/95-12/30/98	2.2E-02	2.3E-02	9.0E-03	No	-7.8E-04	0.41	93.0%	PD	
		12/1/98-6/30/01	7.5E-03	7.3E-03	6.7E-03	No	-3.4E-03	0.89	100.0%	D	

TABLE C.1F
MAROS LINEAR REGRESSION STATISTICS SUMMARY
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Model Time Period	Average Conc (mg/L) [a]	Median Conc (mg/L)	Standard Deviation	All Samples ND? [b]	LN Slope	Coefficient of Variation	Confidence in Trend	Concentration Trend [c]	Designation for Current Analysis
MW-31	T	12/1/95-6/30/01	6.0E-04	5.0E-04	3.3E-04	No	-6.8E-05	0.56	62.1%	S	Sentry
MW-40	T	12/1/95-12/30/98	8.4E-03	9.0E-03	6.5E-03	No	-1.1E-03	0.77	80.5%	S	Sentry
		12/1/98-6/30/01	2.5E-03	5.0E-04	5.1E-03	No	-4.3E-03	2.05	98.0%	D	
MW-49	T	12/1/95-6/30/01	1.6E-03	5.0E-04	2.3E-03	No	8.2E-04	1.43	90.9%	PI	Sentry
		12/1/95-12/30/98	1.2E-03	6.0E-04	1.4E-03	No	1.2E-03	1.19	86.4%	NT	
		12/1/98-6/30/01	2.5E-03	5.0E-04	2.9E-03	No	1.2E-03	1.19	69.8%	NT	
DW-03	T	12/1/95 - 6/30/01	1.8E-03	5.0E-04	2.9E-03	No	-2.2E-03	1.61	99.8%	D	Sentry
Vinyl Chloride (VC)											
MW-30	S	12/1/95-6/30/01	5.1E-02	3.9E-03	9.0E-02	No	-2.7E-03	1.75	99.7%	D	Source
		12/1/95-12/30/98	8.6E-02	6.9E-03	1.1E-01	No	-5.9E-03	1.25	99.8%	D	
		12/1/98-6/30/01	2.7E-03	1.0E-03	3.1E-03	No	3.6E-04	1.16	57.2%	NT	
MW-47	S	12/1/95-12/30/98	1.9E-02	1.7E-02	1.9E-02	No	-2.8E-03	0.99	98.5%	D	Source
		12/1/98-6/30/01	8.6E-04	1.0E-03	3.4E-04	No	-1.5E-03	0.40	92.4%	PD	
MW-46	T	10/30/95-6/30/01	1.1E-02	6.8E-03	1.4E+01	No	-8.5E-04	1.25	99.8%	D	Plume
		12/1/95-12/30/98	1.5E-02	1.0E-02	1.7E-02	No	-1.4E-03	1.11	97.4%	D	
		12/1/98-6/30/01	5.0E-03	4.5E-03	1.1E-03	No	5.4E-05	0.22	56.7%	NT	

[a] mg/L = milligrams per liter.

[b] ND = non-detect.

[c] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[d] The 12/17/98 data for *cis*-1,2-DCE was reported as ND with a detection limit of 1 µg/L. This point was considered an outlier and was removed from the dataset before analyzing trends. Therefore, the time periods analyzed for *cis*-1,2-DCE differ from time periods for TCE.

TABLE C.2F
MAROS MANN-KENDALL STATISTICS SUMMARY
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Model Time Period	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples ND?[a/]	Concentration Trend[b/]	Designation for Current Analysis
Trichloroethene (TCE)										
MW-30	S	12/1/95-6/30/01	12	12	2.30	-50	100.0%	No	D	Source
		12/1/95-12/30/98	7	7	1.84	-21	100.0%	No	D	
		12/1/98-6/30/01	6	6	1.75	-5	76.5%	No	NT	
MW-47	S	12/1/95-12/30/98	7	7	2.30	-18	99.7%	No	D	Source
		12/1/98-6/30/01	6	6	0.92	-9	93.2%	No	PD	
MW-03	T	12/1/95-12/30/98	7	7	0.36	-2	55.7%	No	S	Plume
		12/1/98-6/30/01	6	5	0.81	-12	98.2%	No	D	
MW-10	T	6/1/88-12/1/94	4	4	0.23	-6	95.8%	No	D	Plume
		12/1/95-12/31/98	7	7	0.57	-19	99.9%	No	D	
		12/1/98-6/30/01	6	6	0.34	-3	64.0%	No	S	
MW-28	T	6/1/88-12/31/98	10	10	0.52	15	89.2%	No	NT	Plume
		12/1/95-12/31/98	7	7	0.16	9	88.1%	No	NT	
		12/1/98-6/30/01	5	5	0.43	-2	59.3%	No	S	
MW-29	T	6/1/88-12/31/98	8	8	0.52	-10	86.2%	No	S	Plume
		12/1/95-12/31/98	7	7	0.40	-3	61.4%	No	S	
		12/1/98-6/30/01	6	6	0.27	0	42.3%	No	S	
MW-32	T	6/1/88-12/31/98	9	9	0.24	-12	87.0%	No	S	Plume
		12/1/95-12/31/98	7	7	0.28	-5	71.9%	No	S	
		12/1/98-6/30/01	6	6	0.19	-11	97.2%	No	D	
MW-33	T	12/1/95-12/30/98	7	7	0.47	-2	55.7%	No	S	Plume
		12/1/98-6/30/01	6	6	0.51	-10	95.2%	No	D	
MW-36	T	6/1/88-12/31/98	8	8	0.16	-8	80.1%	No	S	Plume
		12/1/95-12/31/98	6	6	0.19	-7	86.4%	No	S	
		12/1/98-6/30/01	6	6	0.46	-13	99.2%	No	D	
MW-39	T	3/1/91-6/30/01	15	15	0.66	-76	100.0%	No	D	Plume
		3/1/91-12/30/95	4	4	0.43	2	62.5%	No	NT	
		12/1/95-12/31/98	7	7	0.58	-13	96.5%	No	D	
		12/1/98-6/30/01	6	6	0.48	-9	93.2%	No	PD	
MW-46	T	10/30/95-6/30/01	12	3	2.77	-45	100.0%	No	D	Plume
MW-48	T	12/1/95-12/31/98	7	7	0.59	-2	55.7%	No	S	Plume
		12/1/98-6/30/01	6	6	0.28	-12	98.2%	No	D	
MW-52	T	12/1/95-6/30/01	10	10	0.80	-39	100.0%	No	D	Plume
		12/1/95-12/30/98	6	6	0.43	-9	93.2%	No	PD	
		12/1/98-6/30/01	5	5	1.14	-10	99.2%	No	D	
MW-31	T	12/1/95-6/30/01	12	3	0.66	4	58.0%	No	NT	Sentry
MW-40	T	12/1/95-6/30/01	7	5	0.92	-5	71.9%	No	S	Sentry
		12/1/98-6/30/01	6	1	1.74	-9	93.2%	No	PD	
MW-49	T	12/1/95-6/30/01	9	2	1.18	9	79.2%	No	NT	Sentry
		12/1/95-12/30/98	5	1	1.14	4	75.8%	No	NT	
		12/1/98-6/30/01	5	2	1.01	1	50.0%	No	NT	
DW-03	T	12/1/95 - 6/30/01	5	2	1.53	-9	97.5%	No	D	Sentry
cis-1,2-Dichloroethene (cis-1,2-DCE)										
MW-30	S	12/1/95-6/30/01	12	12	1.54	-32	98.4%	No	D	Source
		12/1/95-12/30/98	7	7	1.54	-15	98.5%	No	D	
		12/1/98-6/30/01	6	6	1.59	-3	64.0%	No	NT	
MW-47	S	12/1/95-12/30/98	7	7	1.05	-13	96.5%	No	D	Source
		12/1/98-6/30/01	6	6	1.25	-7	86.4%	No	NT	
MW-03	T	12/1/95-12/30/98	7	7	0.20	-1	50.0%	No	S	Plume
		12/1/98-6/30/01	6	5	0.73	-13	99.2%	No	D	
MW-10	T	12/1/95-12/31/98	7	7	0.59	-19	99.9%	No	D	Plume
		12/1/98-6/30/01	6	6	0.32	-3	64.0%	No	S	
MW-28	T	6/1/88-12/31/98	8	8	0.44	3	59.4%	No	NT	Plume
		12/1/95-12/31/98	7	7	0.45	8	84.5%	No	NT	
		12/1/98-6/30/01	5	5	0.41	-6	88.3%	No	S	
MW-29	T	6/1/88-12/31/98	8	8	0.56	-13	92.9%	No	PD	Plume
		12/1/95-12/31/98	7	7	0.43	-6	76.4%	No	S	
		12/1/98-6/30/01	6	6	0.30	11	97.2%	No	I	
MW-32	T	12/1/95-12/31/98	7	6	0.51	6	76.4%	No	NT	Plume
		12/1/98-6/30/01	6	6	0.36	-12	98.2%	No	D	
MW-33	T	12/1/95-12/30/98	7	7	0.35	-2	55.7%	No	S	Plume
		12/1/98-6/30/01	6	6	0.56	-12	98.2%	No	D	
MW-36	T	12/1/95-12/30/97[c/]	5	5	0.32	-2	59.2%	No	S	Plume
		6/1/99-6/30/01[c/]	5	5	0.72	-10	99.2%	No	D	
MW-39	T	12/1/95-6/30/01	12	12	0.94	-44	99.9%	No	D	Plume
		12/1/95-12/31/98	7	7	0.77	-13	96.5%	No	D	
		12/1/98-6/30/01	6	6	0.56	-8	89.8%	No	S	
MW-46	T	10/30/95-6/30/01	12	12	0.90	-41	99.8%	No	D	Plume
		12/1/95-12/30/98	7	7	0.83	-11	93.2%	No	PD	
		12/1/98-6/30/01	6	6	0.27	-3	64.0%	No	S	
MW-48	T	12/1/95-12/31/98	7	7	0.64	-10	90.7%	No	PD	Plume
		12/1/98-6/30/01	6	6	0.54	-13	99.2%	No	D	

TABLE C.2F
MAROS MANN-KENDALL STATISTICS SUMMARY
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

Well	MAROS Designation (Source/Tail)	Model Time Period	Number of Samples	Number of Detects	Coefficient of Variation	Mann-Kendall Statistic	Confidence in Trend	All Samples ND? [a]	Concentration Trend [b]	Designation for Current Analysis
MW-52	T	12/1/95-6/30/01	10	10	0.74	-35	100.0%	No	D	Plume
		12/1/95-12/30/98	6	6	0.41	-5	76.5%	No	S	
		12/1/98-6/30/01	5	5	0.89	-10	99.2%	No	D	
MW-31	T	12/1/95-6/30/01	12	3	0.56	4	58.0%	No	NT	Sentry
MW-40	T	12/1/95-12/30/98	7	7	0.77	-5	71.9%	No	S	Sentry
		12/1/98-6/30/01	6	1	2.05	-9	93.2%	No	PD	
MW-49	T	12/1/95-6/30/01	9	2	1.43	7	72.8%	No	NT	Sentry
		12/1/95-12/30/98	5	1	1.19	8	95.8%	No	I	
		12/1/98-6/30/01	5	2	1.19	1	50.0%	No	NT	
DW-03	T	12/1/95 - 6/30/01	5	2	1.61	-9	97.5%	No	D	Sentry
Vinyl Chloride (VC)										
MW-30	S	12/1/95-6/30/01	12	9	1.75	-39	99.7%	No	D	Source
		12/1/95-12/30/98	7	6	1.25	-19	99.9%	No	D	
		12/1/98-6/30/01	6	4	1.16	0	42.3%	No	NT	
MW-47	S	12/1/95-12/30/98	7	5	0.99	-13	96.5%	No	D	Source
		12/1/98 - 6/30/01	6	1	0.40	-5	76.5%	No	S	
MW-46	T	10/30/95-6/30/01	12	12	1.25	-39	99.7%	No	D	Plume
		12/1/95-12/30/98	7	7	1.11	-12	94.9%	No	PD	
		12/1/98-6/30/01	6	6	0.22	1	50.0%	No	NT	

[a] ND = non-detect.

[b] I = increasing, PI = probably increasing, S = stable, D = decreasing, PD = probably decreasing, NT = no trend, N/A = not analyzed.

[c] The 12/17/98 data for *cis*- 1,2-DCE was reported as ND with a detection limit of 1µg/L. This point was considered an outlier and was removed from the dataset before analyzing trends. Therefore, the time periods analyzed for *cis*-1,2-DCE differ from time periods for TCE.

TABLE C.3F
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	2/22/1990	2300	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	3/11/1994	25000	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	11/1/1994	32000	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	12/13/1995	7100	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	9/22/1996	1100	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	12/6/1996	880	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	6/26/1997	260	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	12/11/1997	155	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	9/1/1998	130	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	12/17/1998	95	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	6/7/1999	590	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	12/7/1999	4.4	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	6/8/2000	71	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	12/5/2000	6.2	ug/L	1	
MW-30	5.88	5.19	TRICHLOROETHENE (TCE)	6/14/2001	15.1	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	12/13/1995	3600	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	9/22/1996	240	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	12/6/1996	120	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	6/26/1997	19	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	12/11/1997	53	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	9/1/1998	19	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	12/17/1998	12	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	6/7/1999	18	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	12/7/1999	6.1	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	6/8/2000	2.6	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	12/5/2000	1.4	ug/L	1	
MW-47	5.75	5.06	TRICHLOROETHENE (TCE)	6/14/2001	2.62	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	12/13/1995	8	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	9/22/1996	5	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	12/6/1996	5	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	6/26/1997	3	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	12/11/1997	4.4	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	9/1/1998	4.9	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	12/17/1998	8.7	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	6/7/1999	4	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	12/7/1999	4.4	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	6/8/2000	2.3	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	12/5/2000	2.3	ug/L	1	
MW-03	3.38	4.69	TRICHLOROETHENE (TCE)	6/14/2001		ug/L	0.137	ND
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	6/14/1988	180	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	2/20/1990	140	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	3/10/1994	120	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	10/31/1994	110	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	12/13/1995	100	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	9/22/1996	62	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	12/6/1996	77	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	6/26/1997	56	ug/L	1	

TABLE C.3F
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	12/11/1997	44	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	9/1/1998	26	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	12/17/1998	10	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	6/7/1999	23	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	12/7/1999	21	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	6/8/2000	22	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	12/5/2000	13	ug/L	1	
MW-10	4.88	3.63	TRICHLOROETHENE (TCE)	6/14/2001	12.1	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	2/22/1990	90	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	3/11/1994	120	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	11/4/1994	360	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	12/13/1995	90	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	9/22/1996	150	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	12/6/1996	120	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	6/26/1997	140	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	12/11/1997	122	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	9/1/1998	140	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	12/17/1998	150	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	6/7/1999	160	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	12/7/1999	96	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	6/8/2000	180	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	12/5/2000	DRY	ug/L	1	
MW-28	5.31	4.63	TRICHLOROETHENE (TCE)	6/14/2001	45.9	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	11/4/1994	15	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	12/13/1995	11	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	9/22/1996	6	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	12/6/1996	4	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	6/26/1997	5	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	12/11/1997	5.6	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	9/1/1998	4.2	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	12/17/1998	8.5	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	6/7/1999	9	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	12/7/1999	6.2	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	6/8/2000	11	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	12/5/2000	11	ug/L	1	
MW-29	5.50	4.31	TRICHLOROETHENE (TCE)	6/14/2001	5.61	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	2/21/1990	96	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	3/10/1994	94	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	12/13/1995	110	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	9/22/1996	67	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	12/6/1996	90	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	6/26/1997	73	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	12/11/1997	119	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	9/1/1998	88	ug/L	1	

TABLE C.3F
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	12/17/1998	52	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	6/7/1999	61	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	12/7/1999	54	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	6/8/2000	48	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	12/5/2000	45	ug/L	1	
MW-32	4.38	4.13	TRICHLOROETHENE (TCE)	6/14/2001	33.5	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	3/9/1994	71	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	10/31/1994	76	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	12/13/1995	94	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	9/22/1996	74	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	12/6/1996	70	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	6/26/1997	53	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	12/11/1997	78	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	12/17/1998	63	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	6/7/1999	52	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	12/7/1999	55	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	6/8/2000	29	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	12/5/2000	27	ug/L	1	
MW-36	4.44	3.88	TRICHLOROETHENE (TCE)	6/14/2001	16.9	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	3/7/1991	22	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	3/9/1994	11	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	11/4/1994	19	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	12/13/1995	33	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	9/22/1996	22	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	12/6/1996	15	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	6/26/1997	9	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	12/11/1997	10.3	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	9/1/1998	9.7	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	12/17/1998	9.8	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	6/7/1999	6.4	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	12/7/1999	7.2	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	6/8/2000	7.6	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	12/5/2000	5.2	ug/L	1	
MW-39	3.88	2.06	TRICHLOROETHENE (TCE)	6/14/2001	1.03	ug/L	1	
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	12/13/1995		ug/L	50	ND
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	9/22/1996		ug/L	1	ND
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	12/6/1996		ug/L	2	ND
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	6/26/1997		ug/L	2	ND
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	12/11/1997		ug/L	1	ND
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	9/1/1998	1.5	ug/L	1	TR
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	12/17/1998		ug/L	1	ND
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	6/7/1999		ug/L	1	ND
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	12/7/1999		ug/L	1	ND
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	6/8/2000	0.29	ug/L	1	TR

TABLE C.3F
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	12/5/2000	0.44	ug/L	1	TR
MW-46	5.94	5.25	TRICHLOROETHENE (TCE)	6/14/2001		ug/L	0.137	ND
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	12/13/1995	67	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	9/22/1996	18	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	12/6/1996	25	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	6/26/1997	25	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	12/11/1997	25.5	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	9/1/1998	26	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	12/17/1998	17	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	6/7/1999	11	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	12/7/1999	13	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	6/8/2000	11	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	12/5/2000	8.5	ug/L	1	
MW-48	4.25	3.38	TRICHLOROETHENE (TCE)	6/14/2001	8.44	ug/L	1	
MW-52	3.38	3.50	TRICHLOROETHENE (TCE)	12/13/1995	9	ug/L	1	
MW-52	3.38	3.50	TRICHLOROETHENE (TCE)	9/22/1996	7	ug/L	1	
MW-52	3.38	3.50	TRICHLOROETHENE (TCE)	12/6/1996	8	ug/L	1	
MW-52	3.38	3.50	TRICHLOROETHENE (TCE)	6/26/1997	3	ug/L	1	
MW-52	3.38	3.50	TRICHLOROETHENE (TCE)	12/11/1997	2.7	ug/L	1	
MW-52	3.38	3.50	TRICHLOROETHENE (TCE)	12/15/1998	6.3	ug/L	1	
MW-52	3.38	3.50	TRICHLOROETHENE (TCE)	6/7/1999	2.5	ug/L	1	
MW-52	3.38	3.50	TRICHLOROETHENE (TCE)	12/7/1999	1.8	ug/L	1	
MW-52	3.38	3.50	TRICHLOROETHENE (TCE)	12/4/2000	0.48	ug/L	1	TR
MW-52	3.38	3.50	TRICHLOROETHENE (TCE)	6/11/2001	0.262	ug/L	1	TR
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	12/13/1995		ug/L	1	ND
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	9/22/1996		ug/L	1	ND
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	12/6/1996		ug/L	1	ND
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	6/26/1997		ug/L	1	ND
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	12/11/1997		ug/L	1	ND
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	9/1/1998		ug/L	1	ND
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	12/17/1998	1.6	ug/L	1	
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	6/7/1999		ug/L	1	ND
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	12/7/1999		ug/L	1	ND
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	6/8/2000		ug/L	1	ND
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	12/5/2000	0.61	ug/L	1	TR
MW-31	5.25	4.00	TRICHLOROETHENE (TCE)	6/14/2001	1.63	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	12/13/1995	3	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	9/22/1996	3	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	12/6/1996	3	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	6/26/1997	2	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	12/11/1997	1	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	9/1/1998	2.9	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	12/17/1998	5.5	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	6/7/1999	2.2	ug/L	1	

TABLE C.3F
ANALYTICAL DATA - TRICHLOROETHENE (TCE)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	12/7/1999	3	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	6/8/2000	2.2	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	12/5/2000	1.8	ug/L	1	
MW-33	3.50	4.44	TRICHLOROETHENE (TCE)	6/14/2001	1.81	ug/L	1	
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	12/13/1995	4	ug/L	1	
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	9/22/1996	2	ug/L	1	
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	12/6/1996	4	ug/L	1	
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	6/26/1997		ug/L	1	ND
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	12/11/1997		ug/L	1	ND
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	9/1/1998	0.6	ug/L	1	TR
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	12/17/1998	6.4	ug/L	1	
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	6/7/1999		ug/L	1	ND
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	12/7/1999		ug/L	1	ND
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	6/8/2000		ug/L	1	ND
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	12/5/2000		ug/L	1	ND
MW-40	2.81	2.63	TRICHLOROETHENE (TCE)	6/14/2001		ug/L	0.137	ND
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	12/13/1995		ug/L	1	ND
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	9/22/1996	DRY	ug/L	1	
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	12/6/1996	DRY	ug/L	1	
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	6/26/1997		ug/L	1	ND
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	12/11/1997		ug/L	1	ND
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	9/1/1998		ug/L	1	ND
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	12/17/1998	3.1	ug/L	1	
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	6/7/1999		ug/L	1	ND
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	12/7/1999		ug/L	1	ND
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	6/8/2000		ug/L	1	ND
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	12/5/2000	DRY	ug/L	1	
MW-49	4.81	1.75	TRICHLOROETHENE (TCE)	6/14/2001	4.23	ug/L	1	ND
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	12/12/1995	6	ug/L	1	
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	6/25/1997	1	ug/L	1	
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	12/4/1998		ug/L	1	ND
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	6/7/1999		ug/L	1	ND
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	6/5/2001		ug/L	0.137	ND
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	9/23/1996	DRY	ug/L	1	
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	12/10/1996	DRY	ug/L	1	
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	12/9/1997	DRY	ug/L	1	
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	8/31/1998	DRY	ug/L	1	
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	12/6/1999	DRY	ug/L	1	
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	6/6/2000	DRY	ug/L	1	
DW-03	3.00	4.00	TRICHLOROETHENE (TCE)	12/4/2000	DRY	ug/L	1	

[a/] ug/L = micrograms per liter.

[b/] ND = non-detect, TR = trace or estimated value.

TABLE C.4F
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	11/1/1994	39000	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	12/13/1995	11000	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	9/22/1996	2900	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	12/6/1996	2300	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	6/26/1997	320	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	12/11/1997	407	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	9/1/1998	600	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	12/17/1998	150	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	6/7/1999	5000	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	12/7/1999	200	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	6/8/2000	1700	ug/L	1	
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	12/5/2000	220	ug/L	1	TR
MW-30	6.88	5.19	cis-1,2-DICHLOROETHENE	6/14/2001	189	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	12/13/1995	720	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	9/22/1996	1600	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	12/6/1996	740	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	6/26/1997	100	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	12/11/1997	415	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	9/1/1998	120	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	12/17/1998	16	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	6/7/1999	88	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	12/7/1999	23	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	6/8/2000	8.4	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	12/5/2000	4.9	ug/L	1	
MW-47	5.75	5.06	cis-1,2-DICHLOROETHENE	6/14/2001	11	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	12/13/1995	26	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	9/22/1996	24	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	12/6/1996	25	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	6/26/1997	15	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	12/11/1997	20.1	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	9/1/1998	23	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	12/17/1998	30	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	6/7/1999	18	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	12/7/1999	19	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	6/8/2000	10	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	12/5/2000	8.2	ug/L	1	
MW-03	3.38	4.69	cis-1,2-DICHLOROETHENE	6/14/2001		ug/L	0.112	ND
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	10/31/1994	210	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	12/13/1995	220	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	9/22/1996	140	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	12/6/1996	160	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	6/26/1997	110	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	12/11/1997	96	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	9/1/1998	46	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	12/17/1998	26	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	6/7/1999	44	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	12/7/1999	39	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	6/8/2000	54	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	12/5/2000	38	ug/L	1	
MW-10	4.88	3.63	cis-1,2-DICHLOROETHENE	6/14/2001	21	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	11/4/1994	580	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	12/13/1995	300	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	9/22/1996	300	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	12/6/1996	260	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	6/26/1997	220	ug/L	1	

TABLE C.4F
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	12/11/1997	362	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	9/1/1998	320	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	12/17/1998	700	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	6/7/1999	460	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	12/7/1999	290	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	6/8/2000	490	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	6/14/2001	250	ug/L	1	
MW-28	5.31	4.63	cis-1,2-DICHLOROETHENE	12/6/2001	DRY	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	11/4/1994	55	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	12/13/1995	41	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	9/22/1996	21	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	12/6/1996	17	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	6/26/1997	14	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	12/11/1997	20	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	9/1/1998	14	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	12/17/1998	28	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	6/7/1999	46	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	12/7/1999	33	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	6/8/2000	54	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	12/5/2000	50	ug/L	1	
MW-29	5.50	4.31	cis-1,2-DICHLOROETHENE	6/14/2001	66.5	ug/L	1	
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	12/13/1995		ug/L	20	ND
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	9/22/1996	230	ug/L	1	
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	12/6/1996	310	ug/L	1	
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	6/26/1997	210	ug/L	1	
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	12/11/1997	412	ug/L	1	
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	9/1/1998	290	ug/L	1	
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	12/17/1998	230	ug/L	1	
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	6/7/1999	210	ug/L	1	
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	12/7/1999	210	ug/L	1	
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	6/8/2000	170	ug/L	1	
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	12/5/2000	160	ug/L	1	TR
MW-32	4.38	4.13	cis-1,2-DICHLOROETHENE	6/14/2001	108	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	10/31/1994	130	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	12/13/1995	210	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	9/22/1996	120	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	12/6/1996	140	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	6/26/1997	90	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	12/11/1997	170	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	12/17/1998		ug/L	1	ND
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	6/7/1999	120	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	12/7/1999	110	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	6/8/2000	55	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	12/5/2000	37	ug/L	1	
MW-36	4.44	3.88	cis-1,2-DICHLOROETHENE	6/14/2001	8.85	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	11/4/1994	27	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	12/13/1995	74	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	9/22/1996	43	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	12/6/1996	31	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	6/26/1997	10	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	12/11/1997	16.6	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	9/1/1998	15	ug/L	1	

TABLE C.4F
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	12/17/1998	16	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	6/7/1999	9.3	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	12/7/1999	15	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	6/8/2000	16	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	12/5/2000	8.7	ug/L	1	
MW-39	3.88	2.06	cis-1,2-DICHLOROETHENE	6/14/2001	0.667	ug/L	1	TR
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	12/13/1995	1000	ug/L	1	
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	9/22/1996	230	ug/L	1	
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	12/6/1996	380	ug/L	1	
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	6/26/1997	240	ug/L	1	
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	12/11/1997	180	ug/L	1	
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	9/1/1998	270	ug/L	1	
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	12/17/1998	170	ug/L	1	
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	6/7/1999	120	ug/L	1	
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	12/7/1999	210	ug/L	1	
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	6/8/2000	180	ug/L	1	
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	12/5/2000	190	ug/L	1	TR
MW-46	5.94	5.25	cis-1,2-DICHLOROETHENE	6/14/2001	163	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	12/13/1995	140	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	9/22/1996	45	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	12/6/1996	43	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	6/26/1997	41	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	12/11/1997	58.2	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	9/1/1998	45	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	12/17/1998	33	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	6/7/1999	19	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	12/7/1999	18	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	6/8/2000	14	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	12/5/2000	8.3	ug/L	1	
MW-48	4.25	3.38	cis-1,2-DICHLOROETHENE	6/14/2001	8.49	ug/L	1	
MW-52	3.38	3.50	cis-1,2-DICHLOROETHENE	12/13/1995	30	ug/L	1	
MW-52	3.38	3.50	cis-1,2-DICHLOROETHENE	9/22/1996	28	ug/L	1	
MW-52	3.38	3.50	cis-1,2-DICHLOROETHENE	12/6/1996	32	ug/L	1	
MW-52	3.38	3.50	cis-1,2-DICHLOROETHENE	6/26/1997	12	ug/L	1	
MW-52	3.38	3.50	cis-1,2-DICHLOROETHENE	12/10/1997	13	ug/L	1	
MW-52	3.38	3.50	cis-1,2-DICHLOROETHENE	12/15/1998	17	ug/L	1	
MW-52	3.38	3.50	cis-1,2-DICHLOROETHENE	6/7/1999	11	ug/L	1	
MW-52	3.38	3.50	cis-1,2-DICHLOROETHENE	12/7/1999	7.3	ug/L	1	
MW-52	3.38	3.50	cis-1,2-DICHLOROETHENE	12/4/2000	1.5	ug/L	1	
MW-52	3.38	3.50	cis-1,2-DICHLOROETHENE	6/11/2001	0.91	ug/L	0.91	
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	12/13/1995		ug/L	1	ND
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	9/22/1996		ug/L	1	ND
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	12/6/1996		ug/L	1	ND
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	6/26/1997		ug/L	1	ND
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	12/11/1997		ug/L	1.2	ND
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	9/1/1998		ug/L	1.2	ND
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	12/17/1998	1.6	ug/L	1	
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	6/7/1999		ug/L	1	ND
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	12/7/1999		ug/L	1	ND
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	6/8/2000		ug/L	1	ND
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	12/5/2000	0.44	ug/L	1	TR
MW-31	5.25	4.00	cis-1,2-DICHLOROETHENE	6/14/2001	0.684	ug/L	0.68	

TABLE C.4F
ANALYTICAL DATA - cis-1,2-DICHLOROETHENE (cis-1,2-DCE)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a]	DetLim	Flags [b]
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	12/13/1995	16	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	9/22/1996	12	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	12/6/1996	11	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	6/26/1997	10	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	12/11/1997	5	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	9/1/1998	12	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	12/17/1998	18	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	6/7/1999	8.1	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	12/7/1999	8.2	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	6/8/2000	6.5	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	12/5/2000	6.5	ug/L	1	
MW-33	3.50	4.44	cis-1,2-DICHLOROETHENE	6/14/2001	4.25	ug/L	1	
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	12/13/1995	15	ug/L	1	
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	9/22/1996	9	ug/L	1	
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	12/6/1996	16	ug/L	1	
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	6/26/1997	1	ug/L	1	
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	12/11/1997	2.9	ug/L	1	
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	9/1/1998	1.8	ug/L	1	
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	12/17/1998	13	ug/L	1	
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	6/7/1999		ug/L	1	ND
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	12/7/1999		ug/L	1	ND
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	6/8/2000		ug/L	1	ND
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	12/5/2000		ug/L	1	ND
MW-40	2.81	2.63	cis-1,2-DICHLOROETHENE	6/14/2001		ug/L	0.112	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	12/13/1995		ug/L	1	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	9/22/1996	DRY	ug/L	1	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	12/6/1996	DRY	ug/L	1	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	6/26/1997		ug/L	1	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	12/11/1997		ug/L	1.2	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	9/1/1998		ug/L	1.2	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	12/17/1998	3.7	ug/L	1	
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	6/7/1999		ug/L	1	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	12/7/1999		ug/L	1	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	6/8/2000		ug/L	1	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	12/5/2000	DRY	ug/L	1	ND
MW-49	4.81	1.75	cis-1,2-DICHLOROETHENE	6/14/2001	7.09	ug/L	1	
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	12/12/1995	7	ug/L	1	
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	9/23/1996	DRY	ug/L	1	
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	12/10/1996	DRY	ug/L	1	
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	6/25/1997	1	ug/L	1	
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	12/9/1997	DRY	ug/L	1	
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	8/31/1998	DRY	ug/L	1	
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	12/4/1998		ug/L	1	ND
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	6/7/1999		ug/L	1	ND
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	12/6/1999	DRY	ug/L	1	
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	6/6/2000	DRY	ug/L	1	
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	12/4/2000	DRY	ug/L	1	
DW-03	3.00	4.00	cis-1,2-DICHLOROETHENE	6/5/2001		ug/L	0.112	ND

[a] ug/L = micrograms per liter.

[b] ND = non-detect, TR = trace or estimated value.

TABLE C.5F
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-30	6.88	5.19	VINYL CHLORIDE	2/22/1990	28	ug/L	1	
MW-30	6.88	5.19	VINYL CHLORIDE	3/11/1994	440	ug/L	1	
MW-30	6.88	5.19	VINYL CHLORIDE	11/1/1994	360	ug/L	1	
MW-30	6.88	5.19	VINYL CHLORIDE	12/13/1995		ug/L	500	ND
MW-30	6.88	5.19	VINYL CHLORIDE	9/22/1996	180	ug/L	1	
MW-30	6.88	5.19	VINYL CHLORIDE	12/6/1996	160	ug/L	1	
MW-30	6.88	5.19	VINYL CHLORIDE	6/26/1997	2	ug/L	1	
MW-30	6.88	5.19	VINYL CHLORIDE	12/11/1997	6.9	ug/L	1	
MW-30	6.88	5.19	VINYL CHLORIDE	9/1/1998	3.6	ug/L	1	TR
MW-30	6.88	5.19	VINYL CHLORIDE	12/17/1998	1.1	ug/L	1	TR
MW-30	6.88	5.19	VINYL CHLORIDE	6/7/1999	7.5	ug/L	1	
MW-30	6.88	5.19	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-30	6.88	5.19	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-30	6.88	5.19	VINYL CHLORIDE	12/5/2000	0.62	ug/L	1	TR
MW-30	6.88	5.19	VINYL CHLORIDE	6/14/2001	5.89	ug/L	1	
MW-47	5.75	5.06	VINYL CHLORIDE	12/13/1995		ug/L	50	ND
MW-47	5.75	5.06	VINYL CHLORIDE	9/22/1996	55	ug/L	1	
MW-47	5.75	5.06	VINYL CHLORIDE	12/6/1996	27	ug/L	1	
MW-47	5.75	5.06	VINYL CHLORIDE	6/26/1997	4	ug/L	1	
MW-47	5.75	5.06	VINYL CHLORIDE	12/11/1997	17	ug/L	1	
MW-47	5.75	5.06	VINYL CHLORIDE	9/1/1998	4.9	ug/L	1	
MW-47	5.75	5.06	VINYL CHLORIDE	12/17/1998		ug/L	2	ND
MW-47	5.75	5.06	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-47	5.75	5.06	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-47	5.75	5.06	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-47	5.75	5.06	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-47	5.75	5.06	VINYL CHLORIDE	6/14/2001	0.311	ug/L	0.31	TR
MW-03	3.38	4.69	VINYL CHLORIDE	12/13/1995		ug/L	1	ND
MW-03	3.38	4.69	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-03	3.38	4.69	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-03	3.38	4.69	VINYL CHLORIDE	6/26/1997		ug/L	1	ND
MW-03	3.38	4.69	VINYL CHLORIDE	12/11/1997		ug/L	1.1	ND
MW-03	3.38	4.69	VINYL CHLORIDE	9/1/1998		ug/L	1.1	ND
MW-03	3.38	4.69	VINYL CHLORIDE	12/17/1998		ug/L	2	ND
MW-03	3.38	4.69	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-03	3.38	4.69	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-03	3.38	4.69	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-03	3.38	4.69	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-03	3.38	4.69	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-10	4.88	3.63	VINYL CHLORIDE	6/14/1988		ug/L	10	ND
MW-10	4.88	3.63	VINYL CHLORIDE	2/20/1990		ug/L	10	ND
MW-10	4.88	3.63	VINYL CHLORIDE	3/10/1994		ug/L	10	ND
MW-10	4.88	3.63	VINYL CHLORIDE	10/31/1994		ug/L	10	ND
MW-10	4.88	3.63	VINYL CHLORIDE	12/13/1995		ug/L	10	ND
MW-10	4.88	3.63	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-10	4.88	3.63	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-10	4.88	3.63	VINYL CHLORIDE	6/26/1997		ug/L	1	ND

TABLE C.5F
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-10	4.88	3.63	VINYL CHLORIDE	12/11/1997		ug/L	1.1	ND
MW-10	4.88	3.63	VINYL CHLORIDE	9/1/1998		ug/L	1.1	ND
MW-10	4.88	3.63	VINYL CHLORIDE	12/17/1998		ug/L	2	ND
MW-10	4.88	3.63	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-10	4.88	3.63	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-10	4.88	3.63	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-10	4.88	3.63	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-10	4.88	3.63	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-28	5.31	4.63	VINYL CHLORIDE	2/22/1990		ug/L	1	ND
MW-28	5.31	4.63	VINYL CHLORIDE	3/11/1994		ug/L	1	ND
MW-28	5.31	4.63	VINYL CHLORIDE	11/4/1994		ug/L	1	ND
MW-28	5.31	4.63	VINYL CHLORIDE	12/13/1995		ug/L	20	ND
MW-28	5.31	4.63	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-28	5.31	4.63	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-28	5.31	4.63	VINYL CHLORIDE	6/26/1997	0.9	ug/L	1	TR
MW-28	5.31	4.63	VINYL CHLORIDE	12/11/1997	1.5	ug/L	1	
MW-28	5.31	4.63	VINYL CHLORIDE	9/1/1998		ug/L	2.8	ND
MW-28	5.31	4.63	VINYL CHLORIDE	12/17/1998	8.1	ug/L	1	
MW-28	5.31	4.63	VINYL CHLORIDE	6/7/1999	2	ug/L	1	
MW-28	5.31	4.63	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-28	5.31	4.63	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-28	5.31	4.63	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-28	5.31	4.63	VINYL CHLORIDE	12/6/2001	DRY	ug/L	2	
MW-29	5.50	4.31	VINYL CHLORIDE	12/13/1995		ug/L	2	ND
MW-29	5.50	4.31	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-29	5.50	4.31	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-29	5.50	4.31	VINYL CHLORIDE	6/26/1997		ug/L	1	ND
MW-29	5.50	4.31	VINYL CHLORIDE	12/11/1997		ug/L	1.1	ND
MW-29	5.50	4.31	VINYL CHLORIDE	9/1/1998		ug/L	1.1	ND
MW-29	5.50	4.31	VINYL CHLORIDE	12/17/1998	1.4	ug/L	1	TR
MW-29	5.50	4.31	VINYL CHLORIDE	6/7/1999	1.4	ug/L	1	TR
MW-29	5.50	4.31	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-29	5.50	4.31	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-29	5.50	4.31	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-29	5.50	4.31	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-32	4.38	4.13	VINYL CHLORIDE	2/21/1990		ug/L	20	ND
MW-32	4.38	4.13	VINYL CHLORIDE	3/10/1994		ug/L	20	ND
MW-32	4.38	4.13	VINYL CHLORIDE	10/31/1994		ug/L	20	ND
MW-32	4.38	4.13	VINYL CHLORIDE	12/13/1995		ug/L	20	ND
MW-32	4.38	4.13	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-32	4.38	4.13	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-32	4.38	4.13	VINYL CHLORIDE	6/26/1997		ug/L	1	ND
MW-32	4.38	4.13	VINYL CHLORIDE	12/11/1997		ug/L	1.1	ND
MW-32	4.38	4.13	VINYL CHLORIDE	9/1/1998		ug/L	1.1	ND

TABLE C.5F
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-32	4.38	4.13	VINYL CHLORIDE	12/17/1998		ug/L	2	ND
MW-32	4.38	4.13	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-32	4.38	4.13	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-32	4.38	4.13	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-32	4.38	4.13	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-32	4.38	4.13	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-36	4.44	3.88	VINYL CHLORIDE	12/13/1995		ug/L	10	ND
MW-36	4.44	3.88	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-36	4.44	3.88	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-36	4.44	3.88	VINYL CHLORIDE	6/26/1997		ug/L	1	ND
MW-36	4.44	3.88	VINYL CHLORIDE	12/11/1997		ug/L	1.1	ND
MW-36	4.44	3.88	VINYL CHLORIDE	9/1/1998		ug/L	1.1	ND
MW-36	4.44	3.88	VINYL CHLORIDE	12/17/1998		ug/L	2	ND
MW-36	4.44	3.88	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-36	4.44	3.88	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-36	4.44	3.88	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-36	4.44	3.88	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-36	4.44	3.88	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-39	3.88	2.06	VINYL CHLORIDE	3/7/1991		ug/L	2	ND
MW-39	3.88	2.06	VINYL CHLORIDE	3/9/1994		ug/L	2	ND
MW-39	3.88	2.06	VINYL CHLORIDE	11/4/1994		ug/L	2	ND
MW-39	3.88	2.06	VINYL CHLORIDE	12/13/1995		ug/L	2	ND
MW-39	3.88	2.06	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-39	3.88	2.06	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-39	3.88	2.06	VINYL CHLORIDE	6/26/1997		ug/L	1	ND
MW-39	3.88	2.06	VINYL CHLORIDE	12/11/1997		ug/L	1.1	ND
MW-39	3.88	2.06	VINYL CHLORIDE	9/1/1998		ug/L	1.1	ND
MW-39	3.88	2.06	VINYL CHLORIDE	12/17/1998		ug/L	2	ND
MW-39	3.88	2.06	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-39	3.88	2.06	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-39	3.88	2.06	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-39	3.88	2.06	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-39	3.88	2.06	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-46	5.94	5.25	VINYL CHLORIDE	12/13/1995	54	ug/L	1	
MW-46	5.94	5.25	VINYL CHLORIDE	9/22/1996	8	ug/L	1	
MW-46	5.94	5.25	VINYL CHLORIDE	12/6/1996	14	ug/L	1	
MW-46	5.94	5.25	VINYL CHLORIDE	6/26/1997	10	ug/L	1	
MW-46	5.94	5.25	VINYL CHLORIDE	12/11/1997	6.6	ug/L	1	
MW-46	5.94	5.25	VINYL CHLORIDE	9/1/1998	10	ug/L	1	
MW-46	5.94	5.25	VINYL CHLORIDE	12/17/1998	5.7	ug/L	1	
MW-46	5.94	5.25	VINYL CHLORIDE	6/7/1999	4	ug/L	1	
MW-46	5.94	5.25	VINYL CHLORIDE	12/7/1999	4.6	ug/L	1	
MW-46	5.94	5.25	VINYL CHLORIDE	6/8/2000	4.3	ug/L	1	
MW-46	5.94	5.25	VINYL CHLORIDE	12/5/2000	6.9	ug/L	1	

TABLE C.5F
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a/]	DetLim	Flags [b/]
MW-46	5.94	5.25	VINYL CHLORIDE	6/14/2001	4.46	ug/L	1	
MW-48	4.25	3.38	VINYL CHLORIDE	12/13/1995		ug/L	5	ND
MW-48	4.25	3.38	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-48	4.25	3.38	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-48	4.25	3.38	VINYL CHLORIDE	6/26/1997		ug/L	1	ND
MW-48	4.25	3.38	VINYL CHLORIDE	12/11/1997		ug/L	1.1	ND
MW-48	4.25	3.38	VINYL CHLORIDE	9/1/1998		ug/L	1.1	ND
MW-48	4.25	3.38	VINYL CHLORIDE	12/17/1998		ug/L	2	ND
MW-48	4.25	3.38	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-48	4.25	3.38	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-48	4.25	3.38	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-48	4.25	3.38	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-48	4.25	3.38	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-52	3.38	3.50	VINYL CHLORIDE	12/8/1995		ug/L	1	ND
MW-52	3.38	3.50	VINYL CHLORIDE	9/21/1996		ug/L	1	ND
MW-52	3.38	3.50	VINYL CHLORIDE	12/10/1996		ug/L	1	ND
MW-52	3.38	3.50	VINYL CHLORIDE	6/25/1997		ug/L	1	ND
MW-52	3.38	3.50	VINYL CHLORIDE	12/10/1997		ug/L	1.1	ND
MW-52	3.38	3.50	VINYL CHLORIDE	8/31/1998		ug/L	2	ND
MW-52	3.38	3.50	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-52	3.38	3.50	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-52	3.38	3.50	VINYL CHLORIDE	12/4/2000		ug/L	2	ND
MW-52	3.38	3.50	VINYL CHLORIDE	6/11/2000		ug/L	0.114	ND
MW-31	5.25	4.00	VINYL CHLORIDE	12/13/1995		ug/L	1	ND
MW-31	5.25	4.00	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-31	5.25	4.00	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-31	5.25	4.00	VINYL CHLORIDE	6/26/1997		ug/L	1	ND
MW-31	5.25	4.00	VINYL CHLORIDE	12/11/1997		ug/L	1.1	ND
MW-31	5.25	4.00	VINYL CHLORIDE	9/1/1998		ug/L	1.1	ND
MW-31	5.25	4.00	VINYL CHLORIDE	12/17/1998		ug/L	2	ND
MW-31	5.25	4.00	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-31	5.25	4.00	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-31	5.25	4.00	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-31	5.25	4.00	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-31	5.25	4.00	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-33	3.50	4.44	VINYL CHLORIDE	12/13/1995		ug/L	1	ND
MW-33	3.50	4.44	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-33	3.50	4.44	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-33	3.50	4.44	VINYL CHLORIDE	6/26/1997		ug/L	1	ND
MW-33	3.50	4.44	VINYL CHLORIDE	12/11/1997		ug/L	1.1	ND
MW-33	3.50	4.44	VINYL CHLORIDE	9/1/1998		ug/L	1.1	ND
MW-33	3.50	4.44	VINYL CHLORIDE	12/17/1998		ug/L	2	ND
MW-33	3.50	4.44	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-33	3.50	4.44	VINYL CHLORIDE	12/7/1999		ug/L	2	ND

TABLE C.5F
ANALYTICAL DATA - VINYL CHLORIDE (VC)
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUAION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units [a]	DetLim	Flags [b]
MW-33	3.50	4.44	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-33	3.50	4.44	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-33	3.50	4.44	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-40	2.81	2.63	VINYL CHLORIDE	12/13/1995		ug/L	1	ND
MW-40	2.81	2.63	VINYL CHLORIDE	9/22/1996		ug/L	1	ND
MW-40	2.81	2.63	VINYL CHLORIDE	12/6/1996		ug/L	1	ND
MW-40	2.81	2.63	VINYL CHLORIDE	6/26/1997		ug/L	1	ND
MW-40	2.81	2.63	VINYL CHLORIDE	12/11/1997		ug/L	1.1	ND
MW-40	2.81	2.63	VINYL CHLORIDE	9/1/1998		ug/L	1.1	ND
MW-40	2.81	2.63	VINYL CHLORIDE	12/17/1998		ug/L	2	ND
MW-40	2.81	2.63	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-40	2.81	2.63	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-40	2.81	2.63	VINYL CHLORIDE	6/8/2000		ug/L	2	ND
MW-40	2.81	2.63	VINYL CHLORIDE	12/5/2000		ug/L	2	ND
MW-40	2.81	2.63	VINYL CHLORIDE	6/14/2001		ug/L	0.114	ND
MW-49	4.81	1.75	VINYL CHLORIDE	12/8/1995		ug/L	1	ND
MW-49	4.81	1.75	VINYL CHLORIDE	9/21/1996	DRY	ug/L		
MW-49	4.81	1.75	VINYL CHLORIDE	12/10/1996	DRY	ug/L		
MW-49	4.81	1.75	VINYL CHLORIDE	6/25/1997		ug/L	1	ND
MW-49	4.81	1.75	VINYL CHLORIDE	12/10/1997		ug/L	1.1	ND
MW-49	4.81	1.75	VINYL CHLORIDE	8/31/1998		ug/L	1.1	ND
MW-49	4.81	1.75	VINYL CHLORIDE	12/15/1998		ug/L	2	ND
MW-49	4.81	1.75	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
MW-49	4.81	1.75	VINYL CHLORIDE	12/7/1999		ug/L	2	ND
MW-49	4.81	1.75	VINYL CHLORIDE	6/6/2000		ug/L	2	ND
MW-49	4.81	1.75	VINYL CHLORIDE	12/4/2000	DRY	ug/L		
MW-49	4.81	1.75	VINYL CHLORIDE	6/12/2001		ug/L	0.114	ND
DW-03	3.00	4.00	VINYL CHLORIDE	12/12/1995		ug/L	1	ND
DW-03	3.00	4.00	VINYL CHLORIDE	9/23/1996	DRY	ug/L	1	
DW-03	3.00	4.00	VINYL CHLORIDE	12/10/1996	DRY	ug/L	1	
DW-03	3.00	4.00	VINYL CHLORIDE	6/25/1997		ug/L	1	ND
DW-03	3.00	4.00	VINYL CHLORIDE	12/9/1997	DRY	ug/L	1	
DW-03	3.00	4.00	VINYL CHLORIDE	8/31/1998	DRY	ug/L	1	
DW-03	3.00	4.00	VINYL CHLORIDE	12/4/1998		ug/L	2	ND
DW-03	3.00	4.00	VINYL CHLORIDE	6/7/1999		ug/L	2	ND
DW-03	3.00	4.00	VINYL CHLORIDE	12/6/1999	DRY	ug/L	1	
DW-03	3.00	4.00	VINYL CHLORIDE	6/6/2000	DRY	ug/L	1	
DW-03	3.00	4.00	VINYL CHLORIDE	12/4/2000	DRY	ug/L	1	
DW-03	3.00	4.00	VINYL CHLORIDE	6/5/2001		ug/L	0.114	ND

[a] ug/L = micrograms per liter.

[b] ND = non-detect, TR = trace or estimated value.

TABLE C.6F
INPUT PARAMETERS FOR MASS-BASED CALCULATIONS
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

WellName	Theissen Polygon Area (square feet)
MW-03	0.05
MW-10	0.66
MW-28	0.56
MW-29	0.16
MW-30	0.02
MW-31	0.34
MW-32	0.71
MW-33	0.50
MW-36	0.26
MW-39	0.68
MW-40	0.33
MW-46	0.00
MW-47	0.17
MW-48	0.92
MW-49	0.42
MW-52	0.80
Total	6.57

Parameter	Value
Porosity (percentage)	30
Thickness of Contaminated Aquifer (feet)	10

TABLE C.7F
RESULTS OF DISSOLVED MASS ESTIMATION
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

	Mass in kilograms							
	Trichloroethene (TCE)		Dichloroethene (DCE)		Vinyl Chloride (VC)		Total CAHs	
Date	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass	Grid Mass	Theissen Mass
12/13/1995	22.39	14.33	12.42	12.27	0.049	0.00083	39.32	30.96
9/22/1996	4.46	3.97	13.30	12.03	0.260	0.17020	23.03	20.63
12/6/1996	3.91	3.79	10.30	10.52	0.150	0.10016	18.19	18.25
6/26/1997	2.63	3.02	5.28	6.15	0.031	0.01684	9.85	11.39
12/11/1997	2.88	3.37	9.33	10.36	0.085	0.05291	15.70	17.53
12/17/1998	2.19	2.47	7.57	8.86	0.062	0.06507	12.59	14.62
6/7/1999	2.69	2.63	7.16	8.30	0.023	0.01999	12.44	13.93
12/7/1999	1.59	1.93	4.91	5.65	0.004	0.00007	8.25	9.59
6/8/2000	1.98	2.46	5.60	7.03	0.004	0.00007	9.57	12.00
6/14/2001	0.80	1.00	3.10	3.53	0.006	0.00215	5.02	5.78

	Percentage of Total CAH Mass					
	Trichloroethene (TCE)		Dichloroethene (DCE)		Vinyl Chloride (VC)	
Date	Grid Mass	Theissen Mass	Grid Mass	Thies Mass	Grid Mass	Theissen Mass
12/13/1995	56.9%	46.3%	42.8%	53.7%	0.26%	0.01%
9/22/1996	19.4%	19.2%	78.3%	79.0%	2.38%	1.73%
12/6/1996	21.5%	20.7%	76.8%	78.1%	1.73%	1.15%
6/26/1997	26.7%	26.5%	72.7%	73.2%	0.66%	0.31%
12/11/1997	18.3%	19.2%	80.5%	80.2%	1.14%	0.63%
12/17/1998	17.4%	16.9%	81.5%	82.1%	1.04%	0.94%
6/7/1999	21.6%	18.9%	78.0%	80.8%	0.39%	0.30%
12/7/1999	19.2%	20.2%	80.7%	79.8%	0.11%	0.002%
6/8/2000	20.6%	20.5%	79.3%	79.5%	0.08%	0.001%
6/14/2001	16.0%	17.3%	83.7%	82.7%	0.27%	0.08%

S:\ES\Remed\TO24\NA Studies\20000 - CAHs\MassCalcs\Brooks Mass Calcs - Appendix Tables.xls\Concentrations and Percentages

TABLE C.8F
RESULTS OF GIS MASS-BASED CALCULATIONS FOR CENTER OF MASS LOCATION
SITE FPTA-2, BROOKS AFB, TEXAS
FIELD-SCALE EVALUATION OF MNA FOR DISSOLVED CHLORINATED SOLVENT PLUMES

	Trichloroethene (TCE)				Dichloroethene (DCE)				Vinyl Chloride (VC)			
	Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass		Theissen Center of Mass		Grid Center of Mass	
Date	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate	X-coordinate	Y-coordinate
12/13/1995	5.33	4.64	5.12	4.74	5.01	4.17	5.08	4.55	NC	NC	NC	NC
9/22/1996	4.89	4.24	4.86	4.38	5.00	4.39	4.93	4.50	NC	NC	NC	NC
12/6/1996	4.77	4.12	4.77	4.26	4.81	4.26	4.82	4.37	NC	NC	NC	NC
6/26/1997	4.74	4.12	4.67	4.12	4.69	4.16	4.66	4.14	NC	NC	NC	NC
12/11/1997	4.67	4.16	4.59	4.10	4.71	4.28	4.66	4.24	NC	NC	NC	NC
12/17/1998	4.69	4.24	4.59	4.15	4.79	4.44	4.68	4.31	NC	NC	NC	NC
6/7/1999	4.83	4.35	4.80	4.38	4.93	4.50	4.98	4.62	NC	NC	NC	NC
12/7/1999	4.68	4.17	4.56	4.06	4.69	4.31	4.65	4.22	NC	NC	NC	NC
6/14/2001	4.69	4.20	4.61	4.09	4.86	4.47	4.83	4.36	NC	NC	NC	NC

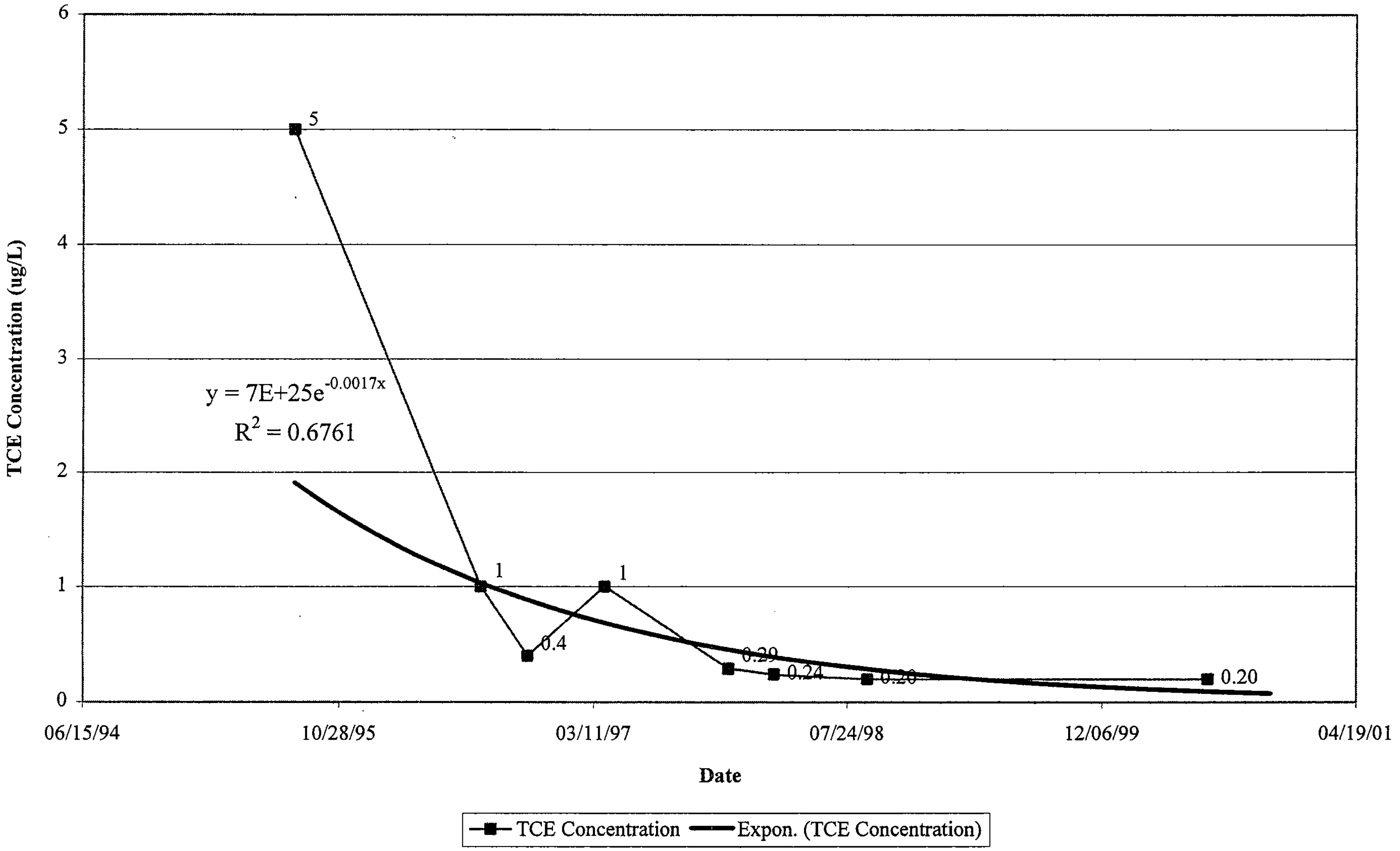
*Note that Brooks coordinates are in "paper space".

NC = Not Calculated.

APPENDIX D

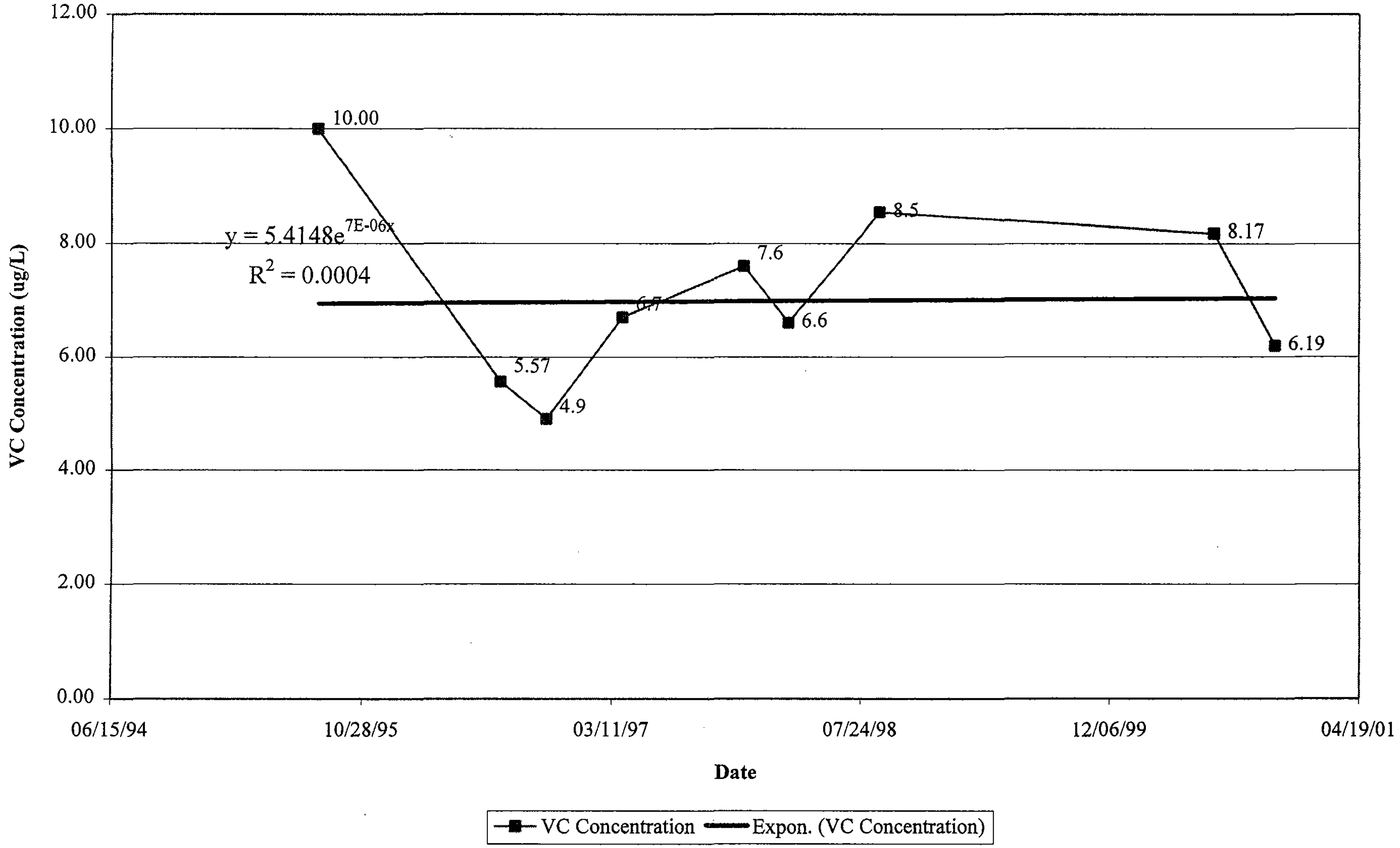
SELECTED FIGURES FROM PREVIOUS STUDIES AT CASE STUDY SITES

FIGURE C.1
W-18 TCE TREND ANALYSIS
SUPPLEMENTAL FEASIBILITY STUDY EVALUATION
FOR INSTALLATION RESTORATION PROGRAM SITE LF-06
COLUMBUS AFB, MISSISSIPPI



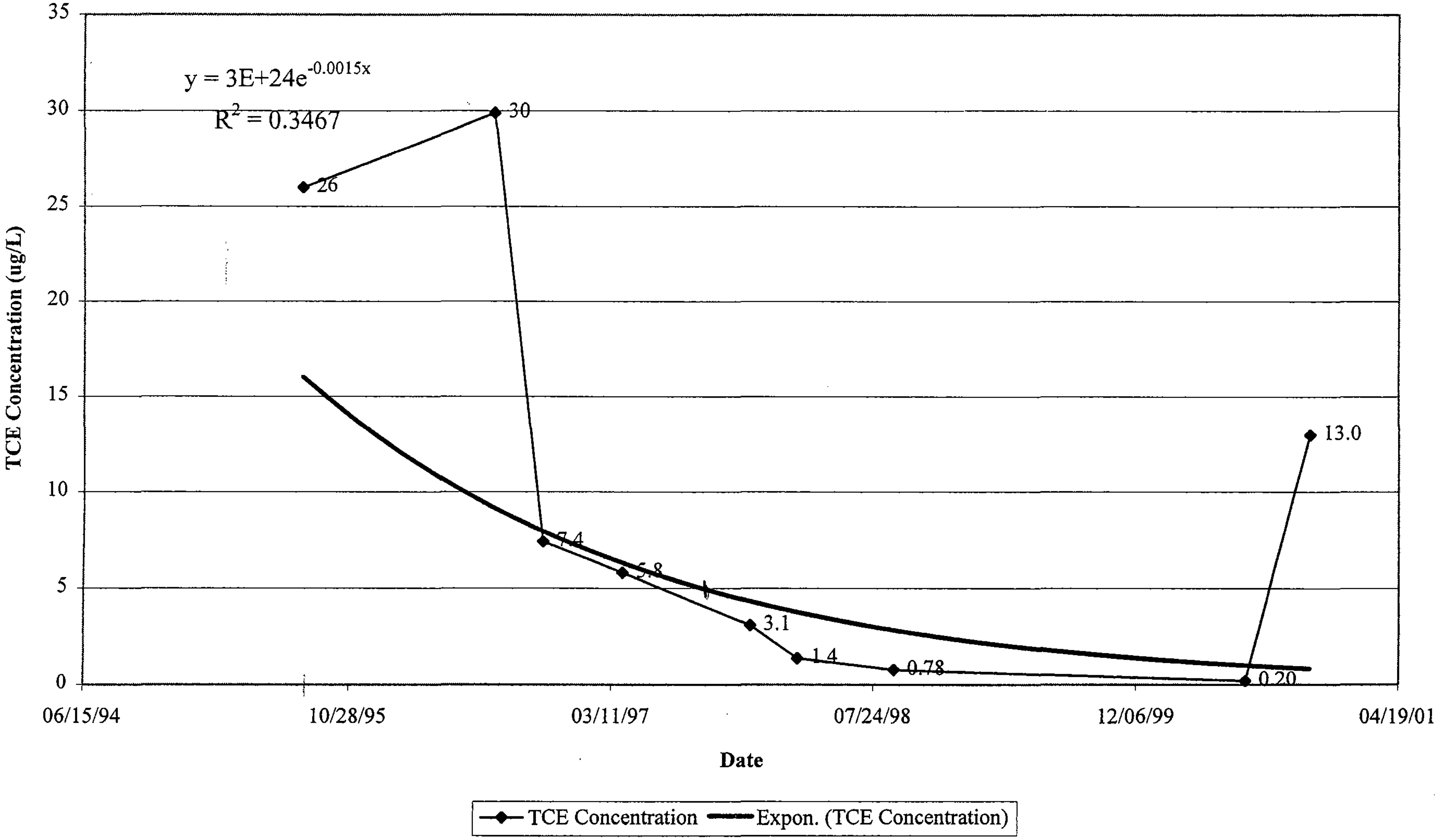
S:\ES\Remed\Columbus\LF06 Sup\LF-06 Trends.xls

FIGURE C.2
W-18 VC TREND ANALYSIS
SUPPLEMENTAL FEASIBILITY STUDY EVALUATION
FOR INSTALLATION RESTORATION PROGRAM SITE LF-06
COLUMBUS AFB, MISSISSIPPI



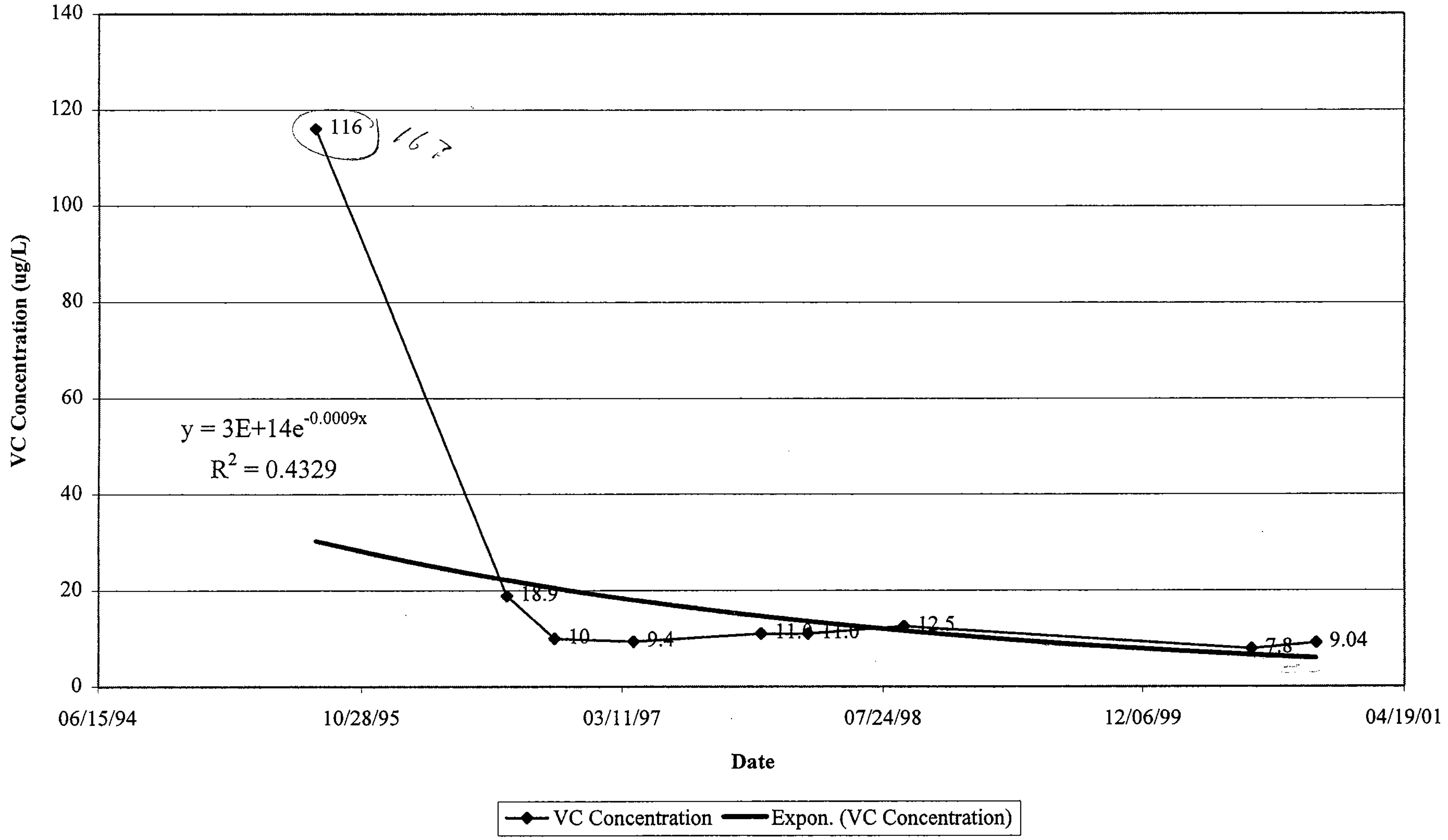
S:\ES\Remed\Columbus\LF06 Sup\LF-06 Trends.xls

FIGURE C.3
W-21 TCE TREND ANALYSIS
SUPPLEMENTAL FEASIBILITY STUDY EVALUATION FOR INSTALLATION RESTORATION PROGRAM SITE LF-06
COLUMBUS AFB, MISSISSIPPI



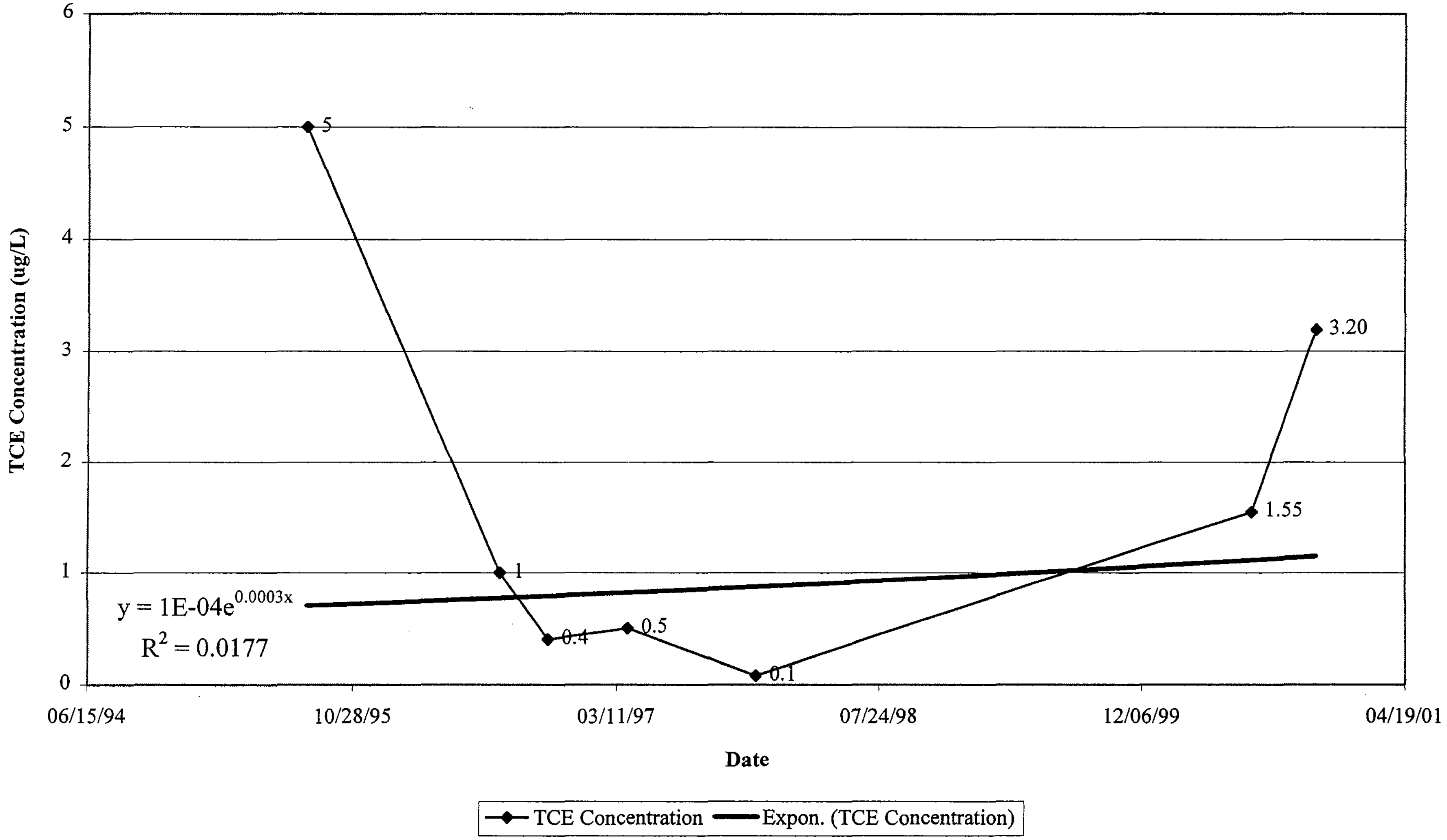
S:\ES\Remed\Columbus\LF06 Sup\LF-06 Trends.xls

FIGURE C.4
W-21 VC TREND ANALYSIS
SUPPLEMENTAL FEASIBILITY STUDY EVALUATION
FOR INSTALLATION RESTORATION PROGRAM SITE LF-06
COLUMBUS AFB, MISSISSIPPI



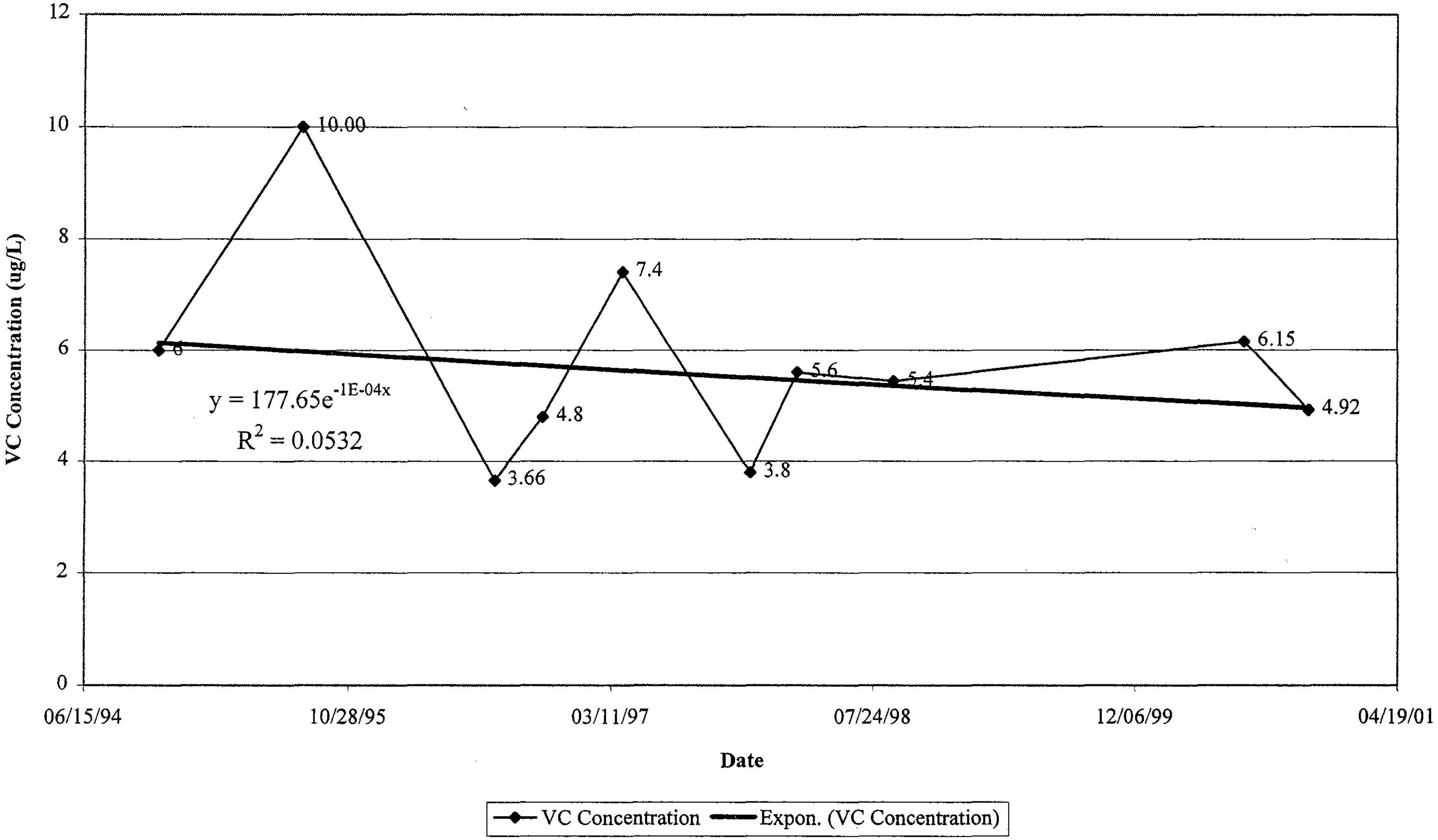
S:\ES\Remed\Columbus\LF06 Sup\LF-06 Trends.xls

FIGURE C.5
W-22 TCE TREND ANALYSIS
SUPPLEMENTAL FEASIBILITY STUDY EVALUATION
FOR INSTALLATION RESTORATION PROGRAM SITE LF-06
COLUMBUS AFB, MISSISSIPPI



S:\ES\Remed\Columbus\LF06 Sup\LF-06 Trends.xls

FIGURE C.6
W-81 VC TREND ANALYSIS
SUPPLEMENTAL FEASIBILITY STUDY EVALUATION
FOR INSTALLATION RESTORATION PROGRAM SITE LF-06
COLUMBUS AFB, MISSISSIPPI



S:\ES\Remed\Columbus\LF06 Sup\LF-06 Trends.xls

APPENDIX E

USING ADVANCED ANALYSIS APPROACHES TO COMPLETE LONG-TERM EVALUATIONS OF NATURAL ATTENUATION PROCESSES ON THE REMEDIATION OF DISSOLVED CHLORINATED SOLVENT CONTAMINATION

FINAL REPORT

HANADI RIFAI

APPENDIX E

TABLE OFCONTENTS

Page

E.1 INTRODUCTION

This report describes the modeling activities that were undertaken in support of the above referenced project. The modeling was aimed at and in response to the SERDP Statement of Need regarding *Assessment of Long-Term Sustainability of Monitored Natural Attenuation of Chlorinated Solvents*. The goal was to determine *cause-and-effect* relationships that influence time of remediation (TOR) estimates at chlorinated solvent sites. An analytical predictive model, Biochlor (Aziz et al., 2000a) was applied to site-specific characterization (baseline) and long-term monitoring data from six (6) sites to evaluate the long-term efficacy of natural attenuation processes at achieving reasonable regulatory goals or endpoints at the sites in question.

The modeling approach involved: (i) characterizing the sensitivity of the Biochlor model results to its input variables in a deterministic mode using a synthetic case study; (ii) characterizing the sensitivity of the Biochlor model results to its input variables in a stochastic or probabilistic mode; and (iii) application of the Biochlor model to the six sites using deterministic and stochastic scenarios.

The next section briefly describes the Biochlor model and illustrates its application and input variables using a synthetic case study in a deterministic mode.

E.2 BIOCHLOR MODEL

The Biochlor Natural Attenuation Decision Support System (Aziz *et al.*, 2000a) simulates the attenuation of chlorinated solvents using an Excel-based interface. Biochlor is based on the Domenico analytical model (Domenico, 1987), and it simulates 1-D advection, 3-D dispersion, linear adsorption, and reductive dechlorination. Reductive dechlorination is assumed to be an anaerobic, first-order decay process. Biochlor can be used to model solute transport without decay, with reductive dechlorination as a sequential first-order decay process, and as a sequential first-order decay process with two different reaction zones and two different biological decay rates. The Biochlor model is intended as a screening tool and can also be used as the primary model at simple, homogeneous sites. Data are easily entered through a spreadsheet interface, and the output is presented in the form of a centerline graph and an array of concentration data.

Typical input for Biochlor includes: hydraulic conductivity, porosity, gradient, distribution coefficients, fraction of organic carbon (to calculate the retardation factor), dispersivity in three-dimensions (longitudinal, transverse, and vertical), source dimensions (width and depth) and source concentrations. Two types of rate constants are needed for the model. The first rate constant is for reductive dechlorination of the chlorinated compounds, and the second rate constant is used to represent the source attenuation over time. These two rate constants are very important as they represent the key removal mechanisms of chlorinated compounds from ground water. Their effect on modeling results is substantial as will be seen in the next section.

E.2.1 Sensitivity of the Biochlor Model Results to Its Input Variables – Deterministic Mode

The Biochlor model input for the synthetic case study used in this sensitivity analysis is shown in Table 1. The modeled aquifer has a seepage velocity of approximately 23 ft/yr. It is assumed that PCE was released at 100 mg/L into the aquifer and that no biodegradation or source decay is occurring. The modeled PCE concentrations for the base case are shown in Figure 1a. As would be expected, PCE concentrations near the source are at 100 mg/L since no source decay was assumed to be occurring. The PCE plume extends almost 2,500 ft and exhibits fairly elevated PCE concentrations for a distance of about 1,000 ft downgradient of the source, again because source decay is not simulated. Additionally, no TCE, cis-DCE or VC are present since biodegradation was not included in the run.

The modeled PCE concentrations in Figure 1a are sensitive to a number of Biochlor input variables. The data in Figure 1b demonstrate that increasing the seepage velocity causes the contaminants to travel further downgradient as would be expected. While a change in adsorption has little affect on contaminant concentrations near the source, at distances greater than 500 ft downgradient, an increased retardation coefficient (>1) limits the downgradient expansion of the contaminant plume due to the decreased contaminant velocity (Figure 1c). Increases in longitudinal, transverse or vertical dispersivity decrease the concentration downgradient as is shown in Figures 2a through 2c.

Source effects are shown in Figures 3a through 3c. Biochlor requires 3 variables to define the source. These include the source width, depth and concentration. As the source width decreases, the distance that the contaminants travel downgradient decreases (Figure 3a). Additionally, for small source widths, the contaminant concentration decreases sharply near the source. As the source depth is increased, the concentration downgradient increases (Figure 3b). Source concentration changes cause the concentration profiles to begin at different starting points on the y-axis as would be expected (Figure 3c). The slope of the line, however, is not affected.

All the sensitivity runs discussed thus far were evaluated at a simulation time of 100 years. The data in Figure 4a illustrate the concentration increases in the base case as time increases from 5 yrs to 100 yrs. These data also illustrate that in the absence of biodegradation and source decay, very little attenuation in PCE concentrations could be expected over time due to the continuous source and lack of destructive mechanisms.

The data in Figure 4b show the attenuation of PCE concentrations due to biodegradation and Figure 4c shows the concentrations of the TCE formed as a result of the biodegradation reaction when the biological reaction rate constant is 3.65 yr^{-1}. As the biodegradation rate increases (Figure 4b), the PCE plume extent decreases and so do the observed concentrations at a given distance downgradient of the source. It is also noted that when comparing the results for the 10 yr and 100 yr simulation times, it can be seen that for larger biodegradation rate constants, less difference is seen between the two simulation times. In fact, and using a biodegradation rate constant of 3.65 yr^{-1}, the lines for the two simulation times cannot be distinguished from one another, reflecting the *quasi steady-state* nature of the plume for the simulated conditions.

In a similar fashion, the effect of source decay on model results is shown in Figure 4d. It is noted that the Biochlor model has a restriction on the source decay rate constant to prevent the calculation of negative concentrations that might occur when source decay rates are too high. The maximum source decay rate constant that can be used is calculated using:

$$k_s \geq \frac{1}{R} \times \left(\lambda + \frac{V_s}{4\alpha_x} \right) \tag{1}$$

where R is the retardation factor [dimensionless], λ is the 1st order biodegradation coefficient [1/T], V_s is the seepage velocity [L/T], and α_x is the longitudinal dispersivity [L]. Using the data for the present modeling scenario (see Table 1), the maximum source decay rate constant was calculated to be 0.049 yr^{-1}. The sensitivity of the model results to the source decay rate constant was undertaken using the range of 0 to 0.049 yr^{-1} as could be seen in Figure 4d. The data in Figure 4d illustrate that the impact of source decay on PCE concentrations is very different from that of biodegradation. In general, source decay does not limit plume extent and only reduces near-source concentrations. In addition, relatively high source decay rate constants cause the plume "peak" or maximum concentration to occur outside the source areas, a phenomenon that has been observed at some field sites. Also, for shorter time frames (10 yrs in this case), source decay has less of an effect on plume concentrations than longer time frames.

The combination of source decay and biodegradation has the net effect of lowering the overall plume concentrations and limiting the extent of plume migration as shown in Figure 5. A comparison of Figure 4b (biodegradation only), Figure 4d (source decay only), and Figure 5 (biodegradation for a given source decay rate) illustrates that increasing the source decay rate constant causes a decrease in the starting concentration, while changing the biodegradation rate does not. Changing the biodegradation rate constant changes the distance to which the PCE plume will migrate downgradient. This demonstrates that both rate constants are very important for the natural attenuation of chlorinated solvents, and that quantifying the two rate constants is critical for assessing the sustainability of natural attenuation for remediating chlorinated plumes.

E.3 MONTE CARLO IMPLEMENTATION OF BIOCHLOR

The modeling results shown in the previous section are based on deterministic evaluations, or single value variable estimates. While very useful, deterministic evaluations do not incorporate the effects of uncertainty in the model input. Assessing uncertainty and its effects on model predictions is very important for understanding the sustainability of natural attenuation and the cause-and-effect relationship between model variables and estimated remediation times.

In this project, a Monte Carlo version of the Biochlor model was developed using the Crystal Ball software from Decisioneering, Inc. In essence, statistical distributions are developed for Biochlor input variables and entered into Crystal Ball. The Crystal Ball software randomly selects model parameters for Biochlor from these parameter distributions and undertakes numerous Biochlor model runs to develop probability distributions of the resulting concentrations in ground water. Thus, instead of using one value for the seepage velocity, for instance, a statistical distribution of possible velocity values is entered into Crystal Ball and numerous model runs are completed with seepage velocities for each run being randomly selected from the statistical distribution for velocity. The modeled concentration for a given downgradient location in the Monte Carlo Biochlor consists of a range of possible concentrations based on these numerous iterations with different seepage velocities.

E.3.1 Sensitivity of the Monte Carlo Biochlor to Its Parameter Distributions

A synthetic base case was developed to determine the effects of uncertainty on Biochlor modeling results. The model input variables and their distributions are shown in Table 2a (note that in this case TCE was used as the contaminant instead of PCE). Lognormal distributions were used for seepage velocity, longitudinal dispersion, soil bulk density, and source width. Uniform distributions were assigned to transverse and vertical dispersion, organic carbon fraction, all biodegradation decay coefficients, and source thickness. The source concentration was fixed at the solubility of TCE of 1,100 mg/L. The distribution ranges assigned to the first order decay coefficients for each constituent were based on the data from Suarez and Rifai (1999).

Based on the above assumptions, stochastic BIOCHLOR simulations were completed for a 10-yr, no biodegradation scenario, and a 10-yr with biodegradation scenario (Figures 6a through 6e). Concentration results were determined at various distances downgradient of the source along the plume centerline. The stochastic simulations were based on a 2500 Monte Carlo iterations using a calculated source decay [see Equation (1) above]. Also shown in Figures 6a through 6e are the results from a deterministic model run using the model variables listed in Table 1 in the *Deterministic* column for illustration purposes. As can be seen, the resulting deterministic model concentrations were between the 75th and 100th percentiles for the stochastic simulations, for all constituents. Figure 6a, for instance illustrates that while the deterministic model run with no biodegradation indicates a travel distance of about 1,400 ft before the predicted concentrations approach the MCL, the stochastic model results indicate that this distance ranges between 600 ft and 700 ft when using the 25th and 75th percentiles as representative limits. Incorporating biodegradation into the run decreases the stochastic travel distance to a range of 200 ft to 400 ft for the 25th and 75th percentiles while the deterministic travel distance decreases to approximately 700 ft. The greatest difference between the deterministic values and the stochastic distributions was evident in concentrations farther from the source, when no biodegradation was assumed to be occurring. Figures 6a through 6e show that the deterministic model results are between the 75th and maximum stochastic model results, possibly due to the differences in assumptions used for estimating the source decay rate constant.

The sensitivity of the stochastic Biochlor model results to its input parameters and their distributions was also evaluated. The data in Figure 7a illustrate that the fraction of organic carbon, seepage velocity, and longitudinal dispersion had the greatest effect on the resulting concentration distributions at the source (0 ft). As the point of interest was moved downgradient (400 ft from the source in this case), the resulting TCE concentration distribution was significantly affected by the velocity, fraction of organic carbon and the biodegradation rate as would be expected (Figure 7b). It is noted that the effect of the source decay rate constant on model results were not evaluated since source decay is a calculated value in the stochastic model.

In addition to evaluating the sensitivity of the stochastic model results to the input parameters, an evaluation of the stochastic model results that places emphasis on the hydrogeologic environment was completed. Table 2b illustrates the various hydrogeologic environments discussed in Newell et al. (1990) and their associated data ranges for seepage velocity, the fraction of organic carbon, and the soil bulk density. The resulting concentration distributions showed a large variation in the concentration distributions at the source (Figure 8a) and 300 ft downgradient (Figure 8b). The concentration distributions for river valley deposits without over bank deposits and outwash materials showed the widest range of modeled concentrations between the 25th and 75th percentiles. The till over sedimentary bedrock, on the other hand, showed the narrowest distribution range of concentrations. Overall, the resulting concentration ranges 300 ft downgradient were wider, with coastal beaches and bedded sedimentary bedrock settings showing wide expected concentration ranges. This analysis underscores the importance of the hydrogeologic characteristics of the aquifer in question in determining the attenuated concentrations in ground water.

The next section describes modeling results from six sites with similar contamination case histories but different hydrogeologic characteristics. All six sites are first modeled using the deterministic version of Biochlor and are then modeled stochastically with Crystal Ball and Biochlor. The deterministic results are compared to their stochastic counterparts at different points in time to illustrate the similarities and differences between the two modeling approaches.

E.4 MODELING OF SIX SITES

E.4.1 Cape Canaveral Air Station, Florida

Biochlor simulations were completed with the data gathered for Facility 1381 at the Cape Canaveral Air Station (CCAS) site. Analytical model predictions were used to simulate the fate of dissolved trichloroethylene (TCE), cis-dichoroethylene (cis-DCE), vinyl chloride (VC), and ethene (ETH) at the site. Previous studies at this site included numerical modeling (see Parsons, 1999a and BEM, 2002) that used two different source scenarios: source decay of 4% per year and source removal. The results from Parsons (1999a) and BEM (2002) indicated that concentrations at the site would require approximately 200 and 100 years, respectively to attenuate to below the maximum concentration level or MCL.

In this project, Biochlor modeling conceptualized the site as a one-reaction zone model. Model results were compared to the remediation estimates from the numerical modeling discussed above.

Site Description. The Cape Canaveral Air Station (CCAS) encompasses approximately 15,800 acres on a barrier island off the east coast of Florida. The Atlantic Ocean, the Banana River, a man-made shipping channel, and the John F. Kennedy Space Center border the CCAS on the east, west, south and north sides, respectively. Since the 1950’s, the CCAS has acted as an assembly and launch facility for missile and space exploration vehicles. Facility 1381 (the Facility), an ordinance support facility, is located in the middle portion of the entire complex and encompasses an area contained within the solid waster management unit 21. Surface elevations at Facility 1381 range between 5 and 9 ft above mean sea level (amsl).

Contaminants at the site consist of fuel hydrocarbons and chlorinated solvents, particularly TCE, DCE, and VC that emanated from residual NAPL within the subsurface. Missile/space testing and research operations at Facility 1381 began in 1958 and a cleaning laboratory utilizing TCE was commissioned in 1968. The US Coast Guard assumed operations in 1977. Groundwater contamination at the site was caused by past accidental releases associated with historic metal cleaning operations.

Preliminary investigations of the Facility were conducted in 1984, with additional assessments undertaken in 1989 and in the 1990s. A total of 37 monitoring wells and piezometers were installed at the Facility.

Geology/Hydrogeology. The regional geology typically consists of marine sands, overlying Pleistocene formations of sands interbedded with coquina (shell fragments) and marl (Anastasia and Caloosahatchee). A shallow semi-confined aquifer (Tamiami) exists below, composed of limestone, marl, sands, and clays. Underlying these units is the Hawthorne group comprising the regional confining unit as well as a limestone aquifer, with the regional Ocala limestone aquifer present to a depth of 1500 ft below mean sea level (bmsl).

Locally, the shell material and fine to coarse-grained sand is present beneath the site from the surface to depths of 35 below ground surface (bgs). A decreased grain size correlates to an increase in silt and clay between 35 and 50 ft bgs, with shell material still present. A continuous 9-ft thick clay unit is present between depths of 49 and 51 ft bgs across the borings drilled at the Facility and is considered a significant confining unit (Parsons, 1999a).

The effective porosity of the unconsolidated sand material was estimated to be 25% (Domenico and Schwartz, 1990). Soil testing indicated an organic carbon fraction of 0.00455 within shallow aquifer material, with an estimated bulk density of 1.72 kg/L Parsons (1999a).

Groundwater is generally expected to discharge to the surface water (Parsons, 1999a). Groundwater elevations across the site were measured a total of 7 times between December 1995 and June 1996, and then again in September 1996 and March 1998 (Parsons, 1999a). Additional measurements were conducted between 2000 and 2002 (BEM, 2002). September 1996 data indicated a vertical difference of 0.8 ft in water levels across the site. Groundwater gradients and the location of the groundwater divide are expected to vary, based on the seasonal fluctuations of the groundwater elevations (Parsons 1999a). The maximum horizontal hydraulic gradient across the northern plume area at the site in 1996 is 0.00059 ft/ft, with flow in a north/northeast direction in the shallow, intermediate, and deeper zones. Flow direction varied in 2002 with a more predominant focus toward the northwest (BEM, 2002).

Vertical upward gradients observed at the Facility indicate minimal potential for downward movement of contaminants to deep aquifers (Parsons, 1999a). Rising head slug tests were performed for a total of 5 nested wells at 2 locations. Based on the variable conductivities beneath the site, 2 vertical zones were identified during the assessment work (Parsons, 1999a). Zone 1 consists of a 15 ft thick shallow saturated zone with hydraulic conductivity values between 30 to 300 ft/d. Zone 2 represents the deeper zone, with a thickness of 35 ft and a conductivity range of 0.3 to 30 ft/d.

Using the horizontal gradient proximate to the plume area (0.00059 ft/ft), a hydraulic conductivity value of 30 ft/d, and an assumed porosity of 25%, the horizontal groundwater flow velocity is calculated to be approximately 26 ft/yr.

Contaminant Plume Assessment. Although TCE concentrations in the source area increased up to 1998, the aerial extent of the plume did not increase and reductive dechlorination appeared to be controlling further plume migration (Parsons, 1999a). Tables 3a and 3b provide the observed concentration data for 1996 and 2001, respectively. The first available data set from 1996 had a maximum TCE concentration of 39.4 g/L in groundwater from well S09, screened at depths between 8 and 13 ft below ground surface (bgs).

The concentration profiles were plotted for TCE, DCE, VC, and ETH concentrations in 1996, 1998, and 2001 (Figures 9a through 9c), with resulting chlorinated solvent biodegradation half-lives ranging between 6 and 64 yrs (Table 4a). Bulk attenuation rates for all constituents between 1996 and 2001 ranged between 0.0005 and 0.09 yr^{-1}. Point attenuation at source wells S09 and S01 indicated decreasing trends for TCE (Figures 10a and b), with a maximum source decay rate of 0.5717 yr^{-1} for well S09 (Table 4b).

Biochlor Model Development. In the Biochlor model for this site, transport of contaminants northward from the source area was considered using a single zone reaction model. All model simulations were completed under the assumption that the fate and transport of the contaminants were under natural gradient conditions. Tables 5a and 5b list the deterministic and stochastic model variables that were used in developing the site model. TCE, cis-DCE, VC, and ETH concentrations were used for calibration and verification since concentrations of these constituents were still found at the site in 2001 at values that exceeded their respective cleanup criteria.

The average horizontal shallow groundwater gradient of 0.00059 ft/ft was utilized in the analytical modeling, and a conductivity value of 30 ft/d (0.013 cm/sec) was assumed in developing the Biochlor model for the site.

Based on the observed extent of the 70 ppb contour of DCE plume during 1996, the plume length was estimated to be 3000 feet. Utilizing the modified Xu and Eckstein (1995) equation [λ_x=0.82*3.28* (log (plume length/3.28))$^{2.446}$], a longitudinal dispersivity of approximately 38 ft was calculated. Ratios of transverse/longitudinal and vertical/longitudinal dispersivity were assumed to be 0.01 and 0.001, respectively. Using a bulk density of 1.72 kg/L and the organic carbon fraction of 0.00455 from site reports, an overall retardation coefficient of 1.2 was used in the modeling.

Biochlor Model Calibration, and Validation. As previously discussed, the purpose of the Biochlor modeling was to simulate the transport of contaminants at the site and predict the length of time for remediation using natural attenuation. Since the facility began operations in 1958, 38 yrs were used for model calibration (1958 to 1996) and 43 yrs were used for verification (1958 to 2001).

A 1,500 ft wide and 3,000 ft long model area was used. An initial modeling scenario assumed a continuous source (i.e., source decay rates were set to zero). The model, as might be expected, over predicted TCE concentrations, thus indicating the need to use source decay and/or biodegradation. Subsequent model development included both source decay and biodegradation of the dissolved constituents. The calibrated model deterministic variables are shown in Table 5a.

Uncertainty Analysis. The Monte Carlo model variables and their distributions are shown in Table 5b. The range for the seepage velocity values at the site was based on the variations observed in the site-specific data gathered for hydraulic conductivity, gradient, and porosity. The high end of the seepage velocity range was then calculated utilizing the highest values of hydraulic conductivity and gradient, coupled with the lowest porosity value expected. The low end of the range was similarly calculated with the lowest values of hydraulic conductivity and gradient, with the highest expected porosity. The range for longitudinal dispersion was calculated by assuming variations between 1% and 10% of the total plume length. A total of 2500 simulations were completed.

Figures 11, 12a and 12b present the stochastic and deterministic Biochlor model results for TCE, DCE, and VC as a function of distance from the source. The TCE concentrations (Figure 11) for the deterministic run fall within the lower range of their stochastic counterparts (minimum to 25th percentile), while the DCE and VC deterministic concentrations fall within the 75th to maximum percentiles.

Concentration distributions were then plotted for the calibration simulation (38 yrs), the verification simulation (43 yrs), and select points in time up to 142 yrs (Figures 13a through 13c). As can be seen in Figure 13a, the stochastic concentration distributions for TCE up to 142 yrs are still above the cleanup level for TCE at the source whereas the deterministic concentrations have attained cleanup. At 300 ft downgradient, however, the stochastic concentration distributions approach the TCE cleanup standard in the 142 yr window. DCE concentrations are shown in Figure 13c and indicate a relatively good agreement between the stochastic and deterministic results.

E.4.2 Shaw Air Force Base, Sumter, South Carolina

Biochlor simulations were completed for the Fire Training Area 1 (FTA-1) of the Operational Unit 4 (OU-4) at the Shaw Air Force Base (AFB) site in Sumter, South Carolina. Analytical model predictions were used to simulate the fate of dissolved chlorinated ethenes and ethanes, specifically 1,1,1-trichloroethane (TCA) at the site.

Analytical modeling conceptualized the site as a one layer, one-reaction zone model. Model results were compared to numerical results previously derived from fate and transport modeling conducted with MODFLOW (McDonald and Harbaugh, 1988) and MT3D (Zheng, 1990) by Parsons Engineering Science, Inc. (Parsons, 1999b). Numerical modeling scenarios of source decay indicated the potential for the 1,1,1-TCA plume to decrease to below 1 mg/L, within a time period of 98 years. Numerical modeling results assumed a reductive dechlorination rate of 2.01 yr^{-1} for the total chlorinated aliphatic hydrocarbons (CAHs).

Site Description. The entire Shaw AFB, located approximately 7 miles west of the City of Sumter, encompasses approximately 3570 acres surrounded by mostly rural and agricultural land (IT Corp, 2003). Since 1941, the Shaw AFB has acted as tactical air support and an international repair depot for engines, weapons and aircraft utilizing a combination of petroleum-based fuels, oils, lubricants, solvents, and other coatings (Parsons, 1999b). Fire training exercises were conducted at FTA-1 between 1941 and 1969 (Parsons, 1999b). Exercises at the site reportedly involved the use of jet fuel, waste oils, hydraulic fluids, solvents, contaminated mixed fuels, and napalm (Parsons, 1999b).

OU-4, located in the northeast area of the site, is approximately 14 acres in size and contains the former fire training area, which borders Long Branch Creek on the east side (Parsons, 1999b). Long Branch creek serves as a drainage area for the east-northeast AFB property line (Parsons, 1999b).

Initial site investigations were undertaken in 1983, and Phase I and II site activities were completed in 1997. Contaminants identified in the groundwater at the site during subsurface investigations consisted of fuel hydrocarbons and chlorinated solvents (ethenes and ethanes).

Geology/Hydrogeology. The Shaw AFB is reportedly underlain by Cretaceous bedrock to Quaternary alluvium. These recent deposits consist of fine to coarse-grained sands, interlayed by clays with bounding clays below at 90 ft bgs.

The local topography of the OU-4 area at the Shaw AFB is generally flat, with steeper slopes associated with Long Branch Creek. The elevation range across the OU-4 area is between 198 ft above mean sea level (amsl) to 216 ft (Parsons, 1999b).

The regional aquifer beneath the AFB is underlain by three aquifers: the Middendorf, the Black Creek, and the Shallow Aquifer system (Parsons, 1999b). Long Branch Creek is fed by groundwater in the area (Parsons, 1999b). Proximate to the area of OU-4, Long Branch Creek is 8 to 10 ft wide, 2 to 4 ft deep, with a flow rate of 1,000 gpm (Parsons. 1999b).

Depth to water values across the area are between the near surface at Long Branch Creek to 20 ft below ground surface (bgs). Groundwater elevation data for wells screened in the shallow zone (6 to 35 ft bgs) were reported from 1997 and 2002 (Parsons, 1999b and IT, 2003). Both data sets indicated a maximum vertical difference of 9.17 ft in water levels across the site.

The horizontal hydraulic gradient across the shallow aquifer at the site in 1997 ranged between 0.0048 and 0.011 ft/ft (average of 0.007 ft/ft), toward the east-northeast.

Contaminant transport is generally toward the east, with lobes toward the southeast and northeast.

Transmissivities were calculated in 1995 from a pump test conducted at TW-101 to yield results for wells TW-101, PZ-101, PZ-102, PZ-103, MW-115, and MW-117. Rising and falling head slug tests were also performed at MW-106 and MW-112 for the determination of hydraulic conductivities.

Using an average horizontal gradient of 0.007 ft/ft, an average hydraulic conductivity value of 17.6 ft/d (0.00621 cm/s), and an estimated effective porosity of 25%, the horizontal groundwater flow velocity is calculated to be approximately 180 ft/yr.

Contaminant Plume Assessment. The source of contaminants at the site is thought to be the fuel and materials utilized during training exercises in an unlined pit and potentially from the extinguishing agents themselves. Dumping of site materials in and around FTA-1 could account for a variety of the additional chemicals identified.

Detections of chlorinated solvents above applicable maximum contaminant levels (MCL) included 1,1,1-TCA, 1,1-DCA, 1,1-DCE, and VC. LNAPL or light non-aqueoues phase liquid accumulations were measured in wells MPB and MPC (Parsons, 1999b) indicating two separate source areas; one proximate to the former burn pit and one near a suspected drum storage area.

Bulk densities were estimated to be 1.72 kg/L assuming an aquifer grain density of 2.65 g/cc and a volumetric porosity of 35% (Parsons, 1999b). Soil testing provided an estimate of the fraction of organic carbon (f_{oc}) of 0.00024. The retardation factor for 1,1,1-TCA is expected to be 1.21, based on the chemical characteristics of the compound and the site organic carbon content (Parsons, 1999b).

Remediation Activities. Between 1993 and 1994, a remedial SVE pilot test, laboratory bench-scale test, and a bioventing pilot system were conducted at the site for evaluation of fuel hydrocarbon remediation. The bioventing system remained operational for at least five years. In 1996, a chemical oxidation and air stripping pilot test was also conducted. Current remedial activities at the site have consisted of the installations of a permeable reactive barrier wall in November of 1998. The barrier is composed of an iron filings trench.

Biochlor Model Development. Transport of contaminants in the shallow zone is considered as one layer. All model simulations were completed using the assumption that the fate and transport of the contaminants were under natural gradient conditions. Tables 5a and 5b lists the stochastic model variable distributions used as well as the discrete values used in model calibration. Modeling goals were to reduce 1,1,1-TCA and DCA to below 1.0 and 1.3 mg/L, respectively. Therefore, TCA and DCA concentrations were used for calibration and verification data. Verification data were limited due to the limited number of sampled wells.

The average horizontal shallow groundwater gradient of 0.007 ft/ft was utilized in the analytical modeling. The effective porosity of the unconsolidated sand material was estimated to be 25% (Domenico and Schwartz, 1990). A conductivity value of 17.6 ft/d (0.00621 cm/sec) was used (It is noted that the numerical model referred to earlier resulted in calibrated horizontal hydraulic conductivity values ranging between 18 and 81 ft/d (0.00621 and 0.03 cm/s)).

Based on the observed extent of the 5 ppb contour of DCA plume during 1997 (the furthest extent of contamination exceeding the appropriate MCL), the plume length was estimated to be 900 feet. Utilizing the modified Xu and Eckstein (1995) equation [α_x=0.82*3.28* (log (plume length/3.28))$^{2.446}$], a longitudinal dispersivity of 23.8 ft was calculated. The ratios of transverse/longitudinal and vertical/longitudinal dispersivity were assumed to be 0.01 and 0.001, respectively.

The source of contaminants at the site as mentioned previously was thought to be predominately TCA. A first-order biodegradation rate for the chlorinated ethanes of 0.9 yr^{-1} was calibrated during the numerical modeling in the near source and plume core area (Parsons, 1999b).

In this modeling study, the concentration profiles along the plume centerline were plotted for TCA, DCA, PCE, TCE, DCE, and VC concentrations in 1997 (Figure 14). First-order biological decay rate constants were calculated by utilizing the Buscheck and Alcantar (1995) method (Table 4a), based on a seepage velocity of 180 ft/yr. Based on the higher velocities expected at the site, the biotransformation rates initially assumed for TCA and DCA for the one-reaction zone Biochlor model were 3.388 and 0.357 yr^{-1}, respectively. These values were adjusted by trial and error during the calibration process.

Plume centerline concentration data from 1997 and 2002 were used in the calibration and validation process (Tables 3a and 3b).

Source concentrations indicated an overall decreasing trend in the data (Figures 15 a and b). An overall source decay rate of 4 x 10^{-4} yr^{-1} was calculated for TCA when comparing recent field data to an initial source concentration of 950 mg/L (TCA water solubility) assuming a starting year of 1941. Based on the source concentrations observed from the field data alone, however, an initial TCA source decay rate of 0.0086 yr^{-1} was calculated (Table 4b).

Biochlor Model Calibration and Validation. The starting date used for the simulation was 1941. A 56-year time period was used for calibrating the model and a 61-year time period was utilized for model verification. However, the limited data set in 2002 (Table 3b) prohibited model verification. The size of the modeled area was 1,440 ft in width and 1,600 ft in length.

A continuous source was initially modeled at the site, and the simulation was first run assuming no biodegradation was occurring. The model over predicted TCA concentrations, indicating the need to simulate the two processes (source decay and biodegradation). First order decay rate constants were then assumed and fitting the TCA biodegradation rate constant and the source zone concentration data allowed the model to be calibrated. Continued model calibration was achieved by altering the DCA decay rate coefficients. CA was not calibrated since no data for the constituent were reported for the selected wells.

Based on the overall concentration trends, the site data were modeled using a decaying source and an overall source decay rate constant of 0.065 yr^{-1} was used.

Uncertainty Analysis. The range of values utilized for each parameter in the Monte Carlo analysis is shown in Table 5b. A total of 2500 simulations were completed using these distributions. Concentration forecasts were obtained for TCA and DCA with biodegradation, as well as the simulations assuming no biodegradation, at six locations along the centerline, downgradient of the source (0, 160, 320, 480, 640, and 800 ft). Figures 16a and 16b illustrate the results from the analysis for TCA and DCA. The data in both figures demonstrate that the deterministic model run at 56 years had higher predicted centerline concentrations than the

25th and 75th percentile concentration profiles. Again, this is due to the use of a range of biodegradation rate constants in the stochastic model.

The deterministic BIOCHLOR modeling indicated that 106 years would be required for concentrations of TCA and DCA to decrease to less than 1 and 1.3 ppm, respectively, across the entire site. The stochastic model predictions at 106 yrs (Figures 17a and 17b) indicate that the modeled concentration range near the source is much lower than the MCL suggesting a shorter cleanup time. Similarly, the modeled concentrations at 320 ft downgradient of the source are also lower than the MCL.

E.4.3 Tinker Air Force Base, Oklahoma City, Oklahoma,

Biochlor simulation runs were completed with the data provided for the Fire Training Area 2 (FTA-2) at the Tinker Air Force Base (AFB) site in Oklahoma City, Oklahoma. Analytical model predictions were used to simulate the fate of dissolved tetrachloroethylene (PCE), trichloroethylene (TCE), cis-dichoroethylene (cis-DCE), vinyl chloride (VC), and ethene (ETH) at the site.

Analytical modeling conceptualized the site using a one layer, one-reaction zone model. Model results were compared to numerical results previously derived from fate and transport modeling conducted with MODFLOW (McDonald and Harbaugh, 1988) and MT3D (Zheng, 1990) by Parsons, engineering Science, Inc. (1999c). Numerical modeling included three scenarios of source decay and source removal, and indicated the potential for the TCE plume to migrate 1000 ft beyond the 1997 location, within a time period of 35 years. The numerical modeling results also indicated that TCE concentrations would attenuate to below the MCL within 100 years (Parsons, 1999c).

Site Description. The entire Tinker Air Force Base encompasses approximately 5,000 acres in the southern area of Oklahoma City. Since 1941, the Tinker AFB has acted as a domestic air depot and an international repair depot for engines, weapons and aircraft (Parsons, 1999c).

The fire training and exercise area 2 (FTA-2) was an unlined pit area located in the south-central portion of the AFB, south of the main northwest/southeast runway at the Base. Fire training exercises commenced in 1962 and utilized jet fuel sprayed on top of water in the pit. Dumping of site waste materials such as solvents, fuels and other liquids was also thought to have occurred in and around FTA-2.

Initial Phase I activities completed in 1981 indicated the potential for contamination in the area of FTA-2. Subsurface soil investigations commenced in 1987, with monitoring well installation first occurring in 1993 and 1995. Contaminants identified in the groundwater at the site during subsurface investigations in 1997 consisted of low concentrations of fuel hydrocarbons and chlorinated solvents. Surface water and soil borings were also completed as part of the investigations in 1997. A total of 30 monitoring wells and piezometers were installed for assessment of the subsurface at FTA-2, with 26 locations utilized for assessment activities. No remedial activities have been completed at the site (Parsons, 1999c).

Geology/Hydrogeology. The local topography of the Tinker AFB is generally flat, with a total elevation difference across the site of 130 ft. Within the area of FTA-2, the relief changes are minimal, approximately 10 ft downward toward the southwest (Parsons, 1999c). Surface drainage is locally toward the southeast, to an arm of Chutcho Creek.

The Tinker AFB is underlain by the Hennessay Group, comprised of silty clay and clayey silt. The Garber Sandstone underlies the units and comprises fine-grained sands with silt and clay lenses. The saturated material at the site consists of an upper saturated zone (USZ) overlying a lower saturated zone (LSZ), separated by a regional clay-silt aquitard. These units are considered to be within the upper third of the Garber-Wellington aquifer at depths less than 200 ft bgs (Parsons, 1999c). The USZ can be further discretized into two units, an upper and lower sand interval.

Groundwater elevation data for wells screened in the USZ (10 to 50 ft bgs) and the LSZ (53 to 82 ft bgs) were reported from 1997 and 1999 (Parsons, 1999c). Both data sets indicated a maximum vertical difference of 5.89 ft across the site.

The horizontal hydraulic gradient across the USZ at the site in 1997 ranged between 0.003 to 0.01 ft/ft, toward the west-southwest. Slug tests were performed at a total of seven wells screened in the USZ. Calculated horizontal hydraulic conductivities ranged between 6.5 and 28 ft/d for the upper sand and 0.9 to 44 ft/d for the lower sand USZ unit.

Using an average horizontal gradient of 0.006 ft/ft, an average hydraulic conductivity value of 15 ft/d (0.00529 cm/s), and an estimated effective porosity of 20%, the horizontal groundwater flow velocity is calculated to be approximately 164 ft/yr in the USZ.

Contaminant Plume Assessment. The source of contamination at the site was thought to be from the fuel utilized during training exercises and potentially from the extinguishing agents themselves. Dumping of site materials in and around FTA-2 could account for a variety of the additional chemicals identified.

Detections of chlorinated solvents above applicable maximum contaminant levels (MCL) included benzene, PCE, TCE, cis-DCE, 1,1-DCE, VC, 1,2-DCA, CB, 1,2-DCB, and 1,4-DCB in the USZ and TCE in the LSZ. Contaminants identified in the groundwater at the site during subsurface investigations consist of low concentrations of fuel hydrocarbons (less than 7 ppb) in the USZ and chlorinated solvents (maximum of 9,440 ppb TCE and 1,200 ppb cis-DCE from an USZ upper sand well located 75 ft upgradient of FTA-2). No direct evidence of a residual non-aqueous phase liquid was found during site assessment work (Parsons, 1999c).

Groundwater that exceeded the appropriate criteria for PCE (5 ppb) was collected from locations 100 to 200 ft upgradient (east and north) of FTA-2, in the USZ. TCE concentrations exceeding the 5 ppb MCL were collected at 11 USZ locations and 1 LSZ location across the area in 1997. Cis-DCE concentrations above the applicable MCL (70 ppb) were measured in locations coincident with the TCE occurrences in the USZ. Higher concentrations were also measured in downgradient locations in the lower sand of the USZ, indicating the potential for contamination by downward vertical migration (Parsons, 1999c). Low trans to cis-DCE ratios indicated that the source of the DCE was probably due to reductive dechlorination from TCE. One sample for 1,1-DCE, VC, Chlorobenzene, and 1,2-DCB exceeded the 7 ppb, 2 ppb, 100 ppb and 600 ppb MCL, respectively in the USZ. Additionally, groundwater samples with concentrations exceeding the MCL of 5 ppb for 1,2-DCA were identified at two USZ locations.

Bulk densities were estimated to be 1.65 kg/L (Parsons, 1999c), with effective porosities assumed at 20% for the numerical modeling (Parsons, 1999c). Soil testing indicated total organic carbon (TOC) values between 63.2% and 96.9%, with an organic carbon fraction average of 0.00813 within the USZ.

Biochlor Model Development. Transport of contaminants in the USZ was considered as one layer. All model simulations were completed under the assumption that the fate and transport of the contaminants were under natural gradient conditions. Tables 5a and 5b present the deterministic and Monte Carlo model input. PCE, TCE, cis-DCE, and VC concentrations were used for calibration and verification (Tables 3a and 3b).

The higher concentrations of chlorinated solvents measured at the site were measured in the shallow zone. Thus, the average horizontal shallow groundwater gradient of 0.006 ft/ft was utilized in the analytical modeling. The effective porosity of the unconsolidated sand material was assumed to be 25% (Domenico and Schwartz, 1990). A conductivity value of 15 ft/d (0.00529 cm/sec) was used in the analytical model.

Based on the observed extent of the 5 ppb contour of TCE plume during 1997, the plume length was estimated to be 1,600 feet. Utilizing the modified Xu and Eckstein (1995) equation [α_x=0.82*3.28* (log (plume length/3.28))$^{2.446}$], a longitudinal dispersivity of 30.2 ft was calculated. The ratios of transverse/longitudinal and vertical/longitudinal dispersivity were assumed to be 0.01 and 0.001, respectively (ASTM, 1995). A retardation factor of 1.9 was used.

The source of contaminants at the site was assumed to be predominately TCE (even though select locations measured low PCE concentrations of < 6 ppb). First-order biological decay rates for TCE of 0.1241 yr^{-1} were calibrated during the numerical modeling in the near source and plume core area (Parsons, 1999c). Decay rates calibrated in the numerical modeling for all three layers across the site ranged between 0.01095 and 0.1241 yr^{-1}.

The concentration profiles along the plume centerline were plotted for PCE, TCE, DCE, and VC concentrations in 1997 and 1999 (Figures 18 and 19). First-order biological decay rate constants were calculated by utilizing the Buscheck and Alcantar (1995) method (Table 4a), based on a seepage velocity of 131.4 ft/yr. Based on the higher velocities expected at the site, the biotransformation rates initially assumed for TCE and DCE for the one-reaction zone Biochlor model were 0.430 and 0.414 yr^{-1}, respectively. These values were adjusted by trial and error during the calibration process.

Source concentrations indicate an overall decreasing trend in the data (Figure 20). An overall source decay rate of 0.146 yr^{-1} was calculated for TCE when comparing recent field data to an assumed initial source concentration of 1,100 mg/L (TCE water solubility) assuming the leak occurred 1962. Based on the decay observed from the field data shown in Figure 20, however, an initial TCE source decay rate of 0.04 yr^{-1} was estimated (Table 4b).

As previously discussed, the purpose of the BIOCHLOR modeling was to simulate the transport of contaminants at the site to predict the applicability of natural attenuation for the site. Model goals (similar to the numerical modeling conducted by Parsons in 1999, see Parsons 1999c) included evaluating the dissolved TCE plume and to predict the future extent and concentrations of TCE.

A start date of 1962 was assumed for the analytical modeling. A 35-year time period was used for calibrating the model and a 37-year time period was used for model verification. The size of the modeled area was 500 ft in width and 1,600 ft in length.

Biochlor Model Calibration and Validation. The model was first run assuming no biodegradation, with a time period of 35 years. The model over predicted TCE concentrations as would be expected. First order biological decay coefficients were then assumed (Table 4a) and fitting the TCE biodegradation rate constant and the source zone concentration data calibrated the model. Continued model calibration was achieved by sequentially altering the DCE and VC decay rate coefficients.

To predict plume stability as defined by the TCE 5 ppb concentrations, the model was run for 91 years from the initial date of contamination (1962). The decaying source scenario indicated that site TCE concentrations would decrease to below 5 ppb after a period of 91 years. Numerical modeling indicated, when assuming a 2% annual source decrease, that the plume would continue to migrate an additional 1,000 ft beyond its current location with concentrations greater than MCL for at least 35 years. Numerical modeling did not extrapolate beyond this time period so it was not possible to compare the 91 yr results to the numerical model. As with the other sites, all concentration profiles over-predict concentrations, when no biodegradation and/or source decay are assumed.

Uncertainty Analysis. A total of 2500 simulations were completed using the probability distributions provided for the select input parameters shown in Table 5b. Concentration forecasts were obtained for TCE, DCE, VC, and ETH with biological decay, as well as the simulations assuming no biodegradation (TCE no decay) at six locations along the centerline. All six locations were downgradient of the source at distances of 0, 160, 320, 480, 640, and 800 ft away from the source. Only one data point was available for PCE therefore, no uncertainty predictions were associated with PCE.

The results from the uncertainty analysis are shown in Figures 21 and 22. For the Tinker site, the deterministic model results were located within the 75th and the maximum Monte Carlo predicted concentrations. Additionally, the deterministic Biochlor modeling indicated that 91 years would be required for concentrations of TCE and DCE to decrease to below 5 and 70 ppb, respectively, across the entire site. Stochastic Modeling results, however, indicated that the median concentrations between 50 and 70 yrs after the release would attenuate to below the MCL for TCE at the source (Figure 23).

E.4.4 F.E. Warren Air Force Base, Cheyenne, Wyoming

Biochlor simulations were completed with the data provided from Landfill Area 3 at the F.E. Warren Air Force Base (AFB) site using a one-reaction zone, one-layer model. Analytical model predictions were used to simulate the fate of dissolved trichloroethylene (TCE), cis-dichoroethylene (cis-DCE), vinyl chloride (VC), and ethene (ETH) at the site.

Model results were compared to numerical results derived from a supplemental monitored natural attenuation groundwater modeling study using MODFLOW and MT3D, completed by URS Corporation (URS, 2002 and 2003). The numerical modeling indicated that approximately 50 years (92 years from emplacement) would be required for TCE concentrations to be reduced below 5 ppb across the site.

Site Description. The entire Warren AFB encompasses approximately 5,900 acres in the western portion of the City of Cheyenne, Wyoming. The Warren AFB (Base) is bordered by agricultural, residential, commercial, and rural areas and has operated as a military installation since the late 1800s. The study area in question at the AFB comprises LF-03, an area approximately 5 acres in size (URS, 2003).

The landfill is located in the southeast portion of the base, between military housing and civilian housing in the City of Cheyenne. Two additional landfills (LF-2C and LF-4A) are located directly north-northeast of LF-03. LF-03 operated from the mid 1950’s through to the late 1960’s (USAF, 2001). All Base refuse was disposed at LF-03 during its operation, with the landfill historically receiving domestic solid waste, waste oils and solvents, battery acid and other waste types. Data collected during previous investigations also suggested that refuse burning occurred at LF-03 (Parsons, 1999d).

Preliminary investigations of the areas adjacent to the landfill were conducted in the mid 1980s, when the landfill was identified as a potential source to human health problems. In 1987, initial groundwater sampling in the area of LF-03 occurred with the installation of three wells. Three additional wells were installed in 1988. In February of 1990, the AFB was placed on the EPA's National Priorities List (NPL) thus bringing the site under the guidelines of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). A 1991 report indicated that LF-03 was the source of the dissolved TCE plume and the other chlorinated solvents and contaminants found in both soil and groundwater in the area.

Point sources from spills, subsequent leaching through refuse material and soil, and dissolution from NAPL sources are thought to have produced the chlorinated solvent plumes at the site. A full-scale groundwater investigation occurred during 1993/94 with the installation of a total of 49 temporary and 26 permanent groundwater wells (Parsons, 1999d). Assessment of the potential for vertical migration of the plume was addressed in 1995 with the installation of nested wells. During these investigations, PCE and TCE were also detected in groundwater off-site to the southeast, underlying the civilian residential area of Nob Hill. Seven additional assessment wells were completed in both the shallow and deeper saturated zones in 1999.

In summary, a total of 70 monitoring wells were sampled for chlorinated solvent constituents between 1987 and 2002. Concurrent to and following the removal of the source area, a total of 24 wells were sampled for both TCE and cis-DCE during 2000, with an additional 5 wells resampled in 2002.

Geology/Hydrogeology. The local topography of the area slopes toward the east-northeast. The Base is reportedly underlain by Quaternary deposits (between 5 to 20 ft) and by the Tertiary-age Ogallala Formation. The Quaternary deposits beneath the area of LF-03 consist of fine-grained material, mainly clay and silt, overlying the interbedded sand, gravel, and cobbles of the fluvial Ogallala formation. The Ogallala is comprised of a heterogeneous sequence of coarse-grained sand and gravel in the lower portion grading upward into fine clay, silt, and sand (NPGD, 2004).

The effective porosity of the unconsolidated material was estimated to be 30% (Domenico and Schwartz, 1990). Soil testing in 1999 indicated an organic carbon fraction that ranged between 0.00018 and 0.00038 within the fine sand to silt material, with an estimated bulk density of 1.65 kg/L.

Groundwater elevations across the site varied from 6080 ft above mean sea level (amsl) in the northeast, to 6137 ft amsl in the southeast. Depth to water across the site ranges between 1.6 ft bgs to 40 ft bgs. On-site investigations did not identify any confining units within the Ogallala Formation at the site. Groundwater elevations were available from select wells for the 1993 and 1999 data sets. Hydraulic gradients varied between an average of 0.01 ft/ft upgradient of the source area to an average value of 0.046 ft/ft observed in the area proximate to the source (URS, 2003). The average horizontal hydraulic gradient across the plume area at the site is 0.026 ft/ft, with flow in a northeasterly direction. Based on the 1993 and 1999 data sets, the maximum groundwater elevation fluctuation was found to be approximately 4.6 ft.

Vertical gradient testing (Parsons, 1999d and URS, 2003) at nested wells from four separate locations in the area of the landfill indicated that there was a local recharge area proximate to the landfill, with the primary discharge area located at Crow Creek, located approximately 2000 ft east-northeast and downgradient of the source area at LF-03. Vertical gradients ranged between 0.029 and 0.214 ft/ft, indicating that vertical contaminant transport plays a role at the site.

In 1995, a total of 19 slug tests were performed from a total of seven wells screened across intervals between 22 and 50 ft bgs, with multiple tests conducted at select wells. Four of the wells were screened across depths greater than 40 ft. An average hydraulic conductivity value was calculated at each well location where several tests were conducted. Average hydraulic conductivity values from individual wells range between 0.03 ft/d, at an average depth of 37 ft bgs from locations southeast of the landfill to 4.46 ft/d at an average depth of 34 ft bgs from a location proximate to the source area of the plume. A geometric mean for the hydraulic conductivity of 0.19 ft/d was calculated from all locations.

During September to November in 2001, two 48-hour pump tests were conducted in two newly installed test wells to serve as a pilot test for a full-scale groundwater extraction system. To further define the uncertainties resulting from the pump tests, an additional 11 short-term pump tests were completed during April and May 2002 (URS, 2003). Proximate to the source area, the hydraulic conductivity was calculated to be equal or greater than 20 ft/d (as high as 92 ft/d at MW-208), while in locations downgradient of the source, the conductivities generally decreased to 1 ft/d or less (URS, 2003).

Based on the heterogeneous nature of the permeability across the site, 3 vertical zones were initially identified (URS, 2002). Later studies, however, partitioned the subsurface into two vertical zones (URS, 2003). The upper shallow permeable zone consists of a saturated silty sand, found from the surface to a depth of 15 ft bgs in the area proximate to the source. The intermediate/deep zone consists of silty sand interbedded with lenses of sandstone and claystone underlain by sandstone, found between depths of 25 to 50 ft bgs in the area downgradient of the source (URS, 2003). Based on the slope of the two zones, the plume was partitioned into a shallow permeable, high yield zone proximate to the source area at the site and into a second less permeable and steeper hydraulic gradient zone located downgradient of the source (URS, 2003).

Although a horizontal seepage velocity of 3 ft/yr was previously determined, this value was considered low for the subsurface conditions present at the site. The following hydrogeologic parameters were derived from the subsurface area proximate to the plume and source: a horizontal gradient of 0.012 ft/ft and a hydraulic conductivity value of 4.45 ft/d (0.00157 cm/s). The conductivity value was obtained from testing completed at well PES-1S, considered to be the well most representative of the plume's vertical and horizontal location. Therefore, using an assumed porosity of 30%, an estimated value of 65 ft/yr was determined for the seepage velocity at the site.

Remediation Activities. In March and April of 2000, the contents of LF-03 were excavated and transported to the waste co-location area of the Warren AFB (USAF, 2001). Approximately 120,000 yd^3 of material was removed, to a maximum depth between 20 and 25 ft below ground surface (bgs). Approximately 50% of the material removed was soil, along with construction debris and domestic waste material. Pump testing in 2001 indicated that a groundwater extraction system was not feasible since full-scale capture of the plume could not be achieved, in part due to the low permeability conditions at the site.

Contaminant Plume Assessment. A total of 34 wells were analyzed for tetrachloroethylene (PCE), trichloroethylene (TCE), 1,1-dichloroethene (1,1-DCE), cis-1,2-dichloroethylene (cis-DCE), trans-1,2-dichloroethylene (trans-DCE), and vinyl chloride

(VC), as well as benzene, ethylbenzene, toluene, and xylenes (BTEX) components during 1993 and 1999. Additional analyses for methyl-tert-butyl ether (MTBE) were conducted in 1999. A total of 24 wells and 5 wells were sampled for TCE and cis-DCE in 2000 and 2002, respectively. No evidence of non-aqueous phase liquid (NAPL) was reported during any of the site investigations.

Detectable contaminants included PCE, TCE, the three isomers of DCE (mainly cis-DCE), and vinyl chloride (VC). The TCE plume, as defined by the 5 ppb contour has slightly decreased in extent between 1993 and 1999, while the plume size has generally remained the same or stable between 1999 and 2002. Concentrations analyzed from the 2000 and 2002 data were collected concurrent to and following the removal of the source area in March 2000.

As of 2000, the total number of wells with groundwater contaminant concentrations greater than their respective criteria is 11 wells for TCE (5 ppb) and 1 well for cis-DCE (70 ppb). The limited 2002 data indicates there are still 4 wells with concentrations greater than 5 ppb TCE. TCE concentrations from the source area increased (well 209), while wells proximate to the source (well 206) show a relative decrease over time.

A maximum TCE concentration of 113 ppb was measured in a well southeast of the landfill in 1993, with groundwater from the same area recording the 2000 maximum of 78.2 ppb from the intermediate/deep zone. A maximum cis-DCE concentration of 129 ppb was also measured in the well southeast of the landfill in 1999, with concentrations decreasing to 111 ppb in 2000. The areal distribution of the 1993, 1999, and 2000 TCE and cis-DCE plumes are coincident with each other and are located directly south of the landfill, centered around well 207/208. The longitudinal axis of each plume is parallel with the direction of groundwater flow. The maximum 1993 VC concentration of 51 ppb was measured in a well directly downgradient of the landfill. The 1993 VC plume was located in the landfill area, directly northwest of the TCE and cis-DCE plumes. No VC concentrations above the detection limit were subsequently measured.

Biochlor Model Devlopment. Transport of contaminants only from the area of the LF-03 is considered. All model simulations were completed using the assumption that the fate and transport of the contaminants were under natural gradient conditions. Tables 5a and 5b summarize the model variables and their distributions. Both TCE and cis-DCE concentrations were used for calibration and verification data since both concentrations are still found at the site in values that exceed their respective criteria.

The start date used for the emplacement of contaminants was 1960. Since four concentration data sets were available, a 33-year time period was used for calibrating the model and a 42-year time period (post source removal) was used for model verification.

Plume centerline concentrations over time are shown in Figure 24a and concentrations plots for selected wells over time are shown in Figures 24b and 24c. Although source well 209 indicated an increased TCE concentration in 1999, a slope of overall decreasing trend for the source area over time (wells HP-18 and 207 between 1993 and 2002) was determined to be around 0.009 yr^{-1}. Additionally, well 206 located near the source area showed a relative decrease over time of 0.73 yr^{-1}. Biodegradation half-lives between 2.7 and 5.3 yrs were calculated for TCE using the Buscheck and Alcantar (1995) equation assuming a seepage velocity of 66 ft/yr, a retardation coefficient of 1.19, and slopes of 0.002 and 0.004/yr as shown in Figure 24a.

Based on the observed extent of the 5 ppb contour of TCE plume during 1993, the plume length was estimated to be 1800 feet. Utilizing the modified Xu and Eckstein (1995) equation [α_x=0.82*3.28* (log (plume length/3.28))$^{2.446}$], a longitudinal dispersivity of 31.6 ft was calculated. Based on ASTM (1995) standards, the ratios of transverse/longitudinal and vertical/longitudinal dispersivity were assumed to be 0.33 and 0.05, respectively.

Using the estimated bulk density of 1.65 kg/L and a calculated average organic fraction of 0.00027, retardation coefficients were calculated for TCE, DCE, and VC. Linear equilibrium partitioning was assumed at the site, utilizing the default K_{oc} values from Biochlor. The resulting retardation coefficient used in the model during calibration was 1.19.

Biochlor Model Calibration and Validation. The simulation was first run assuming no biodegradation, with a time period of 33 years. The model over predicted TCE concentrations, indicating the need to incorporate biodegradation. First order biological decay coefficients were then assumed and the model was calibrated by fitting the TCE biodegradation rate constant and the source decay rate constant. Continued model calibration was achieved by sequentially altering the DCE and VC decay rate coefficients. Although the model predicted ethene concentrations, no ethene data was collected in 1993.

To predict plume stability as defined by the 5 ppb contour, the model was run for 92 (2052) years from the initial date of contamination (1960). Model runs indicated that given a constant source, the plume would become stable after 2009. The decaying source scenario indicated that site TCE concentrations would decrease to below 5 ppb after a period of 92 years, comparable to the predictions from the numerically derived model. All profiles over-predict concentrations, when no biodegradation is considered.

Although the numerical model was calibrated with the 2000 data and verified with the 2002 data, the analytical model was calibrated with the 1993 data and verified utilizing the 2002 data. The analytical modeling indicates that without active groundwater treatment, the TCE plume would not reach desired concentrations within a suitable time frame. Results from both the analytical and numerical modeling also indicate that migration of TCE to Crow Creek (2000 ft downgradient) would not occur, above concentrations of 1 ppb.

Predictions from both models to 2052 (92 years from emplacement) indicated that both analytically and numerically derived model concentrations would be below 5 ppb. Only TCE decay coefficients were obtained for the numerical modeling. The TCE decay coefficient obtained for the analytical decay model (0.173/yr) are below expected values (0.292 to 1.825/yr), but are within the ranges obtained for the numerical modeling (0.04 to 0.495/yr) estimated for locations across the site.

Uncertainty Analysis. A total of 2,500 simulations were completed for the probability distributions provided for the select input parameters. Concentration forecasts were obtained for TCE, DCE, VC, and ETH with biological decay, as well as the simulations assuming no decay (TCE - no decay), at six locations along the centerline, downgradient of the source (0, 250, 500, 750, 1000, and 1250 ft).

Figures 25a, b, and c present the deterministic BIOCHLOR model results, as compared to the 25th, and 75th percentiles of the stochastic Monte Carlo simulations. The deterministic run is based on a calibrated source decay rate and the stochastic BIOCHLOR simulations have a calculated source decay. The TCE values (Figure 25a) for the deterministic simulations along the plume centerline fall outside the 75th percentile range given by the stochastic simulation. This is similar to an evaluation of the DCE simulations (Figure 25b).

Source TCE concentration distributions were plotted for the calibration year (33 years), the verification year (42 yrs), and additional years including the predictive simulation year (92 years) (Figure 26). The deterministic predicted concentration value for the 33-year simulation lies above the maximum stochastic value, and fals between the 75th percentile and the maximum value for all other stochastic models. The 25th to 75th percentile range for the stochastic model is below the TCE MCL at the verification year. The overall range of the concentration distributions increased over time. Deterministic and stochastic model predications at a distance 1000 ft downgradient of the stouce (Figure 27) indicate that the deterministic results fall between the 75th percentile and the maximum value of the stochastic models.

E.4.5 Ashumet Valley, Massachusetts Military Reservation, MA

Site Description. The Ashumet Valley Axial (AVA) plume is located within the Massachusetts Military Reservation (MMR) on Cape Cod in eastern Massachusetts. The Ashumet Valley extends south of the MMR, following Sandwich road between Ashumet Pond and Coonamessett Pond. The primary constituents of concern in the valley are tetrachloroethylene (PCE), trichloroethylene (TCE), and cis-dichloroethylene (cis-DCE) emanating from the former firefighter training area (FTA-1) and the former sewage treatment plant (STP). The fire fighting area, with an areal extent of 3 acres, was in operation between 1958 and 1985, while the treatment plant, with an areal extent of 80 acres, operated between 1936 and 1995.

The STP commenced operations in 1936 and treated sanitary sewer wastewater (which reportedly contained solvent waste) utilizing both primary and secondary units, infiltration beds and sludge drying beds (CH2M Hill, 2003). Dewatered sewage sludge or biosolids were spread across a wooded area and are thought to have been a source for solvent contamination (CH2M Hill, 2003). The FTA-1, located proximate to the southern boundary of the MMR, was host to between 6 and 16 training exercises a year (CH2M Hill, 2003). Fire training exercises were typically carried out in unlined pits and consisted of utilizing flammable liquids such as jet fuel, gasoline, diesel, waste oils, hydraulic fluids, solvents, and contaminated mixed fuels. A concrete pad was utilized for the training activities, but not until 1983.

Geology/Hydrogeology. The AVA plume is located with the Mashpee Pitted plain area. The Mashpee area comprises coarse-grained, outwash, unconsolidated material with an underlying basal till and/or lacustrine unit. No confining units are thought to be present and there is therefore no reported separation between the upper and lower aquifers.

Three separate aquifers were identified: the shallow zone comprised wells screened between 51 ft and -26 ft above mean sea level (amsl), the middle zone comprised wells between -23 ft and -63 ft amsl, and the deeper zone contained wells within the -53 ft to -156 ft amsl range. Depth to water values across the area are approximately 70 ft below ground surface (bgs), with the water table range between 50 ft amsl near the source areas to 20 ft amsl in the downgradient plume area. The surficial, unconfined groundwater unit has a total average thickness of 150 feet and is comprised of outwash (coarse-grained) materials.

The hydraulic gradient across the shallow aquifer at the site ranged between 0.001 and 0.002 ft/ft, with contaminant transport toward the south, south-west. A bulk hydraulic conductivity of 100 to 350 ft/d was estimated in previous studies (JEG, 1999).

Using an average horizontal gradient of 0.0017 ft/ft, an average hydraulic conductivity value of 225 ft/d (0.079 cm/s), and an estimated effective porosity of 30%, the horizontal groundwater flow velocity is calculated to be approximately 465 ft/yr.

Remediation Activities. Remediation at the site consisted of thermal soil treatment in the source area between 1995 and 2002 and in-situ groundwater extraction, treatment and infiltration commencing in November of 1999 to the present day. Prior to system start-up, the plume dimensions were 22,000 ft long, 2,600 ft wide, and 150 ft thick (CH2M Hill, 2003).

Contaminant Plume Assessment. Detections of solvents at dissolved concentrations exceeding the MCL included PCE, TCE, and cis-DCE. The groundwater monitoring network consists of 46, 43, and 31 wells, screened across three zones: shallow, middle and deep, respectively.

The concentration profiles along the plume centerline were plotted for PCE, TCE, and DCE in 1998, 1999, and 2003 (Figures 28a through c). The first-order biodegradation rates were calculated from Buscheck and Alcantar (1995), based on a seepage velocity of 465 ft/yr and a retardation coefficient of 1.28. The biodegradation rates (half-lives) calculated for PCE in 1999 and DCE in 1998 were 47.5 and 18.9 years, respectively (Table 4a). Increasing slopes were observed for all other calculations. Bulk attenuation rates of 0.015 and 0.036/yr were calculated for the PCE data from 1999 and the DCE data from 1998, respectively.

Source concentrations over time indicated an overall decreasing trend and point attenuation rates were calculated for source well 30MW0426B (Figure 28d and Table 4b). A source decay rate of 0.0006/yr was calculated for PCE assuming a hypothetical initial source concentration of 150 mg/L (PCE water solubility) in 1958, as compared to the value of 0.003/yr calculated for data between 1998 and 2003 (Table 4b).

Biochlor Model Development. The shallow zone was considered as one layer. All model simulations were completed using the assumption that the fate and transport of the contaminants were under natural gradient conditions, that is, non-pumping conditions prior to start-up of the remediation system. Tables 5a and 5b lists the parameters used in BIOCHLOR. Modeling goals were to reduce PCE to below 0.005 mg/L. Therefore, PCE and the associated daughter products in 1998 and 1999 were used for calibration and verification data (Tables 3a and 3b, respectively). A start date of 1958 was used for the emplacement of contaminants. A 40-year time period was used for calibrating the model and a 41-year time period was utilized for model verification.

The average horizontal shallow groundwater gradient of 0.0017 ft/ft was utilized in the analytical modeling. Analytical modeling parameters (porosity (30%), dispersivity, total organic carbon fraction (0.00038), and bulk density (1.68 kg/L)) were obtained from previous modeling studies (CH2M Hill, 2003). The average value for hydraulic conductivity of 225 ft/d (0.079 cm/sec) was used.

Based on the observed extent of the 5 ppb contour of PCE plume during 2003/2004 (the furthest extent of contamination exceeding the appropriate MCL), the plume length was estimated to be 14,000 feet. Utilizing the modified Xu and Eckstein (1995) equation, a longitudinal dispersivity of 71 ft was calculated. Based on the previous modeling studies (CH2M Hill, 2003), a transverse /longitudinal dispersivity ratio of 0.3 and a vertical/longitudinal dispersivity ratio of 0.03 were utilized. The size of the modeled area was 2,500 ft in width and 15,000 ft in length.

Biochlor Model Calibration and Validation. Both the source decay and the biodegradation rates were calibrated by fitting the model predicted source and centerline concentrations, respectively to the observed field data. Although PCE, TCE, and DCE were utilized as fitting parameters, field data above detection limits were limited for TCE and DCE. VC and ETH were not calibrated since no data for the constituents were reported for the selected wells.

To match the 1998 source data, an overall source decay value of 0.2/yr was calibrated to the model. The 1998 calibrated PCE and TCE biodegradation first order biodegradation rates (0.27 and 0.98/yr) were within the ranges reported for the 25th and 75th percentiles for all reported anaerobic field rates from Suarez and Rifai (1999), although the VC value was below the 25th percentile.

To predict plume stability as defined by the PCE 5 ppb concentrations, the model was run for 48 years from the initial date of contamination (1958). The decaying source scenario indicated that site TCE concentrations would decrease to below 5 ppb shortly after a period of 48 years.

Uncertainty Analysis. Select parameters were assigned probability distributions, based on the distribution types typically observed for the hydrogeologic and model input parameters (Tables 3a and 3b). The simulation time was fixed for each Monte Carlo run. The range for the seepage velocity at the site was based on the variations observed in the data gathered for hydraulic gradient.

A total of 2,500 simulations were completed for the probability distributions provided for the select input parameters. Concentration forecasts were obtained for PCE, TCE, and DCE with decay, as well as the simulations assuming no decay (TCE no decay), at six locations along the centerline, downgradient of the source (0, 1,500, 3,000, 4,500, 6,000, and 7,500 ft). Figures 29a through c present the uncertainty associated with the simulations for PCE, TCE, and DCE , respectively. All three constituents show deterministic values equivalent to the maximum stochastic distribution.

Concentration distributions were plotted for the calibration simulation (41 yrs), the verification simulation (42 yrs), and other yrs as shown in Figures 30a and b. The deterministic values for PCE at the source (Figure 30a) fall between the 75th percentile and the maximum stochastic distribution for all time periods. Further downgradient, however, deterministic values for PCE are higher than the maximum values for the stochastic distributions (Figure 30b).

E.4.6 Wurtsmith Air Force Base, MI

Site Description. The Wurtsmith AFB is located on the outskirts of Oscoda, Michigan, in northeast Michigan, west of Lake Huron and originally encompassed approximately 5,221 acres (USAF, 2003a). The Wurtsmith AFB operated between 1924 and 1993 and acted as an air support and maintenance facility utilizing a combination of petroleum-based fuels and solvents. Landfills 30/31 comprise a total of 101 acres located in the northern portion of the facility (Figure 4.16).

Landfill 30 operated between 1960 and 1973, receiving both domestic and industrial waste from base operations, in addition to solvent drums buried in trenches and underground tank trailers used for the disposal of fuels and solvents related to aircraft operations (USAF, 2003b). Additional reports indicate the direct disposal of waste TCE across the landfill area. The tank trailers were removed in the 1970's and approximately 3 feet of fill was placed across the area. Landfill 31 operated between 1973 and 1979, receiving sanitary waste in the western portion of the landfill and construction debris in the remaining portions (USAF, 2003b). The local topography of the northern portion of the Wurtsmith AFB is generally flat, with a gentle slope toward Van Etten Lake.

Remediation Activities. Air sparging activities commenced in March of 2002 in the area east of landfill 30 (downgradient edge), at depths of approximately 40 ft. Groundwater extraction and treatment was also initiated in March of 2002 at two wells located on the eastern boundary of the landfill area. The wells operate at approximately 30 gpm with a projected capture area of 110 ft. Treated groundwater was returned to the natural system by means of infiltration upgradient of the landfill area (USAF, 2003b).

Geology/Hydrogeology. The Wurtsmith AFB is reportedly underlain by unconsolidated Pleistocene glacial material including till and meltwater channel material, unconformably overlying Paleozoic sandstone and shale (Gillespie, 1990). Depth to water across the landfill area ranges between 7 and 9 feet. The surficial, unconfined groundwater unit has an average thickness of 65 feet and is comprised of medium to coarse-grained sands with some gravel. Groundwater elevation data were reported for 9 monitoring events between 1980 and 2003 (USAF, 2003b), with seasonal fluctuations in the 1 to 3 foot range (USAF, 2003a).

The horizontal hydraulic gradient across the shallow aquifer at the site ranged between 0.0032 and 0.00065 ft/ft (average of 0.005 ft/ft), toward the east-northeast. Contaminant transport is generally toward the northeast, with two distinct chlorinated solvent plumes evident from the landfill area. An average hydraulic conductivity of 140 ft/d was provided from previous studies (USAF, 2003a).

Using an average horizontal gradient of 0.005 ft/ft, an average hydraulic conductivity value of 140 ft/d (0.049 cm/s), and an estimated effective porosity of 30%, the horizontal groundwater flow velocity is calculated to be approximately 852 ft/yr.

Contaminant Plume Assessment. Detections of fuels and solvents at concentrations exceeding the MCL included benzene, ethylbenzene, toluene, xylenes, TCE, cis-DCE, and VC. The concentration profiles along the plume centerline were plotted for TCE in 1991 and TCE, DCE, and VC in 2001 (Figures 31a and b). The first-order biodegradation rates were calculated from Buscheck and Alcantar (1995), based on a seepage velocity of 852 ft/yr and a retardation coefficient of 1.74. The biodegradation rates (half-lives) calculated for TCE and DCE were 4.7 and 3.5 years, respectively, in 2001 (Table 4a). Average bulk attenuation rates of 1.4 and 0.2/yr were calculated for both TCE and DCE from the concentration profiles for the 1991 and 2001 data, respectively.

Source concentrations over time indicated an overall decreasing trend and point attenuation rates were calculated for source well H127S (Figure 32 and Table 4b). A source decay rate of 0.0005/yr was calculated for TCE assuming a hypothetical initial source concentration of 1,100 mg/L (TCE water solubility) in 1960 (Figure 32), as compared to the value of 0.019/yr calculated for data between 1991 and 2003 (Table 4b).

Biochlor Model Development. The shallow zone was considered as one layer. All model simulations were completed using the assumption that the fate and transport of the contaminants were under natural gradient conditions. Tables 5a and b list the parameters used in BIOCHLOR to model the site. The modeling goal was to estimate the time required to reduce TCE to below 0.005 mg/L, using natural attenuation. Therefore, TCE and the associated daughter products, in 1991and 2001, were used for calibration and verification data, respectively.

The modeled layer was assumed to have a one-reaction zone, from a biodegradation standpoint. A start date of 1960 was assumed for the source. This translates to a 31-year time period release, based on the beginning of the landfill activities, for calibrating the model and a 41-year time period for model verification. The size of the modeled area used was 1,500 ft in width and 3,000 ft in length. An overall decreasing trend in the TCE data at the source was observed, leading to the decaying source used for modeling.

The average horizontal shallow groundwater gradient of 0.005 ft/ft was utilized in the analytical modeling. The effective porosity of the unconsolidated sand and gravel material was assumed to be 30% (Domenico and Schwartz, 1990).

Using the observed extent of the 5 ppb contour of the TCE plume in 1991 (the furthest extent of contamination exceeding the appropriate MCL), the plume length was estimated to be 2,500 feet. Utilizing the modified Xu and Eckstein (1995) equation, a longitudinal dispersivity of approximately 36 ft was calculated. The ratios of transverse/longitudinal and vertical/longitudinal dispersivity were assumed to be 0.01 and 0.001, respectively (ASTM, 1995).

Model Calibration and Validation. Both the source decay and the biodegradation rates were calibrated by fitting the model predicted source and centerline concentrations, respectively to the observed field data. Because of limited field values, only TCE was used as the fitting parameter. The 1991 calibrated TCE biodegradation first order decay rate (3.3/yr) was between the 75th percentile and the maximum value reported for all anaerobic in-situ rates from Suarez and Rifai (1999). DCE and VC were not calibrated since no data for these constituents were reported for the selected wells. To match the 1991 source data, an overall source decay value of 0.228 1/yr was used in the calibrated model.

To predict plume stability as defined by the TCE 5 ppb concentrations, the model was run for 54 years from the initial date of contamination (1960). The decaying source scenario indicated that site TCE concentrations would decrease to below 5 ppb after a period of 54 years.

Uncertainty Analysis. Select parameters were assigned probability distributions, based on the distribution types typically observed for the hydrogeologic and model input parameters (Tables 5a and 5b). The simulation time was fixed for each Monte Carlo run. The minimum and maximum values that bound the lognormal distributions (seepage velocity, dispersion, bulk density, and source width) were based on the variations observed in the data gathered for site.

A total of 2,500 simulations were completed for the probability distributions provided for the select input parameters. Concentration forecasts were obtained for TCE and DCE with decay, as well as the simulations assuming no decay (TCE no decay), at six locations along the centerline, downgradient of the source (0, 300, 600, 900, 1,200, and 1,500 ft).

Figures 33a and b present the uncertainty associated with the BIOCHLOR simulations for TCE and DCE, respectively. Both the TCE and DCE deterministic values were significantly greater than the maximum stochastic values, indicating a much more conservative deterministic evaluation.

Concentration distributions were plotted for the calibration simulation (31 years), the predictive year (54 years), and select points (35, 40, 45, and 50 years) (Figures 34a and b). These simulations allow for a distribution to be obtained for the predictive concentrations for each time period. The deterministic values for TCE at the source (Figure 34a) again greatly exceed the maximum stochastic distributions, for all time periods. At a location 1,500 ft downgradient (Figure 34b), TCE deterministic values again greatly exceed the maximum values for the stochastic distributions. Stochastic results for both locations are similar in magnitude.

Deterministic BIOCHLOR modeling indicated that 54 years would be required for concentrations of TCE to decrease to less than 5 ppb across the entire site but stochastic distributions indicated that the MCL goal had already been achieved.

E.5 DISCUSSION AND ANALYSIS OF MODELING OF SIX SITES

The deterministic and stochastic modeling that was discussed for the six sites above relied on site data for model set-up and parameter estimation. Several observations were made regarding parameter estimation:

1. While concentration versus distance plots along the centerline were used to estimate biodegradation rates, these estimates had to be modified during the process of model calibration. For most sites, the calibrated biodegradation rates were higher than the calculated ones based on field data (Table 6). This is possibly due to the effects of a changing source over time and also possibly due to some of the remediation activities that were undertaken at the sites and that could not be modeled with Biochlor.
2. A similar observation was made for source decay for Warren, Tinker, Wurtsmith, and Ashumet, i.e., the modeled source decay rate constant was higher than the estimated rate from concentration versus time plots for source wells (Table 7). The modeled rate was based on an initial concentration equal to the solubility of the compound in question for the first year of facility operation and the concentration in the source area during the calibration year. These higher source decay rate constants result in shorter remediation times as would be expected.

These findings, particularly when combined with the sensitivity analysis of the Biochlor model presented earlier highlight the importance of source characterization and field-based estimates of biodegradation rates.

E.6 SUMMARY AND CONCLUSIONS

In this study, a Monte Carlo version of the Biochlor analytical model was developed and applied to a synthetic case study as well as to six sites in the US. Results indicated that the stochastic Biochlor model was most sensitive to velocity, longitudinal dispersion, and the fraction of organic carbon at the source. The model was most sensitive to velocity, longitudinal dispersion, fraction of organic carbon and the biodegradation rate constant at distances downgradient from the source. The stochastic model could not be used to evaluate the effects of the source decay rate constant on modeled concentrations since the decay rate constant was a calculated value in the stochastic model. This is a significant difference between the deterministic Biochlor and the stochastic Biochlor that potentially causes deterministic model results to fall between the 75th and maximum predicted values from the stochastic model. The predicted concentration distributions from the stochastic Biochlor model at the source are very sensitive to the hydrogeologic properties, in particular, the contaminant velocity (seepage velocity and retardation). Application of the stochastic model to the six sites confirmed the importance of the contaminant velocity, the biodegradation rate constant and the source decay rate constant for determining cleanup times for natural attenuation.

E.7 REFERENCES CITED

ASTM (American Society for Testing and Materials), 1995. “Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites.” ASTM, Philadelphia.

Aziz, C.E., Newell, C.J., Gonzales, J.R., Haas, P., Clement, T.P., and Sun, T. 2000a. “BIOCHLOR - Natural Attenuation Decision Support System.” User's Manual Version 1.0. Environmental Protection Agency, Washington, DC.

Aziz, C.E., Smith, A.P., and Newell, C.J. (2000b). "BIOCHLOR Chlorinated Solvent Plume Database." U.S. Air Force Center for Environmental Excellence (AFCEE), Brooks AFB, San Antonio, Texas.

BEM Systems, Inc., 2002. “Draft Final Corrective Measures Study (CMS) for Facility 1381, Solid Waste Management Unit C021 (SWMU C021) at Cape Canaveral Air Force Station (CCAS), Florida.” Prepared for U.S. Force Space Command (AF SPACECOM), Patrick Air Force Base, Florida and Air Force Center for Environmental Excellence (AFCEE), Brooks Sir Force Base, Texas.

Buscheck, T.E. and Alcantar, C.M., 1995. “Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation.” In, Proceedings of the 1995 Battelle International Conference on In-Situ and On Site Bioreclamation.

CH2M Hill. (2003). "Final Ashumet Valley Axial 2002 Annual System Performance and Ecological Impact Monitoring Report." Massachusetts Military Reservation.

Domenico, P.A. (1987). "An Analytical Model for Multidimensional Transport of a Decaying Contaminant Species." *Journal of Hydrology*, 91, 49-58.

Domenico P.A, and Schwartz, F.W., 1990. Physical and Chemical Hydrogeology. John Wiley and Sons, New York, New York.

Earth Tech Inc., 2000. “Final Report – Remedial Investigation for Zone C, F.E. Warren Air Force Base, Cheyenne, Wyoming.” Prepared for the Air Force Center for Environmental Excellence and 90 CES/CE F.E. Warren Air Force Base, Cheyenne, Wyoming.

Freeze, R. A. and J. A. Cherry, Groundwater, Prentice-Hall, Englewood Cliffs, NJ, 1979.

IT Corporation, 2003. “*Fourth Quarter 2002, Remedial Action Operation Report, Operable Unit 4 (SWMU 59) at Shaw Air Force Base, Sumter, South Carolina*”. Prepared for the US Army Corps of Engineers, January 28, 2003.

JEG (Jacobs Engineering Group Inc.). (1999). "Final Ashumet Valley Axial Wellfield Design Report." Massachusetts Military Reservation.

Newell, C.J., Hopkins, L.P., and Bedient, P.B. 1990. “A Hydrogeologic Database for Ground-Water Modeling.” *Groundwater*, 28 (5), p.703-714.

North Plains Groundwater District (NPGD) accessed February 11, 2004. http://www.npwd.org.

Parsons Engineering Science, Inc., 1999a. “Remediation by Natural Attenuation, Treatability Study for Facility 1381 (SWMU 21) at Cape Canaveral Air Station, Florida.” Prepared for the Air Force Center for Environmental Excellence, Technology Transfer Division, Brook Air Force Base, San Antonio, Texas and 45th Space Wing Facilities at Cape Canaveral Air Station, Florida..

Parsons Engineering Science Inc., 1999b. "*Final – Treatability Study in Support of Remediation by Natural Attenuation for Groundwater at OU-4 (Site FT-1) at Shaw Air Force Base (AFB), South Carolina*". Prepared for the AFCEE Technology Transfer Division and Shaw AFB, September 1999.

Parsons Engineering Science, Inc., 1999c. "Final Treatability Study in Support of Remediation by Natural Attenuation for Groundwater at Site FTA-2 at Tinker Air Force Base, Oklahoma." Prepared for the Air Force Center for Environmental Excellence, Technology Transfer Division, Brooks Air Force Base, San Antonio, Texas and Tinker Air Force Base, Oklahoma.

Parsons Engineering Science Inc., 1999d. "Treatability Study in Support of Monitored Natural Attenuation for Groundwater at Landfill 3 (Site LF-03), F.E. Warren Air Force Base, Cheyenne, Wyoming." Prepared for the Air Force Center for Environmental Excellence, San Antonio, Texas.

Suarez, M. P., and Rifai, H. S., 1999. "Biodegradation Rates for Fuel Hydrocarbons and Chlorinated Solvents in Groundwater." *Bioremediation Journal*, 3(4), p.337-362.

URS Corporation, 2002. "Supplemental Feasibility Study, Appendix A – Supplemental Monitored Natural Attenuation Groundwater Modeling, Zone C Groundwater" F.E. Warren Air Force Base, Wyoming. Prepared for 90 SW/EM F.E. Warren Air Force Base, Wyoming and the Air Force Center for Environmental Excellence, Brooks Air Force Base, Texas.

URS Corporation, 2003. "Final – Supplemental Feasibility Study, Zone C Groundwater" F.E. Warren Air Force Base, Wyoming. Prepared for 90 SW/EM F.E. Warren Air Force Base, Wyoming and the Air Force Center for Environmental Excellence, Brooks Air Force Base, Texas.

USAF (United States Air Force), 2001. "Final-Treatability Record of Decision for Zone C, Operable Unit 11, Landfill 3." Cheyenne, Wyoming.

USAF (United States Air Force). (2003a). "Performance-Based Environmental Restoration Program Assessment (Perma) of Landfills 30 and 31, Former Wurtsmith Air Force Base." Air Force Center for Environmental Excellence, Oscoda, Michigan.

USAF (United States Air Force). (2003b). "Conceptual Site Model, Site LF-30/31, Wurtsmith AFB." Air Force Real Property Agency, Oscoda, Michigan.

Xu, M., Eckstein, Y., 1995. "Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Field Scale." *Ground Water,* 33(6), p. 905.

Table 1. Model Inputs for Biochlor – Base Case

Input	**Value**
Hydraulic Conductivity	9.0 x 10^{-5} cm/sec
Hydraulic Gradient	0.05
Effective Porosity	0.2
Longitudinal Dispersivity (Alpha x)	50 ft
Transverse Dispersivity/ Longitudinal Dispersivity (Alpha y)/(Alpha x)	0.1
Vertical Dispersivity/ Longitudinal Dispersivity (Alpha z)/(Alpha x)	0.001
Soil Bulk Density	1.5 kg/L
Fraction Organic Carbon	0.001
Partition Coefficients	PCE = 426 L/kg TCE = 130 L/kg DCE = 125 L/kg VC = 30 L/kg ETH = 302 L/kg
Biodegradation 1st Order Decay Coefficients	0 day^{-1}
Simulation Time	100 years
Modeled Area Width	100 ft
Modeled Area Length	2500 ft
Source Thickness in Sat. Zone	5 ft
Source Concentrations	PCE = 100.0 mg/L TCE = 0 mg/L DCE = 0 mg/L VC = 0 mg/L ETH = 0 mg/L
Source Decay	0 day^{-1}

Table 2a: BIOCHLOR Stochastic Model Parameters
Synthetic Case Study

Property	Deterministic Value	Stochastic Distribution	Mean[a]	Standard Deviation	Minimum	Maximum	Comments
Seepage Velocity (ft/yr)	87.6	Lognormal	88	62	26	511	National Average Data (Newell et al., 1990)
Porosity	0.38	Lognormal	0.28	0.04	0.20	0.40	(Aziz et al., 2000b)
Dispersion - α_x (ft)	30.211	Lognormal	30	20	16	160	Based on 1% to 10% of plume length
Dispersion - α_y/α_x (ft)	0.33	Uniform	-	-	0.10	0.33	(ASTM, 1995)
Dispersion - α_z/α_x (ft)	0.05	Uniform	-	-	0	0.10	(Aziz et al., 2000a)
Soil Bulk Density (kg/L)	1.643	Lognormal	1.64	0.05	1.49	1.8	(Freeze and Cherry, 1979)
Fraction Organic Carbon	0.001	Uniform	-	-	0.002	0.020	(Aziz et al., 2000a)
Average Retardation Factor R	1.56	Formula	-	-	-	-	Calculated by BIOCHLOR (Aziz et al., 2000a)
TCE to DCE Biodegradation	0.657	Uniform	-	-	0.237	1.205	25th and 75th values from anaerobic, in-situ studies (Suarez and Rifai, 1999)
DCE to VC Biodegradation	0.621	Uniform	-	-	0.292	1.643	25th and 75th values for cis-DCE from anaerobic, in-situ studies (Suarez and Rifai, 1999)
VC to ETH Biodegradation	0.584	Uniform	-	-	0.292	1.278	25th and 75th values from anaerobic, in-situ studies (Suarez and Rifai, 1999)
TCA to DCA Biodegradation	6.57	Uniform	-	-	0.438	15.70	25th and 75th values from anaerobic, in-situ studies (Suarez and Rifai, 1999)
DCA to CA Biodegradation	0.164	Uniform	-	-	0.069	0.475	25th and 75th values from anaerobic, in-situ studies (Suarez and Rifai, 1999)
CA to Ethane Biodegradation	18.25	Uniform	-	-	11.32	73.0	25th and 75th values from anaerobic, in-situ studies (Suarez and Rifai, 1999)
Simulation Time (yr)	1,10, 25,100	Fixed	-	-	-	-	Variable across simulations
Source Thickness (ft)	20	Uniform	-	-	1	50	(Aziz et al., 2000a)
Source Width (ft)	410	Lognormal	410	162	120	700	(Aziz et al., 2000a)
Source Decay (1/yr)	0.3712	Formula/Uniform	-	-	0	0.12	Calculated by BIOCHLOR (Aziz et al., 2000a)
TCE Source Concentration (mg/L)	1100	Fixed	1100	-	11	1100	1% to 100% of TCE Solubility

[a] Lognormal Distributions

Table 2b: BIOCHLOR Stochastic Input Parameter Distributions: Seepage Velocity (Vs), Fraction of Organic Carbon (foc), and Soil Bulk Density ρ_b)

Synthetic Case Study

Hydrogeologic Environment	Vs Mean (ft/yr) [a]	Vs Standard Deviation [a]	Vs Minimum (ft/yr) [a]	Vs Maximum (ft/yr) [a]	foc Minimum	foc Maximum	ρ_b Minimum	ρ_b Maximum
National average	87.6	1.2	0.256	36500	-	-	-	-
Metamorphic and igneous	51	60	2	547.0	0.00026	0.001	1.21	2.69
Bedded sedimentary rock	40	220	3	2187	0.00026	0.001	1.54	3.17
Till over sedimentary rock	40	2.6	32	49.00	0.0017	0.0019	1.61	2.12
Sand and gravel	uniform		1	146000	0.00017	0.00125	1.37	1.81
River valley and flood plains with overbank deposits	128	500	7	5471	0.00053	0.0012	1.27	1.93
River valleys and floodplains without overbank deposits	438	425	22	3650	0.00053	0.0012	1.27	1.93
Alluvial basins, valleys and fans	230	365	3	3648	0.00017	0.0057	1.01	1.81
Outwash	511	450	32	3651	0.00017	0.00125	1.37	1.81
Till and till over outwash	292	950	15	10814	0.0017	0.0019	1.61	2.12
Unconsolidated and semi-consolidated shallow aquifers	26	36	2	365	0.00053	0.0012	1.27	1.93
Coastal beaches	33	52	1	548.0	0.00026	0.007	1.37	1.81
Solution limestone	100	2000	13	9642	0.00026	0.001	1.21	2.69

[a] Data from the Hydrogeologic Database (Newell et al., 1990)

Table 3a: Calibration Field Data for Six Sites

Warren AFB - 1993 (33 years)

Distance from the Source along the Plume Centerline (ft)	0	180	625	830	1069	1575	1690
TCE Concentration (mg/L)	0.113	0.034	0.044	0.019	0.015	0.005	0.0012
DCE Concentration (mg/L)	0.093	0.028	0.024	0.009	0.005	0.0005	nm
VC Concentration (mg/L)	0.0005	0.0005	0.0009	0.0009	nm	nm	0.004

CCAS - 1996 (38 years)

Distance from the Source along the Plume Centerline (ft)	0	50	175	865	1840
TCE Concentration (mg/L)	39.4	0.239	0.001[1]	0.001[1]	0.001[1]
DCE Concentration (mg/L)	4.3831	2.4237	2.6177	0.7632	0.13
VC Concentration (mg/L)	0.24	0.21	0.836	0.51	0.0163
ETH Concentration (mg/L)	0.006	0.006	0.018	0.013	0.003

Tinker AFB - 1997 (35 years)

Distance from the Source along the Plume Centerline (ft)	10	450	1100
PCE Concentration (mg/L)	0.0061	nm	nm
TCE Concentration (mg/L)	9.44	1.49	0.344
DCE Concentration (mg/L)	1.286	0.1902	0.05
VC Concentration (mg/L)	0.0017	nm	nm

Shaw AFB - 1997 (56 years)

Distance from the Source along the Plume Centerline (ft)	0	100	260	420
TCA Concentration (mg/L)	23	2.03	0.0605	0.0786
DCA Concentration (mg/L)	1.06	8.7	1.153	1.07

Wurtsmith - 1991 (31 years)

Distance from the Source along the Plume Centerline (ft)	0	325	710	2100
TCE Concentration (mg/L)	0.91	0.1	0.01	0.0014
DCE Concentration (mg/L)	0.001[1]	nm	nm	nm

Ashumet Valley, MMR - 1998 (40 years)

Distance from the Source along the Plume Centerline (ft)	1152	3915	12091
PCE Concentration (mg/L)	0.022	0.004	0.0218
TCE Concentration (mg/L)	0.001[1]	0.005[1]	0.00258
cis-DCE Concentration (mg/L)	0.001[1]	0.077	0.001[1]

[1] Detection Limit

nm - not measured

Table 3b: Verification Field Data for Six Sites

Warren AFB - 2002 (42 years)

Distance from the Source along the Plume Centerline (ft)	0	180	403	625	830
TCE Concentration (mg/L)	0.04	0.037	0.024	0.01	0.001
DCE Concentration (mg/L)	0.035	0.023	0.01	0.001	nm

CCAS - 2001 (43 years)

Distance from the Source along the Plume Centerline (ft)	0	50	175	865	1840
TCE Concentration (mg/L)	4.29	0.074	0.001	0.001	0.001
DCE Concentration (mg/L)	0.9928	2.1841	0.1893	0.001	0.0096
VC Concentration (mg/L)	0.042	0.741	0.458	0.001	0.0044

Tinker AFB - 1999 (37 years)

Distance from the Source along the Plume Centerline (ft)	10	450	1100
PCE Concentration (mg/L)	0.0037	nm	nm
TCE Concentration (mg/L)	6.2	0.751	0.186
DCE Concentration (mg/L)	0.703	0.1091	0.0285
VC Concentration (mg/L)	0.001	nm	nm

Shaw AFB - 2002 (61 years)

Distance from the Source along the Plume Centerline (ft)	100
TCA Concentration (mg/L)	0.001[1]
DCA Concentration (mg/L)	0.0078

Wurtsmith - 2001 (41 years)

Distance from the Source along the Plume Centerline (ft)	0	325	1610	2100
TCE Concentration (mg/L)	0.108	0.0112	nm	0.027
DCE Concentration (mg/L)	0.063	0.02968	nm	0.021
VC Concentration (mg/L)	0.001[1]	0.001[1]	0.0022	0.001[1]

Ashumet Valley, MMR - 1999 (41 years)

Distance from the Source along the Plume Centerline (ft)	1152	1958	7485	12091
PCE Concentration (mg/L)	0.026	0.013	0.0057	0.017
TCE Concentration (mg/L)	0.00065	0.001[1]	0.012	0.0016
DCE Concentration (mg/L)	0.002[1]	0.001[1]	0.066	0.001[1]

[1] Detection Limit

nm - not measured

Table 4a: Centerline Concentrations (mg/L) and Calculated Attenuation Rates for Six Sites

Buscheck and Alcantar (1995) Biodegradation (λ) $=[Vc/4\alpha_x]\ [(1+2\alpha_x(k/Vx))^2 - 1]$, $t_{1/2} = Ln2 / \lambda$

Bulk Attenuation (k) = k/v_x * Vc (Newell et al., 2002)

All values reported in mg/L

Warren AFB

Input: Vc (ft/d)= 0.152 α_x (ft) = 31.637

Oct-93	Well	Distance (ft)	TCE	DCE	VC
	HP-18	0	0.113	0.093	0.0005
	209	180	0.034	0.028	0.0005
	210	625	0.044	0.024	0.0009
	211	830	0.019	0.009	0.0009
	interpolated	1069	0.015	0.005	NA
	interpolated	1575	0.005	0.0005	NA
	199	1690	0.0012	NA	NA
k/v_x (1/ft) (from Figure 4.5)			-0.0022	-0.003	
Bulk Attenuation (1/yr)			0.122	0.167	
Biodegradation Rate (1/yr)			0.131	0.183	
Biodegradation Half-life (yr)			5.3	3.8	

Apr-99	Well	Distance (ft)	TCE	DCE	VC
	207	0	0.0331	0.035	0.9457
	209	180	0.0931	0.129	0.7217
	210	625	0.0267	0.0158	1.6899
	211	830	0.0075	0.0033	NA
	interpolated	1069	0.014	0.0029	NA
	interpolated	1575	0.001	0.0005	NA
	199	1690	0.0005	NA	NA
k/v_x (1/ft) (from Figure 4.5)			-0.0027	-0.0032	
Bulk Attenuation (1/yr)			0.150	0.178	
Biodegradation Rate (1/yr)			0.163	0.196	
Biodegradation Half-life (yr)			4.3	3.5	

Aug-02	Well	Distance (ft)	TCE	DCE	VC
	207	0	0.04	0.035	1.1429
	209	180	0.037	0.023	1.6087
	interpolated	403	0.024	0.01	NA
	210	625	0.01	0.001	10.0000
	projected	830	0.001	NA	NA
k/v_x (1/ft) (from Figure 4.5)			-0.0041	-0.0055	
Bulk Attenuation (1/yr)			0.228	0.306	
Biodegradation Rate (1/yr)			0.258	0.359	
Biodegradation Half-life (yr)			2.7	1.9	

Table 4a: Centerline Concentrations (mg/L) and Calculated Attenuation Rates for Six Sites

Buscheck and Alcantar (1995) Biodegradation (λ) $=[Vc/4\alpha_x]\ [(1+2\alpha_x(k/Vx))^2 - 1]$, $t_{1/2} = Ln2 / \lambda$

Bulk Attenuation (k) = $k/v_x * Vc$ (Newell et al., 2002)

All values reported in mg/L

CCAS

Input: Vc (ft/d)= 0.058 α_x (ft) = 38.275

1996

Well	Distance (ft)	TCE	DCE	VC	ETH
S09	0	39.4	4.3831	0.24	0.006
S01	50	0.239	2.4237	0.21	0.006
S03	175	0.001	2.6177	0.836	0.018
S12	865	0.001	0.7632	0.51	0.013
S15	1840	0.001	0.13	0.0163	0.003
k/v_x (1/ft) (from Figure 4.8a)		-0.0037	-0.0018	-0.0015	-0.0005
Bulk Attenuation (1/yr)		0.0789	0.0384	0.0320	0.0107
Biodegradation Rate (1/yr)		0.0901	0.0410	0.0338	0.0109
Biodegradation Half-life (yr)		7.7	16.9	20.5	63.8

1998

Well	Distance (ft)	TCE	DCE	VC	ETH
S09	0	210	8.2949	0.1666	0.006
S01	50	0.819	2.6595	0.47	0.016
S03	175	0.0011	1.0205	0.559	0.011
S12	865	0.001	0.1121	0.0422	0.001
S15	1840	0.001	0.0888	0.0089	0.001
k/v_x (1/ft) (from Figure 4.8b)		-0.0044	-0.0022	-0.0021	-0.0014
Bulk Attenuation (1/yr)		0.0938	0.0469	0.0448	0.0299
Biodegradation Rate (1/yr)		0.1096	0.0509	0.0484	0.0315
Biodegradation Half-life (yr)		6.3	13.6	14.3	22.0

2001

Well	Distance (ft)	TCE	DCE	VC
S09	0	4.29	0.9928	0.042
S01	50	0.074	2.1841	0.741
S03	175	0.001	0.1893	0.458
S12	865	0.001	0.001	0.001
S15	1840	0.001	0.0096	0.0044
k/v_x (1/ft) (from Figure 4.8c)		-0.0029	-0.0031	-0.0026
Bulk Attenuation (1/yr)		0.0618	0.0661	0.0554
Biodegradation Rate (1/yr)		0.0687	0.0739	0.0610
Biodegradation Half-life (yr)		10.1	9.4	11.4

Table 4a: Centerline Concentrations (mg/L) and Calculated Attenuation Rates for Six Sites

Buscheck and Alcantar (1995) Biodegradation (λ) $=[Vc/4\alpha_x]\ [(1+2\alpha_x(k/Vx))^2 - 1]$, $t_{1/2} = Ln2 / \lambda$
Bulk Attenuation (k) = $k/v_x * Vc$ (Newell et al., 2002)
All values reported in mg/L

Tinker AFB

Input: Vc (ft/d)= 0.189 α_x (ft) = 30.21

Aug-97					
Well	Distance (ft)	PCE	TCE	DCE	VC
2-62B	10	0.0061	9.44	1.286	0.0017
CG39B97-43S	450	NA	1.49	0.1902	NA
2-355B	1100	NA	0.344	0.05	NA
k/v_x (1/ft) (from Figure 4.11a)			-0.003	-0.0029	
Bulk Attenuation (1/yr)			0.207	0.201	
Biodegradation Rate (1/yr)			0.226	0.218	
Biodegradation Half-life (yr)			3.1	3.2	
Apr-99					
Well	Distance (ft)	PCE	TCE	DCE	VC
2-62B	10	0.0037	6.200	0.703	0.001
CG39B97-43S	450	NA	0.751	0.1091	NA
2-355B	1100	NA	0.186	0.0285	NA
k/v_x (1/ft) (from Figure 4.11b)			-0.0031	-0.0029	
Bulk Attenuation (1/yr)			0.214	0.201	
Biodegradation Rate (1/yr)			0.234	0.218	
Biodegradation Half-life (yr)			3.0	3.2	

Table 4a: Centerline Concentrations (mg/L) and Calculated Attenuation Rates for Six Sites

Buscheck and Alcantar (1995) Biodegradation (λ) $=[Vc/4\alpha_x] [(1+2\alpha_x(k/Vx))^2 - 1]$, $t_{1/2} = Ln2 / \lambda$

Bulk Attenuation (k) = $k/v_x * Vc$ (Newell et al., 2002)

All values reported in mg/L

Shaw AFB

Input: Vc (ft/d)= 0.407 α_x (ft) = 23.798

May-97					
Well	Distance (ft)	PCE	TCE	cis-DCE	VC
MPC	0	0.0907	0.718	4.590	0.0304
MW-115	100	0.0048	0.0102	1.62	0.4160
TMP-3	260	0.001	0.0039	0.15	0.0596
TMP-2	420	ND	0.0012	0.339	0.0228
Long Branch Creek/SWS-4	460	ND	ND	ND	ND
k/v_x (1/ft) (from Figure 4.14)		-0.0166	-0.0135	-0.007	-0.0026
Bulk Attenuation (1/yr)		2.46	2.00	1.04	0.39
Biodegradation Rate (1/yr)		3.44	2.65	1.21	0.41
Biodegradation Half-life (yr)		0.2	0.3	0.6	1.7

May-97				
Well	Distance (ft)	1,1-DCE	1,1,1-TCA	1,1-DCA
MPC	0	0.7480	23.0000	1.0600
MW-115	100	0.368	2.0300	8.7000
TMP-3	260	0.0402	0.0605	1.1530
TMP-2	420	0.116	0.0786	1.0700
Long Branch Creek/SWS-4	460	ND	ND	ND
k/v_x (1/ft) (from Figure 4.14)		-0.0053	-0.0141	-0.0019
Bulk Attenuation (1/yr)		0.79	2.09	0.28
Biodegradation Rate (1/yr)		0.89	2.80	0.29
Biodegradation Half-life (yr)		0.8	0.2	2.4

Table 4a: Centerline Concentrations (mg/L) and Calculated Attenuation Rates for Six Sites

Buscheck and Alcantar (1995) Biodegradation (λ) $=[Vc/4\alpha_x]\ [(1+2\alpha_x(k/Vx))^2 - 1]$, $t_{1/2} = \mathrm{Ln}2 / \lambda$
Bulk Attenuation (k) = $k/v_x * Vc$ (Newell et al., 2002)
All values reported in mg/L

Wurtsmith AFB

Input: Vc (ft/d)= 1.342 α_x (ft) = 35.82

May-91			
Well	Distance (ft)	TCE	DCE
H127S	0	0.91	0.0011
-	325	0.1	NA
-	710	0.01	NA
H75S	2100	0.0014	NA
k/v_x (1/ft) (from Figure 4.17a)		-0.0028	
Bulk Attenuation (1/yr)		1.37	
Biodegradation Rate (1/yr)		1.51	
Biodegradation Half-life(yr)		0.5	

Oct-01				
Well	Distance (ft)	TCE	DCE	VC
H127S	0	0.108	0.063	0.001
LF30-MW5	325	0.0112	0.02968	0.0011
-	1610			0.0022
H75S	2100	0.027	0.021	0.0011
k/v_x (1/ft) (from Figure 4.17b)		-0.0003	-0.0004	
Bulk Attenuation (1/yr)		0.15	0.20	
Biodegradation Rate (1/yr)		0.15	0.20	
Biodegradation Half-life(yr)		4.7	3.5	

Table 4a: Centerline Concentrations (mg/L) and Calculated Attenuation Rates for Six Sites

Buscheck and Alcantar (1995) Biodegradation (λ) $=[Vc/4\alpha_x]\ [(1+2\alpha_x(k/Vx))^2 - 1]$, $t_{1/2} = \mathrm{Ln}2 / \lambda$

Bulk Attenuation (k) = $k/v_x * Vc$ (Newell et al., 2002)

All values reported in mg/L

Ashumet, MMR

Input: Vc (ft/d)= 0.996 α_x (ft) = 71.54

Jul-98				
Well	Distance (ft)	PCE	TCE	DCE
30MW0426B	1152	0.022	0.001	0.001
30MW0428B	1958	NA	NA	NA
95MW0109B	3915	0.004	0.00049	0.077
30MW0585B	7485	NA	NA	NA
USFW350064	12091	0.0218	0.00258	0.001
k/v_x (1/ft) (from Figure 4.20a)				-0.0001
Bulk Attenuation (1/yr)				0.036
Biodegradation Rate (1/yr)				0.037
Biodegradation Half-life(yr)				18.9
Sep-99				
Well	Distance (ft)	PCE	TCE	DCE
30MW0426B	1152	0.026	0.00065	0.001
30MW0428B	1958	0.013	0.001	0.001
95MW0109B	3915	NA	NA	NA
30MW0585B	7485	0.0057	0.012	0.066
USFW350064	12091	0.017	0.0016	0.001
k/v_x (1/ft) (from Figure 4.20b)		-0.00004		
Bulk Attenuation (1/yr)		0.015		
Biodegradation Rate (1/yr)		0.015		
Biodegradation Half-life(yr)		47.5		
Oct-03				
Well	Distance (ft)	PCE	TCE	DCE
30MW0426B	1152	0.00815	0.00057	0.00025
30MW0428B	1958	0.00025	0.001	0.001
95MW0109B	3915	0.001	0.001	0.001
30MW0585B	7485	0.0011	0.001	0.02
USFW350064	12091	0.00391	0.001	0.001
k/v_x (1/ft) (from Figure 4.20c)		7.00E-05	3.00E-05	0.0002

Note:

All concentrations are mg/L.

No bulk attenuation or biodegradation values were calculated for postive slopes.

NA - Data not available

ND - Non Detect

Table 4b: Temporal Variations in Well Concentrations and Calculated Point Attenuation Rates for Six Sites

Warren AFB

		HP-18/207*	209	210
TCE	10/01/93	0.113	0.034	0.044
	04/01/99	0.0331	0.0931	0.0267
	8/29/02	0.04	0.037	0.01
slope k_s (1/d)		-0.0003	0.0001	-0.0004
slope k_s (1/yr)		-0.1266	0.0259	-0.1591
DCE	10/01/93	0.093	0.028	0.024
	04/01/99	0.035	0.129	0.0158
	8/29/02	0.035	0.023	0.001
slope k_s (1/d)		-0.0003	0.00002	-0.0009
slope k_s (1/yr)		-0.1161	0.0063	-0.3299

*HP-18/207 is considered to be in the source area and the slope values are therefore representative of the source decay rate.

Table 4b: Temporal Variations in Well Concentrations and Calculated Point Attenuation Rates for Six Sites

CCAS

		S09*	S01*	S03	S12	S15
TCE	Sep-96	39.4	0.239	0.001	0.001	0.001
	Mar-98	210	0.819	0.0011	0.001	0.001
	Aug-01	4.29	0.074	0.001	0.001	0.001
slope k_s (1/d)		-0.0016	-0.0009	-0.00001		
slope k_s (1/yr)		-0.5717	-0.3201	-0.0049		
DCE	Sep-96	4.3831	2.4237	2.6177	0.7632	0.13
	Mar-98	8.2949	2.6595	1.0205	0.1121	0.0888
	Aug-01	0.9928	2.1841	0.1893	0.001	0.0096
slope k_s (1/d)		-0.0010	-0.0001	-0.0014	-0.0037	-0.0015
slope k_s (1/yr)		-0.3580	-0.0276	-0.5269	-1.3552	-0.5511
VC	Sep-96	0.24	0.21	0.836	0.51	0.0163
	Mar-98	0.166	0.47	0.559	0.0422	0.0089
	Aug-01	0.042	0.741	0.458	0.001	0.0044
slope k_s (1/d)		-0.0010	0.0006	-0.0003	-0.0034	-0.0007
slope k_s (1/yr)		-0.3628	0.2348	-0.1111	-1.2374	-0.2557

*S09 and S01 are considered to be in the source area and the slope values are therefore representative of the source decay rate.

Table 4b: Temporal Variations in Well Concentrations and Calculated Point Attenuation Rates for Six Sites

Tinker AFB

		2-62B*	2-64B	2-65B
PCE	12/10/1993	NA	NA	NA
	9/13/1995	NA	NA	0.022
	7/24/1996	NA	NA	0.044
	7/31/1997	0.0061	NA	0.052
	4/8/1999	0.0037	0.0013	0.154
slope k_s (1/d)				0.00141
slope k_s (1/yr)				0.5154

		2-62B*	2-64B	2-65B
TCE	12/10/1993	8.3	0.096	0.099
	9/13/1995	9.1	0.16	0.068
	7/24/1996	4.3	0.47	0.055
	7/31/1997	9.44	0.914	0.09
	4/8/1999	6.2	2.13	0.25
slope k_s (1/d)		-0.0001	0.0017	0.0005
slope k_s (1/yr)		-0.0440	0.6189	0.1716
DCE	12/10/1993	1.736	0.039	0.024
	9/13/1995	1.102	0.035	0.014
	7/24/1996	0.961	0.18	0.037
	7/31/1997	1.286	0.1716	0.0395
	4/8/1999	0.703	0.3603	0.1573
slope k_s (1/d)		-0.0004	0.0013	0.0010
slope k_s (1/yr)		-0.1410	0.4617	0.3727
VC	12/10/1993	0.001	NA	NA
	9/13/1995	0.001	NA	NA
	7/24/1996	0.001	NA	0.002
	7/31/1997	0.0017	NA	0.0013
	4/8/1999	0.001	NA	0.0051
slope k_s (1/d)		0.0001		0.0011
slope k_s (1/yr)		0.0323		0.3925

*2-62B is considered to be in the source area and the slope values are therefore representative of the source decay rate.

Table 4b: Temporal Variations in Well Concentrations and Calculated Point Attenuation Rates for Six Sites

Shaw AFB

		MW-115	MW-117
TCA	May-97	2.030	4.69
	Apr-98	0.220	11
	Jan-99	0.012	7
	Jan-00	NA	2.8
	Jan-01	NA	0.61
	Jan-02	NA	0.51
	Apr-02	NA	0.327
	Jul-02	NA	1.24
	Oct-02	NA	1.9
slope k_s (1/d)		-0.0086	-0.0013
slope k_s (1/yr)		-3.1252	-0.4814

		MW-115	MW-117
1,1-DCA	5/15/1997	8.7	0.481
	4/1/1998	0.095	0.55
	1/1/1999	0.0046	0.14
	1/1/2000	0.011	0.083
	1/1/2001	0.011	0.098
	1/1/2002	0.0023	0.0212
	4/1/2002	0.00317	0.121
	7/1/2002	0.00523	0.14
	10/1/2002	0.0078	
slope k_s (1/d)		-0.0027	-0.0010
slope k_s (1/yr)		-0.9857	-0.3764

1,1-DCE	5/15/1997	0.368	0.148
	4/1/1998	0.095	0.55
	1/1/1999	0.009	6
	1/1/2000	0.011	0.14
	1/1/2001	0.011	0.083
	1/1/2002	0.00230	0.098
	4/1/2002	0.00317	0.0212
	7/1/2002	0.00523	0.121
	10/1/2002	0.00780	0.14
slope k_s (1/d)		-0.0019	-0.0012
slope k_s (1/yr)		-0.7003	-0.4203

VC	1/1/1999	0.056	0.22
	1/1/2000	0.18	0.097
	1/1/2001	0.2	0.22
	1/1/2002	0.098	0.32
	4/1/2002	0.0524	0.127
	7/1/2002	0.0553	0.133
	10/1/2002	0.00026	0.064
slope k_s (1/d)		-0.0021	-0.0003
slope k_s (1/yr)		-0.7706	-0.1194

*MW-115 is considered to be in the source area and the slope values are therefore representative of the source decay rate.

Table 4b: Temporal Variations in Well Concentrations and Calculated Point Attenuation Rates for Six Sites

Wurtsmith AFB

		H127S
TCE	1991	0.910
	1995	0.180
	1997	0.230
	1998	0.85
	1999	1.671
	2000	0.799
	2001	0.108
	2002	0.531
	2003	0.353
slope k_s (1/d)		-0.0001
slope k_s (1/yr)		0.01925
DCE	1995	0.243
	1997	0.44
	1998	0.52
	1999	0.651
	2000	0.828
	2001	0.063
	2002	0.11
	2003	0.217
slope k_s (1/d)		-0.0001
slope k_s (1/yr)		0.0275

Table 4b: Temporal Variations in Well Concentrations and Calculated Point Attenuation Rates for Six Sites

Ashumet, MMR

		30MW0426B
PCE	7/22/1998	0.022
	9/27/1999	0.026
	10/15/2003	0.00815
slope ks (1/d)		-8E-06
slope ks (1/yr)		3E-03
TCE	7/22/1998	0.001
	9/27/1999	0.00065
	10/15/2003	0.00057
slope ks (1/d)		-2E-07
slope ks (1/yr)		7E-05
DCE	7/22/1998	0.001
	9/27/1999	0.001
	10/15/2003	0.00025
slope ks (1/d)		-4E-07
slope ks (1/yr)		0.0002

Note:

NA - no data available

All concentrations mg/L

Table 5a: Deterministic BIOCHLOR Model Parameters for Six Sites

Property	Warren AFB	CCAS	Tinker AFB	Shaw AFB	Wurtsmith AFB	Ashumet MMR
Hydraulic Conductivity - K (ft/yr)	1657	11389	5487	6419	51135	82181
Hydraulic Gradient - i (ft/ft)	0.012	0.00059	0.006	0.007	0.005	0.0017
Porosity - n	0.3	0.25	0.25	0.25	0.3	0.3
Velocity, seepage (ft/yr)	66	26	131	180	852	465
Plume Length - Lp (ft)	1800	3000	1600	900[a]	900[c]	21880
Dispersion - α_x (ft)	31.64	38.28	30.21	23.80	35.82	71.54
Dispersion - $\alpha y / \alpha_x$ (ft)	0.33	0.01	0.01	0.01	0.01	0.33
Dispersion - $\alpha z / \alpha_x$ (ft)	0.05	0.001	0.001	0.001	0.001	0.05
Soil Bulk Density (kg/L)	1.66	1.72	1.65	1.72	1.7	1.68
Fraction of Organic Carbon - foc	0.00027	0.0046	0.0081	0.00024	0.001	0.00038
Average Retardation Coefficient R - calculated by BIOCHLOR	1.19	1.21 [e]	1.9 [e]	1.21	1.74	1.28
Time of Source Emplacement	1960	1958	1962	1941	1960	1958
Calibration Simulation Time (yrs)	33	38	35	56	31	40
Verification Simulation Time (yrs)	42	43	37	61	41	41
Model Area Width (ft)	1000	1500	500	1440	1500	2500
Model Area Length (ft)	2500	3000	1600	1600	3000	25000
Source Thickness (ft)	50	50	6	10	45	150
Source Width (ft)	489	450	100	240	200	1500
Source Decay ks (1/yr) - calibrated	0.28	0.087	0.14	0.065	0.23	0.22
Source Concentration (mg/L)	1100	1100	1100	950[b]	1100	150[d]

[a] East South-East plume

[b] Source is TCA

[c] North Plume

[d] Source is PCE

[e] Value taken from field studies

Table 5b: Stochastic BIOCHLOR Model Distributions for Six Sites

Warren AFB

Property	Deterministic Value	Distribution Type	Mean	Minimum	Maximum
Seepage Velocity (ft/yr)	66	Lognormal	66	52	82
Dispersion - α_x (ft)	32	Lognormal	32	24	42
Soil Bulk Density (kg/L)	1.66	Lognormal	1.65	1.52	1.81
TCE to DCE 1st Order Biodegradation	0.45	Uniform	-	0	8.4
DCE to VC 1st Order Biodegradation	1.02	Uniform	-	0	47.5
VC to ETH 1st Order Biodegradation	0.66	Uniform	-	0	2.6
Simulation Time (yr)	33	Fixed	-	-	-
Source Thickness (ft)	50	Uniform	-	1	50
Source Width (ft)	489	Lognormal	489	432	552
Source Decay (1/yr)	0.278	Formula	-	-	-
Source Concentration (mg/L)	1100	Fixed	-	-	-

CCAS

Property	Deterministic Value	Distribution Type	Mean	Minimum	Maximum
Seepage Velocity (ft/yr)	26	Lognormal	25.8	8	74
Dispersion - α_x (ft)	38	Lognormal	38	30	300
Soil Bulk Density (kg/L)	1.72	Lognormal	1.72	1.56	1.88
TCE to DCE 1st Order Biodegradation	7	Uniform	-	0	8.40
DCE to VC 1st Order Biodegradation	0.25	Uniform	-	0	47.45
VC to ETH 1st Order Biodegradation	1.3	Uniform	-	0	2.56
Simulation Time (yr)	38	Fixed	-	-	-
Source Thickness (ft)	50	Uniform	-	1	50
Source Width (ft)	450	Lognormal	450	394	513
Source Decay (1/yr)	0.087	Formula	-	-	-
Source Concentration (mg/L)	1100	Fixed	-	-	-

Table 5b: Stochastic BIOCHLOR Model Distributions for Six Sites

Tinker, AFB

Property	Deterministic Value	Distribution Type	Likeliest/Mean	Minimum	Maximum
Seepage Velocity (ft/yr)	131	Lognormal	131	30	164.3
Dispersion - α_x (ft)	30	Lognormal	68.67	16	160
Soil Bulk Density (kg/L)	1.65	Lognormal	1.65	1.51	1.81
TCE to DCE 1st Order Biodegradation	0.64	Uniform	-	0.3	8.40
DCE to VC 1st Order Biodegradation	3.19	Uniform	-	0.3	47.45
VC to ETH 1st Order Biodegradation	0	Uniform	-	0.5	2.56
Simulation Time (yr)	35	Fixed	-	-	-
Source Thickness (ft)	6	Uniform	-	1	40
Source Width (ft)	100	Lognormal	100	54	177
Source Decay (1/yr)	0.136	Formula	-	-	-
Source Concentration (mg/L)	1100	Fixed	-	-	-

Shaw AFB

Property	Deterministic Value	Distribution Type	Mean	Minimum	Maximum
Seepage Velocity (ft/yr)	180	Lognormal	180	21	770
Dispersion - α_x (ft)	24	Lognormal	23.8	9	90
Soil Bulk Density (kg/L)	1.72	Lognormal	1.72	1.58	1.87
TCA to DCA 1st Order Biodegradation	3.3	Uniform	-	0.004	73
DCA to CA 1st Order Biodegradation	1.85	Uniform	-	0.11	7.3
Simulation Time (yr)	56	Fixed	-	-	-
Source Thickness (ft)	10	Uniform	-	1	20
Source Width (ft)	240	Lognormal	240	187	300
Source Decay (1/yr)	1.25	Formula	-	-	-
Source Concentration (mg/L)	950	Fixed	-	-	-

Table 5b: Stochastic BIOCHLOR Model Distributions for Six Sites

Wurtsmith AFB

Property	Deterministic Value	Distribution Type	Mean	Minimum	Maximum
Seepage Velocity (ft/yr)	852	Lognormal	840	788	855
Dispersion - α_x (ft)	36	Lognormal	36	9	90
Soil Bulk Density (kg/L)	1.7	Lognormal	1.65	1.51	1.81
TCE to DCE 1st Order Biodegradation	3.3	Uniform	-	0	8.40
Simulation Time (yr)	31	Fixed	-	-	-
Source Thickness (ft)	45	Uniform	-	1	45
Source Width (ft)	200	Lognormal	200	171	235
Source Decay (1/yr)	0.228	Formula	-	-	-
Source Concentration (mg/L)	1100	Fixed	-	-	-

Ashumet Valley, MMR

Property	Deterministic Value	Distribution Type	Likeliest/Mean	Minimum	Maximum
Seepage Velocity (ft/yr)	465	Lognormal	466	260	530
Dispersion - α_x (ft)	10	Lognormal	10	10	500
Soil Bulk Density (kg/L)	1.68	Lognormal	1.65	1.51	1.81
PCE to DCE 1st Order Biodegradation	0.3	Uniform	-	0	1.83
TCE to DCE 1st Order Biodegradation	1.67	Uniform	-	0	8.40
DCE to VC 1st Order Biodegradation	0.29	Uniform	-	0	47.45
Simulation Time (yr)	40	Fixed	-	-	-
Source Thickness (ft)	150	Uniform	-	1	150
Source Width (ft)	1500	Lognormal	1500	960	2200
Source Decay (1/yr)	0.2	Formula	-	-	-
Source Concentration (mg/L)	150	Fixed	-	-	-

Note:

Zero values for biodegradation were represented as 1 X 10^{-6}

Table 6: Evaluation of Biodegradation Rates (1/yr) for Six Sites

Site		B&A Calculated Rate (1/yr)			Calibrated Rate (1/yr)
Warren AFB		**1993**	**1999**	**2002**	
	TCE	0.13	0.16	0.26	0.45
	DCE	0.18	0.20	0.36	1.02
	VC	NA	IS	IS	0.66
CCAS		**1996**	**1998**	**2001**	
	TCE	0.09	0.11	0.07	7.00
	DCE	0.04	0.05	0.07	0.25
	VC	0.03	0.05	0.06	1.30
	ETH	0.01	0.03	nda	nda
Tinker AFB		**1997**	**1999**		
	TCE	0.23	0.23		0.64
	DCE	0.22	0.22		3.19
Shaw AFB		**1997**			
	PCE	3.44			NA
	TCE	2.65			NA
	DCE	1.21			NA
	VC	0.41			NA
	TCA	2.80			3.30
	DCA	0.29			1.85
Wurtsmith AFB		**1991**	**2001**		
	TCE	1.51	0.15		3.30
	DCE	nda	0.2		nda
Ashumet MMR		**1998**	**1999**	**2003**	
	PCE	IS	0.02	IS	0.27
	TCE	IS	IS	IS	0.98
	DCE	0.04	IS	IS	0.18

Values are presented in 1/yr

nda - not enough data to analyze

IS - increasing slope

NA - not analyzed

B & A - Buscheck and Alcantar (1995)

Table 7: Deterministic and Stochastic Evaluation of Source Decay Rates and Remediation Times for Six Sites

Site Location		Calculated Point Attenuation in Source Area Wells (1/yr)		Initial Concentration (mg/L)	Remediation Time (yrs)[a]	BIOCHLOR Calibrated Rate (1/yr)	Remediation Time (yrs) [a]	Deterministic BIOCHLOR Remediation Time (yrs)	Stochastic BIOCHLOR Remediation Time (yrs) [b]
Warren AFB									
		HP-18/207							
	TCE	0.127		0.113	58	0.28	44	44	32 - 39
	DCE	0.116		0.093	35				
CCAS		**S09**	**S01**	**S09**					
	TCE	0.572	0.320	39.400	54	0.09	141	440	>142
	DCE	0.358	0.028	4.383	50				
	VC	0.363	IS	0.240					
Tinker AFB		**2-62B**							
	TCE	0.044		8.300	200	0.14	84	91	150-300
	DCE	0.141		1.736					
	VC	IS							
Shaw AFB		**MW-115**							
	1,1-DCE	0.700		0.368	58				
	VC	0.771		0.056	62				
	TCA	3.125		2.030	56	0.07	148	106	0 - 12
	DCA	0.986		8.700	58				
Wurtsmith AFB		**H127S**							
	TCE	0.019		0.910	301	0.23	54	54	bMCL
	DCE	0.028		0.243	80				
Ashumet MMR		**30MW0426B**							
	PCE	0.003		0.022	534	0.22	47	48	0 - 38
	TCE	0.00007							
	DCE	0.00015							

Notes:

[a] Calculated Remediation Time from formula: $t = -Ln(C_{goal}/C_{start}) / k_{point}$

[b] Stochastic remediation times are based on the 25th and 75th percentiles from Figures 6.4a through f

IS Increasing slope

All remediation times are projected from the time of source emplacement

bMCl Indicates the remediaiton goal has been achieved

Remediation Goal = MCL

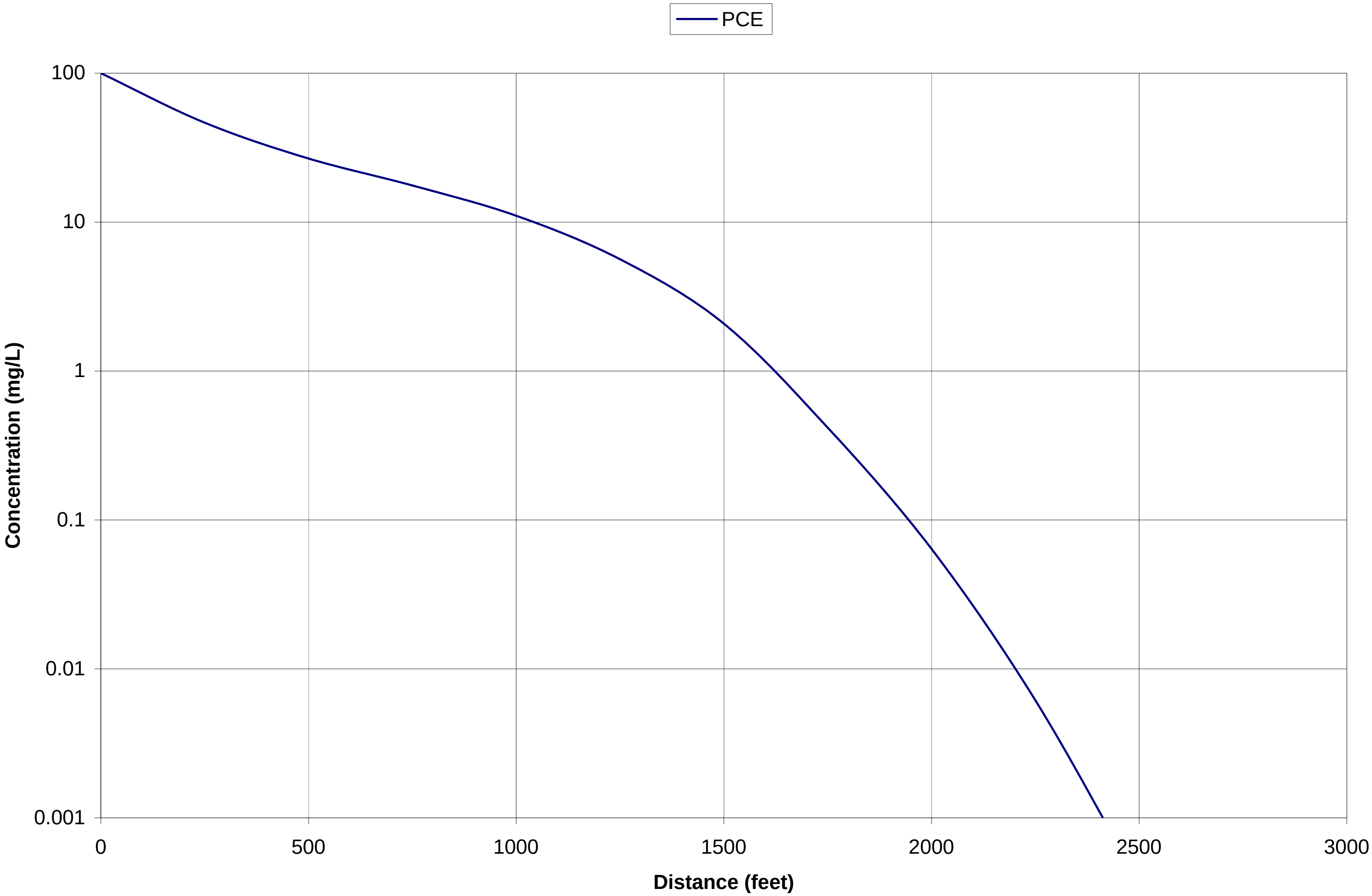


Figure 1a: Base Case - No Biodegradation and No Source Decay

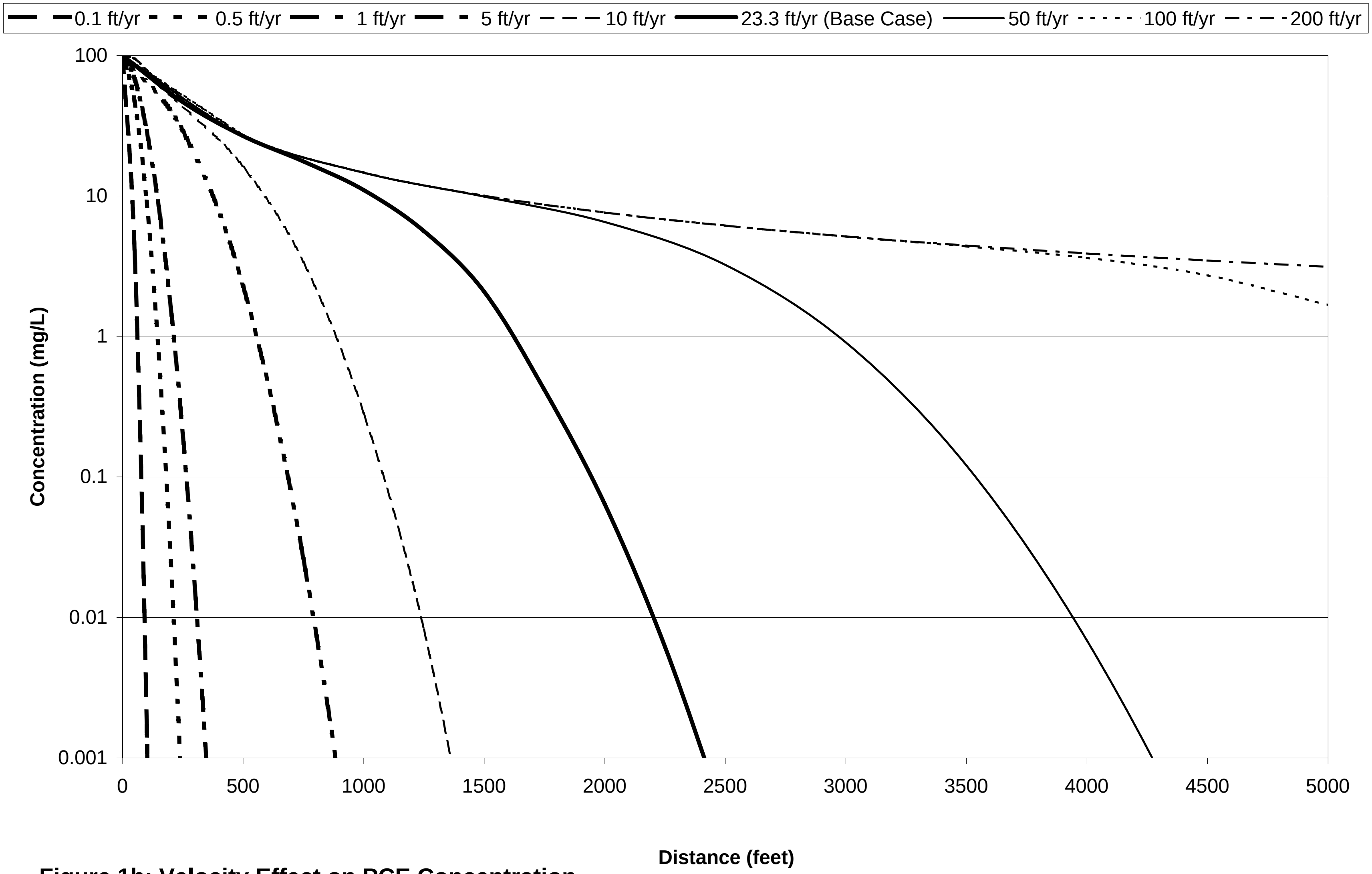


Figure 1b: Velocity Effect on PCE Concentration

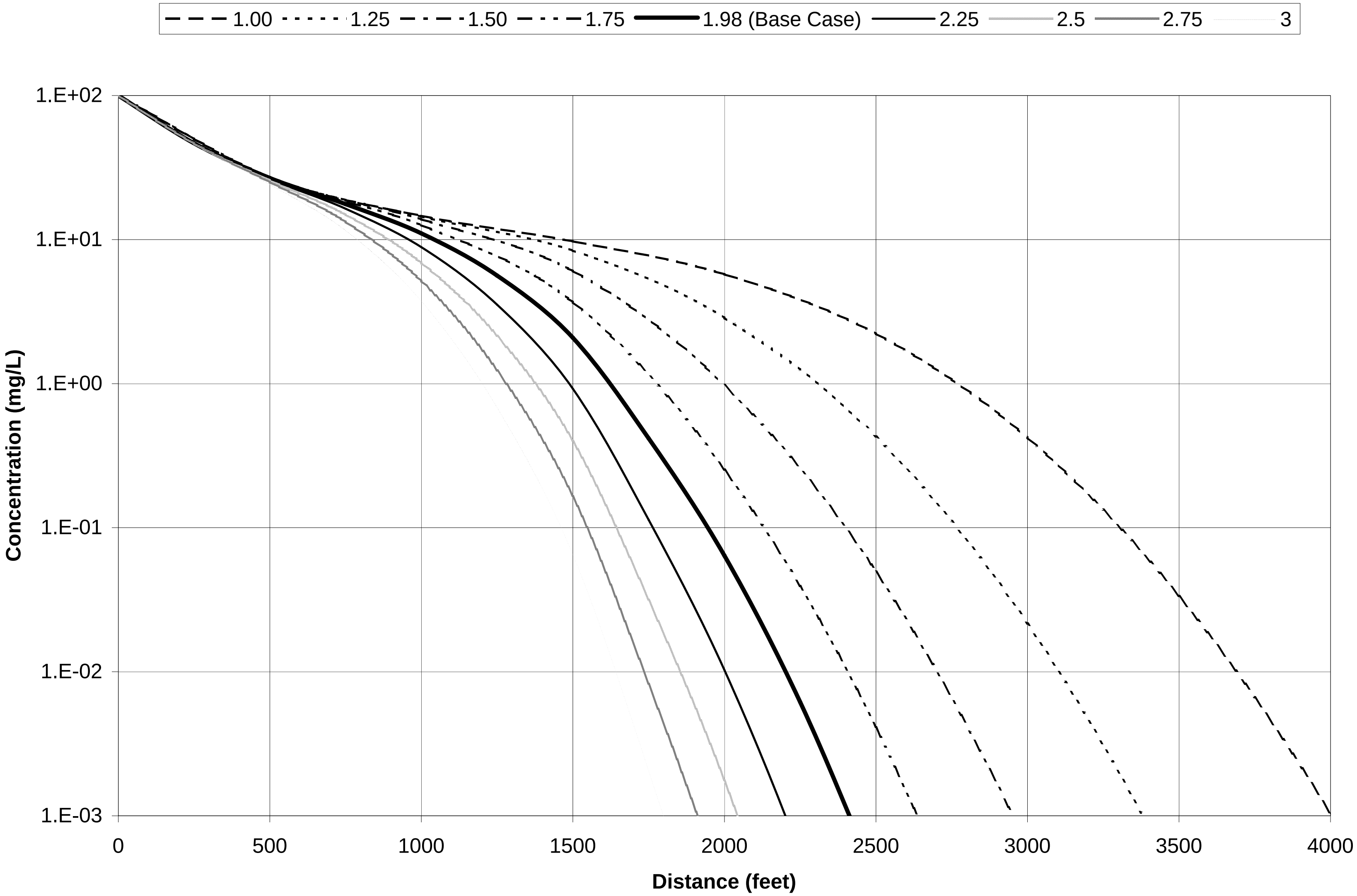


Figure 1c: Retardation Effects on PCE Concentration

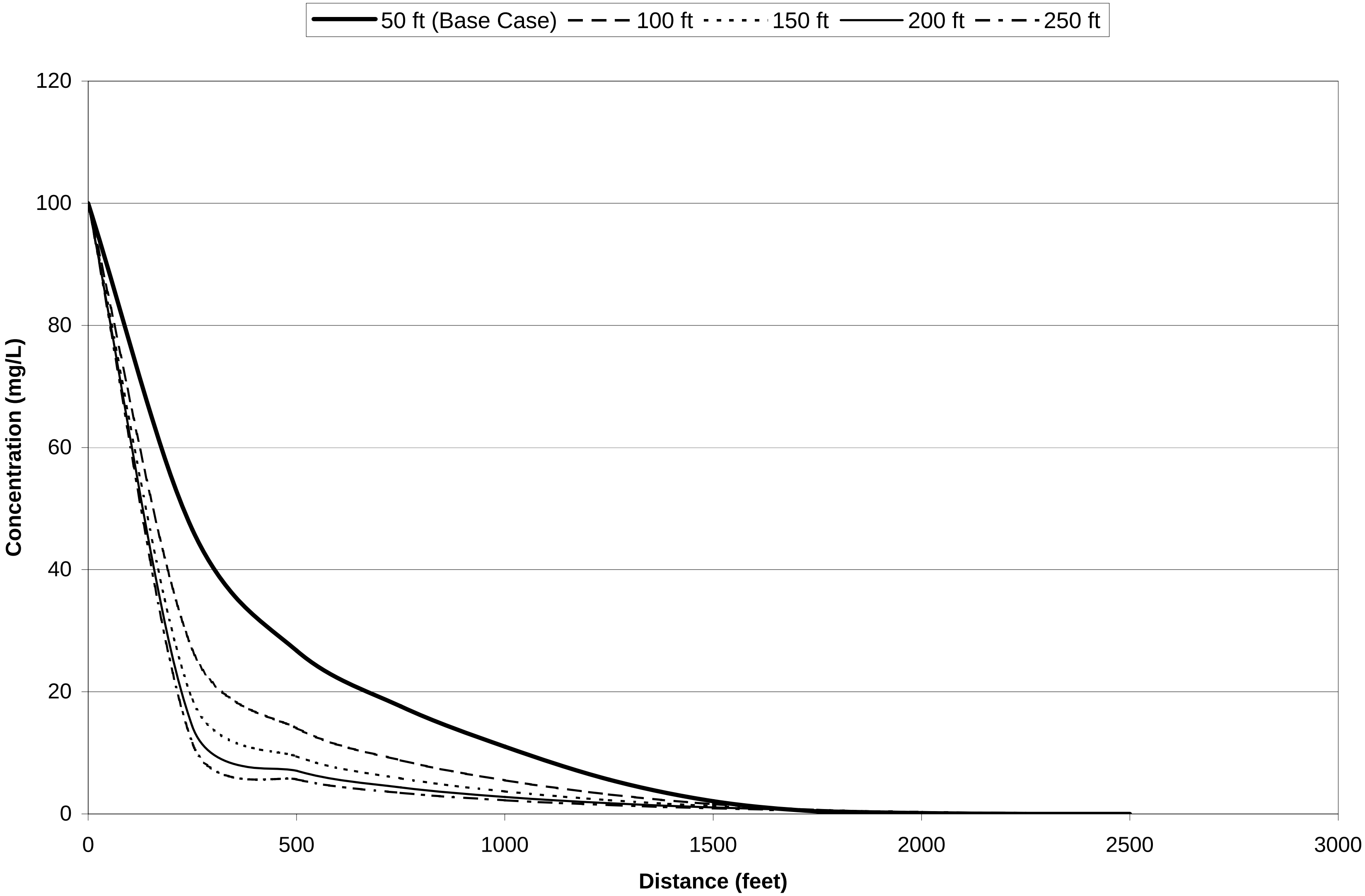


Figure 2a: Effect of Longitudinal Dispersivity

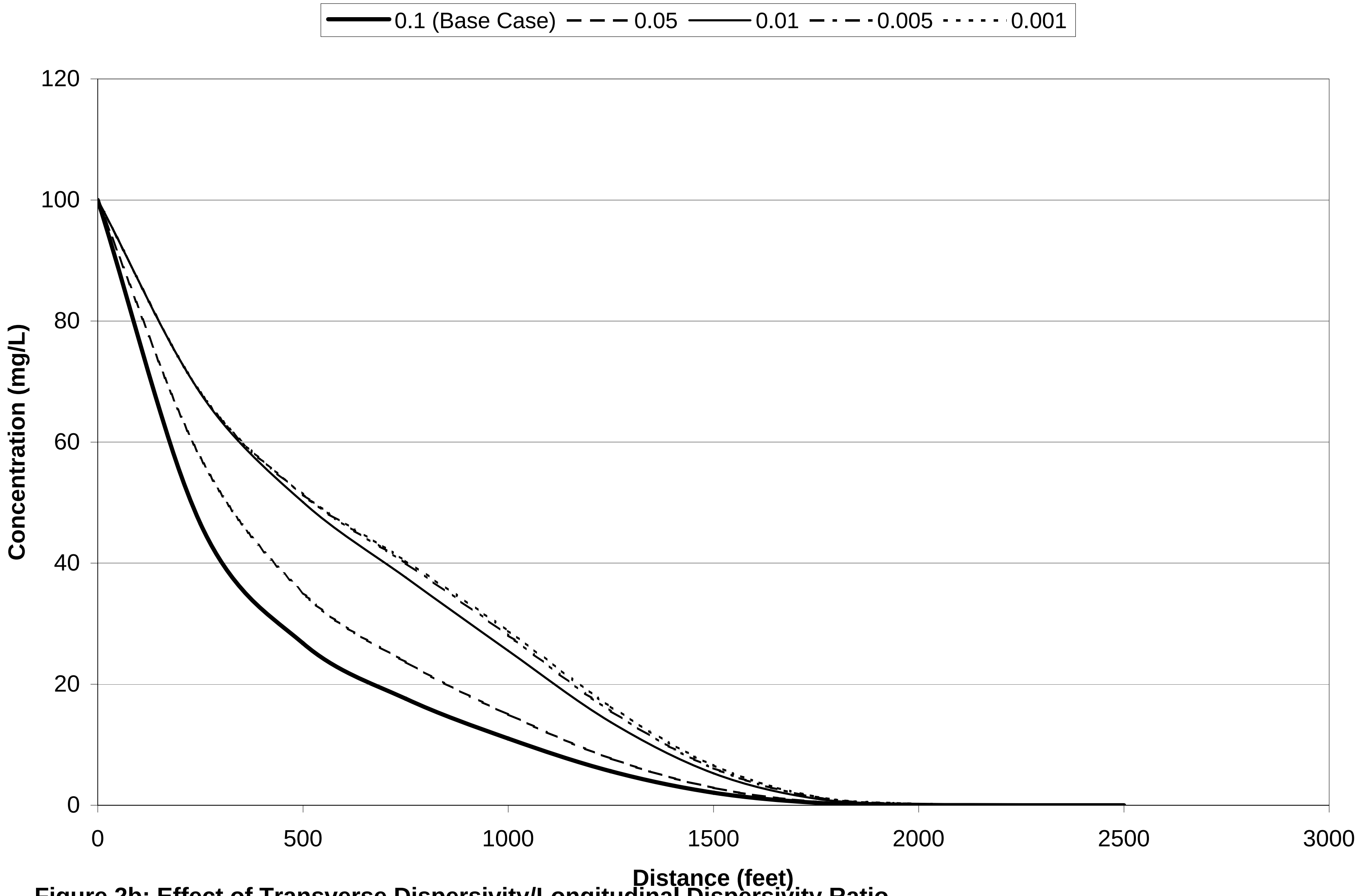


Figure 2b: Effect of Transverse Dispersivity/Longitudinal Dispersivity Ratio

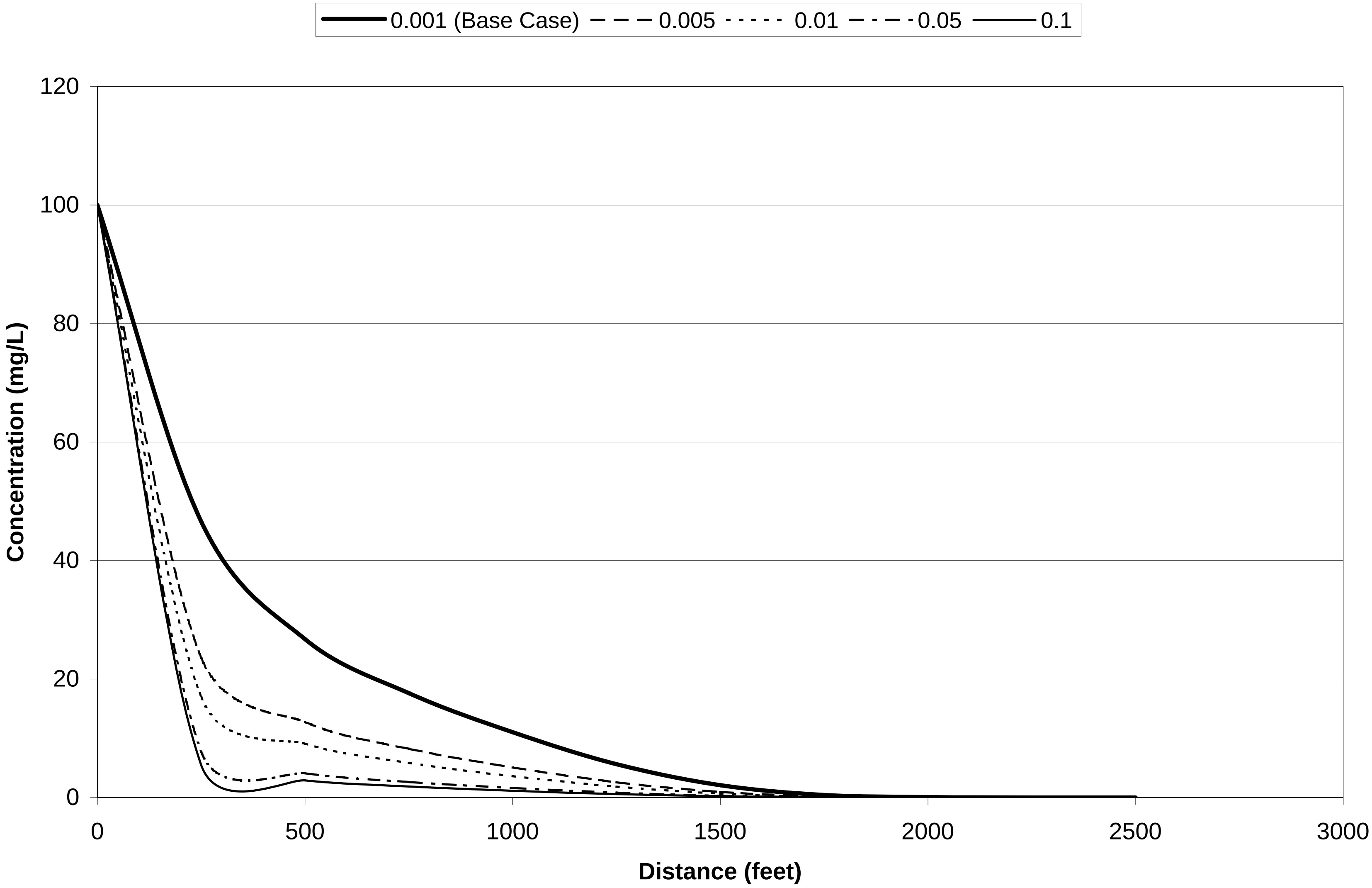
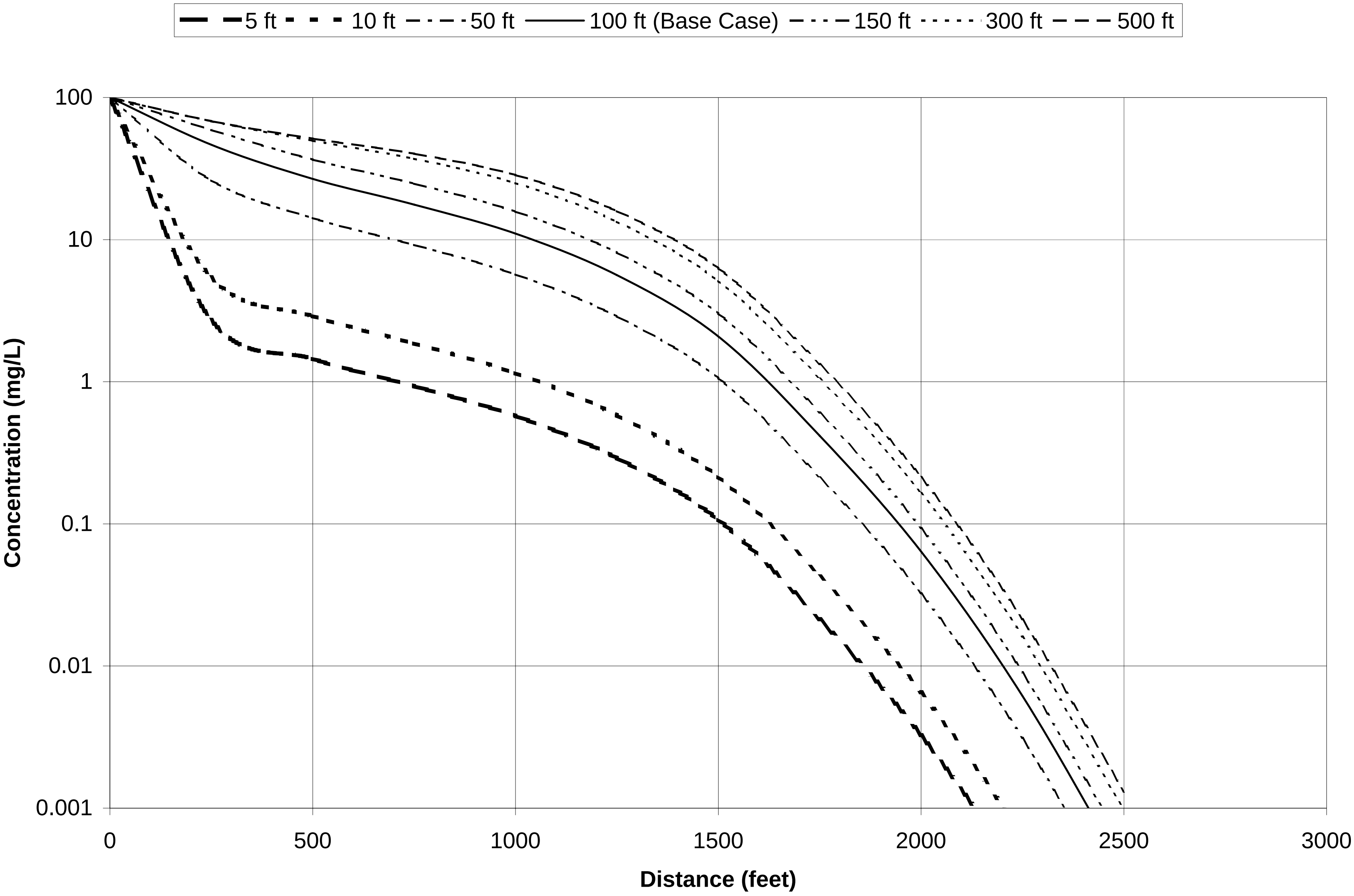


Figure 2c: Effect of Vertical Dispersivity/Longitudinal Dispersivity Ratio



Figue 3a: Source Width Effects

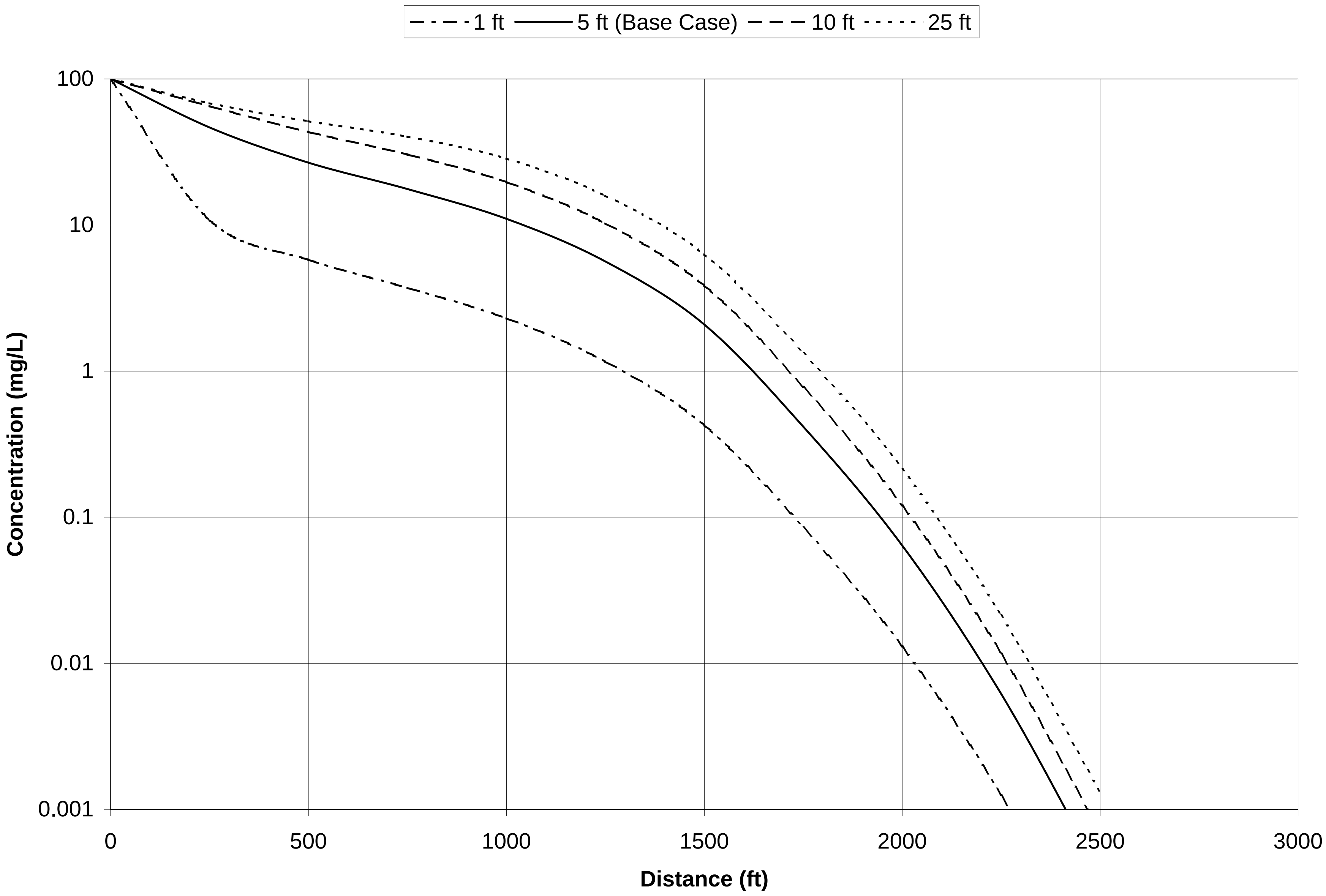


Figure 3b: Source Depth Effects

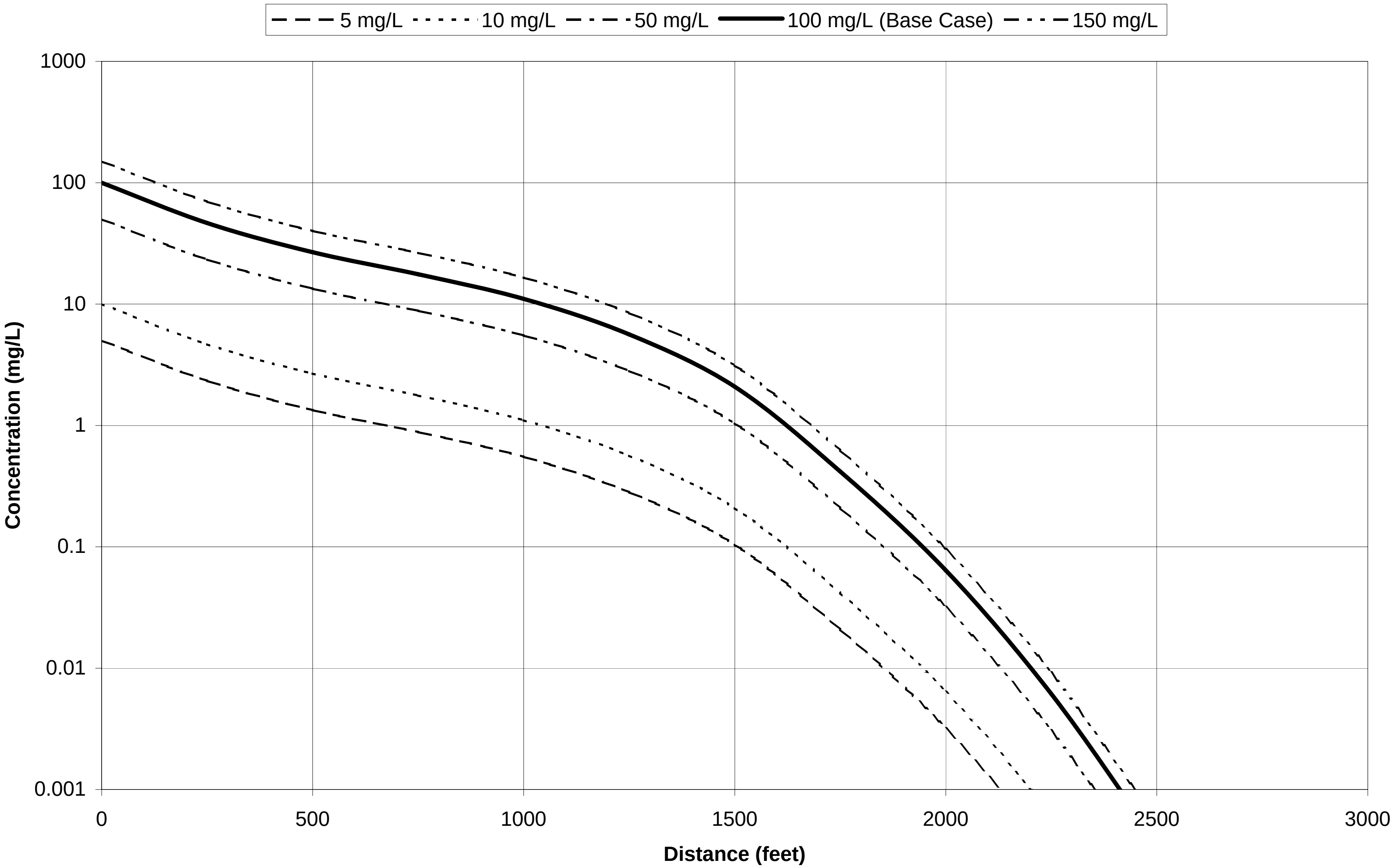


Figure 3c: Source Concentration Effects

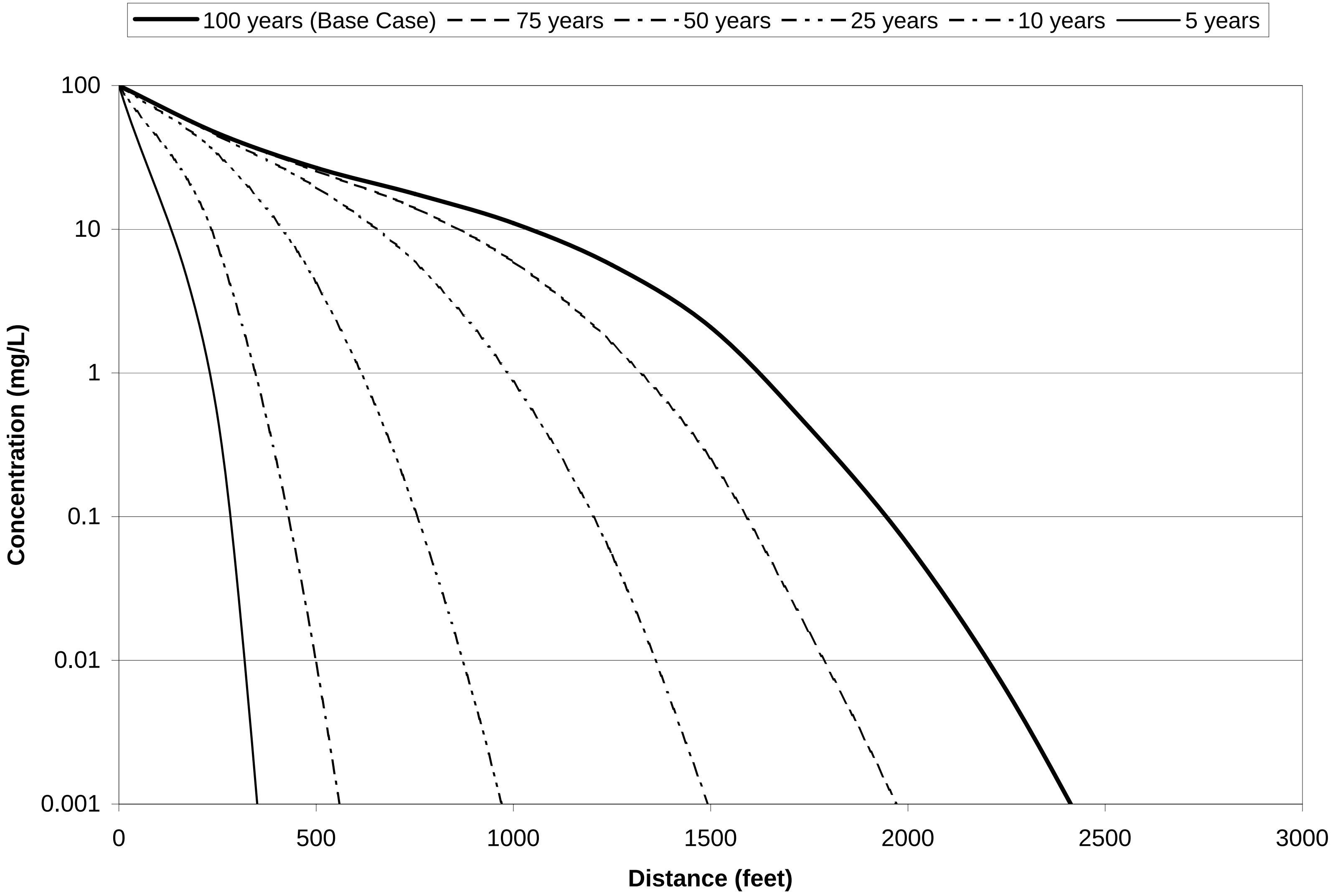


Figure 4a: Concentration Profiles for Different Simulation Times

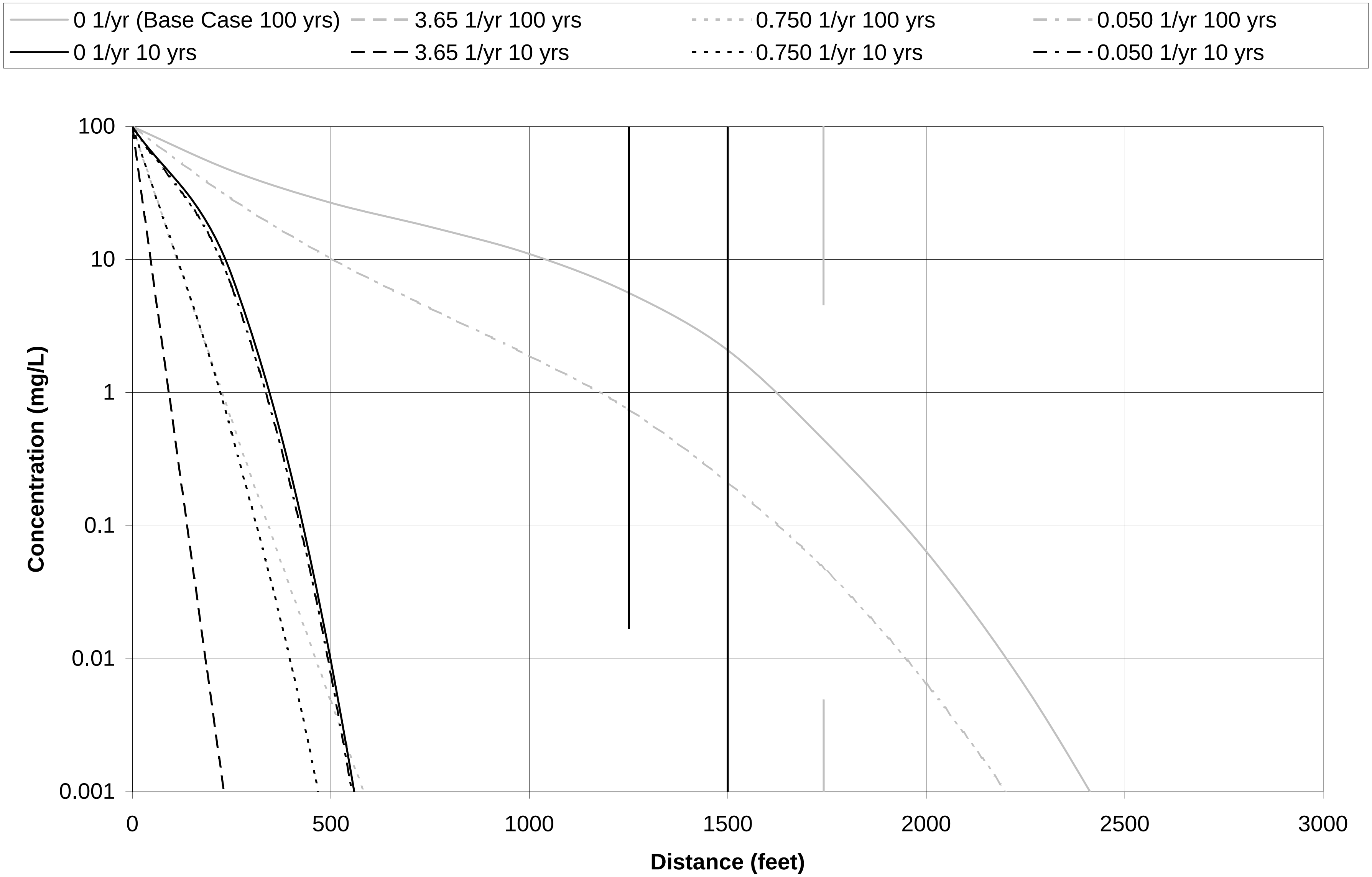


Figure 4b: Biodegradation Effects

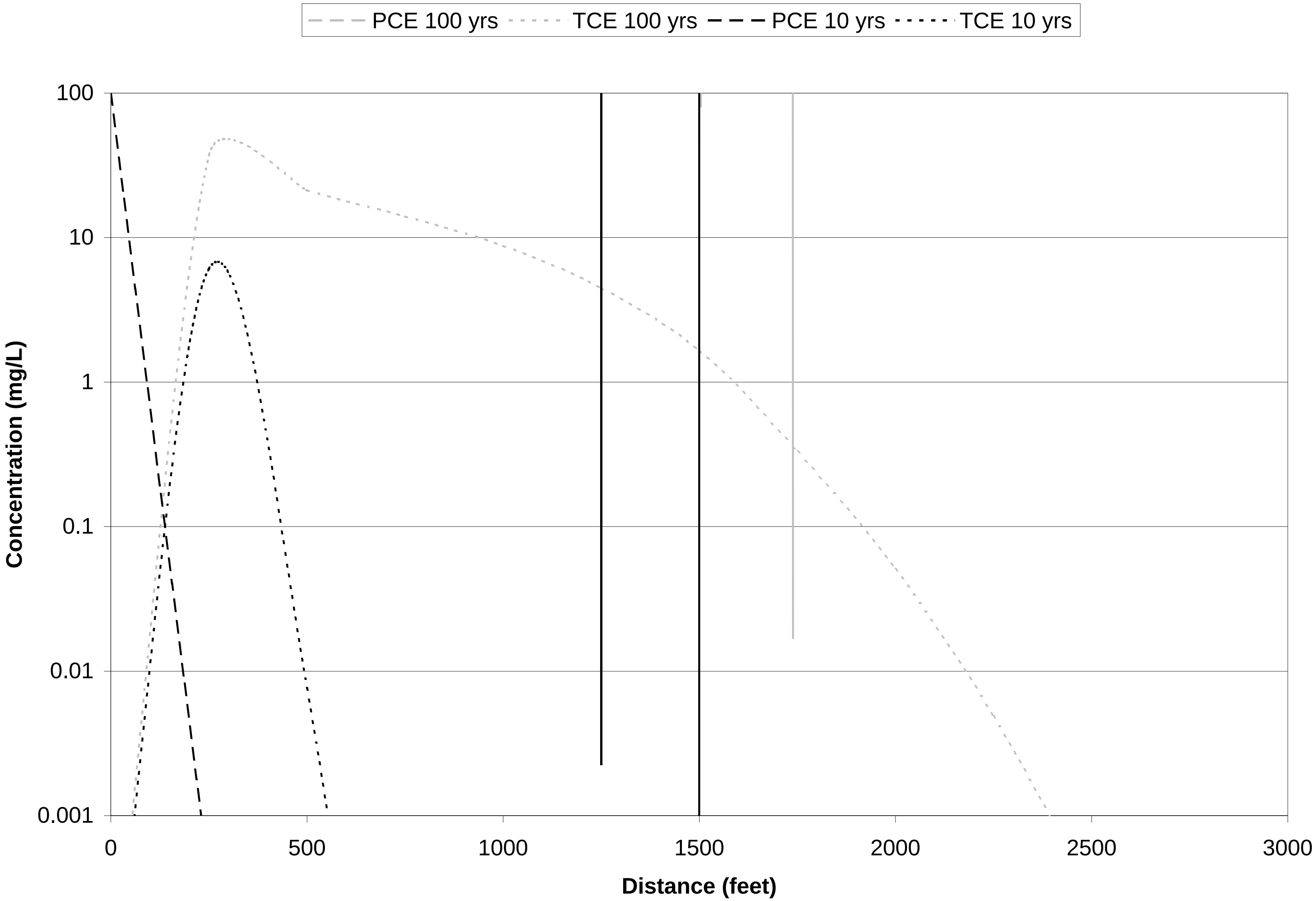


Figure 4c: Biodegradation of PCE to TCE for 3.65 1/yr

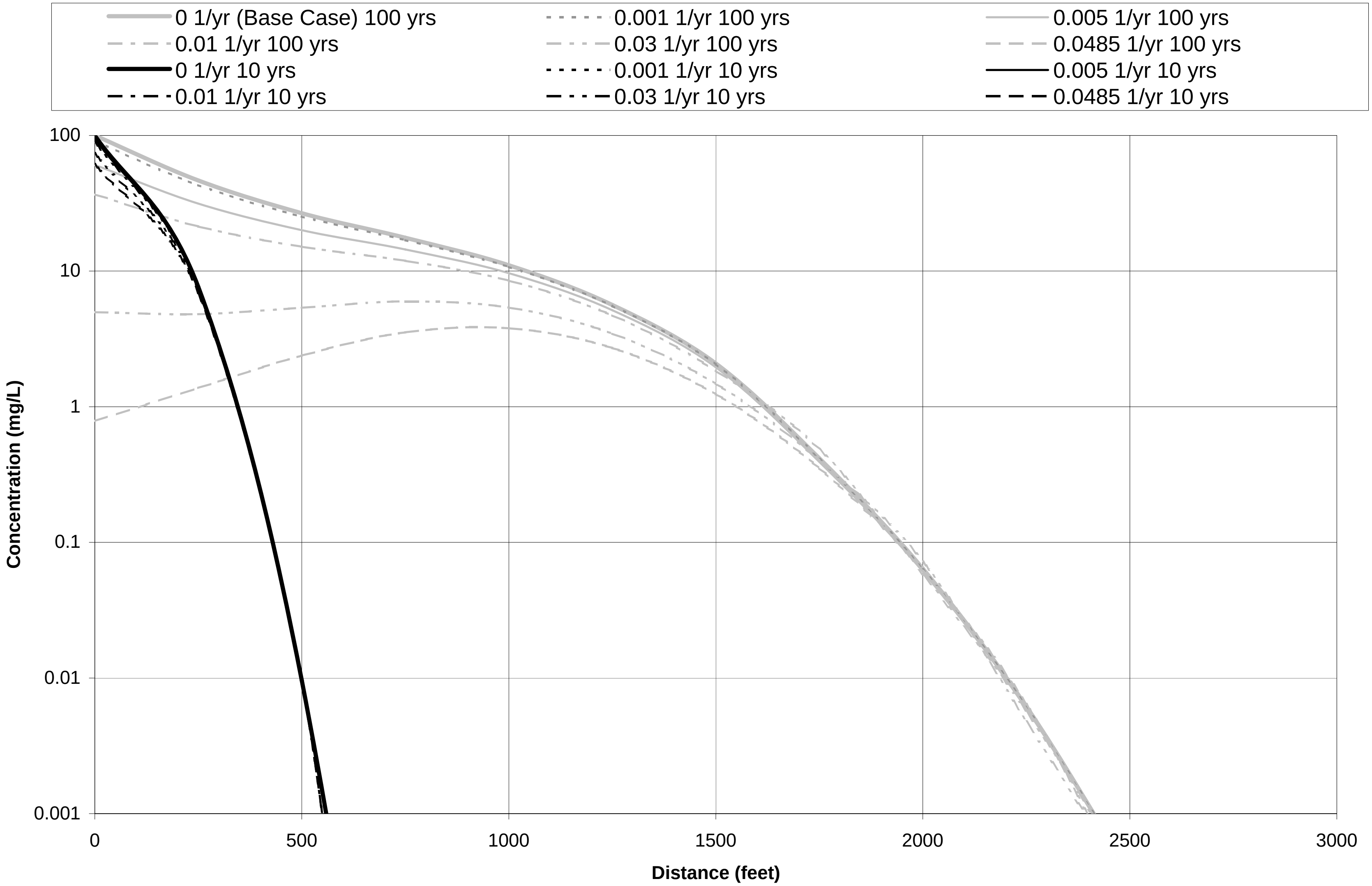


Figure4d: Source Decay Effects

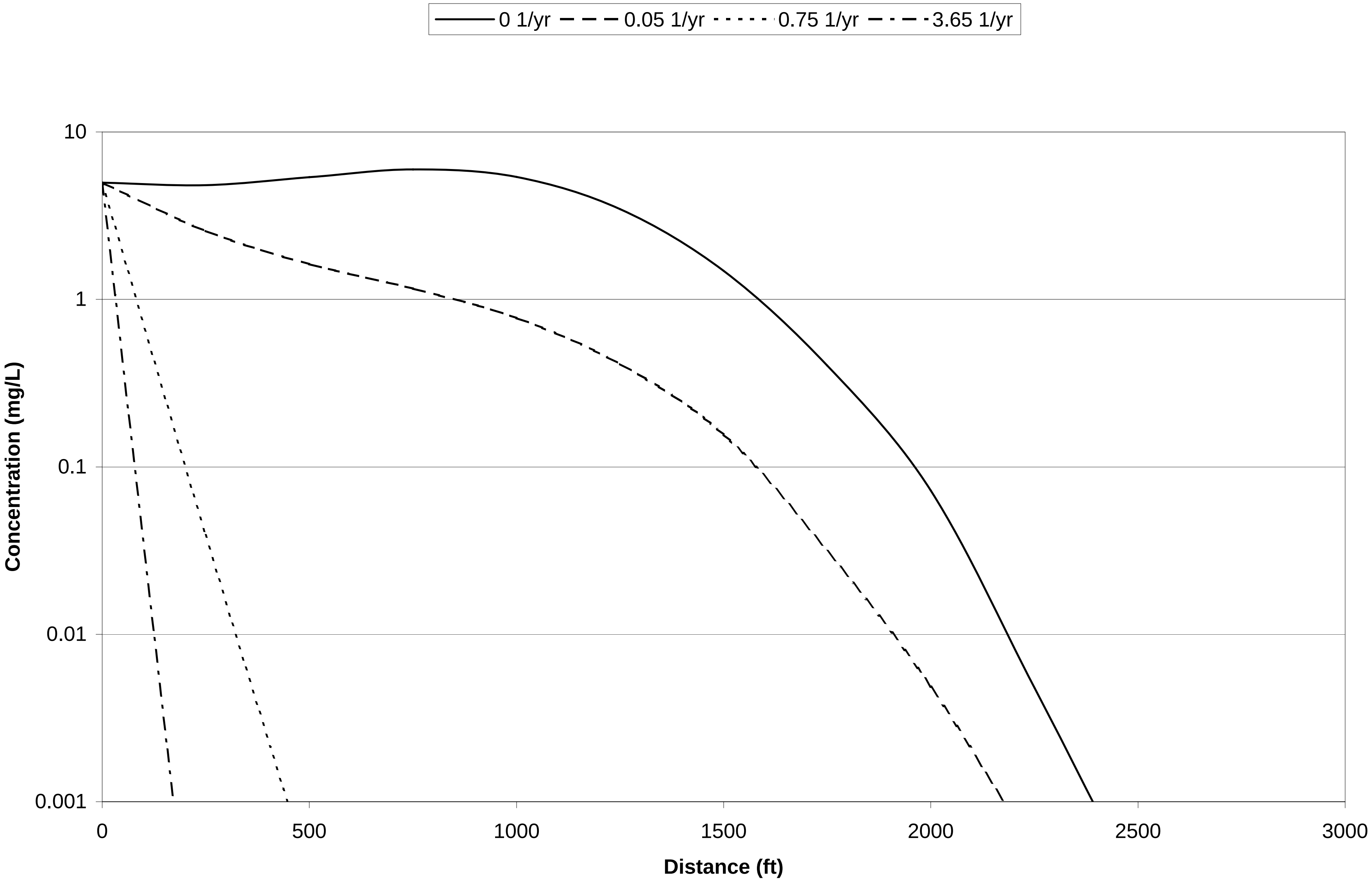


Figure 5: Effect of Biodegradation at a Constant Source Decay of 0.03 1/yr

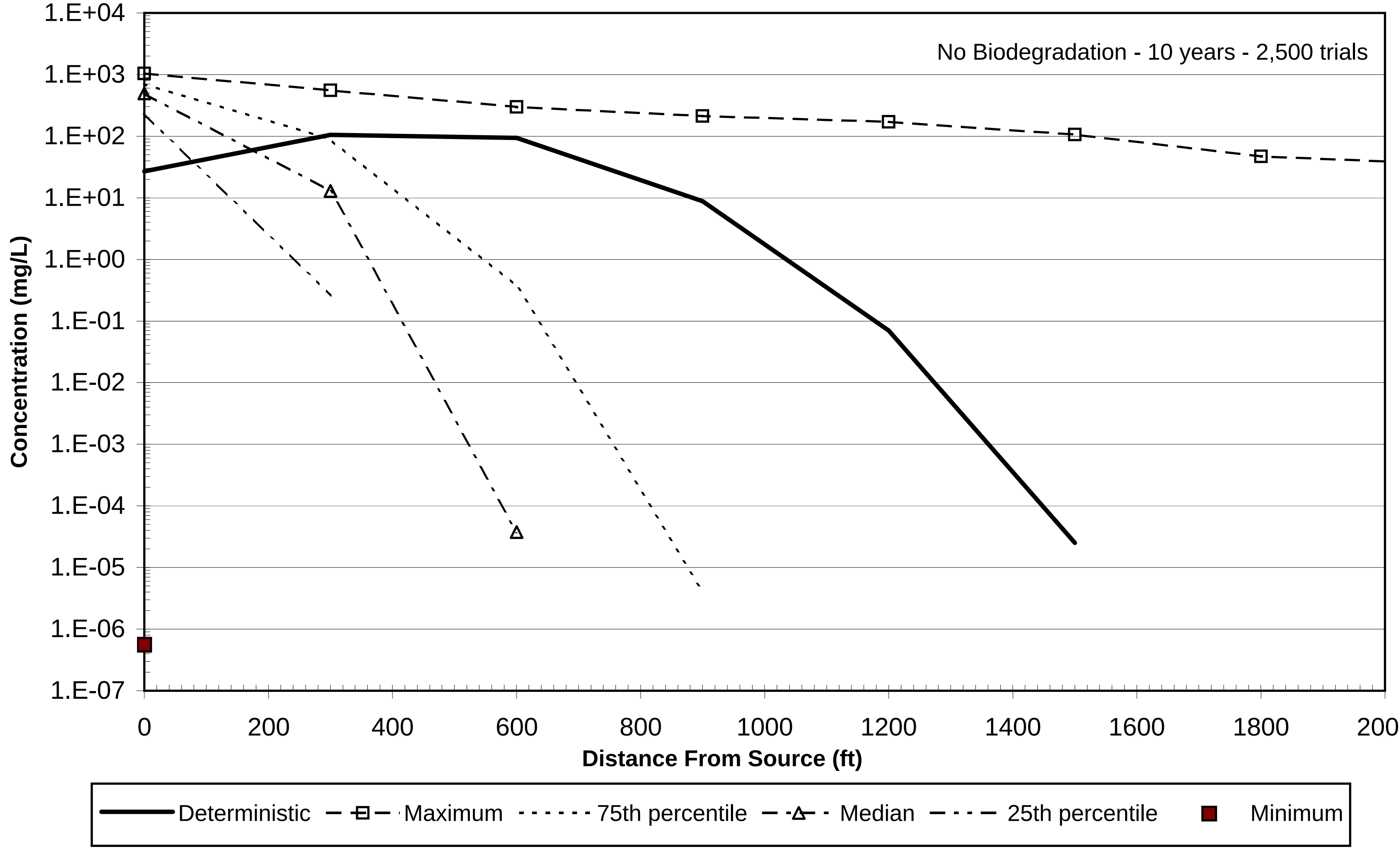


Figure 6a: Deterministic and Stochastic Concentrations Under Non-Biodegrading Conditions
Synthetic Case Study

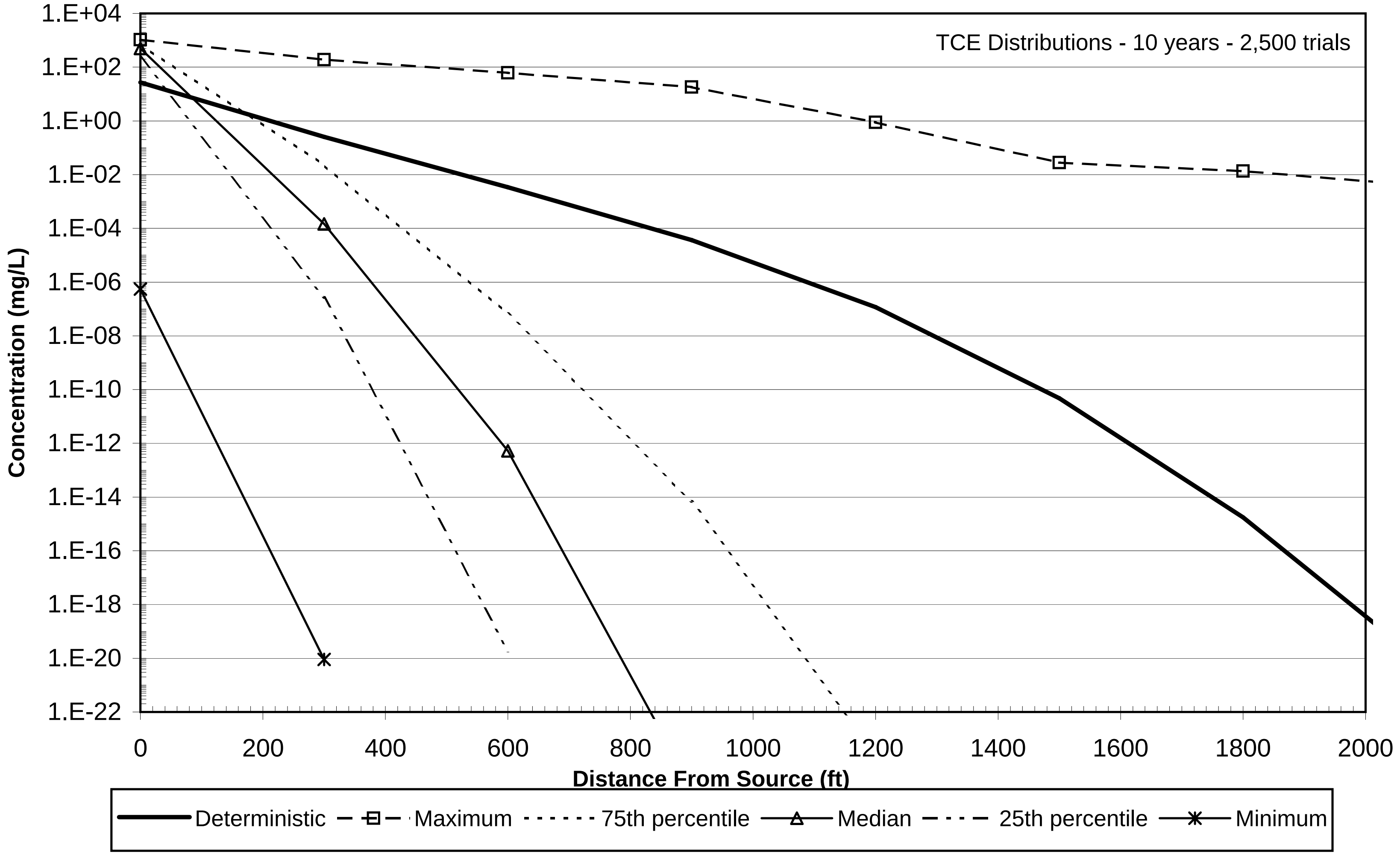


Figure 6b: Deterministic and Stochastic TCE Concentrations with Biodegradation
Synthetic Case Study

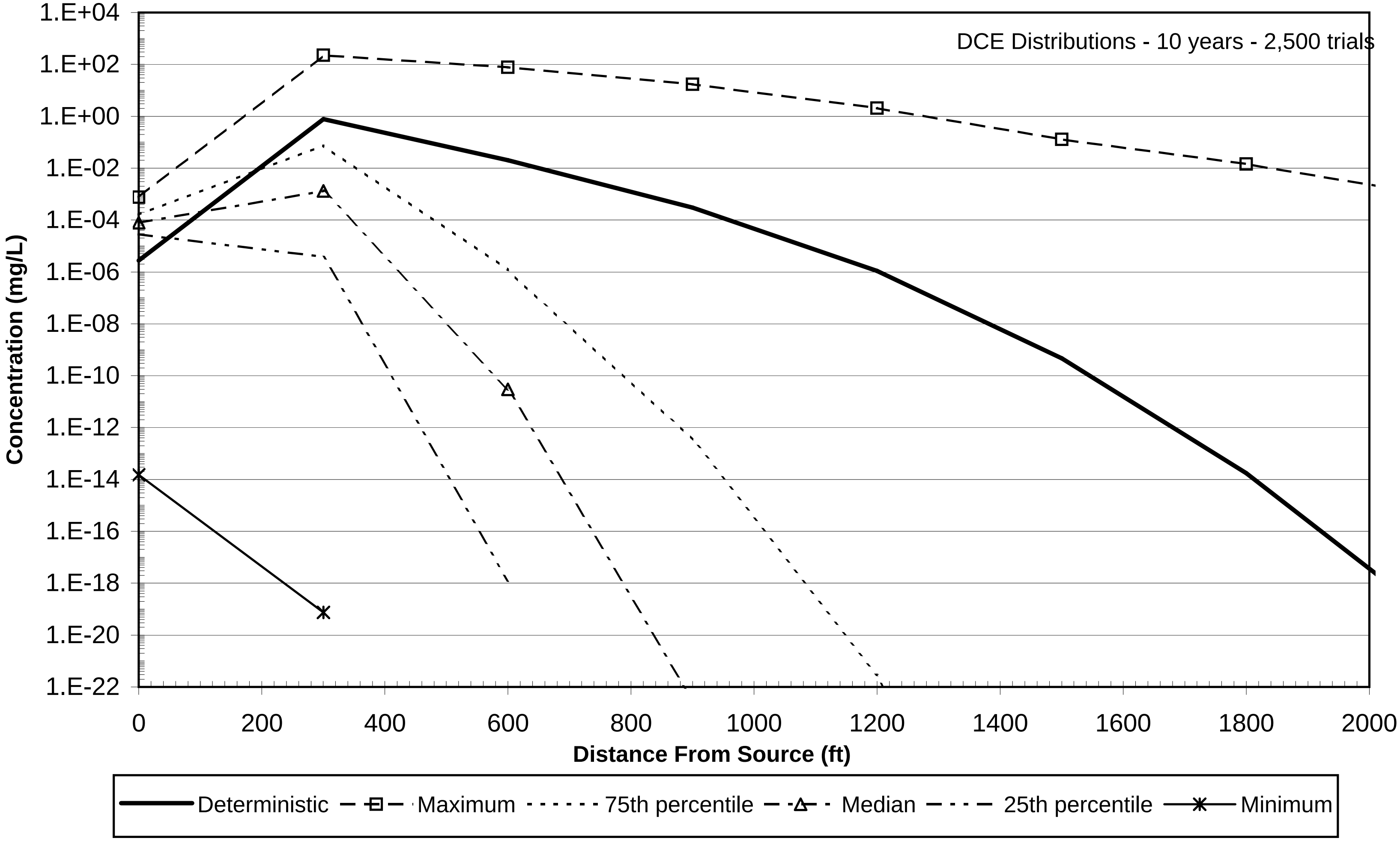


Figure 6c: Deterministic and Stochastic DCE Concentrations with Biodegradation
Synthetic Case Study

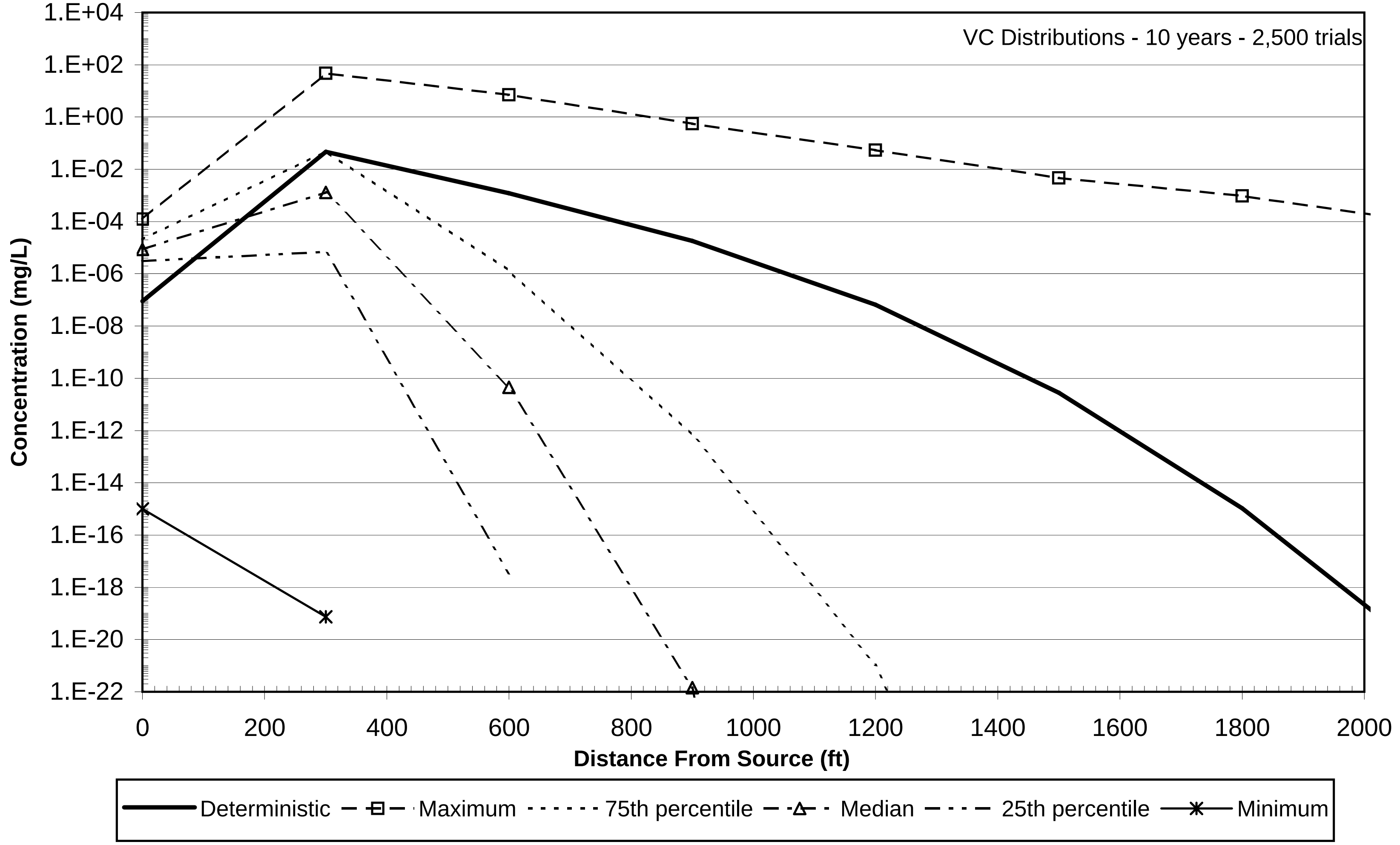


Figure 6d: Deterministic and Stochastic VC Concentrations with Biodegradation
Synthetic Case Study

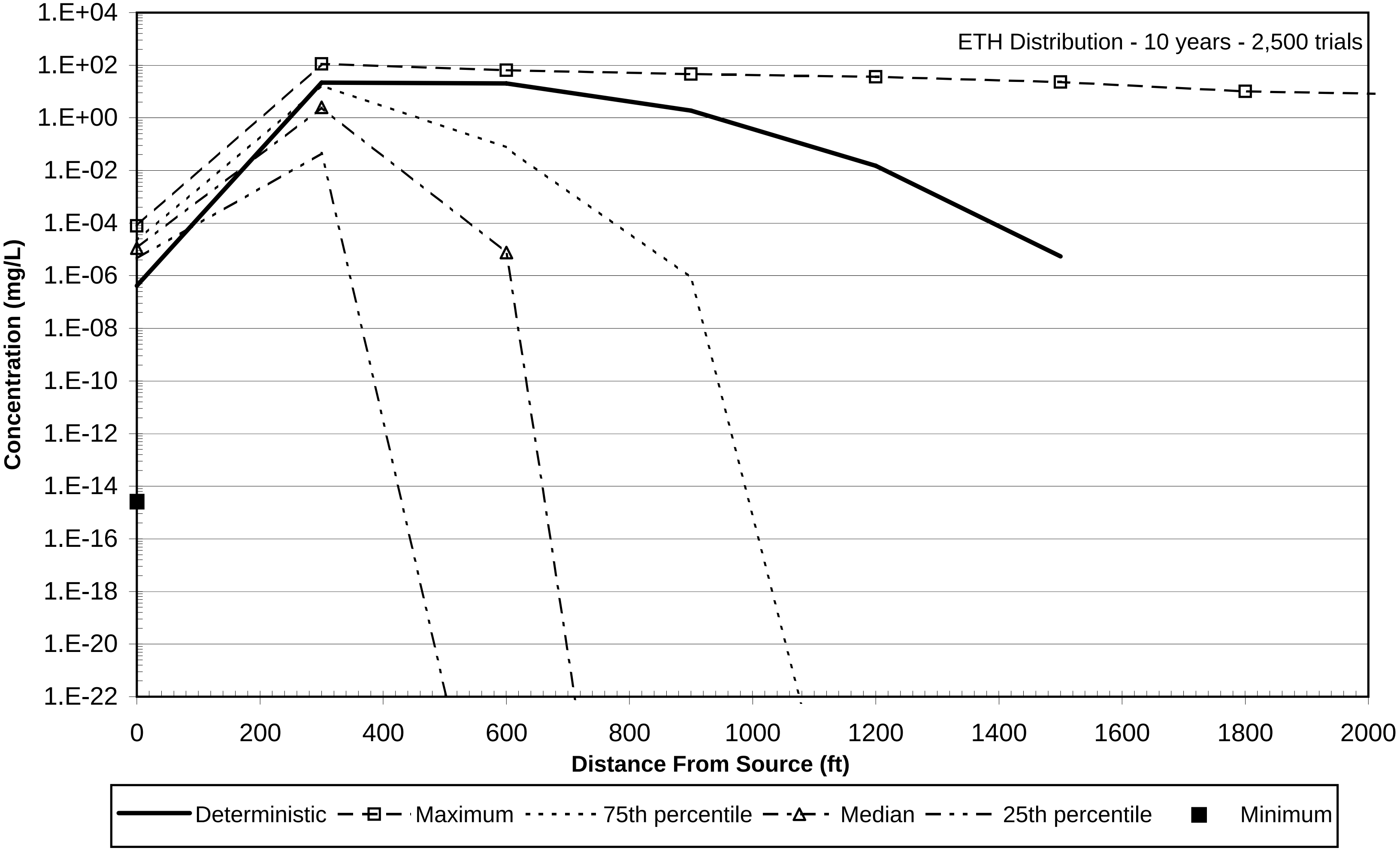


Figure 6e: Deterministic and Stochastic ETH Concentrations with Biodegradation
Synthetic Case Study

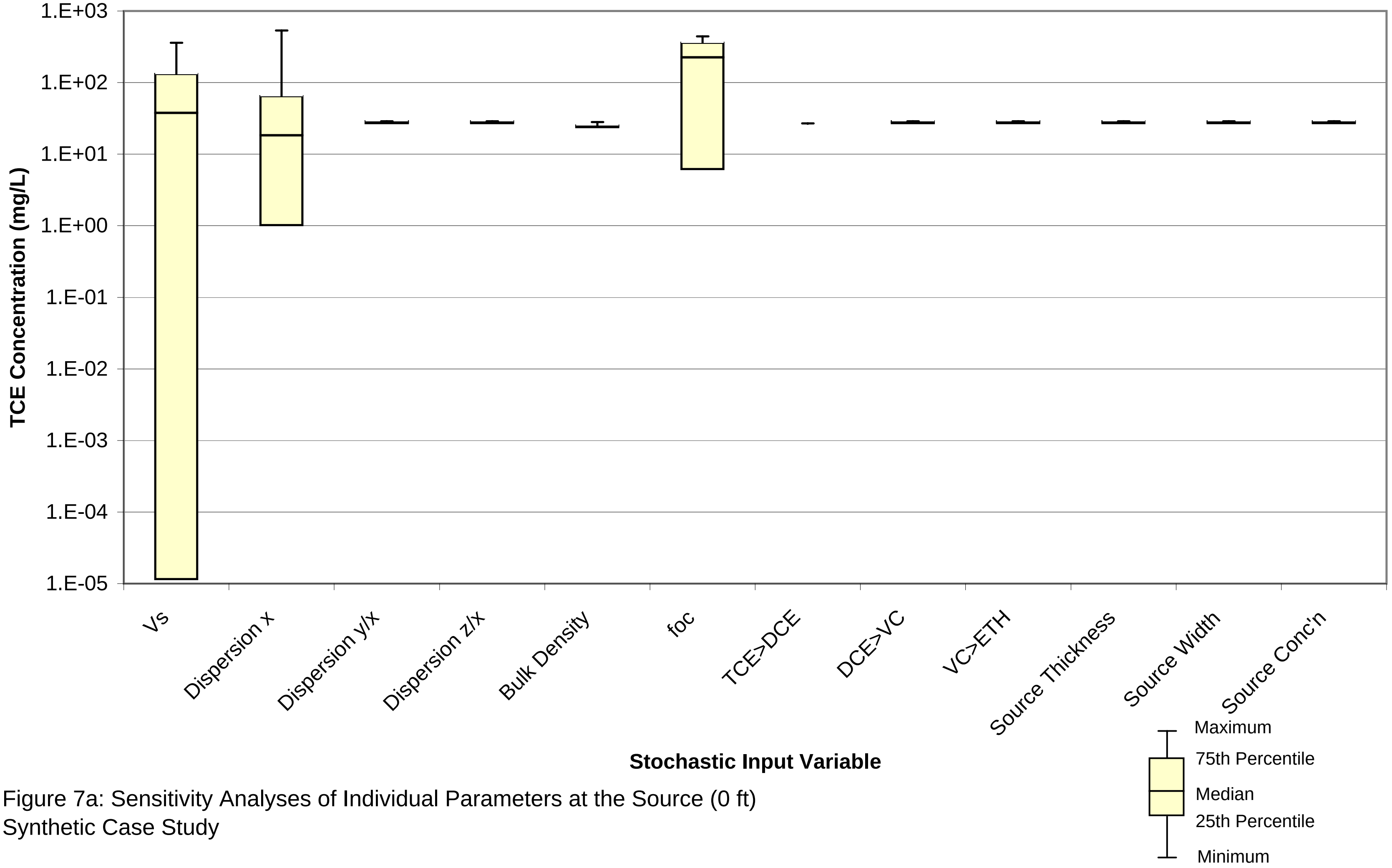


Figure 7a: Sensitivity Analyses of Individual Parameters at the Source (0 ft)
Synthetic Case Study

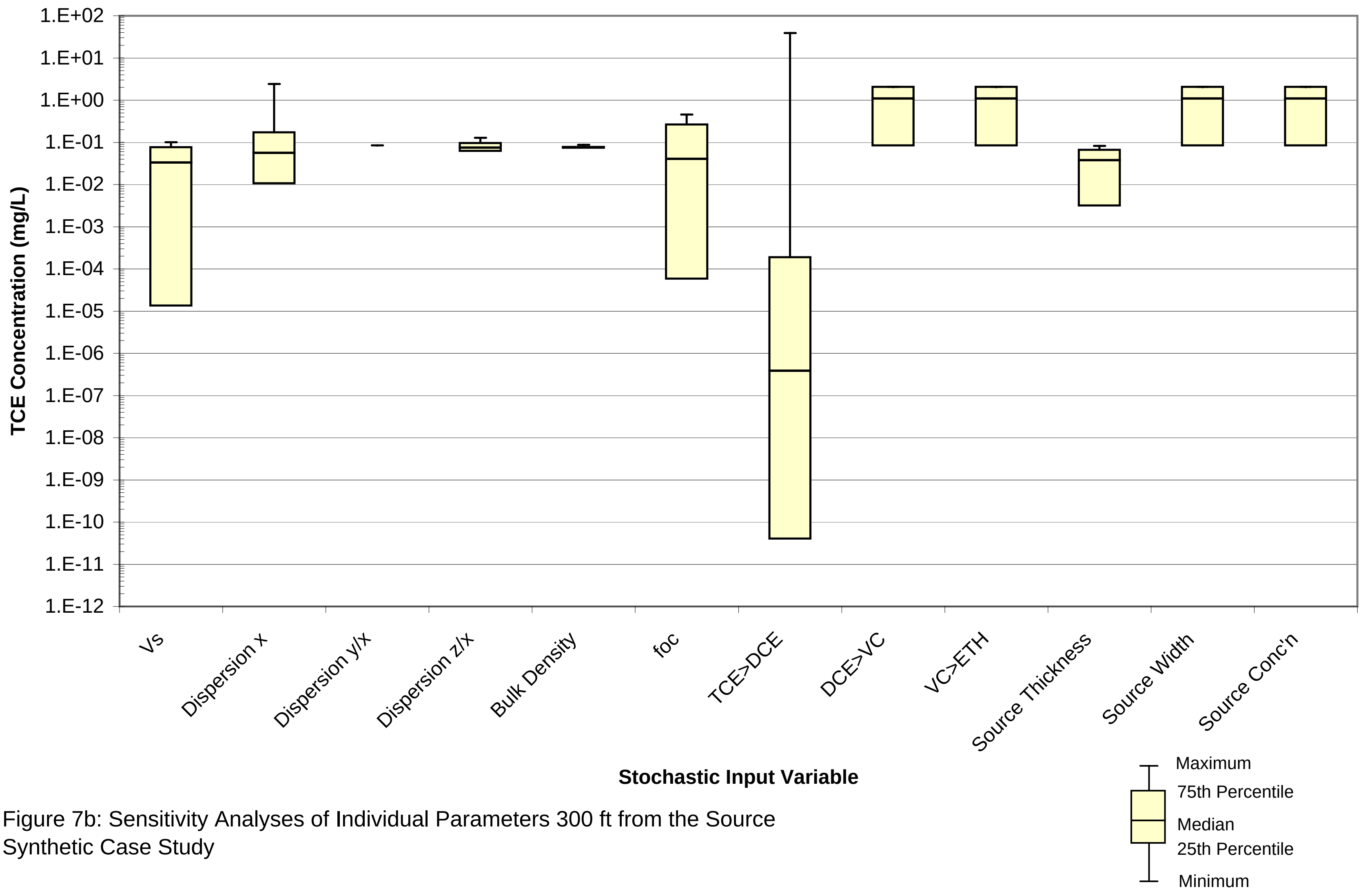


Figure 7b: Sensitivity Analyses of Individual Parameters 300 ft from the Source
Synthetic Case Study

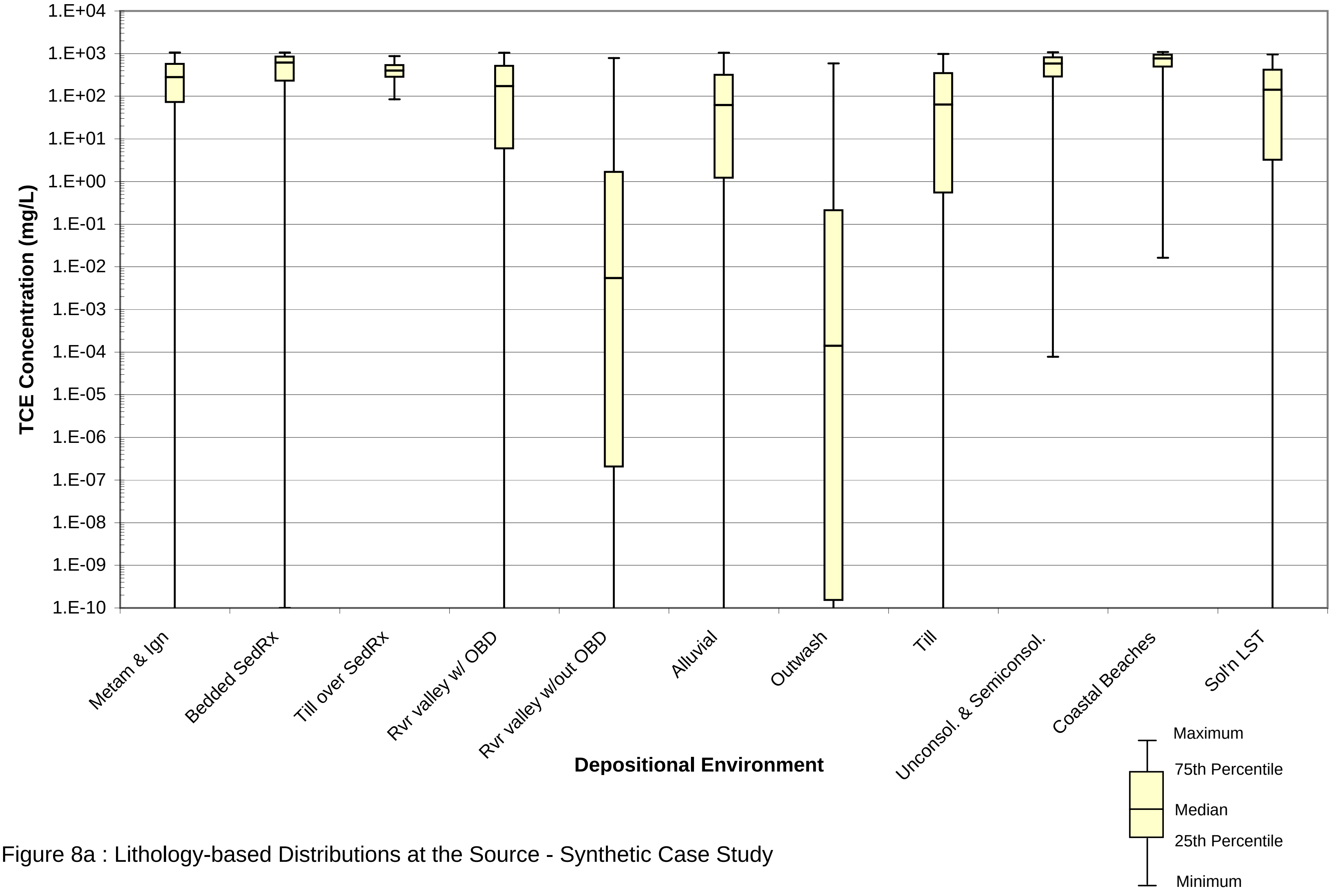


Figure 8a : Lithology-based Distributions at the Source - Synthetic Case Study

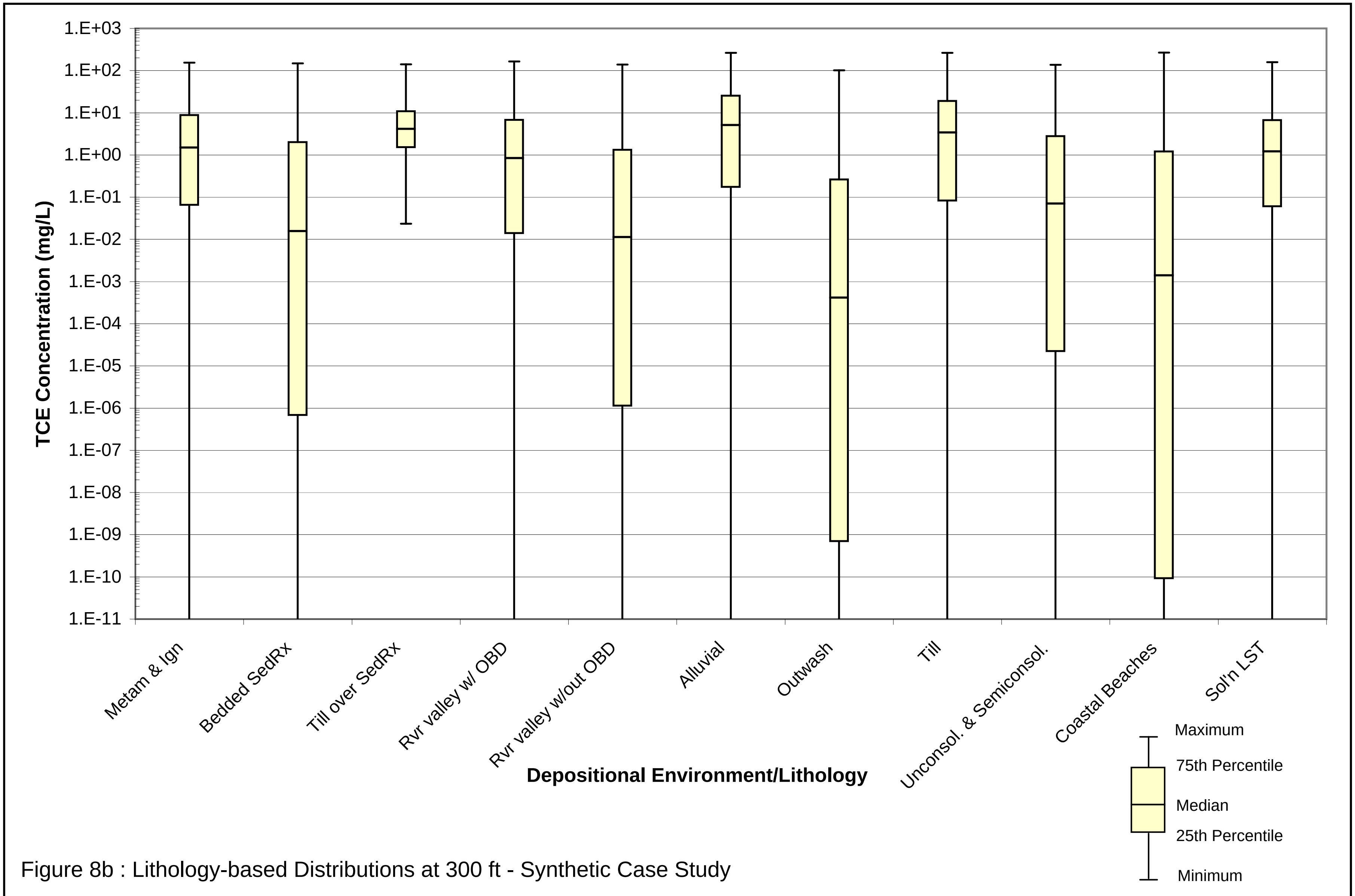


Figure 8b : Lithology-based Distributions at 300 ft - Synthetic Case Study

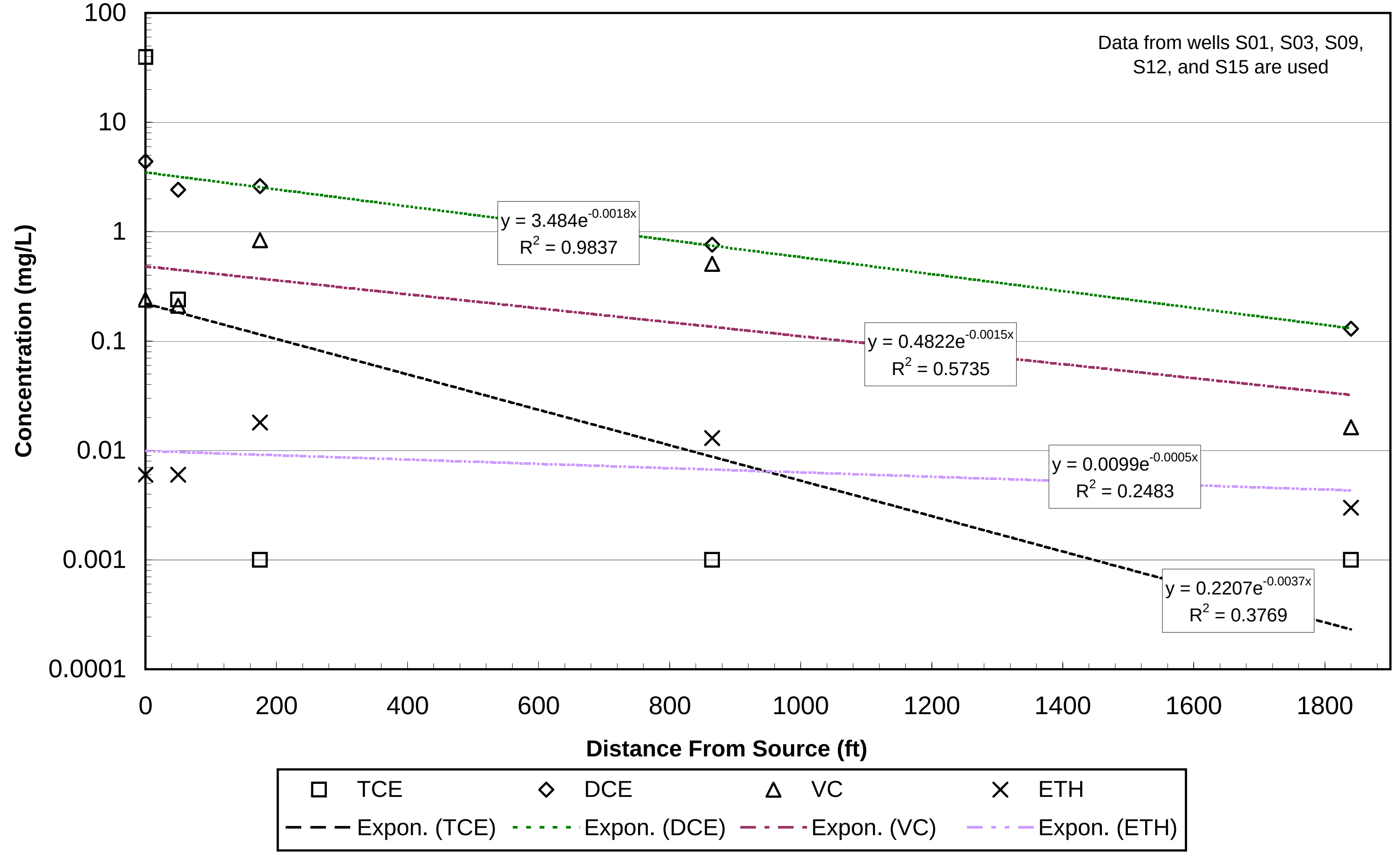


Figure 9a: 1996 Plume Centerline Concentrations - CCAS

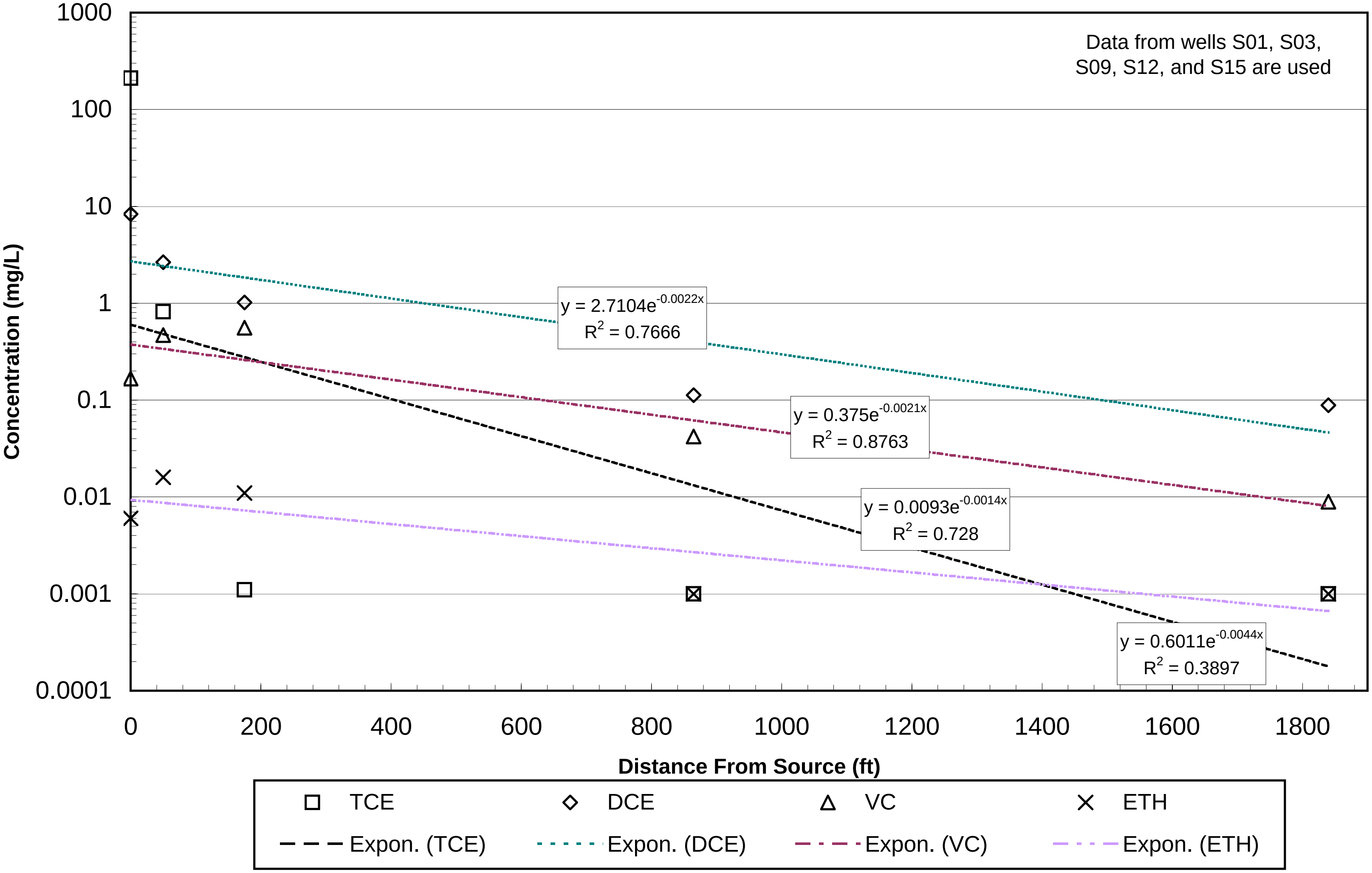


Figure 9b: 1998 Plume Centerline Concentrations - CCAS

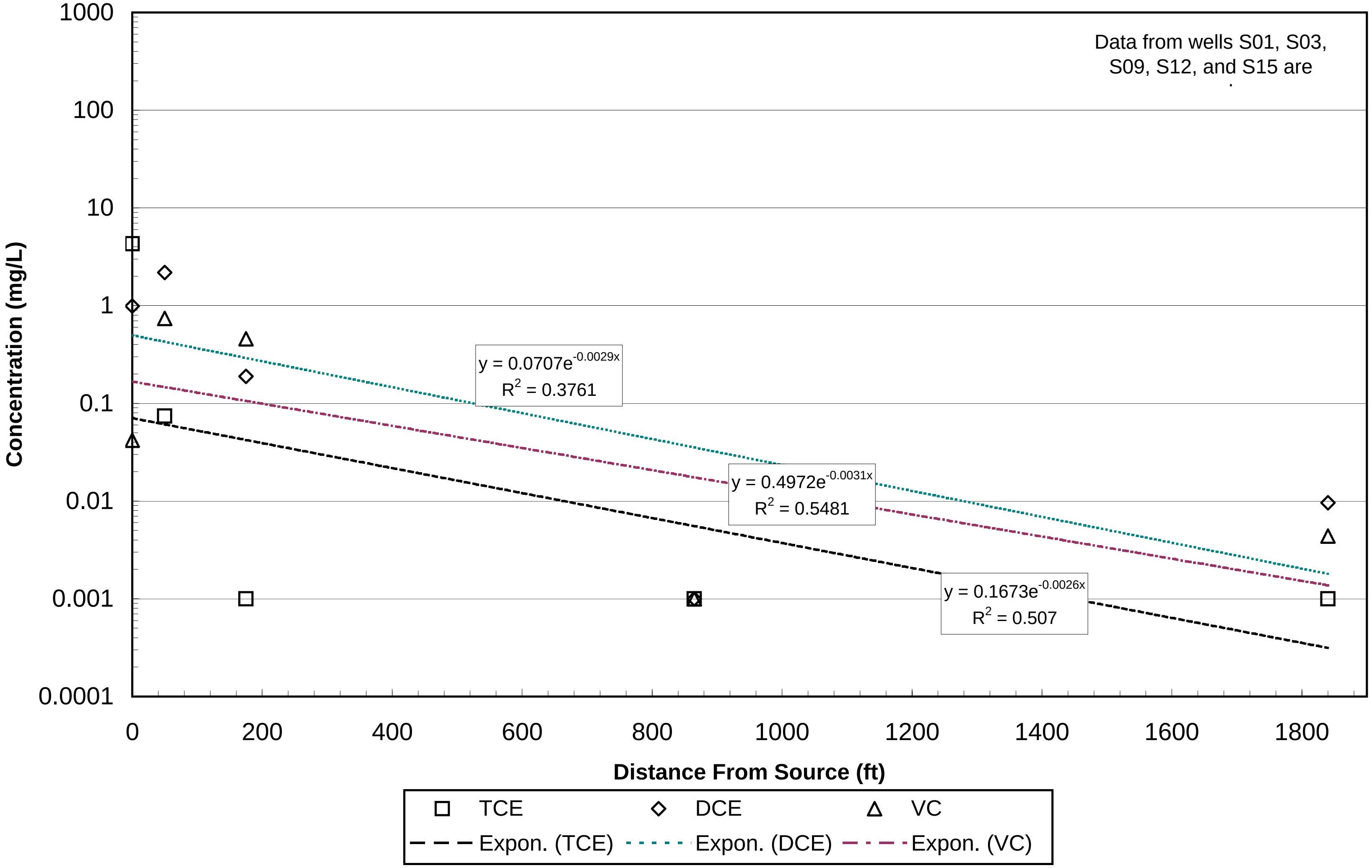


Figure 9c: 2001 Plume Centerline Concentrations - CCAS

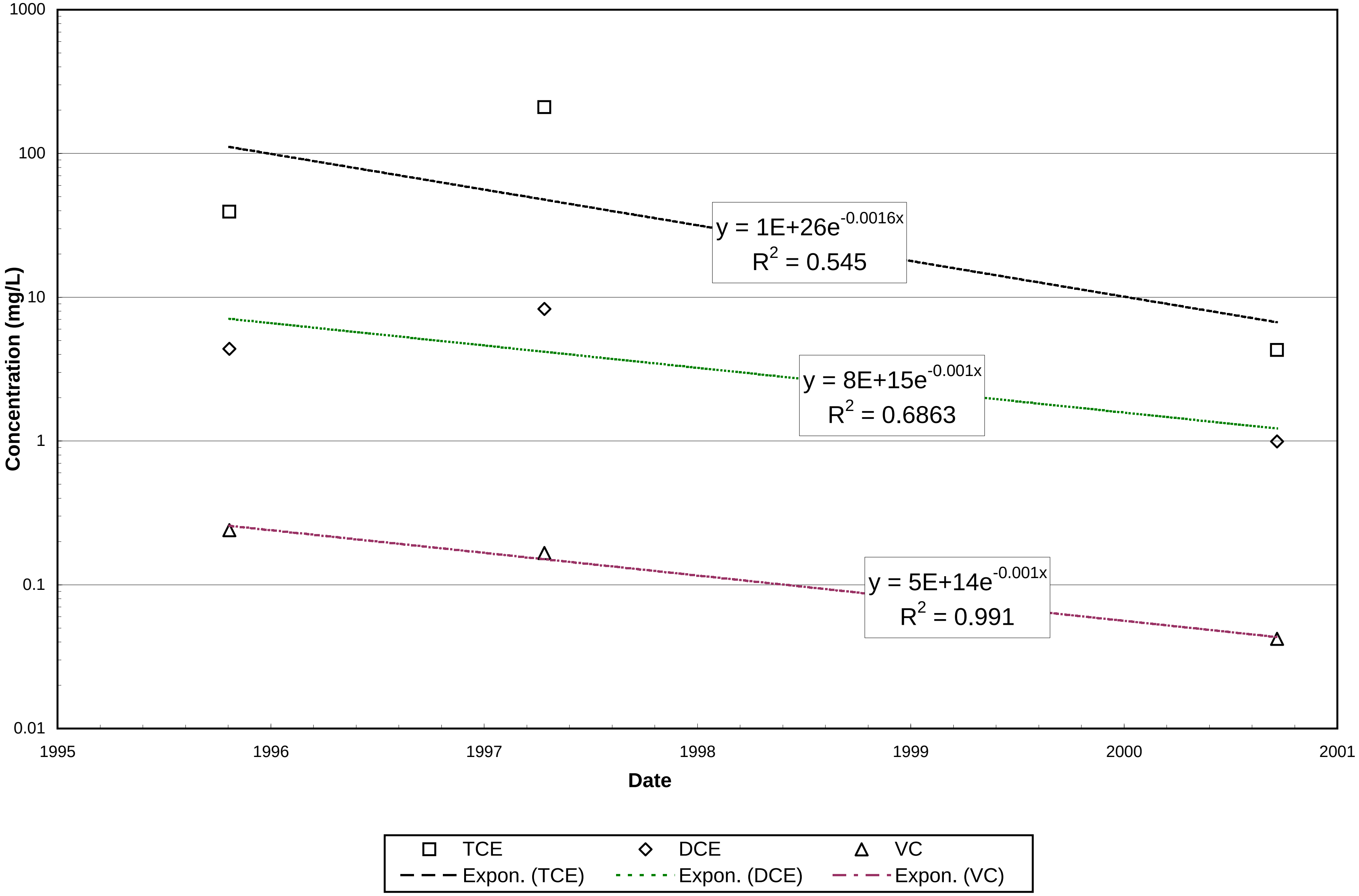


Figure 10a: Source Decay Rates in well S09 - CCAS

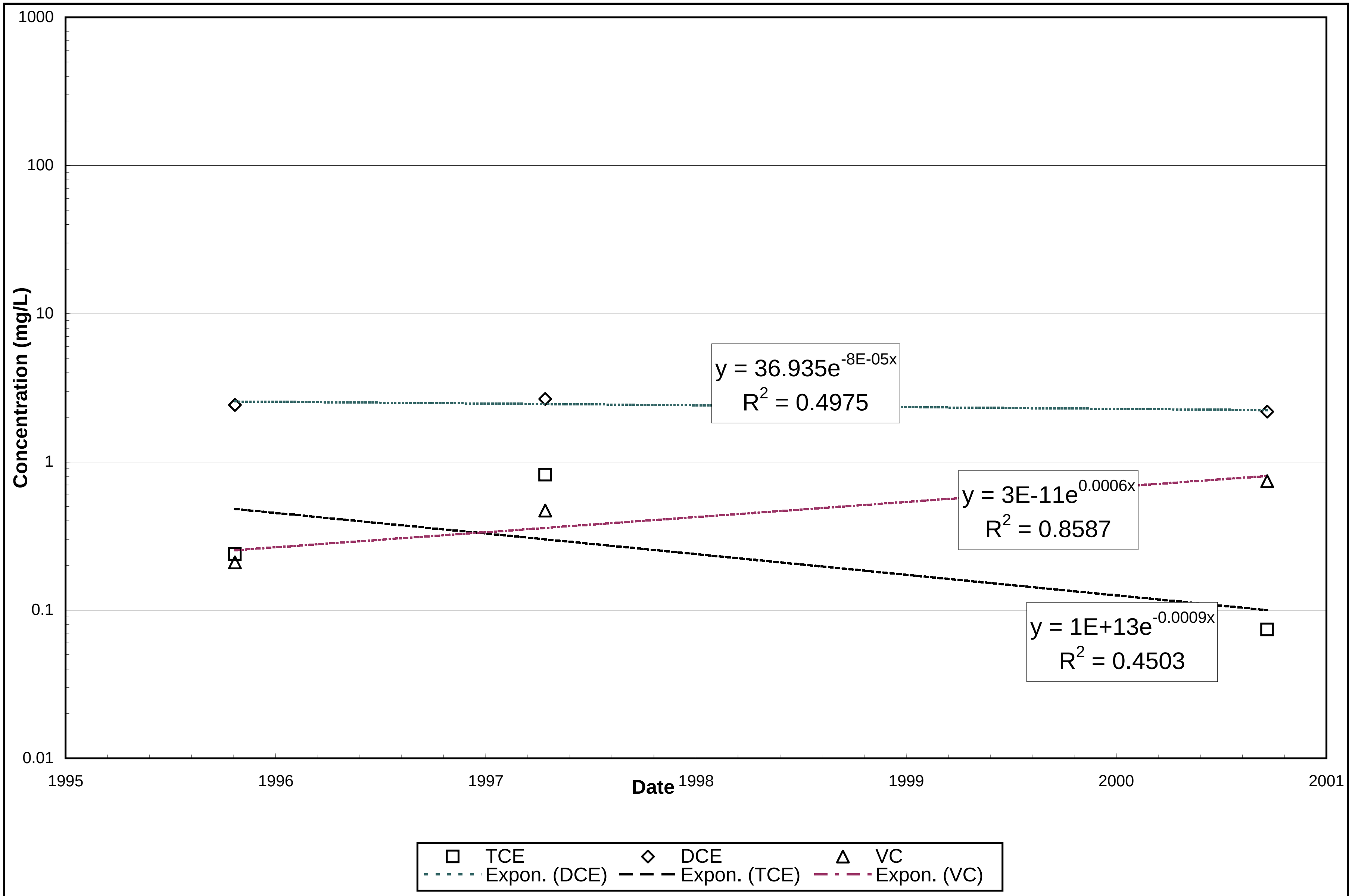


Figure 10b: Source Decay Rates in well S01 - CCAS

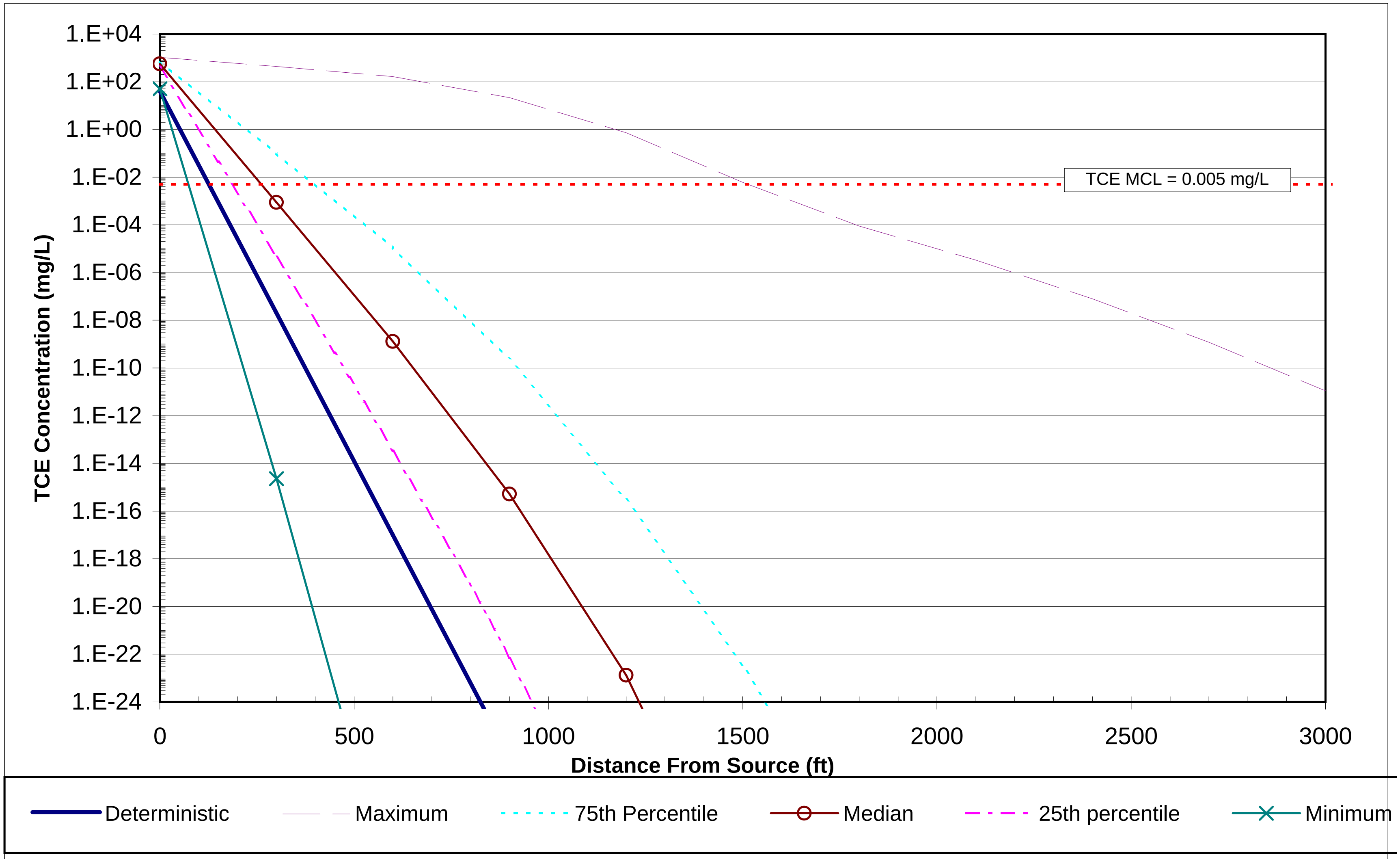


Figure 11: TCE Deterministic and Stochastic Modeled Concentrations in 1996 - CCAS

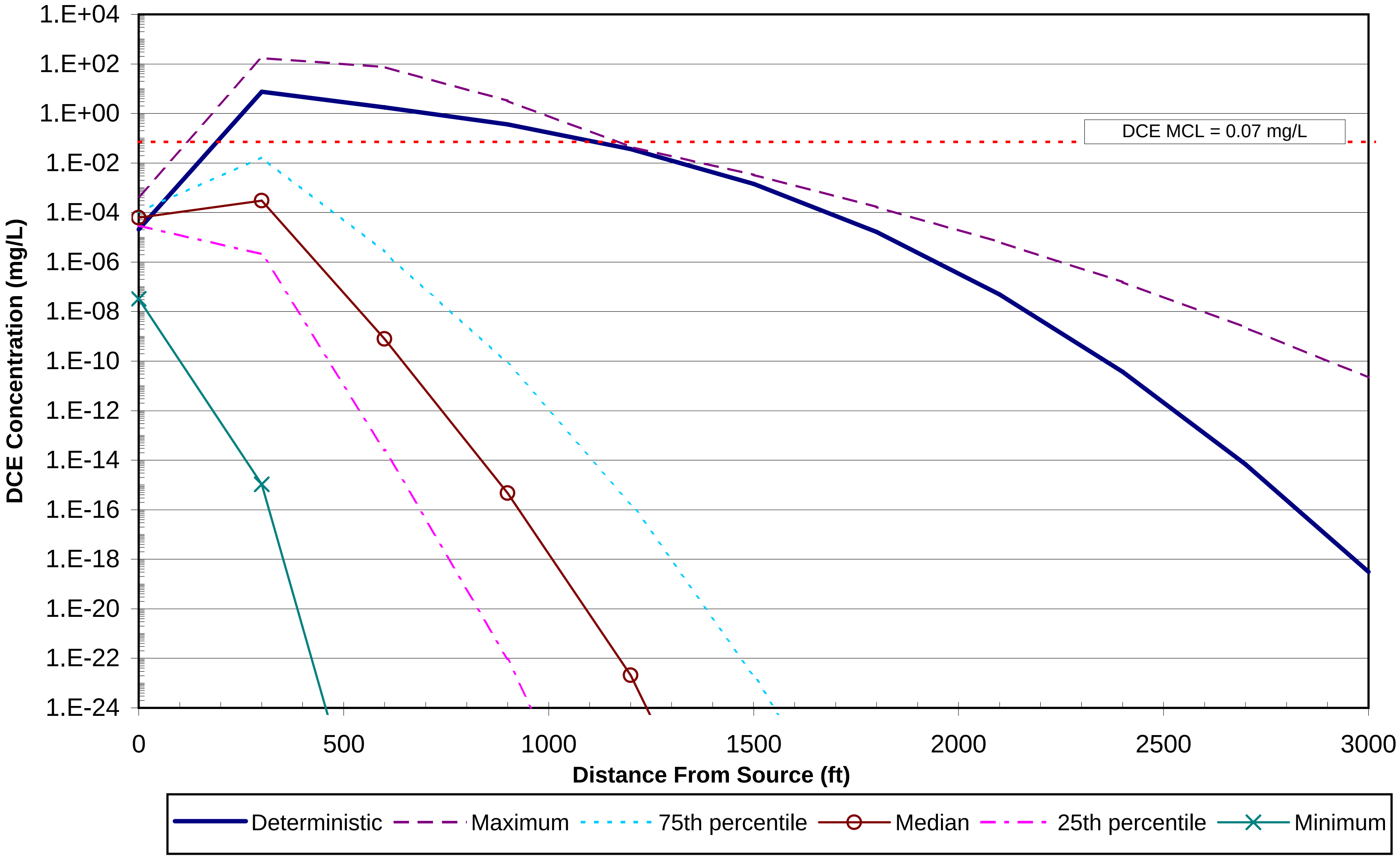


Figure 12a: DCE Deterministic and Stochastic Modeled Concentrations in 1996 - CCAS

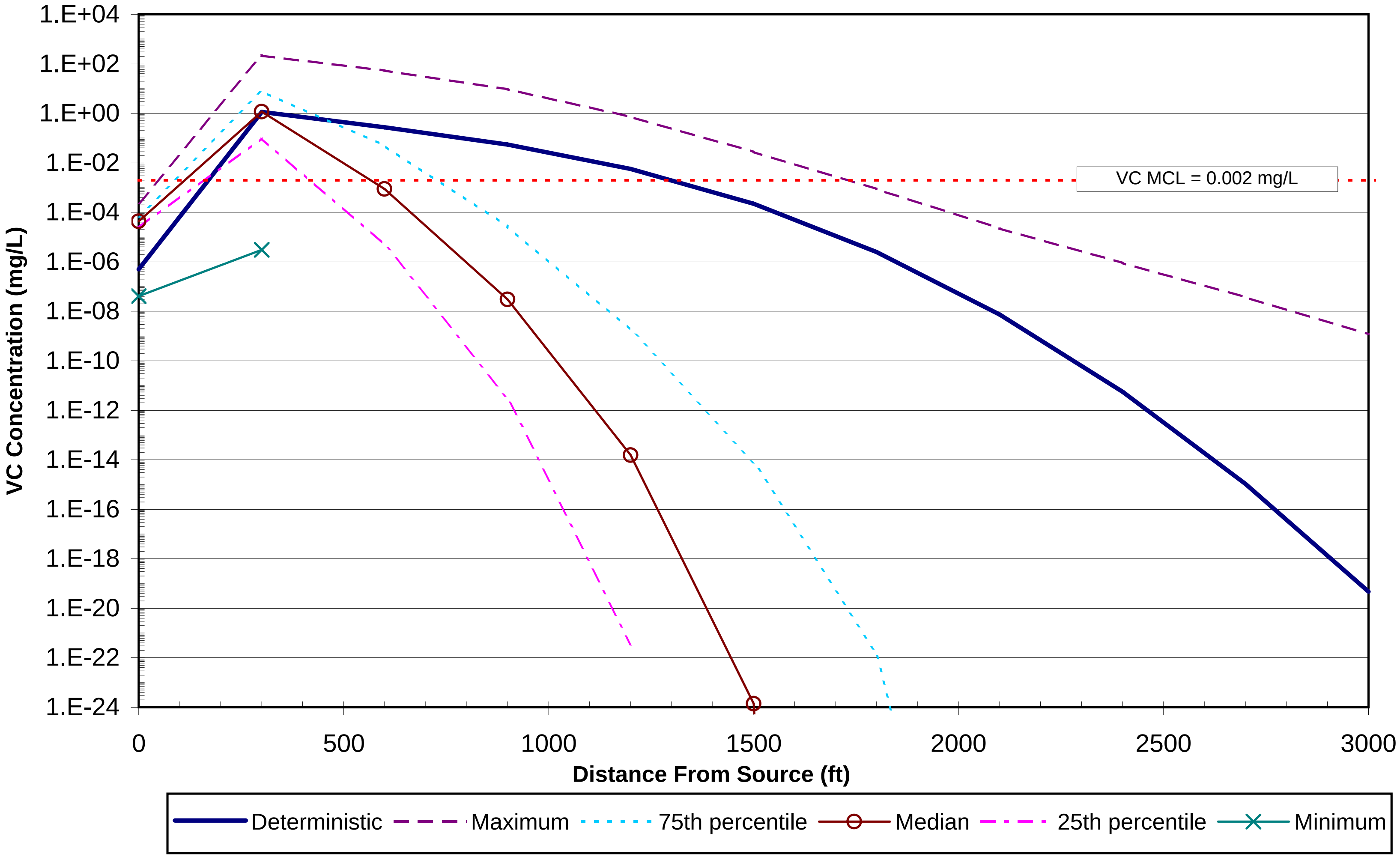


Figure 12b: VC Deterministic and Stochastic Modeled Concentrations in 1996 - CCAS

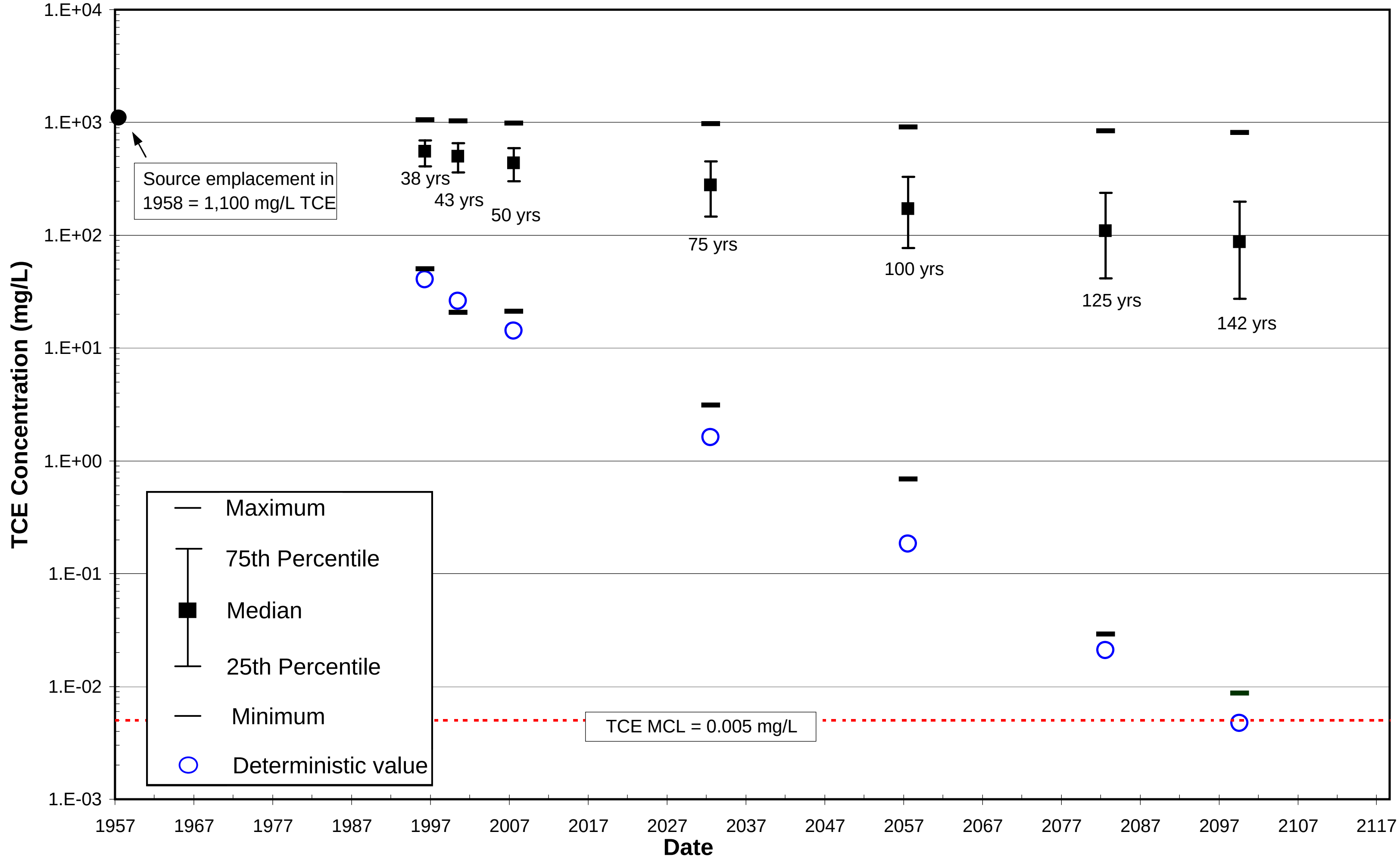


Figure 13a: BIOCHLOR Deterministic and Stochastic Model TCE Predictions at the Source Over Time - CCAS

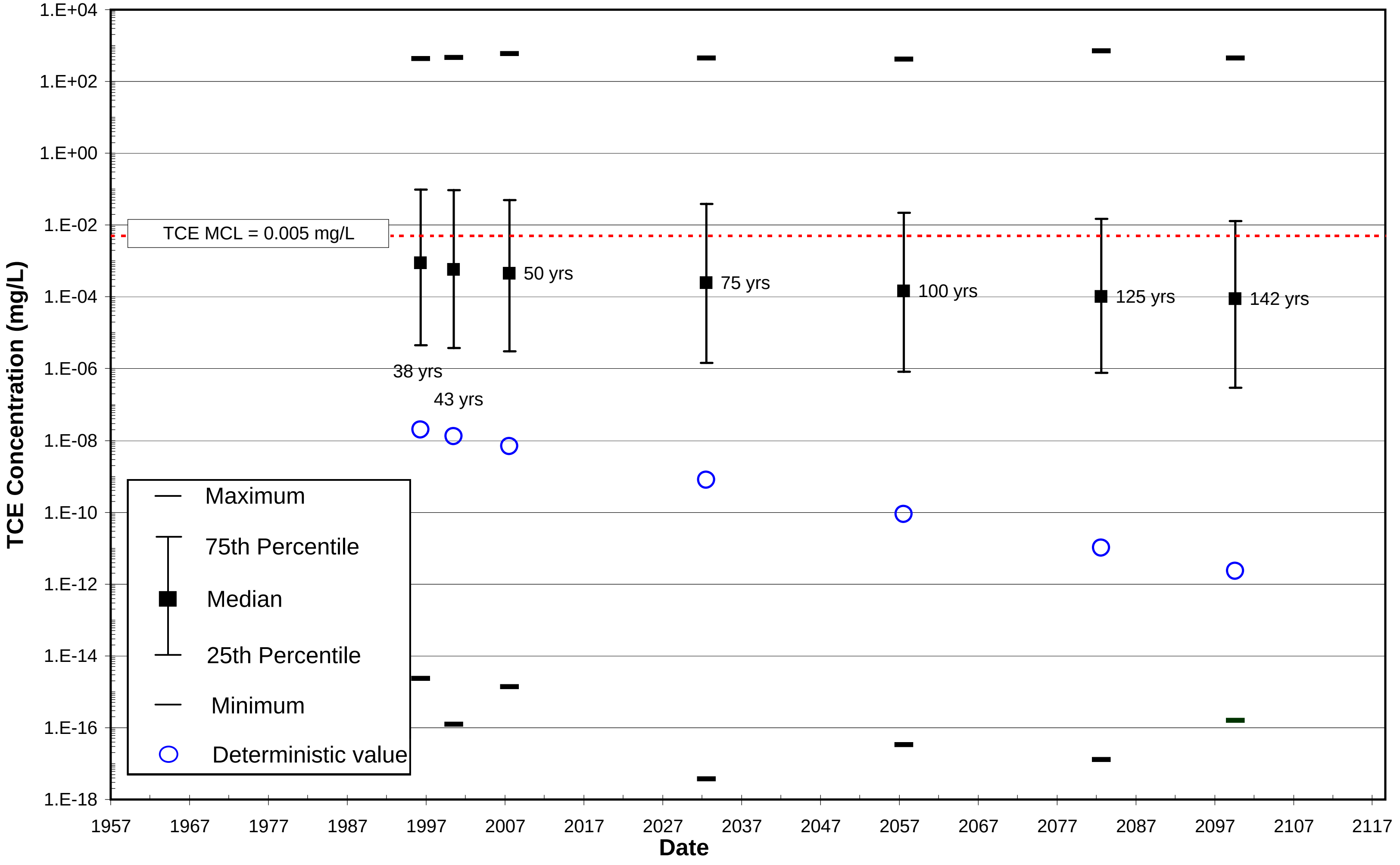


Figure 13b: BIOCHLOR Deterministic and Stochastic Model TCE Predictions at 300 ft Downgradient of the Source Over Time - CCAS

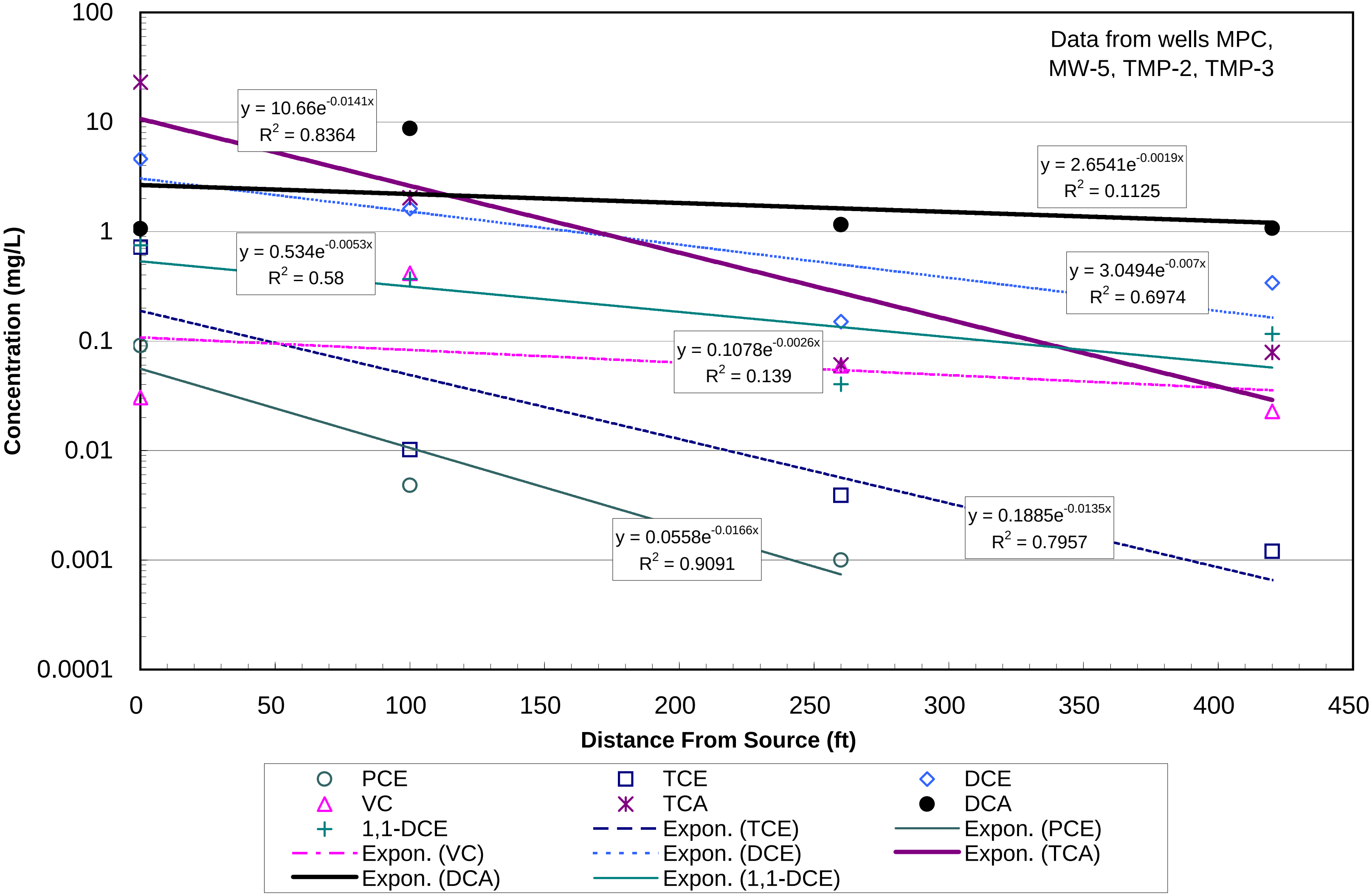


Figure 14: 1997 Centerline Concentrations - Shaw AFB

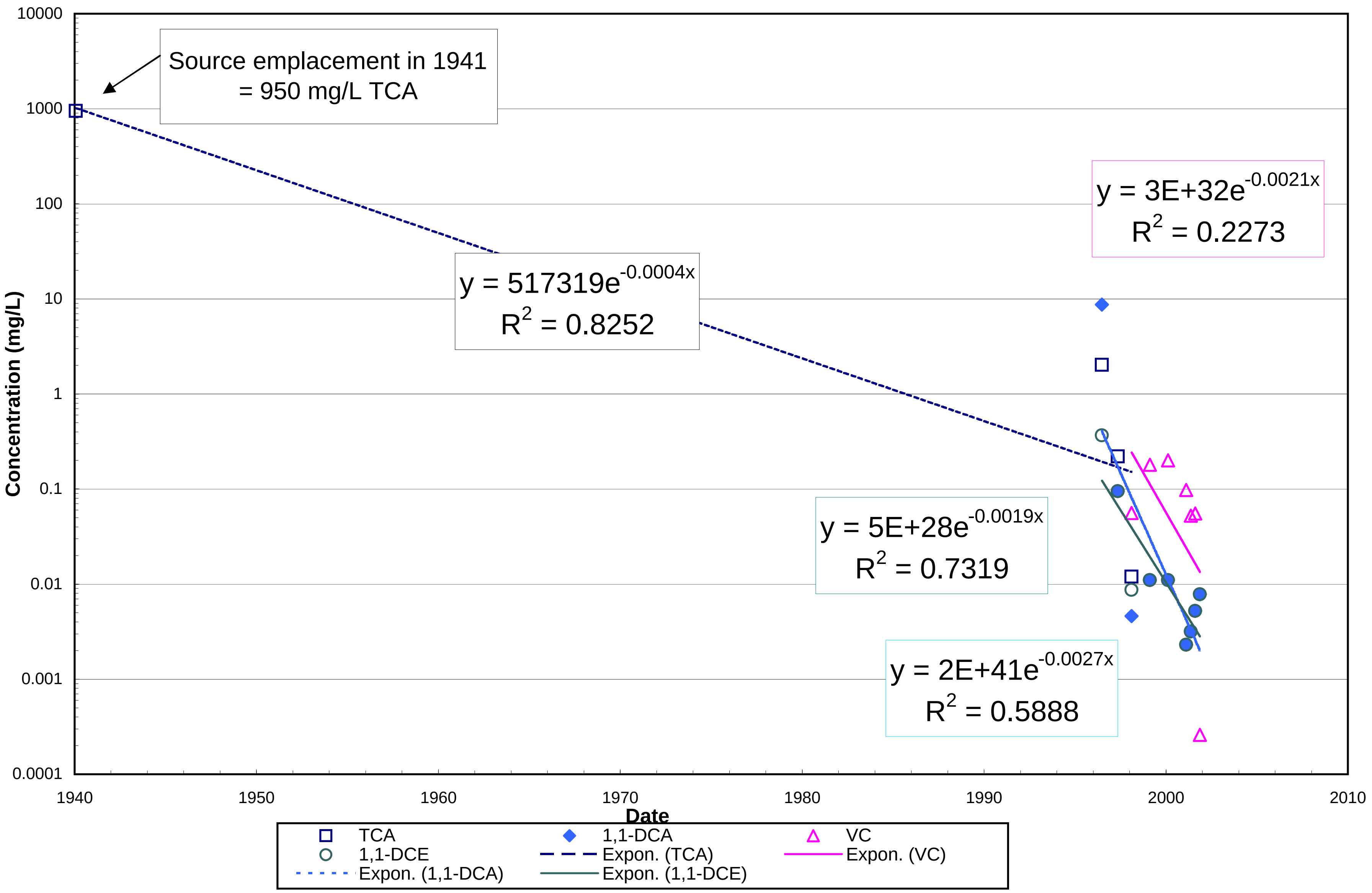


Figure 15a: Source Decay Rates in well MW-115 - Shaw AFB

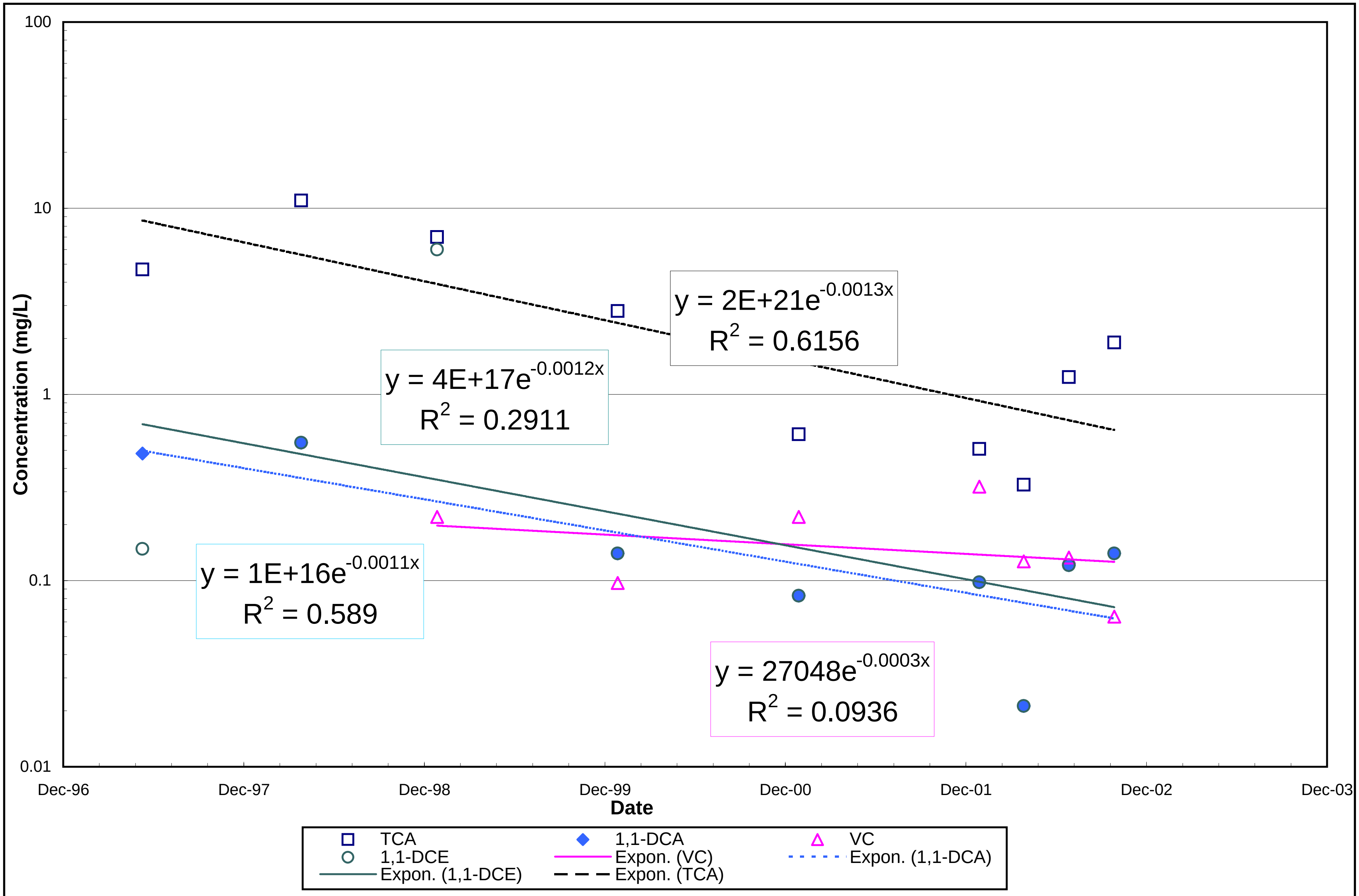


Figure 15b: Source Decay Rates in well MW-117 - Shaw AFB

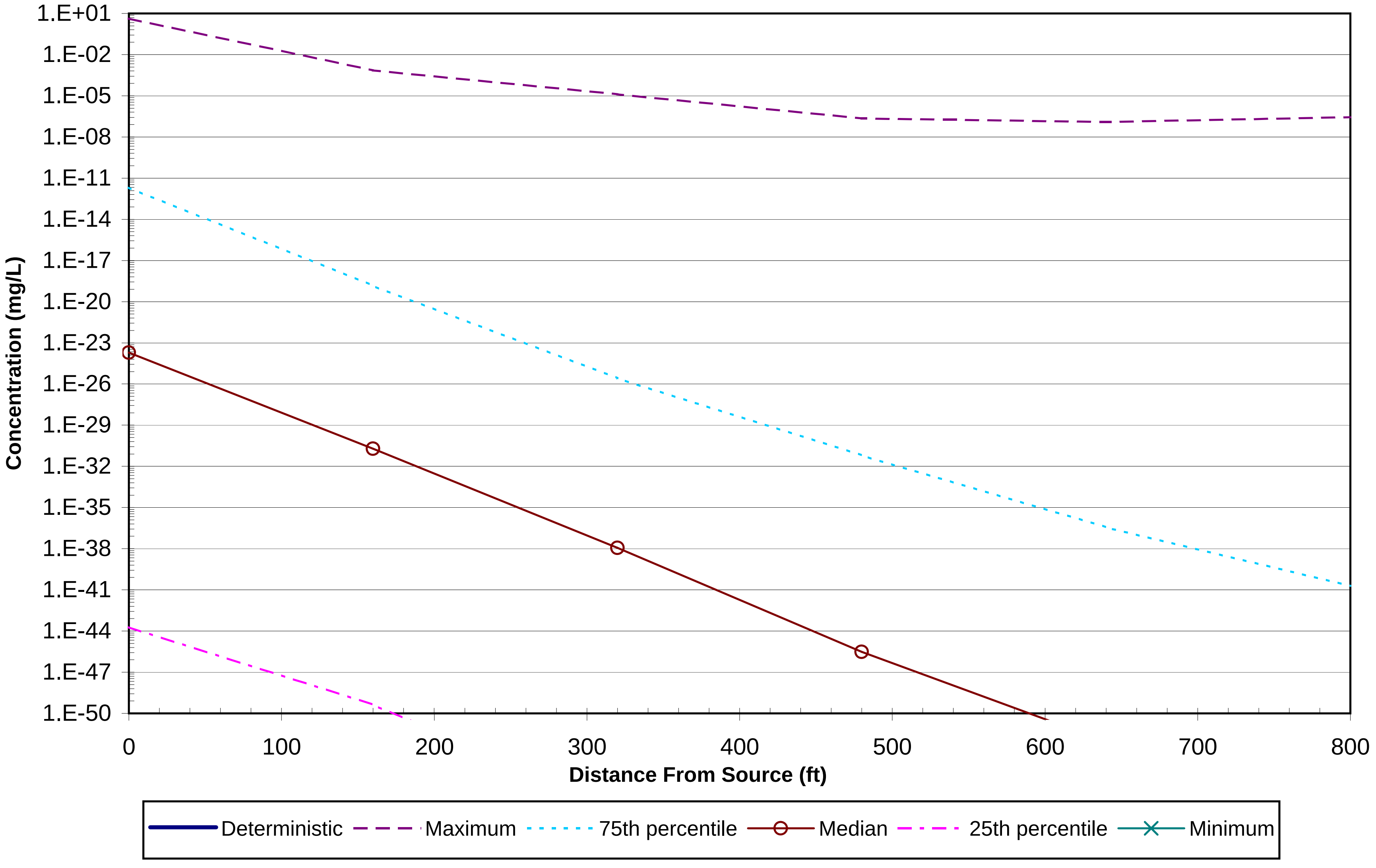
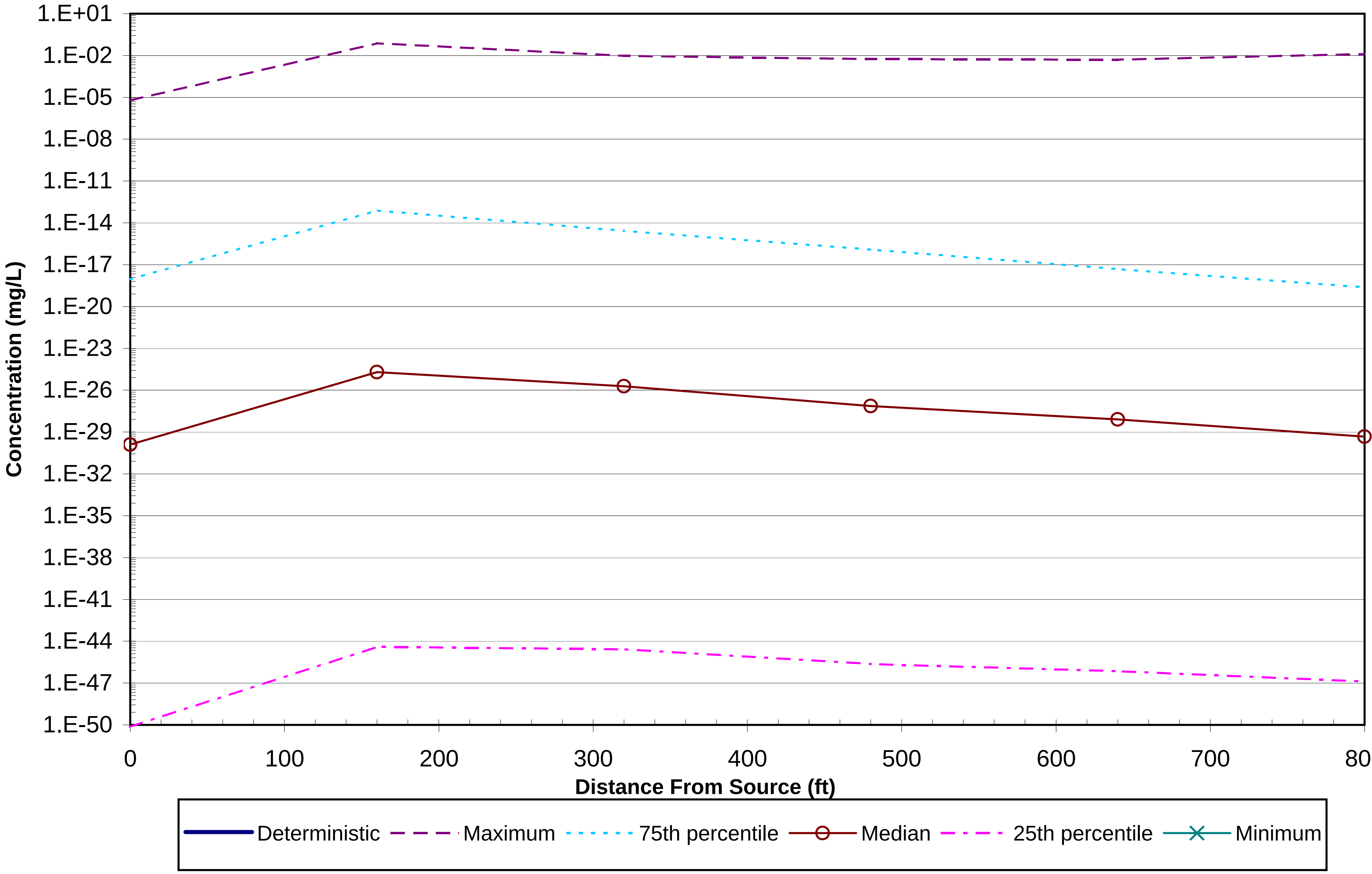


Figure 16a: TCA Deterministic and Stocahstic Modeled Concentrations in 1997 - Shaw AFB

Note: Minimum values <= E-253



Note: Minimum values <= E-249

Figure 16b: DCA Deterministic and Stochastic Modeled Concentrations in 1997 - Shaw AFB

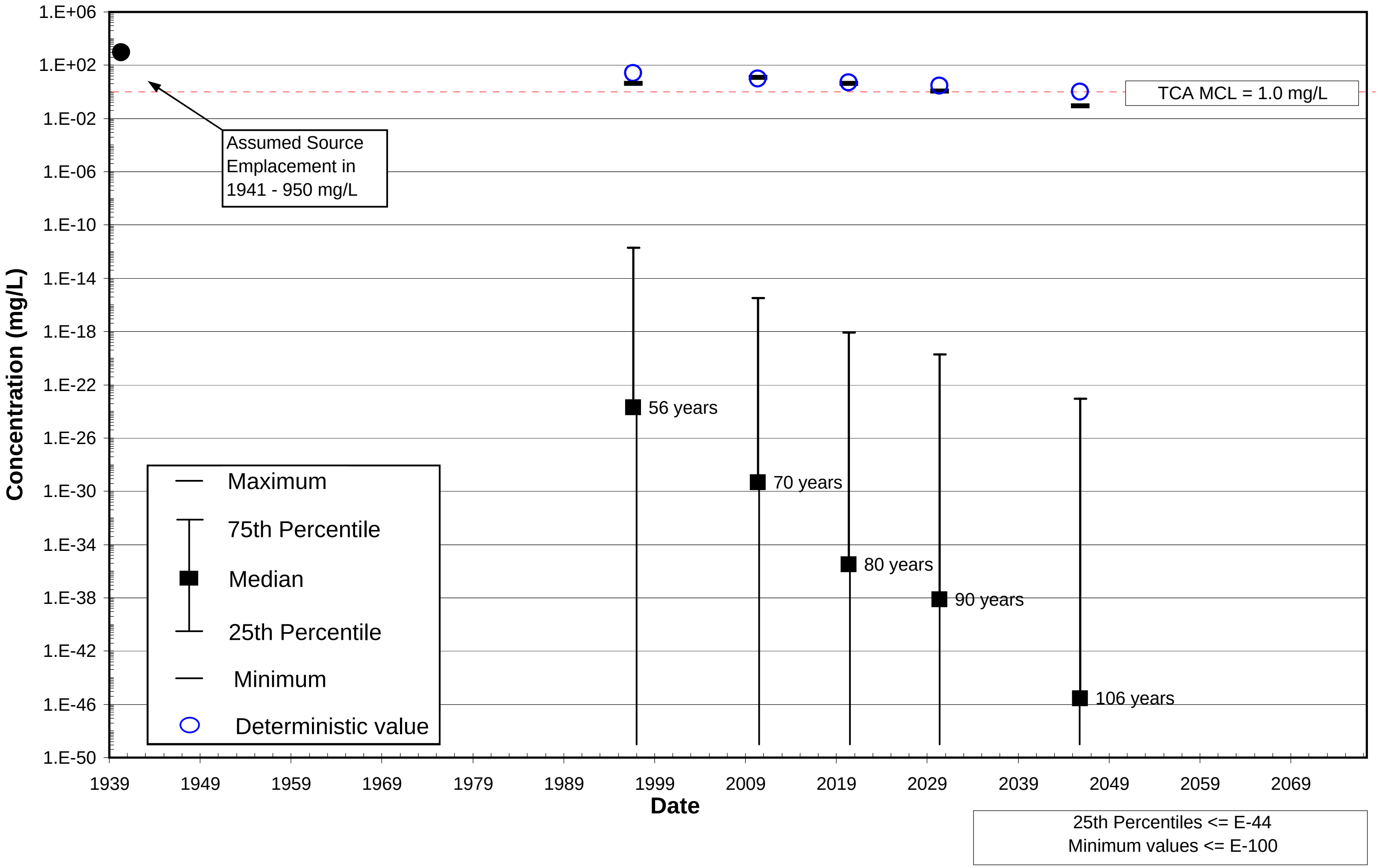


Figure 17a: BIOCHLOR Deterministic and Stochastic Model TCA Predictions at the Source Over Time - Shaw AFB

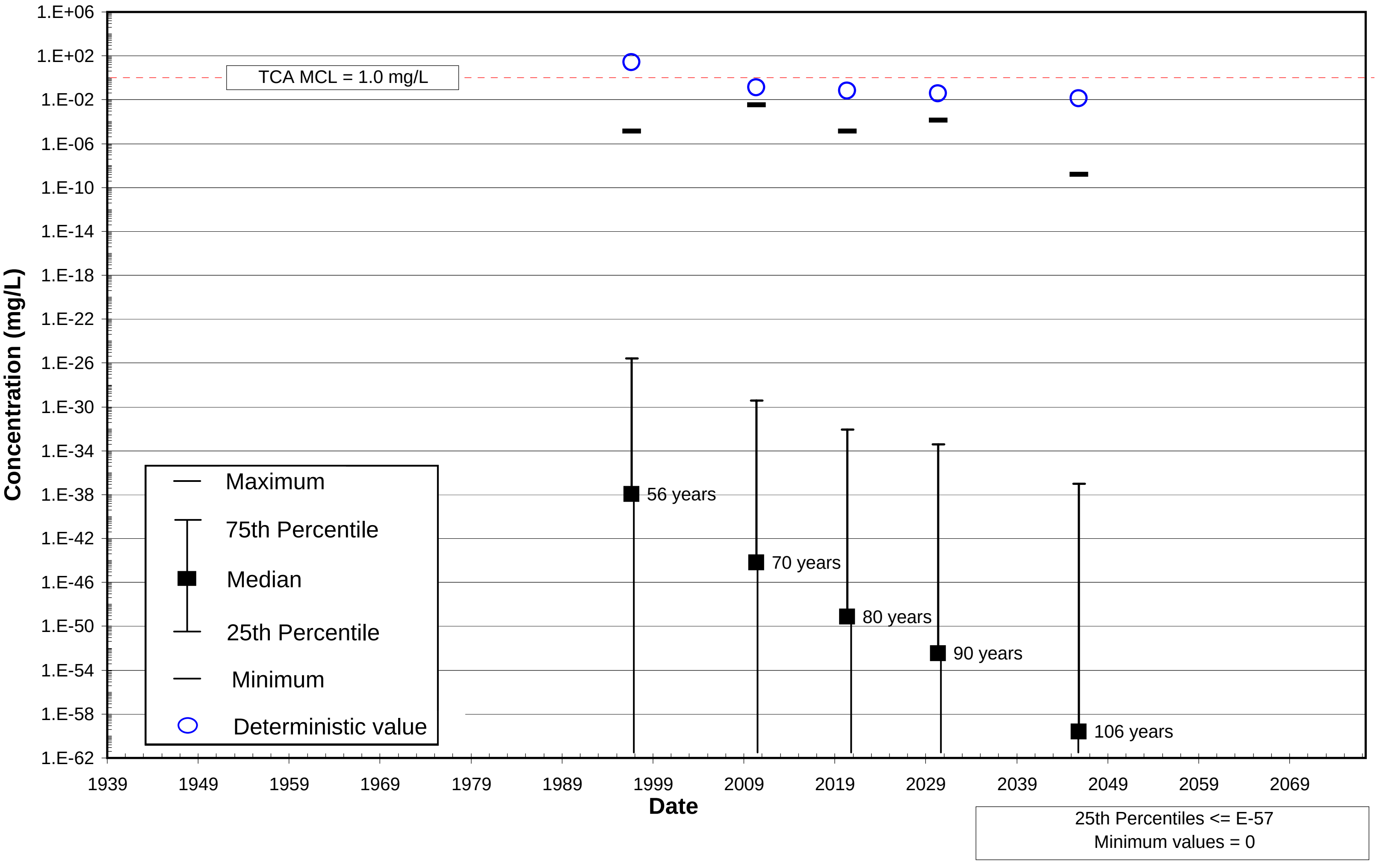


Figure 17b: BIOCHLOR Deterministic and Stochastic Model TCA Predictions at 320 ft from the Source Over Time - Shaw AFB

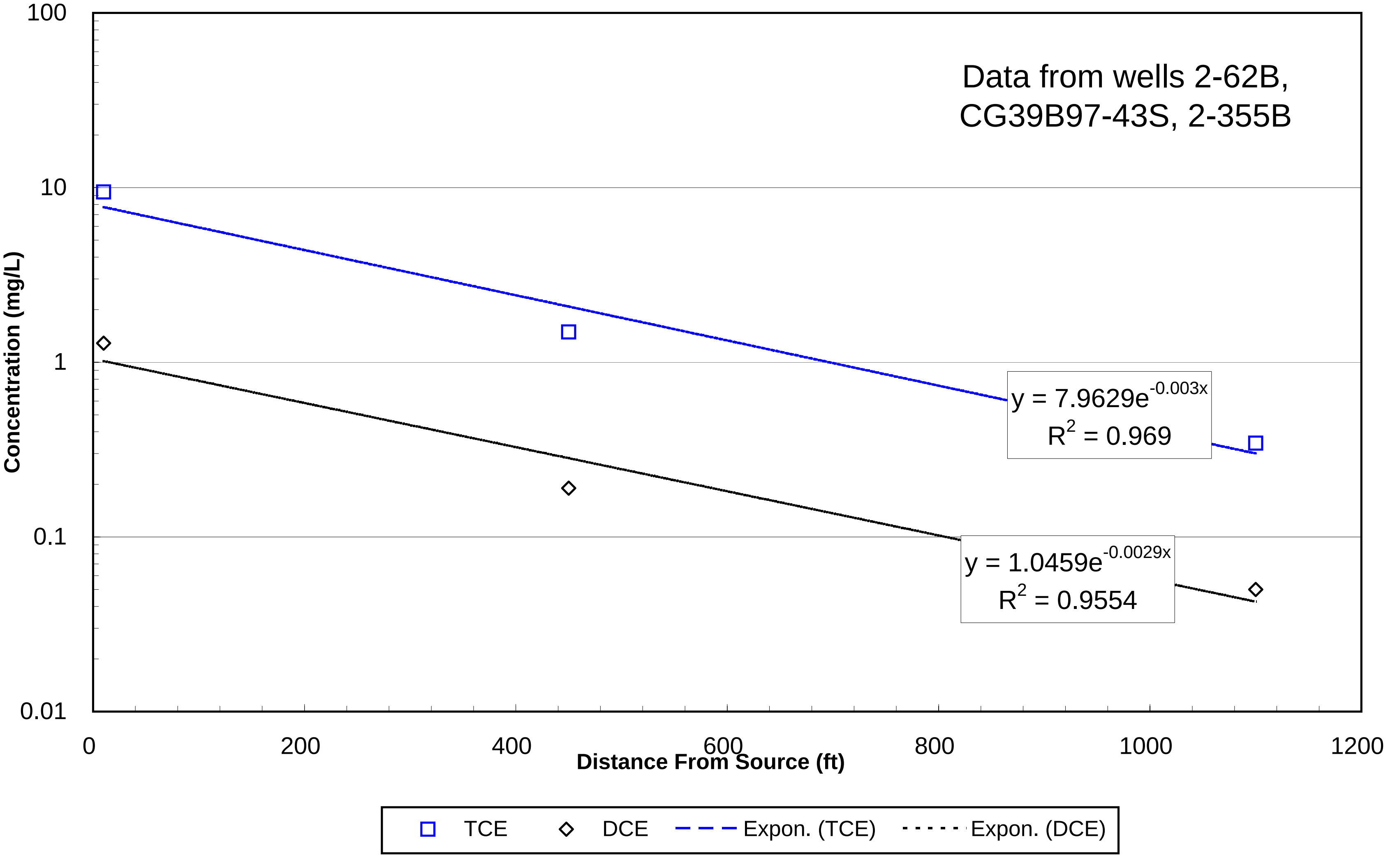


Figure 18: 1997 Centerline Concentrations - Tinker AFB

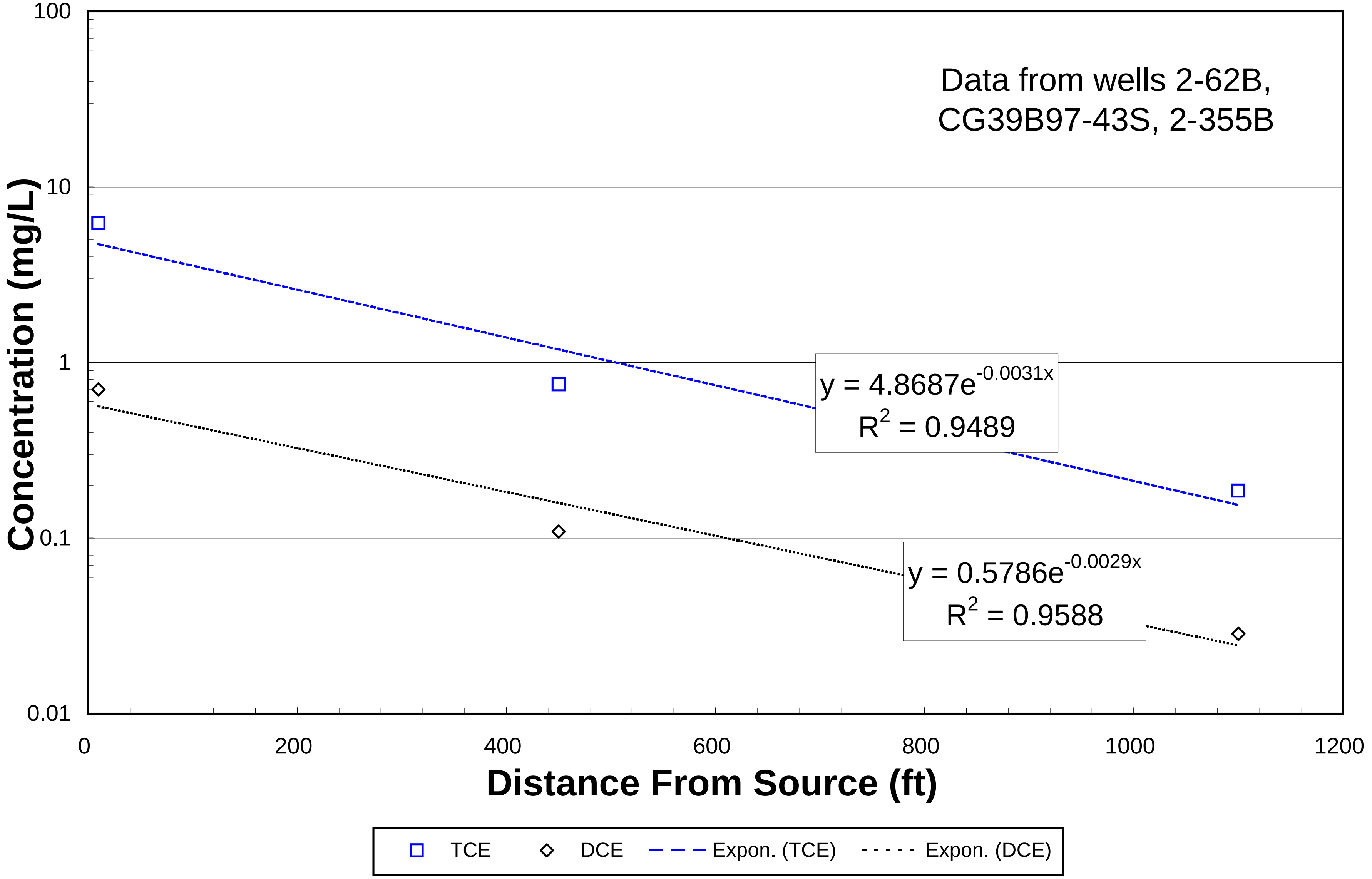


Figure 19: 1999 Centerline Concentrations - Tinker AFB

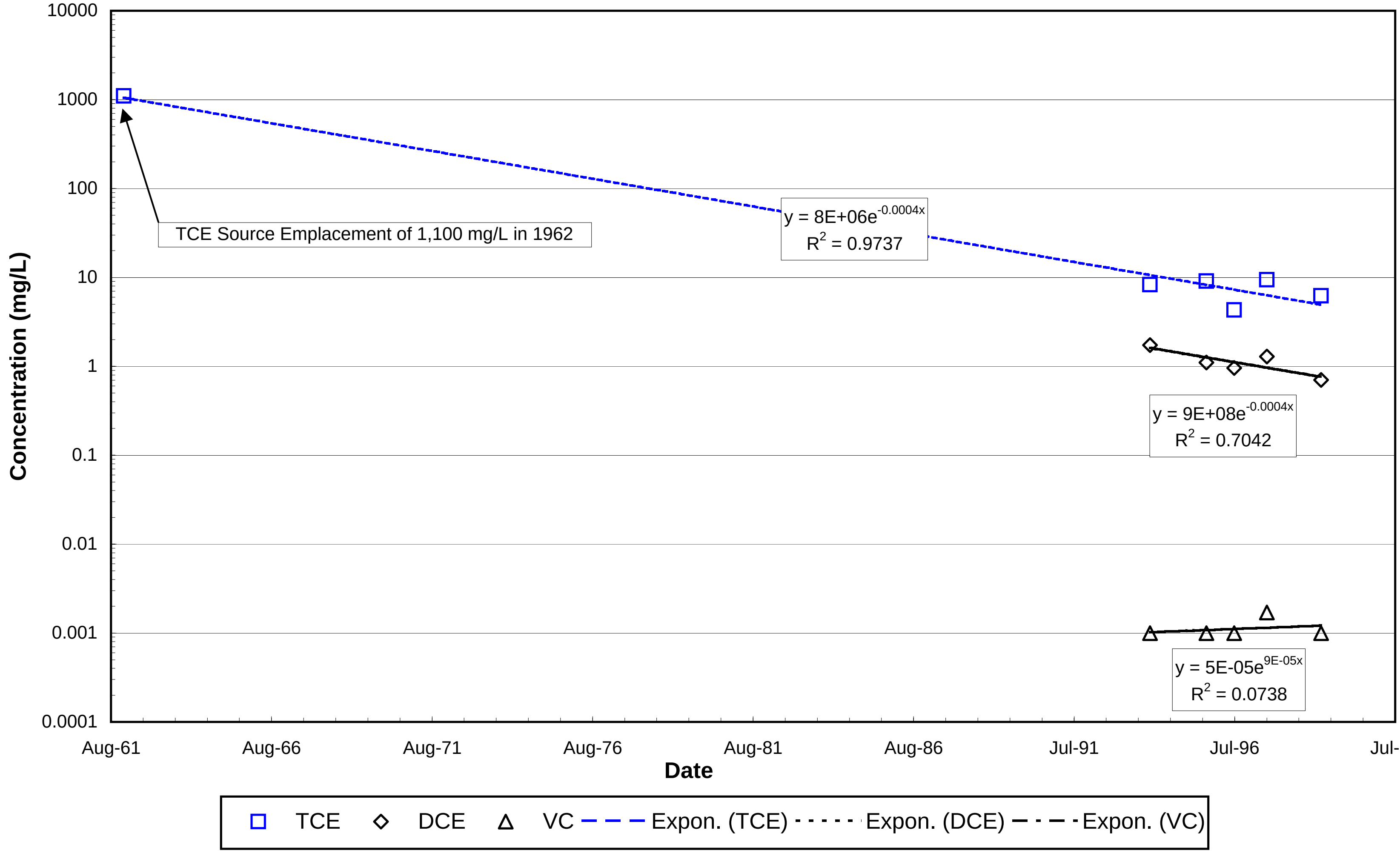


Figure 20: Source Decay Rates in well 2-62B - Tinker AFB

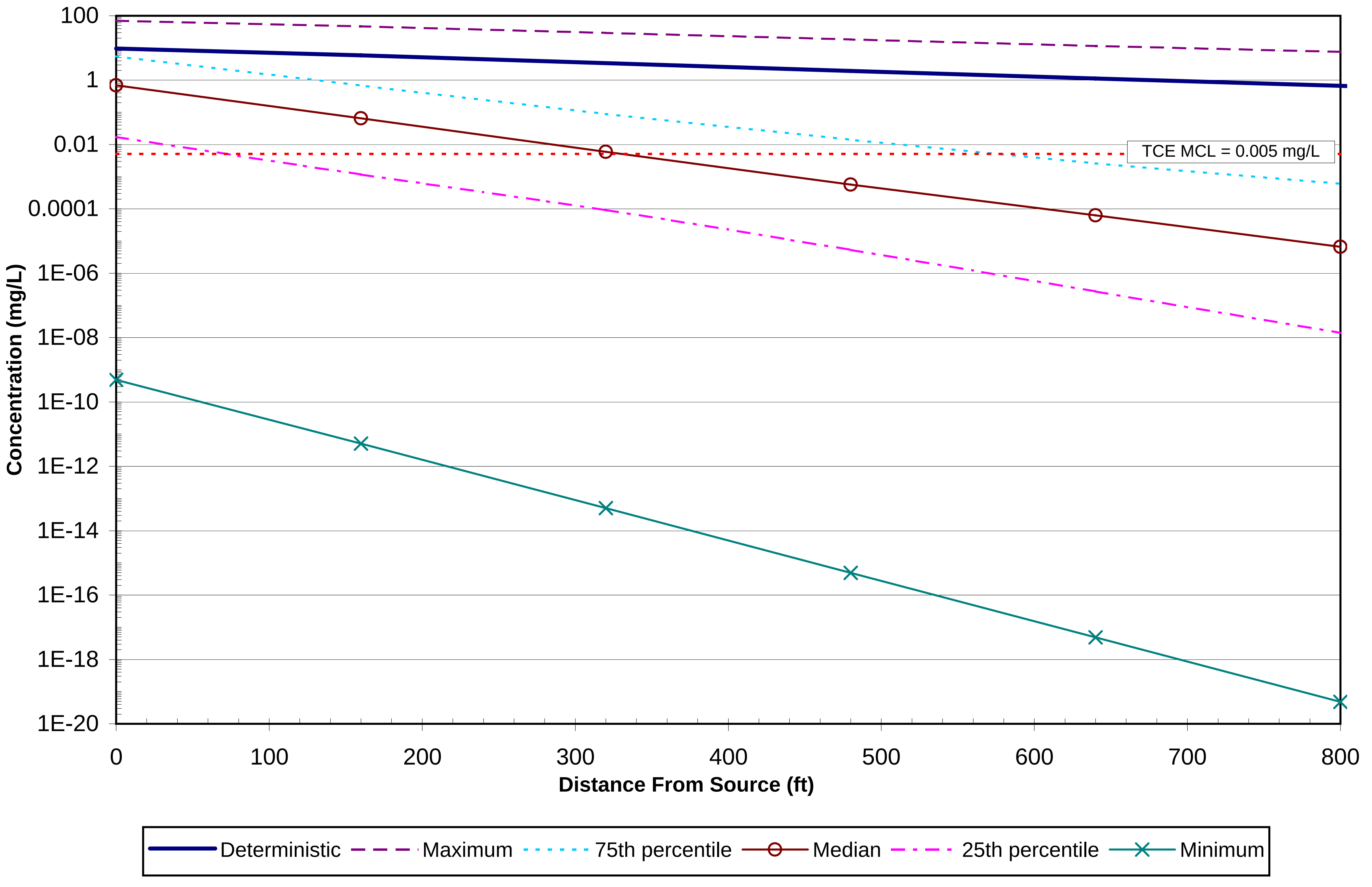


Figure 21: TCE Deterministic and Stochastic Modeled Concentrations in 1997 - Tinker AFB

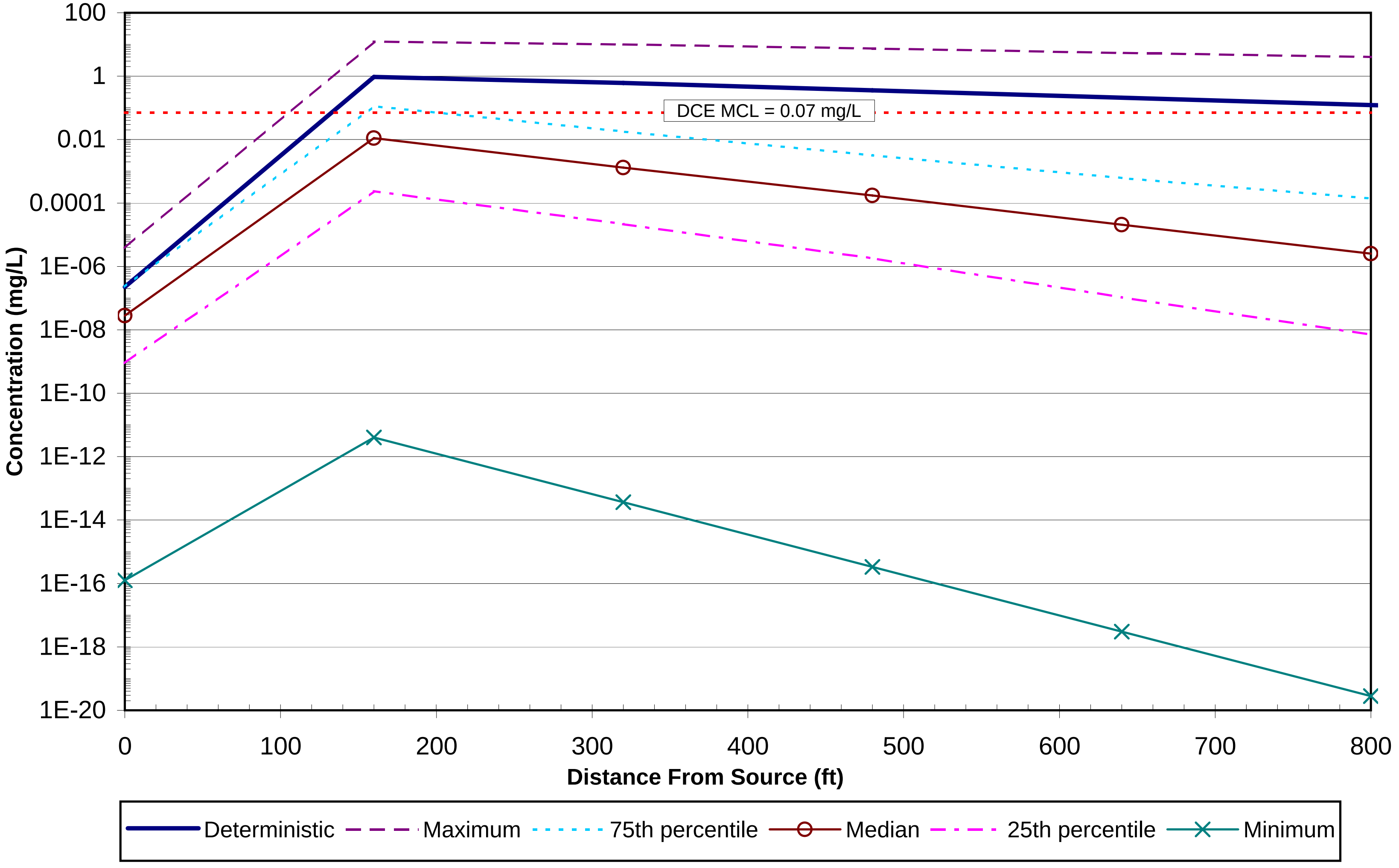


Figure 22: DCE Deterministic and Stochastic Modeled Concentrations in 1997 - Tinker AFB

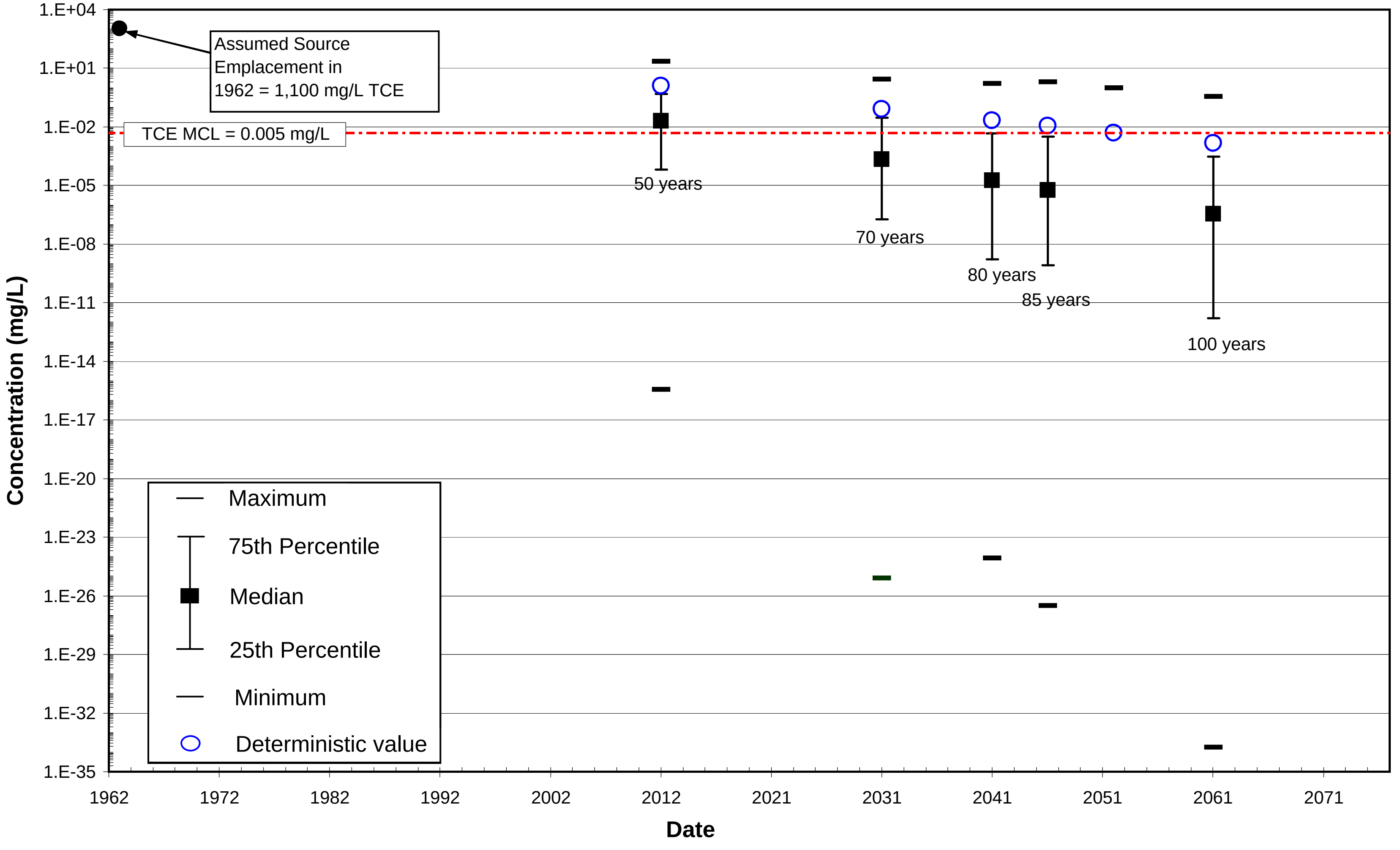


Figure 23: BIOCHLOR Deterministic and Stochastic Model TCE Predictions at the Source Over Time - Tinker AFB

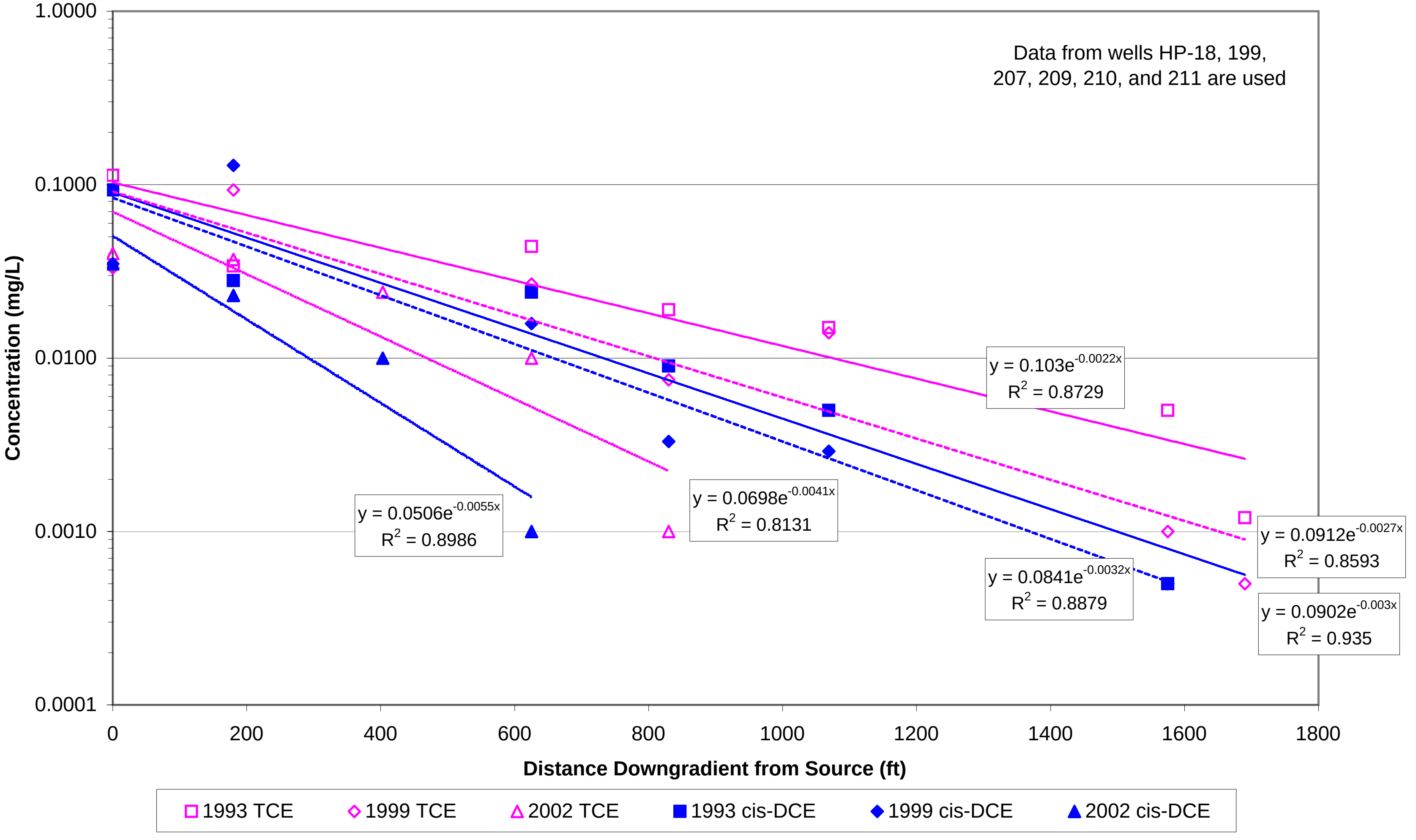


Figure 24a: Plume Centerline Concentrations Over Time - Warren AFB

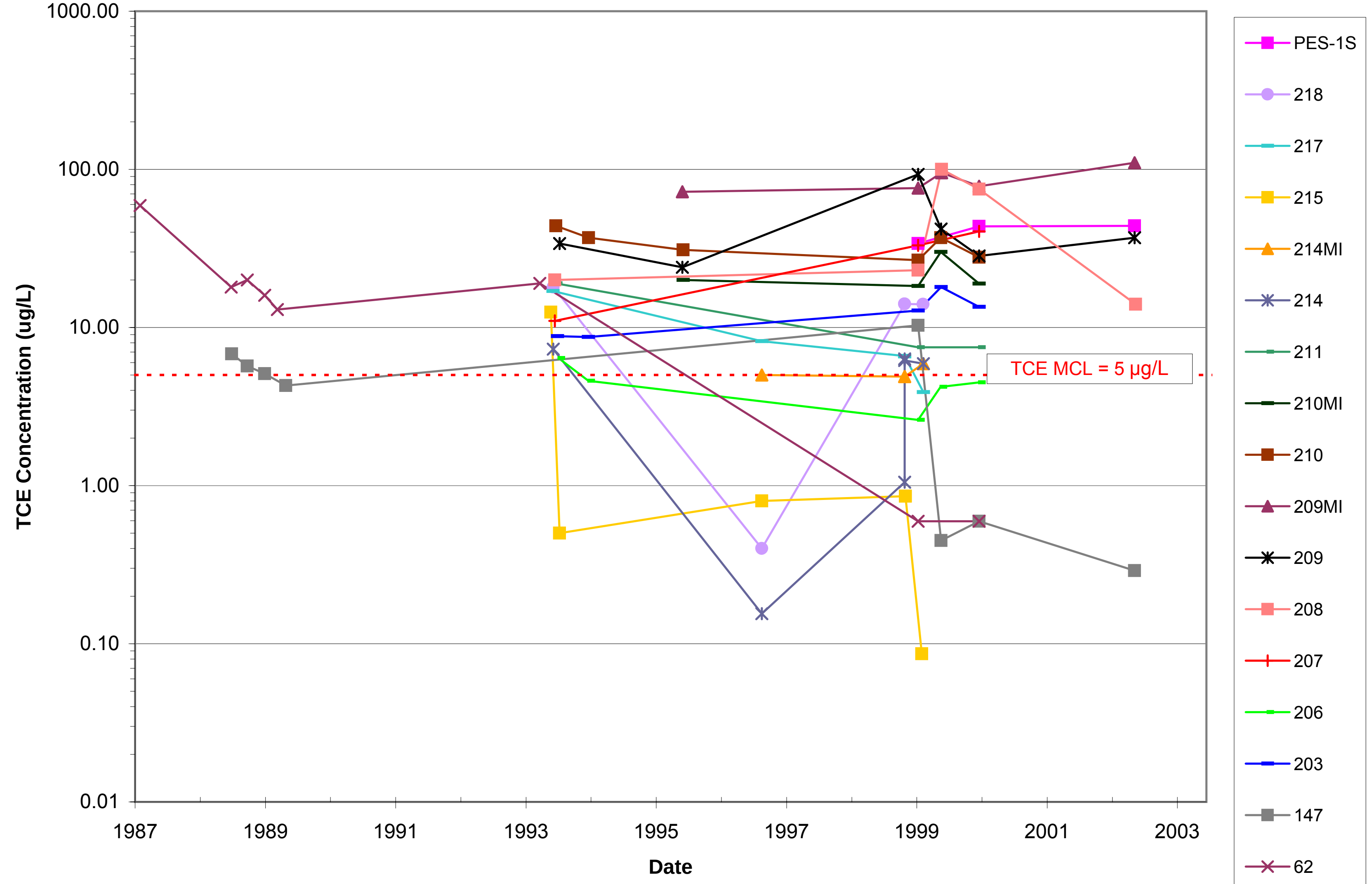
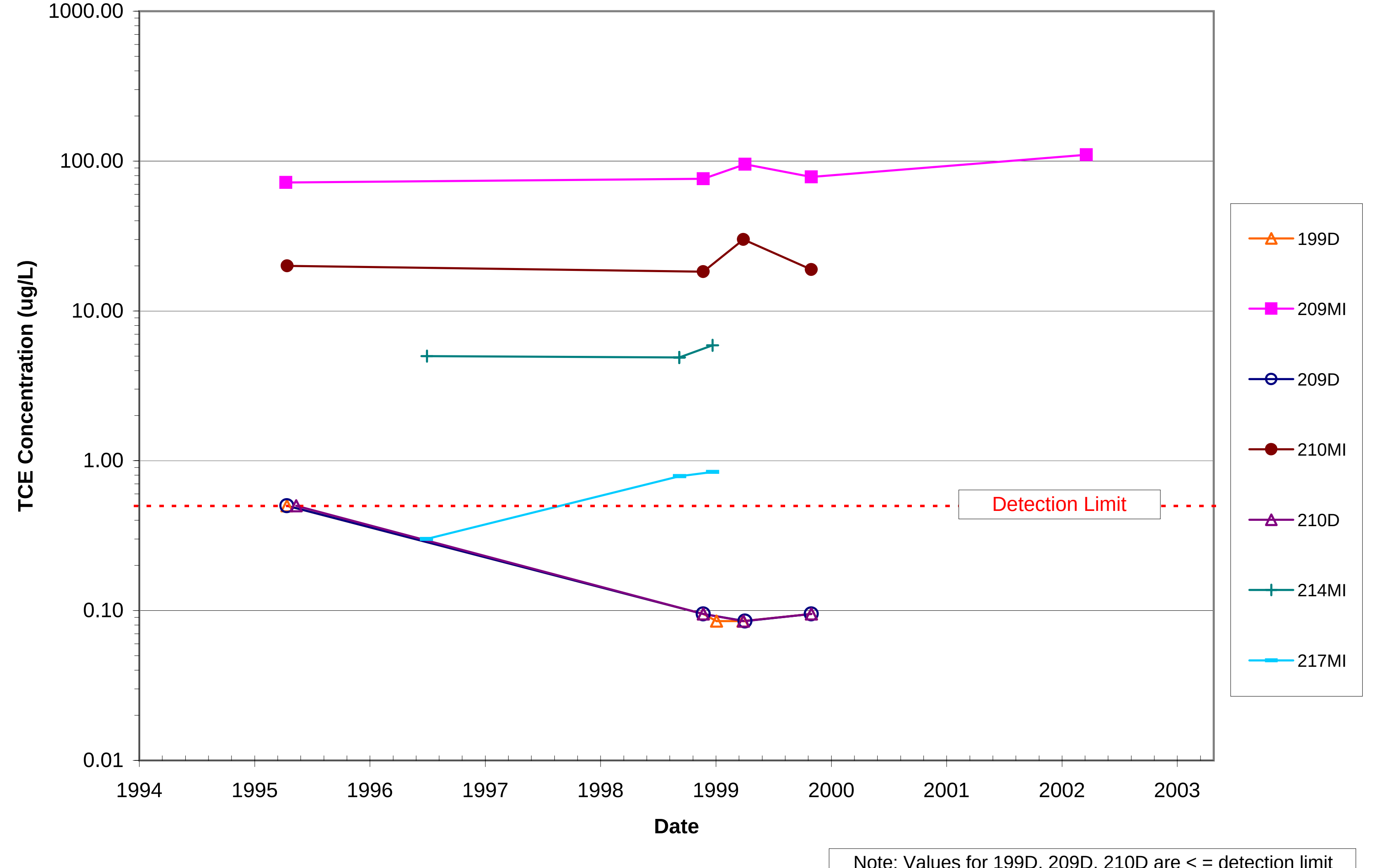


Figure 24b: TCE Concentrations in Wells Over Time - Warren AFB



Note: Values for 199D, 209D, 210D are < = detection limit

Figure 24c: Deep Zone Concentration Changes Over Time - Warren AFB

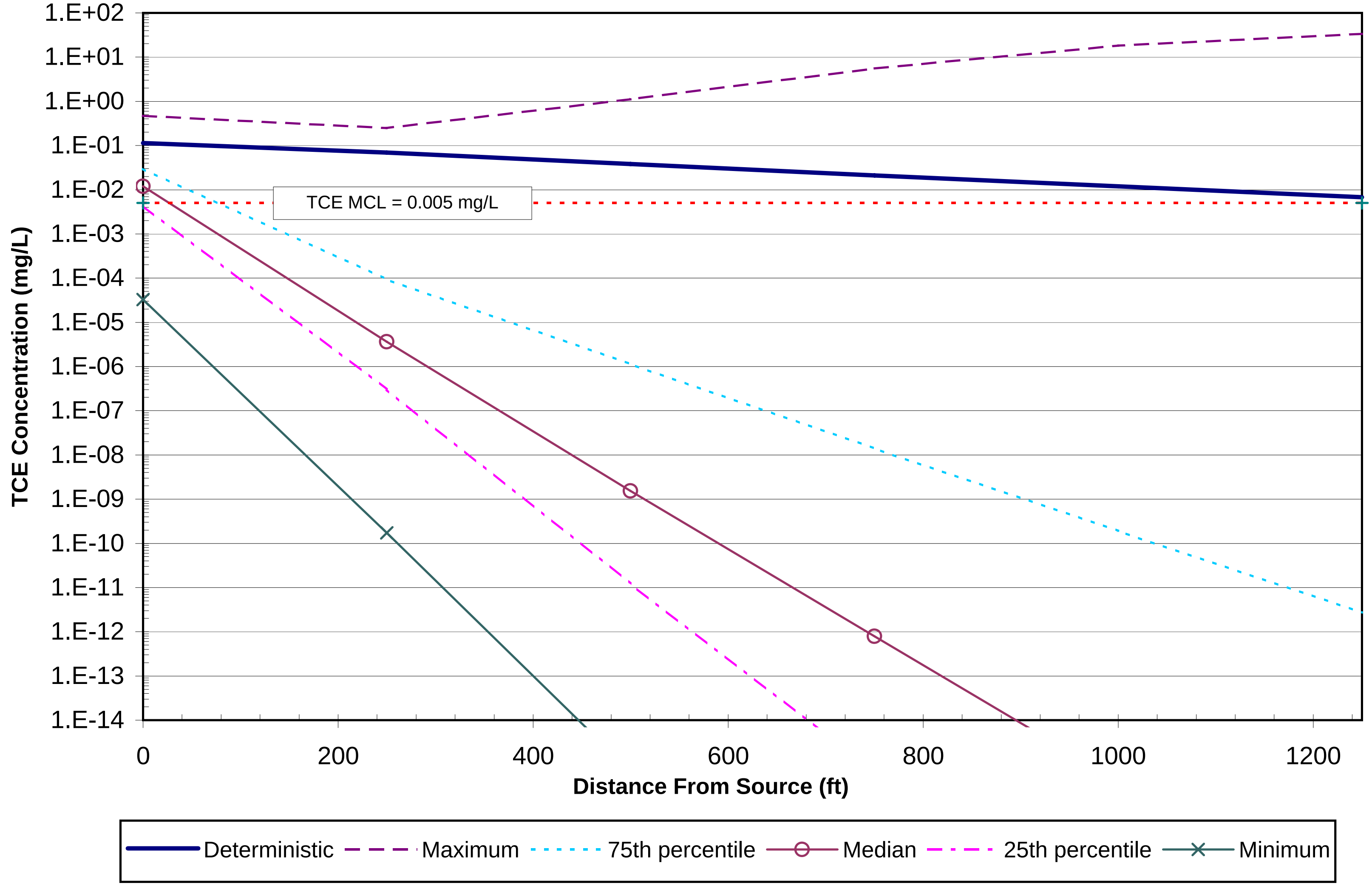


Figure 25a: TCE Deterministic and Stochastic Modeled Concentrations in 1993 - Warren AFB

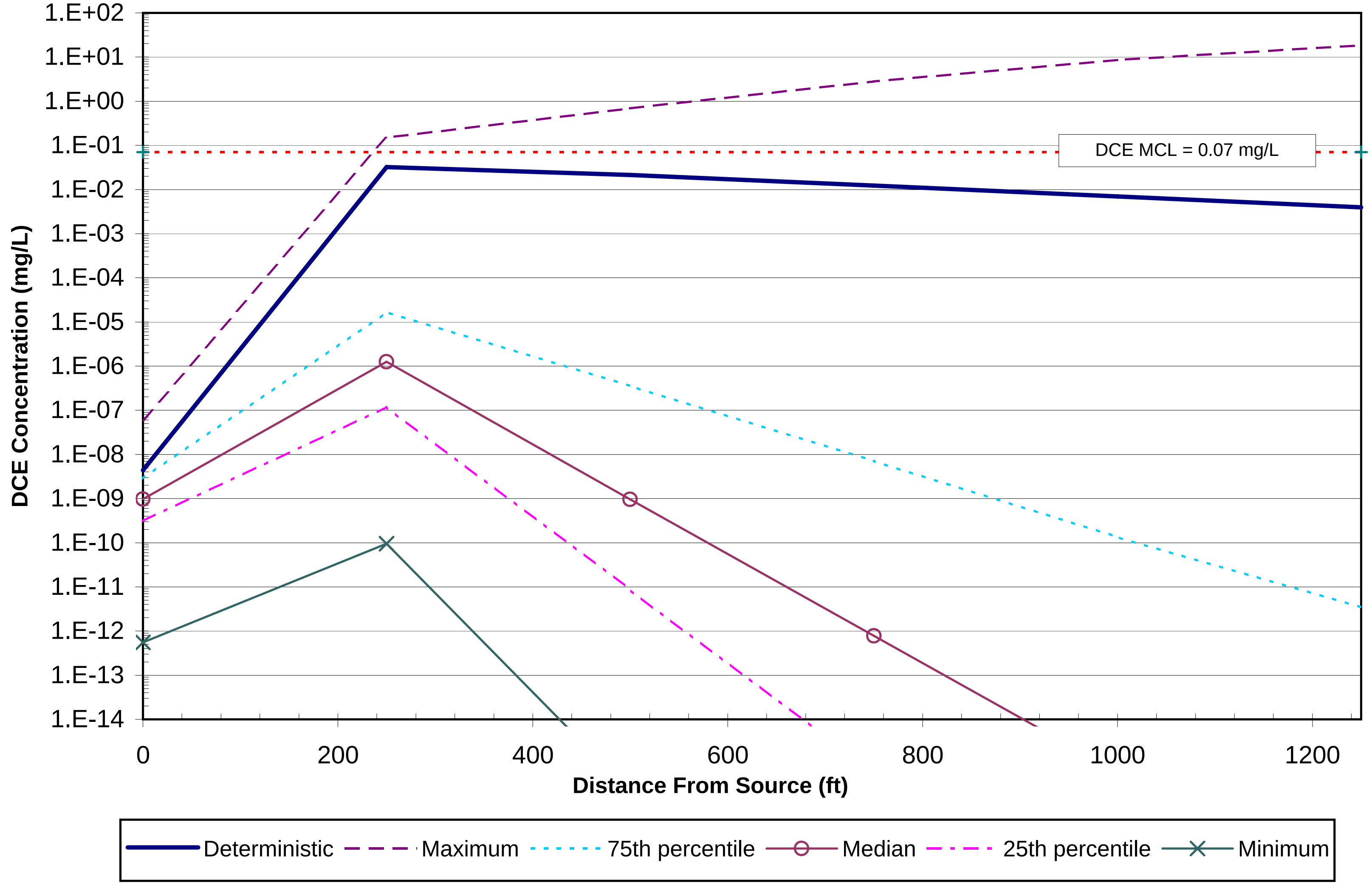


Figure 25b: DCE Deterministic and Stochastic Modeled Concentrations in 1993 - Warren AFB

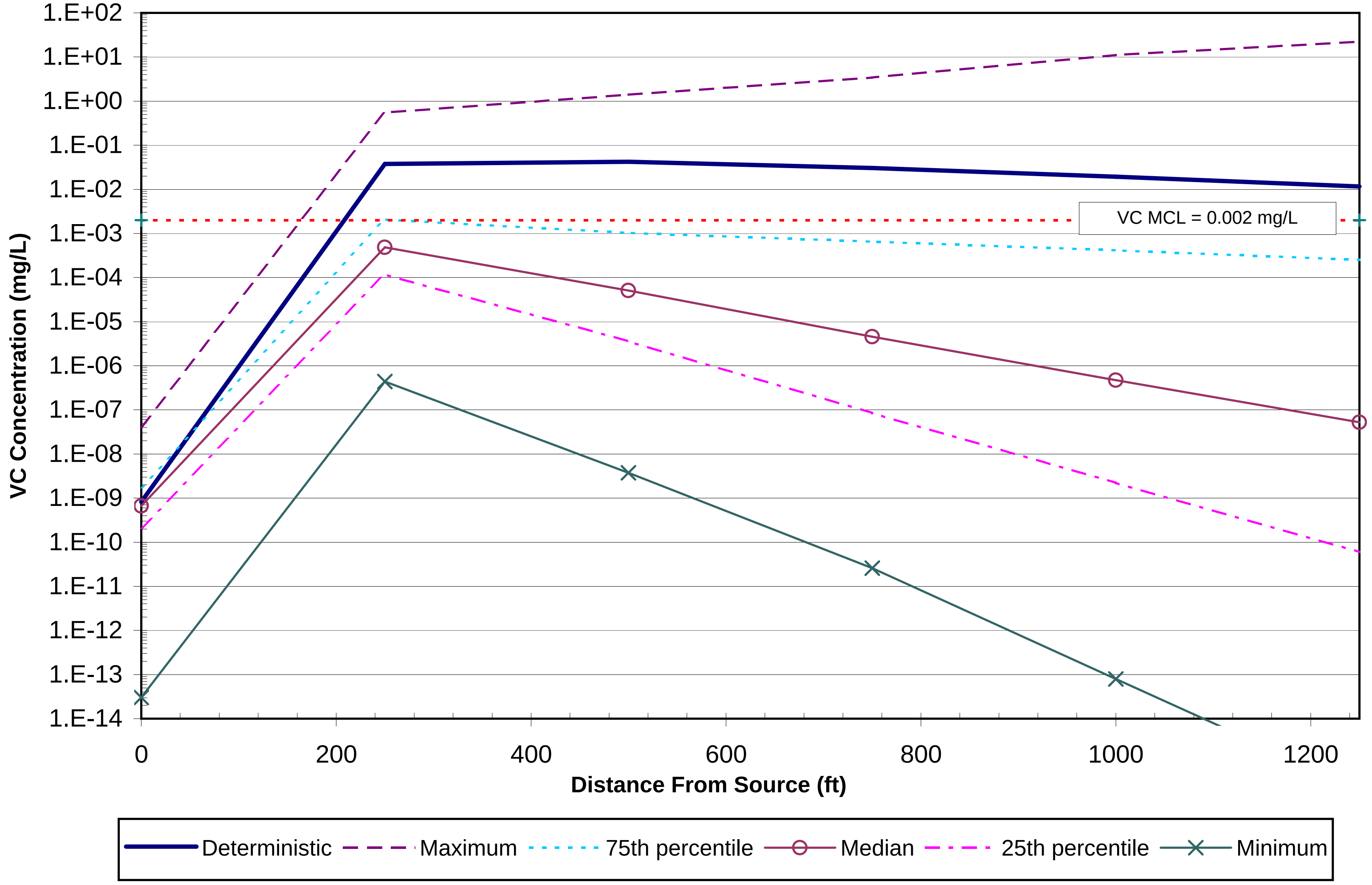


Figure 25c: VC Deterministic and Stochastic Modeled Concentrations in 1993 - Warren AFB

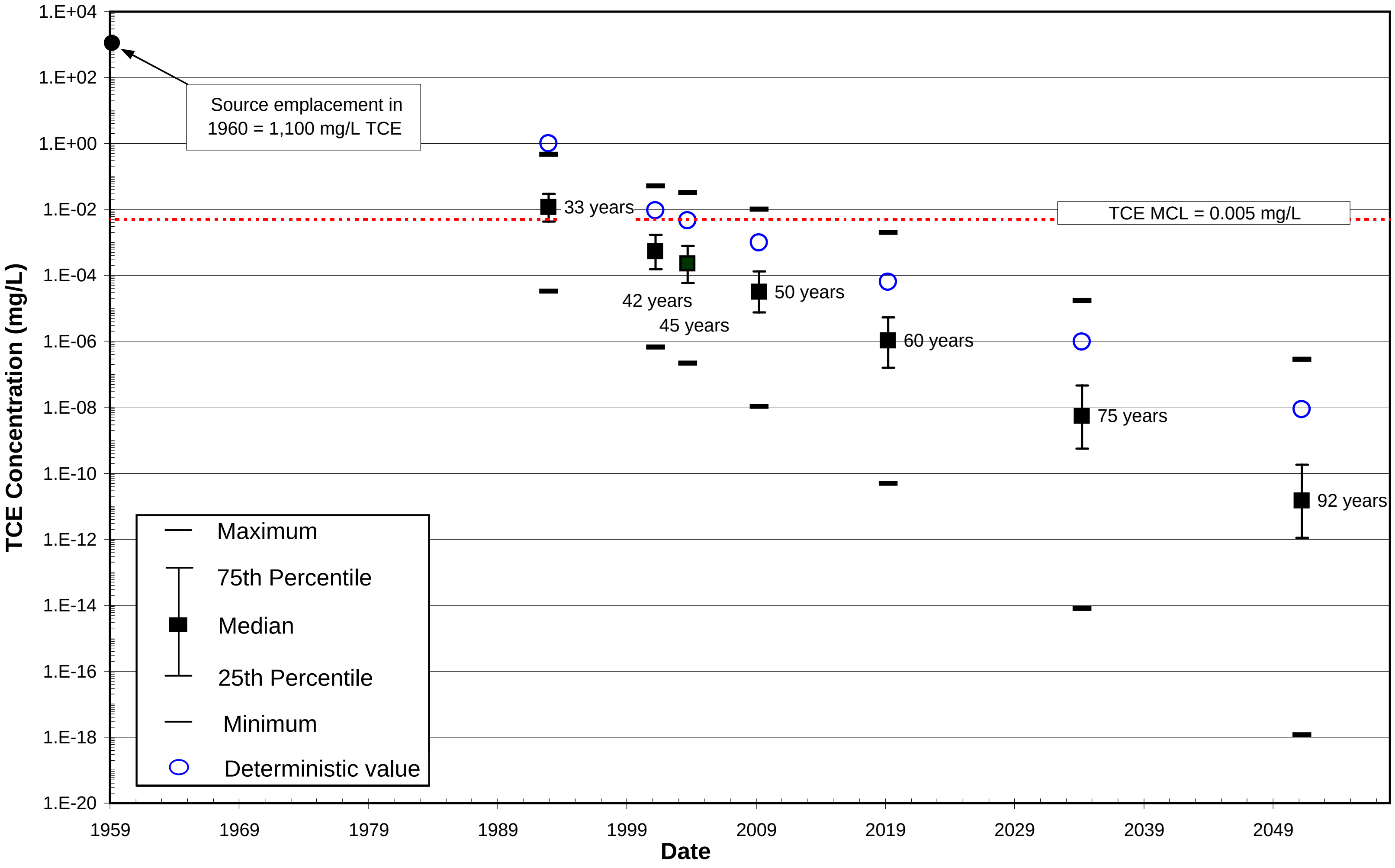


Figure 26: BIOCHLOR Deterministic and Stochastic Model TCE Predictions at the Source Over Time - Warren AFB

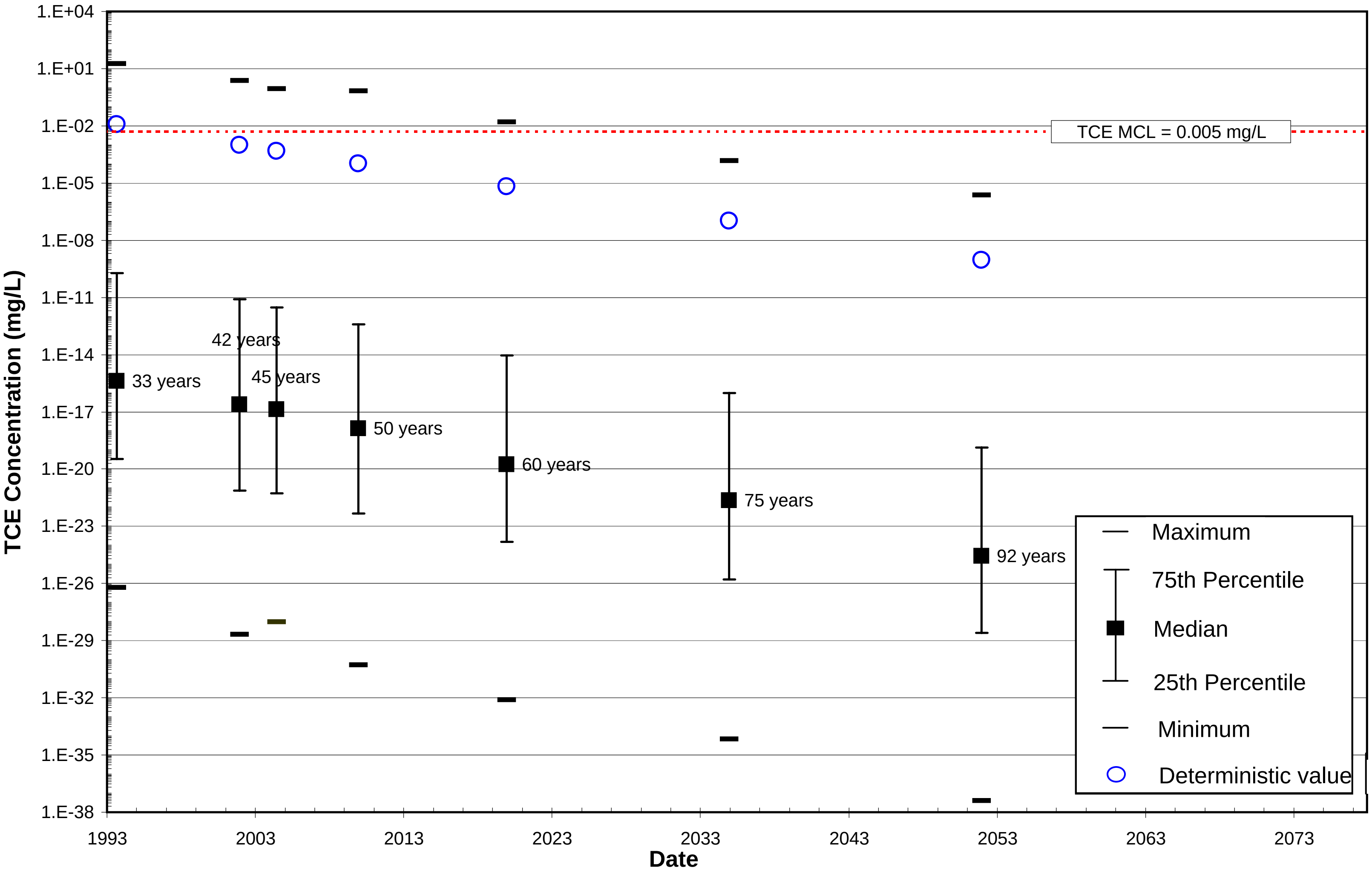


Figure 27: BIOCHLOR Deterministic and Stochastic Model TCE Predictions 1,000 ft Downgradient of the Source Over Time - Warren AFB

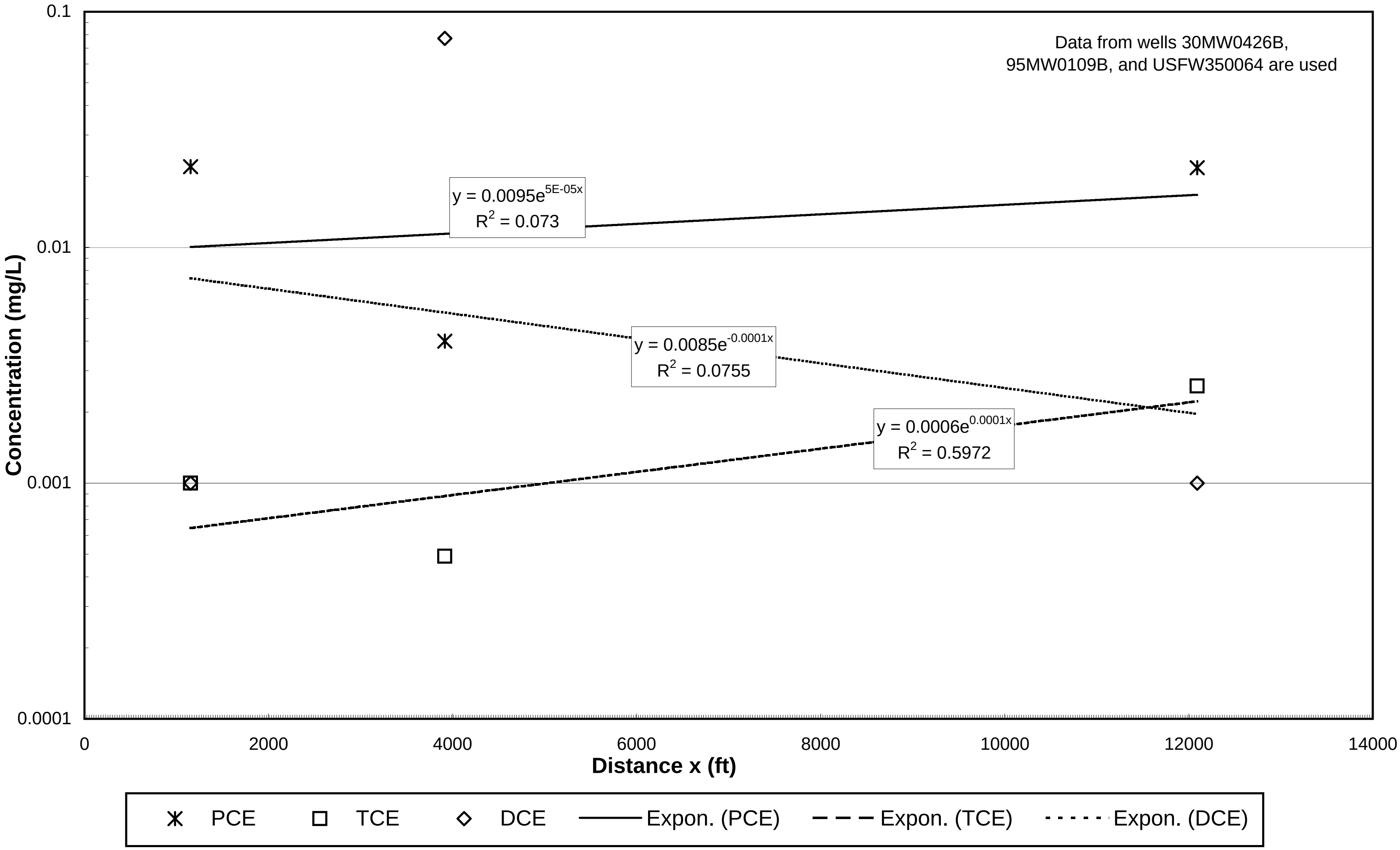


Figure 28a: 1998 Plume Centerline Concentrations - Ashumet, MMR

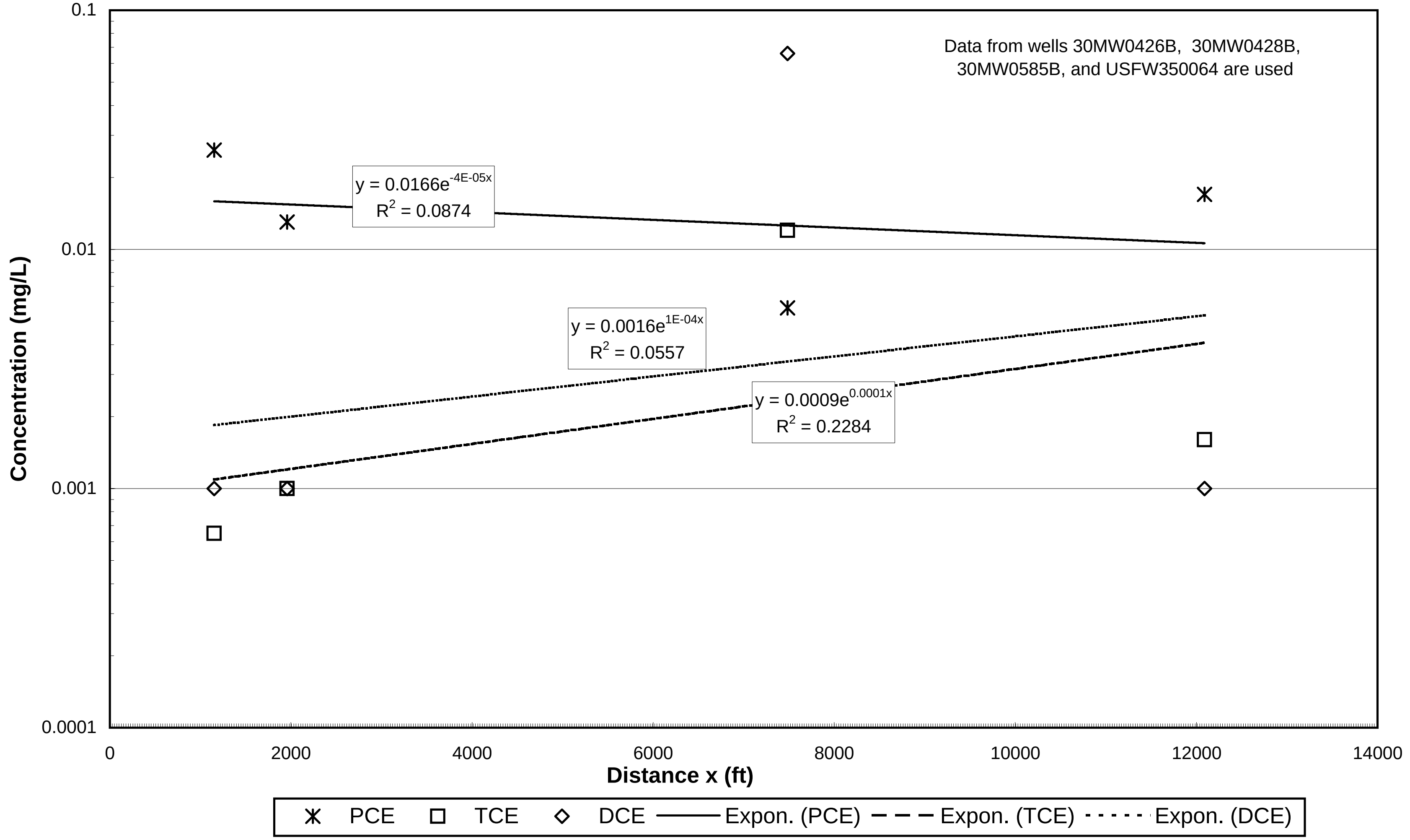


Figure 28b: 1999 Plume Centerline Concentrations - Ashumet, MMR

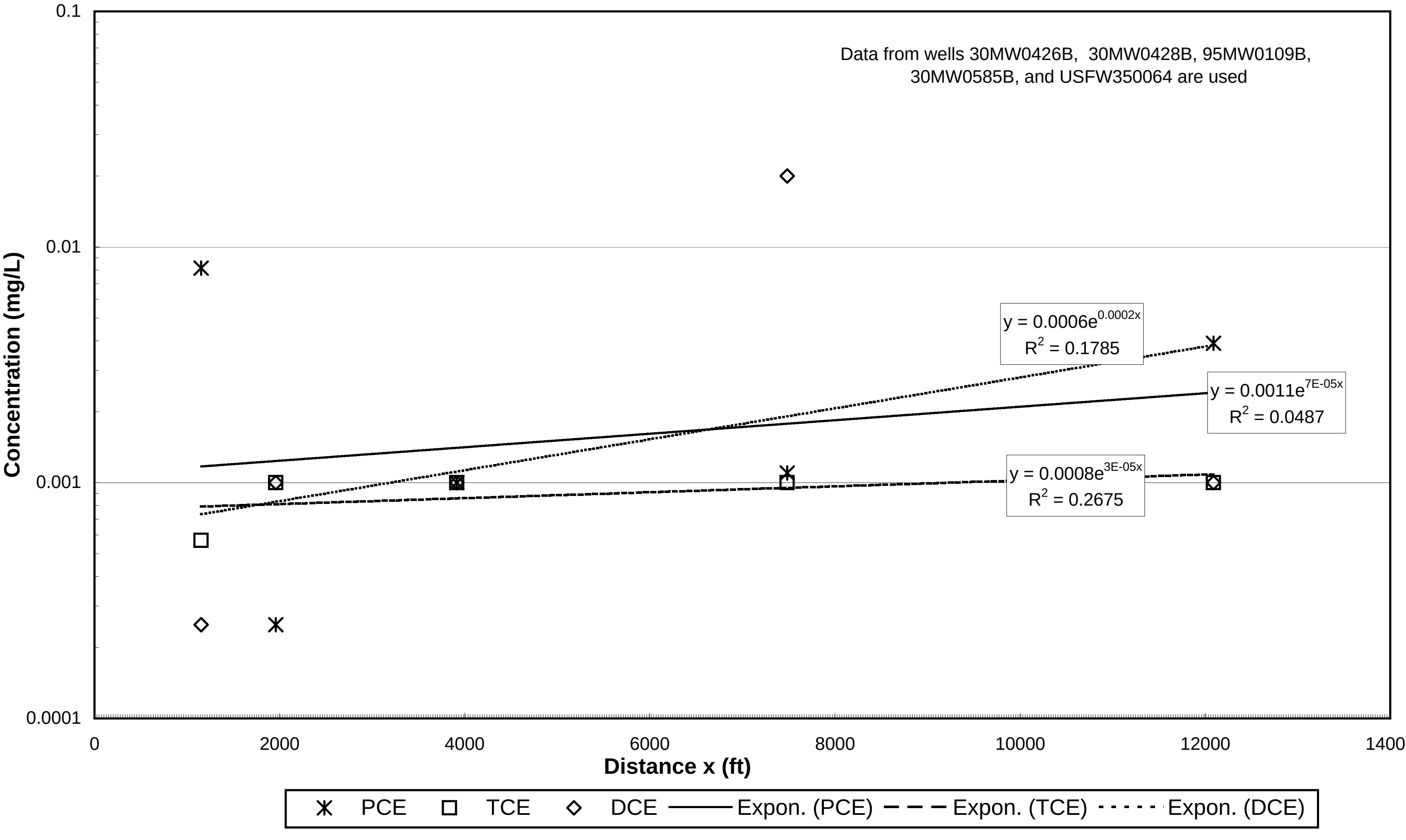


Figure 28c: 2003 Plume Centerline Concentrations - Ashumet, MMR

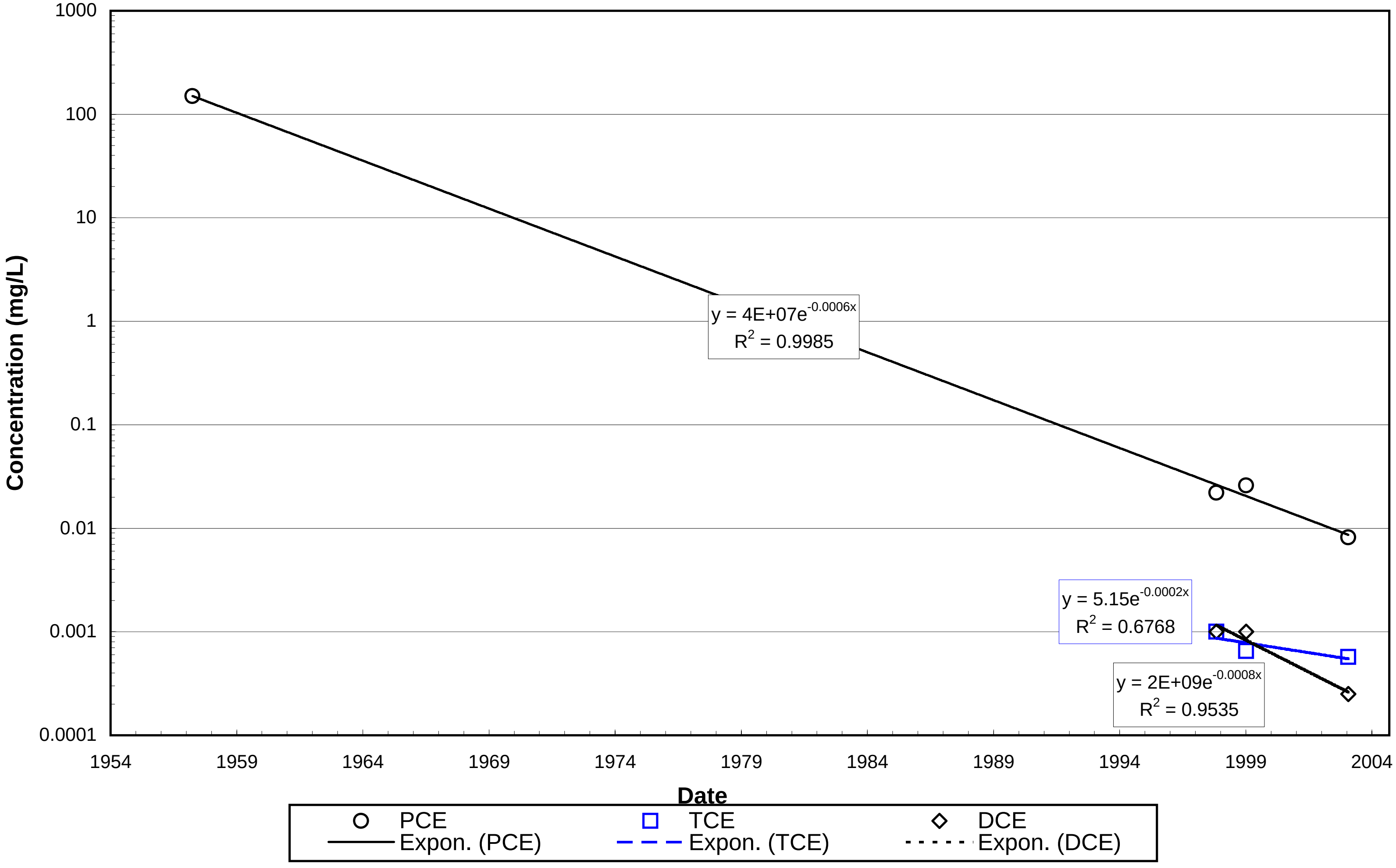


Figure 28d: Source Decay Rate in well 30MW0426B - Ashumet, MMR

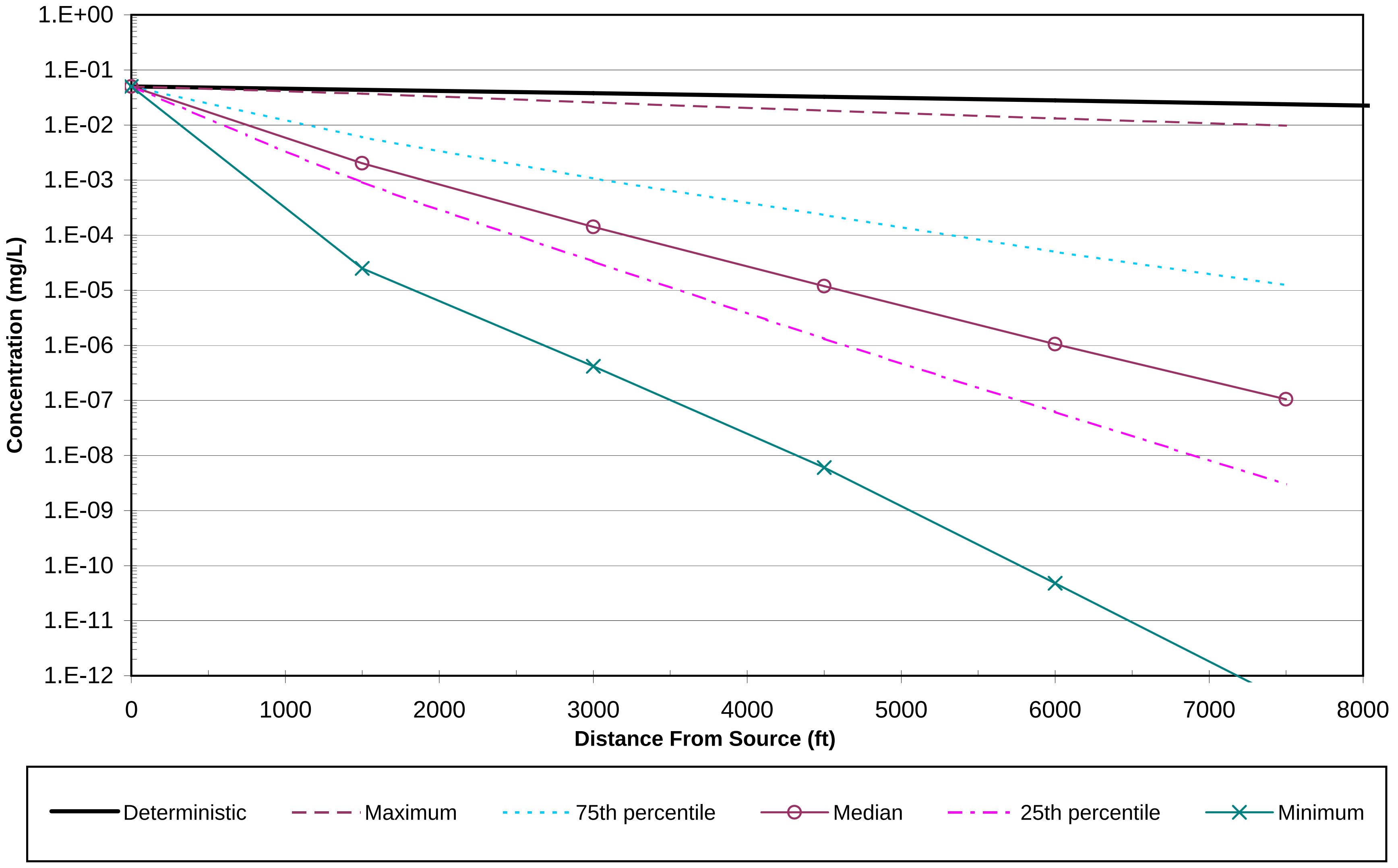


Figure 29a: PCE Deterministic and Stochastic Modeled Concentrations in 1998 - Ashumet Valley, MMR

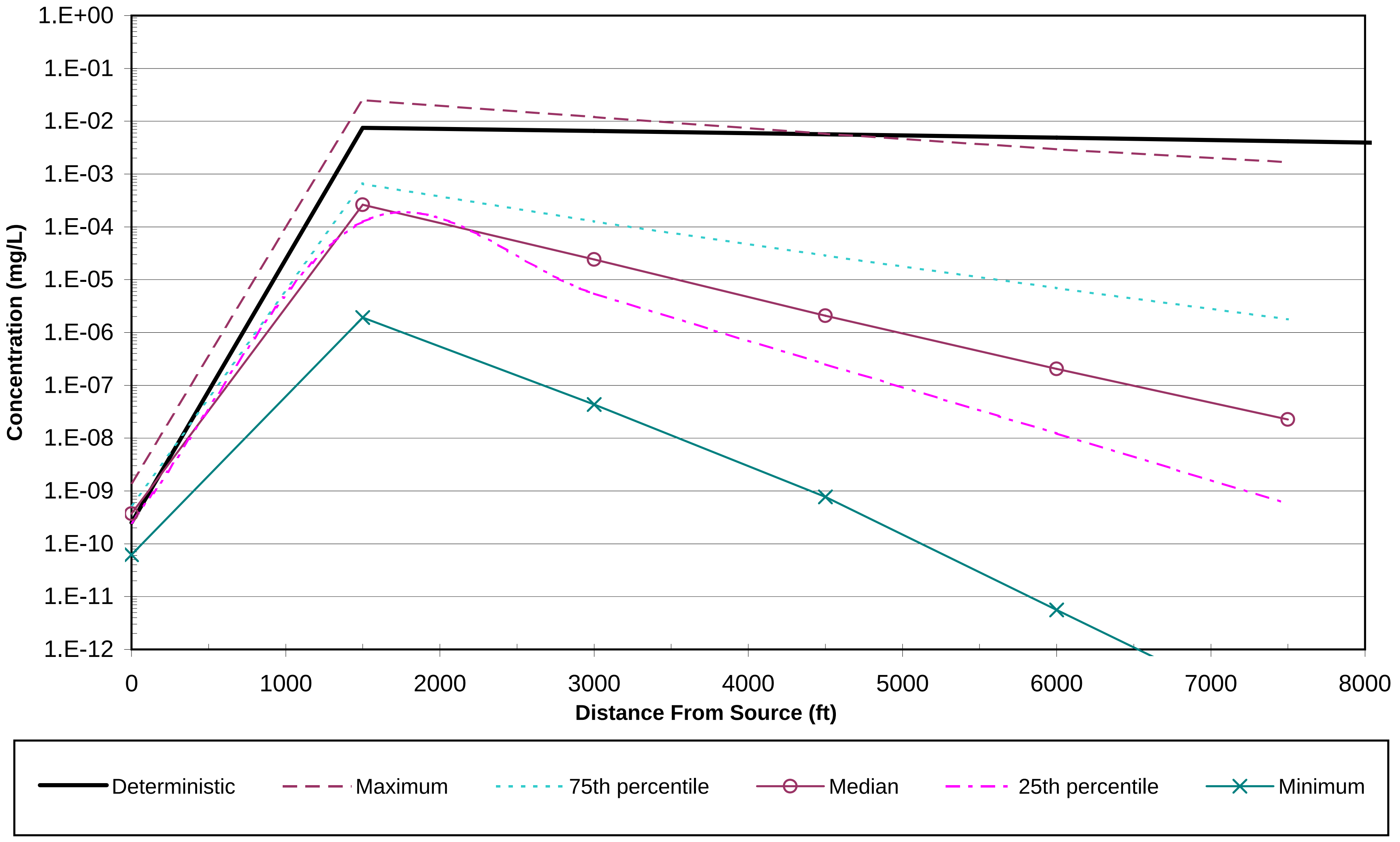


Figure 29b: TCE Deterministic and Stochastic Modeled Concentrations in 1998 - Ashumet Valley, MMR

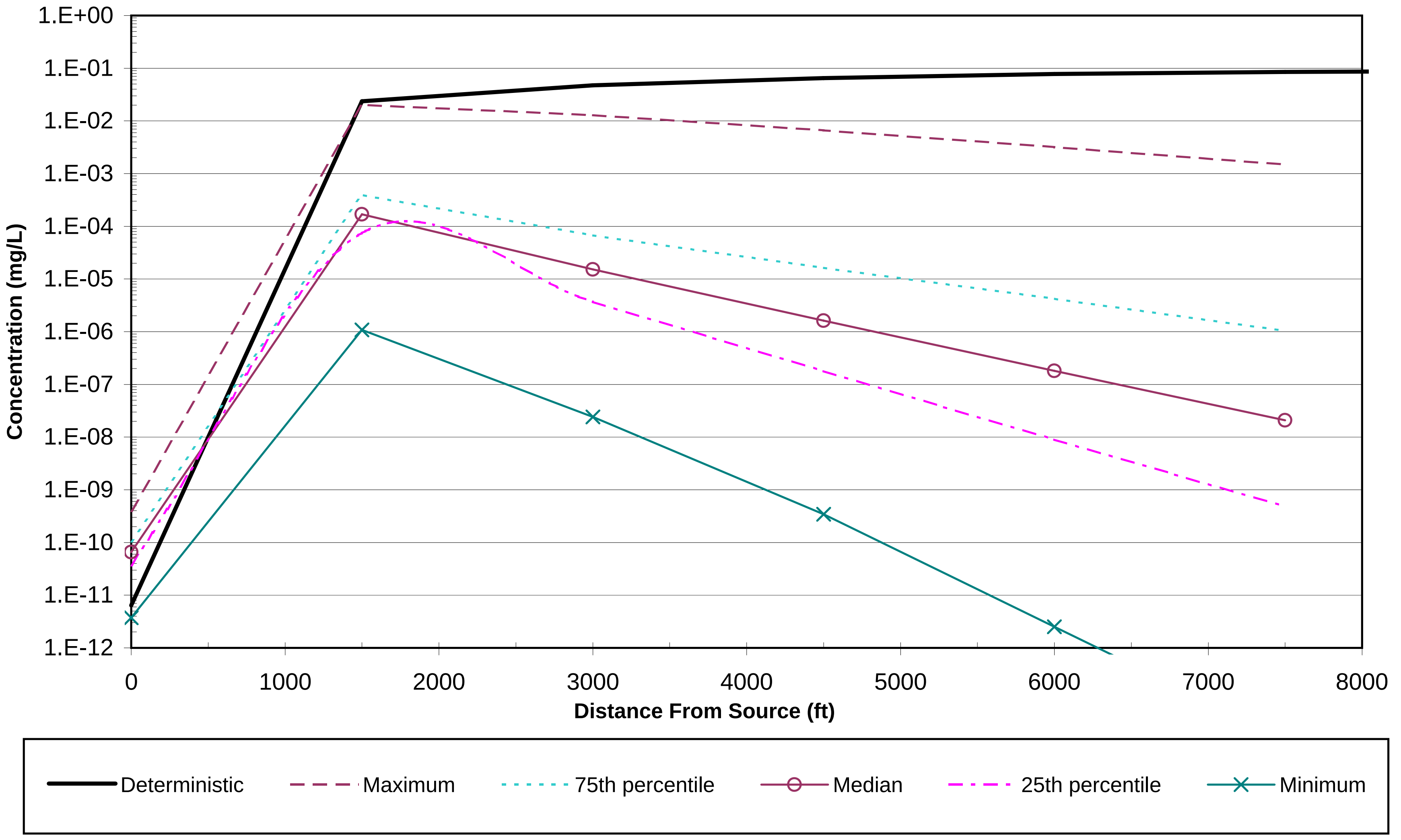


Figure 29c: DCE Deterministic and Stochastic Modeled Concentrations in 1998 - Ashumet Valley, MMR

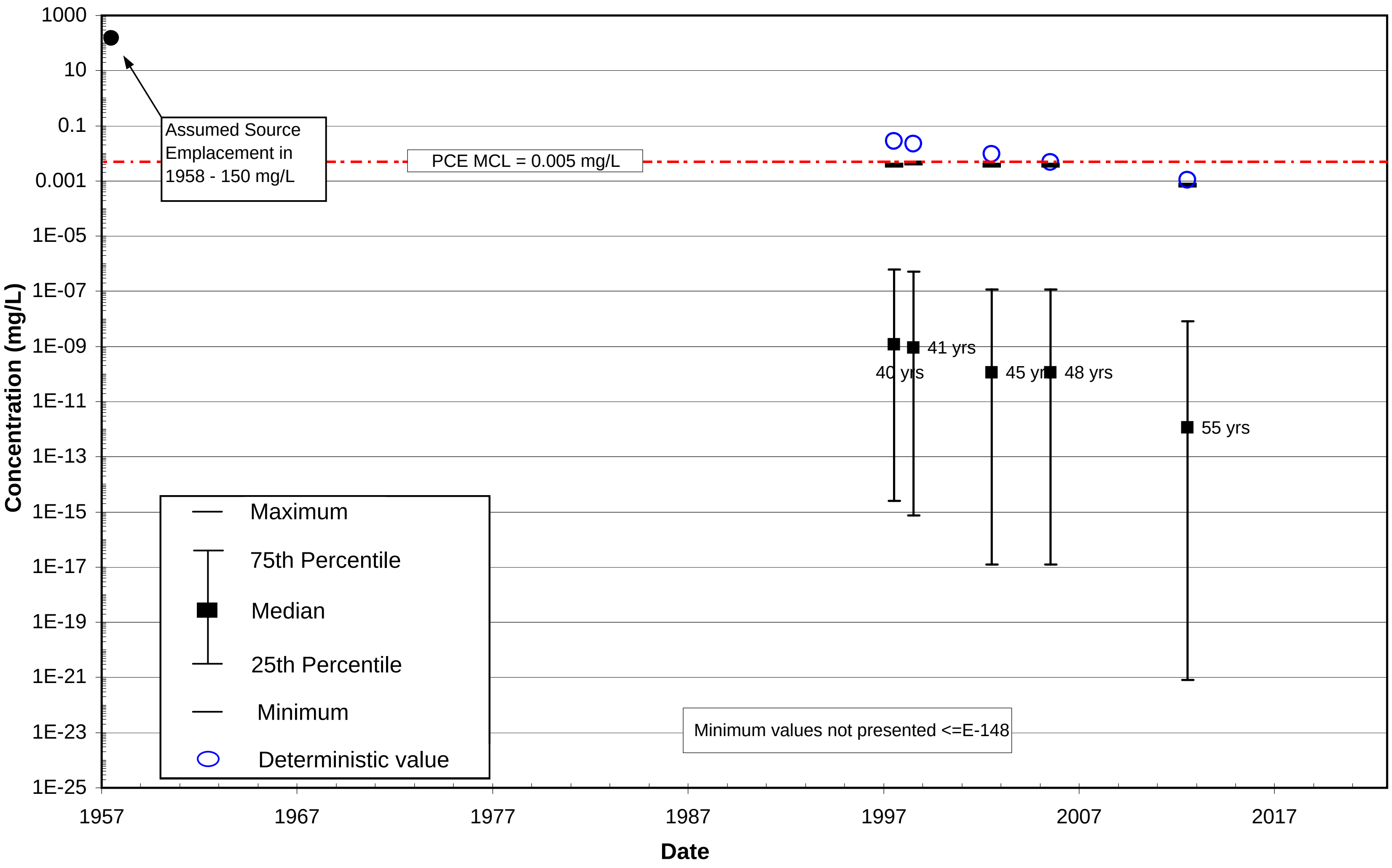


Figure 30a: BIOCHLOR Deterministic and Stochastic Model PCE Predictions at the Source Over Time - Ashumet Valley, MMR

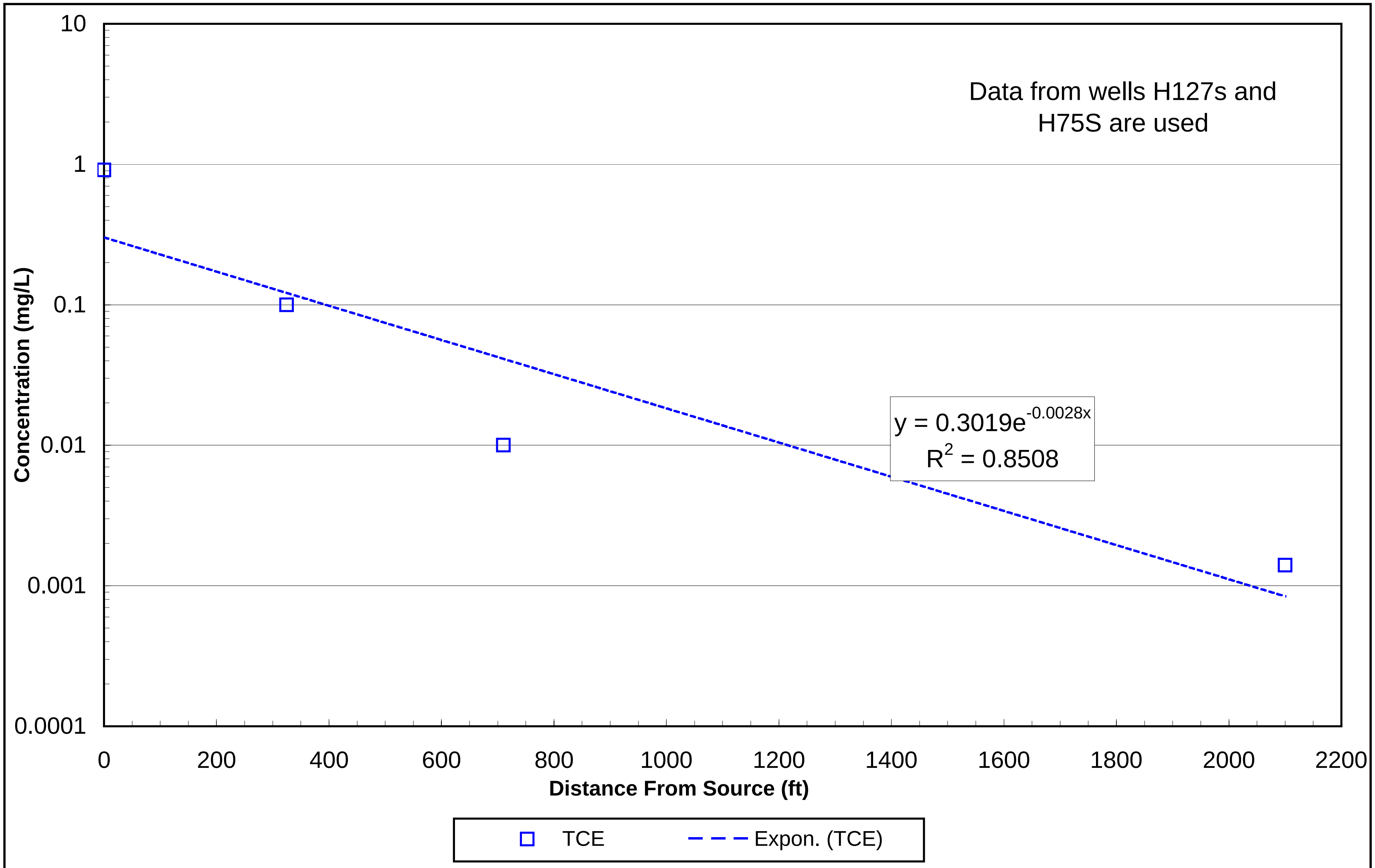


Figure 31a: 1991 Plume Centerline Concentrations - Wurtsmith AFB

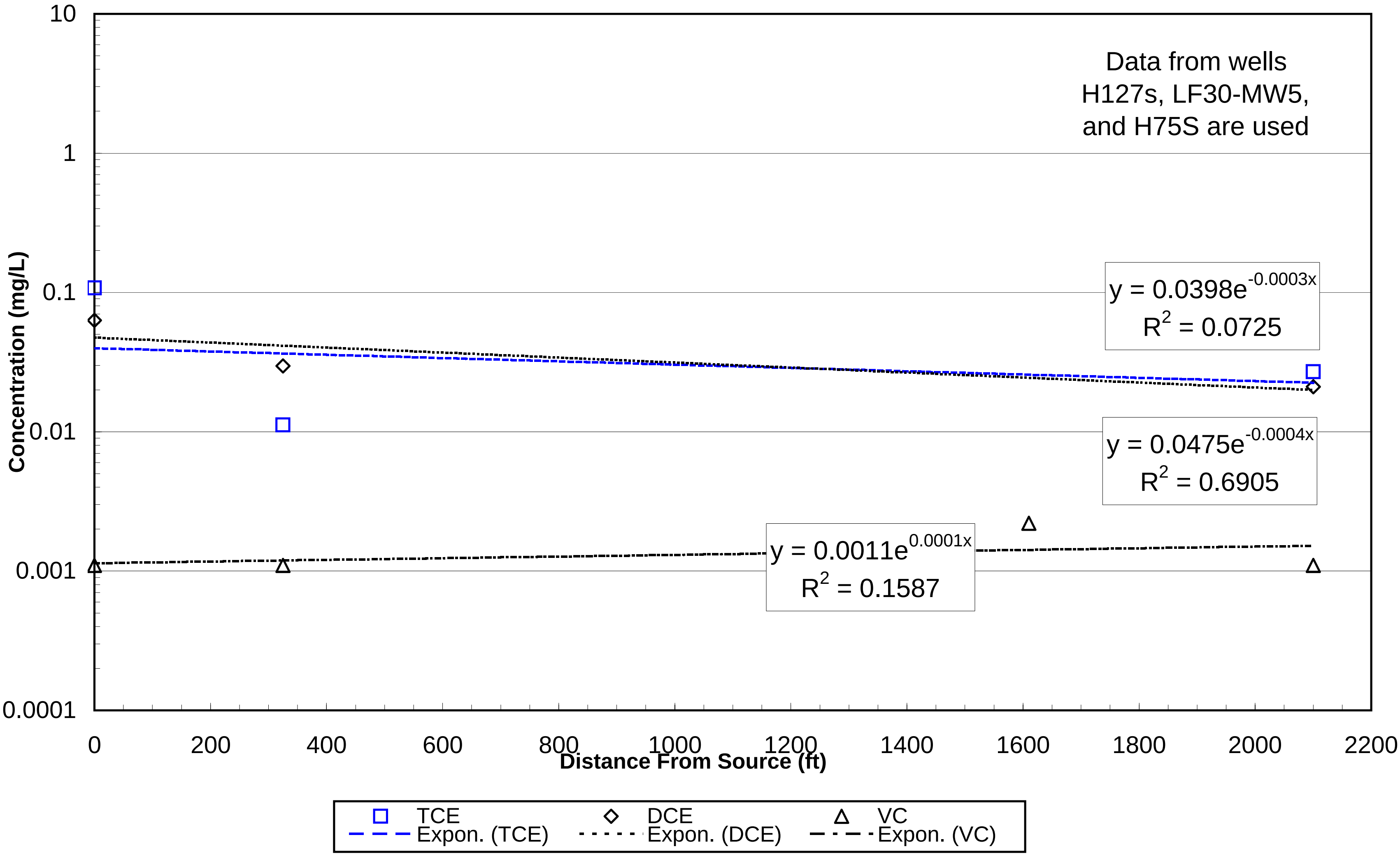


Figure 31b: 2001 Plume Centerline Concentrations - Wurtsmith AFB

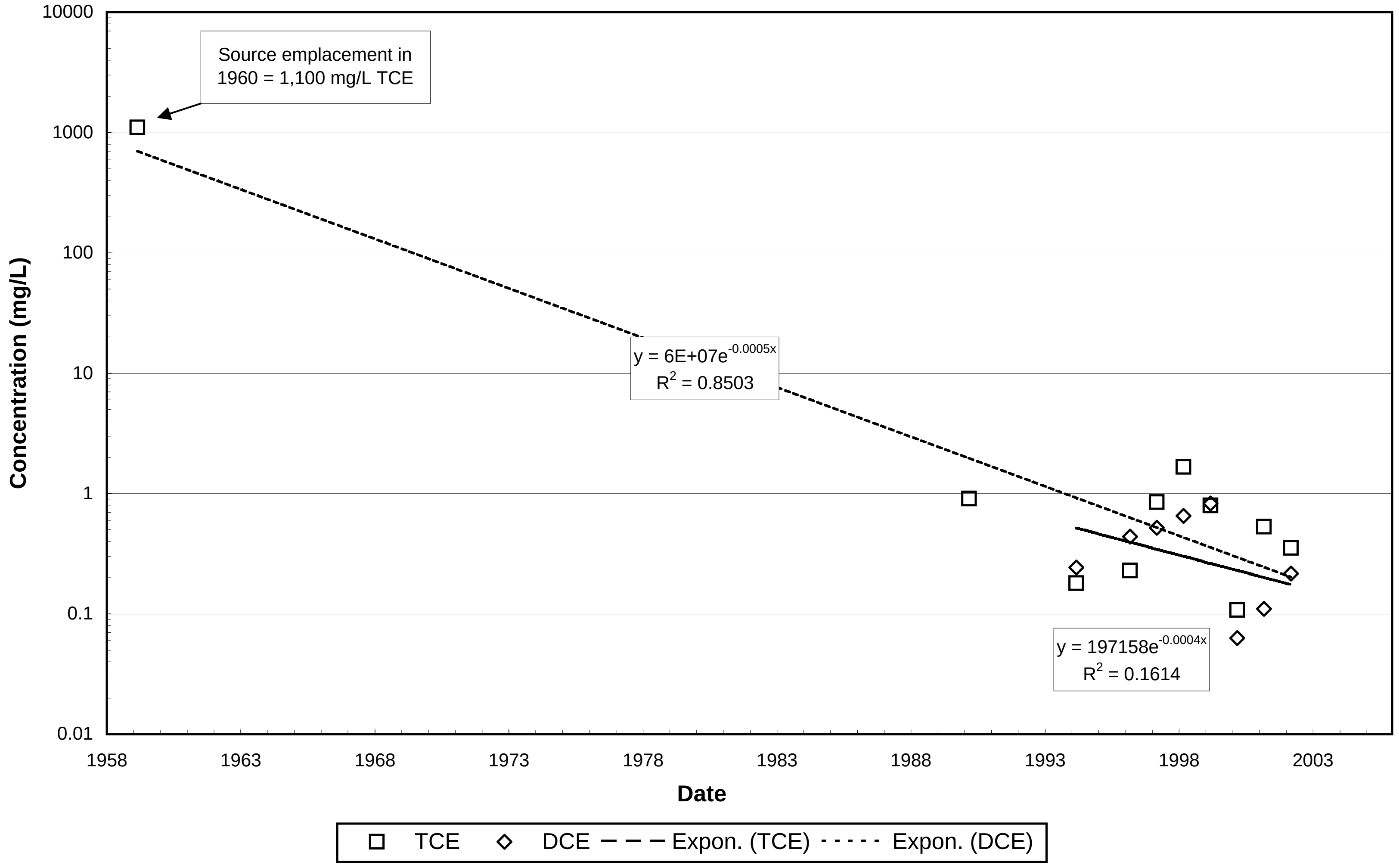
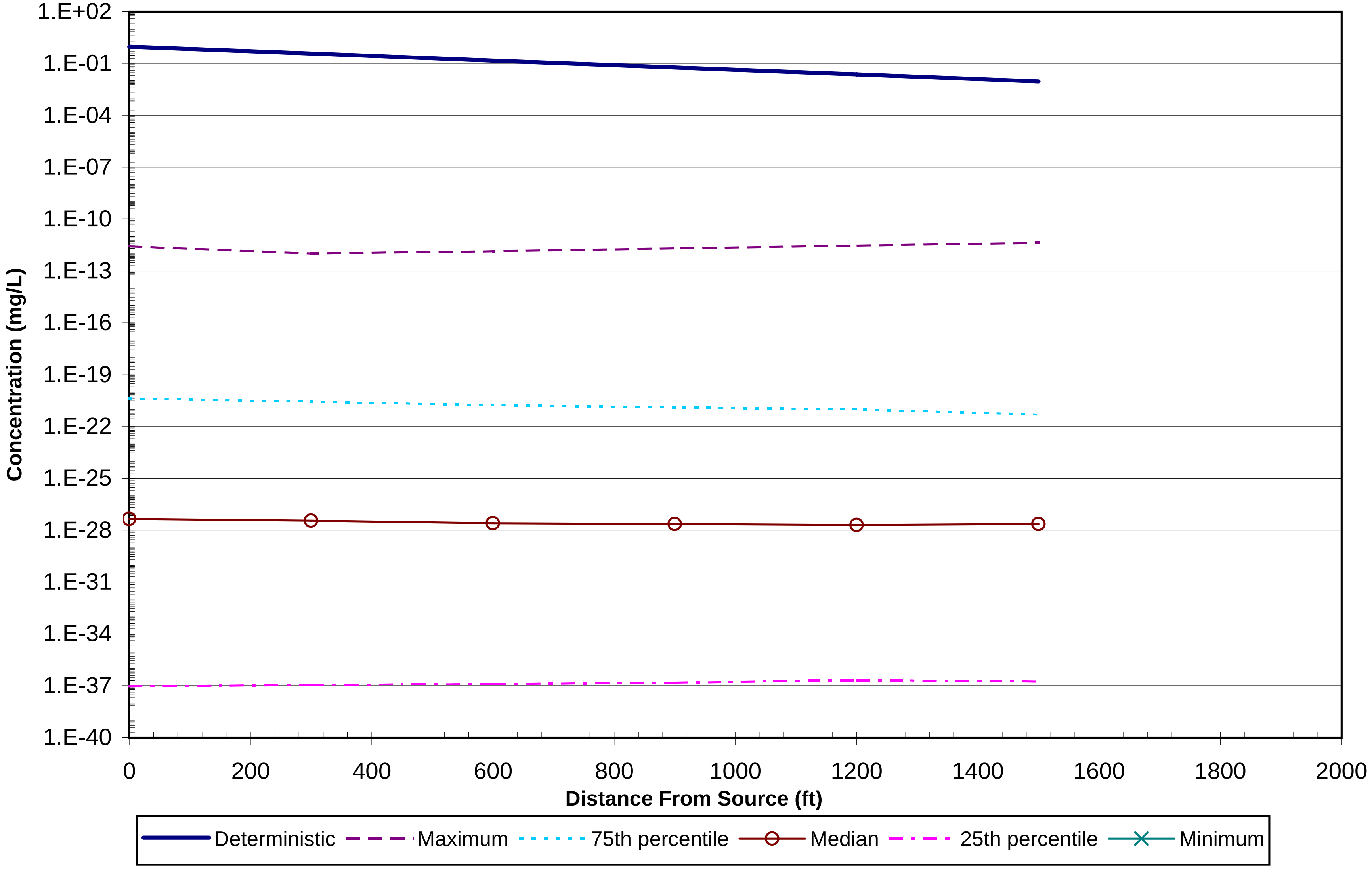
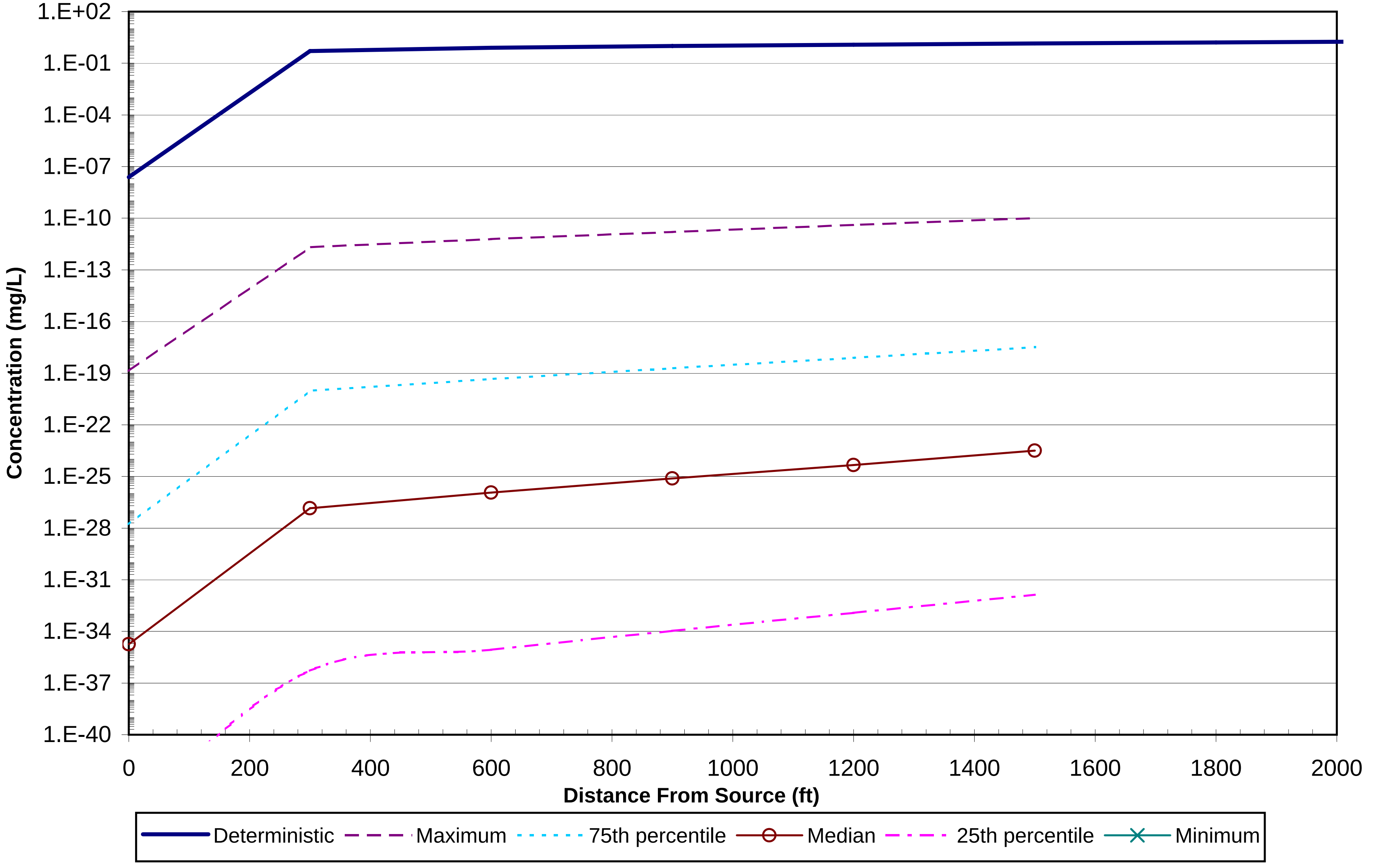


Figure 32: Source Decay Rate in well H127S - Wurtsmith AFB



Minimum values <= E-113

Figure 33a: TCE Deterministic and Stochastic Modeled Concentrations in 1991 - Wurtsmith AFB



Minimum values <= E-107

Figure 33b: DCE Deterministic and Stochastic Modeled Concentrations in 1991 - Wurtsmith AFB

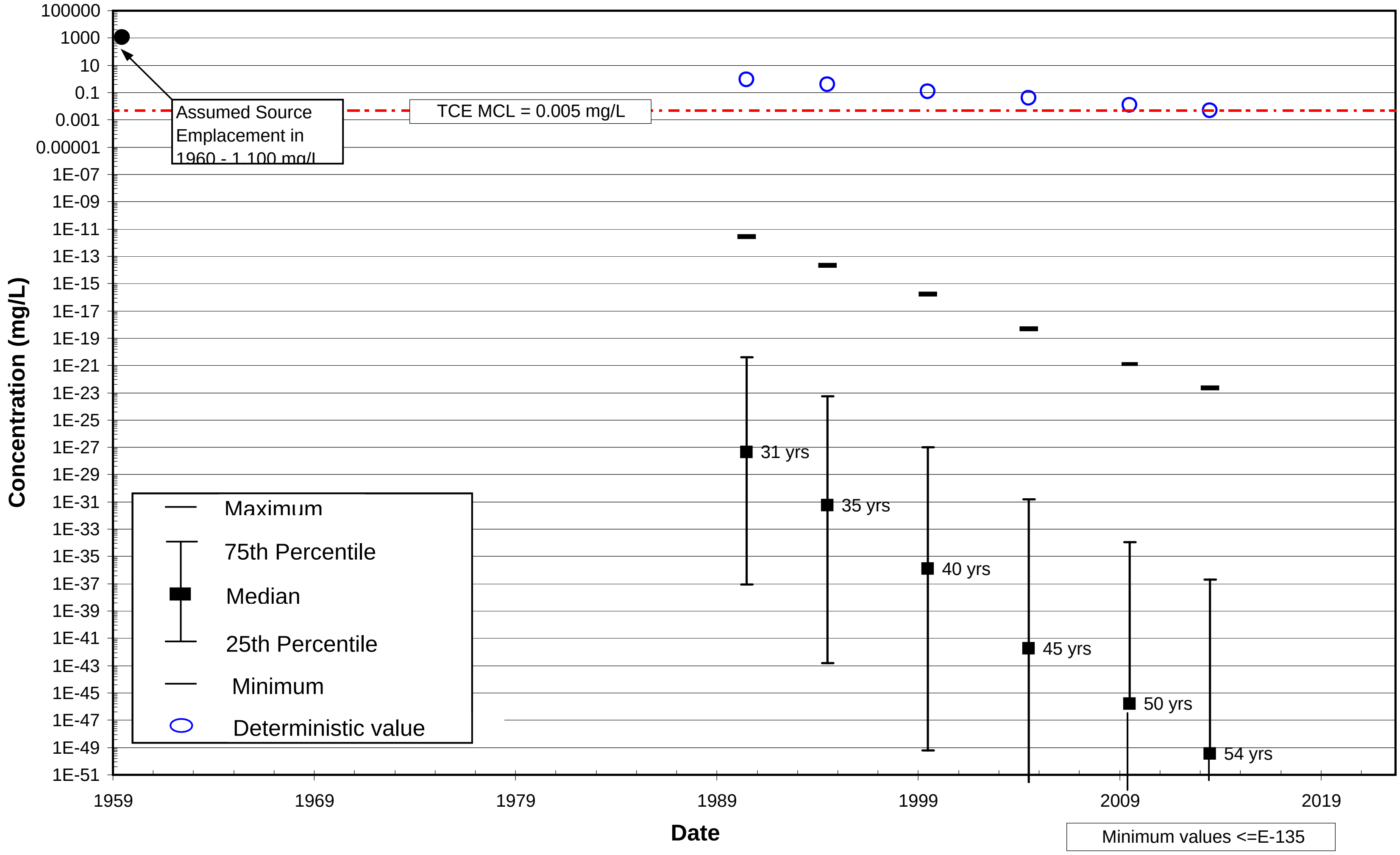


Figure 34a: BIOCHLOR Deterministic and Stochastic Model TCE Predictions at the Source Over Time - Wurtsmith AFB

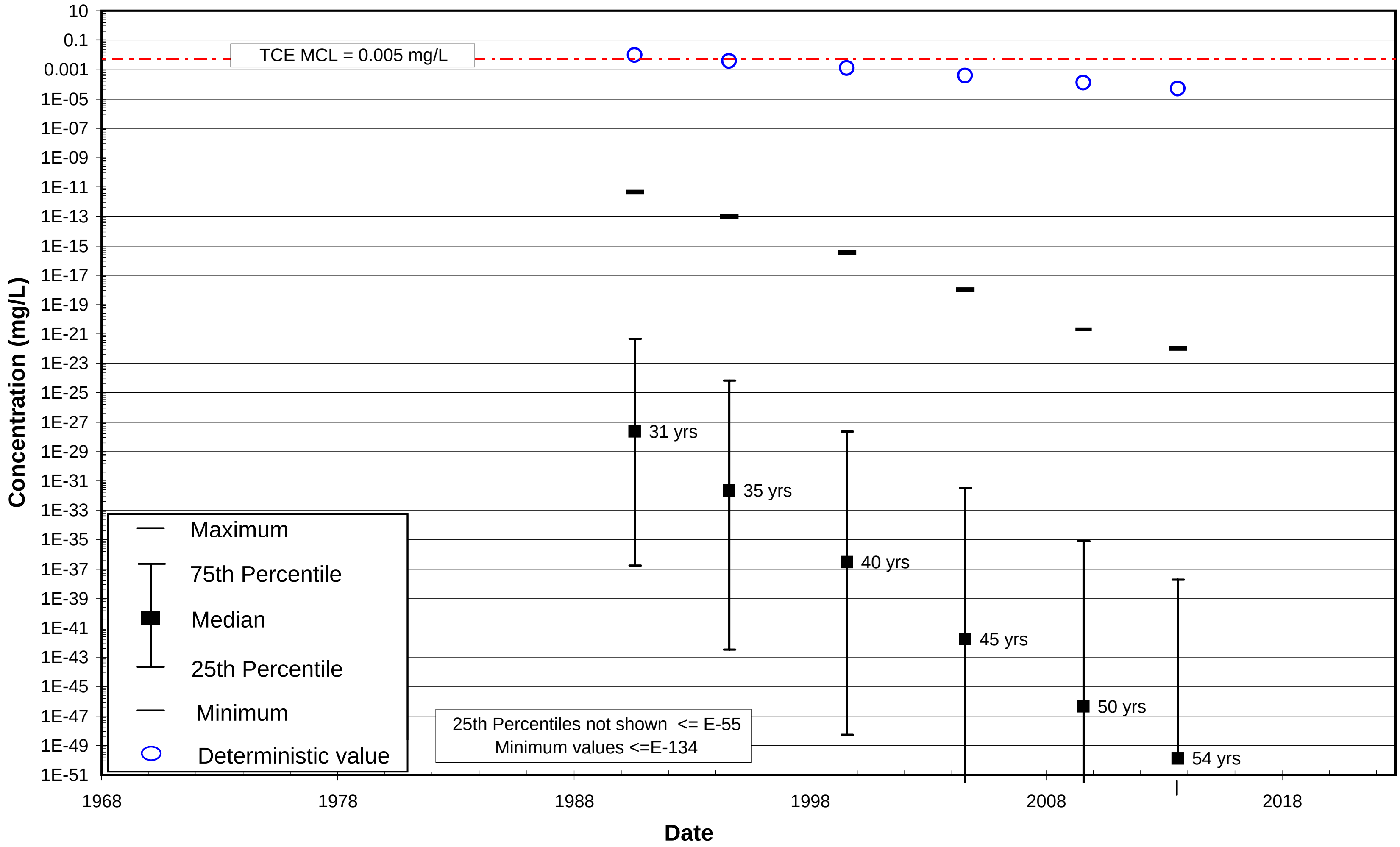


Figure 34b: BIOCHLOR Deterministic and Stochastic Model TCE Predictions at 1,500 ft from the Source Over Time - Wurtsmith AFB