

FINAL

**Treatability Study in Support of
Remediation by Natural Attenuation
for Groundwater at Area A**



**Tinker Air Force Base
Oklahoma**

Prepared For

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

and

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**FINAL
TREATABILITY STUDY IN SUPPORT OF
REMEDATION BY NATURAL ATTENUATION
FOR GROUNDWATER AT AREA A**

at

TINKER AIR FORCE BASE, OKLAHOMA

December 1999

Prepared for:

**AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS**

and

**TINKER AIR FORCE BASE
OKLAHOMA**

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EXECUTIVE SUMMARY

This report presents the results of a treatability study (TS) performed by Parsons Engineering Science, Inc. (Parsons ES) at the Area A Service Station (Area A), Tinker Air Force Base (AFB), Oklahoma, to evaluate remediation by natural attenuation (RNA) of dissolved chlorinated aliphatic hydrocarbons (CAHs) and fuel hydrocarbons in groundwater. The TS focused on the fate and transport of dissolved CAHs, particularly trichloroethene (TCE), which are present at high concentrations. Petroleum hydrocarbons [including benzene, toluene, ethylbenzene, and xylenes (BTEX)] are also present in site groundwater and were considered in this TS. The site history and results of previous soil and groundwater investigations are also summarized in this report.

Comparison of CAH, BTEX, electron acceptor, and biodegradation byproduct isopleth maps for Area A provides strong qualitative evidence of biodegradation of dissolved CAHs and BTEX. These geochemical data indicate that reductive dehalogenation of dissolved CAHs has been occurring at the site with microbes utilizing natural organic carbon, BTEX, and other fuel hydrocarbons as substrates. Patterns observed in the distribution of CAHs, daughter products of CAHs, electron acceptors, and biodegradation byproducts also suggest dehalogenation has reduced the concentration of CAHs dissolved in site groundwater. Field-scale, first-order decay rates computed using data from Area A include total chlorinated ethene decay rates of 0.04 and 0.21 yr^{-1} (half-lives of 15.75 and 3.32 years), and TCE decay rates ranging from 0.27 yr^{-1} to 2.65 yr^{-1} (half-lives of 2.53 to 0.26 years).

BTEX has undergone biodegradation by the biologically facilitated processes of aerobic respiration, denitrification, sulfate reduction, methanogenesis, and to a lesser extent iron reduction. Field-scale, first-order decay rates computed using data from Area A include total BTEX biodegradation rates ranging from 0.09 yr^{-1} to 0.36 yr^{-1} (half-lives of 8.08 to 1.91 years), and benzene decay rates ranging from 0.12 yr^{-1} to 0.43 yr^{-1} (half-lives of 5.64 to 1.60 years).

An important component of this study was to assess the potential for groundwater contamination to migrate from the source areas to potential receptor exposure points (i.e., water supply wells or surface water discharge points downgradient from the source). The finite-difference models MODFLOW and MT3D96[®] were used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and biodegradation of TCE dissolved in groundwater. Model parameters that were not measured at the site were estimated using reasonable literature values. The TCE plume modeled in conjunction with this report was calibrated to site conditions as of May 1997, before a VEP system started operation. Because the VEP system was too complicated to accurately model, predictive models based on the occurrence of RNA alone were run for comparison to results of the VEP system.

Model results indicate RNA of dissolved TCE contamination is occurring at Area A. Conservative modeling suggests that under conditions of May 1997, the TCE plume is at steady-state, and dissolved TCE would not migrate off-Base or to potential groundwater or surface water exposure points. The estimated rates of biodegradation combined with the effects of sorption, dispersion, and dilution result in a stable TCE groundwater plume.

However, the model also suggests that without source removal, TCE concentrations would persist above federal drinking water standards for at least 50 years.

Remediation by natural attenuation with LTM was then compared to preliminary monitoring results of VEP system monitoring from June 1997 to June 1998 (WC, 1998a and 1998b). Groundwater concentrations of BTEX, TPH, and naphthalene have been effectively reduced by the VEP system at Area A. Natural attenuation processes should further reduce any low concentrations of BTEX detected at downgradient locations (i.e., wells 2-149B and 2-163B), particularly as the source of BTEX is being reduced.

The VEP system is less effective at reducing TCE concentrations, although an overall reduction has been observed. Analytical data collected between November 1997 and June 1998 indicate the VEP system is reducing TCE contaminant concentrations at Area A, albeit at a slower rate relative to BTEX. The VEP system has induced aerobic redox conditions in USZ groundwater at Area A, and biodegradation of CAHs (TCE in particular) due to reductive dehalogenation is likely no longer occurring. Different source locations for CAHs versus BTEX may also account for differences in the VEP system effectiveness in reducing TCE concentrations relative to BTEX. Relatively high concentrations of both TCE and BTEX detected at wells 2-4 and 2-51B, located on the upgradient portion of the BTEX source area, may indicate the VEP system radius of influence is not extending to the most upgradient portion of the source area.

The VEP system has been effective in removing BTEX, CAHs, and naphthalene from USZ groundwater at Area A. However, reductive dehalogenation of CAHs (TCE in particular) is likely no longer occurring, and the Air Force recommends physical removal of CAHs by continued operation of the VEP system until CAH concentrations are reduced to regulatory guidelines. Long term monitoring (LTM) at the compliance wells and some additional site related wells is recommended for five years following shutdown of the VEP system to further evaluate the effectiveness of source control measures and to monitor the migration of site-related contaminants (TCE in particular). LTM should include parameters to monitor changes in site geochemistry that reflect biodegradation processes. If data collected under the LTM program indicate that CAH concentrations at downgradient well locations have not been reduced to levels considered protective of human health and the environment, additional operation of the VEP system may be required to contain and remediate groundwater at the site. Development of site-specific risk-based screening levels (RBSLs) for CAHs may also be appropriate for the site, if considered by the governing regulatory agency.

TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY	ES-1
ACRONYMS AND ABBREVIATIONS	viii
SECTION 1 - INTRODUCTION	1-1
1.1 Scope and Objectives	1-2
1.2 Base and Area A Background	1-4
1.3 Other Site Remediation Activity	1-9
SECTION 2 - SITE CHARACTERIZATION ACTIVITIES	2-1
2.1 Groundwater Sampling	2-1
2.1.1 Groundwater Sampling Locations	2-3
2.1.2 Preparation and Equipment Cleaning	2-3
2.1.3 Groundwater Sampling Procedures	2-3
2.1.3.1 Preparation of Location	2-3
2.1.3.2 Water Level and Total Depth Measurements	2-3
2.1.3.3 Monitoring/Extraction Well Purging	2-4
2.1.3.4 Sample Collection	2-4
2.1.4 Onsite Chemical Parameter Measurement	2-4
2.1.5 Sample Handling	2-5
2.2 Aquifer Testing	2-5
SECTION 3 - PHYSICAL CHARACTERISTICS OF THE STUDY AREA	3-1
3.1 Topography, Surface Hydrology, and Climate	3-1
3.2 regional geology and Hydrogeology	3-3
3.2.1 Regional Geology	3-3
3.2.2 Regional Hydrogeology	3-7
3.3 Area A Geology and Hydrogeology	3-11
3.3.1 Site Geology	3-11
3.3.2 Site Hydrogeology	3-11
3.4 Groundwater Use	3-16
SECTION 4 - CONTAMINANT DISTRIBUTION AND EVIDENCE OF BIODEGRADATION	4-1
4.1 Overview of Hydrocarbon Biodegradation	4-1
4.1.1 Biodegradation of Dissolved BTEX	4-1
4.1.2 Biodegradation of Dissolved CAHs	4-2

TABLE OF CONTENTS (Continued)

	Page
4.1.2.1 Electron Acceptor Reactions (Reductive Dehalogenation)	4-5
4.1.2.2 Electron Donor Reactions	4-7
4.1.2.3 Cometabolism	4-7
4.1.2.4 Abiotic Degradation of Chlorinated Solvents	4-9
4.1.2.5 Behavior of Chlorinated Solvent Plumes	4-10
4.1.2.5.1 Type 1 Behavior	4-10
4.1.2.5.2 Type 2 Behavior	4-10
4.1.2.5.3 Type 3 Behavior	4-10
4.1.2.5.4 Mixed Behavior	4-10
4.2 Nature and Extent of Contamination	4-11
4.2.1 Contaminant Sources	4-11
4.2.2 Hydrocarbons in Soil	4-13
4.2.3 Fuel Hydrocarbons in Groundwater	4-13
4.2.4 Dissolved CAHs and Daughter Products	4-18
4.3 Analysis of Hydrocarbon Biodegradation	4-26
4.3.1 Field-Scale Contaminant Mass Loss	4-26
4.3.1.1 Fuel Hydrocarbons over Time	4-26
4.3.1.2 TCE over Time	4-26
4.3.2 Electron Donors, Electron Acceptors, and Metabolic Byproducts	4-26
4.3.2.1 Total Organic Carbon in Soil	4-29
4.3.2.2 Total Organic Carbon in Groundwater	4-29
4.3.2.3 Dissolved Oxygen	4-30
4.3.2.4 Nitrate/Nitrite	4-32
4.3.2.5 Ferrous Iron	4-34
4.3.2.6 Sulfate	4-36
4.3.2.7 Methane	4-36
4.3.3 Additional Geochemical Indicators of Biodegradation	4-39
4.3.3.1 ORP	4-39
4.3.3.2 pH	4-42
4.3.3.3 Temperature	4-42
4.3.3.4 Alkalinity and Carbon Dioxide Evolution	4-42
4.3.3.5 Volatile Fatty Acids and Phenols	4-44
4.3.3.6 Ammonia	4-44
4.3.4 Expressed Assimilative Capacity	4-47
4.3.5 Additional Evidence of CAH Reductive Dehalogenation	4-48
4.3.5.1 Presence of Daughter Products	4-48
4.3.5.2 Chloride as an Indicator of Dehalogenation	4-51
4.3.5.3 Screening Table for CAH Degradation	4-54
4.3.6 Approximation of Biodegradation Rates	4-57
4.4 Summary	4-59

TABLE OF CONTENTS (Continued)

	Page
SECTION 5 - GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL	5-1
5.1 General Overview and Model Description	5-1
5.2 Model Objectives	5-2
5.3 Conceptual Model Design and Assumptions	5-2
5.4 Initial Model Setup	5-3
5.4.1 Grid Design	5-3
5.4.2 Groundwater Flow Model	5-5
5.4.2.1 Boundary Conditions	5-5
5.4.2.2 Recharge and Evapotranspiration	5-6
5.4.2.3 Aquifer Properties	5-6
5.4.2.4 Aquifer Storage	5-6
5.4.2.5 Aquifer Stresses	5-7
5.4.3 Contaminant Transport Model	5-7
5.4.3.1 Source	5-7
5.4.3.2 Dispersivity	5-8
5.4.3.3 Retardation	5-9
5.4.3.4 Biodegradation	5-9
5.5 Model Calibration	5-9
5.5.1 Groundwater Flow Model	5-9
5.5.2 Plume Calibration	5-14
5.5.2.1 Source Concentrations	5-14
5.5.2.2 Dispersivity	5-14
5.5.2.3 TCE Decay Rates	5-14
5.5.2.4 Sorption	5-15
5.5.2.5 Effective Porosity	5-15
5.5.2.6 Transport Calibration Results	5-15
5.6 Sensitivity Analysis	5-17
5.6.1 Sensitivity to Variations in Hydraulic Conductivity	5-18
5.6.2 Sensitivity to Variations in the Distribution Coefficient	5-18
5.6.3 Sensitivity to Variations in Dispersivity	5-18
5.6.4 Sensitivity to Variations in the Decay Rate Constant	5-20
5.6.5 Sensitivity to Variations in Source Concentrations	5-20
5.6.6 Summary of Sensitivity Analysis Results	5-20
5.7 Model Predictions	5-21
SECTION 6 - SOURCE REMEDIATION BY VEP AT AREA A	6-1
6.1 VEP System Overview	6-1
6.2 Evaluation of VEP Effectiveness	6-3
6.2.1 Total BTEX and Benzene	6-3

TABLE OF CONTENTS (Continued)

	Page
6.2.2 Naphthalene	6-9
6.2.3 Total Petroleum Hydrocarbons	6-9
6.2.4 TCE	6-11
6.2.5 MTBE	6-11
6.3 Conclusions.....	6-14
SECTION 7 - REMEDIAL EVALUATION AND COST COMPARISON.....	7-1
7.1 Evaluation Criteria	7-1
7.1.1 Effectiveness, Implementability and Cost	7-1
7.1.2 Remedial Action Objectives	7-1
7.2 Alternative 1 - RNA with LTM	7-3
7.2.1 Alternative 1 - Effectiveness.....	7-3
7.2.2 Alternative 1 - Implementability.....	7-3
7.2.2.1 Alternative 1 LTM Plan Overview	7-4
7.2.2.2 LTM Sampling Strategy.....	7-4
7.2.2.3 Sampling Duration and Frequency.....	7-4
7.2.2.4 Analytical Protocol.....	7-4
7.2.2.5 Periodic LTM Plan Review.....	7-8
7.2.3 Alternative 1 - Cost.....	7-8
7.3 Alternative 2 - VEP System Operation.....	7-8
7.3.1 Alternative 2 - Effectiveness	7-8
7.3.2 Alternative 2 - Implementability	7-9
7.3.2 Alternative 2 - Cost	7-9
7.4 REMEDIAL APPROACH	7-9
SECTION 8 - CONCLUSIONS AND RECOMMENDATIONS	8-1
8.1 Conclusions.....	8-1
8.2 Recommendations.....	8-2
SECTION 9 - REFERENCES	9-1

TABLE OF CONTENTS (Continued)

APPENDICES

- A - Pertinent Tables, Figures, and Slug Test Data from Previous Reports
- B - Geologic Logs, Monitoring Wells Construction, Diagrams, Monitoring Well Sampling Forms, and Slug Test Data
- C - Laboratory Analytical Data
- D - Model Input Parameters, Related Calculations, and Sensitivity Analysis Results
- E - Model Input and Output Files
- F - Remedial Alternative Cost Calculations
- G - Responses to Comments

LIST OF TABLES

No.	Title	Page
2.1	Analytical Protocols for Groundwater and Free Product Samples	2-2
3.1	Major Geologic Units in the Vicinity of Tinker AFB.....	3-4
3.2	Monitoring Well Summary and Groundwater Elevations	3-14
3.3	Hydraulic Conductivities and Average Groundwater Velocities.....	3-17
4.1	Coupled Oxidation Reactions	4-3
4.2	Fuel Hydrocarbons in Groundwater.....	4-15
4.3	Chlorinated Aliphatic Hydrocarbons in Groundwater April/May 1997	4-19
4.4	Groundwater Geochemical Data April/May 1997	4-24
4.5	Mass Ratio of Alkalinity (as CaCO ₃) Produced to BTEX Degraded During Aerobic Respiration, Denitrification, Iron (III) Reduction, and Sulfate Reduction.....	4-43
4.6	Concentrations of Phenols, Aliphatic Acids, and Aromatic Acids in Groundwater April/May 1997.....	4-45
4.7	Expressed Assimilative Capacity of USZ Groundwater.....	4-47
4.8	Analytical Parameters and Weighting for Preliminary Screening	4-54
4.9	Interpretation of Points Awarded During Natural Attenuation Screening.....	4-57
4.10	Decay Rate Summary	4-60
5.1	Common Designations for Several Important Boundary Conditions	5-6
5.2	Calculation of Retardation Coefficients.....	5-10
5.3	Summary of Sensitivity Analysis Results.....	5-19
6.1	Summary of Groundwater Analytical Results	6-4
7.1	Groundwater Quality Standards.....	7-2
7.2	Long-Term Monitoring Analytical Protocol for Groundwater	7-6
7.3	Estimated Alternative 1 Costs.....	7-8
7.4	Estimated Alternative 2 Costs.....	7-10

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

No.	Title	Page
1.1	Location of Tinker Air Force Base	1-5
1.2	Location of Area A	1-6
1.3	Site Features and Sample Location Map	1-7
3.1	Topographic Map of Area A Service Station.....	3-2
3.2	Surface Geologic Map	3-6
3.3	Location of Hydrogeologic Cross-Sections A-A' and B-B'	3-8
3.4	Hydrogeologic Cross-Section A-A'	3-9
3.5	Hydrogeologic Cross-Section B-B'	3-10
3.6	Hydrogeologic Cross-Section C-C Area A Service Station.....	3-12
3.7	Hdyrogeologic Cross-Section D-D' Area A Service Station	3-13
3.8	Upper Saturated Zone Potentiometric Surface May 1997.....	3-15
3.9	Lower Saturated Zone Potentiometric Surface May 1997.....	3-18
4.1	Anaerobic Reductive Dehalogenation	4-6
4.2	Aerobic Degradation Pathways.....	4-8
4.3	Free Product (LNAPL) Plume in USZ Groundwater May 1997	4-12
4.4	Total BTEX Concentrations in Soil at Approximately 10 Feet bgs	4-14
4.5	Concentrations of Total Fuel Carbon in USZ Groundwater May 1997.....	4-16
4.6	Concentrations of Total BTEX in USZ Groundwater May 1997	4-17
4.7	Concentrations of TCE in USZ Groundwater May 1997	4-20
4.8	Concentrations of cis-1,2-DCE in USZ Groundwater May 1997.....	4-22
4.9	Concentrations of Vinyl Chloride in USZ Groundwater May 1997.....	4-23
4.10	Concentrations of Ethene and Ethane in USZ Groundwater May 1997	4-25
4.11	Dissolved Total BTEX Concentrations Over Time at Selected Groundwater Sampling Locations	4-27
4.12	Dissolved TCE Concentrations Over Time at Selected Groundwater Sampling Locations	4-28
4.13	Concentrations of Dissolved Oxygen in USZ Groundwater May 1997	4-31
4.14	Concentrations of Dissolved Nitrate (as N) in USZ Groundwater May 1997.....	4-33
4.15	Concentrations of Ferrous Iron in USZ Groundwater May 1997	4-35
4.16	Concentrations of Sulfate in USZ Groundwater May 1997.....	4-37
4.17	Concentrations of Methane in USZ Groundwater May 1997	4-38
4.18	Sequence of Microbially Mediated Redox Processes	4-40
4.19	Redox Potential in USZ Groundwater May 1997.....	4-41
4.20	CAHs vs Distance from Source Area at Groundwater Monitoring Wells 2-3, 2-50B, and VEP-9.....	4-49
4.21	CAHs vs Distance from Source Area Groundwater Monitoring Wells 2- 3, VEP-12, VEP-10, and VEP-11	4-50
4.22	Ratio of Parent to Daughter Products vs Distance from Source Area at Groundwater Monitoring Wells 2-3, 2-50B, and VEP-9.....	4-52

TABLE OF CONTENTS (Continued)

LIST OF FIGURES (Continued)

No.	Title	Page
4.23	Ratio of Parent to Daughter Products vs Distance from Source Area at Groundwater Monitoring Wells 2-3, VEP-12, VEP-10, and VEP-11	4-53
5.1	Model Grid Superimposed on area A Site Location	5-4
5.2	Calibrated Groundwater Surface.....	5-12
5.3	Calibrated versus Observed Groundwater Elevations	5-13
5.4	Calibrated TCE Plume in USZ Groundwater	5-16
5.5	Predicted Concentrations of USZ Groundwater After 50 Years (Assuming no Source Remediation)	5-22
6.1	VEP System at Area A.....	6-2
6.2	Effect of VEP System on Total BTEX in USZ Groundwater Over Time	6-8
6.3	Dissolved Total BTEX Concentrations Over Time at Select Groundwater Sampling Locations	6-10
6.4	Effect of VEP System on TCE in USZ Groundwater Over Time	6-12
6.5	Dissolved TCE Concentrations Over Time at Select Groundwater Sampling Locations	6-13
7.1	Proposed Long-Term Monitoring Sampling Locations.....	7-5

ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
°C	degrees centigrade
$\Delta G^\circ r$	Gibbs free energy of the reaction
$\mu\text{g/kg}$	micrograms per kilogram
$\mu\text{g/L}$	micrograms per liter
$\mu\text{S/cm}$	microsiemens per centimeter
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AOC	Area of Concern
ASCII	American Standard Code for Information Exchange
bgs	below ground surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
CA	chloroethane
CAH	chlorinated aliphatic hydrocarbon
CaCO_3	calcium carbonate
cm/sec	centimeter per second
DCA	dichloroethane
DCE	dichloroethene
DNAPL	dense nonaqueous-phase liquid
DO	dissolved oxygen
DOD	Department of Defense
DRO	diesel-range organics
ERI	Environmental Recovery, Inc.
ET	evapotranspiration
FPRW	Free Product Recovery Well
Fe^{2+}	Ferrous iron
Fe^{3+}	ferric iron
feet bgs	feet below ground surface
ft/day	feet per day
ft/ft	feet per foot
ft/mile	feet per mile
ft msl	feet above mean sea level
ft/yr	feet per year
ft^2/yr	square feet per year
ft^3/yr	cubic feet per year
gal/day	gallons per day
GC	gas chromatography
gpd/ft^2	gallons per day per square foot
gpm	gallons per minute
GRO	gasoline-range organics
HDPE	high density polyethylene
HWBZ	Hennessey Water-Bearing Zone

iron (II)	ferrous iron
iron (III)	ferric iron
IRP	Installation Restoration Program
IT	International Technology Corporation
K_d	distribution coefficient
kg/L	kilograms per liter
K_{oc}	soil sorption coefficient
L/kg	liters per kilogram
LSZ	lower saturated zone
LTM	long-term monitoring
LNAPL	light non-aqueous phase liquid
MCL	maximum contaminant level
mg	milligram
mg/L	milligrams per liter
MOC	method of characteristics
MS	mass spectrometer
MSL	mean sea level
MTBE	methyl tertiary-butyl ether
mV	millivolts
N	nitrogen
NAPL	nonaqueous-phase liquid
NGVD	National Geodetic Vertical Datum
NO_3^-	nitrate
NRMRL	National Risk Management Research Laboratory
OAC	Oklahoma Administrative Code
ODEQ	Oklahoma Department of Environmental Quality
ORBCA	Oklahoma Risk-Based Corrective Action
ORD	Office of Research and Development
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
PAH	polynuclear aromatic hydrocarbons
Parsons ES	Parsons Engineering Science, Inc.
PCE	tetrachloroethene
POC	point of compliance
POTW	public owned treatment works
QC	quality control
RAO	remedial action objective
RBSL	risk-based screening level
RCRA	Resource Conservation and Recovery Act
redox	reduction-oxidation
RI/FS	remedial investigation/feasibility study
RMS	root mean squared
RNA	remediation by natural attenuation
RW	recovery well
SAP	sampling and analysis plan

SVOC	semivolatile organic compound
SWMU	Solid Waste Management Unit
TCA	trichloroethane
TCE	trichloroethene
TMB	trimethylbenzene
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TS	treatability study
USEPA	United States Environmental Protection Agency
UST	underground storage tank
USZ	upper saturated zone
VC	vinyl chloride
VEP	Vacuum Enhanced Pumping
VEW	Vapor Extraction Well
VFA	volatile fatty acid
VOC	volatile organic compound
WC	Woodward-Clyde Federal Services
WSCI	Water and Soil Consultants, Inc.
yr ⁻¹	per year

SECTION 1

INTRODUCTION

This report was prepared by Parsons Engineering Science, Inc. (Parsons ES) and presents the results of a treatability study (TS) conducted to evaluate the use of remediation by natural attenuation (RNA) for groundwater contaminated with chlorinated aliphatic hydrocarbons (CAHs) and benzene, toluene, ethylbenzene, and xylenes (BTEX) at the former service station (Area A) located at Tinker Air Force Base (AFB), in Oklahoma City, Oklahoma (the Base). As used in this report, RNA refers to a management strategy that relies on natural attenuation mechanisms to remediate contaminants dissolved in groundwater and to control receptor exposure risks associated with contaminants in the subsurface. The United States Environmental Protection Agency (USEPA) Offices of Research and Development (ORD) and Solid Waste and Emergency Response (OSWER) define natural attenuation as (Wilson, 1996):

The biodegradation, dispersion, sorption, volatilization, and/or chemical and biochemical stabilization of contaminants to effectively reduce contaminant toxicity, mobility, or volume to levels that are protective of human health and the ecosystem.

As suggested by this definition, mechanisms for natural attenuation of CAHs and BTEX include advection, dispersion, dilution from recharge, sorption, volatilization, abiotic chemical transformation, and biodegradation. Of these processes, biodegradation is the predominant mechanism working to transform contaminants into innocuous byproducts. During natural biodegradation, indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the engineered addition of nutrients. Patterns and rates of natural attenuation can vary markedly from site to site depending on governing physical and chemical processes.

RNA is advantageous for the following reasons:

- Contaminants can be transformed to innocuous byproducts (e.g., carbon dioxide, ethene, or water), not just transferred to another phase or location within the environment;
- Current pump-and-treat technologies are energy intensive and generally not effective in reducing residual contamination;
- The process is nonintrusive and allows continuing use of infrastructure during remediation;

- Engineered remedial technologies may pose a greater risk to potential receptors than RNA (e.g., contaminants may be transferred into another environmental medium during remediation activities); and
- RNA is less costly than conventional, engineered remedial technologies.

A potential disadvantage of RNA is that, in some cases, natural attenuation rates are too slow to make RNA a practical remedial alternative. In addition, biodegradation of highly chlorinated compounds, such as trichloroethene (TCE), can produce vinyl chloride (VC), which is relatively toxic. Under certain geochemical conditions, vinyl chloride may accumulate in the environment rather than be transformed to innocuous byproducts.

The main emphasis of the work described herein was to evaluate the potential for naturally occurring degradation mechanisms to reduce dissolved CAH and BTEX concentrations in groundwater to levels that are protective of human health and the environment. This study is not intended to be a contamination assessment report or a remedial action plan; rather, it is provided as supplemental information to be used by the Base and its prime environmental contractor(s) in any future decision making regarding this site.

1.1 SCOPE AND OBJECTIVES

Parsons ES, in conjunction with researchers of the USEPA National Risk Management Research Laboratory (NRMRL), was retained by the United States Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division to conduct site characterization and groundwater modeling to evaluate the scientific defensibility of RNA with long-term monitoring (LTM) as a remedial option for contaminated groundwater at Area A.

The following tasks were performed to fulfill the project objectives:

- Review existing hydrogeologic and soil/groundwater quality data for the site;
- Conduct site characterization activities to more thoroughly characterize the nature and extent of groundwater contamination;
- Collect geochemical data in support of RNA;
- Develop a conceptual hydrogeologic model of the upper saturated zone (USZ), which is separated by a regional clay-silt aquitard from the lower saturated zone (LSZ);
- Develop a conceptual model of the current distribution of contaminants in the USZ;
- Evaluate site-specific data to determine whether naturally occurring processes of contaminant attenuation and destruction are occurring in USZ groundwater at the site;

- Design and execute a groundwater flow and contaminant fate and transport model for site USZ hydrogeologic conditions;
- Simulate the fate and transport of CAHs (e.g., TCE) and BTEX (e.g., benzene) in groundwater under the influence of advection, dispersion, adsorption, and biodegradation using the calibrated model;
- Evaluate a range of model input parameters to determine the sensitivity of the model to those parameters and to consider several contaminant fate and transport scenarios;
- Determine if natural processes are minimizing expansion of the dissolved CAH and BTEX plumes so that groundwater quality standards can be met at a downgradient point of compliance (POC);
- Conduct a preliminary exposure pathways analysis for potential current and future receptors;
- Use modeling results to assess the effect of current or planned future remedial actions on the CAH and BTEX plumes; and
- Provide a LTM plan that includes LTM and POC wells and a sampling and analysis plan (SAP).

Field work conducted under this program was oriented toward the collection of supplementary hydrogeologic and chemical data necessary to document and model the effectiveness of RNA with LTM for restoration of CAH- and BTEX-contaminated groundwater. Site characterization activities in support of RNA included static groundwater level measurement and groundwater sample collection and analysis from preexisting site monitoring wells and recently installed vacuum enhanced extraction wells.

Site-specific data were used to develop a solute fate and transport model for the site and to conduct a preliminary receptor exposure pathways analysis. The modeling effort was used to predict the future extent and concentration of the dissolved TCE and benzene plumes by modeling the combined effects of advection, dispersion, sorption, and biodegradation. Results of the model were used to assess the potential for completion of other exposure pathways involving groundwater and to identify whether RNA with LTM is an appropriate and defensible remedial option for contaminated groundwater, in conjunction with ongoing and planned engineered remedial actions. The results will be used to provide technical support for the RNA with LTM remedial option during regulatory negotiations, as appropriate.

This TS contains nine sections, including this introduction, and five appendices. Section 2 summarizes site characterization activities. Section 3 summarizes the physical characteristics of the study area. Section 4 describes the nature and extent of soil and groundwater contamination and the evidence of contaminant biodegradation in groundwater at the site. Section 5 describes the fate and transport model and design of the conceptual hydrogeologic model for the site; lists model assumptions and input

parameters; and describes sensitivity analysis results. Section 6 describes the effects of current remedial actions on the TCE and benzene plumes. Section 7 presents a evaluation and comparison of site conditions with and without the current remedial actions. Section 8 provides conclusions and recommendations based on this TS, and Section 9 lists the references used to develop this document. Appendix A contains pertinent figures and tables from previous reports such as the remedial investigation (RI) report for Area A [International Technology Corporation (IT), 1996]. Appendix B contains geologic boring logs, well construction diagrams, and monitoring well sampling forms. Appendix C presents groundwater analytical results for samples collected as a part of this TS. Appendix D contains model input parameters, calculations related to model calibration, and sensitivity analysis results. Appendix E contains model input and output in American Standard Code for Information Interchange (ASCII) format on a diskette. Appendix F contains cost calculations for retained remedial alternatives.

1.2 BASE AND AREA A BACKGROUND

Tinker AFB covers approximately 5,000 acres in the southeastern Oklahoma City metropolitan area (Figure 1.1). The Base has supported aircraft operations since its founding as the Midwest Air Depot in July 1941.

Tinker AFB currently operates under a Resource Conservation and Recovery Act (RCRA) Hazardous Waste Management Permit issued by the USEPA (July 1, 1991). This permit requires Tinker AFB to investigate all solid waste management units (SWMUs) and Areas of Concern (AOCs), including Area A, and to perform corrective action at those sites identified as posing a potentially unacceptable threat to human health or the environment. Because the Base is a Department of Defense (DOD) facility, site investigation and remediation have progressed through the stages outlined under the Installation Restoration Program (IRP). In addition, soil and groundwater investigations at Area A are mandated under Oklahoma Administrative Code (OAC) 165:25-3-76.

Area A is located at the corner of "E" Avenue and Fifth Street in the north-central portion of the Base (Figure 1.2). The site was the location of the Base service station facility for military vehicles from 1942 to 1992. Two 12,000-gallon underground storage tanks (USTs), Tanks 438 and 439 (Figure 1.3), were installed in 1942 to store leaded gasoline, and were later used to store unleaded fuel. Two additional USTs were installed in 1975. Tank 411, with a 10,000-gallon capacity, was used to store unleaded gasoline, and Tank 402, of unknown size, was used to store diesel fuel. In 1978, USTs 438 and 439 were suspected of leaking and were consequently taken out of service on May 5, 1978. In 1982, Tank 411 developed a leak and was replaced with a tank of the same size and in the same location. USTs 411 and 402 were taken out of service in October 1990. The service station was officially closed in April 1991. All four USTs (Tanks 402, 411, 438, and 439) and associated piping were removed from the site in January 1996.

Site investigations and remedial measures were instituted in response to the leaking fuel tanks at the Area A Service Station. The following studies and remedial activities have been completed:

OKLAHOMA

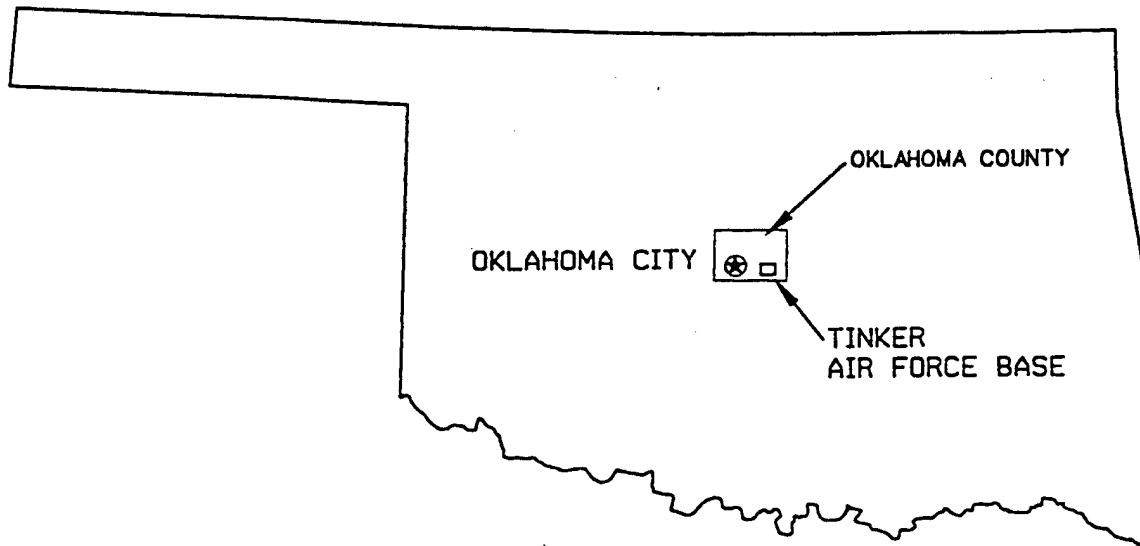


FIGURE 1.1

LOCATION OF TINKER AIR FORCE BASE

Area A
RNA TS
Tinker AFB, Oklahoma

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Denver, Colorado

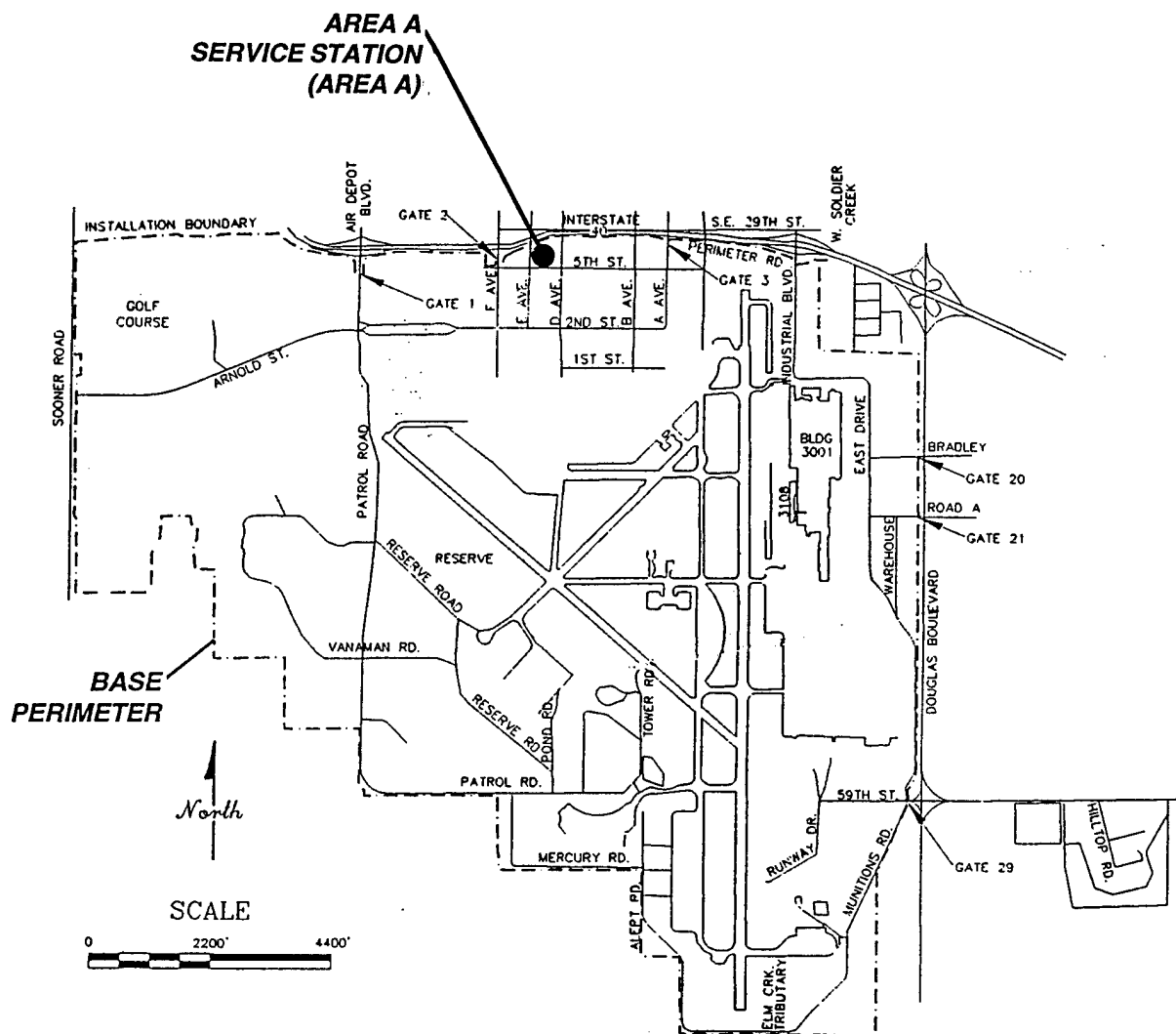


FIGURE 1.2

LOCATION OF AREA A

Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

- An initial site investigation was performed by Environmental Recovery, Inc. (ERI) in July 1990. The investigation included five soil boreholes near Tanks 438 and 439. Soil and soil vapor samples were analyzed for BTEX, total petroleum hydrocarbons (TPH), and total lead (ERI, 1990).
- A second site investigation was performed by Water and Soil Consultants, Inc. (WSCI) in 1991 and 1992 (WSCI, 1992). The investigation included a soil vapor survey in February 1991. On the basis of the vapor survey, eight soil boreholes were drilled, and soil samples were collected and analyzed for BTEX, TPH, and total lead. Three of the soil boreholes were completed as monitoring wells. A free product recovery system consisting of three product recovery wells (WSCI, 1992) also was installed by WSCI in July 1992.
- IT conducted a soil and groundwater investigation from October 1993 to March 1994 (IT, 1995a and 1993). Three soil boreholes were drilled, and soil samples were collected and analyzed for volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), TPH, metals, and geotechnical parameters. Three monitoring wells also were installed, and collected groundwater samples were analyzed for VOCs, SVOCs, TPH, metals, and total organic carbon (TOC). An additional four monitoring wells were installed in November and December 1993 as deeper well pairs.
- In January 1994 and January 1995, groundwater samples were collected from existing site monitoring wells and analyzed for VOCs, SVOCs, and metals (IT, 1996).
- A temporary groundwater probe investigation was conducted by IT from April to May 1995 (IT, 1995c). Groundwater samples were collected from 20 temporary groundwater points and analyzed for VOCs.
- Ten additional monitoring wells were installed in June 1995 by IT (IT, 1995b). In October 1995 groundwater samples were collected from existing site monitoring wells and analyzed for VOCs, SVOCs, and metals.
- Two additional monitoring wells were installed by Tinker AFB in June 1996. In August 1996 groundwater samples were collected from existing site monitoring wells and analyzed for VOCs, SVOCs, and metals (Tinker AFB, 1996).
- Four vacuum-enhanced pumping (VEP) wells were installed by Brown and Root, Inc. in April 1997.

Free product continues to persist on the USZ groundwater surface at Area A. Compound-specific fuel hydrocarbons historically detected in USZ groundwater include BTEX, trimethylbenzene (TMB) compounds, and naphthalene (IT, 1996). In addition, CAH compounds, primarily chlorinated solvents, have been historically detected at Area A in both USZ and LSZ groundwater. Detected chlorinated solvents include TCE, *cis*-1,2-dichloroethene (*cis*-1,2-DCE), 1,2-dichloroethane (1,2-DCA), tetrachloroethene (PCE), and VC. Many of the chlorinated solvents detected in Area A groundwater also

have been detected in upgradient monitoring wells, making it difficult to determine whether Area A is a source of these solvents.

There are currently 20 groundwater monitoring wells (2-2, 2-2A, 2-3, 2-4, 2-4A, 2-50B, 2-51A, 2-51B, 2-52A, 2-52B, 2-146B, 2-149A, 2-149B, 2-163B, 2-164B, 2-165B, 2-166B, 2-173B, 2-264B, and 2-265B), three product recovery wells (RW-1 through RW-3), and 12 VEP wells (VEP-1 through VEP-12), associated with Area A (Figure 1.3). Additional upgradient and cross-gradient monitoring wells associated with other sites (wells 2-145B, 2-148A, 2-148B, 2-152A, 2-152B, and 70) were also evaluated during the TS to determine the extent of groundwater contamination in the general area.

1.3 OTHER SITE REMEDIATION ACTIVITY

After the RNA field work was complete, the VEP system was started in June 1997. The period between June and November 1997 was primarily a system testing and shakedown period. Two eductor wells were installed in August and September 1997. The eductor wells were designed to recover groundwater via a jet pump-type system. They were installed to capture lower zone chlorinated solvent contamination, and for vertical control of contaminants which may seep through the confining layer which separates the USZ and LSZ. Results of VEP system operation have been described in the first and second quarterly monitoring reports (WC, 1998c [April] and 1998b [July]), and in a special case investigation report (WC, 1998a [August]). The reports all concluded that the VEP was containing the free product plume and reducing dissolved and vapor phase concentrations of VOCs. The last report (August 1998) recommended that the system continue to operate and that groundwater samples be collected monthly from selected compliance wells for three additional months, at which time quarterly monitoring would be evaluated.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

To meet the requirements of the RNA demonstration, additional data were required to evaluate groundwater geochemistry and contamination. Site characterization activities consisted of collecting groundwater samples from existing monitoring wells and recently installed VEP wells. The scope of the activities for sampling the monitoring wells was described in the work plan for this RNA TS (Parsons ES, 1997) with the work performed May 5. In addition, four VEP wells were sampled on April 23, 1997, after the wells had been developed but before they were operational as part of the VEP recovery system. The opportunity to sample the VEP wells made installation of additional monitoring points as described in the work plan unnecessary.

The physical and chemical data listed below were collected during the field work phase of the TS:

- Depth from measurement datum to free product, if present;
- Depth from measurement datum to the water table or potentiometric surface in 30 groundwater and monitoring and VEP wells;
- Groundwater geochemical data [pH, temperature, electrical conductivity, total alkalinity, oxidation-reduction potential (ORP), dissolved oxygen (DO), carbon dioxide, chloride, nitrate+nitrite [as nitrogen (N)], ammonia, ferrous iron, sulfate, TOC, phenols, aliphatic and aromatic acids, methane, ethane, and ethene; and
- Groundwater concentrations of chlorinated and aromatic VOCs.

The following sections describe the procedures followed during data collection. Additional details regarding investigative activities are presented in the work plan (Parsons ES, 1997).

2.1 GROUNDWATER SAMPLING

In order to maintain a high degree of quality control (QC) during this sampling event, the procedures described in the site work plan (Parsons ES, 1997) and summarized in the following sections were followed. Analytical protocols for groundwater samples are listed on Table 2.1.

TABLE 2.1
ANALYTICAL PROTOCOLS FOR
GROUNDWATER AND FREE PRODUCT SAMPLES
AREA A RNA TS
TINKER AFB, OKLAHOMA

MATRIX	METHOD	FIELD (F) OR ANALYTICAL LABORATORY (L)
Analyte		
WATER		
Ferrous Iron (Fe^{+2})	Colorimetric, Hach Method 8146	F
Hydrogen Sulfide	Colorimetric, Hach Method 8131	F
Redox Potential	Direct-reading meter	F
Dissolved Oxygen	Direct-reading meter	F
pH	Direct-reading meter	F
Conductivity	Direct-reading meter	F
Temperature	Direct-reading meter	F
Alkalinity (Carbonate [CO_3^{-2}] and Bicarbonate [HCO_3^{-1}])	Titrimetric, Hach Method 8221	F
Carbon Dioxide	Titrimetric, Hach Method 1436-01	F
Nitrate+Nitrite	E353.1	L
Ammonia	E350.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane, Ethane, Ethene	RSKSOP ^{a/} -175/RSKSOP-194	L
Total Organic Carbon	RSKSOP-102	L
VOCs, Fuel Carbon	RSKSOP-133	L
Semi-volatiles	E8270A	L
CAHs	RSKSOP-148	L
Phenols, aliphatic/ aromatic acids	RSKSOP-177	L

^{a/}RSKSOP = Robert S. Kerr Laboratory standard operating procedure.

2.1.1 Groundwater Sampling Locations

Groundwater samples were collected from 23 previously installed monitoring wells, and from four recently installed and developed VEP wells (Figure 1.3). Samples were not obtained from LSZ monitoring wells 2-51A and 2-52A due to malfunctioning dedicated sample pumps.

2.1.2 Preparation and Equipment Cleaning

All equipment used for sampling was assembled and properly cleaned and calibrated (if required) prior to use in the field. Calibrations were performed in accordance with the manufacturer's specifications. An electric water level meter or an oil/water interface probe was used to measure the static water level and free product level (if present) in the monitoring well prior to initiation of purging. Prior to each use, the water level probe was cleaned with a potable water and phosphate-free, laboratory-grade detergent solution, followed by a distilled-water rinse. In addition, a clean pair

of new, disposable latex or nitrile gloves was worn each time a different monitoring well was sampled.

For the majority of sampling locations, dedicated Grundfos® sample pumps and tubing were used to purge and sample the wells, eliminating the need for decontaminating these items. Dedicated high density polyethylene (HDPE) and silicone tubing were used in conjunction with a peristaltic pump at locations 2-50B and 2-52B, eliminating the need for decontaminating these items. The VEP wells were purged and sampled with a portable Grundfos® pump, which was decontaminated before and after sampling each well by cleaning with a potable water and phosphate-free, laboratory-grade detergent solution, followed by a distilled-water rinse.

2.1.3 Groundwater Sampling Procedures

2.1.3.1 Preparation of Location

To prevent sampling equipment from inadvertently contacting debris around the monitoring well, the area was cleared of foreign materials, such as vegetation, rocks, and debris prior to sampling. The integrity of the monitoring well also was inspected, and any irregularities in the visible portions of the well, protective cover, or concrete pad were noted.

2.1.3.2 Water Level and Total Depth Measurements

An electrical water level probe was used to measure the depth to groundwater below the well datum to the nearest 0.01 foot prior to removing any water from the monitoring well. If the monitoring well depth was not known, the water level probe was then lowered to the bottom of the well for measurement of total depth (recorded to the nearest 0.1 foot). The saturated casing volume for each well was calculated based on measured water level and total depth, or using total depth recorded on well construction diagrams (IT, 1996; Tinker AFB, 1997).

2.1.3.3 Monitoring/Extraction Well Purging

Prior to sampling, each monitoring well was purged to remove stagnant water from the well casing. Where possible, the volume of water removed from each well was at least three times the calculated saturated casing volume. Where it was not possible to remove three times the calculated casing volume (i.e., the well was purged dry), the well was allowed to recharge until sufficient water was present to obtain the necessary sample quantity. Purging continued until pH, DO concentration, conductivity, and temperature stabilized between successive readings. Physical and chemical parameters were measured at the well head using field meters and a quasi-flow-through cell consisting of an Erlenmeyer flask. A dedicated Grundfos® pump or a peristaltic pump with dedicated silicone and HDPE tubing was used for well evacuation. All purge water was containerized and disposed of at a Base groundwater storage tank located onsite. Purging and sampling field forms are contained in Appendix B.

2.1.3.4 Sample Collection

A dedicated Grundfos® or a peristaltic pump with dedicated silicone and HDPE tubing was used to extract groundwater samples from each sampled well. In almost all cases, the sampling was performed immediately following well purging. For example, at wells where a peristaltic pump was used, the pump was not turned off between purging and sampling activities. In a few instances, the monitoring well was purged dry, and the samples were collected after sufficient recharge had occurred (Appendix B). All samples were collected within 24 hours of purging.

The samples were transferred directly into the appropriate sample containers. The water was carefully poured down the inner walls of each sample bottle to minimize aeration of the sample. Sample bottles for aromatic and chlorinated VOCs and dissolved gases (methane and ethene) were filled so that there was no headspace or air bubbles within the container.

2.1.4 Onsite Chemical Parameter Measurement

Groundwater samples were analyzed in the field by Parsons ES and USEPA personnel for pH, conductivity, temperature, DO, ORP, total alkalinity, ferrous iron, carbon dioxide, and hydrogen sulfide. Analyses for BTEX, TMBs, fuel carbon, CAHs, nitrate+nitrite [as nitrogen (N)], ammonia, chloride, sulfate, methane, ethane, ethene, dissolved TOC, and aliphatic and aromatic (fatty) acids were performed at the NRMRL in Ada, Oklahoma.

DO measurements were taken using either an Orion® Model 840 or a YSI® Model 55 DO meter in a flow-through cell at the outlet of the purge pump. DO concentrations were recorded after the readings stabilized, and in all cases represent the lowest DO concentration observed.

Because the electrical conductivity, ORP, and temperature of the groundwater change significantly within a short time following sample acquisition, these parameters were measured in the field, in the same flow-through cell used for DO measurements. Measured values were recorded on the groundwater sampling records (Appendix B). Other time sensitive parameters, including pH, ferrous iron, alkalinity, carbon dioxide,

and hydrogen sulfide, were analyzed at the USEPA mobile laboratory immediately after sample collection.

2.1.5 Sample Handling

The fixed-base analytical laboratory (NRMRL) provided pre-preserved sample containers where appropriate. The sample containers were filled as described in Section 2.1.3.4, and the container lids were tightly closed. The samples were labeled as described in the work plan.

After the samples were sealed and labeled, they were transported to the onsite USEPA mobile laboratory where the remaining field analyses were performed. USEPA personnel packaged the samples submitted for fixed-base laboratory analyses to prevent breakage and leakage or vaporization from the containers. Sample shipment to NRMRL and the associated chain-of-custody documentation was the responsibility of the USEPA/NRMRL field personnel.

2.2 AQUIFER TESTING

During the RI, IT (1996) performed slug tests in seven monitoring wells. These data were deemed sufficient for use in developing and calibrating a groundwater flow and solute transport model for Area A. Therefore, additional aquifer testing was not performed during the TS field program.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

Existing site-specific data were reviewed and supplemented with data collected by Parsons ES in April and May 1997 to develop a synopsis of Area A physical characteristics. In addition to field investigation results from this TS, data from the following sources are included:

- Final Report, Investigation for Soil and Groundwater Cleanup Report, Area A Service Station, Tinker Air Force Base, Oklahoma (IT, 1996); and
- Temporary Groundwater Probe Investigation Report, Area A Service Station, Tinker Air Force Base, Oklahoma (IT, 1995c).

3.1 TOPOGRAPHY, SURFACE HYDROLOGY, AND CLIMATE

Tinker AFB is located in central Oklahoma, and topography at the Base varies from almost level to gently rolling. The local relief is a result of dissection by erosion and stream channel development. Ground surface elevations at Tinker AFB range from 1,190 feet above the National Geodetic Vertical Datum (NGVD) near the northwest corner of the Base where Crutch Creek intersects the Base boundary, to 1,320 feet NGVD at Area D, located east of the main installation. A topographic map of Area A at Tinker AFB is presented as Figure 3.1.

Surface water runoff from the Base primarily drains to diversion structures and then to intermittently flowing surface streams. The north and west portions of the Base drain to Crutch Creek, a tributary of the North Canadian River. Kuhlman Creek also collects drainage from the northwest portion of the Base and discharges into Crutch Creek north of the Base. The northeast portion of the Base is drained primarily by tributaries of Soldier Creek, which also is a tributary of Crutch Creek. Two small unnamed intermittent tributaries of Elm Creek cross installation boundaries south of the main runway, but these tributaries generally do not receive significant quantities of Base runoff because site grading is designed to preclude such drainage. These streams, when flowing, extend to Stanley Draper Lake, approximately one-half mile south of the Base.

The natural ground surface slopes to the west and elevations range from 1,230 to 1,247 feet NGVD within the northern part of the Base where Area A is located. Surface drainage from the site is directed primarily into Kuhlman Creek to the west of the site. Kuhlman Creek discharges into Crutch Creek north of the Base. A local topographic low (1,220 feet NGVD) exists within the Interstate 40 underpass at "F" Avenue (Figures 1.3 and 3.1). The underpass diverts surface drainage to a storm water collection system.

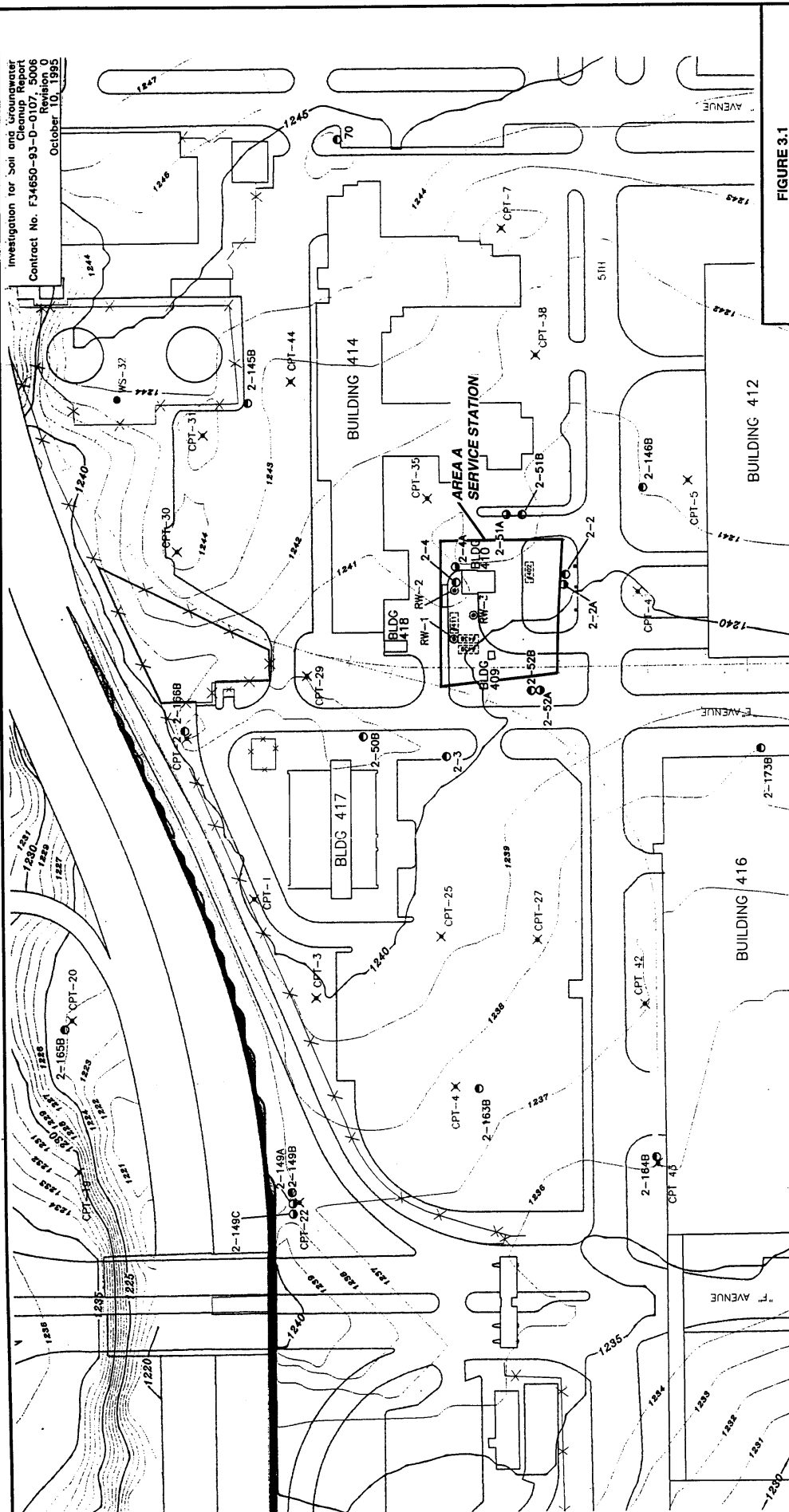


FIGURE 3.1

TOPOGRAPHIC MAP OF AREA A SERVICE STATION

Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
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Denver, Colorado

- LEGEND**
- RECOVERY WELL LOCATION AND ID NUMBER (WSCL 1992)
 - TEMPORARY GROUNDWATER PROBE
 - SAMPLE LOCATION AND ID NUMBER
 - UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
 - LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
 - WATER SUPPLY WELL
 - FORMER LOCATION OF UNDERGROUND STORAGE TANK
 - FENCE
 - 5 FOOT CONTOUR INTERVAL (FEET - DATUM: NGVD)
 - 1 FOOT CONTOUR INTERVAL (FEET - DATUM: NGVD)



0 100
FEET

The climate in central Oklahoma is continental, and is characterized by cold winters, hot summers, and moderate rainfall. Precipitation averages 33 inches per year. Annually, potential evaporation usually exceeds precipitation. Maximum evaporation occurs during June, July, and August.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

3.2.1 Regional Geology

Tinker AFB is located within the Central Redbed Plain Section of the Central Lowland Physiographic Province (Bingham and Moore, 1975), which is tectonically stable. No major faults or fracture zones have been mapped near Tinker AFB. Tinker AFB is underlain by several thousand feet of sedimentary strata that range in age from Cambrian to Permian and overlie a Precambrian igneous basement. The major lithologic units in the area of Tinker AFB are relatively flat-lying and have a regional westward dip of approximately 40 feet per mile (ft/mile) (Bingham and Moore, 1975).

Geologic units that outcrop at Tinker AFB consist of, in descending order, Quaternary Alluvium, the Hennessey Group, the Garber Sandstone, and the Wellington Formation (Table 3.1, Figure 3.2). Quaternary alluvium and terrace deposits overlie bedrock in and near present-day stream valleys. Quaternary deposits consist of unconsolidated soils from weathered bedrock, eolian sands, and interfingering lenses of fluvial sands, silts, clays, and gravels. Terrace deposits are exposed where stream valleys downcut through older strata, leaving them topographically higher than present day valley floors. Alluvial sediments range in thickness from less than a foot to nearly 20 feet.

The Hennessey Group, Garber Sandstone, and Wellington Formation are Permian in age (230 to 280 million years ago), and consist of a conformable sequence of sands, silts, and clays with lenticular beds that vary in thickness over short horizontal distances. Because of similar lithologies and the lack of fossils or key beds, the Garber Sandstone and the Wellington Formation are difficult to distinguish and are informally grouped as the Garber-Wellington Formation. Together these three units are approximately 900 feet thick beneath Tinker AFB.

The Hennessey Group outcrops on the central, southern, and western portions of the Base, generally to the west and south of Crutch Creek (Figure 3.2). The Hennessey Group includes the Kingman Siltstone and the Fairmont Shale (Miser *et al.*, 1954; Bingham and Moore, 1975), which are composed of red shale and thin beds of fine-grained sandstone. The Hennessey Group thins from approximately 70 feet in the southwest part of the Base towards its erosional edge across the northeastern part of the Base. The conformable contact between the Hennessey group and the underlying Garber Sandstone is often difficult to distinguish.

The Garber Sandstone outcrops across the northern, central, and eastern portions of the Base, and is generally covered by a thin veneer of soil or alluvium up to 20 feet thick (Figure 3.2). The Garber Sandstone consists predominantly of fine-grained sandstone, with lesser amounts of siltstone and shale. Outcrops north of the Base are characterized by small to medium channels with cross-bedded sandstones featuring cut and fill

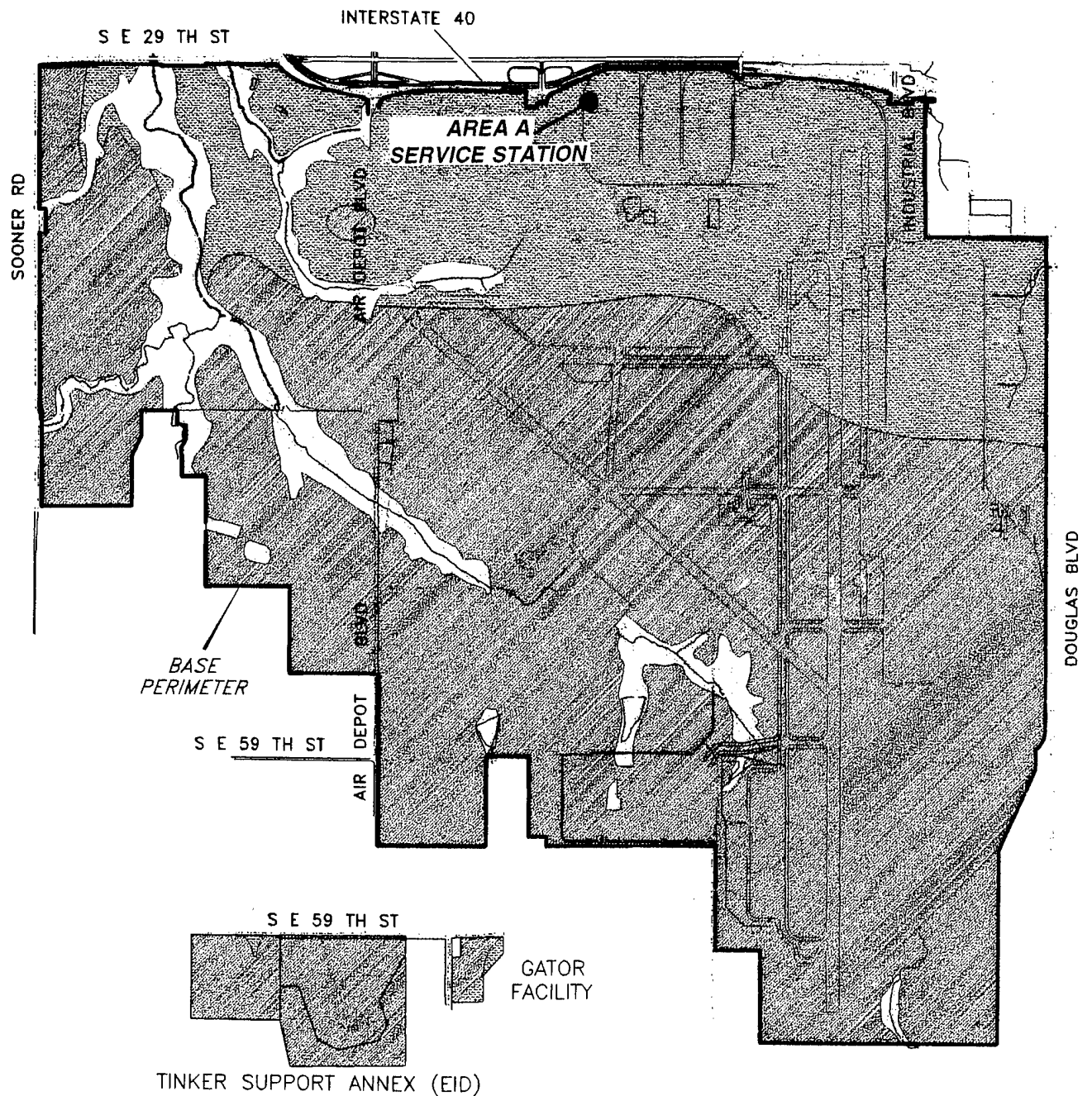
TABLE 3.1
MAJOR GEOLOGIC UNITS IN THE VICINITY OF TINKER AFB
FTA 2 RNA TS
TINKER AFB, OKLAHOMA

System	Series	Stratigraphic unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
Q U A T E R N A Y	R E C E N T	Alluvium	0-70	Unconsolidated, with interfingering lenses of sand, silt, clay, and gravel in flood plains and stream channels.	Moderately permeable. Yields small to moderate quantities of water in valleys of larger streams. Water is very hard, but suitable for most uses, unless contaminated by industrial wastes or oil field brines
	P L E I S T O C E N E	Terrace deposits	0-100	Unconsolidated, with interfingering lenses of sand, silt, gravel, and clay that occur at one or more levels above flood plains and principal streams.	Moderately permeable. Where deposits have sufficient saturated thickness, they are capable of yielding moderate quantities of water to wells. Water is moderately hard to very hard, but less mineralized than water in other aquifers. Suitable for most uses unless contaminated by oil field brines.

TABLE 3.1 (Continued)
MAJOR GEOLOGIC UNITS IN THE VICINITY OF TINKER AFB
FTA 2 RNA TS
TINKER AFB, OKLAHOMA

System	Series	Stratigraphic unit	Thickness (feet)	Description and Distribution	Water-Bearing Properties
P E R M	L	Hennessey	700	Deep-red clay shale containing thin beds of red sandstone and white or greenish bands of sandy or limey shale. Forms relatively flat to gently rolling grass-covered prairie.	Poorly permeable. Yields meager quantities or very hard, moderately to highly mineralized water to shallow domestic and stock wells. In places, water contains elevated levels of sulfate.
	O	Group (includes Kingmen			
	W	Siltstone and			
	E	Fairmont Shale)			
	R				
I A N	M				
	P				
	E				
	R				
	M				
I A N	I	Garber	500 ±	Deep-red to reddish-orange sandstone, massive and cross-bedded and interfingering with red shale and siltstone.	Poorly to moderately permeable. Important source of groundwater in Cleveland and Oklahoma counties.
	A	Sandstone			Yields small to moderate quantities of water to deep wells; heavily pumped for industrial and municipal uses in the Norman and Midwest City areas. Water from shallow wells hard to very hard; water from deep wells moderately hard to soft. Lower part contains water too salty for domestic and most industrial uses.
I A N	N	Wellington Formation	500 ±	Deep-red to reddish-orange massive and cross-bedded fine-grained sandstone interbedded with red, purple, maroon, and gray shale. Base of formation not exposed in the area.	

Source: Modified from Wood and Burton, 1968.



0 2400
APPROXIMATE SCALE IN FEET

EXPLANATION

- HENNESSEY GROUP
- GARBER SANDSTONE/
WELLINGTON FORMATION
- ALLUVIUM

FIGURE 3.2

SURFACE GEOLOGIC MAP TINKER AIR FORCE BASE

Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

Source: Tinker AFB, 1991; IT, 1996.

structures. The Wellington Formation, underlying the Garber Sandstone, crops out to the east of Tinker AFB. Geophysical and lithologic logs of soil boreholes drilled on Base indicate that 65 to 70 percent of the Garber Sandstone and Wellington Formation are composed of sandstone. The sandstones are typically fine to very fine grained, friable, and poorly cemented. However, the sandstone intervals are locally cemented, typically at the base of sandstone lenses, by quartz, carbonate or iron-bearing minerals. These cemented intervals form horizons resistant to drilling. Shale intervals are generally discontinuous, and range in thickness from a few inches to 40 feet.

3.2.2 Regional Hydrogeology

Tinker AFB overlies a regional source of potable water, the Central Oklahoma aquifer system. The productive formations of the aquifer include the Permian redbeds, including parts of the Permian Garber Sandstone and Wellington Formation, and Quaternary alluvium and terrace deposits. The Central Oklahoma aquifer has been classified as a Class IA aquifer by the State of Oklahoma, signifying that it is an irreplaceable source of public water supply (State of Oklahoma Water Resources Board, 1994). Water from the Central Oklahoma aquifer is used for municipal, industrial, domestic, and agricultural purposes. Tinker AFB presently derives most of its water from a system of 26 operable water wells constructed generally along the east and west margins of the Base, and from the Oklahoma City Water Department. All Base wells are completed in the Garber-Wellington Formation at depths of 400 to 1,100 feet.

Groundwater in the Central Oklahoma aquifer is derived primarily from precipitation infiltrating outcrops of the geologic units. Infiltration of surface waters from streams crossing the outcrops is believed to be a minor source of recharge to the aquifer (Parkhurst *et al.*, 1993). Tinker AFB is located in the outcrop area of the Garber Sandstone and is therefore in the recharge zone of the aquifer.

The groundwater system at Tinker AFB has been divided into four hydrogeologic zones: the Hennessey Water-Bearing Zone (HWBZ), the Upper and Lower Saturated Zones (USZ and LSZ), and the Producing Zone of the regional Garber-Wellington aquifer. The HWBZ occurs within the Hennessey Group and is perched above the USZ over the southwest portion of the Base. The LSZ and USZ are regionally considered to be in the upper third of the Garber-Wellington aquifer and generally are present at depths of less than 200 feet below ground surface (bgs). The Producing Zone generally is considered to be greater than 200 feet bgs, and is used for water supply at Tinker AFB.

The locations of regional hydrogeologic cross-sections A-A' (Figure 3.4) and B-B' (Figure 3.5) are shown on Figure 3.3. The HWBZ is perched within the Hennessey Group on the southwestern portion of the Base (Figure 3.4). The USZ generally behaves as a water table aquifer in the eastern part of the Base, but could be confined in localized portions of the Base where intra-USZ clay lenses intersect the USZ piezometric surface. The depth to the USZ water table ranges from zero feet bgs northeast and east of the Base to approximately 40 feet bgs in the southwest part of the Base. The regional stratigraphic dip of 0.0076 feet per foot (ft/ft) to the west-southwest produces a general westward groundwater flow pattern in the USZ. Hydraulic gradients in the USZ across Tinker AFB range from 0.0034 to 0.018 ft/ft and average 0.0076 ft/ft. A low-permeability zone,

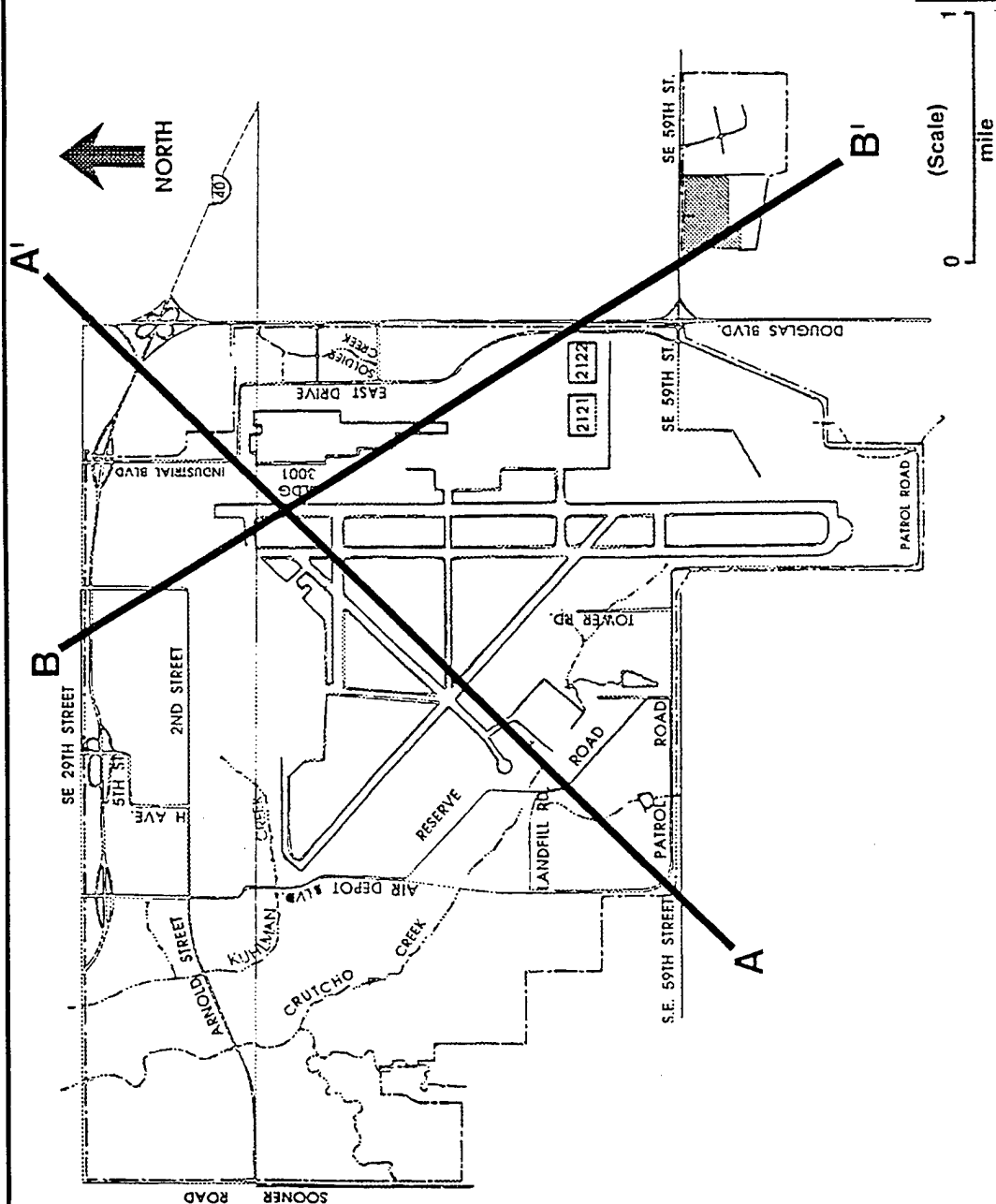


FIGURE 3.3

LOCATION OF HYDROGEOLOGIC
CROSS-SECTIONS A-A' AND B-B'

Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
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Denver, Colorado

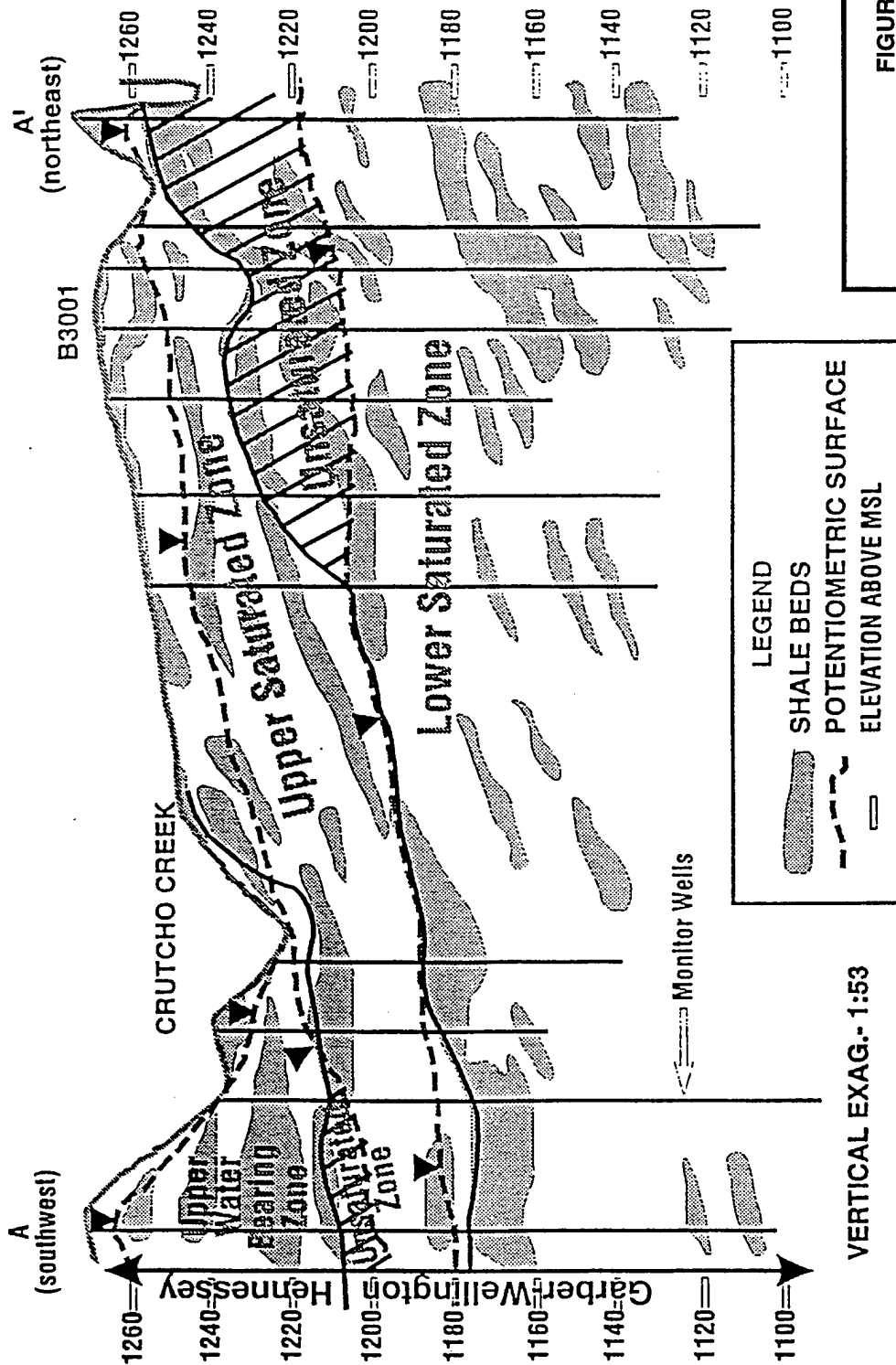


FIGURE 3.4

HYDROGEOLOGIC CROSS-SECTION A-A'

Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
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Denver, Colorado

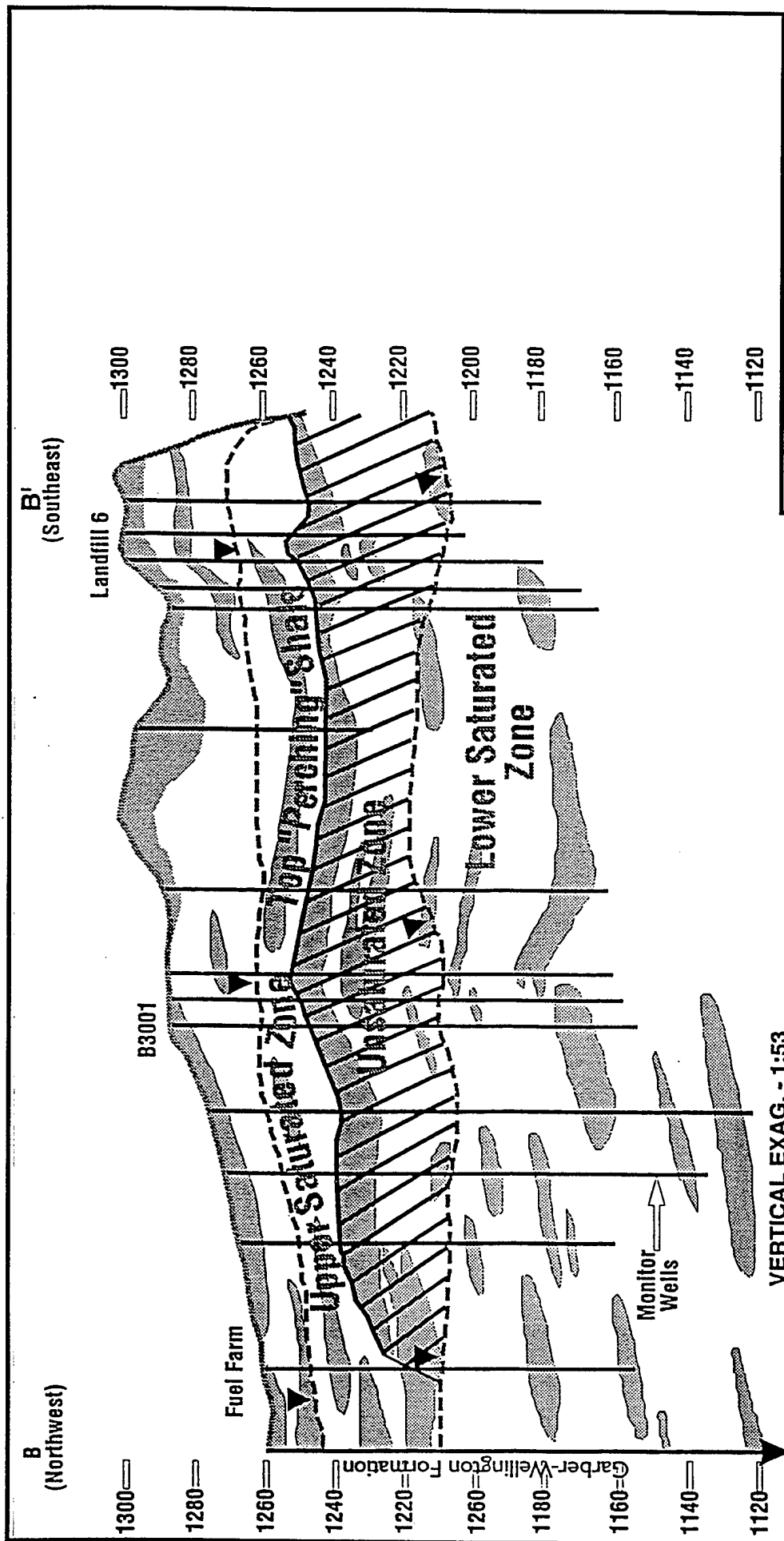
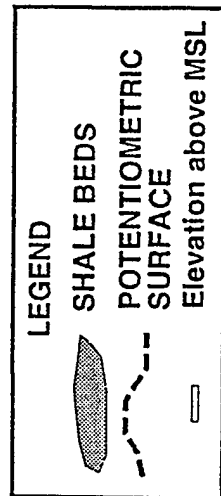


FIGURE 3.5

HYDROGEOLOGIC CROSS-SECTION B-B'

Area A
RNA TS
Tinker AFB, Oklahoma

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characterized by high clay content and well-cemented silts and sands in the USZ, acts as an aquitard between the USZ and the LSZ.

The LSZ is considered one hydraulic unit from the USZ/LSZ aquitard to an approximate depth of 200 feet bgs. Due to variations in topography, the top of the LSZ is found at depths of 10 to 100 feet bgs. The LSZ extends east of the Base beyond the limits of the USZ and is the shallowest groundwater zone screened in off-Base wells. Across the northern and eastern portion of the Base, an unsaturated zone is present between the USZ/LSZ aquitard and the top of the USZ potentiometric surface (Figure 3.5), indicating poor hydraulic connection between the USZ and LSZ in this area. Across the central and southwestern portion of the Base, the unsaturated zone at the top of the LSZ disappears where the LSZ potentiometric surface rises above the overlying aquitard, and the LSZ is confined. A low-permeability zone at the base of the LSZ (characterized by high clay content) acts as an aquitard between the LSZ and the Producing Zone. The Producing zone extends from 200 to greater than 1,100 feet bgs and is under confined conditions.

3.3 AREA A GEOLOGY AND HYDROGEOLOGY

3.3.1 Site Geology

Stratigraphy through the center of the site perpendicular and parallel to the direction of groundwater flow is illustrated hydrogeologic cross sections C-C' (Figure 3.6) and D-D' (Figure 3.7), respectively. The Garber Sandstone is present from ground surface to the maximum depth drilled (86 feet bgs) beneath Area A. Approximately 10 to 20 feet of clay, silty clay, and clayey silt (intra-USZ clays) are present at the surface. Beneath this clay unit are approximately 15 to 28 feet of fine-grained sands, which comprise the USZ, with discontinuous silt and clay lenses peripheral to the area immediately beneath the Area A service station. The USZ-LSZ aquitard occurs approximately 35 bgs and consists of a five- to seven-foot thick interval with high clay content and cemented siltstone. Fine-grained sands of the LSZ and intra-LSZ clays and clayey silts occur beneath the aquitard.

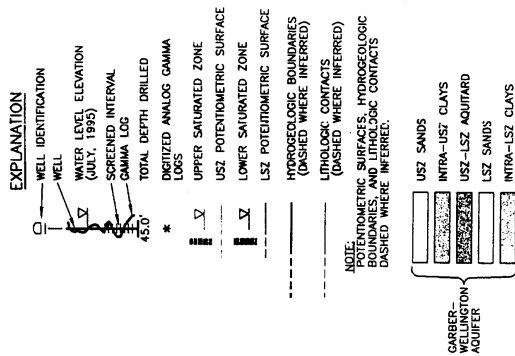
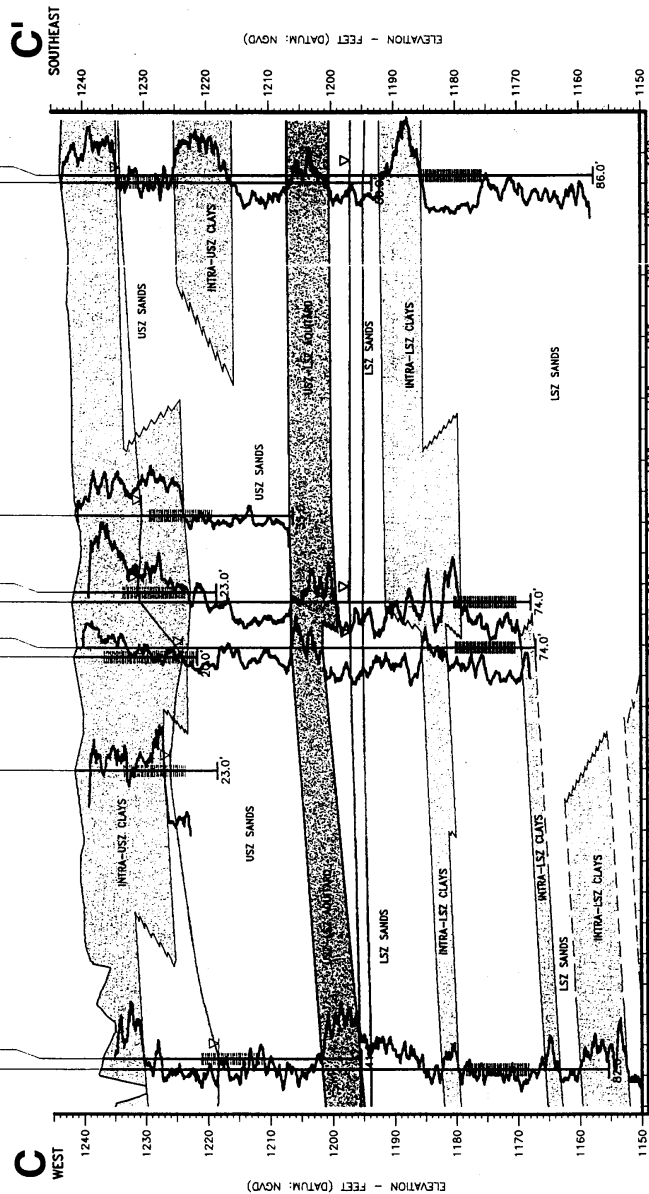
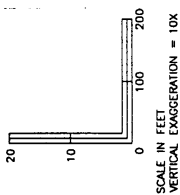
3.3.2 Site Hydrogeology

Groundwater in the USZ generally is under unconfined conditions, but may be locally confined immediately beneath the Area A service station where the USZ potentiometric surface lies within intra-USZ clays. The USZ groundwater surface is approximately 10 to 20 feet bgs within USZ sands. Groundwater elevations and monitoring well completion data are listed in Table 3.2. Available geologic boring logs and monitoring well completion records for Area A are included in Appendix B. Available slug test data from previous reports are included in Appendix A.

Figure 3.8 is a groundwater elevation contour map for the USZ based on data from May 1997. Flow direction in the immediate vicinity of Area A is generally toward the north to southwest, and predominantly west beneath the Area A service station. A local area of low groundwater elevations is present at monitoring well 2-149B, located

NOTE:

1. ABBREVIATIONS USED ON CROSS-SECTIONS:
 USZ → UPPER SATURATED ZONE
 LSZ → LOWER SATURATED ZONE
 LLSZ → LOWER-LOWER SATURATED ZONE
 PZ → PRODUCING ZONE



NOTE:
 POTENTIOMETRIC SURFACES, HYDROGEOLOGIC BOUNDARIES, AND LITHOLOGIC CONTACTS DASHED WHERE INFERRED.

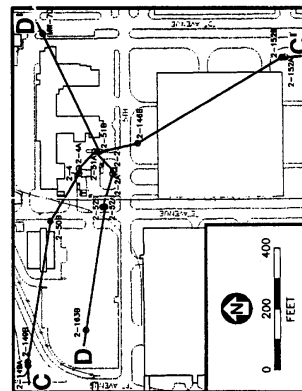
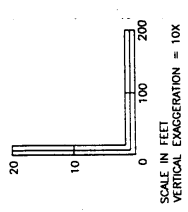


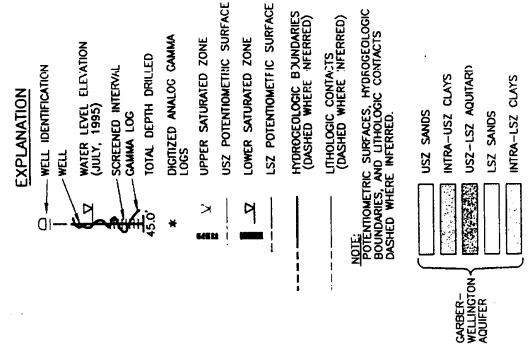
FIGURE 3.6
 HYDROGEOLOGIC
 CROSS-SECTION C-C'
 AREA A SERVICE STATION

Area A
 RNA TS
 Tinker AFB, Oklahoma

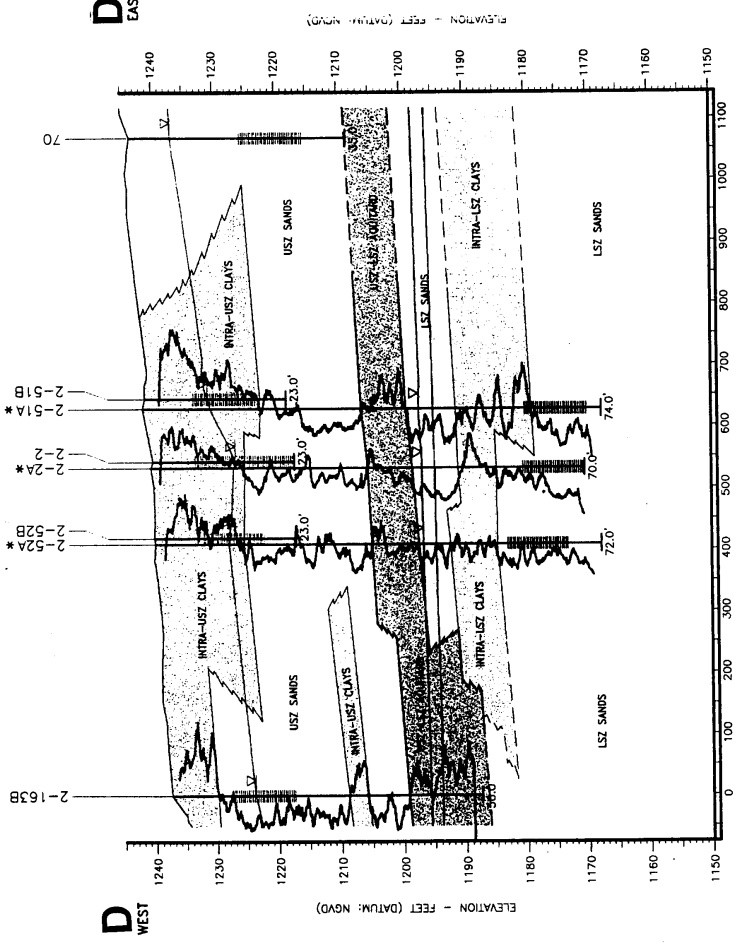
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 Denver, Colorado



NOTE:
1. ABBREVIATIONS USED ON CROSS-SECTIONS:
USZ -> UPPER SATURATED ZONE
LSZ -> LOWER SATURATED ZONE
LSZ -> LOWER-LOWER SATURATED ZONE
PZ -> PRODUCING ZONE



D' EAST



D WEST

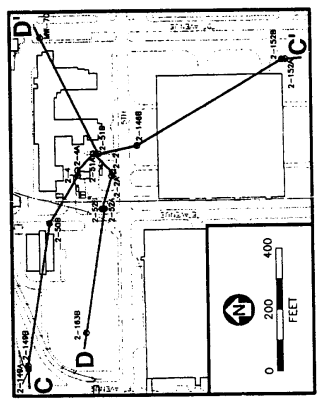


FIGURE 3.7
HYDROGEOLOGIC
CROSS-SECTION D-D'
AREA A SERVICE STATION

Area A
RNA TS
Tinker AFB, Oklahoma
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TABLE 3.2
MONITORING WELL SUMMARY AND GROUNDWATER ELEVATIONS

AREA A RNA TS
TINKER AFB, OKLAHOMA

Well/Borehole Identification	Total Depth (feet bgs) ^{a/}	Screened Interval (feet bgs)	Survey Northing (State Plane)	Survey Easting (State Plane)	Elevation Datum-TOC ^{b/} (feet msl) ^{d/}	Elevation Datum-TAP ^{b/} (feet msl)	Depth to Water (ft blap) ^{d/} May 1997	Depth Product (ft blap) May 1997	Product Thickness May 1997	Groundwater Elevation May 1997	Groundwater Elevation September 1996	Groundwater Elevation July 1995
Upper Saturated Zone												
2-2	23.00	7-23	158257.42	2180366.34	1241.99	1242.06	12.00	— ^{e/}	—	1230.06	1229.97	1226.65
2-3	26.40	9.5-24.5	158378.69	2180180.29	1242.34	1242.41	14.08	—	—	1228.33	1228.12	1226.55
2-4	21.90	5-20	158368.05	2180358.92	1243.16	1243.16 ^{f/}	10.93	9.62	1.31	1233.28 ^{g/}	1229.55	1223.86
2-50B	18.10	8.0-17.85	158461.79	2180201.11	1241.30	1241.30 ^{f/}	13.48	13.23	0.25	1228.02 ^{g/}	1226.90	1226.00
2-51B	18.00	8.0-17.85	158301.11	2180427.53	1241.29	1241.36	9.20	—	—	1232.16	1233.86	1231.14
2-52B	20.30	8.1-17.85	158292.47	2180247.69	1241.81	1241.81 ^{f/}	12.49	12.49	Trace	1229.32	1229.19	1227.66
2-163B	23.14	10-20	158347.12	2179842.46	1237.10	1237.17	12.91	—	—	1224.26	1223.56	1223.85
2-164B	30.70	15-25	158168.82	2179771.82	1239.90	1239.97	13.60	—	—	1226.37	1225.50	1225.47
2-165B	24.70	9-19	158763.17	2179903.68	1223.60	1223.67	4.44	—	—	1219.23	1198.90	1218.53
2-166B	26.67	13-23	158641.13	2180207.24	1244.97	1245.04	17.80	—	—	1227.24	1226.81	1227.01
2-173B	14.07	12-22	158062.21	2180186.91	1240.41	1240.48	13.13	—	—	1227.35	1227.14	NA ^{h/}
2-264B	32.00	19-29	158467.86	2179427.90	1234.86	1234.93	14.77	—	—	1220.16	1219.31	NA
2-265B	33.00	20-30	158291.51	2179373.38	1236.63	1236.70	15.60	—	—	1221.10	1220.80	NA
70	31.60	17.8-28.4	158485.40	2180809.30	1246.23	1246.30	9.40	—	—	1236.90	1236.93	NA
2-146B	27.71	12-22	158179.06	2180454.43	1240.70	1240.77	10.23	—	—	1230.54	1230.42	1230.41
2-148B	30.77	15-25	NA	NA	1250.12	1250.19	7.90	—	—	1242.29	1241.41	NA
2-149B	29.06	16-26	158535.20	2179737.35	1236.55	1236.62	18.02	—	—	1218.60	1218.27	1218.35
2-145B	24.03	11-21	158576.19	2180541.42	1242.75	1242.82	9.50	—	—	1233.32	NA	1232.66
2-152B	22.00	9-19	NA	NA	1246.06	1246.13	12.85	—	—	1233.28	NA	NA
Lower Saturated Zone												
2-2A	73.10	60.0-70.0	158259.23	2180356.15	1242.96	1243.03	47.00	—	—	1196.03	1195.90	1196.77
2-4A	74.00	61.0-70.0	158368.78	2180374.66	1240.81	1240.88	44.44	—	—	1196.44	NR	1197.07
2-51A	71.60	61.6-71.6	158317.01	2180427.68	1241.65	1241.72	45.00	—	—	1196.72	1196.42	1197.32
2-52A	69.50	56.8-66.5	158283.58	2180247.93	1241.98	1242.05	46.24	—	—	1195.81	1195.72	1196.58
2-148A	78.00	65-75	NA	NA	1250.11	1250.18	51.00	—	—	1199.18	1199.31	NA
2-149A	72.21	59-69	158534.34	2179725.83	1236.72	1236.79	42.28	—	—	1194.51	1194.34	1195.45
2-152A	71.00	58-68	NA	NA	1246.36	1246.43	50.37	—	—	1196.06	1195.92	NA

a/ feet bgs indicates elevation in feet below ground surface.

b/ TOC indicates surveyed elevation at top of well casing. TAP indicates top of access port for dedicated pumps using a correction factor of 0.07 feet.

c/ feet msl indicates elevation in feet above mean sea level.

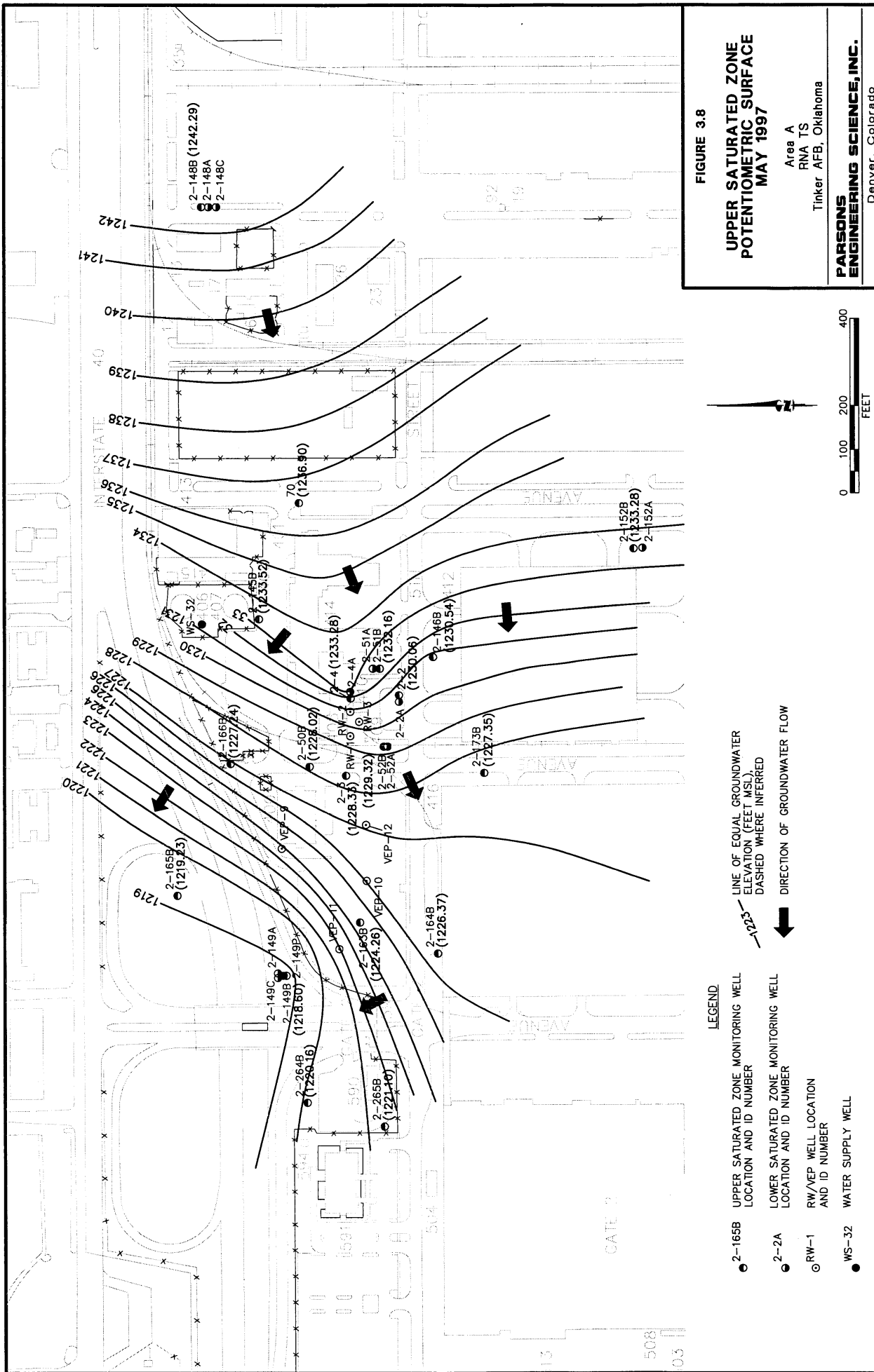
d/ blap indicates feet below top of dedicated pump access port.

e/ — indicates no measurable amount of free product present.

f/ No dedicated pump present, elevation datum equals top of well casing.

g/ Groundwater elevation corrected for the presence of free product using a product specific gravity of 0.80.

h/ NA indicates the data were not recorded or are not available.



immediately adjacent to the Interstate 40 underpass. The storm water drainage system at the base of the underpass appears to act as a local groundwater discharge point.

The USZ horizontal hydraulic gradient across the site ranges from approximately 0.007 to 0.03 ft/ft, and averages approximately 0.015 ft/ft. The flow direction and gradient in the USZ for 1997 are consistent with groundwater flow direction and gradient data observed in July 1995 (IT, 1996) and September 1996 (Parsons ES, 1997). Hydraulic conductivity ranges over two orders of magnitude from 0.04 to 3.6 feet per day (ft/day) based on slug tested conducted in three USZ monitoring wells (IT, 1996) (Table 3.3). Assuming an effective porosity of 20 percent, advective groundwater velocity ranges from approximately 1.1 to 99 feet per year (ft/yr) for the USZ.

Unconfined groundwater occurs in the LSZ approximately 2 to 4 feet beneath the base of the USZ-LSZ aquitard at a depth of approximately 45 feet bgs (Figure 3.6). The LSZ may be confined to the west of Area A where the LSZ potentiometric surface rises above the USZ-LSZ aquitard (Figure 3.7). Figure 3.9 is a potentiometric surface elevation contour map for the LSZ based on data from May 1997. Groundwater flow in the LSZ is towards the west and southwest with an approximate horizontal hydraulic gradient of 0.003 ft/ft. Hydraulic conductivity averages 1.5 ft/day based on slug tests conducted in four LSZ monitoring wells (IT, 1996). The flow direction and horizontal gradient in the LSZ for May 1997 are consistent with groundwater flow direction and gradient data observed in July 1995 (IT, 1996) and September 1996 (Parsons ES, 1997). Assuming an effective porosity of 20 percent, an average advective groundwater velocity of 8.4 ft/yr was calculated for the LSZ.

3.4 GROUNDWATER USE

Groundwater from the USZ and LSZ at Tinker AFB is not extracted for beneficial use. Water used at the Base is supplied by two water supply wells screened nearly 400 feet bgs in the Garber-Wellington Aquifer and supplemented by water purchased from Oklahoma City. The two Base water supply wells are located approximately one mile west of Area A. Water supply well WS-32 is located to the northeast of the Area A service station and is a potential receptor exposure point. Midwest City also obtains potable water from deep wells screened in the Garber-Wellington Aquifer at depths of 400 to 1,100 feet.

TABLE 3.3
HYDRAULIC CONDUCTIVITIES AND AVERAGE GROUNDWATER VELOCITIES
AREA A RNA TS
TINKER AFB, OKLAHOMA

Monitoring Well	Screened Interval (ft bgs) ^{b/}	Hydraulic Conductivity ^{a/}			Estimated Effective Porosity	Average Hydraulic Gradient (ft/ft)	Maximum Groundwater Velocity (ft/yr)
		(ft/day) ^{c/}	(K) (cm/sec) ^{d/}	(gpd/ft ²) ^{e/}			
Upper Saturated Zone (USZ)							
2-50B	8 - 18	3.6	1.3E-03	27	0.20	0.015	99
2-51B	8 - 18	0.04	1.4E-05	0	0.20	0.015	1.1
2-52B	8 - 18	0.55	1.9E-04	4	0.20	0.015	15
Average:		1.4	0.0	10.4	0.20	0.015	38
Lower Saturated Zone (LSZ)							
2-2A	60 - 70	0.53	1.9E-04	4	0.20	0.003	2.9
2-4A	61 - 70	2.0	7.1E-04	15	0.20	0.003	11
2-51A (slug in)	62 - 72	1.9	6.7E-04	14	0.20	0.003	10
2-51A (slug out)	62 - 72	1.9	6.7E-04	14	0.20	0.003	10
2-52A (slug in)	57 - 67	1.5	5.3E-04	11	0.20	0.003	8.2
2-52A (slug out)	57 - 67	1.4	4.9E-04	10	0.20	0.003	7.7
Average:		1.5	0.0	11.5	0.20	0.003	8.4

a/ IT, 1996

b/ ft bgs = Feet below ground surface.

c/ ft/day = Feet per day.

d/ cm/sec = Centimeters per second.

e/ gpd/ft² = Gallons per day per square foot.

f/ ft/ft = feet per foot.

g/ ft/yr = Feet per year.

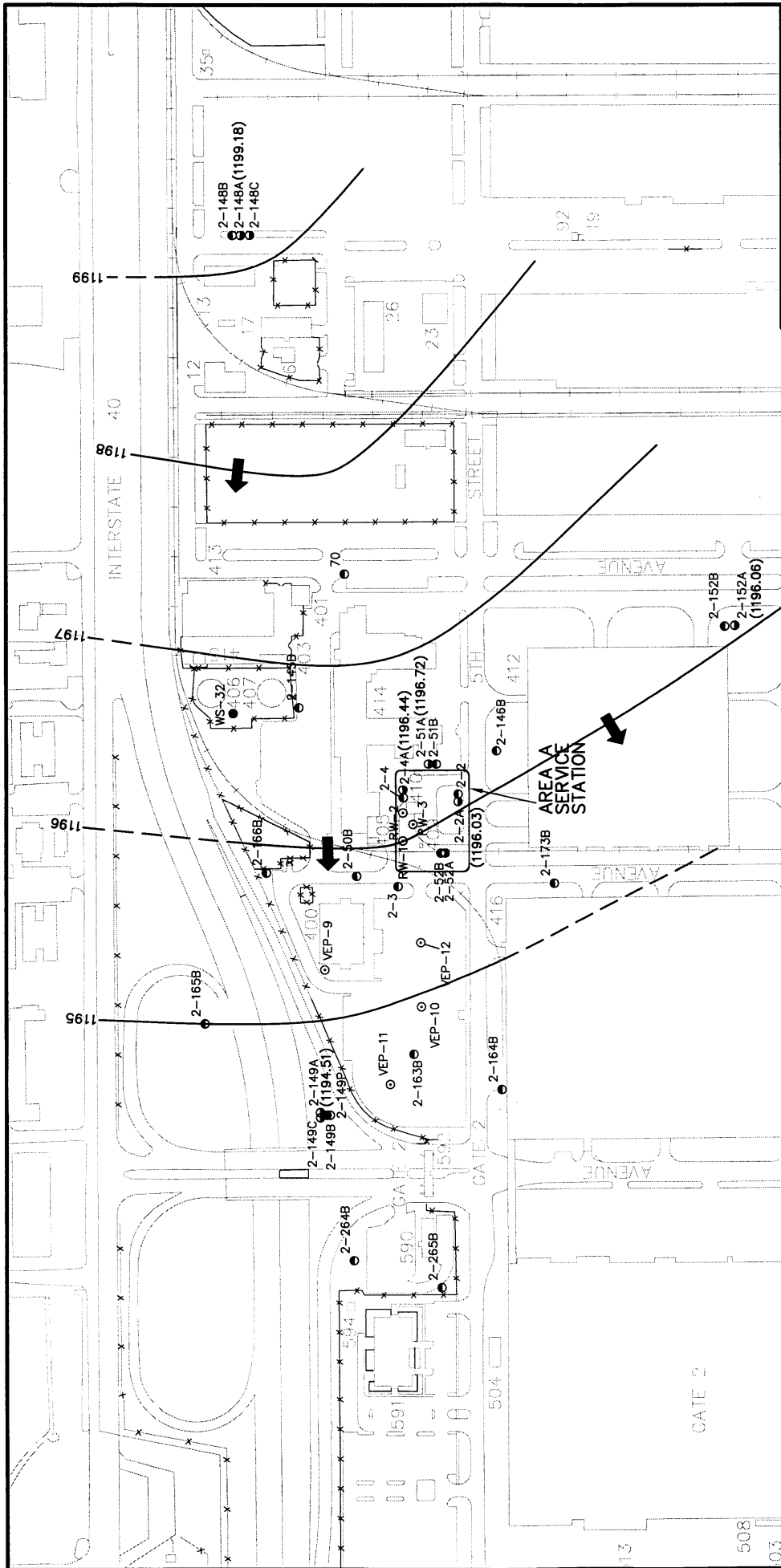


FIGURE 3.9

**LOWER SATURATED ZONE
POTENTIOMETRIC SURFACE
MAY 1997**

Area A
RNA TS
Tinker AFB, Oklahoma

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3-18

LEGEND

- 2-165B UPPER SATURATED ZONE MONITORING WELL
LOCATION AND ID NUMBER
- 2-2A LOWER SATURATED ZONE MONITORING WELL
LOCATION AND ID NUMBER
- RW-1 RW/VEP WELL LOCATION
AND ID NUMBER
- WS-32 WATER SUPPLY WELL

— LINE OF EQUAL GROUNDWATER
ELEVATION (FEET MSL);
DASHED WHERE INFERRED

➡ DIRECTION OF GROUNDWATER FLOW

0 100 200 400
FEET

SECTION 4

CONTAMINANT DISTRIBUTION AND EVIDENCE OF BIODEGRADATION

Contaminants at Area A were introduced as a result of leaking USTs at the former Base service station. The RI performed by IT (1996) focused on defining the nature and extent of contamination at the site. Pertinent RI results are summarized in the following subsections along with TS field investigation data. In particular, this section focuses on data useful for evaluating and modeling natural attenuation of BTEX and CAHs following a summary of hydrocarbon biodegradation.

4.1 OVERVIEW OF HYDROCARBON BIODEGRADATION

Groundwater quality data obtained during the RI (IT, 1996) and this TS indicate that BTEX and CAH compounds are the primary contaminants of concern in groundwater at Area A. Primary mechanisms for natural attenuation of BTEX and CAHs include biodegradation, dispersion, dilution from recharge and upgradient flow, sorption, and volatilization. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. When indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients, these biodegradation processes are considered intrinsic.

4.1.1 Biodegradation of Dissolved BTEX

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of fuel hydrocarbons, including the BTEX compounds (e.g., Jamison *et al.*, 1975; Atlas, 1981, 1984, 1988; Gibson and Subramanian, 1984; Reinhard *et al.*, 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, and 1990; Barker *et al.*, 1987; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989 and 1990; Cozzarelli *et al.*, 1990; Leahy and Colewell, 1990; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Ball *et al.*, 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991; Edwards *et al.*, 1991 and 1992; Evans *et al.*, 1991a and 1991b; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Hutchins *et al.*, 1991a and 1991b; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994). Biodegradation of fuel hydrocarbons can occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the aquifer and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms.

Microorganisms obtain energy for cell production and maintenance by facilitation of thermodynamically advantageous oxidation/reduction (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at Area A may include natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Native electron acceptors are elements or compounds that occur in relatively oxidized states, and include DO, nitrate, ferric iron [Fe^{3+} or iron (III)], sulfate, and carbon dioxide.

The driving force of BTEX degradation is electron transfer, which is quantified by the Gibbs free energy of the reaction (ΔG°_r) (Stumm and Morgan, 1981; Bouwer, 1994; Godsey, 1994). The value of ΔG°_r represents the quantity of free energy consumed or yielded to the system during the reaction. Table 4.1 lists the stoichiometry of the redox equations involving BTEX and the resulting ΔG°_r . Although thermodynamically favorable, most of the reactions involved in BTEX oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy (i.e., $\Delta G^\circ_r < 0$). Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms typically use electron acceptors (as available) in the following order of preference: nitrate, ferric iron hydroxide, sulfate, and finally carbon dioxide. Because the biodegradation of fuel hydrocarbons should deplete the concentrations of these electron acceptors, construction of isopleth maps depicting their concentrations can provide evidence of whether biodegradation is occurring and the degree to which it is occurring.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, ferric iron, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese or nitrate reduction may dominate if the physical and chemical conditions in the subsurface favor use of these electron acceptors. Anaerobic destruction of BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990). Environmental conditions and microbial competition ultimately determine which processes will dominate. Vroblesky and Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in an aquifer with fuel hydrocarbon contamination.

4.1.2 Biodegradation of Dissolved CAHs

Biodegradation of CAHs, while similar in principle to biodegradation of BTEX, typically results from a more complex series of processes. Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Wilson and Wilson, 1985; Miller and Guengerich, 1982; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990;

TABLE 4.1
COUPLED OXIDATION REACTIONS
AREA A RNA TS
TINKER AFB, OKLAHOMA

Coupled Benzene Oxidation Reactions	ΔG°_r (kcal/mole Benzene)	ΔG°_r (kJ/mole Benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$7.5 O_2 + C_6H_6 \Rightarrow 6 CO_{2,g} + 3 H_2O$ <i>Benzene oxidation / aerobic respiration</i>	-765.34	-3202	3.07:1
$6 NO_3 + 6 H^+ + C_6H_6 \Rightarrow 6 CO_{2,g} + 6 H_2O + 3 N_{2,g}$ <i>Benzene oxidation / denitrification</i>	-775.75	-3245	4.77:1
$30 H^+ + 15 MnO_2 + C_6H_6 \Rightarrow 6 CO_{2,g} + 15 Mn^{2+} + 18 H_2O$ <i>Benzene oxidation / manganese reduction</i>	-765.45	-3202	10.56:1
$60 H^+ + 30 Fe(OH)_{3,a} + C_6H_6 \Rightarrow 6 CO_2 + 30 Fe^{2+} + 78 H_2O$ <i>Benzene oxidation / iron reduction</i>	-560.10	-2343	21.5:1 ^{a/}
$7.5 H^+ + 3.75 SO_4^{2-} + C_6H_6 \Rightarrow 6 CO_{2,g} + 3.75 H_2S^o + 3 H_2O$ <i>Benzene oxidation / sulfate reduction</i>	-122.93	-514.3	4.61:1
$4.5 H_2O + C_6H_6 \Rightarrow 2.25 CO_{2,g} + 3.75 CH_4$ <i>Benzene oxidation / methanogenesis</i>	-32.40	-135.6	0.77:1 ^{b/}

Coupled Toluene Oxidation Reactions	ΔG°_r (kcal/mole Toluene)	ΔG°_r (kJ/mole Toluene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$9 O_2 + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 4 H_2O$ <i>Toluene oxidation / aerobic respiration</i>	-913.76	-3823	3.13:1
$7.2 NO_3 + 7.2 H^+ + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 7.6 H_2O + 3.6 N_{2,g}$ <i>Toluene oxidation / denitrification</i>	-926.31	-3875	4.85:1
$36 H^+ + 18 MnO_2 + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 18 Mn^{2+} + 22 H_2O$ <i>Toluene oxidation / manganese reduction</i>	-913.89	-3824	10.74:1
$72 H^+ + 36 Fe(OH)_{3,a} + C_6H_5CH_3 \Rightarrow 7 CO_2 + 36 Fe^{2+} + 94 H_2O$ <i>Toluene oxidation / iron reduction</i>	-667.21	-2792	21.86:1 ^{a/}
$9 H^+ + 4.5 SO_4^{2-} + C_6H_5CH_3 \Rightarrow 7 CO_{2,g} + 4.5 H_2S^o + 4 H_2O$ <i>Toluene oxidation / sulfate reduction</i>	-142.86	-597.7	4.7:1
$5 H_2O + C_6H_5CH_3 \Rightarrow 2.5 CO_{2,g} + 4.5 CH_4$ <i>Toluene oxidation / methanogenesis</i>	-34.08	-142.6	0.78:1 ^{b/}

TABLE 4.1 (Concluded)
COUPLED OXIDATION REACTIONS
AREA A RNA TS
TINKER AFB, OKLAHOMA

Coupled Ethylbenzene Oxidation Reactions	ΔG°_r (kcal/mole Ethyl- benzene)	ΔG°_r (kJ/mole Ethyl- benzene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 5 H_2O$ <i>Ethylbenzene oxidation / aerobic respiration</i>	-1066.13	-4461	3.17:1
$8.4 NO_3 + 8.4 H^+ + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 9.2 H_2O + 4.2 N_{2,g}$ <i>Ethylbenzene oxidation / denitrification</i>	-1080.76	-4522	4.92:1
$42 H^+ + 21 MnO_2 + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 21 Mn^{2+} + 26 H_2O$ <i>Ethylbenzene oxidation / manganese reduction</i>	-1066.27	-4461	17.24:1
$84 H^+ + 42 Fe(OH)_{3,a} + C_6H_5C_2H_5 \Rightarrow 8 CO_2 + 42 Fe^{2+} + 110 H_2O$ <i>Ethylbenzene oxidation / iron reduction</i>	-778.48	-3257	22:1 ^{a/}
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_5C_2H_5 \Rightarrow 8 CO_{2,g} + 5.25 H_2S^o + 5 H_2O$ <i>Ethylbenzene oxidation / sulfate reduction</i>	-166.75	-697.7	4.75:1
$5.5 H_2O + C_6H_5C_2H_5 \Rightarrow 2.75 CO_{2,g} + 5.25 CH_4$ <i>Ethylbenzene oxidation / methanogenesis</i>	-39.83	-166.7	0.79:1 ^{b/}

Coupled m-Xylene Oxidation Reactions	ΔG°_r (kcal/mole m-xylene)	ΔG°_r (kJ/mole m-xylene)	Stoichiometric Mass Ratio of Electron Acceptor to Compound
$10.5 O_2 + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 5 H_2O$ <i>m-Xylene oxidation / aerobic respiration</i>	-1063.25	-4448	3.17:1
$8.4 NO_3 + 8.4 H^+ + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 9.2 H_2O + 4.2 N_{2,g}$ <i>m-Xylene oxidation / denitrification</i>	-1077.81	-4509	4.92:1
$46 H^+ + 22 MnO_2 + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 22 Mn^{2+} + 28 H_2O$ <i>m-Xylene oxidation / manganese reduction</i>	-1063.39	-4449	11.39:1
$84 H^+ + 42 Fe(OH)_{3,a} + C_6H_4(CH_3)_2 \Rightarrow 8 CO_2 + 42 Fe^{2+} + 110 H_2O$ <i>m-Xylene oxidation / iron reduction</i>	-775.61	-3245	22:1 ^{a/}
$10.5 H^+ + 5.25 SO_4^{2-} + C_6H_4(CH_3)_2 \Rightarrow 8 CO_{2,g} + 5.25 H_2S^o + 5 H_2O$ <i>m-Xylene oxidation / sulfate reduction</i>	-163.87	-685.6	4.75:1
$5.5 H_2O + C_6H_4(CH_3)_2 \Rightarrow 2.75 CO_{2,g} + 5.25 CH_4$ <i>m-Xylene oxidation / methanogenesis</i>	-36.95	-154.6	0.79:1 ^{b/}

^{a/} Mass of ferrous iron produced during microbial respiration.

^{b/} Mass of methane produced during microbial respiration.

Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). CAHs may undergo biodegradation through three different pathways: use as an electron acceptor, use as an electron donor, or cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although at many sites the use of CAHs as electron acceptors appears to be the most important.

In a pristine aquifer, native organic carbon is utilized as an electron donor and DO is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or less chlorinated CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH biodegradation is occurring. In addition, because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors), maps showing the distribution of these compounds will also provide evidence on the types of biodegradation processes acting at a site.

As with BTEX, the driving force behind redox reactions resulting in CAH degradation is electron transfer. Although thermodynamically favorable, most of the reactions involved in CAH reduction and oxidation cannot proceed abiotically because of the lack of activation energy. Microorganisms are capable of providing the necessary activation energy; however, they will facilitate only those redox reactions that have a net yield of energy. A more complete description of the main types of biodegradation reactions affecting CAHs is presented in the following subsections.

4.1.2.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a chloride atom is removed and replaced with a hydrogen atom. The transformation of chlorinated ethenes via reductive dehalogenation is illustrated in Figure 4.1. In general, reductive dehalogenation occurs by sequential dehalogenation from PCE to TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dehalogenation, all three isomers of DCE theoretically can be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers. Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride concentrations.

Reductive dehalogenation affects each of the chlorinated ethenes differently. PCE is the most susceptible of these compounds to reductive dehalogenation because it is the most oxidized. Conversely, VC is the least susceptible to reductive dehalogenation, because it is the least oxidized of these compounds. The rate of reductive dehalogenation

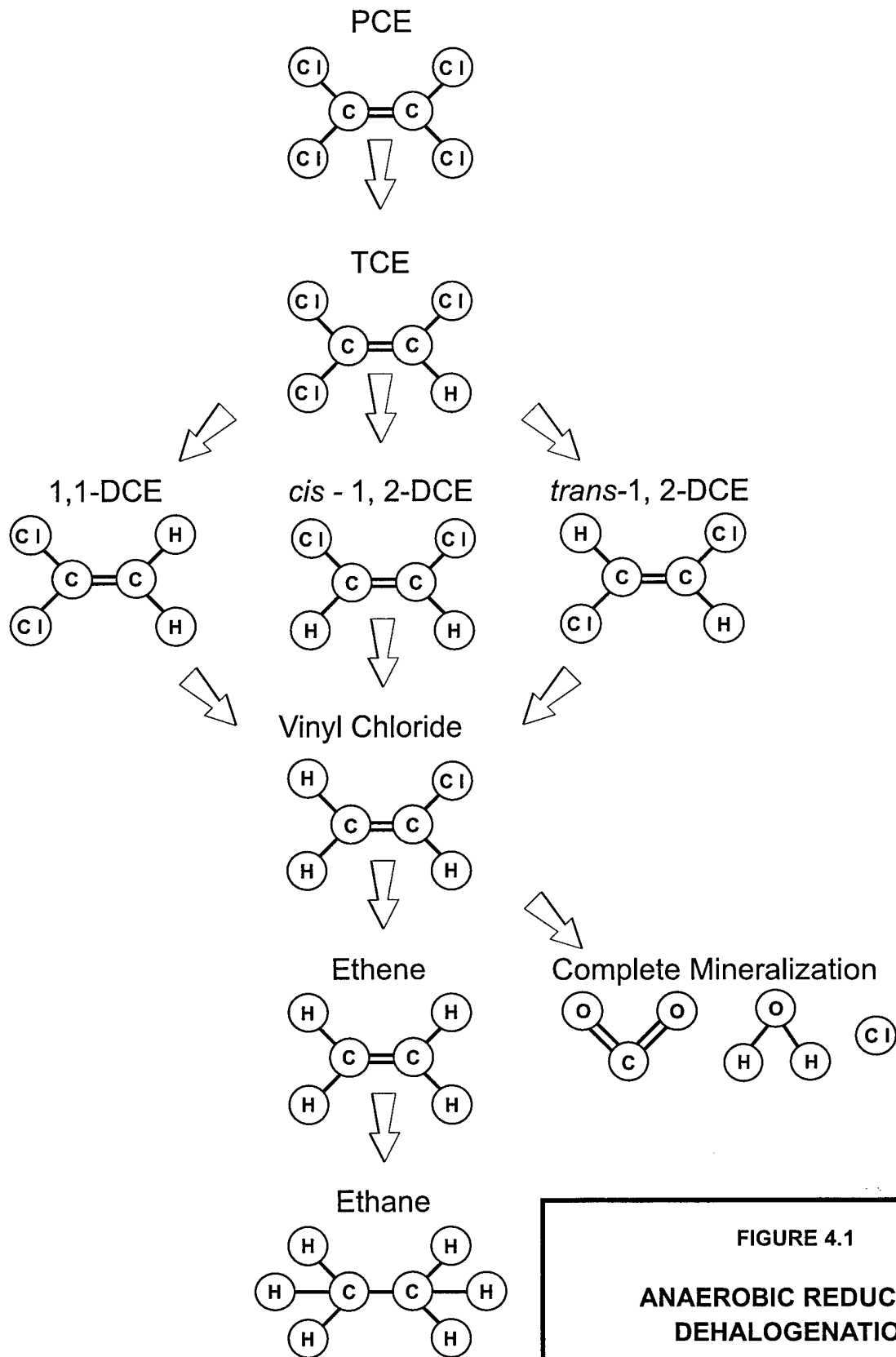


FIGURE 4.1

**ANAEROBIC REDUCTIVE
DEHALOGENATION**

Area A
RNA TS
Tinker AFB, Oklahoma

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Denver, Colorado

also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dehalogenation. Reductive dehalogenation has been demonstrated under nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994).

Because CAH compounds are used as electron acceptors, there must be an appropriate source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, fuel hydrocarbons, or less-chlorinated compounds such as VC, DCE, or DCA.

4.1.2.2 Electron Donor Reactions

Under aerobic conditions, some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. Microorganisms are generally believed to be incapable of growth using TCE and PCE, although other less chlorinated CAHs have been documented as substrates (Murray and Richardson, 1993). McCarty and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates, and they document that dichloromethane has the potential to function as a primary substrate in either aerobic or anaerobic environments. In addition, Bradley and Chapelle (1996) show evidence of mineralization of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III). Klier *et al.* (1996) demonstrated aerobic mineralization of all three isomers of DCE. Aerobic metabolism of VC, DCA, or DCE may be characterized by a loss of VC, DCA, or DCE mass or a decreasing molar ratio of VC, DCA, or DCE to other CAH compounds.

4.1.2.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH; rather the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. Aerobic biodegradation pathways for chlorinated ethenes are illustrated in Figure 4.2. It has been reported that under aerobic conditions chlorinated ethenes (with the exception of PCE) are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of dehalogenation decreases.

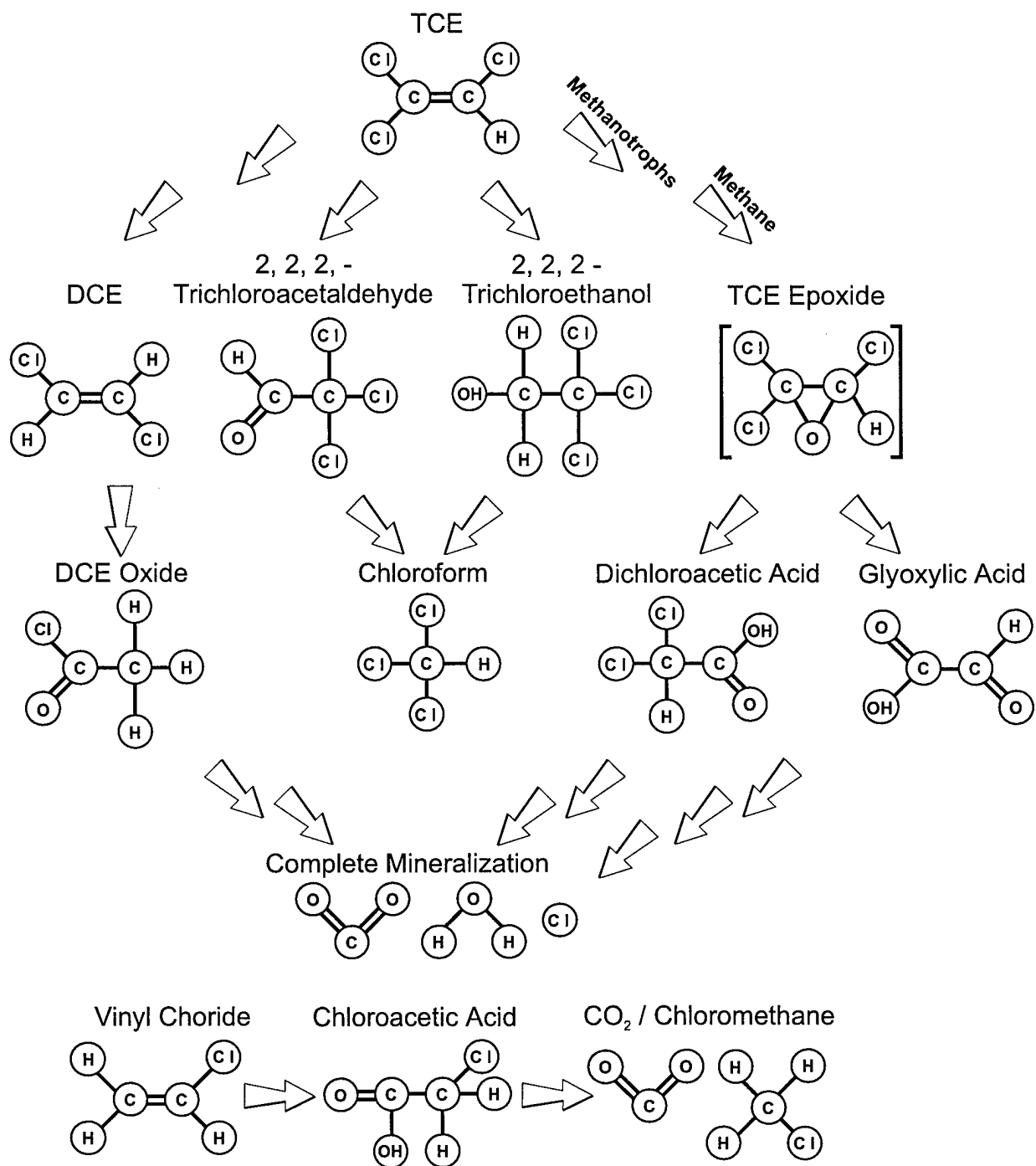


FIGURE 4.2

AEROBIC DEGRADATION PATHWAYS

Area A
RNA TS
Tinker AFB, Oklahoma

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During the cometabolic process, TCE is indirectly transformed by bacteria using another organic carbon substrate as an energy source. TCE does not enhance the degradation of carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates (organic carbon sources) may limit cometabolism of CAHs.

4.1.2.4 Abiotic Degradation of Chlorinated Solvents

Chlorinated solvents dissolved in groundwater also may degrade by abiotic mechanisms, although the reactions may not be complete and often result in the formation of a toxic intermediate. The most common abiotic reactions affecting chlorinated solvents are hydrolysis and dehydrohalogenation. Hydrolysis is a substitution reaction in which a chloride ion is replaced with a hydroxyl (OH⁻) group from a water molecule. Dehydrohalogenation is an elimination reaction in which a halogen is removed from a carbon atom, followed by removal of a hydrogen atom from an adjacent carbon atom, with a double bond between the carbon atoms being produced. Other possible reactions include oxidation and reduction, although no abiotic oxidation reactions involving common halogenated solvents have been reported in the literature (Butler and Barker, 1996).

Hydrolysis of chlorinated methanes and ethanes has been well-demonstrated in the literature (e.g., Vogel *et al.*, 1987; Jeffers *et al.*, 1989; Vogel, 1994; Butler and Barker, 1996). The likelihood that a solvent will hydrolyze is partly dependent upon the number of halogen ions, typically with fewer halogens resulting in more rapid hydrolysis. Dehydrohalogenation, on the other hand, is more likely to take place as the number of halogen ions increases. One common solvent for which abiotic degradation reactions have been well-documented is 1,1,1-trichloroethane (TCA). 1,1,1-TCA may be transformed through a series of abiotic processes (including hydrolysis) to acetic acid. 1,1,1-TCA can also dehydrohalogenate to 1,1-DCE (Vogel and McCarty, 1987), and 1,1,2-TCA can react to form 1,1-DCE (Jeffers *et al.*, 1989). Once TCA is reductively dehalogenated to chloroethane (CA), it can then hydrolyze to ethanol (Vogel and McCarty, 1987) or dehydrohalogenate to VC (Jeffers *et al.*, 1989).

Attributing changes in the presence, absence, or concentration of halogenated solvents to abiotic processes is usually difficult, particularly on the field scale (Butler and Barker, 1996). Solvents may undergo both biotic and abiotic degradation, and discerning the effects of each mechanism (on the field scale), if possible, is difficult. Also, the breakdown products of some reactions such as hydrolysis (e.g., acids and alcohols) may be further degraded (biotically or abiotically) to products, which require additional analyses that may not be feasible for a field investigation (Butler and Barker, 1996). CAH hydrolysis has not been successfully demonstrated at the field scale (Butler and Barker, 1996). Evidence of dehydrohalogenation is also difficult to collect, although the presence of 1,1-DCE in conjunction with 1,1,1-TCA can provide a tentative indication that the process is ongoing. The presence of 1,1-DCE provides strong evidence of dehydrohalogenation where it is known that no DCE has been released.

4.1.2.5 Behavior of Chlorinated Solvent Plumes

Chlorinated solvent plumes can exhibit three types of behavior depending on the amount of solvent, the amount of organic (native and/or anthropogenic) carbon in the aquifer, the distribution and concentration of natural electron acceptors, and the types of electron acceptors being utilized. Individual plumes may exhibit all three types of behavior in different portions of the plume.

4.1.2.5.1 Type 1 Behavior

Type 1 behavior occurs where the primary substrate is anthropogenic carbon (e.g., BTEX or landfill leachate), and this anthropogenic carbon drives reductive dehalogenation. When evaluating RNA of a plume exhibiting type 1 behavior, the following questions must be answered:

1. Does electron acceptor supply exceed demand (i.e., is the electron acceptor supply adequate)? Will the microorganisms degrading the CAH plume strangle before they starve [i.e., will they run out of CAHs (electron acceptors) before they run out of primary substrate (anthropogenic carbon)]?
2. What is the role of competing electron acceptors?
3. Are VC and DCE oxidized or reduced?

4.1.2.5.2 Type 2 Behavior

Type 2 behavior dominates in areas characterized by relatively high native organic carbon concentrations, and this carbon source drives reductive dehalogenation (i.e., the primary substrate for microorganism growth is native organic carbon). When evaluating RNA of a type 2 chlorinated solvent plume, the same questions as those posed in the description of type 1 behavior must be answered.

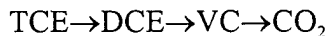
4.1.2.5.3 Type 3 Behavior

Type 3 behavior dominates in areas characterized by low native and/or anthropogenic carbon concentrations where dissolved oxygen concentrations are greater than 1.0 milligram per liter (mg/L). Under these conditions, the plume is aerobic and reductive dehalogenation will not occur. Thus, there is no biodegradation of PCE and TCE, and natural attenuation mechanisms for these compounds are advection, dispersion, and sorption only. However, VC, DCA, and DCE can be oxidized under these conditions.

4.1.2.5.4 Mixed Behavior

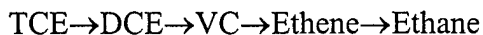
A single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This mixed behavior can be beneficial for natural biodegradation of CAH plumes. For example, Wiedemeier *et al.* (1996b) describe a plume at Plattsburgh AFB, New York, that exhibits type 1 behavior in the source area and type 3 behavior downgradient from the source. The best scenario involves a plume in which TCE and DCE are reductively dechlorinated (type 1 or 2 behavior), then VC is oxidized (type 3

behavior), either aerobically or anaerobically (via iron reduction). Vinyl chloride is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in this type of plume:



In general, the TCE, DCE, and VC are attenuated at approximately the same rate, and thus the reductive dehalogenation reactions may be confused with simple dilution. Note that no ethene is produced, and VC is removed from the system much faster under oxidizing conditions than it is under VC-reducing conditions.

A less desirable scenario involves a plume in which all CAHs are reductively dechlorinated (type 1 or 2 behavior). Vinyl chloride is reduced to ethene which is further reduced to ethane. The following sequence of reactions occur in this type of plume:



In a reductive plume, DCE and VC degrade more slowly than TCE, and thus they tend to accumulate (Freedman and Gossett, 1989).

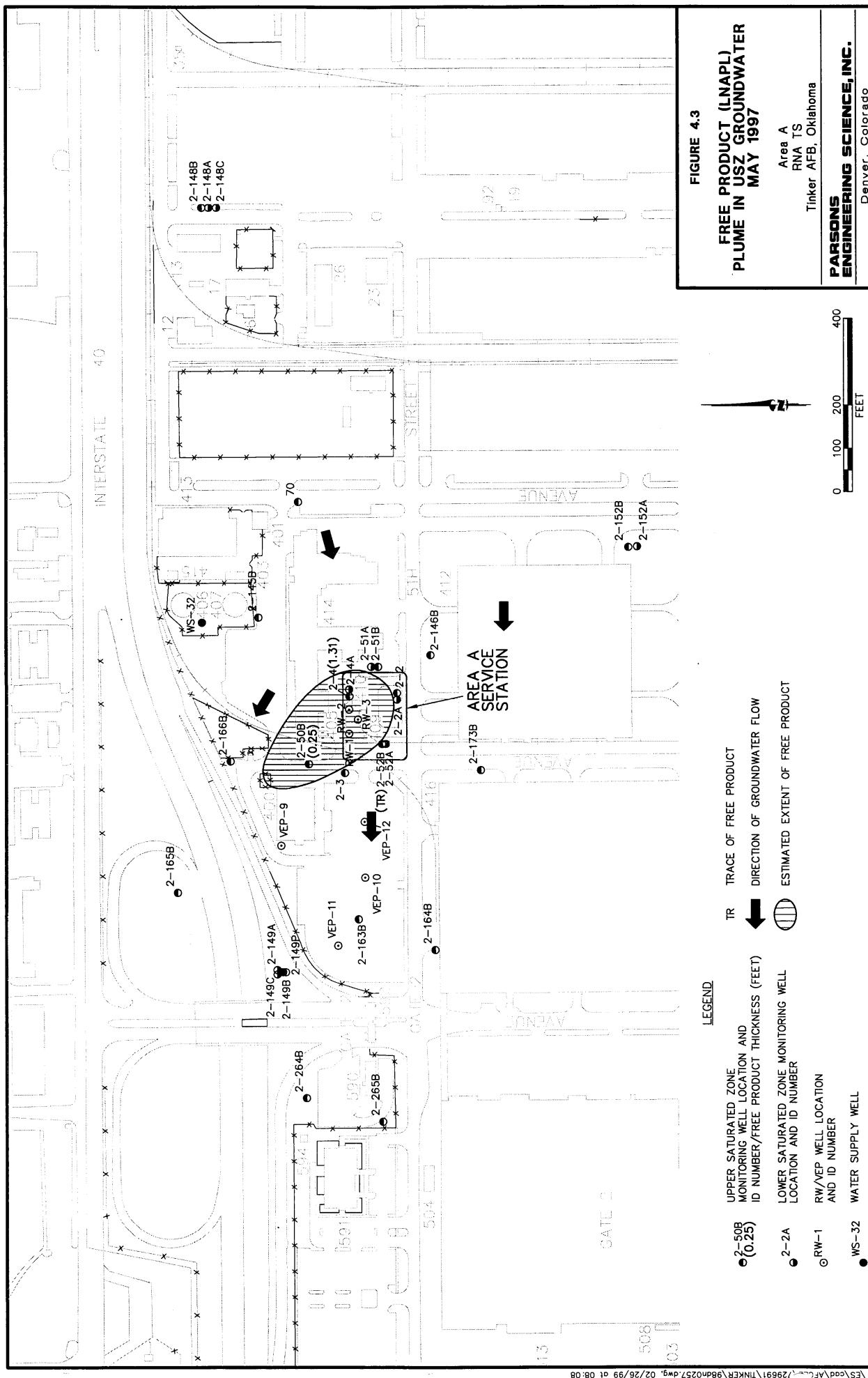
4.2 NATURE AND EXTENT OF CONTAMINATION

The nature and extent of contamination at Area A described herein is based on analytical data collected during the RNA TS field investigations. This description represents site conditions prior to activation of the VEP source control remediation.

4.2.1 Contaminant Sources

Light non-aqueous phase liquid (LNAPL) constitutes a continuing source of fuel hydrocarbons to groundwater at the site. The estimated lateral extent of mobile LNAPL, defined as LNAPL that is free to flow in the aquifer and that will flow from the aquifer matrix into a well under the influence of gravity, is shown on Figure 4.3. Mobile LNAPL was identified in three site monitoring wells in May 1997 (2-4, 2-50B, and 2-52B) (Table 3.2), and measured LNAPL thickness measured in May 1997 ranged from a trace of product on the surface of the groundwater in well 2-52B to 1.31 feet in well 2-4. Mobile LNAPL thickness in well 2-50B had decreased since 1994, but measured LNAPL thickness had increased in wells 2-4 and 2-52B since 1994. On the basis of Figure 4.3, the mobile LNAPL plume appears to originate from the location of the former USTs and has migrated to the northwest. The lack of LNAPL detection in wells 2-3 and 2-166B suggests either that LNAPL migration rates are very low or that the LNAPL plume is stable or attenuating.

The source of CAHs at Area A is not well defined. Significant concentrations of CAHs are associated with the site, indicating the service station is a source area for CAH contaminants. However, low concentrations of CAHs also are detected in upgradient wells. Solvents at service station sites are typically used for maintenance and cleaning operations. Release of CAHs to the environment could be a result of improper storage, use, or containment of solvents at the site.



4.2.2 Hydrocarbons in Soil

Soil samples were not collected during this RNA field investigation, because a substantial volume of soil quality data were collected during the initial site investigations and the RI. Soil samples collected and analyzed from Area A during initial site investigations include 11 samples from five soil boreholes drilled in 1990 by ERI, and 50 samples from eight soil boreholes drilled by WSCI in 1991. These samples were analyzed for BTEX, TPH, and total lead. An additional 35 samples from ten soil boreholes were collected by IT from October 1993 to January 1994 and analyzed for VOCs (including BTEX), SVOCs [including polynuclear aromatic hydrocarbons (PAHs)], and metals. All soil samples were collected from the USZ stratigraphic interval. Analytical summary tables for soil sampling results at Area A are provided in Appendix A.

Soil borehole locations and the distribution of total BTEX in soil at an approximate depth of 10 feet bgs in the former service station area are shown on Figure 4.4. The highest concentrations of BTEX (greater than 1,000,000 micrograms per kilogram [$\mu\text{g/kg}$]) were measured in soil samples from boreholes located within 20 to 40 feet of the former UST locations.

Cis-1,2-DCE was detected in a soil sample collected from the 20- to 21-foot depth interval at SB-006, at a concentration of 8.8 micrograms per kilogram ($\mu\text{g/kg}$). The source of this detection is believed to be contaminated groundwater. No other CAHs were detected in soil above the method detection limit.

4.2.3 Fuel Hydrocarbons in Groundwater

Groundwater samples collected from monitoring wells at the site during May 1997 were analyzed for dissolved total fuel carbon, BTEX, and trimethylbenzenes (TMBs). Analytical results are summarized in Table 4.2. The areal distribution of total fuel carbon and total BTEX concentrations measured in May 1997 are shown on Figures 4.5 and 4.6, respectively.

Total fuel carbon was measured as an indicator of gross fuel hydrocarbon contamination. Total fuel carbon was detected at a maximum concentration of 46,000 micrograms per liter ($\mu\text{g/L}$) for the groundwater sample collected from monitoring well 2-50B (Figure 4.5). Because free product was detected in this well, the maximum concentrations of fuel hydrocarbons partitioning from the LNAPL plume into groundwater are presumed to occur at the LNAPL-groundwater interface. The well was therefore slowly purged and sampled in order to extract a sample from immediately below the free product. Consequently, concentrations detected in well 2-50B are assumed to be the upper limit for dissolved concentrations at Area A. The maximum total fuel carbon concentration outside of the free product plume (shown on Figure 4.3) was detected at well VEP-9 (6,030 $\mu\text{g/L}$), located immediately downgradient from well 2-50B and the product plume.

Maximum dissolved BTEX concentrations at Area A also were detected in the groundwater sample from well 2-50B at 14,200 $\mu\text{g/L}$ benzene, 17,500 $\mu\text{g/L}$ toluene,

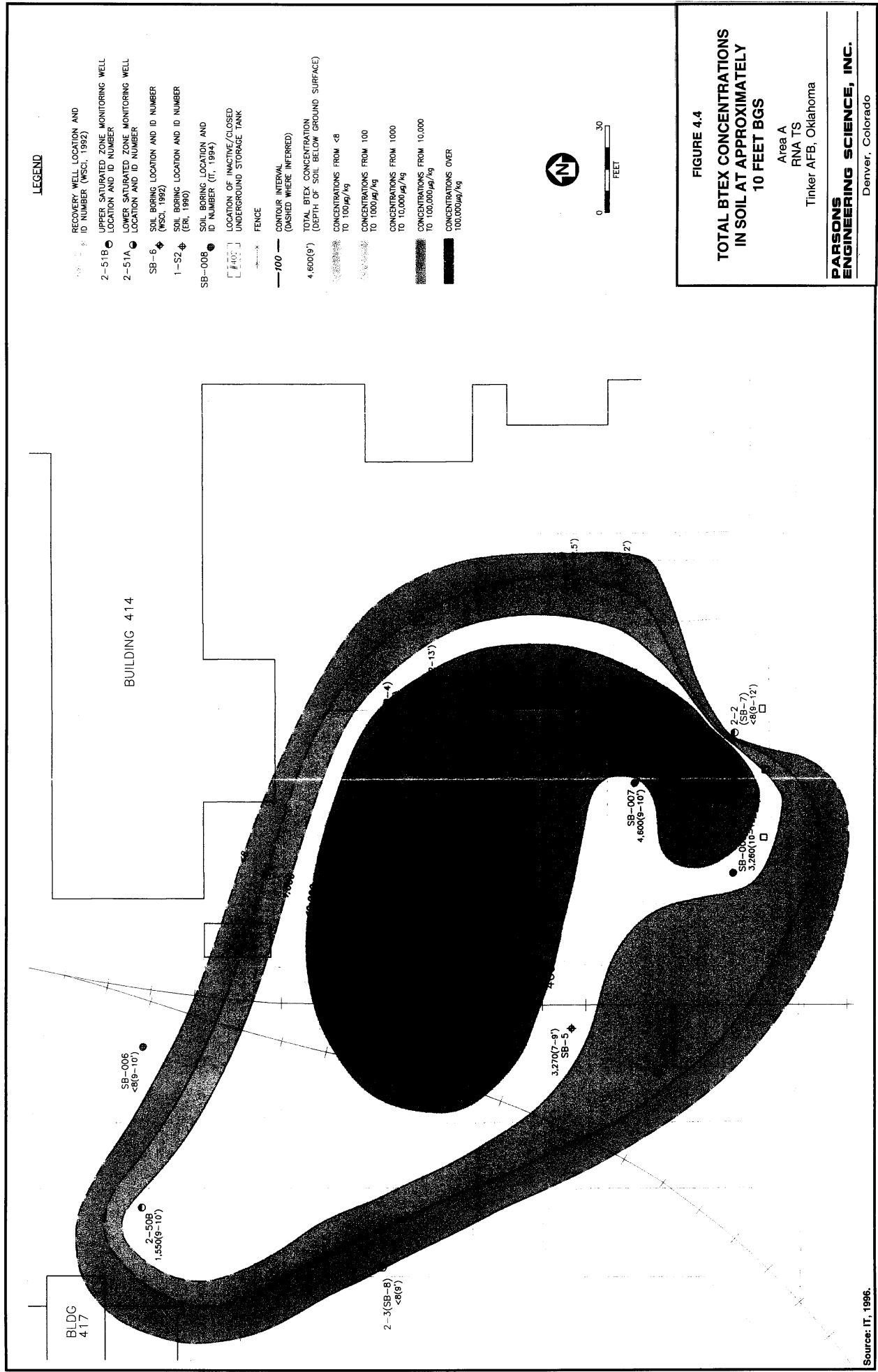


TABLE 4.2
FUEL HYDROCARBONS IN GROUNDWATER
APRIL/MAY 1997
AREA A RNA TS
TINKER AFB, OKLAHOMA

Sample Location	Sample Date	Total Fuel Carbon (µg/L) ^a	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
MCL ^d		— ^e	5	1,000	700	—	—	—	10,000	—	—	—	—
Upper Saturated Zone													
2-2	5/8/1997	1,800	453	12.3	136	12	16.2	7.2	35.4	637	2.9	1.5	13.1
2-3	5/8/1997	2,600	476	10.8	96.5	24.9	4.9	4.5	34.3	618	2	3.3	17
2-50B	5/8/1997	46,000	14,200	17,500	1,800	1,930	4,460	2,840	9,230	42,700	355	1,270	407
2-51B	5/8/1997	1,800	182	2.5	25.8	19	6	11.2	36.2	247	1.5	15.0	12.6
2-52B	5/8/1997	1,000	1	ND ^b	2.2	ND	ND	ND	ND	3.1	<1	ND	6.5
2-52B (dup) ^c	5/8/1997	1,250	<1	ND	2.7	<1	ND	ND	<1	2.7	0.9	ND	7
2-145B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-146B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-148B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-149B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-152B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-163B	5/8/1997	<1	<1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-163B (dup)	5/8/1997	<1	<1	<1	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-164B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-165B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-166B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-173B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-264B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-265B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-265B (dup)	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
70	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VEP-9	4/23/1997	6,030	3,690	292	375	172	54	133	359	4,720	10	126	32
VEP-10	4/23/1997	294	50	6	11	6	2	5	13	80	1	4	1
VEP-10 (dup)	4/23/1997	280	46	6	10	5	2	4	11	73	1	4	1
VEP-11	4/23/1997	126	18	4	8	4	1	3	8	38	1	2	1
VEP-12	4/23/1997	1,100	313	16	38	12	4	9	25	392	1	5	3
Lower Saturated Zone													
2-2A	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-4A	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-148A	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-149A	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-152A	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

^a µg/L = micrograms per liter.

^b ND = not detected.

^c Duplicate of preceding sample.

^d MCL = Maximum Contaminant Level, U.S. EPA Primary Drinking Water Regulations, May 14, 1996.

^e — = No standard listed.

1,800 µg/L ethylbenzene, and 9,240 µg/L total xylenes. Again, the BTEX concentrations detected in well 2-50B are assumed to be the upper limit for dissolved BTEX at Area A. The maximum BTEX concentrations outside of the free product plume were detected at well VEP-9, located downgradient from well 2-50B and the product plume. Concentrations of BTEX constituents detected at well VEP-9 were 3,690 µg/L for benzene, 292 µg/L for toluene, 375 µg/L for ethylbenzene, and 359 µg/L for total xylenes.

No total fuel carbon or BTEX were detected in any upgradient USZ wells, indicating that the former Area A service station is the sole source of fuel hydrocarbons in the Area A USZ. The fuel carbon/BTEX plume in the USZ is well-defined in the down- and cross-gradient directions based on May 1997 laboratory results for groundwater samples collected from wells 2-149B, 2-164B, 2-165B, 2-166B, 2-264B, and 2-265B.

Neither total fuel carbon nor BTEX were detected in any groundwater sample from the LSZ, indicating that the fuel hydrocarbon plume has not migrated downward through the USZ/LSZ aquitard. The USZ/LSZ aquitard is composed of laterally continuous, cemented silty and clayey interbeds that form an effective barrier to downward migration of fuel hydrocarbons beneath Area A.

The trimethylbenzene isomers 1,3,5-TMB, 1,2,4-TMB, and 1,2,3-TMB were detected at concentrations ranging from below laboratory detection limits to a maximum in the groundwater sample from well 2-50B of 355 µg/L, 1,270 µg/L, and 407 µg/L, respectively. Trimethylbenzenes are constituents of fuel hydrocarbons that do not readily degrade under anaerobic conditions thereby acting as conservative tracers for evaluating anaerobic biodegradation rates.

4.2.4 Dissolved CAHs and Daughter Products

Groundwater samples collected from the site in May 1997 also were analyzed for CAHs and daughter products. Analytical results are summarized in Table 4.3.

PCE was detected at concentrations ranging from below detection to 5.2 µg/L in groundwater samples collected from the USZ in May 1997. The highest concentration was detected in the groundwater sample collected from well 2-3 (5.2 µg/L). PCE also was detected in wells 70, VEP-9, VEP-10, VEP-11, and VEP-12 at concentrations of less than 5 µg/L. PCE was not detected in any groundwater sample collected from the LSZ in May 1997.

TCE was detected in 11 of the 22 groundwater samples collected from the USZ in May 1997. The highest concentration was detected in the groundwater sample from well 2-3 (1,120 µg/L), approximately 100 feet west of the former service station (Figure 4.7). The source of the TCE in the area of the former service station is unclear, but maintenance activities at the former Area A service station may be responsible for the groundwater contamination. The TCE plume reaches as far downgradient as well VEP-11 (5.5 µg/L), approximately 400 feet west of well 2-3. Low concentrations of TCE were detected upgradient of the site at wells 2-148B (5.7 µg/L), 2-145B (6.9 µg/L), and 2-166B (7.7 µg/L).

TABLE 4.3
CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER
APRIL/MAY 1997
AREA A RNA TS
TINKER AFB, OKLAHOMA

Sample Location	Sample Date	PCE ^{a/} (µg/L) ^{b/}	TCE ^{a/} (µg/L)	1,1-DCE ^{a/} (µg/L)	cis-1,2-DCE (µg/L)	trans-1,2-DCE (µg/L)	VC ^{a/} (µg/L)	1,1-DCA ^{a/} (µg/L)	1,2-DCA (µg/L)	1,4-DCB ^{a/} (µg/L)	1,2-DCB (µg/L)	Chloroform (µg/L)	Carbon Tetrachloride (µg/L)
MCL ^{d/}		5	5	7	70	100	2	— ^{d/}	5	75	600	—	5
Upper Saturated Zone													
2-2	5/8/1997	ND	37	ND	12.7	ND	ND ^{d/}	ND	ND	ND	ND	ND	ND
2-2 (dup) ^{b/}	5/8/1997	ND	37.6	ND	12.8	ND	1.9	ND	ND	ND	ND	ND	ND
2-3	5/8/1997	5.2	1,120	< 1 ^{b/}	158	ND	37.1	ND	ND	ND	ND	11.9	ND
2-50B	5/8/1997	ND	ND	ND	407	ND	64	ND	ND	ND	ND	ND	ND
2-51B	5/8/1997	ND	ND	ND	< 1	ND	ND	ND	ND	ND	ND	ND	ND
2-52B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-145B	5/8/1997	ND	6.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-146B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-148B	5/8/1997	ND	5.7	ND	ND	ND	ND	ND	2.3	ND	ND	4.9	83.5
2-149B	5/8/1997	ND	< 1	ND	< 1	ND	ND	ND	1.7	ND	ND	ND	ND
2-149B (dup)	5/8/1997	ND	< 1	ND	< 1	ND	ND	ND	1.6	ND	ND	ND	ND
2-152B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-163B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	35.1	ND	ND	ND	ND
2-164B	5/8/1997	ND	< 1	ND	ND	ND	ND	ND	1.3	ND	ND	< 1	ND
2-165B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-166B	5/8/1997	ND	7.7	ND	< 1	ND	ND	ND	ND	ND	ND	< 1	ND
2-173B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-264B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-265B	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	< 1	ND
70	5/8/1997	1	< 1	ND	< 1	ND	ND	ND	ND	ND	ND	< 1	ND
VEP-9	4/23/1997	1.3	ND	3.1	1,680	126	787	3.5	ND	1.2	7.6	9.5	ND
VEP-10	4/23/1997	1.3	252	ND	15.8	ND	1.5	ND	53.2	< 1	< 1	2.1	ND
VEP-11	4/23/1997	< 1	5.5	ND	3.8	ND	1	ND	17.7	ND	ND	ND	ND
VEP-11 (dup)	4/23/1997	< 1	5.6	ND	3.7	ND	< 1	ND	16.1	ND	ND	ND	ND
VEP-12	4/23/1997	< 1	13.9	< 1	141	ND	2.9	ND	ND	< 1	< 1	ND	ND
Lower Saturated Zone													
2-2A	5/8/1997	ND	54.8	ND	1	ND	ND	ND	1.4	ND	ND	< 1	5.3
2-4A	5/8/1997	ND	39.9	ND	< 1	ND	ND	ND	< 1	ND	ND	< 1	< 1
2-148A	5/8/1997	ND	17.3	ND	2.2	ND	ND	ND	ND	ND	ND	1.6	1.6
2-149A	5/8/1997	ND	< 1	ND	ND	ND	ND	ND	ND	ND	ND	ND	< 1
2-152A	5/8/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

^{a/} VC = vinyl chloride, DCE = dichloroethene, DCA = dichloroethane, TCA = trichloroethane, TCE = trichloroethene, PCE = tetrachloroethene, DCB = dichlorobenzene.

^{b/} µg/L = micrograms per liter.

^{d/} — = No standard listed.

TCE also was detected in groundwater samples from wells screened within the LSZ in May 1997. The highest concentration of TCE detected in groundwater from the LSZ was detected in the groundwater sample collected from well 2-2A (54.8 µg/L), located approximately 150 feet southeast of the former service station. TCE also was detected at concentrations greater than 1 µg/L in groundwater collected from LSZ wells 2-148A (17.3 µg/L) and 2-4A (39.9 µg/L).

Given the site geology and the upgradient LSZ CAH contamination, it is not likely that the source of the LSZ contamination originated at the Area A service station. However, the high concentration of TCE at well 2-3 indicates at least one source of CAH contamination at or near the former service station. It is possible, though not documented, that past disposal practices (of degreasers used to clean engine blocks, for instance) resulted in the chlorinated solvent contamination in the USZ at this site.

1,1-DCE, *cis*-1,2-DCE, and *trans*-1,2-DCE were detected in groundwater samples collected from the USZ in May 1997. *Cis*-1,2-DCE was the most prevalent isomer of DCE, exceeding concentrations of the other isomers by at least an order of magnitude at every location. The highest concentration of *cis*-1,2-DCE was detected in the groundwater sample collected from well VEP-9 (1,680 µg/L) (Figure 4.8), approximately 220 feet downgradient from well 2-3, where the highest TCE concentration was detected. All DCE concentrations in excess of 100 µg/L were detected in USZ groundwater coinciding with and downgradient from the TCE "hot spot". As discussed in Section 4.1, the DCE isomers measured in groundwater samples collected downgradient from Area A are a strong indicator of microbially mediated TCE degradation. *Cis*-1,2-DCE also was detected in groundwater collected from wells screened in the LSZ (Table 4.2). The highest concentration, however, was 2.2 µg/L detected in the groundwater sample from well 2-148A, approximately 1,200 feet upgradient from the USZ plume area.

VC was detected in 7 of the 22 groundwater samples collected at Area A. The highest concentration of VC in USZ groundwater was detected in the groundwater sample collected from well VEP-9 (787 µg/L) (Figure 4.9). The VC plume coincides with the *cis*-1,2-DCE plume, and, as discussed in Section 4.1, the VC is likely a daughter product of the reductive dehalogenation of TCE and DCE. No VC was detected in the groundwater samples collected from wells screened within the LSZ or upgradient USZ wells (Table 4.2).

Groundwater samples also were analyzed for ethene and ethane. Analytical results are summarized in Table 4.4. Ethene is the end product in the series of reductive dehalogenation reactions that can begin with TCE. The highest concentration of ethene at the site was detected in the groundwater sample collected from well VEP-11 (0.219 mg/L), approximately 500 feet west of the former service station (Figure 4.10). With the exception of the maximum ethene concentration at VEP-11, the ethene plume coincides with the *cis*-1,2-DCE and VC plumes. Ethane, a degradation product of ethene, was detected in groundwater samples collected from wells VEP-9, 2-50B, and 2-3 (Figure 4.10). These wells also contain the three highest *cis*-1,2-DCE and VC concentrations.

Other CAHs detected during the May 1997 groundwater sampling event include 1,1-DCA, chloroform, carbon tetrachloride, 1,2-DCA, 1,4-DCB, and 1,2-DCB (Table 4.3).

TABLE 4.4
GROUNDWATER GEOCHEMICAL DATA
APRIL/MAY 1997
AREA A RNA TS
TINKER AFB, OKLAHOMA

Sample Location	Ethene (mg/L) ^{a/}	Ethane (mg/L)	Methane (mg/L)	TOC ^{b/} (mg/L)	Dissolved Oxygen (mg/L)	Nitrate + Nitrite (mg/L)	Ferrous Iron (mg/L)	Sulfate (mg/L)	Total Alkalinity (mg/L)	Carbon Dioxide (mg/L)	Ammonia (mg/L)	Chloride (mg/L)	Redox Potential (mV) ^{c/}	pH ^{d/}	Temp (°C) ^{e/}	Conductivity (µS/cm) ^{f/}
Upper Saturated Zone																
2-2	0.016	ND ^{g/}	4.15	24.9	0.4	< 0.05 ^{h/}	3.7	< 0.5	678	180	< 0.05	361	11	7.0	19.0	2,250
2-3	0.063	0.033	4.41	5.47	0.1	< 0.05	2.1	25.4	535	330	< 0.05	224	11	7.1	19.3	1,590
2-4	NM ^{i/}	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
2-50B	0.086	0.234	3.28	157	0.1	< 0.05	1.9	< 0.5	539	282	< 0.05	188	-243	7.1	20.3	1,530
2-51B	0.043	< 0.003	1.03	34.1	0.2	< 0.05	4.0	< 0.5	632	440	< 0.05	931	-215	7.0	23.3	3,900
2-52B	ND	ND	0.53	2.03	0.3	< 0.05	0.2	13.2	275	104	< 0.05	15.9	-265	7.4	17.4	600
2-145B	ND	ND	ND	5.42	0.3	2.79	< 0.05	197	540	230	< 0.05	94	70	7.2	20.8	1,660
2-146B	ND	ND	< 0.001	6.50	0.3	0.99	< 0.05	36.7	565	240	< 0.05	41	129	7.1	19.1	1,220
2-148B	ND	ND	ND	2.66	4.4	2.27	< 0.05	329	372	230	< 0.05	555	7	7.1	21.0	2,940
2-149B	ND	ND	0.01	5.78	1.4	17	< 0.05	30.6	520	340	< 0.05	168	366	6.9	19.0	1,600
2-152B	ND	ND	< 0.001	4.70	0.9	3.13	< 0.05	251	431	250	< 0.05	938	197	7.2	23.7	3,680
2-163B	0.166	ND	3.41	6.40	0.5	< 0.05	2.0	9.67	560	344	0.59	49.9	-172	6.9	22.6	2,690
2-164B	< 0.002	ND	0.38	4.56	0.2	14.2	< 0.05	12.6	475	204	< 0.05	269	70	6.9	22.9	1,630
2-165B	ND	ND	ND	6.87	0.6	1.33	< 0.05	46.6	510	300	< 0.05	156	182	6.9	16.4	1,560
2-166B	ND	ND	ND	2.02	1.4	5.01	< 0.05	155	395	230	< 0.05	119	44	7.2	19.4	1,320
2-173B	ND	ND	ND	1.77	2.0	8.51	< 0.05	126	433	185	< 0.05	93.4	204	6.9	19.0	953
2-264B	ND	ND	< 0.001	2.94	1.8	9.96	< 0.05	18.1	555	NA	< 0.05	18	465	7.1	18.5	1,340
2-265B	ND	ND	ND	2.62	2.5	2.9	< 0.05	89.4	390	NA	< 0.05	156	157	7.1	19.1	1,350
70	ND	ND	ND	1.79	1.5	2.38	< 0.05	78.9	425	230	< 0.05	123	1	7.2	20.3	1,340
VEP-9	0.112	0.268	3.07	12.2	NM	NM	7.4	NM	625	432	NM	NM	-113	7.0	NM	2,090
VEP-9 (dup)	0.107	0.258	3.14	7.82	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
VEP-10	0.027	ND	0.68	3.81	NM	NM	< 0.05	NM	526	400	NM	NM	> 5	6.9	NM	2,240
VEP-11	0.219	ND	4.75	3.77	NM	NM	1.3	NM	525	300	NM	NM	-36	7.1	NM	1,660
VEP-12	0.013	ND	1.27	6.08	NM	NM	0.8	NM	520	314	NM	NM	15	7.0	NM	1,540
Lower Saturated Zone																
2-2A	ND	ND	0.00	0.78	5.0	4.31	< 0.05	12.6	335	110	< 0.05	179	70	7.2	20.6	1,240
2-4A	ND	ND	0.00	6.87	4.7	3.69	0.4	18	348	226	< 0.05	195	83	7.2	20.6	1,300
2-51A	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
2-52A	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM
2-148A	ND	ND	ND	1.71	5.4	2.35	< 0.05	21.1	302	186	< 0.05	134	51	7.3	23.8	1,070
2-149A	ND	ND	ND	2.60	4.8	2.31	< 0.05	NM	184	NM	< 0.05	NM	145	9.5	19.0	576
2-152A	ND	ND	ND	5.69	6.7	1.32	< 0.05	6.78	287	170	< 0.05	60.6	233	7.4	20.6	711

^{a/} mg/L = milligrams per liter.

^{b/} TOC = total organic carbon.

^{c/} mV = millivolts.

^{d/} Well head measurement not made;

value reported is measurement made in on-base field laboratory.

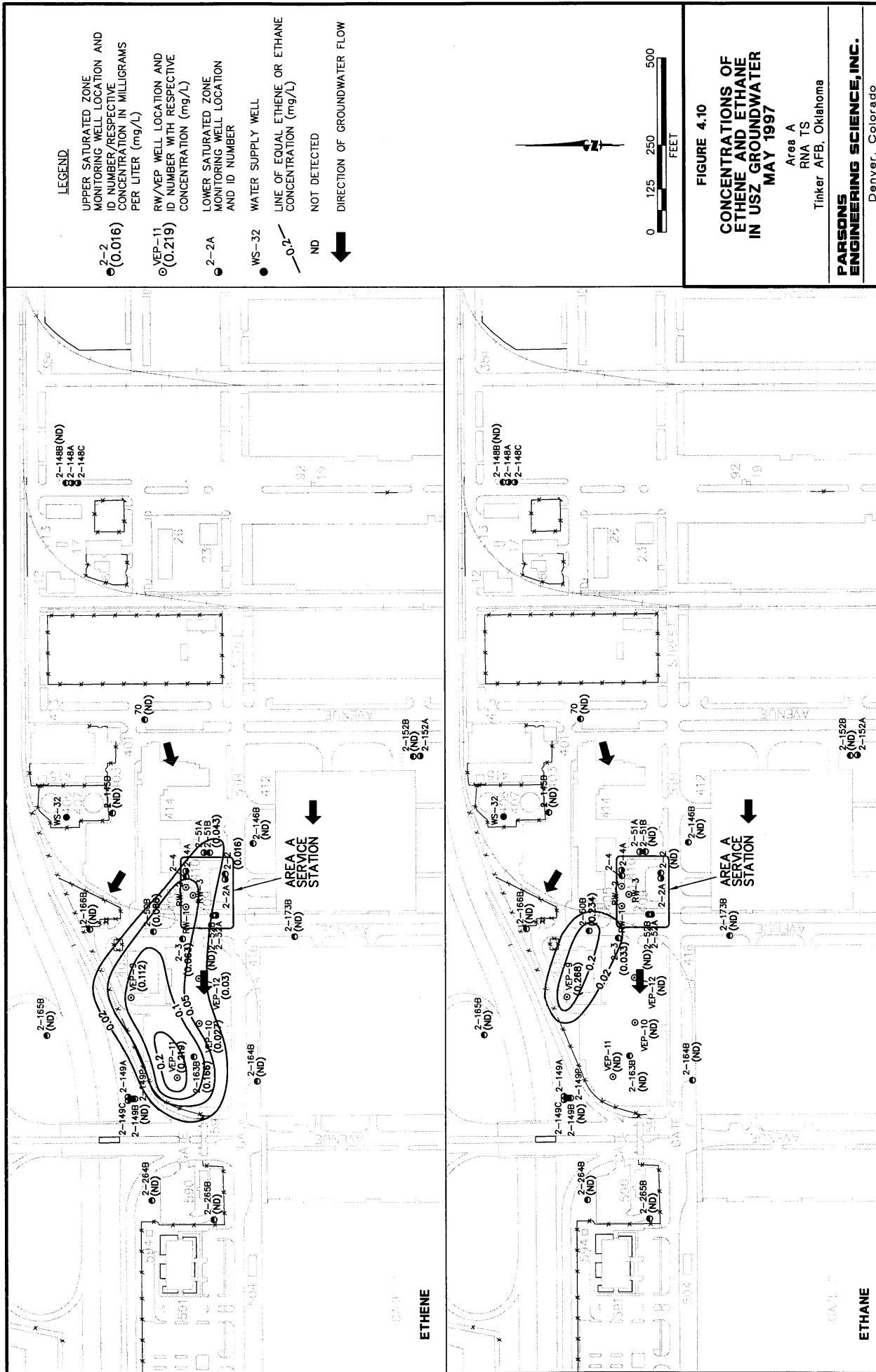
^{e/} °C = degrees Centigrade.

^{f/} µS/cm = microsiemens per centimeter.

^{g/} ND = not detected.

^{h/} Measured value (e.g., <0.05) is less than the estimated reporting limit for this compound.

^{i/} NM = not measured.



The highest concentrations of these CAHs were generally found in the groundwater samples collected from wells where the highest concentrations TCE, DCE, and VC were found, with the exception of carbon tetrachloride. Carbon tetrachloride was only detected in USZ groundwater in a sample collected from upgradient well 2-148B, at a concentration of 83.5 µg/L.

4.3 ANALYSIS OF HYDROCARBON BIODEGRADATION

4.3.1 Field-Scale Contaminant Mass Loss

Groundwater quality data collected between January 1994 and May 1997 were reviewed to assess temporal changes in contaminant concentrations due to natural attenuation over time. Decreasing concentration trends can be used to demonstrate field-scale reductions in contaminant mass due to natural attenuation processes.

4.3.1.1 Fuel Hydrocarbons over Time

BTEX concentrations in well 2-2 have fluctuated with time, but an overall decrease from 3,750 µg/L total BTEX in January 1994 to 618 µg/L total BTEX in May 1997 has been observed (Figure 4.11). The May 1997 benzene concentration in well 2-3 is higher than the concentration measured in October 1996; however, the 1996 benzene concentration is substantially lower than the concentration measured in January 1994. BTEX concentrations in well 2-4 have not changed substantially since January 1994, likely due to the persistence of free product in the well. BTEX concentrations in well 2-50B have decreased slightly since January 1994, while BTEX concentrations in well 2-51B have fluctuated with time with an overall decrease since January 1994. These data indicate that the overall concentrations of BTEX dissolved in groundwater at the site from January 1994 to May 1997 has been decreasing due to natural attenuation.

4.3.1.2 TCE over Time

Concentrations of TCE in groundwater samples collected from wells 2-2, 2-3, 2-4, 2-50B, 2-51B, and 2-52B from January 1994 to May 1997 are shown on Figure 4.12. TCE concentrations in wells 2-2 and 2-50B have shown an overall decrease from January 1994, and TCE concentrations in well 2-4 decreased to below 500 µg/L by August 1996. TCE concentrations in well 2-3 have fluctuated with time showing no overall trend. No TCE was detected in the groundwater sample from well 2-51B in May 1997. These data indicate that while concentrations of TCE may fluctuate in individual wells over time, the overall concentration of TCE dissolved in groundwater at the site appears to be stable due to natural attenuation processes.

4.3.2 Electron Donors, Electron Acceptors, and Metabolic Byproducts

One of the most straightforward methods for evaluating the site-specific occurrence and method(s) of biodegradation of fuel hydrocarbons and CAHs is to measure the distribution of the geochemical parameters that reflect the processes driving biodegradation. Biodegradation of organic compounds, whether natural or anthropogenic, brings about measurable changes in the chemistry of groundwater in the

FIGURE 4.11
 DISSOLVED TOTAL BTEX CONCENTRATIONS OVER TIME
 AT SELECTED GROUNDWATER SAMPLING LOCATIONS
 AREA A RNA TS
 TINKER AFB, OKLAHOMA

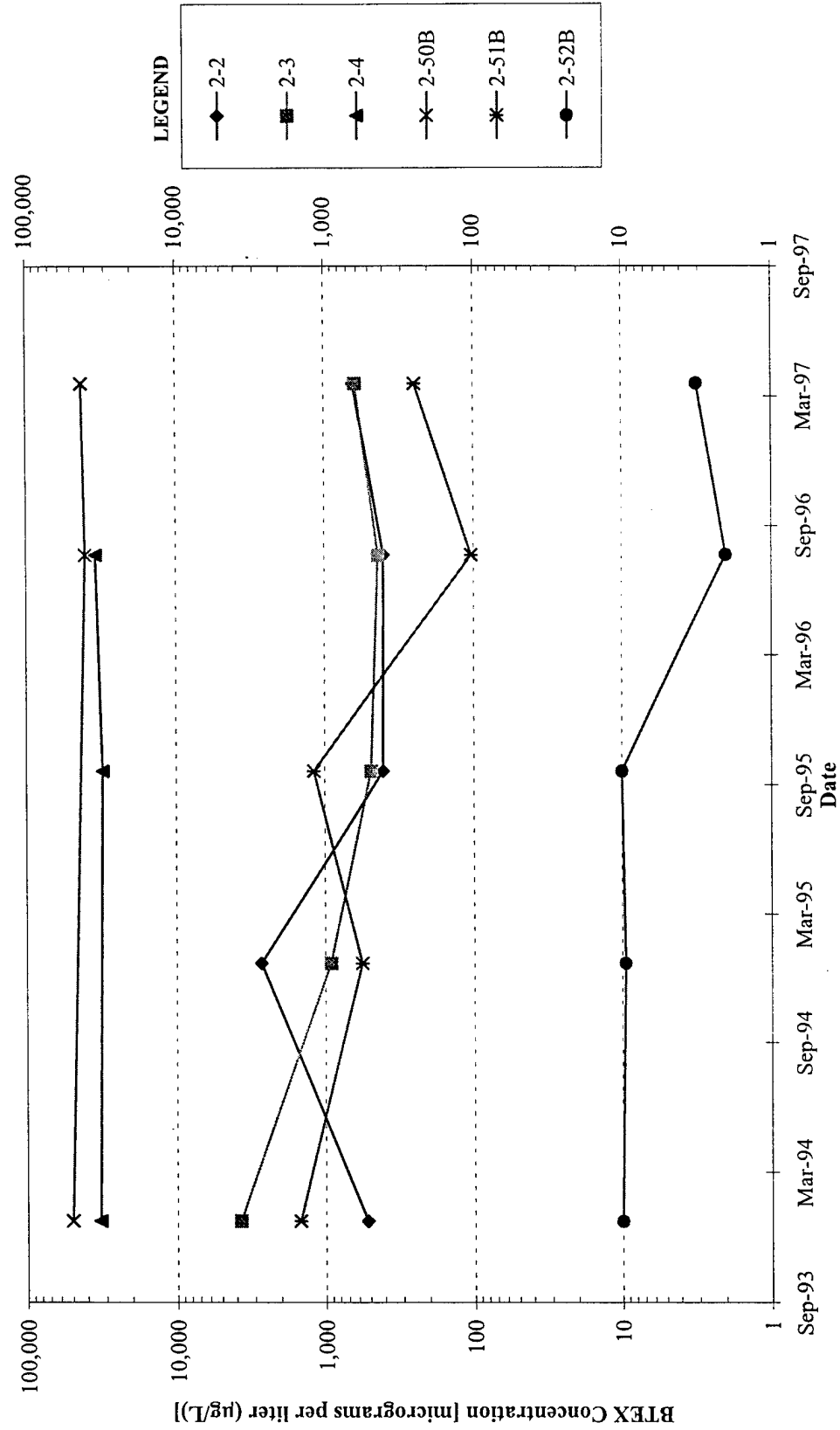
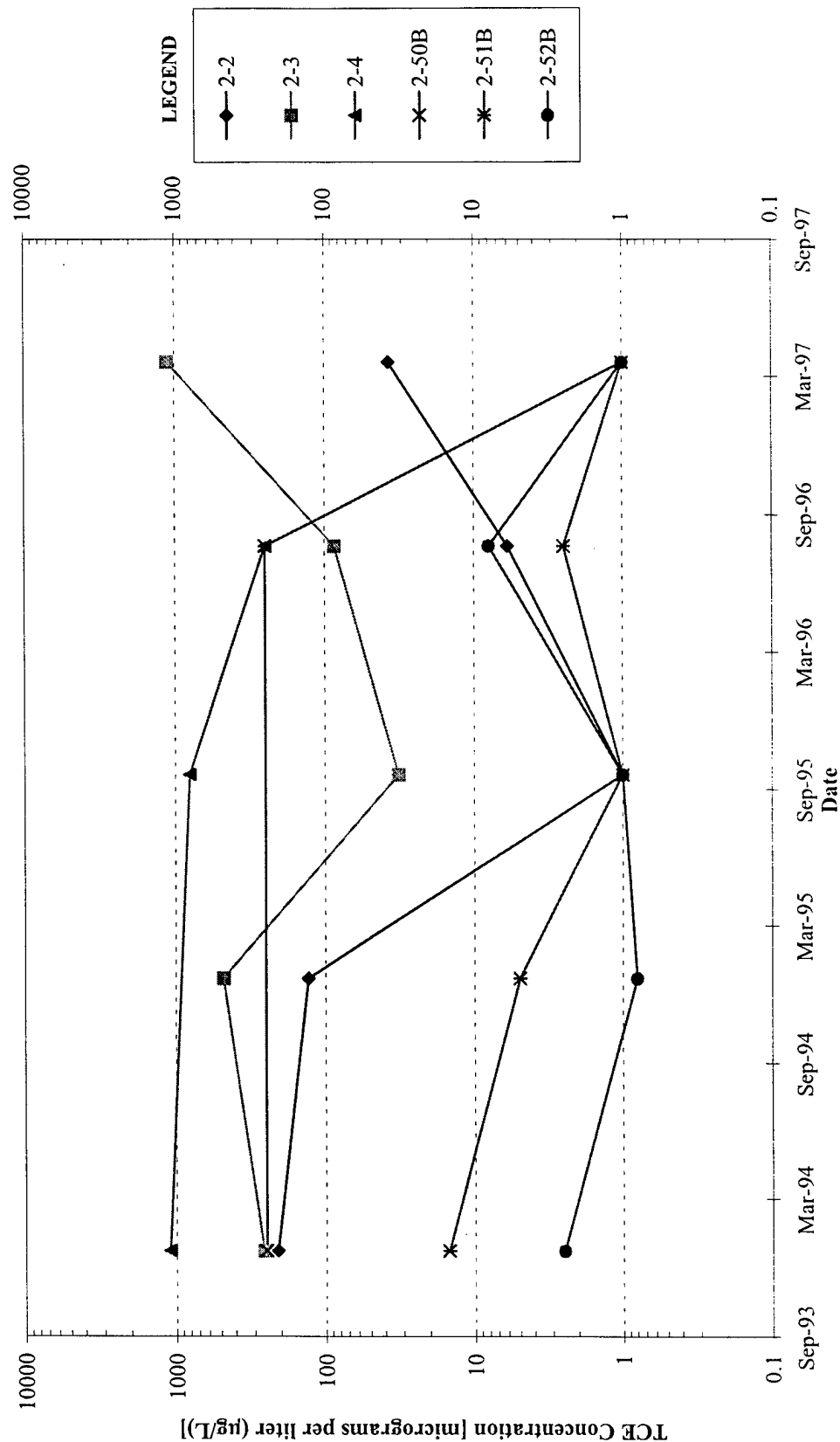


FIGURE 4.12
 DISSOLVED TCE CONCENTRATIONS OVER TIME
 AT SELECTED GROUNDWATER SAMPLING LOCATIONS
 AREA A RNA TS
 TINKER AFB, OKLAHOMA



affected area. Concentrations of compounds used as electron acceptors (e.g., DO, nitrate, and sulfate) are depleted, and byproducts of electron acceptor reduction e.g., ferrous iron [Fe^{2+}], methane, and sulfide) are enhanced. By measuring these geochemical changes in groundwater conditions, it is possible to evaluate the importance of natural attenuation at a site.

4.3.2.1 Total Organic Carbon in Soil

TOC can be used as a gross indicator of organic compounds that are available as a source of carbon and electrons (i.e., substrate) for microbial activity. Soil TOC concentrations have not been measured in any Area A samples collected outside or near the margins of the BTEX and CAH plumes. Published ranges of TOC concentrations in soils consisting primarily of sand or silt range from 0.017 percent to 0.108 percent (Spitz and Moreno, 1996). Soil samples collected from USZ sands at Fire Training Area 2 at Tinker AFB by Parsons ES in July 1997 had TOC concentrations ranging from 0.632 to 0.969 percent. Although native organic carbon may not provide an ample substrate at the site, it is anticipated that, where present, fuel hydrocarbons provide a substantial carbon source for microbial activity.

TOC concentrations also are used to estimate the amount of organic matter sorbed to soil particles or trapped in the interstitial passages of a soil matrix. The TOC concentration in the saturated zone is an important parameter used to estimate the amount of contaminant that could potentially be sorbed to the aquifer matrix. Sorption results in retardation of the contaminant plume relative to the average groundwater flow velocity.

4.3.2.2 Total Organic Carbon in Groundwater

Dissolved native organic carbon also can act as a source of electron donors (an energy source) during the reductive dehalogenation of CAHs. Dissolved TOC concentrations can be used as an indicator of the presence of such native carbon compounds in wells outside of the area containing dissolved organic contamination (anthropogenic organic compounds, such as BTEX and CAHs, also will be measured by method RSKSOP-102). Dissolved TOC concentrations in excess of 20 mg/L are desirable to drive dehalogenation reactions (Wiedemeier *et al.*, 1996a). At Area A in April/May 1997, TOC concentrations in groundwater (Table 4.4) outside the BTEX plume ranged from 1.77 mg/L to 6.5 mg/L and averaged 3.7 mg/L, indicating that native carbon may not be present in sufficient concentrations to drive reductive dehalogenation outside of the BTEX plume.

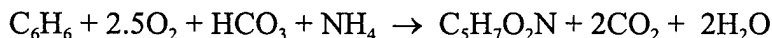
Dissolved anthropogenic organic carbon, such as BTEX, in the same area as the CAH plume can also create favorable conditions for reductive dehalogenation, because the BTEX can provide a source of electron donors and facilitate microbial reactions that lower groundwater ORP. BTEX concentrations greater than 100 $\mu\text{g/L}$ often provide a carbon and energy source sufficient to stimulate reductive dehalogenation (Wiedemeier *et al.*, 1996a). Groundwater samples with concentrations of BTEX greater than 100 $\mu\text{g/L}$ were collected from several wells in the CAH plume area, including wells 2-2, 2-3, 2-50B, 2-51B, VEP-9, and VEP-12 (Figure 4.6). With the exception of well 2-51B, all of these locations also have CAH concentrations in excess of 100 $\mu\text{g/L}$.

4.3.2.3 Dissolved Oxygen

DO concentrations measured at USZ monitoring wells during the May 1997 sampling event are summarized in Table 4.4 and displayed on Figure 4.13. Areas with elevated total BTEX concentrations correspond to areas with depleted DO concentrations based on comparison of Figure 4.13 with the dissolved BTEX isopleth map (Figure 4.6). This relation indicates that aerobic biodegradation of BTEX is occurring, and that DO is an important electron acceptor at the site. Likewise, DO concentrations within the CAH plume ranged from 0.1 mg/L to 0.4 mg/L, indicating anaerobic conditions are present within the CAH plume area. DO concentrations in LSZ wells ranged from 4.7 mg/L to 6.7 mg/L and averaged 5.3 mg/L, indicating aerobic conditions normally predominate within the LSZ.

The stoichiometry of BTEX mineralization to carbon dioxide and water caused by aerobic microbial biodegradation is presented in Table 4.1. The average mass ratio of oxygen to total BTEX is approximately 3.14 to 1. This translates to a mineralization of approximately 0.32 milligrams (mg) of BTEX for every 1.0 mg of DO consumed. The average observed background USZ groundwater DO concentration in May 1997 was 2.2 mg/L (wells 2-148B, 70, 2-152B, and 2-173), and the minimum observed DO concentration within the BTEX plume was 0.1 mg/L. Therefore, approximately 2.1 mg/L of DO appears to have been consumed as a result of aerobic respiration processes. On the basis of the oxygen-reduction stoichiometry presented above, the shallow groundwater at this site had the capacity to assimilate a maximum of approximately 0.67 mg/L (670 µg/L) total BTEX through aerobic biodegradation.

The BTEX consumption rate of 0.67 mg/L may be a conservative estimate of the assimilative capacity resulting from oxygen reduction because microbial cell mass production was not taken into account. As a microbial population in the saturated zone grows in response to the introduction of fuel hydrocarbons into the groundwater, new cell mass is generated. When cell mass production is accounted for, the mineralization of benzene to carbon dioxide and water is given as:

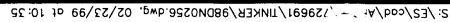


This equation indicates that 5.0 fewer moles of DO are required to mineralize 1 mole of benzene when cell mass production is taken into account. On a mass basis, the ratio of DO to benzene for this reaction is given by:

Benzene	$6(12) + 1(6) = 78 \text{ gm}$
Oxygen	$2.5(32) = 80 \text{ gm}$

$$\text{Mass Ratio of Oxygen to Benzene} = 80/78 = 1.03:1$$

If cell mass production is taken into account, 1.03 mg of oxygen are required to mineralize 1 mg of benzene, or approximately 0.97 mg of BTEX is mineralized to carbon dioxide and water for every 1.0 mg of DO consumed. Similar calculations can be made for toluene, ethylbenzene, and the xylenes.



CONCENTRATIONS OF
DISSOLVED OXYGEN IN
USZ GROUNDWATER
MAY 1997

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4-31

Although cell mass production results in more efficient utilization of electron receptors, it is only applicable as the net cell mass of the microbial population continues to grow. Because groundwater contamination has been present at the site for at least several years, assimilation of BTEX may have reached steady-state. Therefore, the cell mass reaction equations would no longer apply, and the assimilative capacity estimate based on no biomass production is considered more conservative. The steady-state production of cell mass as applied to anaerobic mechanisms is also likely, and the following calculations of anaerobic assimilative capacity estimates assume steady-state (i.e., biomass production represents a very small fraction of energy use).

Reductive dehalogenation of CAHs is an anaerobic process with highly chlorinated compounds such as PCE, TCE, and TCA being biologically recalcitrant under aerobic conditions. DO concentrations in excess of 0.5 mg/L may cause the reductive dehalogenation pathway to be suppressed (Wiedemeier *et al.*, 1996a). The anaerobic nature of the USZ BTEX plume coinciding with the CAH plume promotes conditions for reductive dehalogenation of CAHs.

4.3.2.4 Nitrate/Nitrite

After DO has been depleted, nitrate may be used as an electron acceptor for anaerobic biodegradation of organic carbon via denitrification. Nitrate concentrations below background in areas with high organic carbon concentrations and low DO are indicative of denitrification. The oxidation of organic carbon via the process of denitrification (using nitrate as an electron acceptor) yields a relatively large amount of free energy to microbial populations.

Concentrations of nitrate + nitrite (as N) were measured in groundwater samples collected from site monitoring wells in May 1997. Measured nitrate and nitrite (as N) concentrations are summarized in Table 4.4, and a map showing the distribution of nitrate + nitrite (as N) in groundwater during the TS sampling event is presented on Figure 4.14. Comparison of Figures 4.6 and 4.14 indicates that areas with elevated total BTEX concentrations also have depleted nitrate + nitrite concentrations. This relation provides evidence that anaerobic biodegradation of the BTEX compounds is occurring at the site through the microbially mediated process of denitrification.

The stoichiometry of BTEX mineralization to carbon dioxide, water, and nitrogen caused by denitrification in the absence of microbial cell production is presented in Table 4.1. The average mass ratio of nitrate to total BTEX is approximately 4.9 to 1. This translates to a mineralization of approximately 0.21 mg of BTEX for every 1.0 mg of nitrate consumed assuming that nitrate nitrogen is reported as ionic nitrate (NO_3^-) instead of elemental nitrogen (N). The nitrate + nitrite concentrations shown in Table 4.4 are reported as N, and must be multiplied by 4.42 to convert into ionic nitrate concentrations as NO_3^- . The nitrate conversion assumes that all or most of the nitrogen concentrations reported in Table 4.4 are composed of nitrate, and that nitrite concentrations are relatively insignificant, which is typically the case.

The average background nitrate (as N) concentration in May 1997 is estimated to be 3.80 mg/L (16.8 mg/L as NO_3^-). The minimum nitrate concentration within the dissolved

BTEX plume in May 1997 was <0.05 mg/L as N (<0.22 mg/L as NO_3^-). Assuming that minimum nitrate concentrations were 0.11 mg/L as NO_3^- , approximately 16.7 mg/L of nitrate (as NO_3^-) had been consumed as a result of denitrification in May 1997. The USZ groundwater at this site thus had the capacity to assimilate 3.5 mg/L ($3,500$ $\mu\text{g/L}$) of total BTEX due to denitrification in May 1997.

Nitrate is energetically favored (preferred) compared to use of CAHs as electron acceptors. If nitrate concentrations exceed 1 mg/L, then anaerobic microorganisms may preferentially use nitrate instead of CAHs to produce energy for their use (Wiedemeier *et al.*, 1996a). All measured nitrate/nitrite concentrations within the CAH plume were <0.05 mg/L, indicating that nitrate/nitrite will not inhibit reductive dehalogenation of CAHs.

4.3.2.5 Ferrous Iron

The reduction of ferric iron (Fe^{3+}) is a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). The reduction of Fe^{3+} results in the formation of ferrous iron (Fe^{2+}), and elevated concentrations of Fe^{2+} are often found in anaerobic groundwater systems. Ferrous iron concentrations once were attributed to the spontaneous and reversible abiotic reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as BTEX. However, recent evidence suggests that the reduction of Fe^{3+} cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to Fe^{2+} under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of Fe^{3+} requires mediation by microorganisms with the appropriate enzymatic capabilities.

Fe^{2+} concentrations measured at selected groundwater monitoring wells in May 1997 are summarized in Table 4.4 and displayed on Figure 4.15. Fe^{2+} concentrations within the CAH plume ranged from 0.2 mg/L to 7.4 mg/L and averaged 2.68 mg/L. Fe^{2+} concentrations greater than 1 mg/L within the CAH plume indicate active microbial degradation under anaerobic conditions (Wiedemeier *et al.*, 1996a).

The stoichiometry of BTEX oxidation to carbon dioxide, sulfur, and water by iron reduction through anaerobic microbial biodegradation is presented in Table 4.1. The average mass ratio of iron to total BTEX is approximately 21.8 to 1 . This translates to a mineralization of approximately 0.02 mg of total BTEX for every 1.0 mg of Fe^{3+} consumed.

The maximum Fe^{2+} concentration within the BTEX plume in May 1997 was 7.4 mg/L. The average Fe^{2+} concentration outside of the plume in May 1997 was <0.05 mg/L. Assuming that the minimum Fe^{2+} concentration was 0.025 mg/L, approximately 7.38 mg/L of Fe^{2+} had been produced as a result of Fe^{3+} reduction in May 1997. USZ groundwater at this site thus had the capacity to assimilate 0.15 mg/L (150 $\mu\text{g/L}$) of total BTEX as a result of Fe^{3+} reduction in May 1997.

4.3.2.6 Sulfate

Sulfate also may be used as an electron acceptor during microbial degradation of fuel hydrocarbons under anaerobic conditions (Grbic-Galic, 1990). The sulfate reduction reaction occurs when sulfate is reduced to sulfide during the oxidation of natural or anthropogenic organic carbon. To investigate the potential for sulfate reduction at Area A, total sulfate concentrations were measured at groundwater monitoring wells during the May 1997 sampling event. Sampling results are summarized in Table 4.4 and illustrated on Figure 4.16.

Comparison of Figure 4.16 with Figure 4.6 indicates some correspondence between areas with elevated total BTEX concentrations and areas exhibiting depleted sulfate concentrations. The relation between BTEX and sulfate concentrations suggests that anaerobic biodegradation of BTEX compounds was occurring at the site in May 1997 through the microbially mediated process of sulfate reduction.

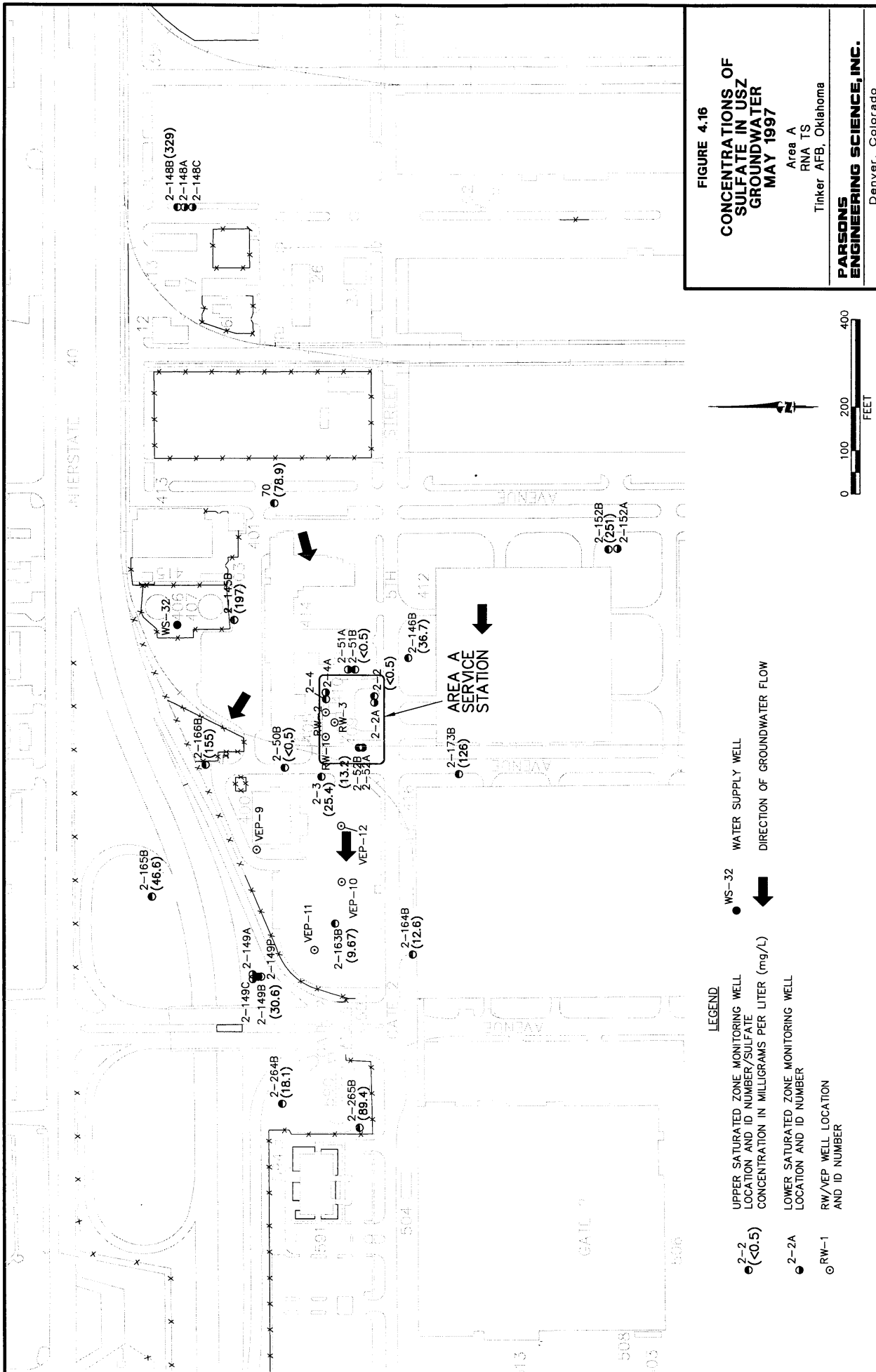
The stoichiometry of BTEX oxidation to carbon dioxide, sulfur, and water by sulfate reduction through anaerobic microbial biodegradation is presented in Table 4.1. The average mass ratio of sulfate to total BTEX is approximately 4.7 to 1. This translates to a mineralization of approximately 0.21 mg of total BTEX for every 1.0 mg of sulfate consumed.

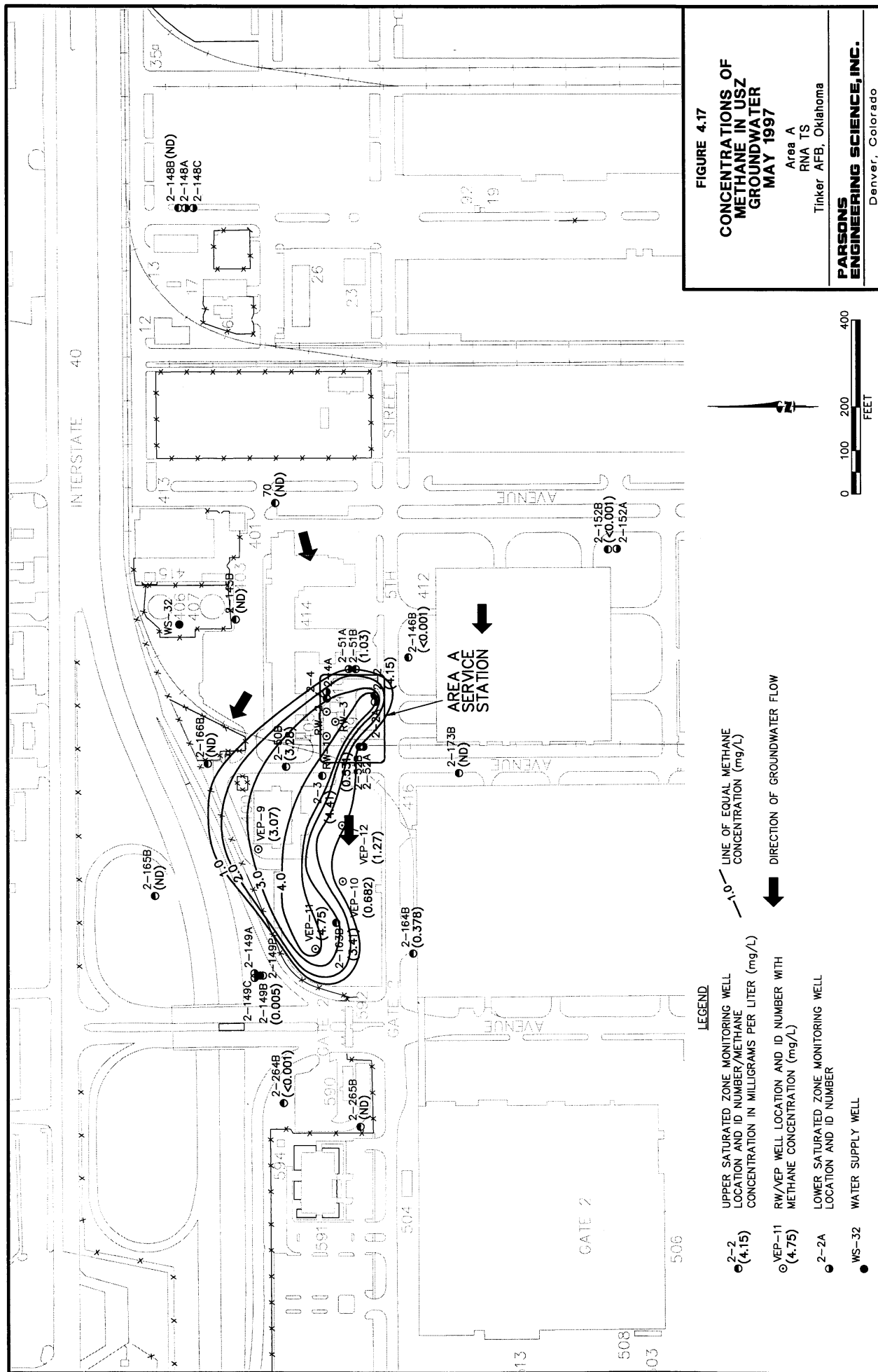
The average background sulfate concentration in May 1997 was 141 mg/L. The minimum sulfate concentration within the plume in May 1997 was <0.5 mg/L. Assuming that minimum sulfate concentration was 0.25 mg/L, approximately 141 mg/L of sulfate had been consumed as a result of sulfate reduction in May 1997. The shallow groundwater at this site thus had the capacity to assimilate 29.6 mg/L (29,600 µg/L) of total BTEX as a result of sulfate reduction in May 1997.

Wiedemeier *et al.* (1996a) report that sulfate may compete with CAHs as an electron acceptor (sulfate may be preferentially used by microorganisms instead of CAHs) if sulfate concentrations exceed approximately 20 mg/L. Sulfate concentrations within the plume ranged from <0.5 mg/L to 25.4 mg/L. Sulfate has been depleted within the plume and should not inhibit reductive dehalogenation.

4.3.2.7 Methane

Although anaerobic degradation may occur under nitrate- and sulfate-reducing conditions (Vogel *et al.*, 1987; Chapelle, 1996), the most rapid biodegradation rates occur under methanogenic conditions (Bouwer, 1994). Methane concentrations were measured in groundwater samples collected in May 1997 to assess whether methanogenic conditions are present in Area A groundwater. Methane concentrations are listed in Table 4.4, and the distribution of methane in USZ groundwater is shown on Figure 4.17. The presence of methane within and downgradient from the product source area indicates that reducing conditions have been sufficient to induce anaerobic biodegradation via the microbially mediated process of methanogenesis (carbon dioxide reduction).





The stoichiometry of BTEX oxidation to carbon dioxide and methane by methanogenesis is presented in Table 4.1. On average, approximately 1 mg of total BTEX is degraded for every 0.78 mg of methane produced.

Analytical data indicate that background methane concentrations at the site are less than 0.001 mg/L. The maximum methane concentration within or downgradient from the dissolved plume was 4.75 mg/L in May 1997. Assuming a background methane concentration of 0.0005 mg/L, the shallow groundwater thus had the capacity to assimilate approximately 6.09 mg/L (6,090 µg/L) of total BTEX in May 1997 as a result of methanogenesis.

4.3.3 Additional Geochemical Indicators of Biodegradation

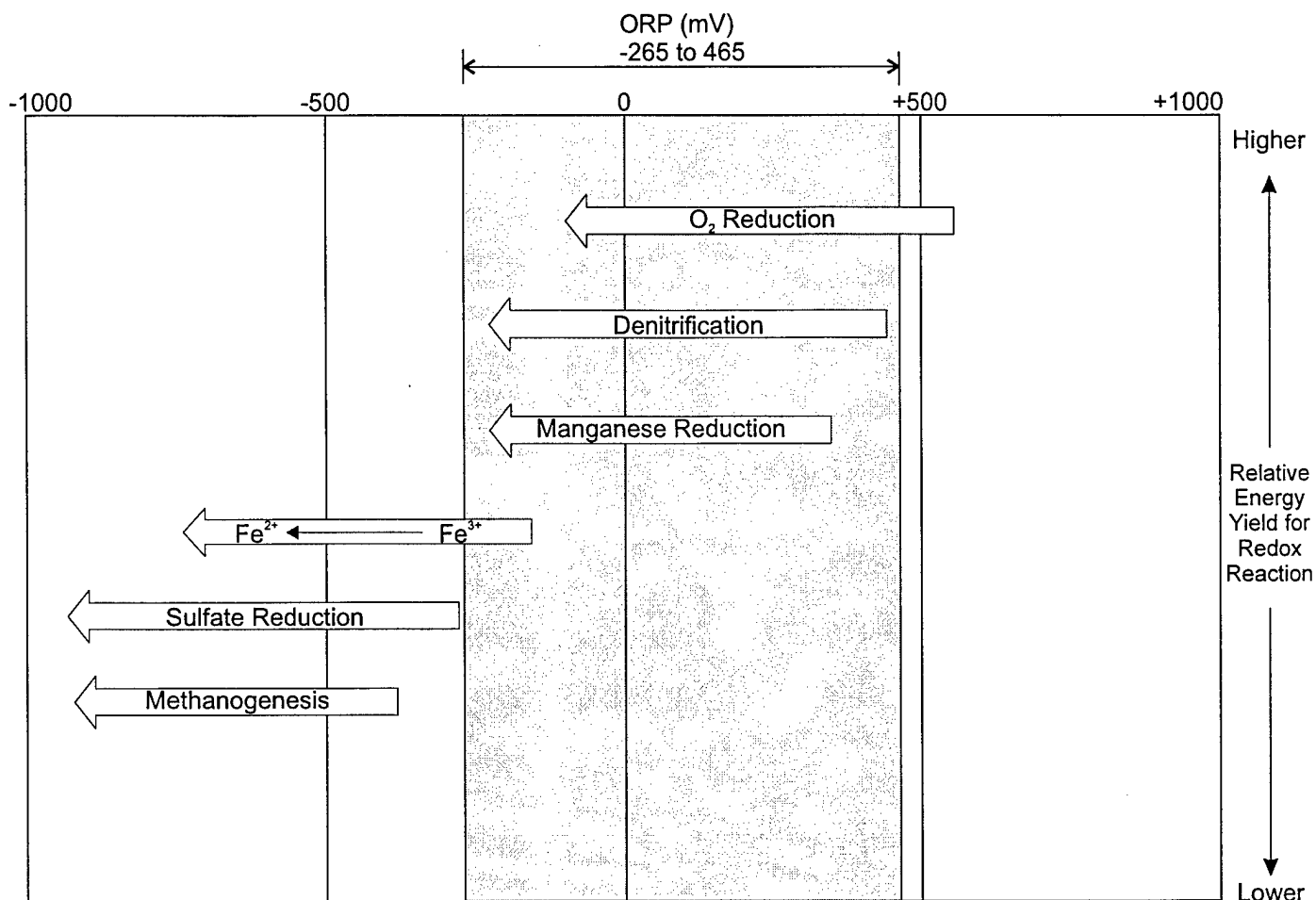
Other geochemical data collected for this evaluation can be used to further interpret and support the contaminant, electron donor, electron acceptor, and byproduct data previously discussed. These parameters provide additional qualitative indications of which processes may be operating at the site.

4.3.3.1 ORP

Microorganisms will facilitate only those redox reactions that will yield energy. For example, by coupling the oxidation of fuel hydrocarbon compounds (or native organic carbon), which requires energy, to the reduction of other compounds (e.g., oxygen, nitrate, manganese, Fe^{3+} , sulfate, carbon dioxide, and possibly *cis*-1,2-DCE), which yields energy, the overall reaction will yield energy.

The sequence of microbially mediated redox processes and the approximate ranges of ORPs that are favorable for each process are presented on Figure 4.18. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981; Godsey, 1994). Oxygen reduction would be expected in an aerobic environment with microorganisms capable of aerobic respiration, because oxygen reduction yields significant energy (Bouwer, 1992; Chapelle, 1993). However, once the available oxygen is depleted and anaerobic conditions dominate the interior regions of a contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate (denitrification), manganese (manganese reduction), Fe^{3+} (iron reduction), sulfate (sulfate reduction), and finally carbon dioxide (methanogenesis). Each successive redox reaction provides less energy to the system, and each step down in redox energy yield requires an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

ORPs measured in groundwater from within the BTEX and CAH plumes at Area A ranged from -265 millivolts (mV) to 15 mV in May 1997 (Figures 4.18 and 4.19), indicating favorable conditions for oxygen reduction, denitrification, manganese reduction, and Fe^{3+} reduction in the Area A USZ. Wiedemeier *et al.* (1996a) indicate that ORP measurements of less than -100 mV are considered conducive to CAH reductive dehalogenation. Outside of the BTEX and CAH plumes, ORP was as high as 465 mV. ORPs measured in groundwater from wells screened within the LSZ (2-2A, 2-4A, 2-148A, 2-149A, and 2-152A) ranged from 51.2 mV to 233.4 mV. Unlike the central



Notes

ORP = Oxidation Reduction Potential

 Range of ORP measured at Area A

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

FIGURE 4.18

SEQUENCE OF MICROBIALY MEDIATED REDOX PROCESSES

Area A
RNA TS
Tinker AFB, Oklahoma

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Denver, Colorado

Adapted from Stumm and Morgan, 1981.

portion of the dissolved BTEX and CAH plumes, the background USZ and all LSZ groundwater is not conducive to CAH reductive dehalogenation. Many authors have noted that field ORP data alone cannot be used to reliably predict the electron acceptors that may be operating at a site, because the platinum electrode probes are not sensitive to some redox couples (e.g., sulfate/sulfide) (Stumm and Morgan, 1981; Godsey, 1994; Lovley *et al.*, 1994).

4.3.3.2 pH

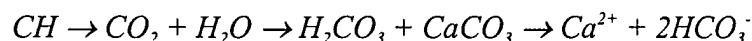
pH was measured while purging groundwater monitoring in May 1997 (Table 4.4). The pH of a solution is the negative logarithm of the hydrogen ion concentration $[H^+]$. Groundwater pH measured at the site ranged from 6.9 to 7.4 standard units, which is within the optimal range for most microbial populations that degrade organic matter.

4.3.3.3 Temperature

Groundwater temperature was measured while purging monitoring wells in May 1997 (Table 4.4). Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures generally resulting in higher growth rates. Temperatures in the USZ varied from 16.4 degrees Celsius ($^{\circ}C$) to 23.7 $^{\circ}C$. Wiedemeier *et al.* (1996a) report that biochemical processes are accelerated at groundwater temperatures greater than 20 $^{\circ}C$. Temperatures above 20 $^{\circ}C$ were measured at Area A wells 2-50B, 2-51B, 2-145B, 2-148B, 2-152B, 2-163B, 2-164B, and 70. There does not appear to be an evident pattern of high temperatures at the site.

4.3.3.4 Alkalinity and Carbon Dioxide Evolution

Carbon dioxide is produced during the biodegradation of petroleum hydrocarbons. In aquifers that have carbonate minerals as part of the matrix, carbon dioxide forms carbonic acid, which dissolves these minerals, increasing the alkalinity of the groundwater. Alkalinity is a measure of the ability of groundwater to buffer changes in pH. Changes in alkalinity are most pronounced during aerobic respiration, manganese reduction, denitrification, iron reduction, and sulfate reduction, and less pronounced during methanogenesis. In addition, Willey *et al.* (1975) show that short-chain aliphatic acid ions, which can be produced as intermediates during biodegradation of fuel hydrocarbons, can contribute to alkalinity in groundwater. The alkalinity-enhancing reactions follow the generalized stoichiometry:



The mass ratio of alkalinity produced during oxidation of BTEX can be calculated. The molar ratio of alkalinity [as calcium carbonate ($CaCO_3$)] produced during benzene oxidation via aerobic respiration, denitrification, iron reduction, and sulfate reduction is given by:



Therefore, six moles of CaCO_3 are produced during the metabolism of one mole of benzene. On a mass basis, the ratio of alkalinity to benzene is given by:

Molecular weights: Benzene $6(12)+6(1)=78$ gm

Alkalinity (as CaCO_3) $6(40)+6(12)+18(16)=600$ gm

Mass ratio of alkalinity to benzene = $600:78 = 7.69:1$

Therefore, 7.69 mg of CaCO_3 are produced during the metabolism of 1 mg of benzene. This means that for every 1 mg of alkalinity produced, 0.13 mg of BTEX are destroyed. Similar calculations can be made for toluene, ethylbenzene, and xylene. Results of alkalinity mass ratio calculations for all of the BTEX compounds during aerobic respiration, denitrification, iron reduction, and sulfate reduction are presented in Table 4.5. An increase in alkalinity (measured as CaCO_3) in an area with BTEX concentrations elevated above background conditions can be used to infer the amount of petroleum hydrocarbon destroyed through aerobic respiration, denitrification, manganese reduction, iron reduction, and sulfate reduction. Carbon dioxide produced in these aerobic and anaerobic reactions can be cycled in the methanogenic reactions to continue BTEX biodegradation through methanogenesis, but methanogenesis itself does not cause significant changes in alkalinity.

TABLE 4.5
MASS RATIO OF ALKALINITY (AS CaCO_3) PRODUCED TO BTEX
DEGRADED DURING AEROBIC RESPIRATION, DENITRIFICATION,
IRON (III) REDUCTION, AND SULFATE REDUCTION
AREA A RNA TS
TINKER AFB, OKLAHOMA

Alkalinity Production Reaction	Stoichiometric Mass Ratio of Alkalinity Produced to BTEX Degraded	Mass of Compound Degraded (mg) per unit mass of Alkalinity Produced (mg)
$\text{C}_6\text{H}_6 \rightarrow 6\text{CO}_2 \rightarrow 6\text{CaCO}_3$ <i>Benzene Oxidation</i>	600:78	0.13
$\text{C}_7\text{H}_8 \rightarrow 7\text{CO}_2 \rightarrow 7\text{CaCO}_3$ <i>Toluene Oxidation</i>	700:92	0.13
$\text{C}_8\text{H}_{10} \rightarrow 8\text{CO}_2 \rightarrow 8\text{CaCO}_3$ <i>Ethylbenzene Oxidation</i>	800:104	0.13
$\text{C}_8\text{H}_{10} \rightarrow 8\text{CO}_2 \rightarrow 8\text{CaCO}_3$ <i>Xylene Oxidation</i>	800:104	0.13

Free carbon dioxide was measured in groundwater samples collected in May 1997 (Table 4.4). Carbon dioxide evolution, as indicated by above-background concentrations

in wells 2-3, 2-50B, 2-51B, VEP-9, VEP-10, VEP-11, and VEP-12 may be occurring as a result of biodegradation processes. A direct estimate of the aquifer assimilative capacity based on carbon dioxide evolution is not possible because of the complex carbonate/bicarbonate balance. However, total alkalinity (as CaCO_3) also was measured in groundwater samples collected in May 1997 (Table 4.4), and it can be used in certain situations to estimate the assimilative capacity of groundwater (Wiedemeier *et al.*, 1995).

The highest alkalinity values were measured within and immediately downgradient from the source area, where dissolved BTEX concentrations also were substantially elevated. This is expected because the microbially mediated reactions causing biodegradation of fuel hydrocarbons produce carbon dioxide (Table 4.1). The magnitude of the detected alkalinity values, and the lack of pH values less than 7 standard units within the contaminant plume, indicate that alkalinity in site groundwater helps to buffer potential changes in pH caused by biologically mediated BTEX oxidation reactions. The neutral pH values also suggest that aerobic and/or anaerobic biodegradation processes are occurring without detrimental shifts in pH.

The background alkalinity in May 1997 ranged from 395 mg/L to 565 mg/L and averaged 465 mg/L based on data from wells 2-145B, 2-146B, 2-152B, 2-166B, and 2-173B. The maximum alkalinity value measured within the dissolved BTEX plume was 678 mg/L in May 1997. Using these values and the alkalinity reaction stoichiometry described in Table 4.1, the shallow groundwater had the capacity to assimilate approximately 28 mg/L (27,700 $\mu\text{g/L}$) of total BTEX in May 1997.

4.3.3.5 Volatile Fatty Acids and Phenols

Volatile fatty acids (VFAs) are produced when the bacterial cell has obtained the required energy from metabolism of a carbon source (i.e., BTEX, CAHs, or naturally occurring organic carbon). After VFAs are secreted from the bacterial cell, they volatilize fairly rapidly; therefore detection of VFAs in groundwater is a strong indication of recent metabolic activity and possibly biodegradation of BTEX or CAHs. The standard method of VFA analysis performed by USEPA researchers is a gas chromatography/mass spectrometry method in which groundwater samples are compared to a standard mixture containing 58 phenols, aromatic acids, and aliphatic acids.

Samples for VFA analysis were collected from four wells at Area A (wells 2-3, 2-51B, 2-163B, and VEP-9). Each of these wells contained elevated BTEX and CAH concentrations. Analysis results are presented in Table 4.6. Each of the 58 compounds in the standard were detected in the samples, although several of the compounds were not detected above the quantitation limit of 3 $\mu\text{g/L}$. The relative profusion of VFAs indicates that oxidation of organic matter is occurring.

4.3.3.6 Ammonia

The presence of ammonia in groundwater can result from either nitrate reduction (facilitated by microbes) or fixing of atmospheric nitrogen (also a microbial process). Because nitrate appears to be widespread in groundwater within the USZ (Figure 4.14), and because fixation of atmospheric nitrogen only occurs under reducing conditions [ORP less than -500 mV (Stumm and Morgan, 1981)], ammonia production via nitrate reduction would probably be more common than by fixation of atmospheric nitrogen. In

TABLE 4.6
CONCENTRATIONS OF PHENOLS, ALIPHATIC ACIDS, AND
AROMATIC ACIDS IN GROUNDWATER
APRIL/MAY 1997
AREA A RNA TS
TINKER AFB, OKLAHOMA

Compound	2-3	2-51B	2-163B	VEP-9
	(concentrations in µg/L) ^{a/}			
propanoic acid	3	3	< 3 ^{b/}	< 3
butyric acid	4	< 3	< 3	< 3
hexanoic acid	3	5	4	9
octanoic acid	< 3	3	< 3	< 3
benzoic acid	23	11	5	11
decanoic acid	< 3	< 3	< 3	< 3
2-methylpropanoic acid	4	< 3	< 3	< 3
trimethylacetic acid	< 3	< 3	< 3	< 3
2-methylbutyric acid	3	< 3	< 3	< 3
3-methylbutyric acid	12	< 3	< 3	< 3
3,3-dimethylbutyric acid	4	< 3	< 3	< 3
pentanoic acid	< 3	< 3	< 3	< 3
2,3-dimethylbutyric acid	< 3	< 3	< 3	< 3
2-ethylbutyric acid	< 3	ND ^{c/}	< 3	< 3
2-methylpentanoic acid	< 3	< 3	< 3	< 3
3-methylpentanoic acid	4	< 3	< 3	< 3
4-methylpentanoic acid	ND	< 3	< 3	< 3
2-methylhexanoic acid	< 3	< 3	ND	< 3
phenol	15	5	< 3	16
cyclopentanecarboxylic acid	18	< 3	ND	< 3
5-methylhexanoic acid	< 3	ND	< 3	ND
o-cresol	9	< 3	< 3	ND
2-ethylhexanoic acid	32	47	28	64
heptanoic acid	< 3	< 3	< 3	< 3
m-cresol	5	< 3	< 3	< 3
p-cresol	8	< 3	ND	ND
1-cyclopentene-1-carboxylic acid	< 3	< 3	ND	ND
o-ethylphenol	7	< 3	ND	< 3
cyclopentaneacetic acid	< 3	< 3	< 3	ND
2,6-dimethylphenol	12	< 3	ND	< 3
2,5-dimethylphenol	9	< 3	ND	ND
cyclohexanecarboxylic acid	7	< 3	< 3	< 3
3-cyclohexene-1-carboxylic acid	< 3	< 3	ND	ND
2,4-dimethylphenol	6	ND	ND	< 3
3,5-dimethylphenol & m-ethylphenol	6	3	ND	< 3
2,3-dimethylphenol	4	< 3	ND	ND
p-ethylphenol	< 3	ND	ND	ND
3,4-dimethylphenol	< 3	< 3	ND	ND
m-methylbenzoic acid	27	< 3	ND	< 3
1-cyclohexene-1-carboxylic acid	ND	< 3	ND	ND
cyclohexaneacetic acid	< 3	< 3	ND	ND
2-phenylpropanoic acid	< 3	< 3	ND	ND
o-methylbenzoic acid	9	< 3	ND	< 3
phenylacetic acid	3	< 3	< 3	7
m-tolyacetic acid	7	3	ND	11
o-tolyacetic acid	< 3	< 3	< 3	< 3
2,6-dimethylbenzoic acid	< 3	< 3	< 3	< 3

TABLE 4.6 (Concluded)
CONCENTRATIONS OF PHENOLS, ALIPHATIC ACIDS, AND
AROMATIC ACIDS IN GROUNDWATER
APRIL/MAY 1997
AREA A RNA TS
TINKER AFB, OKLAHOMA

Compound	2-3	2-51B	2-163B	VEP-9
	(concentrations in µg/L) ^{a/}			
p-tolyacetic acid	6	8	ND	12
p-methylbenzoic acid	7	< 3	ND	< 3
3-phenylpropanoic acid	< 3	ND	3	ND
2,5-dimethylbenzoic acid	5	< 3	ND	6
2,4-dimethylbenzoic acid	9	33	ND	18
3,5-dimethylbenzoic acid	4	ND	ND	< 3
2,3-dimethylbenzoic acid	4	< 3	ND	< 3
4-ethylbenzoic acid	3	< 3	ND	< 3
2,4,6-trimethylbenzoic acid	9	53	< 3	25
3,4-dimethylbenzoic acid	10	< 3	ND	10
2,4,5-trimethylbenzoic acid	4	12	ND	< 3

^{a/} µg/L = micrograms per liter.

^{b/} <3 = detected at concentrations less than established reporting limit.

^{c/} ND = not detected.

either case, the presence of ammonia in groundwater is a strong indication of microbial activity.

Ammonia concentrations measured in groundwater samples collected in May 1997 are summarized in Table 4.4. Ammonia was detected only in one of the samples analyzed. The scarcity of ammonia detections in USZ groundwater suggests that microbial activity connected with nitrate reduction may be limited.

4.3.4 Expressed Assimilative Capacity

Degradation of BTEX (and possibly less chlorinated CAH) compounds is likely occurring primarily through the microbially mediated processes of oxygen reduction, denitrification, sulfate reduction, and methanogenesis. The expressed BTEX assimilative capacity of groundwater at the site was at least 40,000 µg/L in May 1997 (Table 4.7). In comparison, an expressed assimilative capacity of 27,700 mg/L was calculated using alkalinity data for May 1997.

TABLE 4.7
EXPRESSED ASSIMILATIVE CAPACITY OF USZ GROUNDWATER
AREA A RNA TS
TINKER AFB, OKLAHOMA

Electron Acceptor/Process	Expressed BTEX Assimilative Capacity (µg/L) (May 1997)
Dissolved Oxygen/Oxygen Reduction	670
Nitrate/Denitrification	3,500
Ferric Iron/Iron Reduction	150
Sulfate/Sulfate Reduction	29,600
Carbon Dioxide/Methanogenesis	6,090
Expressed Assimilative Capacity	40,000
Expressed Assimilative Capacity from Alkalinity Measurements	27,700
Highest Observed Total BTEX Concentration	42,700

A closed system with two liters of water can be used to help visualize the physical meaning of assimilative capacity. Assume that the first liter contains no fuel hydrocarbons, but it contains fuel-degrading microorganisms and has an assimilative capacity of exactly "x" µg of fuel hydrocarbons. The second liter has no assimilative capacity; however, it contains fuel hydrocarbons. As long as these two liters of water are kept separate, biodegradation of the fuel hydrocarbons will not occur. If these two liters are combined in a closed system, biodegradation will commence and continue until the fuel hydrocarbons are depleted, the electron acceptors are depleted, or the environment

becomes acutely toxic to the fuel-degrading microorganisms. Assuming a non-lethal environment, if fewer than "x" µg of fuel hydrocarbons were in the second liter, all of the fuel hydrocarbons will eventually degrade given a sufficient time; likewise, if greater than "x" µg of fuel hydrocarbons were in the second liter of water, only "x" µg of fuel hydrocarbons would ultimately degrade.

The groundwater beneath the site is an open system that continually receives additional electron receptors from flow through the aquifer and infiltration of precipitation. This means that the assimilative capacity is not fixed as it is in a closed system, and therefore cannot be compared directly to contaminant concentrations in the groundwater. Rather, the expressed assimilative capacity of groundwater is intended to serve as a qualitative tool. The actual fate of BTEX in groundwater and the potential impact on receptors are dependent on the relationship between the kinetics of biodegradation and the solute transport velocity (Chapelle, 1994).

4.3.5 Additional Evidence of CAH Reductive Dehalogenation

The CAH plume in Area A groundwater appears to be degrading, primarily by reductive dehalogenation. The anaerobic nature of the groundwater throughout most of the CAH plume area, combined with evidence that BTEX biodegradation is occurring, indicates that type 1 behavior is prevalent (see Section 4.2.4).

4.3.5.1 Presence of Daughter Products

The presence of daughter products that were not used in Base operations, particularly *cis*-1,2-DCE, also provides strong evidence that TCE is being reductively dechlorinated. A type 1 CAH plume pattern with reductive dehalogenation would have TCE (and or PCE) concentrations highest in the source area, with elevated DCE concentrations (consisting mostly of *cis*-1,2-DCE) in and just downgradient from the source area. Vinyl chloride concentrations could be present along the entire plume length, with the highest VC concentrations likely to be found near the downgradient end of the CAH plume. If VC is being reductively dechlorinated, dissolved ethene will also be present downgradient from the source area, in the vicinity of the highest concentrations of VC.

The distribution of CAHs downgradient from the source area in two series of USZ groundwater monitoring wells are shown on Figure 4.20 (wells 2-3, 2-50B, and VEP-9) and Figure 4.21 (wells 2-3, VEP-10, and VEP-11). The CAH distribution at Area A along the 2-3, 2-50B, and VEP-9 well series mimics this theoretical pattern with decreasing concentrations of TCE and increasing concentrations of *cis*-1,2-DCE, VC, ethene, and ethane. Along the 2-3, VEP-12, VEP-10, and VEP11 well series, a type 1 pattern in CAH concentrations is less apparent. However, the magnitude of decrease in TCE concentration along this flowpath and the presence of VC, ethene, and ethane, is significant.

Progressive transformation of CAHs to their daughter products (e.g., TCE to *cis*-1,2-DCE) as the contamination migrates away from the source area can be evaluated by computing the ratio of daughter products to parent compounds at different distances from the source area. The ratios of *cis*-1,2-DCE to TCE in groundwater samples from wells located along the plume axis (2-3, 2-50B, and VEP-9) during the May 1997 sampling

FIGURE 4.20
 CAHS VS DISTANCE FROM SOURCE AREA
 AT GROUNDWATER MONITORING WELLS 2-3, 2-50B, and VEP-9
 AREA A RNA TS
 TINKER AFB, OKLAHOMA

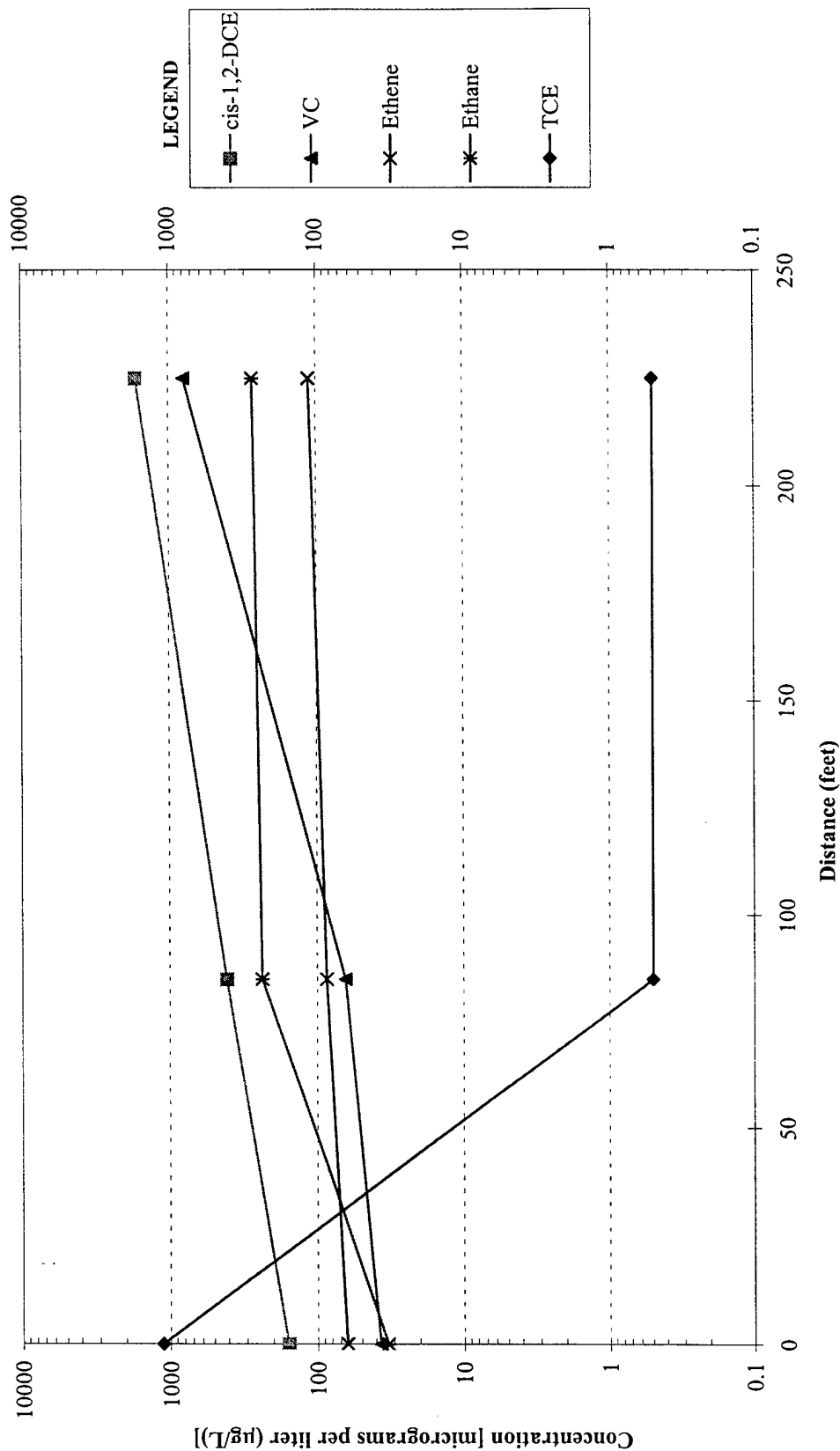
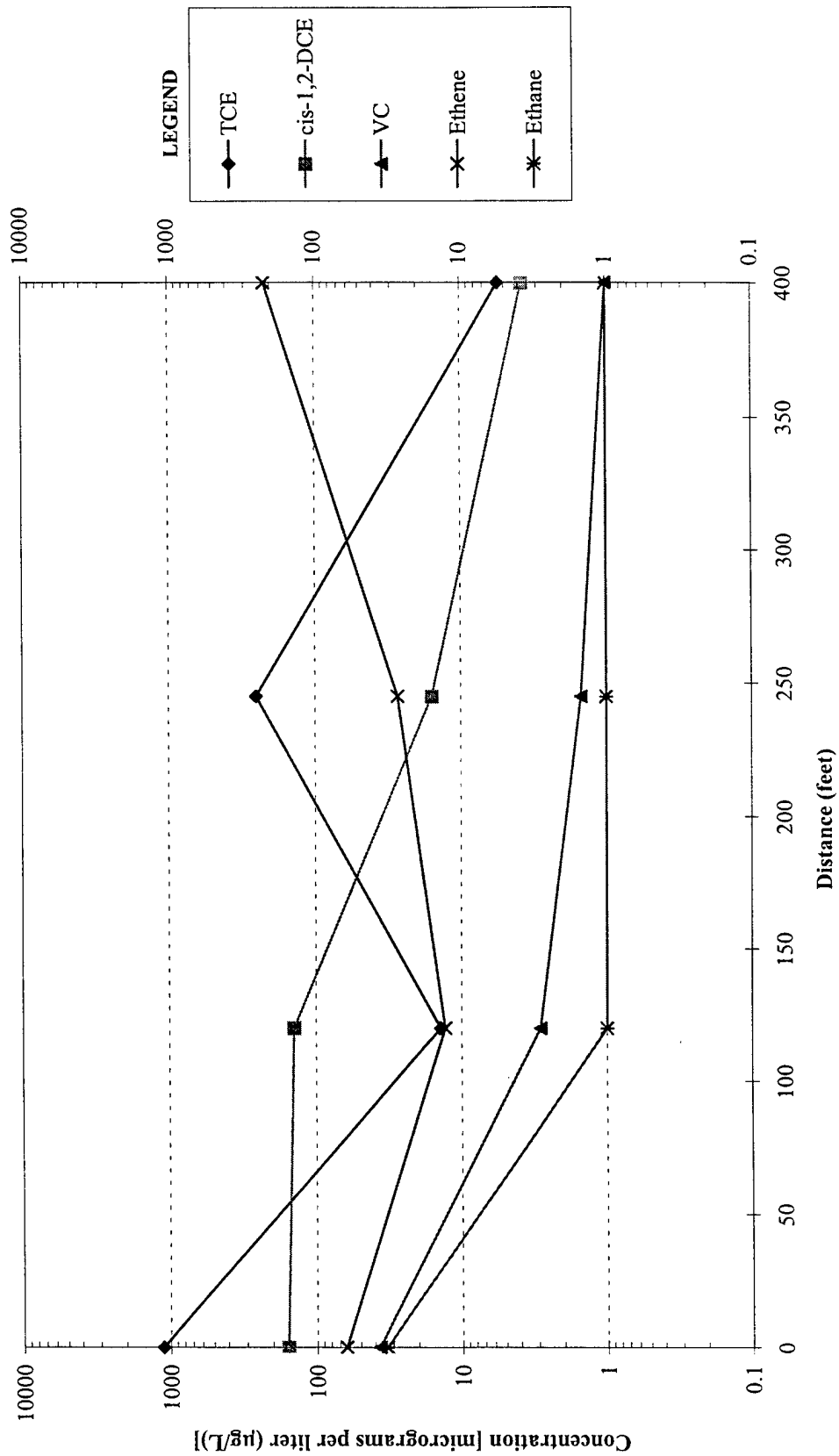


FIGURE 4.21
CAHS VS DISTANCE FROM SOURCE AREA
GROUNDWATER MONITORING WELLS 2-3, VEP-12, VEP-10, and VEP-11
AREA A RNA TS
TINKER AFB, OKLAHOMA



event are shown on Figure 4.22. TCE was not detected in groundwater collected at monitoring wells 2-50B and VEP-9; however, for the purposes of the plot, a low value (0.5 µg/L TCE) was used to show the marked decrease in the ratio along this flowpath. The ratio decrease of TCE to *cis*-1,2-DCE directly downgradient from the source area is indicative of reductive dehalogenation in this region of the CAH plume. Reductive dehalogenation along the flowpath from monitoring well 2-3 to VEP-9 is further supported by the pattern of extremely low redox potentials measured at these wells (Figure 4.18).

The ratio patterns of *cis*-1,2-DCE /VC; VC/ethene; and ethene/ethane also follow the concept of the typical CAH plume pattern (Figure 4.22). The decrease of *cis*-1,2-DCE/VC downgradient from the source area indicates that VC concentrations are increasing relative to *cis*-1,2-DCE. The VC/ethene ratio similarly increases as a result of the elevated VC concentrations. Ethene is the end product of reductive dehalogenation reactions, and ethane in turn is a degradation product of ethene (Section 4.2.4). Based on this relation, ethane is being produced downgradient from the source area through reductive dehalogenation of VC (Figure 4.22).

The ratios of parent to daughter products during the May 1997 sampling event are shown along a flow path originating at the source area and traveling downgradient along monitoring wells 2.3, VEP-12, VEP-10, and VEP-11 in Figure 4.23. The TCE/*cis*-1,2-DCE ratio decreases from source area well 2-3 to downgradient well VEP-12, indicating that reductive transformation of TCE to *cis*-1,2-DCE is prevalent just downgradient from the source area. However, the ratios for wells VEP-10 and VEP-11 were relatively low indicating that reductive dehalogenation is not a significant process in this portion of the plume. Groundwater data collected in May 1997 indicate abnormally high TCE concentrations at downgradient monitoring well VEP-10 suggesting a preferential flow path between 2-3 and VEP-10. VEP-12 likely is positioned outside of this preferential flow path in an area where more anaerobic conditions promote reductive dehalogenation of TCE.

4.3.5.2 Chloride as an Indicator of Dehalogenation

Chlorine is removed from CAHs during reductive dehalogenation and enters solution. Therefore, chloride concentrations in groundwater should increase above background levels in areas where reductive dehalogenation is taking place.

Chloride concentrations measured in May 1997 are presented in Table 4.4. Background chloride concentrations in groundwater ranged from 18 to 938 mg/L and averaged 234 mg/L based on data from wells 2-146B, 2-152B, 2-165B, 2-173B, 2-264B and 2-265B. Each of these wells is located outside of the area where CAHs have historically been detected.

The chloride concentrations within the CAH plume ranged from 15.9 mg/L to 931 mg/L, and averaged 344 mg/L. Because of the variability in chloride concentrations in the background and throughout the plume, it is not possible to determine whether the reductive dehalogenation process is producing excess chloride in the plume area.

FIGURE 4.22
 RATIO OF PARENT TO DAUGHTER PRODUCTS VS DISTANCE FROM SOURCE AREA AT
 GROUNDWATER MONITORING WELLS 2-3, 2-50B, AND VEP-9
 AREA A RNA TS
 TINKER AFB, OKLAHOMA

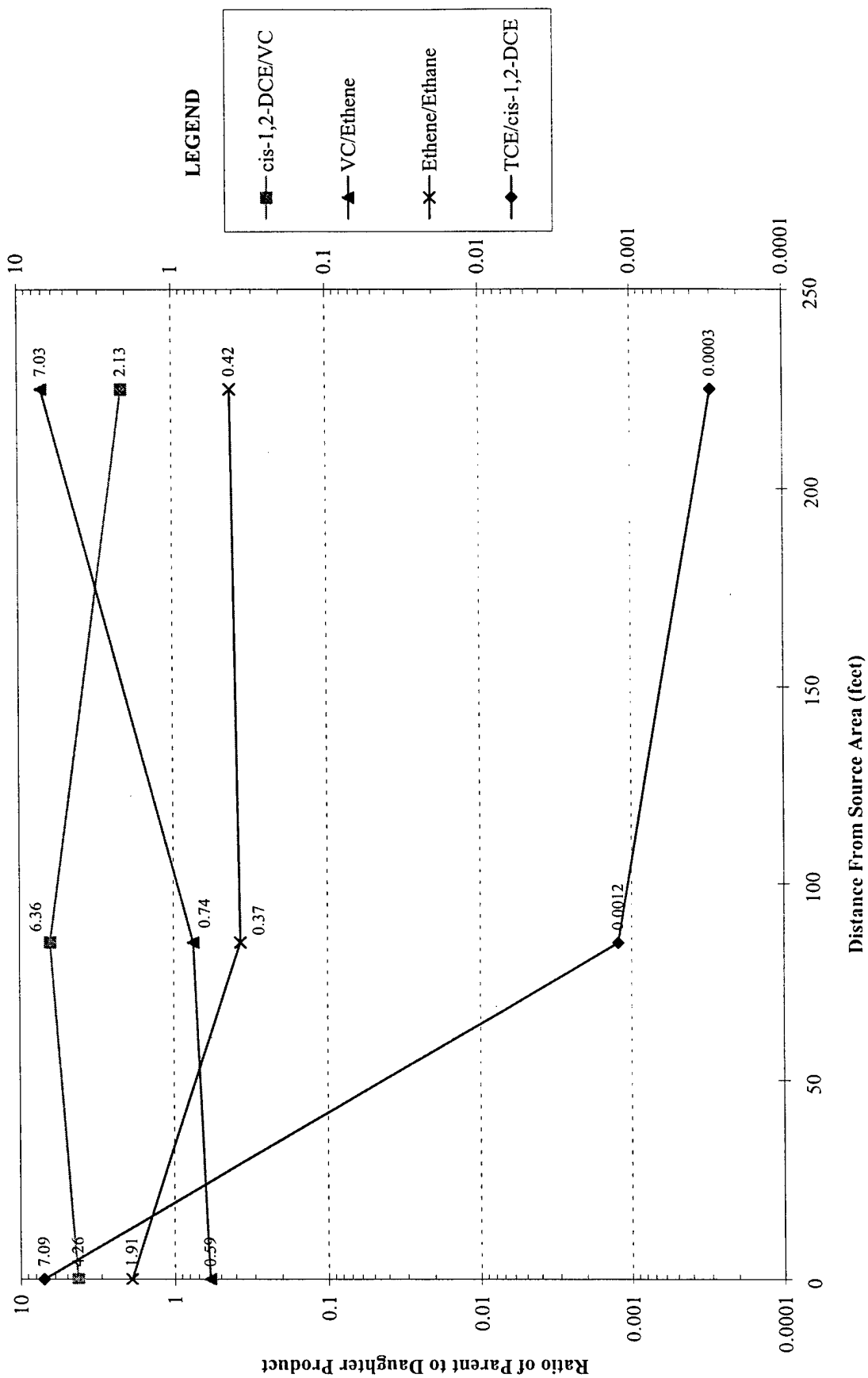
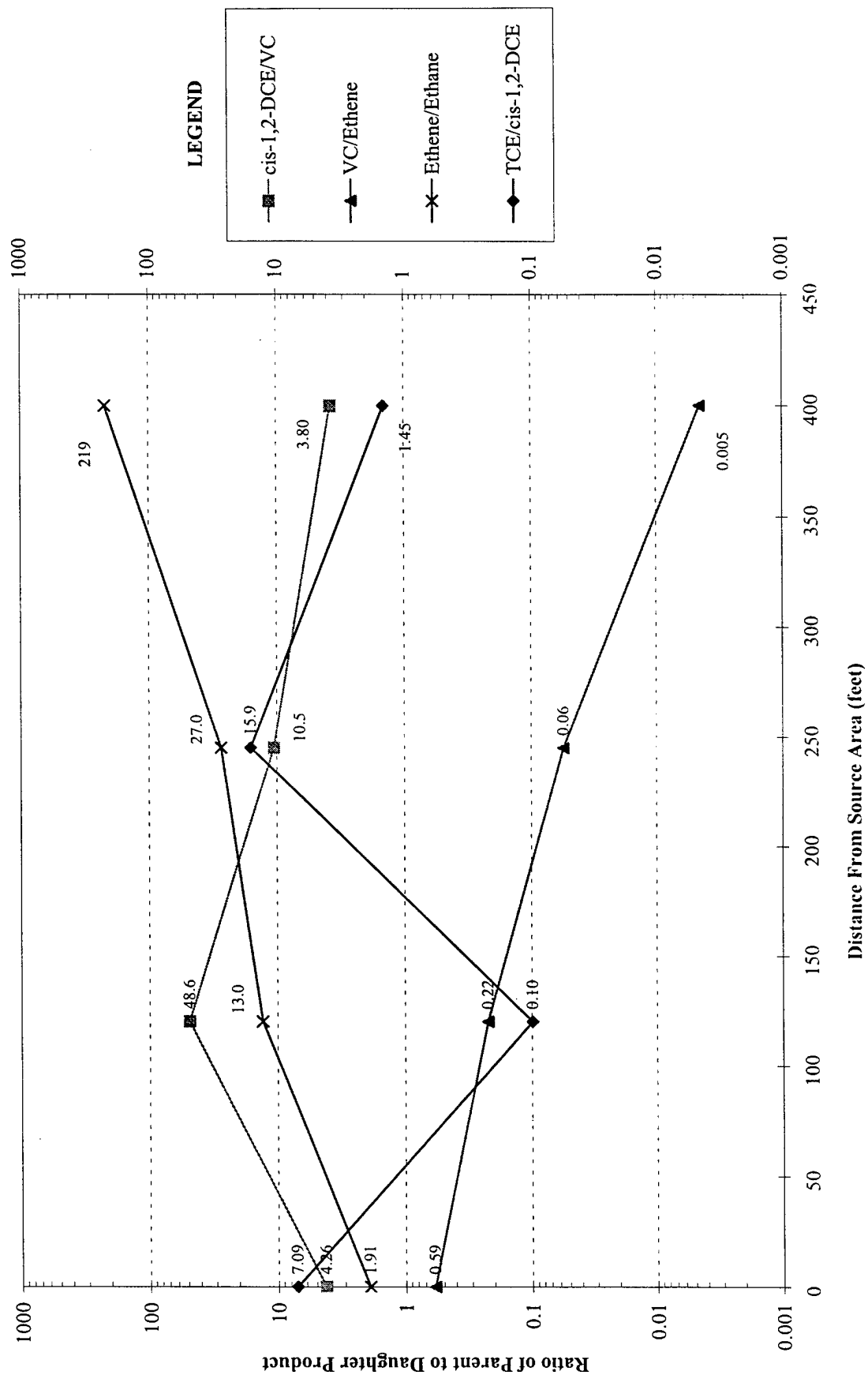


FIGURE 4.23
RATIO OF PARENT TO DAUGHTER PRODUCTS VS DISTANCE FROM SOURCE AREA AT
GROUNDWATER MONITORING WELLS 2-3, VEP-12, VEP-10, and VEP-11
AREA A RNA TS
TINKER AFB, OKLAHOMA



4.3.5.3 Screening Table for CAH Degradation

Wiedemeier *et al.* (1996a) present a worksheet to allow an initial assessment of the prominence of the natural attenuation of CAHs at a site. The worksheet, including the point values determined for Area A, are included as Table 4.8.

The interpretation of points awarded during the screening process outlined in Table 4.8 is shown in Table 4.9. The score for Area A computed using Table 4.8 is 24, indicating that evidence for biodegradation of chlorinated organics is strong.

TABLE 4.8
ANALYTICAL PARAMETERS AND WEIGHTING FOR PRELIMINARY
SCREENING
AREA A RNA TS
TINKER AFB, OKLAHOMA

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value	Area A Score
Oxygen	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	3	3
	>1 mg/L	VC may be oxidized aerobically	-3	
Nitrate	<1 mg/L	At higher concentrations may compete with reductive pathway	2	2
Iron II	>1 mg/L	Reductive pathway possible	3	1
Sulfate	<20 mg/L	At higher concentrations may compete with reductive pathway	2	2
Sulfide	>1 mg/L	Reductive pathway possible	3	--
Methane	<0.5 mg/L	VC oxidizes	0	3
	>0.5 mg/L	Ultimate reductive daughter product, VC accumulates	3	

TABLE 4.8 (Continued)
ANALYTICAL PARAMETERS AND WEIGHTING FOR PRELIMINARY
SCREENING
AREA A RNA TS
TINKER AFB, OKLAHOMA

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value	Area A Score
Oxidation Reduction Potential (ORP)	<50 millivolts (mV)	Reductive pathway possible	1	2
	<-100mV	Reductive pathway likely	2	
pH	5 < pH < 9	Optimal range for reductive pathway	0	0
	5 > pH > 9	Outside optimal range for reductive pathway	-2	
TOC	> 20 mg/L	Carbon and energy source; drives dehalogenation	2	0
Temperature	> 20°C	At T >20°C biochemical process is accelerated	1	0
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	1	0
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	1	0
Chloride	>2x background	Daughter product of organic chlorine	2	0
Hydrogen	>1 nM/L	Reductive pathway possible, VC may accumulate	3	--
	<1 nM/L	VC oxidized	0	
Volatile Fatty Acids	> 0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	2	2
BTEX	> 0.1 mg/L	Carbon and energy source; drives dehalogenation	2	2
PCE		Material released	0	0
TCE		Material released	0	0
		Daughter product of PCE	2 ^d	

TABLE 4.8 (Continued)
ANALYTICAL PARAMETERS AND WEIGHTING FOR PRELIMINARY
SCREENING
AREA A RNA TS
TINKER AFB, OKLAHOMA

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value	Area A Score
1,2-DCE		Material released Daughter product of TCE. If <i>cis</i> is greater than 80% of total DCE it is likely a daughter product of TCE	0 2 ^d	2
VC		Material released Daughter product of DCE	0 2 ^d	2
Ethene/Ethane	>0.01mg/L >0.1 mg/L	Daughter product of VC/ethene	2 3	3
Chloroethane		Daughter product of VC under reducing conditions	2	--
1,1,1-Trichloroethane		Material released	0	--
1,2-Dichlorobenzene		Material released	0	--
1,3-Dichlorobenzene		Material released	0	--
1,4-Dichlorobenzene		Material released	0	--
Chlorobenzene		Material released or daughter product of dichlorobenzene	2 ^d	--
1,1-DCE		Daughter product of TCE or chemical reaction of 1,1,1-TCA	2 ^d	--
Total				24

TABLE 4.9
INTERPRETATION OF POINTS AWARDED DURING NATURAL
ATTENUATION SCREENING
AREA A RNA TS
TINKER AFB, OKLAHOMA

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

4.3.6 Approximation of Biodegradation Rates

Estimation of biodegradation rate constants is necessary to accurately simulate the fate and transport of contaminants dissolved in groundwater. Several methodologies, including first- and second-order approximations, may be used to estimate the rate of biodegradation of hydrocarbon compounds. Use of the first-order approximation can be appropriate to estimate biodegradation rates for BTEX or for chlorinated compounds where the rate of biodegradation is assumed to be controlled solely by the concentration of the contaminant. However, the use of a first-order approximation may not be appropriate when more than one substrate is limiting microbial degradation rates or when microbial mass is increasing or decreasing. In such cases, a second- or higher-order approximation may provide a better estimate of biodegradation rates. The preferable method of contaminant biodegradation rate-constant determination is by use of field data.

As with a large number of processes, the change in solute concentration in the groundwater over time often can be described by the following ordinary differential equation:

$$dC/dt = -kC$$

where: C = concentration at time t [M/L³]
 k = overall attenuation rate (first-order rate constant) [1/T]

Solving this differential equation yields:

$$C = C_0 e^{-kt}$$

An overall first-order attenuation rate groups all processes acting to reduce contaminant concentrations and includes advection, dispersion, dilution from recharge, sorption, and biodegradation. To determine the portion of the overall attenuation that can

be attributed to biodegradation, these effects must be accounted for, and subtracted from the total attenuation rate. Three methods for determining first-order biodegradation rates of contaminants at the field scale are described below. The first method involves the use of a conservative tracer to compute a decay rate. The second method, derived by Buscheck and Alcantar (1995), is valid only for steady-state plumes. The third method, derived by Moutoux *et al.* (1996), calculates a first-order biodegradation rate for total chlorinated ethenes.

In the conservative tracer technique, a tracer that is not susceptible to biodegradation, but is similarly susceptible to the other non-destructive attenuation mechanisms as the target compound is used to "correct" target compound concentrations at downgradient locations. TMB is a commonly used conservative tracer for anaerobic plumes, because it is relatively recalcitrant under anaerobic conditions yet reacts similarly to non-destructive attenuation mechanisms as many target compounds (e.g., BTEX, CAHs) (Wiedemeier *et al.*, 1996a). Substituting the TMB-corrected concentration at a downgradient point for C in the equation, and the measured concentration at an upgradient point for C_0 , this relationship becomes:

$$C_{\text{corr}} = C_{0, \text{measured}} e^{-\lambda t}$$

where: C_{corr} = TMB-corrected contaminant concentration at time t at downgradient point

$C_{0, \text{measured}}$ = measured contaminant concentration at upgradient point

λ = first-order biological decay rate (first-order rate constant) $[1/T]$

Buscheck and Alcantar (1995) derive a relationship that allows calculation of first-order biodegradation rate constants for steady-state plumes. This method involves coupling the regression of contaminant concentration (plotted on a logarithmic scale) versus distance downgradient (plotted on a linear scale) to an analytical solution for one-dimensional, steady-state, contaminant transport that includes advection, dispersion, sorption, and biodegradation (Bear, 1979). For an expanding plume, this first-order approximation can be viewed as an upper bound on the biodegradation rate. Use of this method results in an overestimation of the rate of biodegradation because a typical expanding plume exhibits decreasing source area concentrations, increasing downgradient concentrations, or both. Over time, these changes result in a decreasing slope on a log-linear plot, and consequently a decreasing biodegradation rate.

A third method for estimating dehalogenation rates of CAHs is described by Moutoux *et al.* (1996). This method can be used to estimate the theoretical contaminant concentration resulting from reductive dehalogenation alone for every point along a flow path on the basis of the measured contaminant concentration at the point of plume origin and the contaminant/tracer ratios between consecutive points along the flow path. This series of points can then be used to estimate a first-order rate of biodegradation. The carbon core of the CAH compounds, which is subject to the same non-destructive attenuation mechanisms that act on the larger chlorinated molecule, but is unaffected by biologically mediated reductive dehalogenation, is used as the tracer. This method provides a total dehalogenation rate for all dehalogenation steps. All rates (including the

rapid TCE to DCE rate and the slow VC to ethene rate) are averaged in the Moutoux *et al.* (1996) method. Because abiotic reactions and reactions that involve CAHs in the role of an electron donor are not included in this rate, the rate should be considered a lower bound on the destructive attenuation rate. In fact, if CAH compounds are used as electron donors, this method produces an even more conservative rate.

Although a first-order rate assumption may provide a reasonable approximation of how CAH compounds are degrading in groundwater systems, this approach may not provide the best approximation of how CAH compounds are dechlorinated in the presence of an electron donor such as BTEX. These reactions may be more appropriately approximated by a second-order rate expression. Unfortunately, currently available fate and transport models are incapable of using second-order rates.

The first-order methods described above were used to estimate first-order biodegradation rate constants for total BTEX, benzene, TCE, *cis*-1,2-DCE, VC and total chlorinated ethenes at Area A. The decay rates are summarized in Table 4.10. The decay rate calculations are summarized in Appendix D.

4.4 SUMMARY

Several lines of chemical and geochemical evidence indicate that dissolved BTEX and CAHs at Area A are undergoing biodegradation. The evidence supporting the occurrence of biodegradation is summarized below:

- Data indicate that BTEX and CAH concentrations in groundwater are declining over time;
- Dissolved BTEX concentrations are sufficient to provide a source of electron donors and facilitate microbial reactions that drive bioremediation of site CAH compounds;
- The presence and distribution of *cis*-1,2-DCE, VC, ethene, and ethane are direct indications that CAHs are being reductively dehalogenated.
- Low DO concentrations conducive to CAH reductive dehalogenation are present throughout the CAH contaminant plume;
- ORP data indicate that the groundwater is sufficiently reducing to support the occurrence of aerobic respiration as well as anaerobic processes;
- The presence of Fe^{2+} and methane within the contaminant plume indicates conditions conducive to the reductive dehalogenation of CAHs;
- The low nitrate and sulfate concentrations throughout the contaminant plume indicate that these anions have been depleted and that use of CAHs as electron acceptors will not be inhibited due to preferential use of these anions as alternate electron acceptors; and
- The presence of VFAs in groundwater further supports the observation that microbial biodegradation of hydrocarbons is occurring in Area A groundwater.

TABLE 4.10
DECAY RATE SUMMARY
AREA A RNA TS
TINKER AIR FORCE BASE, OKLAHOMA

CONTAMINANT	METHOD	FLOW PATH	RATE (1/yr)	Half-Life (yr)
Total BTEX	Buscheck and Alcantar	2-3, VEP-12, VEP-10, VEP-11	0.36	1.91
Total BTEX	Conservative Tracer	2-3, VEP-12, VEP-10, VEP-11	0.09	8.08
Total BTEX	Conservative Tracer	2-50B, VEP-9	0.11	6.42
Benzene	Buscheck and Alcantar	2-3, VEP-12, VEP-10, VEP-11	0.43	1.60
Benzene	Conservative Tracer	2-3, VEP-12, VEP-10, VEP-11	0.20	3.41
Benzene	Conservative Tracer	2-50B, VEP-9	0.12	5.64
TCE	Buscheck and Alcantar	2-3, VEP-12, VEP-10, VEP-11	0.63	1.09
TCE	Buscheck and Alcantar	2-3, VEP-9	2.65	0.26
TCE	Conservative Tracer	2-3, VEP-10, VEP-11	0.27	2.53
<i>cis</i> -1,2-DCE	Buscheck and Alcantar	2-3, VEP-12, VEP-10, VEP-11	0.51	1.36
VC	Buscheck and Alcantar	2-3, VEP-12, VEP-10, VEP-11	0.45	1.55
Total Chlorinated Ethenes	Buscheck and Alcantar	2-3, VEP-10, VEP-11	0.21	3.32
Total Chlorinated Ethenes	Moutoux	2-3, VEP-10, VEP-11	0.04	15.8

SECTION 5

GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL

Computer simulations of USZ groundwater flow and the transport of dissolved TCE are used to evaluate migration and natural attenuation of TCE dissolved in groundwater at Tinker AFB Area A. Both BTEX and CAHs were present in groundwater at concentrations exceeding regulatory guidelines in May 1997. Biodegradation of BTEX is evident, and remedial efforts at the site are specifically designed to address BTEX contamination. The biodegradation of TCE at the site is more complex and less well understood. Therefore, the modeling effort was used to assess TCE fate and transport at Area A. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes.

The VEP remediation system started operation at Area A in June 1997, after the May 1997 sampling event, and the impacts of the VEP remediation system are too complex to accurately model. Therefore, predictive model runs are intended as a screening level assessment to analyze how the TCE contaminant plume would behave in the absence of engineered remediation. This allows for a comparative analysis of the effectiveness of the remediation system, which is described in Section 6.

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

The computer programs "A Modular Three-Dimensional Finite-Difference Groundwater Flow Model" (MODFLOW) (McDonald and Harbaugh, 1988) and MT3D (Zheng, 1990) were used to evaluate dissolved TCE at the site. MODFLOW was used to compute hydraulic heads and groundwater fluxes, and MT3D was used to compute solute transport of dissolved TCE due to advection, dispersion, adsorption, and biodegradation. The pre- and post-processors contained in Visual MODFLOW, Version 2.50 (Waterloo Hydrogeologic Software, 1997) were used to build a site-specific model for Tinker AFB Area A. The graphic user interface facilitated model development and analysis as well as presentation of model results.

MODFLOW is a three-dimensional groundwater flow simulation computer program published by the U.S. Geological Survey (McDonald and Harbaugh, 1988) and incorporated into Visual MODFLOW. MODFLOW uses implicit solution techniques to solve the transient groundwater flow equation for hydraulic head (McDonald and Harbaugh, 1988). The solution techniques are based on a one-, two-, or three-dimensional, block-centered, finite difference grid, which is superimposed on the model area. The aquifer properties can be heterogeneous and anisotropic, and aquifer layers can be simulated as confined, unconfined, or a combination of both (McDonald and

Harbaugh, 1988). Results of a MODFLOW simulation include the distribution of hydraulic head within each model layer as well as groundwater fluxes through the model area.

The MT3D code incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. The MODFLOW-computed heads and fluxes are used by MT3D to compute groundwater flow velocity and thus solute transport. MT3D solution routines are based on the Method of Characteristics (MOC) solute transport model [e.g., as developed by Konikow and Bredehoeft (1978) for the US Geological Survey (USGS) two-dimensional (2-D) MOC model code]. The MOC model was modified by Zheng (1990) to allow three-dimensional (3-D) solutions, and to allow use of a modified MOC that reduces numerical dispersion. The modified model is called MT3D and is incorporated into Visual MODFLOW.

5.2 MODEL OBJECTIVES

The modeling effort had four primary objectives: 1) provide an analysis of natural attenuation in controlling dissolved TCE at the site by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) predict the potential future extent and concentrations of the dissolved TCE contaminant plume in the absence of engineered remediation; 3) assess the potential for downgradient receptors to be exposed to contaminants (TCE) at concentrations above regulatory levels of concern; and 4) provide a comparison to assess the effectiveness of the VEP remediation system.

5.3 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

On the basis of the data presented in Section 3, the upper saturated zone was conceptualized and modeled as a heterogeneous, unconfined aquifer. Hydrogeologic profiles of the site (Figures 3.6 and 3.7) show the major water-bearing unit of the USZ is a fine-grained sand and the CAH plume is migrating primarily through the fine-grained sand of the USZ. The aquitard that separates the USZ from the LSZ acts as a permeability barrier to vertical transport, although TCE was detected beneath the source area in LSZ wells 2-2A and 2-4A (Table 4.3). Depth to groundwater within the USZ is approximately 10 to 20 feet bgs. The configuration of groundwater elevation isopleths on Figure 3.8 indicates that groundwater flows west at a horizontal hydraulic gradient ranging from 0.007 to 0.03 ft/ft and averaging approximately 0.015 ft/ft. These data are generally consistent with the data collected by IT in January 1996; therefore, it was assumed that the observed May 1997 water levels are a reasonable representation of steady-state conditions. Because the USZ/LSZ aquitard limits vertical flow at this site, a 2D solution is appropriate. The shallow water table (USZ) across the study area was assumed to be influenced by continuous recharge at the upgradient site boundary. Groundwater discharges at the downgradient site boundary and to a storm-water drain located under the I-40 overpass. It also was assumed that no recharge from precipitation enters the groundwater system in the source area, which is almost entirely paved.

As described in Section 1.2, Area A was the Base service station from 1942 to 1991. The date(s) of CAH introduction to the groundwater and the location(s) of the CAH source(s) are not well known. For modeling purposes, it was assumed that TCE was first

introduced to groundwater when the service station became operational in 1942. Although the timing of TCE releases is not known, if dense nonaqueous-phase liquid (DNAPL) was present in the subsurface it may have acted as a continuous source of dissolved TCE.

Important assumptions made when using the MT3D code are that dispersion, sorption, and biodegradation are significant factors controlling contaminant fate and transport at the site. Dispersivity, which is a characteristic of the porous medium, is a measure of the longitudinal and lateral spreading of the contaminant plume caused by local heterogeneity that causes deviations from the average linear solute migration velocity. The magnitude of dispersion is generally believed to be scale-dependent: the longer the plume flowpath, the greater the dispersion. Given the considerable length of the plume flowpath (approximately 600 to 700 feet) and the documented presence of subsurface heterogeneity (Section 3), it is reasonable to assume that dispersion is an important parameter influencing solute transport in the study area. According to data presented in Sections 3 and 4, concentrations of organic carbon within the site soils may support significant sorption. Data also indicate that anaerobic biodegradation of TCE is occurring within the contaminant plume. Dispersion is estimated using literature values and accepted rules-of-thumb; sorption (assumed to be a linear process) is simulated using a coefficient of retardation; and biodegradation is simulated using a first-order decay constant. Selection of values for these model-input parameters is discussed in Section 5.4.3.

5.4 INITIAL MODEL SETUP

The initial setup for this model was based on site-specific data where possible. Where site-specific data were not available (e.g., for effective porosity), reasonable assumptions were made on the basis of widely accepted literature values for materials similar to those found in the USZ at Area A. The following sections describe the basic model setup. Those model parameters varied during model calibration are discussed in Section 5.5.

5.4.1 Grid Design

The model area for Area A includes the FTA-1 source area and the downgradient area encompassing the TCE plume. The model domain for Area A is represented using one layer with a 40-cell by 62-cell horizontal grid (Figure 5.1). The long axis of the model grid is oriented east to west, parallel to the primary direction of USZ groundwater flow. The model cells were varied in size, with dimensions of 10 feet (west-to-east) by 10 feet (north-to-south) in the center of the source area. Grid cell dimensions were expanded to a maximum of 20 feet (west-to-east) by 20 feet (north-to-south) outside the center of the source area. The model grid covers an area of 930,160 square feet or approximately 21 acres. The grid thickness is approximately 35 feet from the top of the USZ/LSZ aquitard to the approximate ground surface. The TCE plume is migrating primarily through the USZ hydrogeologic unit. The USZ/LSZ aquitard that separates the USZ from the LSZ acts as a permeability barrier to vertical transport. Therefore, a one-layer 2-D model was used with the base of the model representing the USZ/LSZ aquitard.

5.4.2 Groundwater Flow Model

This section presents the initial input parameters used for the groundwater flow simulations. Contaminant transport input parameters are discussed in Section 5.4.3.

5.4.2.1 Boundary Conditions

Boundary conditions describe the interaction between the system being modeled and its surroundings or, for transport models, the loading of contaminant mass into the system. Boundary conditions are used to include the effects of the system outside the area being modeled with the system being modeled, while at the same time allowing the isolation of the desired model domain from the larger system. In effect, the boundaries of the model tell the area immediately inside the boundaries what to expect from the outside world. The solution of any differential equation requires specification of the conditions at the periphery of the system. Model boundaries are thus mathematical statements that specify the dependent variable (head or contaminant concentration) or the flux at the model grid boundaries.

Three types of boundary conditions are generally used to describe groundwater flow and solute transport. Boundary conditions are referred to as specified-head type (Dirichlet), specified-flux type (Neumann), and head-dependent or mixed type (Cauchy). Table 5.1 summarizes boundary conditions for groundwater flow and solute transport.

In flow models, boundary conditions are ideally used to specify actual hydrogeologic boundaries to the system, such as a geologic feature that may bound a system or areas where properties (e.g., flux) are known and can be defined. When using a numerical flow model, hydrologic boundaries such as constant-head features (e.g., lakes, streams, etc.) or constant-flux features (e.g., groundwater divides, confining units, etc.) should, when possible, coincide with the perimeter of the model. In areas that lack obvious hydrologic boundaries, constant-head or constant-flux boundaries can be specified at the numerical model perimeter as long as the perimeter is far enough removed from the contaminant plume that transport calculations would not be affected by inaccuracies in the simulated boundary conditions.

Specified-head cells were defined at the eastern and western ends of the model layer (Appendix D). The specified heads were estimated by projecting heads from the May 1997 groundwater flow map. These constant-head cells were placed far enough upgradient from the TCE plume to avoid potential boundary interference. Along the northern and southern boundaries of the model grid, a no-flow (specified-flux) boundary was assumed to be present in the areas where groundwater flow was approximately parallel to the grid boundary. Although some vertical contaminant transport is indicated by the detection of TCE in wells 2-2A and 2-4A (screened in the LSZ), a no-flow boundary was specified at the base of the model layer. The base, or lower boundary, of the model was set at a uniform elevation of 1,205 feet above mean sea level (ft msl) as defined using borehole data and geophysical logs. The upper model boundary is defined by the simulated water table surface, although an arbitrary top of the model domain was set at 1,240 ft msl to accommodate potential water table fluctuations during the iterative head solution procedure.

TABLE 5.1
COMMON DESIGNATIONS FOR SEVERAL
IMPORTANT BOUNDARY CONDITIONS
AREA A RNA TS
TINKER AFB, OKLAHOMA

Boundary Condition	Formal Name	General Mathematical Description	
		Groundwater Flow	Contaminant Transport
Specified-Head or Specified-Concentration	Dirichlet	$H = f(x, y, z, t)$	$C = f(x, y, z, t)$
Specified-Flux	Neumann	$\frac{\partial H}{\partial n} = f(x, y, z, t)$	$\frac{\partial C}{\partial n} = f(x, y, z, t)$
Head-Dependent or Concentration-Dependent Flux (mixed-boundary condition)	Cauchy	$\frac{\partial H}{\partial n} + cH = f(x, y, z, t)$	$\frac{\partial C}{\partial n} + cC = f(x, y, z, t)$

(Modified from Franke *et al.*, 1987)

5.4.2.2 Recharge and Evapotranspiration

Recharge and evapotranspiration (ET) were assumed negligible in the model domain and were not included in the model due to the scarcity of vegetation, the abundance of pavement, the water table depth, and the presence of fine-grained sediments in the vadose zone that inhibit significant downward percolation of precipitation.

5.4.2.3 Aquifer Properties

Hydraulic conductivity values were obtained from results of slug and pumping tests performed by IT (1996). The calculated values are summarized in Table 3.3, and discussed in Section 3.3.2. Calculated hydraulic conductivity in the USZ ranges over three orders of magnitude from 0.04 ft/day to 3.6 ft/day. An initial hydraulic conductivity of 1.0 ft/day was assigned to the model area. Hydraulic conductivity values was varied from 0.1 ft/day to 5.0 ft/day to reflect changes across the site (Figure 3.8 and Appendix D).

The effective porosity is the percentage of a rock or sediment through which fluids can travel. An effective porosity value of 20 percent was defined for the USZ on the basis of grain-size observed in soil boreholes for the USZ aquifer sands (Spitz and Moreno, 1996).

5.4.2.4 Aquifer Storage

Although steady-state groundwater flow was assumed, MT3D treats the input flow field calculated by MODFLOW as if it were transient. Aquifer storage properties must therefore be assigned for the solute transport model. In general, the model area is largely

unconfined, and a specific yield of 0.20 was assigned. Specific yield is similar to effective porosity of the aquifer, because it represents the water that can drain from the aquifer material pore spaces.

5.4.2.5 Aquifer Stresses

A low in the USZ water table corresponds to a topographic low in the vicinity of the I-40 underpass (Figure 3.8). Storm-water drains in the underpass collect surface water runoff and influence the shallow water table. Therefore, a drain was placed at the underpass location in the model domain. The elevation of the drain bottom and the hydraulic conductivity (conductance) of the aquifer/drain interface were specified and varied in the model until the simulated drain discharge accurately simulated the observed water table elevation in the underpass area. The drain elevation was set to the approximate topographic elevation at the base of the underpass (1,210 feet MSL), and the conductance was set to 10,000 square feet per year (ft²/yr).

Three product recovery wells (RW-1, RW-2, and RW-3) are currently located in the model domain (Figure 1.3). These pumping wells were used for product recovery from July 1992 until approximately September 1996 (IT, 1996, and Woodward-Clyde Federal Services [WC], 1998a). The three recovery wells were added to the model domain and pumped at an initial rate of 1 gpm. The rates were varied from 0.1 gpm at RW-1 to 5 gpm at well RW-2 to simulate water table elevations observed in July 1995 (IT, 1996) (Appendix D).

5.4.3 Contaminant Transport Model

Subsequent to performing groundwater flow simulations, the model was used to simulate fate and transport of TCE. Biodegradation rates calculated in Section 4 primarily represent reductive dehalogenation. The TCE concentrations obtained from April to May 1997 laboratory analytical results for 17 monitoring and VEP wells were used as targets for model calibration. Table 4.3 presents dissolved TCE concentration data for April to May 1997, and Figure 4.7 shows the spatial distribution of dissolved TCE in May 1997.

5.4.3.1 Source

Transport models use boundary conditions to express the influence of contaminant sources such as mobile and residual nonaqueous-phase liquid (NAPL), biodegradation of parent compounds, and dissolved mass entering through recharge, injection wells, surface water bodies, or leaking structures. Sources such as NAPL bodies may be represented as specified-concentration boundaries (limited by solubility constraints or observed maximum concentrations) or as specified-flux boundaries (for which the chemical loading rate must be known or estimated). However, in most cases, only the effects of the source are measured; the detailed source characteristics and history are typically unknown (Spitz and Moreno, 1996). The source must therefore be represented as a "black box" that produces appropriate contaminant concentrations or fluxes at selected points in the model. The source may be misrepresented under such a scenario, but there is often little choice in the matter. Estimating contaminant flux into groundwater from

NAPL is difficult and is dependent upon several parameters, most of which cannot be measured (Abriola, 1996; Feenstra and Guiguer, 1996).

Rather than using various calculations to attempt to estimate TCE partitioning from residual NAPL into groundwater, the "black-box" source approach was used for this application. Experience modeling contaminated sites as part of the AFCEE Natural Attenuation Initiative indicates that this is currently the best available method for reproducing observed plumes. At Area A, the TCE is assumed to enter groundwater in the study area through contact between groundwater and residual NAPL at or below the water table. It has not been determined whether free product at the site is a source of TCE, or whether a separate NAPL source containing TCE is present. Because the BTEX and TCE groundwater plumes originate from the same general area, partitioning of TCE into groundwater was simulated by specifying source area dissolved concentrations in 42 model cells coinciding with the free product plume at the site (Appendix D).

It is possible that contaminants were first introduced into groundwater when the Area A service station opened in 1942 (IT, 1996). The service station was officially closed in April 1991, and all USTs and associated piping were removed by January 1996. Solvents and other liquid wastes may have been used for cleaning and dumped or spilled onto the ground or into surface drainage at the site. For the model it was assumed that low levels of contaminants first entered the groundwater upon operations in 1942, and that residual NAPL contamination associated with the leached waste has acted as a continuous source. It was assumed that source concentrations of TCE increased to a maximum from 1977 to 1992. After 1992, model source concentrations were reduced to represent mass removal by the product recovery system.

For predictive modeling after May 1997, it was assumed that in the absence of engineered remediation, the source would begin to weather (lose mass) due to processes such as volatilization, dissolution, and biodegradation, and that the mass of contaminants entering groundwater would decline. Past experience with the AFCEE Natural Attenuation Initiative has suggested that residual NAPL sources can weather at rates as rapid as 10 percent per year. However, to be conservative, and because the contaminant sources are poorly characterized, it was assumed that the source at Area A will weather at about three percent per year. Thus, the model assumes that after 1997, the source loading rates decreased geometrically by three percent per year (each year's source strength was decreased by three percent from the previous year's strength).

5.4.3.2 Dispersivity

Published data summarized by Spitz and Moreno (1996) indicate that, in general, longitudinal dispersivity is approximately one-tenth the travel distance of the plume (from the source to the downgradient toe). At Area A, the total plume length is approximately 600 to 700 feet (Figure 4.7), so an initial longitudinal dispersivity of 60 feet was assigned to the model area. The initial transverse dispersivity was estimated as one-tenth of the longitudinal dispersivity value (6 feet), and vertical dispersivity was assumed to be one-hundredth of the longitudinal dispersivity (0.6 feet) (Domenico and Schwartz, 1990).

5.4.3.3 Retardation

Retardation of contaminants relative to the advective velocity of the groundwater occurs when contaminant molecules are sorbed to organic carbon, silt, or clay in the aquifer matrix. Using TOC concentrations taken from literature for fine sand (Wiedemeier, 1996a; Spitz and Moreno, 1996), an assumed bulk density of 1.72 kilograms per liter (kg/L), and published values of the TCE soil sorption coefficient (K_{oc}) (as listed in Wiedemeier *et al.*, 1996a), the coefficient of retardation for TCE was calculated. Results of these calculations are summarized in Table 5.2, with retardation values for other compounds detected at the site listed for comparison. The lower the assumed coefficient of retardation, the faster the TCE plume will migrate downgradient. Initially, a bulk density of 1.72 kilograms per liter (kg/L), an effective porosity of 0.20, and an average K_d value of 0.1177 liters per kilogram (L/kg) were specified in the model to simulate a retardation coefficient of 2.0 for TCE (Table 5.2).

5.4.3.4 Biodegradation

As listed in Table 4.10, first-order TCE decay rates for the plume flowpath between wells 2-3 and VEP-11 range from 0.27 per year (yr^{-1}) (half life of 2.53 years) to 0.63 yr^{-1} (half life of 1.09 years). A first-order TCE decay rate of 2.65 yr^{-1} (half life of 0.26 years) was also calculated for the USZ between wells 2-50B and VEP-9. The higher TCE decay rate was observed in areas where reductive dehalogenation was occurring and was not used during model calibration.

An initial first-order decay rate of 0.6 yr^{-1} (half-life of 1.15 years) was defined for the USZ sediments corresponding to the portion of the model domain under anaerobic (DO less than 0.5 mg/L, Figure 4.13) and reductive (redox less than 0 mv, Figure 4.19) conditions. This decay rate is between the estimated upper and lower bound rates computed for both flowpaths. A lower rate of 0.2 yr^{-1} (half life of 3.46 years) was assigned outside of this area where aerobic conditions prevail.

5.5 MODEL CALIBRATION

Model calibration is an important component in the development of any numerical groundwater model. Calibration of the flow model demonstrates that the model is capable of matching hydraulic conditions observed at the site. Calibration of a contaminant transport model (using the calibrated flow field as input) helps demonstrate that contaminant loading and transport conditions are being appropriately simulated. Model input and output summaries are included in Appendix D.

5.5.1 Groundwater Flow Model

Groundwater elevation data collected in May 1997 and presented on Figure 3.8 were used to calibrate the flow model. Water level elevation data from 15 monitoring wells were used to compare measured and simulated heads for calibration. The selected locations are listed in Appendix D.

The numerical flow model was calibrated by altering hydraulic conductivity and constant-head elevations at the model boundaries in a trial-and-error fashion until

TABLE 5.2
CALCULATION OF RETARDATION COEFFICIENTS
AREA A RNA TS
TNKR AFB, OKLAHOMA

Compound	K_{oc} (L/kg ^{a/})	Maximum Fraction Organic Carbon ^{b/}	Minimum Fraction Organic Carbon ^{b/}	Average Fraction Organic Carbon ^{b/}	Distribution Coefficient K_d (L/kg)			Bulk Density (kg/L) ^{d/}	Effective Porosity ^{d/}	Coefficient of Retardation	
					Maximum ^{e1/}	Minimum ^{e2/}	Average ^{e3/}			Maximum	Minimum Average
PCE	263	0.002	0.0002	0.0011	0.5260	0.0526	0.2893	1.72	0.20	5.52	1.45 3.49
TCE	107	0.002	0.0002	0.0011	0.2140	0.0214	0.1177	1.72	0.20	2.84	1.18 2.01
1,1-DCE	65	0.002	0.0002	0.0011	0.1300	0.0130	0.0715	1.72	0.20	2.12	1.11 1.61
cis-1,2-DCE	65	0.002	0.0002	0.0011	0.1300	0.0130	0.0715	1.72	0.20	2.12	1.11 1.61
trans-1,2-DCE	59	0.002	0.0002	0.0011	0.1180	0.0118	0.0649	1.72	0.20	2.01	1.10 1.56
VC	2.5	0.002	0.0002	0.0011	0.0050	0.0005	0.0028	1.72	0.20	1.04	1.00 1.02
Benzene	79	0.002	0.0002	0.0011	0.1580	0.0158	0.0869	1.72	0.20	2.36	1.14 1.75
Toluene	190	0.002	0.0002	0.0011	0.3800	0.0380	0.2090	1.72	0.20	4.27	1.33 2.80
Ethylbenzene	468	0.002	0.0002	0.0011	0.9360	0.0936	0.5148	1.72	0.20	9.05	1.80 5.43
Xylenes	394	0.002	0.0002	0.0011	0.7880	0.0788	0.4334	1.72	0.20	7.78	1.68 4.73
Total BTEX	283	0.002	0.0002	0.0011	0.5660	0.0566	0.3113	1.72	0.20	5.87	1.49 3.68
1,2,3-TMB	884	0.002	0.0002	0.0011	1.7680	0.1768	0.9724	1.72	0.20	16.20	2.52 9.36
1,2,4-TMB	772	0.002	0.0002	0.0011	1.5440	0.1544	0.8492	1.72	0.20	14.28	2.33 8.30
1,3,5-TMB	676	0.002	0.0002	0.0011	1.3520	0.1352	0.7436	1.72	0.20	12.63	2.16 7.39

^{a/} From technical protocol (Wiedemeier et al., 1996b); Knox et al., 1993; Montgomery et al., 1990; and Abdul et al., 1987.

^{b/} From literature values for sand and silt (Weideimeier et al., 1996b; Spitz and Moreno, 1996)

^{c1/} K_d = Maximum Fraction Organic Carbon x K_{oc}

^{c2/} K_d = Minimum Fraction Organic Carbon x K_{oc}

^{c3/} K_d = Average Fraction Organic Carbon x K_{oc}

^{d/} Estimated Value.

simulated heads approximated observed field values within a prescribed accuracy. In general, hydraulic conductivity was varied within the limits of the observed data, although some values were increased slightly beyond the measured range. The flow model was initially calibrated as a steady-state model. Later, it was run as a transient model to simulate the recovery wells and facilitate the transport solution. The steady-state heads were used as initial heads for the transient model, and the heads did not change significantly because the transient system quickly matched the steady-state system.

Figure 5.2 shows the calibrated water table. Calibrated model horizontal hydraulic conductivity ranged between 0.01 and 15 ft/day. A higher conductivity value (10 ft/day) was used for the USZ along the contaminant transport pathway between well 2-3 and VEP-10, a lower value (0.01 ft/day) was used for a low permeability area around well 2-51B (Table 3.3), and intermediate values (1.0 to 5.0 ft/day) were used for the remainder of the model area. For all materials the anisotropy ratio of y-direction (north-south) horizontal conductivity to x-direction horizontal conductivity was 1:1. Hydraulic conductivity distributions are presented in Appendix D.

The root mean squared (RMS) error is commonly used to express the average difference between simulated and measured heads. RMS error is the average of the squared differences between measured and simulated heads and can be expressed as:

$$\text{RMS} = \left[\frac{1}{n} \sum_{i=1}^n (h_m - h_s)_i^2 \right]^{0.5}$$

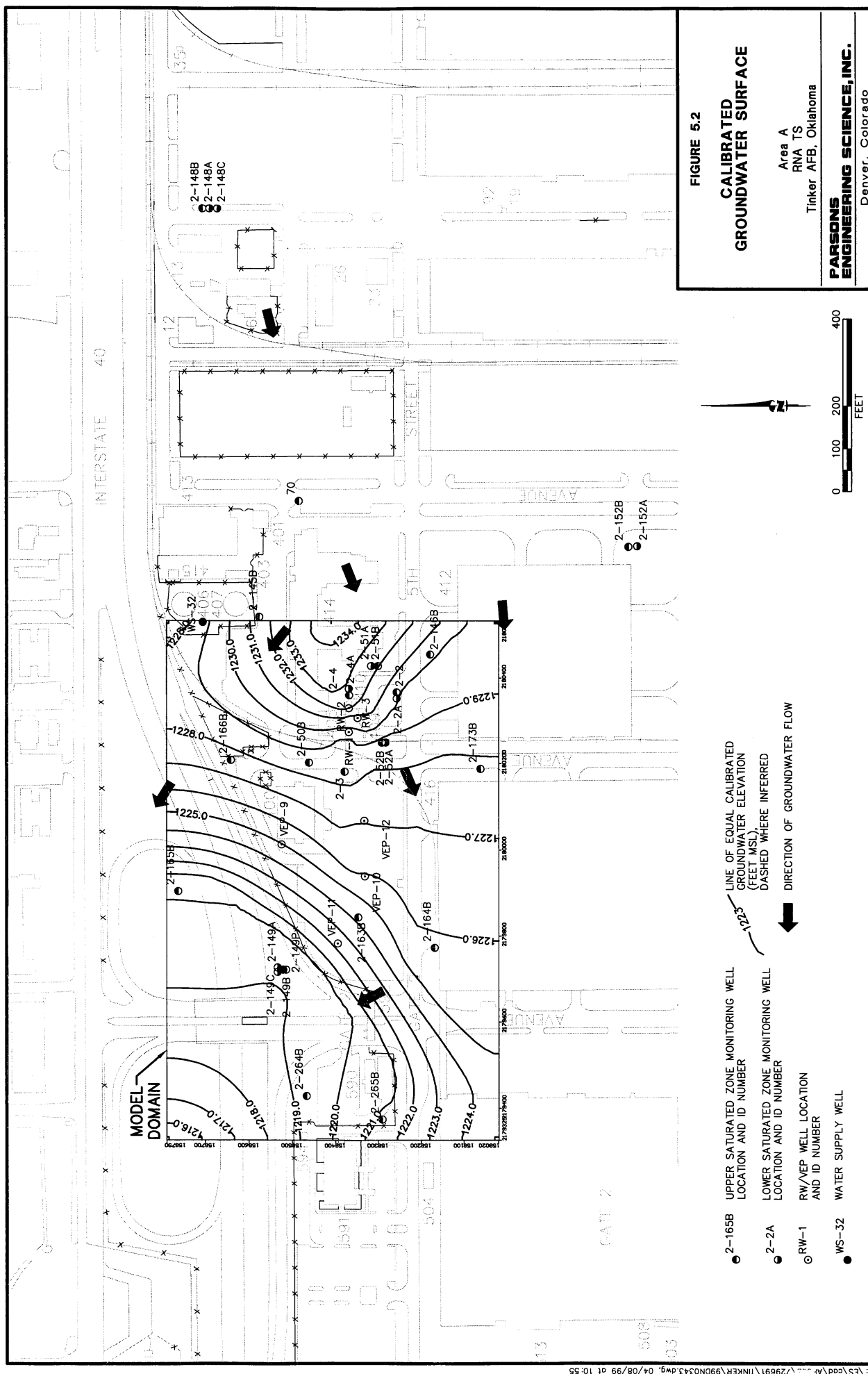
where: n = the number of points where heads are being compared,

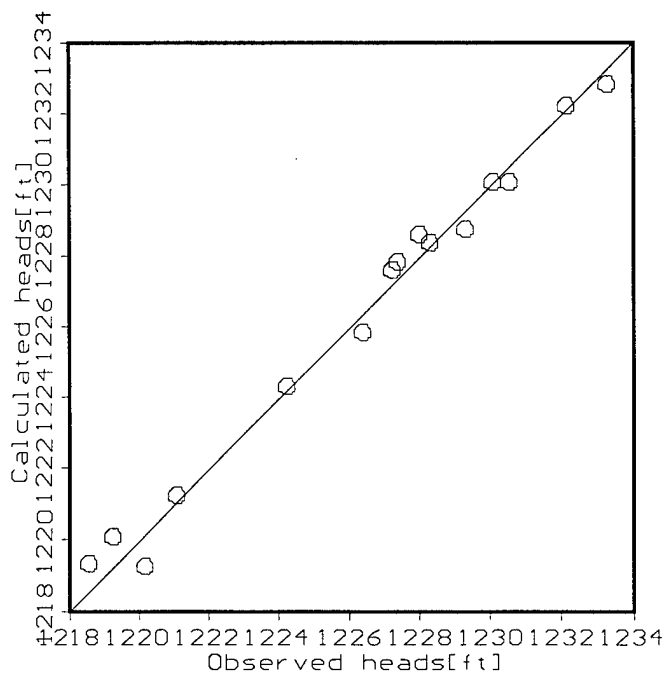
h_m = measured head value, and

h_s = simulated head value.

The RMS error between observed and calibrated values at 15 well location was 0.51 feet, which corresponds to a calibration error of 3.46 percent. Figure 5.3 shows the relation between measured heads and simulated heads and the resulting RMS. This plot provides a qualitative method of checking the calibrated head distribution; the points should scatter randomly about the straight line (Anderson and Woessner, 1992). In general, this is the case for the Area A model.

In solving the groundwater flow equation, Visual MODFLOW establishes the water table surface and calculates an overall hydraulic balance that accounts for the numerical difference between flux into and out of the system. To the number of decimal places reported by Visual MODFLOW, the hydraulic mass balance for the calibrated flow model had a 0.0 percent discrepancy. This is more than adequate to accomplish the objectives of the modeling effort. According to Anderson and Woessner (1992), a mass balance error of around 1 percent is acceptable, while Konikow and Bredehoeft (1978) indicates an error of less than 0.1 percent is ideal.





Period: 17
Step: 10

Mean error: 0.0297214

Mean abs. err: 0.419217

RMS error: 0.508348

FIGURE 5.3

**CALIBRATED VERSUS
OBSERVED GROUNDWATER
ELEVATIONS**

Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

5.5.2 Plume Calibration

After calibration of the final flow model, the numerical solute transport model was calibrated by altering the contaminant specified-flux rate in the source cells and contaminant transport parameters in a trial-and-error fashion until the simulated plume approximated observed field values. For plume calibration, the model was run for a 55-year period (1942 to 1997). The transport parameters varied during plume calibration were the source-cell loading concentrations, the plume dispersivity, the TCE decay rate constant, the distribution coefficient for contaminant sorption, and effective porosity. The dissolved TCE concentrations obtained from April and May 1997 laboratory analytical data from 17 monitoring wells were used to calibrate the contaminant transport model. Calibration sample locations and names are presented in Appendix D.

5.5.2.1 Source Concentrations

The 55-year time period was divided into five-year increments from 1942 until 1992, and into approximately one-year increments from 1992 to 1997. The concentration history at each source cell was specified as a step function, with constant concentration specified for any given period. The 42 source cells are adjacent to each other, coinciding with the free product plume and well 2-3 (Appendix D), where the highest TCE concentrations were observed (1,120 $\mu\text{g/L}$ in 1997). The source cells lie along a line trending north-northeast from well 2-62B. Of the 42 cells, the major TCE contribution is from nine cells immediately upgradient of well 2-3. At these cells, specified source concentrations were steadily increased from 500 $\mu\text{g/L}$ in 1942 to 3,200 $\mu\text{g/L}$ in 1977, then held constant from 1977 to 1992. From 1992 until 1997, the specified source concentrations were decreased from the high of 3,200 $\mu\text{g/L}$ to 1,100 $\mu\text{g/L}$. For the remaining source cells, specified source concentrations were steadily increased from 100 $\mu\text{g/L}$ in 1942 to 400 $\mu\text{g/L}$ in 1977, then held constant from 1977 until 1992. From 1992 until 1997, the remaining specified source concentrations were decreased from the high of 400 $\mu\text{g/L}$ to 250 $\mu\text{g/L}$. All specified source concentrations were at least two orders of magnitude below the solubility limit for TCE in water (greater than 1,000,000 $\mu\text{g/L}$).

5.5.2.2 Dispersivity

The initial longitudinal dispersivity of 60 feet produced a simulated plume far longer and wider than that observed in 1997. Field-scale longitudinal dispersivity used for modeling input is subject to constraints of model cell size. Therefore, this value was gradually decreased to five feet and to produce the calibrated plume.

5.5.2.3 TCE Decay Rates

The decay rate was varied during plume calibration but did not significantly change the transport calibration. The higher rates in the near-source and plume core area are reflective of Type 1 behavior and are in agreement with Section 4 conclusions. It should be noted that zones of degradation actually evolve through time, whereas here they are simulated as static. Unfortunately, the process of adapting a general-purpose transport code to handle such non-linearity is highly problem-dependent and time-consuming. The

rates obtained from the calibration process should therefore be viewed as averages over the calibration period.

5.5.2.4 Sorption

During plume calibration, the retardation coefficient was not varied, and the calibrated model used a value of 2.0 throughout the model domain. Domenico and Schwartz (1990) note that sorption of organic compounds estimated on the basis of TOC alone is often underestimated, because the role of sorption onto clays and other mineral surfaces is ignored. In addition, Ball and Roberts (1991) note that partitioning coefficients (used to calculate retardation coefficients in conjunction with TOC data) can be underestimated, because the laboratory studies used to derive the partitioning coefficients are performed on a short time scale (days to months). In reality, most field-scale situations (such as Area A) involve time scales of tens of years. While it was found that the model retardation coefficients resulted in a reasonable calibration, there may be other combinations of transport parameters involving higher sorption that match measured TCE concentrations equally well.

5.5.2.5 Effective Porosity

The initial uniform effective porosity value of 0.2 was found to give reasonable calibration results and was not varied.

5.5.2.6 Transport Calibration Results

The calibrated plume calculated by the model (Figure 5.4) is similar, but not identical, to the observed May 1997 plume (Figure 4.7). The overall shape and TCE concentrations of the simulated plume are a reasonable match to the actual plume. The RMS error of prediction over the 17 observations wells was 8.1 $\mu\text{g/L}$.

In general, simulated TCE concentrations along the plume axis to a downgradient location between wells 2-163B and VEP-10 are a relatively close match to measured concentrations. Beyond this point, predictions were high at well 2-163B (23.8 $\mu\text{g/L}$ vs. a measured concentration below detection). Further downgradient at well VEP-11, the predicted TCE concentration was reasonable (6.0 $\mu\text{g/L}$ vs. 5.5 $\mu\text{g/L}$ measured). To the north, the predictions were high at well VEP-9 (8.8 $\mu\text{g/L}$ vs. a measured concentration below detection).

Prediction error is largest at the lateral plume margins where steep concentration gradients from the plume core to outlying undetectable levels exist. It appears the simulated plume is slightly wider and longer than the measured plume at concentrations of approximately 10 $\mu\text{g/L}$ or less. The inability to reproduce a narrower plume while maintaining an accurate calibration along the plume axis may be due to numerical dispersion. However, the actual downgradient extent of the 10 $\mu\text{g/L}$ isopleth is not known with precision, and therefore the simulated plume is not necessarily incorrect. In fact, the detection of 2.6 $\mu\text{g/L}$ and 4.1 $\mu\text{g/L}$ TCE in downgradient wells 2-149B and 2-163B, respectively, in January 1995 (IT, 1996; Table 6.1) indicates that the 10 $\mu\text{g/L}$ TCE isopleth may have at one time extended farther west than shown on Figure 4.7.

Given the history of specified source area concentrations, it appears that adequate TCE mass was introduced to the system. Areas enclosed by isopleths appear to be very similar for simulated and measured TCE concentrations. This is important to note, because the introduction of sufficient contaminant mass facilitates conservative predictions of downgradient receptor impacts and of plume persistence by accurately reproducing TCE concentrations in the downgradient portions of the plume.

5.6 SENSITIVITY ANALYSIS

The purpose of a sensitivity analysis is to determine the effect of varying model input parameters on model output. The sensitivity analysis was conducted by varying hydraulic conductivity, retardation (i.e., the distribution coefficient K_d), dispersivity, the first-order decay rate, and source concentrations.

To perform the sensitivity analyses, the calibrated model was adjusted by systematically changing the aforementioned parameters individually and then comparing the new simulations to results of the calibrated model. The models were run for a 55-year period, just as the calibrated model was, so the independent effect of each variable could be assessed. Ten sensitivity runs of the calibrated model were made with the following variations:

1. All hydraulic conductivity values increased by a factor of three;
2. All hydraulic conductivity values decreased by a factor of three;
3. Distribution coefficients doubled, which resulted in retardation coefficient set to 3.0;
4. Distribution coefficients reduced to zero, which resulted in retardation coefficient set to 1.0;
5. Longitudinal dispersivity values increased by a factor of four;
6. Longitudinal dispersivity values decreased by a factor of four;
7. Decay rates increased one-order of magnitude;
8. Decay rates decreased one order of magnitude;
9. Source concentrations doubled;
10. Source concentrations halved;

The results of the sensitivity analyses are discussed in the following subsections and summarized in Table 5.3 and Appendix D. As described in the following paragraphs, the parameter modifications listed above generally caused substantial changes in the resulting plumes. The plume shape and distribution are most sensitive to changes in hydraulic conductivity and least sensitive to changes in longitudinal dispersivity.

5.6.1 Sensitivity to Variations in Hydraulic Conductivity

Hydraulic conductivity is an important aquifer characteristic that represents the ability of the water-bearing strata to transmit groundwater. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer. As a result, models used to estimate contaminant transport are particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume. Higher values of hydraulic conductivity result in a faster-moving plume. The effects of varying hydraulic conductivity are summarized in columns A and B of Table 5.3.

Uniformly increasing the hydraulic conductivity by a factor of three greatly increased the extent of the plume so the 10- $\mu\text{g/L}$ isopleth reached approximately 600 feet farther downgradient (Appendix D) than for the calibrated case, and the simulated concentrations downgradient of the source area were much higher than for the calibrated model. In contrast, decreasing the hydraulic conductivity by a factor of three slowed overall plume migration and resulted in a shorter plume with contaminant mass occupying a much smaller area.

5.6.2 Sensitivity to Variations in the Distribution Coefficient

The effects of varying the distribution coefficient (K_d) are summarized in columns C and D of Table 5.3. Uniformly increasing K_d 's by a factor of two increased the retardation factor R to 3.0. This increase produced a shorter and slightly narrower plume with concentrations outside of the source area less than those in the calibrated model. This reflects the increased mass of TCE sorbed to the soil matrix. Uniformly setting K_d to zero resulted in a retardation factor of 1.0 (no retardation). This significantly increased the length and width of the TCE plume and increased TCE concentrations outside of the source area.

5.6.3 Sensitivity to Variations in Dispersivity

The effects of varying dispersivity are summarized in columns E and F of Table 5.3. Longitudinal and transverse dispersivity were both varied for this analysis, and the ratio of longitudinal-to-transverse dispersivity was kept at the calibrated value. Increasing dispersivity by a factor of four, and decreasing dispersivity by a factor of four, then resulted in similar factors of increase/decrease for transverse components of dispersivity.

Increasing the dispersivity components by a factor of four lowered TCE concentrations and spread more of the contaminant mass to the margins of the plume. The result was a plume with a slightly larger footprint, lower peak values, and slightly lower concentration gradients. Accordingly, concentrations at all wells increased except at well 2-3 immediately adjacent to the plume source cells, which remained constant at 1,100 $\mu\text{g/L}$. Decreasing the dispersivity components had the opposite effect, resulting in a slightly smaller plume with higher peak concentrations, lower marginal concentrations, and slightly steeper concentration gradients.

TABLE 5.3
SUMMARY OF SENSITIVITY ANALYSIS RESULTS
AREA A RNATS
TINKER AFB, OKLAHOMA

Well	Observed Concentration (µg/L)	Calibrated Concentration (µg/L)	A (µg/L)	B (µg/L)	C (µg/L)	D (µg/L)	E (µg/L)	F (µg/L)	G (µg/L)	H (µg/L)	I (µg/L)	J (µg/L)
2-2	37.0	33.8	48.1	7.3	28.1	41.3	40.5	31.9	0.2	122.7	67.6	16.9
2-3	1,120	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	2,200	550
2-50B	ND	2.9	4.3	0.2	1.9	4.6	19.8	0.8	0.0	44.3	5.9	1.5
2-51B	2.5	1.7	3.2	0.4	1.4	2.1	13.5	0.1	0.0	5.8	3.4	0.9
2-52B	ND	2.2	12.9	0.0	1.1	4.7	8.9	1.0	0.0	163.5	4.5	1.1
2-146B	ND	0.0	0.0	0.0	0.0	0.1	1.1	0.0	0.0	0.4	0.1	0.0
2-149B	ND	3.5	110.0	0.0	1.0	12.8	5.9	2.8	0.0	803.1	6.9	1.7
2-163B	ND	23.8	84.3	0.5	13.2	44.6	37.2	14.4	0.0	382.7	47.7	11.9
2-164B	ND	0.4	8.1	0.0	0.1	1.1	0.6	0.3	0.0	38.2	0.7	0.2
2-165B	ND	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.6	0.0	0.0
2-173B	ND	1.0	0.8	0.0	0.6	1.9	2.7	0.6	0.0	15.6	2.1	0.5
2-264B	ND	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
2-265B	ND	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VEP-9	ND	8.8	83.2	0.1	3.9	21.0	24.0	5.6	0.0	525.9	17.5	4.4
VEP-10	252	257	372	27	187	351	331	132	0	1170	513	128
VEP-11	5.5	6.0	52.7	0.0	2.6	14.9	10.9	3.9	0.0	296.7	12.1	3.0
VEP-12	13.9	10.8	108.0	0.4	5.8	22.4	64.9	2.1	0.0	279.8	21.5	5.4
Flow RMS	--	0.51	0.63	0.50	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
TCE RMS	--	8.09	55.53	55.32	17.18	27.62	26.44	29.84	62.03	351.91	269.90	141.60

Column: A : Hydraulic Conductivity x 3.

B: Hydraulic Conductivity /3.

C: Retardation = 3.0.

D: Retardation = 1.0.

E: Dispersivity x 4.

F: Dispersivity /4.

G: Decay rate increased one order-of-magnitude.

H: Decay rate decreased one-order-of magnitude.

I: Source concentration x 2.

J: Source concentration /2.

5.6.4 Sensitivity to Variations in the Decay Rate Constant

The effects of varying the first-order TCE decay rate are summarized in columns G and H of Table 5.3. Uniformly increasing decay rates by an order of magnitude resulted in rapid degradation of dissolved contaminants and produced a much smaller plume with lower concentrations everywhere outside the source area than the calibrated model. Uniformly decreasing degradation rates by an order of magnitude resulted in a much larger plume with higher concentrations outside the source area than the calibrated model.

5.6.5 Sensitivity to Variations in Source Concentrations

The results of doubling and halving source concentrations are summarized in columns I and J of Table 5.3. Doubling source concentrations approximately doubled TCE concentrations throughout the plume, although the plume expanded significantly less than when hydraulic conductivity was increased or the decay rate was decreased. The opposite effect resulted from halving the source concentrations with TCE concentrations approximately halved throughout the plume and with a slightly smaller plume.

5.6.6 Summary of Sensitivity Analysis Results

The results of the sensitivity analysis show that, compared to the calibrated model, all parameter variations caused a noticeable degradation in the goodness-of-fit between predictions and measurements. This indicates that, if the underlying conceptual model is appropriate, the calibrated model discussed in Section 5.4 is a reasonable and useful approximation of site conditions.

Based on the sensitivity analysis, transport parameters can be ordered from most to least significant as follows: degradation rate, hydraulic conductivity, source concentration, dispersivity, and distribution coefficient. More specifically, the parameter variations can be ranked according to the degree of deviation from the calibrated "fit" they cause. From the greatest deviation to the least, these are

1. Decreasing the decay rate constant by an order of magnitude
2. Increasing hydraulic conductivity by a factor of three
3. Doubling source concentrations
4. Halving source concentrations
5. Increasing the decay rate constant by an order of magnitude
6. Decreasing hydraulic conductivity by a factor of three
7. Decreasing dispersivity by a factor of four
8. Decreasing retardation to 1.0
9. Increasing dispersivity by a factor of four
10. Increasing retardation to 3.0

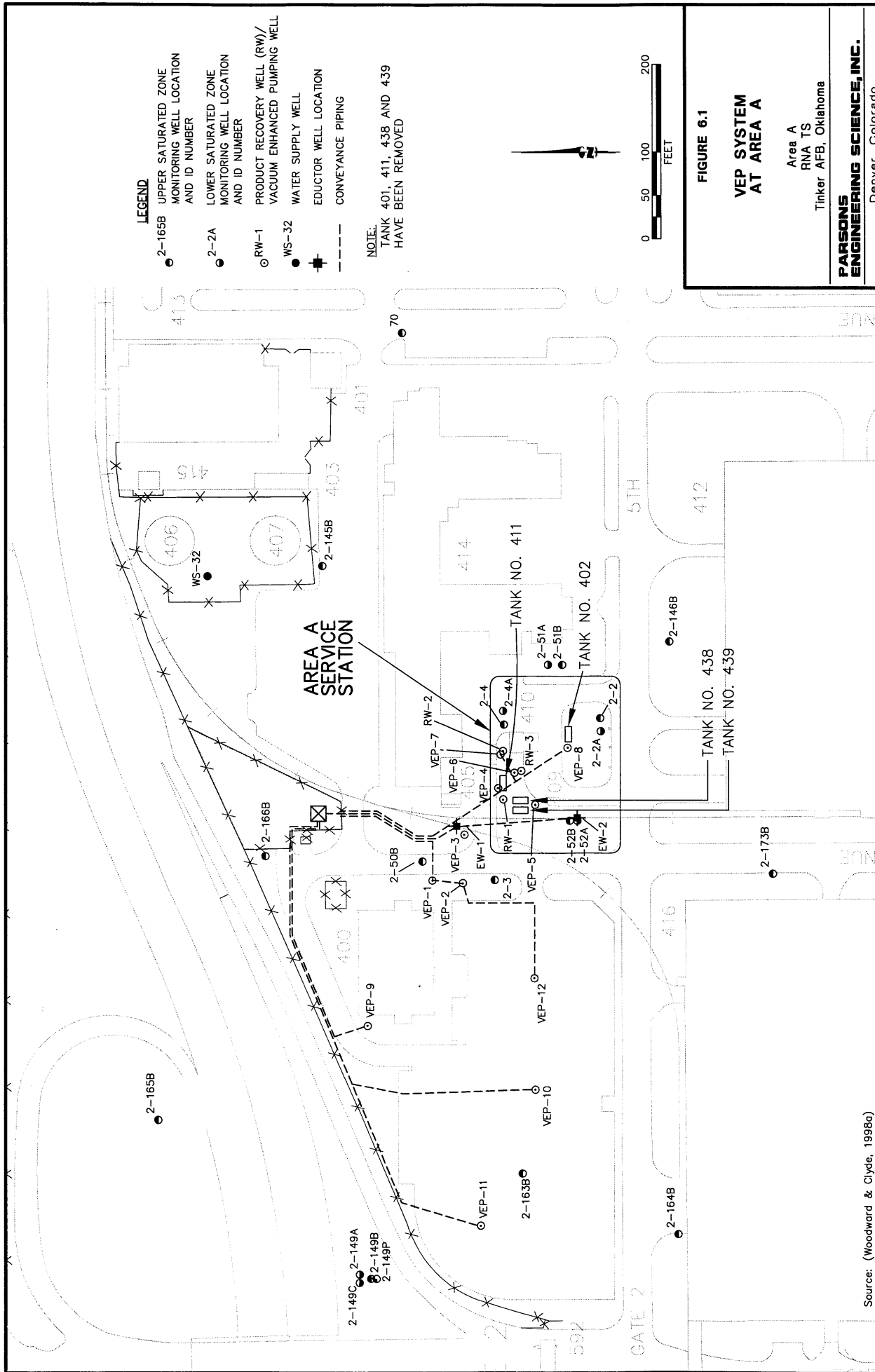
It should be kept in mind that typical percentage variations in field-measured or estimated values of these parameters are site-specific. For example, at a particular site dispersivity may vary from the mean value by less than a factor of two, while the decay rate vary over orders of magnitude. In this case, a model would be more sensitive to "typical" variations in decay rate than to "typical" variations in dispersivity, even if, for the same percentage change, the model were determined to be more sensitive to dispersivity.

5.7 MODEL PREDICTIONS

To evaluate the future extent of the TCE plume under steady-state conditions (May 1997), the calibrated MODFLOW and MT3D numerical contaminant transport model was used to predict the future extent of TCE groundwater contamination. Given the underlying conceptual model of a TCE source coinciding with the Area A free product plume, the calibration exercise has yielded a useful tool for evaluation of TCE transport. However, data uncertainties leave open the possibility that alternative conceptual models may explain the TCE plume as well. Among factors contributing to these uncertainties are the unknown locations and history of CAH disposal at Area A and the inability to document any obvious contaminated soil "hot spots".

Given these facts, the observed TCE plume is the result of typical downgradient transport from a single, relatively disperse source. The predicted TCE plume is primarily controlled by the effectiveness of natural processes to minimize contaminant migration and reduce contaminant mass or concentrations over time. Predictive simulations assume the TCE source from the calibrated model continues to contribute TCE to USZ groundwater for another 50 years (total simulation time of 105 years from initial source release). The TCE source is modeled with a conservative source weathering rate of three percent per year, due to processes such as volatilization, dissolution, and biodegradation (Section 5.4.4.1). Thus, the model assumes that after 1997, the source loading rates decreased geometrically by three percent per year (each year's source strength was decreased by three percent from the previous year's strength).

The predicted extent of TCE in the USZ after 50 years (year 2047) is shown on Figure 5.5. The predicted extent of TCE contamination after 50 years is also used as the basis for long-term monitoring discussed in Section 7. The model predicts maximum TCE concentrations of up to 250 $\mu\text{g/l}$ in the vicinity of well 2-3 after 50 years, and it predicts the plume will extend west of well VEP-10 approximately 100 feet. Site data suggest that natural attenuation mechanisms are sufficient to control migration of the TCE plume and significantly reduce TCE concentrations, if anaerobic conditions continue to support reductive dehalogenation of TCE at the site.



time adjustments were made to the system to optimize extraction rates and the cone of depression at the USZ water table. Quarterly monitoring of groundwater began November 19, 1997 and continues to date.

As of May 31, 1998 the groundwater recovery system has produced at rates of 355 to 26,000 gallons per day (gal/day) while in operation. From initial operation through May 31, 1998, the eductor wells and VEP wells produced total liquid volumes of 863,870 gallons and 2,643,432 gallons, respectively (WC, 1998a). Approximately 700 gallons of free product were recovered during well installation and development. Since then, free product recovery has only been observed in the sight glass of the liquid/vapor separator. Free product in the liquid/vapor separator is held under sufficient vacuum (20-25 inches of mercury) to be volatilized and thermally destroyed during the VEP recovery and treatment process (WC, 1998a).

6.2 EVALUATION OF VEP EFFECTIVENESS

Thirteen groundwater monitoring wells were sampled by WC between the months of May 1997 and June 1998 to determine the effectiveness of the VEP remediation system at Tinker AFB, Area A. Analytical results for BTEX, TPH - gasoline range organics (GRO), TPH - diesel range organics (DRO), naphthalene, methyl tertiary-butyl ether (MTBE), and TCE summarized herein were originally presented by WC (1998a and 1998b).

6.2.1 Total BTEX and Benzene

Since operation of the VEP system, BTEX concentrations in USZ groundwater have been significantly reduced. As of June 1998, only well 2-51B had detectable concentrations of BTEX. In all other wells shown on Figure 4.11, BTEX concentrations were reduced to below detection limits, although well 2-50B was not sampled as part of the VEP system compliance monitoring.

In May 1997, total BTEX was identified in seven of the thirteen monitoring wells sampled in conjunction with the VEP system at Area A (2-2, 2-3, 2-4, 2-51B, 2-52B, 2-149B, and 2-163B) (Table 6.1). BTEX in May 1997 was found at a maximum concentration of 26,200 µg/L at monitoring well 2-4. By September 1997, BTEX was reduced to 226 µg/L at well 2-4, and reduced to below detection limits by December 1997. By January 1998, BTEX concentrations decreased to non-detectable levels in four of the seven monitoring wells, the exceptions being monitoring wells 2-51B, 2-3, and 2-163B. At 2-51B BTEX concentrations have fluctuated between a minimum concentration of 30.8 µg/L in March 1998, and a maximum concentration of 540J µg/L (J-flag indicates an estimated concentration) in June 1998.

The distribution of total BTEX in May 1997, September 1997, and January 1998 is shown on Figure 6.2. BTEX was detected at monitoring well 2-149B at a concentration of 88 µg/L in September 1997, indicating the total BTEX plume apparently expanded in a downgradient direction. However, maximum BTEX concentrations were significantly reduced at the same time. By January 1998, the BTEX plume receded to within the source area. Data from April and June 1998 confirmed the BTEX plume had receded,

TABLE 6.1
SUMMARY OF GROUNDWATER ANALYTICAL RESULTS
JANUARY 1994 TO JUNE 1998
AREA A RNA TS
TINKER AFB, OKLAHOMA

Location	Date Sampled	Benzene (µg/L) ^u	Toluene (µg/L)	Ethylbenzene (µg/L)	Total Xylenes (µg/L)	Total BTEX ^u (µg/L)	Naphthalene (SVOC) ^u (µg/L)	TPH GRO ^u (µg/L)	TPH DRO ^u (µg/L)	TCE ^a (µg/L)	MTBE ^a (µg/L)
MCL^d		5	1,000	700	— ^d	—	—	—	—	5	—
Upper Saturated Zone											
2-2 (MW2-002)	Jan-94	330	32	79	81	522	2.4	NA ^e	NA	210	NA
	Jan-95	1,100	130	740	730	2,700	56	NA	NA	130	NA
	Oct-95	390	ND ^b	14	ND	404	ND	NA	NA	ND	NA
	Aug-96	400	< 12	< 12	< 12	400	16	NA	NA	< 12	NA
	Apr-97	453	12.3	136	35.4	637	NA	NA	NA	37	NA
	May-97	236	16	72	35	359	3J	1,370	3,310	127	NA
	Sep-97	20	ND	ND	ND	20	ND	ND	3,030	250	ND
	Jan-98	ND	ND	ND	ND	ND	NA	ND	ND	2J	ND
	Apr-98	ND	ND	ND	ND	ND	ND	ND	ND	280	ND
2-3 (MW2-003)	Aug-94	3,700	16	6.2	27	3,750	4.4	NA	NA	260	NA
	Jan-95	920	< 1	< 1	< 1	920	< 4	NA	NA	480	NA
	Oct-95	110	25	250	102	487	76	NA	NA	32	NA
	Aug-96	110	25	210	89	434	86	NA	NA	86	NA
	Apr-97	476	10.8	96.5	34.3	618	NA	NA	NA	1,120	NA
	May-97	459	9	42	13J	523J	4J	2,540	1,230	1,460	NA
	Jul-97	98	ND	11	6	115	ND	NA ^u	NA	1,630	NA
	Aug-97	28	ND	ND	ND	28	ND	NA	NA	2,150	NA
	Sep-97	14J	ND	17J	ND	31J	2J	123	1,100	370	23
	Nov-97	46	ND	ND	ND	46	ND	930J	ND	3,200	80J
	Dec-97	ND	ND	ND	ND	ND	ND	960J	ND	1,700	24J
	Jan-98	ND	ND	ND	ND	ND	ND	480	ND	370	ND
	Feb-98	ND	ND	ND	ND	ND	ND	310	ND	NA	NA
	Mar-98	ND	ND	ND	ND	ND	ND	100J	ND	370	6.9J
	Apr-98	4.9J	ND	ND	3.7J	8.6J	ND	ND	ND	230	ND
	Jun-98	1J	ND	ND	ND	1J	ND	270	ND	150	ND
2-4 (MW2-004)	Jan-94	6,500	16,000	1,700	8,700	32,900	470	NA	NA	1,100	NA
	Oct-95	6,500	13,000	1,700	10,100	31,300	1,000	NA	NA	800	NA
	Aug-96	9,800	14,000	1,700	9,100	34,600	940	NA	NA	< 500	NA
	Apr-97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	May-97	8,410	11,400	1,060	5,280	26,200	145	76,900	3,060	216	NA
	Sep-97	140	34	8	44	226	5J	273	3,900	2,300	21
	Dec-97	ND	ND	ND	ND	ND	ND	ND	NA	35	ND
2-50B (MW2-050B)	Jan-94	15,000	24,000	2,000	9,200	50,200	410	NA	NA	< 500	NA
	Aug-96	12,000	17,000	2,200	9,300	40,500	980	NA	NA	< 500	NA
	Apr-97	14,200	17,500	1,800	9,240	42,700	NA	NA	NA	ND	NA
2-51B (MW2-051B)	Jan-94	1,400	17	23	51	1,490	5.6	NA	NA	15	NA
	Jan-95	530	6	18	11	565	3	NA	NA	< 10	NA
	Oct-95	1,100	ND	90	ND	1,190	ND	NA	NA	ND	NA
	Aug-96	81	< 5	8	15	104	24	NA	NA	< 5	NA
	Apr-97	182	2.5	25.8	36.2	247	NA	NA	NA	ND	NA
	May-97	240	ND	15	11	266	ND	2,320	8,470	ND	NA
	Jul-97	395	ND	44	10	449	5J	NA	NA	13	NA
	Aug-97	245	ND	48	8	301	6J	NA	NA	15	NA
	Sep-97	340	4J	11	4J	351J	6J	ND	420	2J	ND
	Nov-97	500	ND	28	ND	528	6J	3,100	2,300	ND	ND
	Dec-97	200	2J	5J	2J	209J	ND	2,000	1,800	ND	ND
	Jan-98	450	ND	11	ND	461	ND	3,700	2,500	ND	ND
	Feb-98	NA	NA	NA	NA	NA	ND	960	4,200	NA	NA
	Mar-98	28	ND	2.1	0.68	31	ND	340	2,200	1.4J	ND
	Apr-98	340	5.3J	7.8J	3.9J	357J	ND	1,400	2,800	3.4J	ND
	Jun-98	500	7J	26J	6.8J	540J	ND	3,600	4,100	ND	ND

TABLE 6.1 (Continued)
SUMMARY OF GROUNDWATER ANALYTICAL RESULTS
JANUARY 1994 TO JUNE 1998
AREA A RNA TS
TINKER AFB, OKLAHOMA

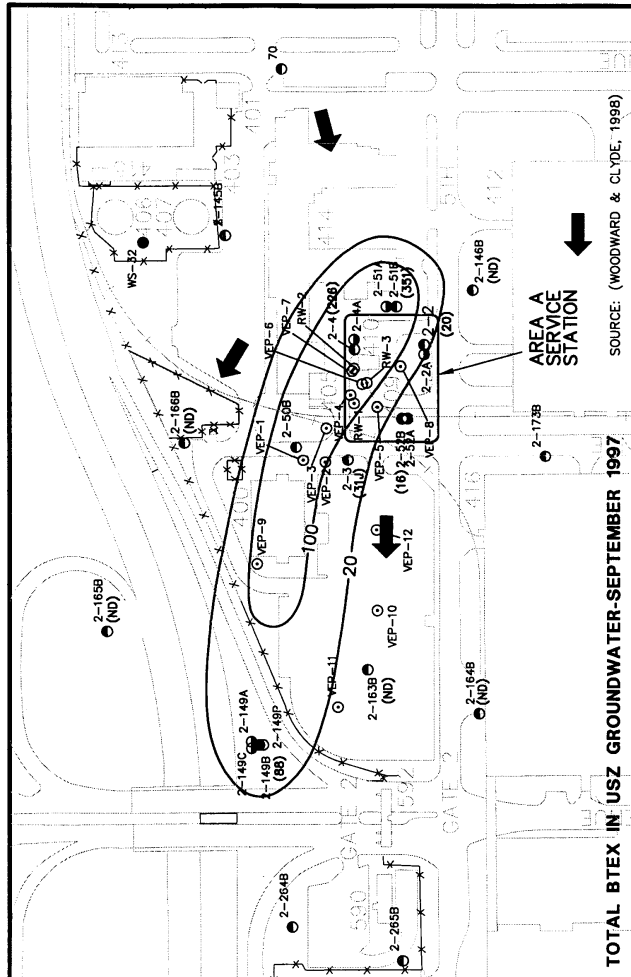
Location	Date Sampled	Benzene (µg/L) ^b	Toluene (µg/L)	Ethylbenzene (µg/L)	Total Xylenes (µg/L)	Total BTEX ^a (µg/L)	Naphthalene (SVOC) ^a (µg/L)	TPH GRO ^a (µg/L)	TPH DRO ^a (µg/L)	TCE ^a (µg/L)	MTBE ^a (µg/L)
MCL^c		5	1,000	700	— ^d	—	—	—	—	5	—
2-52B (MW2-052B)	Jan-94	< 5	< 5	< 5	< 5	ND	< 10	NA	NA	< 5	NA
	Jan-95	< 1	< 1	< 1	1	1	8	NA	NA	0.8	NA
	Oct-95	ND	ND	9	1	10	5	NA	NA	ND	NA
	Aug-96	< 1	< 1	< 1	< 1	ND	2	NA	NA	8	NA
	Apr-97	1	ND	2.2	ND	3.1	NA	NA	NA	ND	NA
	May-97	ND	NA	4J	ND	4J	2J	1,150	500	31	NA
	Sep-97	ND	NA	16	ND	16	3J	183	1,300	ND	ND
	Nov-97	ND	NA	ND	ND	ND	NA	ND	ND	75	NA
	Jan-98	ND	NA	ND	ND	ND	NA	ND	NA	25J	NA
2-145B (MW2-145B)	Jan-95	< 0.84	< 0.87	< 0.81	< 1.3	ND	< 0.57	NA	NA	< 0.92	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	1	NA
	Apr-97	ND	ND	2.7	< 1	2.7	NA	NA	NA	6.9	NA
	Sep-97	ND	ND	ND	ND	ND	ND	ND	ND	9	ND
	Nov-97	ND	ND	ND	ND	ND	ND	ND	ND	5	ND
	Jan-98	ND	ND	ND	ND	ND	ND	ND	ND	4J	ND
	Apr-98	ND	ND	ND	ND	ND	ND	ND	ND	4.1	ND
2-146B (MW2-146B)	Jan-95	< 0.84	< 0.87	< 0.81	< 1.3	ND	< 0.57	NA	NA	< 0.92	NA
	Aug-96	< 1	< 1	< 1	< 1	ND	< 1	NA	NA	0.8J	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	ND	NA
	May-97	ND	NA	ND	ND	ND	ND	ND	ND	ND	NA
	Sep-97	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Nov-97	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Jan-98	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-98	ND	NA	ND	ND	ND	ND	ND	ND	0.34J	ND
2-148B (MW2-148B)	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	11	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	5.7	NA
2-149B (MW2-149B)	Jan-95	< 0.84	< 0.87	< 0.81	< 1.3	ND	< 0.57	NA	NA	2.6	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	2	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	< 1	NA
	May-97	ND	13	2J	6	21J	ND	77	ND	ND	NA
	Jul-97	ND	15	29	185	229	ND	NA	NA	ND	NA
	Aug-97	ND	ND	5	47	52	7J	NA	NA	ND	NA
	Sep-97	ND	12	6	70	88	ND	218	141	ND	160
	Nov-97	ND	ND	ND	6J	6J	ND	ND	ND	ND	300
	Dec-97	ND	ND	ND	ND	ND	ND	110J	ND	ND	300
	Jan-98	ND	ND	ND	ND	ND	ND	ND	ND	ND	290
	Feb-98	NA	NA	NA	NA	NA	ND	ND	ND	NA	NA
	Mar-98	ND	ND	ND	ND	ND	ND	ND	ND	ND	180
	Apr-98	ND	ND	ND	ND	ND	ND	160	ND	ND	31
	Jun-98	ND	ND	ND	ND	ND	ND	ND	ND	ND	100
2-152B (MW2-152B)	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	ND	NA
2-163B (MW2-163B)	Jan-95	< 0.84	< 0.87	< 0.81	< 1.3	ND	< 0.57	NA	NA	4.1	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
	Aug-96	< 1	< 1	< 1	< 1	ND	< 1	NA	NA	< 1	NA
	Apr-97	< 1	ND	ND	ND	ND	NA	NA	NA	ND	NA
	May-97	ND	ND	ND	ND	ND	ND	66	ND	ND	NA
	Aug-97	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
	Sep-97	ND	ND	ND	ND	ND	ND	13	ND	ND	ND
	Nov-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Dec-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Jan-98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Feb-98	NA	NA	NA	NA	NA	ND	ND	ND	NA	ND
	Mar-98	0.96J	ND	ND	ND	0.96J	NA	NA	NA	ND	ND
	Apr-98	0.63J	ND	ND	ND	0.63J	NA	NA	NA	ND	ND
	Jun-98	8.9	0.63J	0.83J	ND	10.4J	NA	NA	NA	ND	ND

TABLE 6.1 (Continued)
SUMMARY OF GROUNDWATER ANALYTICAL RESULTS
JANUARY 1994 TO JUNE 1998
AREA A RNA TS
TINKER AFB, OKLAHOMA

Location	Date Sampled	Benzene (µg/L) ^{bi}	Toluene (µg/L)	Ethyl- benzene (µg/L)	Total Xylenes (µg/L)	Total BTEx ^{vi} (µg/L)	Naphthalene (SVOC) ^{vi} (µg/L)	TPH GRO ^v (µg/L)	TPH DRO ^v (µg/L)	TCE ^a (µg/L)	MTBE ^a (µg/L)
MCL ^{vi}		5	1,000	700	— ^d	—	—	—	—	5	—
2-164B (MW2-164B)	Jan-95	< 0.84	< 0.87	< 0.81	< 1.3	ND	< 0.57	NA	NA	< 0.92	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
	Aug-96	< 1	< 1	< 1	< 1	ND	< 1	NA	NA	< 1	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	< 1	NA
	May-97	ND	ND	ND	ND	ND	ND	93	ND	ND	NA
	Sep-97	ND	ND	ND	ND	ND	ND	ND	40	ND	ND
	Nov-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Jan-98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-165B (MW2-165B)	Jan-95	< 0.84	< 0.87	< 0.81	< 1.3	ND	< 0.57	NA	NA	< 0.92	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
	Aug-96	< 1	< 1	< 1	< 1	ND	< 1	NA	NA	< 1	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	ND	NA
	May-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA
	Jul-97	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
	Aug-97	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
	Sep-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Nov-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Dec-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Jan-98	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Feb-98	NA	NA	NA	NA	NA	ND	ND	ND	NA	NA
	Mar-98	NA	NA	NA	NA	NA	ND	ND	ND	ND	ND
	Apr-98	NA	NA	NA	NA	NA	ND	170	ND	ND	ND
	Jun-98	NA	NA	NA	NA	NA	ND	ND	ND	ND	ND
2-166B (MW2-166B)	Jan-95	< 0.84	< 0.87	< 0.81	< 1.3	ND	< 0.57	NA	NA	10.2	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	6	NA
	Aug-96	< 1	< 1	< 1	0.9J	0.9J	< 1	NA	NA	10	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	7.7	NA
	May-97	ND	ND	ND	ND	ND	ND	ND	ND	6	NA
	Sep-97	ND	ND	ND	ND	ND	ND	ND	ND	8	ND
	Nov-97	ND	ND	ND	ND	ND	ND	ND	ND	6	ND
	Jan-98	ND	ND	ND	ND	ND	ND	ND	ND	3J	ND
	Apr-98	ND	ND	ND	ND	ND	ND	ND	ND	3.3	ND
2-173B (MW2-173B)	Jan-95	< 0.84	< 0.87	< 0.81	< 1.3	ND	< 0.57	NA	NA	2.4	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	ND	NA
	Sep-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Nov-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Jan-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	ND	ND	ND	ND	ND	ND	200	ND	ND	ND
2-264B (MW2-264B)	Aug-96	< 0.8	< 0.8	< 0.5	< 0.5	ND	< 0.8	NA	NA	< 0.8	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	ND	NA
2-265B (MW2-265B)	Aug-96	< 0.8	< 0.8	< 0.5	< 0.5	ND	< 0.8	NA	NA	< 0.8	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	ND	NA
70 (MW-70)	Jan-95	< 1	< 1	< 1	< 1	ND	< 4	NA	NA	< 1	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	< 1	NA
VEP-9	Apr-97	3690	292	375	359	4,720	NA	NA	NA	ND	NA
VEP-10	Apr-97	50	6	11	13	80	NA	NA	NA	252	NA
VEP-11	Apr-97	18	4	8	8	38	NA	NA	NA	5.5	NA
VEP-12	Apr-97	313	16	38	25	392	NA	NA	NA	13.9	NA

TABLE 6.1 (Concluded)
SUMMARY OF GROUNDWATER ANALYTICAL RESULTS
JANUARY 1994 TO JUNE 1998
AREA A RNAs
TINKER AFB, OKLAHOMA

Location	Date Sampled	Benzene (µg/L) ^b	Toluene (µg/L)	Ethyl- benzene (µg/L)	Total Xylenes (µg/L)	Total BTEX ^a (µg/L)	Naphthalene (SVOC) ^a (µg/L)	TPH GRO ^a (µg/L)	TPH DRO ^a (µg/L)	TCE ^a (µg/L)	MTBE ^a (µg/L)
MCL^c		5	1,000	700	— ^d	—	—	—	—	5	—
Lower Saturated Zone											
2-2A (MW2-002A)	Jan-94	< 5	< 5	< 5	< 5	ND	< 10	NA	NA	6.8	NA
	Jan-95	< 1	< 1	< 1	< 1	ND	< 4	NA	NA	32	NA
	Oct-95	< 5	ND	ND	ND	ND	ND	NA	NA	120	NA
	Aug-96	< 5	< 5	< 5	< 5	ND	< 5	NA	NA	31	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	54.8	NA
2-4A (MW2-004A)	Jan-94	< 5	< 5	< 5	< 5	ND	< 10	NA	NA	13	NA
	Jan-95	< 1	< 1	< 1	< 1	ND	< 4	NA	NA	38	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	53	NA
	Aug-96	< 2	< 2	< 2	< 2	ND	< 2	NA	NA	45	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	39.9	NA
2-51A	Jan-94	< 5	2.6J	< 5	< 5	2.6J	< 10	NA	NA	29	NA
	Jan-95	< 1	< 1	< 1	< 1	ND	< 4	NA	NA	130E	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	85	NA
2-52A	Jan-94	< 5	< 5	< 5	< 5	ND	< 10	NA	NA	15	NA
	Jan-95	< 1	< 1	< 1	< 1	ND	< 4	NA	NA	36	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	45	NA
2-148A (MW2-148A)	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	16	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	17.3	NA
2-149A (MW2-149A)	Jan-95	10.5	2.5	1.1	< 1.3	14.1	< 0.57	NA	NA	< 0.92	NA
	Oct-95	ND	1	ND	ND	1	ND	NA	NA	ND	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	< 1	NA
2-152A (MW2-152A)	Jan-94	< 5	< 5	< 5	< 5	ND	< 10	NA	NA	15	NA
	Jan-95	< 1	< 1	< 1	< 1	ND	< 4	NA	NA	36	NA
	Oct-95	ND	ND	ND	ND	ND	ND	NA	NA	ND	NA
	Apr-97	ND	ND	ND	ND	ND	NA	NA	NA	ND	NA
2-151A (MW2-151A)	Jan-94	< 5	2.6	< 5	< 5	2.6	< 10	NA	NA	29	NA
	Jan-95	< 1	< 1	< 1	< 1	ND	< 4	NA	NA	130	NA
^a BTEX = total benzene, toluene, ethylbenzene, and xylene concentration, SVOC = semi-volatile organic compounds, TPH = total petroleum hydrocarbons, GRO = gas range organics, DRO = diesel range organics, TCE = trichloroethene, MTBE = methyl tertiary butyl ether. ^b µg/L = micrograms per liter. ^c MCL = Maximum contaminant level, U.S. EPA Primary Drinking Water Regulations, May 14, 1996. ^d — = No standard listed. ^e NA = not analyzed. ^f ND = not detected.											



TOTAL BTEX IN USZ GROUNDWATER-MAY 1997

SOURCE: (PARSONS ES)

AREA A
SERVICE
STATION

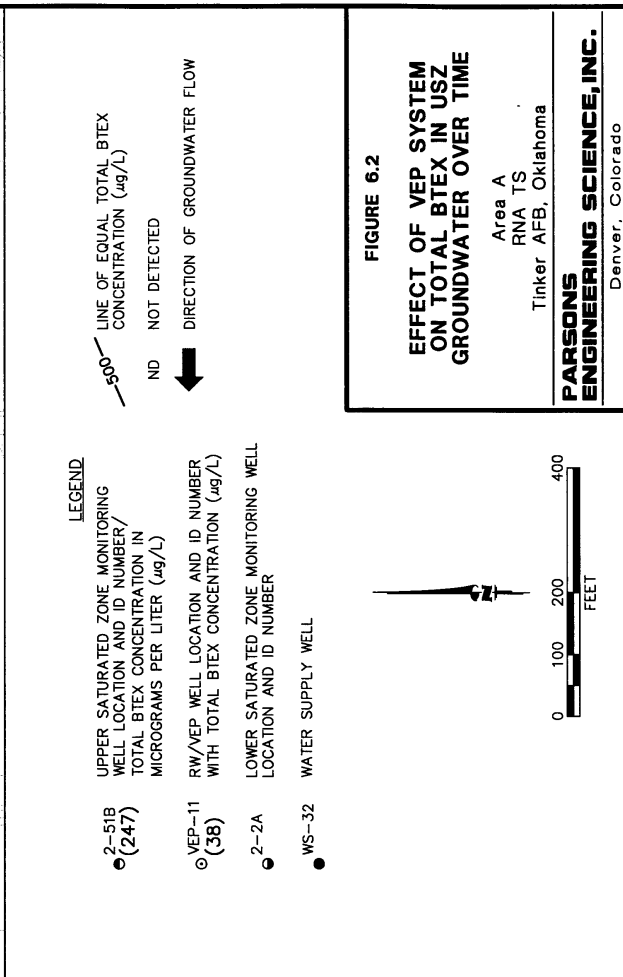
SOURCE: (WOODWARD & CLYDE, 1998)

AREA A
SERVICE
STATION

TOTAL BTEX IN USZ GROUNDWATER-SEPTEMBER 1997

SOURCE: (WOODWARD & CLYDE, 1998)

AREA A
SERVICE
STATION



TOTAL BTEX IN USZ GROUNDWATER-JANUARY 1998

SOURCE: (WOODWARD & CLYDE, 1998)

AREA A
SERVICE
STATION

AREA A
SERVICE
STATION

LEGEND

- 2-51B (247) UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER/ TOTAL BTEX CONCENTRATION IN MICROGRAMS PER LITER ($\mu\text{g/L}$)
- VEP-11 (38) RW/VEP WELL LOCATION AND ID NUMBER WITH TOTAL BTEX CONCENTRATION ($\mu\text{g/L}$)
- 2-2A LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- WS-32 WATER SUPPLY WELL

500 LINE OF EQUAL TOTAL BTEX CONCENTRATION ($\mu\text{g/L}$)

ND NOT DETECTED

DIRECTION OF GROUNDWATER FLOW

FIGURE 6.2

EFFECT OF VEP SYSTEM ON TOTAL BTEX IN USZ GROUNDWATER OVER TIME

Area A
RNA TS
Tinker AFB, Oklahoma

**PARSONS
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Denver, Colorado

although low concentrations of BTEX (less than 20 µg/L) were detected at wells 2-3 and 2-163B (Table 6.1).

The temporal trends in BTEX concentrations at Area A, between May 1997 and June 1998 are presented on Figure 6.3. BTEX concentrations were significantly reduced to levels below detection at wells 2-2, 2-4, and 2-52B. Concentrations were also significantly reduced at well 2-3, although low concentrations (less than 20 µg/L) persist at that location. Well 2-51B is the only location not responding to the VEP system. BTEX concentrations at 2-51B have increased from 266 µg/L in May 1997 to 540J µg/L in June 1998. Well 2-51B is located on the upgradient edge of the source area, and approximately 100 feet from the nearest VEP wells (VEP-7 and VEP-8, Figure 6.1). The VEP system radius of influence apparently does not reach well location 2-51B.

Benzene was detected in five of the thirteen monitoring wells sampled between May 1997 and June 1998 (2-2, 2-3, 2-4, 2-51B, and 2-163B). Wells 2-2, 2-3, 2-4, and 2-51B are close to the former UST locations at Area A, and monitoring well 2-163B is downgradient of the source area. Benzene concentrations decreased to non-detectable levels by January 1998 in two of the five monitoring wells where benzene was detected (2-2 and 2-4) (Table 6.1). The most significant decrease in concentration was observed at monitoring well 2-4, where benzene was reduced from 8,410 µg/L (May 1997) to non-detectable levels by December 1997. While concentrations at monitoring well 2-3 have decreased significantly, trace benzene concentrations were detected in April 1998 and in June 1998. Benzene was not detected at 2-163B until the second quarter of monitoring associated with the VEP system. Benzene concentrations at monitoring well 2-51B are variable and have fluctuated between 28 µg/L (March 1998) and 500 µg/L (June 1998) showing no decreasing temporal trend.

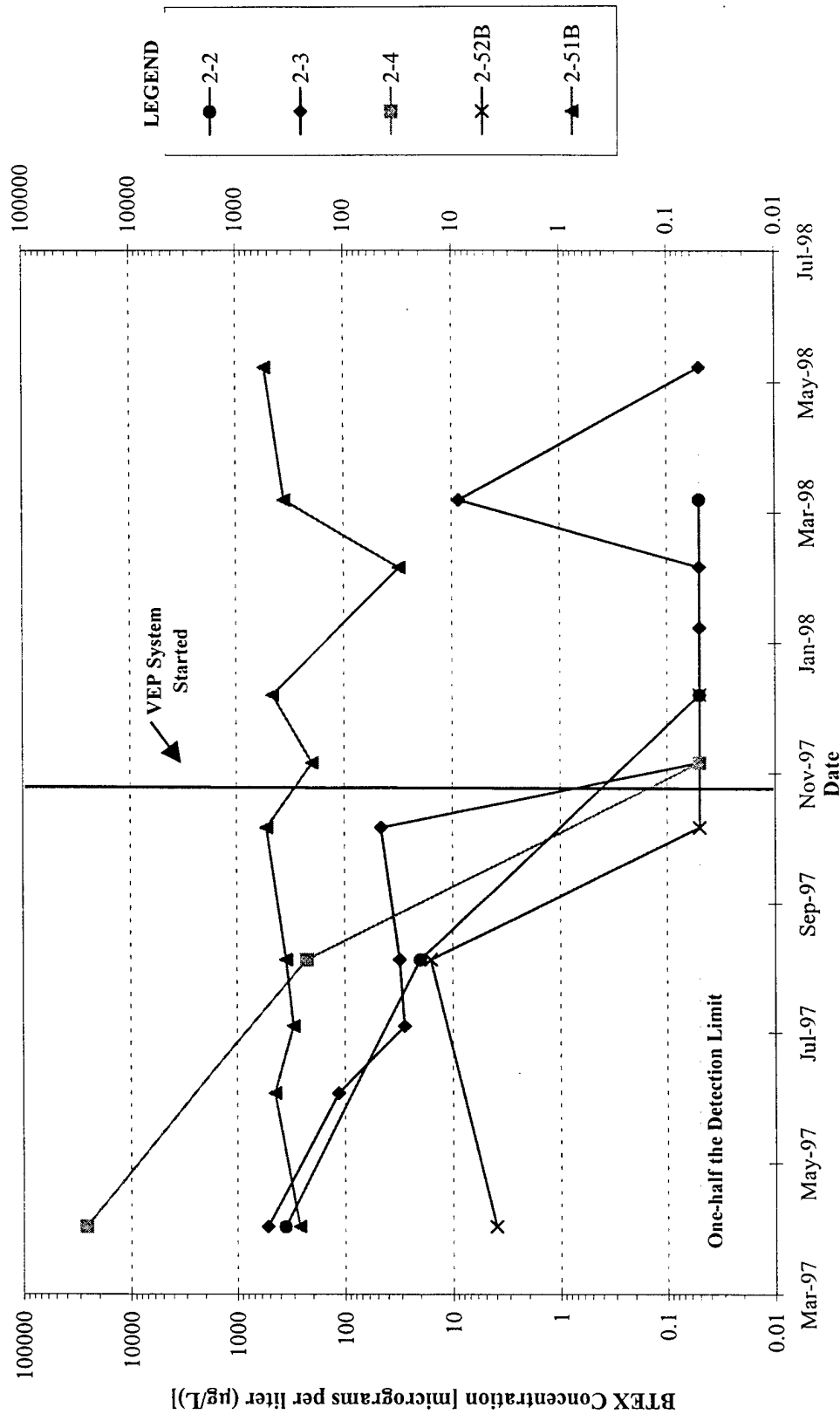
6.2.2 Naphthalene

Between May 1997 and November 1997, naphthalene was detected at concentrations ranging from 2J (2-52B) to 145 µg/L (2-4), in six of the thirteen monitoring wells sampled in conjunction with the VEP system at Area A (Table 6.1). In May 1997, monitoring well 2-4 had the highest concentrations of naphthalene, BTEX, and TPH; however, after September 1997, neither naphthalene, BTEX, nor TPH-GRO was detected at this groundwater sampling location. After November 1997, naphthalene was not detected in any of the eleven monitoring wells sampled at Area A.

6.2.3 Total Petroleum Hydrocarbons

TPH-GRO was detected in nine of the thirteen monitoring wells sampled in conjunction with the VEP system at Area A between May 1997 and June 1998 (2-2, 2-3, 2-4, 2-51B, 2-52B, 2-149B, 2-163B, 2-164B, and 2-165B) (Table 6.1). At the most contaminated sampling location (2-4), TPH-GRO was reduced from 76,900 µg/L (May 1997) to non-detectable levels by December 1997. Concentrations of TPH-GRO were reduced to non-detectable levels in five additional monitoring wells by December 1997. TPH-GRO was detected at monitoring wells 2-149B and 2-165B only once between December 1997 and June 1998. TPH-GRO concentrations at monitoring well 2-3 are variable, but show an overall decrease from 2,540 µg/L in May 1997 to 270 µg/L in June

FIGURE 6.3
DISSOLVED TOTAL BTEX CONCENTRATIONS OVER TIME
AT SELECT GROUNDWATER SAMPLING LOCATIONS
AREA A RNA TS
TINKER AFB, OKLAHOMA



1998. Concentrations of TPH-GRO at well 2-51B are variable and do not show any decreasing temporal trend, possibly the result of being located outside the radius of influence of the VEP system.

TPH-DRO was detected in seven of the thirteen monitoring wells sampled in conjunction with VEP system monitoring at Area A between May 1997 and June 1998 (2-2, 2-3, 2-4, 2-51B, 2-52B, 2-149B, and 2-164B) (Table 6.1). Concentrations of TPH-DRO were reduced to non-detectable levels in five of the seven contaminated monitoring wells by January 1998. TPH-DRO concentrations at monitoring well 2-51B are variable, ranging between 420 µg/L (September 1997) and 8,470 µg/L (May 1998), and do not show a temporal decreasing trend. At well 2-4, no TPH-DRO analyses were performed after September 1997, and there are insufficient data to conclude that concentrations at this sampling location have been reduced to non-detectable levels.

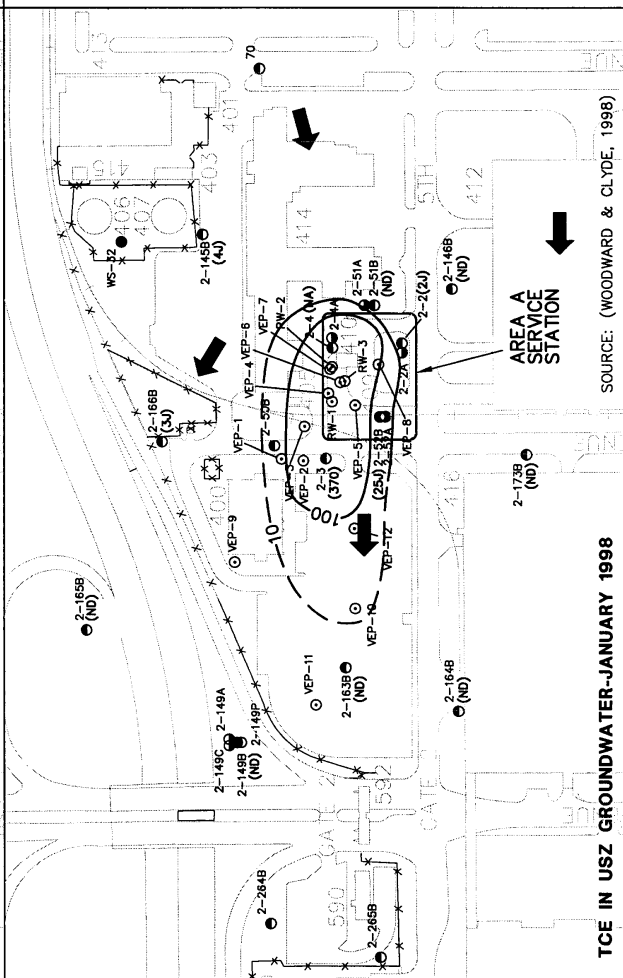
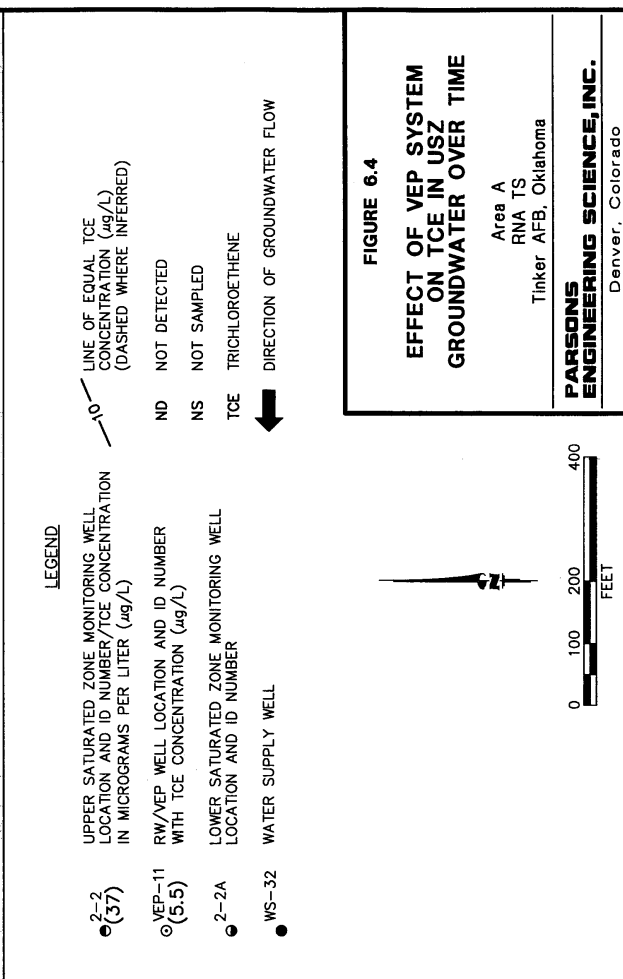
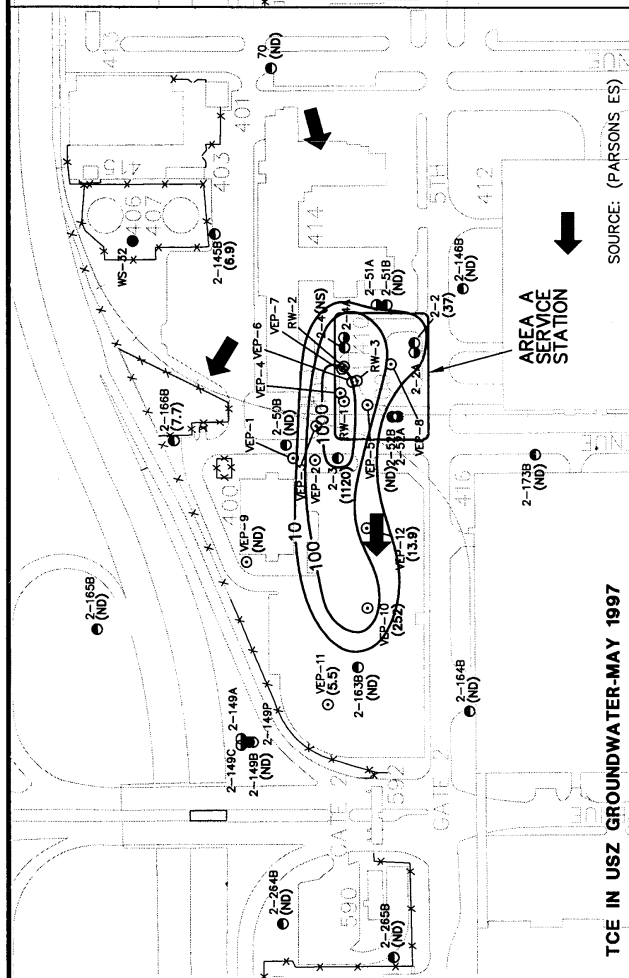
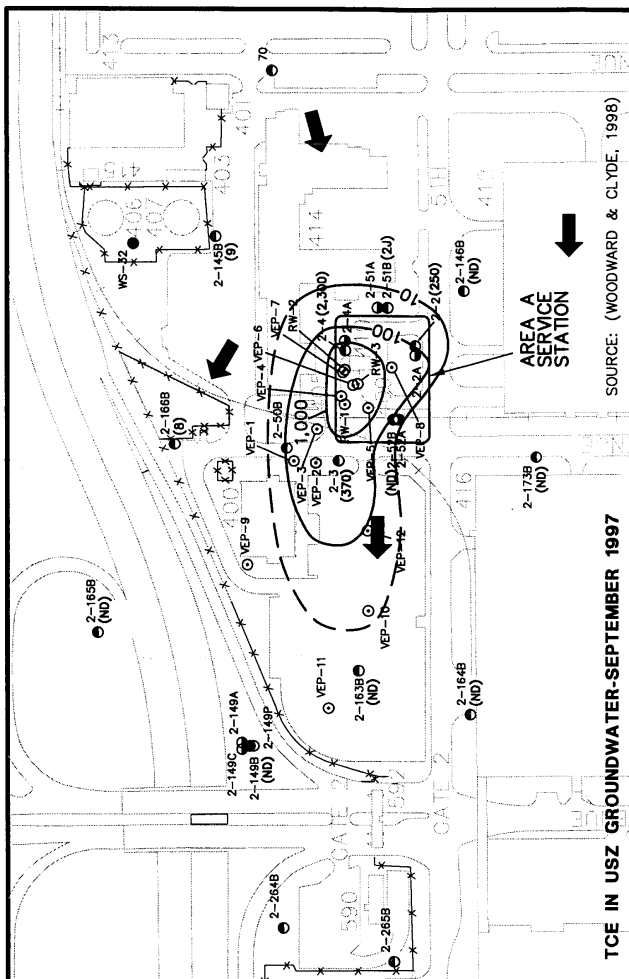
6.2.4 TCE

TCE was detected at concentrations ranging from 3,200 µg/L to 3J µg/L in eight of the thirteen monitoring wells sampled in conjunction with VEP system monitoring at Area A between May 1997 and June 1998 (2-2, 2-3, 2-4, 2-51B, 2-52B, 2-145B, 2-146B, and 2-166B) (Table 6.1). The distributions of TCE in May 1997, September 1997, and January 1998 are shown on Figure 6.4. The overall extent of the TCE plume is stable with an overall decrease in concentrations between May 1997 and June 1998. However, the TCE plume has not receded or decreased in concentration as rapidly as BTEX at the site. Low concentrations of TCE in wells 2-145B, 2-146B, and 1-166B are likely a result of a source upgradient from Area A.

Temporal trends of TCE at select Area A monitoring wells are presented on Figure 6.5. TCE concentrations in wells located in the general source area (2-2, 2-3, 2-4, 2-51B, and 2-52B) have been relatively erratic. TCE concentrations at monitoring well 2-2 have varied between 2J µg/L to 280 µg/L, with the higher concentration measured more recently in June 1998. TCE concentrations at monitoring well 2-3 have been erratic, with concentrations increasing to a maximum of 3,200 µg/L in November 1997, then decreasing to 150 µg/L in June 1998. Likewise, TCE concentrations at well 2-4 increased to 2,300 µg/L in September 1997, before decreasing to 35 µg/L in December 1997. TCE concentrations at wells 2-51B and 2-52B also demonstrate no clear trends.

6.2.5 MTBE

In September 1997, MTBE was added to the target analyte list for quarterly compliance groundwater monitoring. MTBE was detected in two of the twelve monitoring wells sampled between September 1997 and June 1998. MTBE was detected at well 2-3 located immediately downgradient of the source area, and at well 2-149B located on the downgradient edge of the BTEX plume as identified in September 1997 (Figure 6.2). MTBE concentrations at monitoring well 2-3 have generally decreased with time, from a maximum of 80J µg/L in November 1997, to below detection limits in April and June 1998. At well 2-149B, MTBE concentrations are variable, ranging from 300 µg/L in November and December 1997 to 31 µg/L in April 1998. Concentrations from the most recent sampling events indicate decreasing concentrations of MTBE at well



LEGEND

UPPER SATURATED ZONE MONITORING WELL
LOCATION AND ID NUMBER/TCE CONCENTRATION
IN MICROGRAMS PER LITER (µg/L)
(DASHED WHERE INFERRED)

2-2
(37)

RW/VEP WELL LOCATION AND ID NUMBER
WITH TCE CONCENTRATION (µg/L)

VEP-11
(5.5)

LOWER SATURATED ZONE MONITORING WELL
LOCATION AND ID NUMBER

2-2A

WATER SUPPLY WELL

WS-32

ND NOT DETECTED

NS NOT SAMPLED

TCE TRICHLOROETHENE

DIRECTION OF GROUNDWATER FLOW

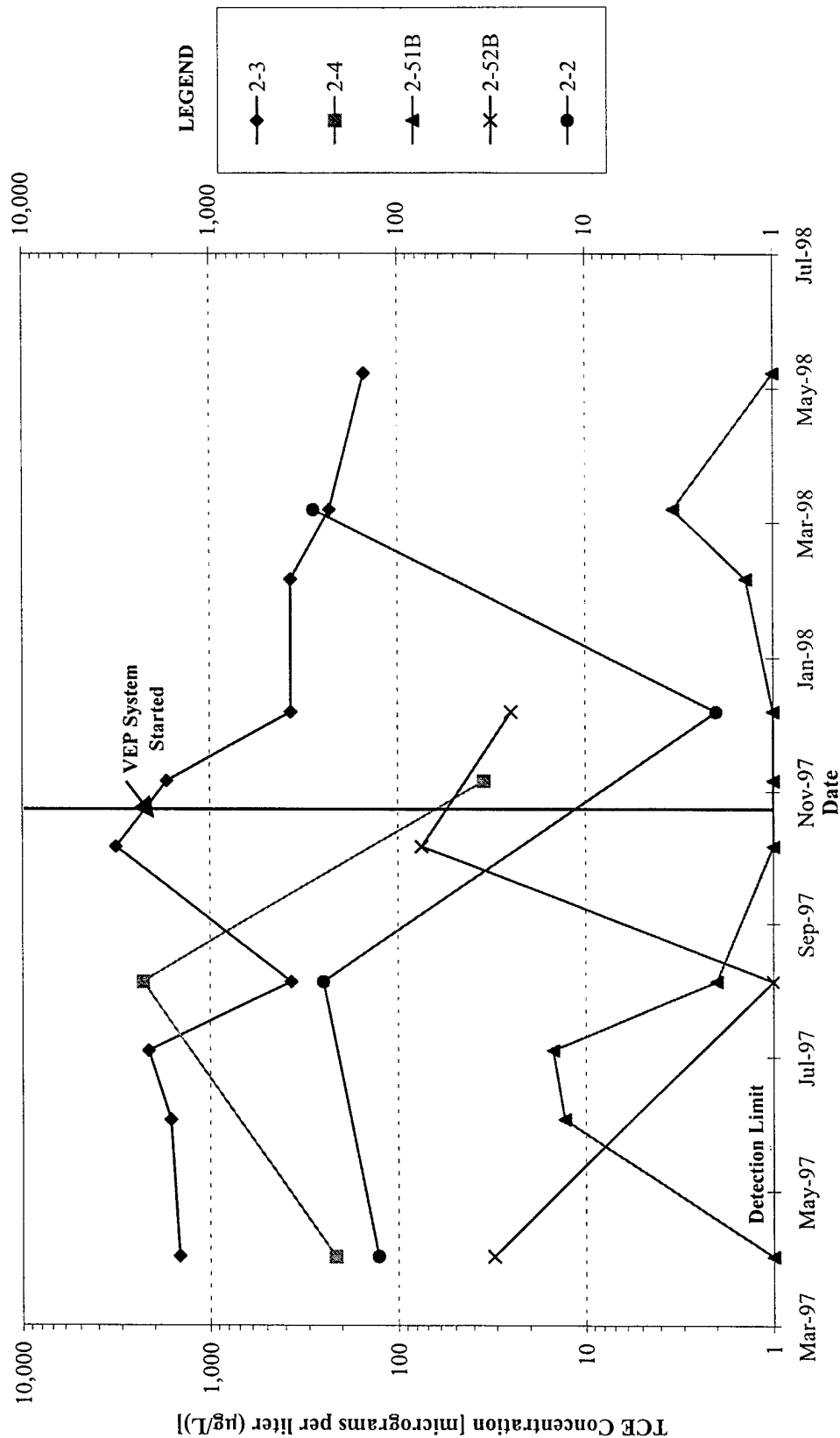
FIGURE 6.4

EFFECT OF VEP SYSTEM ON TCE IN USZ GROUNDWATER OVER TIME

Area A
RNA TS
Tinker AFB, Oklahoma

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Denver, Colorado

FIGURE 6.5
DISSOLVED TCE CONCENTRATIONS OVER TIME
AT SELECT GROUNDWATER SAMPLING LOCATIONS
AREA A RNA TS
TINKER AFB, OKLAHOMA



2-149B. MTBE migrates at higher velocities (i.e., is less retarded) and is more recalcitrant to biodegradation relative to BTEX and CAHS. Therefore, elevated MTBE concentrations at well 2-149B are likely a result of the unique physical and chemical properties of MTBE. Containment of MTBE in the source area should reduce MTBE concentrations in downgradient portions of the plume over time.

6.3 CONCLUSIONS

Groundwater concentrations of BTEX, TPH, and naphthalene have been effectively reduced by the VEP system at Area A. Natural attenuation processes should further reduce any low concentrations of BTEX detected at downgradient locations (i.e., wells 2-149B and 2-163B), particularly as the source of BTEX is being remediated. The VEP system is less effective at reducing TCE concentrations, although an overall reduction has been observed. Analytical data collected between November 1997 and June 1998 indicate the VEP system is reducing TCE contaminant concentrations at Area A, albeit at a slower rate relative to BTEX. Factors that may account for differences in the VEP system effectiveness for reducing TCE concentrations relative to BTEX include volatilization, sorption, biodegradation, and source area locations.

Volatilization from groundwater to the vapor phase is expected to be similar for TCE and the BTEX compounds based on their similar vapor pressures and Henry's Law constants. The sorption coefficient of TCE (K_{oc} of 107 L/kg) is also similar, being between benzene (K_{oc} of 79 L/kg) and the average of all the BTEX compounds (K_{oc} of 283 L/kg) (Table 5.2). Given a similar distribution of BTEX and TCE in soil and groundwater, volatilization and sorption are not expected to account for the difference between VEP system effectiveness for BTEX removal versus that for TCE removal.

Biodegradation of BTEX compounds in groundwater at Area A consumed dissolved oxygen and generated anaerobic conditions prior to VEP system installation. These anaerobic conditions in turn promoted reductive dehalogenation of TCE within the BTEX plume. The VEP system enhanced aerobic BTEX biodegradation by adding atmospheric oxygen to the USZ groundwater system and shifting the subsurface redox conditions from anaerobic to aerobic. This approach is effective for BTEX compounds, which degrade more rapidly in the presence of oxygen. However, the increase in dissolved oxygen within the BTEX plume apparently decreased reductive dehalogenation rates for TCE. Aerobic TCE degradation occurs at a much slower rate than reductive dehalogenation, although TCE may still degrade by cometabolic processes under aerobic conditions. The introduction of oxygen, and the resulting shift to aerobic subsurface redox conditions, caused by the VEP system likely explains at least part of the difference between VEP system efficiency for BTEX removal versus that for TCE removal.

A difference in locations for the BTEX and TCE sources may also explain in part the difference in VEP system effectiveness. During the VEP system trial period, BTEX concentrations near the former USTs (presumed BTEX source area) decreased through time. This observation is consistent with expectations that the VEP system was extracting mass from an area of maximum BTEX concentrations (source area). However, TCE concentrations at wells 2-2, 2-3, and 2-4 increased during the VEP system trial operation from June 1997 to November 1997. These increased TCE concentrations may

indicate the presence of a separate TCE source area, from which the VEP system extracted groundwater with higher TCE concentrations.

Relatively high concentrations of both TCE and BTEX detected at wells 2-4 and 2-51B, located on the upgradient portion of the BTEX source area, may indicate the VEP system radius of influence is not extending to the upgradient portion of the source area. Additional long term monitoring (LTM) at most of the compliance wells and some additional site related wells is suggested to further evaluate the effectiveness of source control measures and to monitor the migration of site-related contaminants (TCE in particular).

SECTION 7

REMEDIAL EVALUATION AND COST COMPARISON

The objective of this report was to determine the effectiveness of natural attenuation in controlling the fate and transport of fuel hydrocarbons and CAHs at Area A. The VEP source control remediation system at Area A has effectively controlled and reduced BTEX contamination in groundwater. The system has been less effective in reducing CAH concentrations (i.e., TCE), but it is anticipated to do so given sufficient time. To evaluate the relative advantages of RNA and the VEP system for remediation of TCE, a comparison between two remedial alternatives was performed. Alternative 1 is RNA with long term groundwater monitoring, assuming no source control measures; and Alternative 2 is operation of the VEP system. Although Alternative 1 can no longer be implemented as presented herein due to geochemical changes induced by operation of the VEP system, it is included for comparison purposes.

7.1 EVALUATION CRITERIA

7.1.1 Effectiveness, Implementability and Cost

The comparative analysis of the two remedial alternatives is based on effectiveness and implementability. Both remedial alternatives should effectively reduce potential hydrocarbon migration and toxicity in groundwater. Both alternatives should be acceptable to the public and regulatory agencies, because they are protective of human health and the environment and reduce groundwater contamination. However, both of the alternatives have implementability concerns. The total cost (present worth) of both alternatives was estimated following USEPA (1993) guidance. An estimate of capital costs, and operations and post-implementation costs for site monitoring and controls are included. An annual adjustment (discount) factor of seven percent was assumed in present-worth calculations (USEPA, 1993). The discount rate is the difference between the rate of inflation and the cost of money.

7.1.2 Remedial Action Objectives

Remedial action objectives (RAOs) developed to protect potential receptors at Area A are listed in Table 7.1. The Oklahoma Corporation Commission (OCC) is currently regulating BTEX and naphthalene at Area A, and RAOs listed for the site include OCC Oklahoma Risk-Based Corrective Action (ORBCA) Tier 1 and Tier 1A risk-based screening levels (RBSLs) developed for BTEX and naphthalene (Parsons ES 1999). The Tier 1/1A RBSLs were developed for the commercial worker and the construction worker. For the commercial worker, sub-surface soil and shallow groundwater inhalation and dermal contact scenarios were considered. For the construction worker, sub-surface

TABLE 7.1
GROUNDWATER QUALITY STANDARDS
AREA A RNA TS
TINKER AFB, OKLAHOMA

Compound	ORBCA ^{a/} Tier 1 (µg/L) ^{c/}	ORBCA Tier 1A (µg/L)	USEPA MCL ^{b/} (µg/L)
Benzene	239	239	5
Toluene	17,896	254,150	1,000
Ethylbenzene	5,441	127,070	700
Total Xylenes	100,664	2,541,490	10,000
Naphthalene	2,334	50,830	-
Tetrachloroethene	-	-	5
Trichloroethene	-	-	5
<i>cis</i> -1,2-Dichloroethene	-	-	70
<i>Trans</i> -1,2-Dichloroethene	-	-	100
Vinyl Chloride	-	-	2
1,1-Dichloroethane	-	-	5

a/ ORBCA RBSL = Oklahoma Risk-Based Corrective Action Tier 1 and Tier 1A Risk-Based Screening Levels for Tinker AFB, Area A (Parsons ES, 1999).

b/ USEPA MCL = US Environmental Protection Agency (1996) Maximum Contaminant Level.

c/ µg/L = micrograms per liter.

soil and shallow groundwater ingestion, inhalation, and dermal contact scenarios were evaluated. Groundwater pathways for the on-base and off-base resident child, resident adult, and commercial worker are considered incomplete, and soil exposure pathways for the resident child and adult are also considered incomplete. ORBCA RBSLs do not consider groundwater at the site a source for drinking water.

CAHS at the site are subject to ODEQ contaminant standards. RAOs for CAHs used, and listed, for comparison in this report are based on USEPA MCLs for drinking water (USEPA, 1996). Drinking water MCLs are also listed for BTEX and naphthalene for comparison to ORBCA standards.

7.2 ALTERNATIVE 1 - RNA WITH LTM

7.2.1 Alternative 1 - Effectiveness

Alternative 1 relies entirely on natural attenuation mechanisms that minimize contaminant migration and reduce contaminant mass over time. To evaluate the long-term effectiveness of RNA at Area A for TCE, the calibrated flow and transport model presented in Section 5 was used to predict the future extent and persistence of TCE groundwater contamination. The calibrated model was used to simulate the migration and degradation of the TCE plume assuming that only natural physical weathering (e.g., dissolution, volatilization, biodegradation) decreases TCE loading in the source area. Model results indicate that elevated dissolved TCE concentrations may persist for more than 50 years if the source area "hotspot" is not remediated (Figure 5.5). Downgradient plume migration is predicted to be negligible, because the plume is stable under current conditions and is unlikely to impact potential downgradient receptors. However, because TCE has been detected in LSZ wells 2-2A, 2-4A, 2-51A, and 2-52A, there is potential for migration of TCE to lower aquifer zones.

The effectiveness of this remedial alternative requires that only properly protected site workers conduct future intrusive site activities or construction activities within the source area. Reasonable land use assumptions for the plume area indicate that exposure is unlikely unless excavation or drilling activities bring contaminated soil and/or groundwater to the surface. Existing health and safety plans should therefore be enforced to reduce worker exposure during any site excavation or installing and monitoring additional wells. Long-term land use restrictions would also be required to ensure that shallow groundwater is not pumped or removed for potable use within a radius of approximately 500 feet from the margins of the existing CAH plume.

7.2.2 Alternative 1 - Implementability

Alternative 1 is not technically difficult to implement. Long-term management efforts would be required to ensure proper sampling and analysis procedures are followed. Periodic site reviews should be conducted to confirm the adequacy and completeness of LTM data and verify the effectiveness of this remediation approach. The following Section provides a recommended LTM plan.

7.2.2.1 Alternative 1 LTM Plan Overview

The objectives of the LTM are as follows:

- Assess site conditions over time;
- Confirm the effectiveness of source control measures and naturally occurring processes at reducing contaminant mass and minimizing contaminant migration;
- Evaluate the need for additional remediation.

For planning and budgeting purposes, the Alternative 1 LTM plan for Area A assumes a 50-year monitoring period. This plan was devised on the basis of analytical data collected in May 1997 (prior to activation of VEP source control system) and model results discussed in Section 5. The LTM strategy is designed to monitor plume migration over time and to verify that RNA is occurring at rates sufficient to protect potential receptors and eventually meet the site RAOs (Table 7.1). In the event that data collected under this LTM program indicate that naturally occurring and engineered processes are insufficient to protect human health and the environment, additional engineered controls to more aggressively remediate the dissolved BTEX and CAH plumes would be necessary.

7.2.2.2 LTM Sampling Strategy

Seventeen monitoring wells should initially be included in the LTM program. This includes eleven monitoring wells currently utilized as VEP compliance monitoring wells (2-2, 2-3, 2-4, 2-51B, 2-52B, 2-146B, 2-149B, 2-163B, 2-164B, 2-165B, and 2-166B), one centrally located well not included with VEP compliance monitoring (2-50B), and five LSZ monitoring wells (2-2A, 2-4A, 2-51A, 2-52A, and 2-149A) (Figure 7.1). The wells targeted for sampling should be reevaluated as additional LTM data are collected, and wells should be added to or dropped from the LTM program as appropriate.

7.2.2.3 Sampling Duration and Frequency

Based on predictive model results, the estimated time frame for TCE concentrations to decrease below the USEPA MCL is greater than 50 years. A minimum of 50 years of monitoring may therefore be required to accomplish the LTM objectives listed in Section 7.2.2.1. Each of the LTM wells would be sampled annually for 50 years to monitor plume migration and to ensure that potential downgradient receptors are not endangered by discontinuation of groundwater recovery.

7.2.2.4 Analytical Protocol

All LTM wells will be sampled and analyzed to verify the effectiveness of naturally occurring remediation processes at the site. At the beginning of each sampling event, water levels should be measured in all site monitoring wells. Groundwater samples collected from the LTM wells should be analyzed for the parameters listed in Table 7.2. A site-specific SAP should be prepared as part of a remedial action plan prior to initiating the LTM program.

TABLE 7.2
LONG-TERM MONITORING ANALYTICAL PROTOCOL FOR GROUNDWATER
AREA A RNA TS
TINKER AFB, OKLAHOMA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Temperature	E170.1, direct-reading meter	Field only, measure at well-head.	Metabolism rates for microorganisms depend on temperature.	Each sampling event	Measure at well-head using a flow-through cell.	Field
Dissolved Oxygen	Dissolved oxygen meter	Measure at well-head, Refer to Method A4500 for a comparable laboratory procedure	Concentrations less than 1 mg/L generally indicate an anaerobic pathway.	Each sampling event	Collect water during purging in a flow-through cell or plastic container; analyze immediately.	Field
pH	E150.1/SW9040, direct reading meter	Measure at well-head. Protocols/ Handbook methods ^{a/}	Aerobic and anaerobic processes are pH-sensitive.	Each sampling event	Collect 100–250 mL of water in a glass or plastic container; analyze immediately, or measure at well-head using a flow-through cell.	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system.	Each sampling event	Collect 100–250 mL of water in a glass or plastic container and analyze immediately, or measure at well-head using a flow-through cell.	Field
Redox potential	A2580 B, direct reading meter.	Measurements are made with electrodes using a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the groundwater redox potential may range from 200 mV to less than -400 mV.	Each sampling event	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Ferrous Iron (Fe ²⁺)	Colorimetric A3500-Fe D or Colorimetric Hach® 25140-25	Field only, filter if turbid.	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction.	Each sampling event	Collect 100 mL of water in a glass container; acidify with hydrochloric acid per method	Field

TABLE 7.2 (Concluded)
LONG-TERM MONITORING ANALYTICAL PROTOCOL FOR GROUNDWATER
AREA A RNA TS
TINKER AFB, OKLAHOMA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Nitrate	IC method E300 or method SW9056; colorimetric method E353.2.	Method E300 is a Handbook method. Method SW9056 is an equivalent procedure.	Substrate for microbial respiration if oxygen is depleted.	Each sampling event	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base
Sulfate (SO ₄ ²⁻)	IC method E300 or method SW9056 or Hach® Sulfa Ver 4 method	Method E300 is a photometric Handbook method; method SW9056 is an equivalent procedure.	Substrate for anaerobic microbial respiration	Each sampling event	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for Hach® method)
Methane, Ethane, and Ethene	RSKSOP-114 modified to analyze water samples for methane by headspace sampling with dual thermal conductivity and flame ionization detection.	Method published and used by the USEPA Robert S. Kerr Laboratory	The presence of methane indicates the presence of sufficiently reducing conditions for reductive dehalogenation to occur	Each sampling event	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps (zero headspace); cool to 4°C	Fixed-base
Volatile Organics	GC/MS method SW8260B	Handbook method	Measured for regulatory compliance	Each sampling event	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH < 2	Fixed-base

a/ Protocol analytical methods are those presented by Wiedemeier *et al.* (1996a). Handbook refers to "AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigation/Feasibility Study (RI/FS).

7.2.2.5 Periodic LTM Plan Review

The LTM plan should be periodically reviewed and revised as appropriate on the basis of available groundwater quality data. If the data collected during the proposed time period support the effectiveness of the selected remedial alternative at this site, it may be possible to reduce or eliminate sampling. If the data collected at any time during the monitoring period indicate the need for additional remedial activities at the site, sampling frequency should be adjusted accordingly.

7.2.3 Alternative 1 - Cost

The present-worth cost of implementing Alternative 1 for a 50-year period beginning in 1999 is summarized in Table 7.3. Included in the total present-worth cost of \$505,000 are the estimated costs for performing the recommended groundwater monitoring (see Section 7.2.2), maintaining institutional controls, public education, project management, and reporting. Cost calculations are contained in Appendix F.

TABLE 7.3
ESTIMATED ALTERNATIVE 1 COSTS
AREA A RNA TS
TINKER AFB, OKLAHOMA

<u>Capital Costs</u>	<u>Present Worth Cost</u>
None	\$0.00

<u>Monitoring Costs</u>	<u>Present Worth Cost</u>
Conduct annual monitoring of 17 wells from 1999 to 2048	\$422,000
Site management (maintain institutional controls/public education) (50 years)	<u>\$82,800</u>
<u>Total Present Worth of Alternative 1</u> ^{a/}	\$505,000

^{a/} Based on an annual discount factor of seven percent (USEPA, 1993).

7.3 ALTERNATIVE 2 - VEP SYSTEM OPERATION

7.3.1 Alternative 2 – Effectiveness

Alternative 2 relies on continued operation of the VEP system with LTM to minimize contaminant migration and reduce contaminant mass over time. Based on system performance to date, the VEP system has induced aerobic redox conditions in USZ groundwater, possibly enhancing BTEX biodegradation rates. However, TCE

biodegradation by reductive dehalogenation likely is no longer occurring at the site due to the aerobic redox conditions. The VEP system is currently removing BTEX and CAHs from USZ groundwater, and continued system operation should effectively reduce BTEX and CAH concentrations below MCLs after an estimated two to three years of operation (June 1997 to June 2000).

Alternative 2 should provide reliable, continuous protection for downgradient groundwater receptors. Groundwater monitoring should be continued during system operation to verify the removal of CAHs prior to system shut down, and LTM should be continued for an additional five years to monitor for potential increases in CAH concentrations. In addition, land-use restrictions and institutional controls can be relaxed after VEP system shut down and monitoring, because the risk to site workers will be reduced.

7.3.2 Alternative 2 – Implementability

Alternative 2 is not technically difficult to implement, because the system is already operational. Long-term management efforts would be required to ensure proper sampling procedures are followed, and a five-year time frame is assumed for site management activities. Periodic site reviews should be conducted to confirm the effectiveness of the remedial alternative and completeness of the LTM data.

7.3.2 Alternative 2 – Cost

Actual cost for installation and operation of recovery wells and the VEP system unit is approximately \$800,000. An additional total present worth cost estimate for Alternative 2 for five years of LTM and five years of site management is \$150,100 (Table 7.4). Additional costs include operation and maintenance of the system for up to an additional year. The Alternative 2 total cost is approximately twice the cost estimated for 50 years of LTM in Alternative 1. However, Alternative 2 is estimated to reduce remediation time by ten times (5 years versus 50 years).

7.4 REMEDIAL APPROACH

Two alternatives were evaluated for remediation of dissolved BTEX and CAHs in USZ groundwater at Area A. Alternative 1 consists of RNA with LTM and institutional controls for 50 years. Alternative 2 includes continued operation of the VEP groundwater remediation system until at least June 1999 followed by five years of LTM.

Alternative 2 is the recommended remedial alternative for USZ groundwater at Area A, because it will reduce the level of contamination and maintain the necessary degree of protection to potential receptors at or downgradient from the site. The VEP system is already operational at the site and is effectively reducing BTEX and CAH concentrations in USZ groundwater. The VEP system has also induced aerobic redox conditions in USZ groundwater, and biodegradation of TCE via reductive dehalogenation is no longer occurring. Continued VEP system operation is therefore necessary to physically remove TCE from USZ groundwater, and continued groundwater monitoring is necessary to verify the removal of dissolved CAHs prior to system shutdown. Continued operation of the VEP system is expected to reduce BTEX and CAH groundwater concentrations to

TABLE 7.4
ESTIMATED ALTERNATIVE 2 COSTS
AREA A RNA TS
TINKER AFB, OKLAHOMA

<u>Capital Costs</u>	<u>Present Worth Cost</u>
Estimated Cost-to-Date: \$800,000	\$0
<u>Monitoring Costs</u>	<u>Present Worth Cost</u>
Conduct annual monitoring of 17 wells from 1999 to 2003	\$125,000
Site management (maintain institutional controls/public education) (5 years)	\$24,600
<u>Total Present Worth of Alternative 2</u> ^{a/}	\$150,000

a/ Based on an annual discount factor of seven percent (USEPA, 1993).

below MCLs within three years of system startup (by June 2000). LTM will be required for at least five years following system shutdown to monitor for increased CAH concentrations subsequent to remediation.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

This report presents the results of a TS conducted to evaluate the use of natural attenuation for remediation of CAH and BTEX contaminated groundwater in the vicinity of Area A at Tinker AFB, Oklahoma. To obtain the data necessary for the RNA demonstration, groundwater samples were collected from the site and analyzed. Physical and chemical data collected under this program were supplemented (where necessary) with data collected during previous site characterization events and accepted literature values.

Several lines of chemical and geochemical evidence indicate that prior to activation of a VEP system both fuel hydrocarbons (BTEX) and chlorinated solvents (CAHs) at Area A were undergoing biologically facilitated degradation. BTEX was undergoing biodegradation by the biologically facilitated processes of aerobic respiration, denitrification, sulfate reduction, methanogenesis, and to a lesser extent iron reduction. Field-scale, first-order decay rates computed using data from Area A include total BTEX biodegradation rates ranging from 0.09 yr^{-1} to 0.36 yr^{-1} (half-lives of 8.08 to 1.91 years), and benzene decay rates ranging from 0.12 yr^{-1} to 0.43 yr^{-1} (half-lives of 5.64 to 1.60 years).

CAHs were undergoing degradation by reductive dehalogenation within and downgradient from the contaminant source area prior to operation of the VEP system. The strongest evidence supporting CAH biodegradation include the presence BTEX at concentrations sufficient to provide a source of electron donors and to facilitate microbial reactions; the distribution of TCE daughter products (i.e., *cis*-1,2-DCE, VC, ethene, and ethane); patterns in DO and redox indicating reducing conditions within the contaminant plume; and correlating patterns in depleted nitrate and sulfate and elevated Fe^{2+} . Field-scale, first-order decay rates computed using data from Area A include total chlorinated ethene decay rates of 0.04 and 0.21 yr^{-1} (half-lives of 15.75 and 3.32 years), and TCE decay rates ranging from 0.27 yr^{-1} to 2.65 yr^{-1} (half-lives of 2.53 to 0.26 years).

The numerical models MODFLOW and MT3D⁹⁶® were used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and biodegradation of TCE dissolved in groundwater. The TCE plume modeled in conjunction with this report was calibrated to site conditions as of May 1997, before a VEP system started operation. A sensitivity analysis indicated the selected model input parameters were reasonable, and the model predictions are useful approximations for the evaluation of remedial alternatives at Area A. Because the VEP system was too

complicated to accurately model, predictive models based on the occurrence of RNA alone were run for comparison to monitoring results of the VEP system.

The TCE plume evaluated and modeled herein is based on the assumption of natural attenuation alone, without any source control measures. The model results suggest that without source control, the TCE plume will persist above USEPA MCL drinking water standards for at least 50 years. The cost of performing RNA alone with the LTM plan described in Section 7 is \$505,194.

Remediation by natural attenuation with LTM was compared to preliminary monitoring results of the VEP system from June 1997 to June 1998 (WC, 1998a and 1998b). Groundwater concentrations of BTEX, TPH, and naphthalene have been effectively reduced by the VEP system at Area A. Natural attenuation processes should further reduce any low concentrations of BTEX detected at downgradient locations (i.e., wells 2-149B and 2-163B) particularly as the source of BTEX is being reduced.

The VEP system is less effective at reducing TCE concentrations, although an overall reduction has been observed. Analytical data collected between November 1997 and June 1998 indicate the VEP system is reducing TCE contaminant concentrations at Area A, albeit at a slower rate relative to BTEX. The VEP system has induced aerobic redox conditions in USZ groundwater at Area A, and biodegradation of CAHs (TCE in particular) due to reductive dehalogenation is likely no longer occurring. Different source locations for CAHs versus BTEX may also account for differences in the VEP system effectiveness in reducing TCE concentrations relative to BTEX. Relatively high concentrations of both TCE and BTEX detected at wells 2-4 and 2-51B, located on the upgradient portion of the BTEX source area, may indicate the VEP system radius of influence is not extending to the most upgradient portion of the source area. The cost of performing VEP with LTM as described in Section 7 is estimated to be approximately \$1,000,000.

8.2 RECOMMENDATIONS

The VEP system has been effective in removing BTEX, CAHs, and naphthalene from USZ groundwater at Area A. However, reductive dehalogenation of CAHs (TCE in particular) is likely no longer occurring, and the Air Force recommends physical removal of CAHs by continued operation of the VEP system until CAH concentrations are reduced to regulatory guidelines. LTM at the compliance wells and some additional site related wells is recommended for five years following shutdown of the VEP system to further evaluate the effectiveness of source control measures and to monitor the migration of site-related contaminants (TCE in particular). Development of site-specific RBSLs for CAHs may also be appropriate for the site, if considered by the governing regulatory agency.

SECTION 9

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APPENDIX A

**PERTINENT TABLES, FIGURES, AND SLUG TEST DATA FROM
PREVIOUS REPORTS**

Table 5-7
Analytical Results for Soil Samples
Borings 1-S1 Thru 1-S5
Area A Service Station

OCC Category II Cleanup Standards		Benzene (ug/kg)	Toluene (ug/kg)	Ethylbenzene (ug/kg)	Xylenes (ug/kg)	Total BTEX ¹ (ug/kg)	TPH (mg/kg)	Total Lead (mg/kg)
Boring Number	Sample Depth (Feet)							
1-S1	10	950,000	1,600,000	500,000	1,500,000	4,550,000	6,300	<.002
	12	1,000,000	1,700,000	300,000	950,000	3,950,000	11,000	148
1-S2	5	<2	<2	<2	<2	<8	<10	22.8
	10	5,600	61,000	19,000	110,000	195,600	500	10.5
	15	1,000,000	2,000,000	510,000	1,600,000	5,110,000	8,000	10.4
1-S3	10	1,000,000	1,600,000	430,000	1,200,000	4,230,000	12,000	8.99
	15	59,000	380,000	77,000	460,000	976,000	9,600	8.7
1-S4	10	300,000	1,700,000	430,000	2,400,000	4,830,000	85,000	9.77
	15	1,200,000	2,300,000	570,000	1,900,000	5,970,000	86,000	19.4
1-S5	10	<50	1,700	1,100	8,500	11,350	160	12.1
	15	13,000	61,000	17,000	110,000	201,000	860	9.1

Source: ERI, 1990.

Samples Collected May 23-30, 1990

Shaded results indicate exceedance of OCC Cleanup Standards or Background

BTEX - (Benzene, Toluene, Ethylbenzene, Xylenes) by Method 8020

TPH - Total Petroleum Hydrocarbons by Method 418.1

Total Lead By Method 6010

¹Total BTEX computed by summation of BTEX compounds

²Background concentration (IT, 1995b)

Table 5-8
Analytical Results for Soil Samples
Borings SB-1 Thru SB-8
Area A Service Station

		Benzene (ug/kg)	Toluene (ug/kg)	EthylBenzene (ug/kg)	Xylenes (ug/kg)	Total BTEX ¹ (ug/kg)	TPH (mg/kg)	Total Lead (mg/kg)
OCC Category II Cleanup Standards		5,000	400,000	150,000	1,000,000	1,555,000	500	26 ²
Boring Number	Sample Depth (Feet)							
SB-1	12-15	26,400	140,000	63,300	247,000	476,700	6170	13.5(.7*)
	15-17	12,300	109,000	53,800	215,000	390,100	3140	7.6(.4*)
	19	ND	322	187	1080	1,589	ND	ND
SB-2	3	1.0(E)	1.7	ND	ND	2.70	11.2(.6*)	
	6	8.1	ND	ND	ND	8.1	ND	7.4(.4*)
	9	126	669	422	1810	3,027	23.7	11.3(.6*)
	12	824(E)	13,400	6680	37,900	58,804	73.7	7.7(.4*)
	15	ND	9020	7380	46,700	63,100	58.4	ND
	18	ND	1.9	ND	ND	1.9	15.6	ND
	21	1.2	2.9	0.7(E)	2.3	7.10	ND	ND
SB-3	2.5-5.5	ND	ND	ND	ND	ND	ND	6.1(.3*)
	5.5-7	ND	1.7	1.8	12.5	16.0	ND	ND
	8	ND	1440	2050	13,600	17,090	42.3	ND
	11	1720	23,600	17,000	90,300	132,620	1040	6.2(.3*)
	13.5-16	705(E)	18,300	10,500	59,200	88,705	412	ND
	19	257	237	24.5	106	624.50	ND	ND
SB-4	3	2.0	0.5(E)	ND	1.1	3.60	ND	13.0(.7*)
	6	35.8	2.2	1.0(E)	3.0	42.00	ND	17.4(.9*)
	9	1110(E)	6790	3590	12,700	24,190	161.1	4.7(.2*)
	12	ND	10,700	9740	42,700	63,140	280	ND
	15	ND	ND	ND	0.8(E)	0.8	ND	ND
SB-5	3	3.0	3.1	19.2	16.6	41.90	ND	12.7(.6*)
	6	ND	ND	ND	ND	ND	ND	6.1(.3*)
	7-9	ND	390	876	2000	3,266	43.2	8.7(.4*)
	12	ND	ND	ND	ND	ND	ND	6.2(.3*)
	15	ND	ND	ND	ND	ND	ND	ND
	18	ND	ND	ND	ND	ND	ND	ND
	21	ND	ND	ND	ND	ND	ND	ND
SB-6	3	ND	ND	ND	ND	ND	ND	13.7(.7*)
	6	ND	ND	ND	ND	ND	ND	7.9(.4*)
	10-12	ND	10,100	8040	44,700	62,840	310	16.9(.8*)
	12-17	6.0	ND	ND	7.6	13.60	ND	ND
	21-22	ND	ND	ND	ND	ND	ND	ND
	22-23	5.6	6.0	2.7	10.0	24.30	ND	ND
	23-24	1.8	2.2	ND	2.3	6.30	ND	ND
SB-7	2-7	ND	ND	ND	ND	ND	ND	12.3(.6*)
	9-12	ND	ND	ND	ND	ND	114	7.8(.4*)
	12-15	ND	ND	ND	ND	ND	12.1	ND
	15-17	0.9(E)	ND	ND	ND	0.9	ND	ND
	17-20	ND	ND	ND	ND	ND	ND	5.4(.3*)
	20-22	ND	1.0(E)	ND	ND	1.0	ND	ND
	22-23	1.2	ND	ND	ND	1.2	ND	ND
SB-8	3	ND	ND	ND	ND	ND	ND	10.8(.5*)
	7	ND	ND	ND	ND	ND	ND	9.6(.5*)
	9	ND	ND	ND	0.7(E)	0.7	ND	6.3(.3*)
	12	ND	ND	14.7	27	41.70	14.1	6.3(.3*)
	15	ND	ND	1.3	2.7	4.00	ND	4.4(.2*)
	15-17	ND	ND	ND	ND	ND	ND	ND
	20	ND	ND	ND	ND	ND	ND	ND
	22-25	5.8	ND	ND	ND	5.8	ND	4.3(.2*)

Source: WSCI, 1992; Samples Collected May 20-23, 1991

Shaded results indicate exceedance of OCC Cleanup Standards or Background BTEX - (Benzene, Toluene, Ethylbenzene, Xylenes) by Method 8020

TPH - Total Petroleum Hydrocarbons by Method 8015 Modified

Total Lead By Method 6010

* - Equivalent Concentration by TCLP Extraction Method

ND - Not Detected at the Practical Quantitation Limit

E - Estimated Concentration

¹Total BTEX computed by summation of BTEX compounds²Background concentration (IT, 1995b)

Table 5-9
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
Contract No. F34650-93-D-0107-5006
Revision 0
October 10, 1995
Page 5-21

Well Number: Sample Number: Depth:	Background/Cleanup Levels		SB-006 A1312 4 - 5		SB-006 A1313 9 - 10		SB-006 A1315 12 - 13		SB-006 A1316 17 - 18		SB-006 A1317 20 - 21		
	Parameters	Background ¹	OCC Cat. II ²	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
	Metals (mg/kg)												
	Arsenic	23		4.5	N	2.3	N			1.0	N	2.1	N
	Barium	1,770		310	N	75	N	600				140	
	Cadmium	0.58		1.6		1.3						0.98	
	Chromium	34		20		19		15		12		79	
	Lead	26		11		5.6		1.4	N	0.76	N	2.9	N
	Zinc	52		24		21		19		4.2		18	
	Semi-Volatiles (mg/kg)												
	Di-n-octylphthalate			0.083	JB			0.17	JB				
	Volatiles (µg/kg)												
	1,2-Dichloroethane											1.6	J
	2-Butanone									5.5	JB	25	JB
	Acetone			13	JB	10	JB	18	JB	19	JB	49	JB
	Benzene		5,000									1.8	J
	Chlorobenzene									0.4	J		
	Ethylbenzene		150,000							0.2	J		
	Methylene Chloride			12	B	11	B	7.7	JB	0.7	JB	1.2	JB
	Toluene		400,000									1.6	J
	Trichloroethene											2.8	J
	Xylenes (total)		1,000,000									1.3	JB
	cis-1,2-Dichloroethene											8.8	

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
 Contract No. F34650-93-D-0107-5006
 Revision 0
 October 10, 1995
 Page 5-23

Well Number: Sample Number: Depth:	Background/Cleanup		SB-008 A1178 9 - 10		SB-008 A1179 10 - 11		SB-008 A1180 17 - 18		2-2A A1354 2 - 2.5		2-2A A1355 8.5 - 9	
	Background ¹	OCC Cat. II ²	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
Parameters												
General Parameters (mg/kg)												
Total Petroleum Hydrocarbons		500										
Metals (mg/kg)												
Arsenic	23											
Barium	1,770											
Cadmium	0.58											
Chromium	34											
Lead	26											
Zinc	52											
Semi-Volatiles (mg/kg)												
2-Methylnaphthalene												
Acenaphthene												
Dibenzofuran												
Fluorene												
Naphthalene												
Phenanthrene												
Pyrene												
Volatiles (µg/kg)												
2-Butanone												
Acetone												
Ethylbenzene		150,000										
Methylene Chloride		400,000										
Toluene		1,000,000										
Xylenes (total)												

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

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²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

D = Compound identified at a secondary dilution factor

* = Duplicate analysis outside control limits

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
Contract No. F34650-93-D-0107-5006
Revision 0
October 10, 1995
Page 5-24

Well Number: Sample Number: Depth:	Parameters	Background/Cleanup		2-2A A1356 10.5 - 11		2-4A A1358 4 - 5		2-4A A1359 8.5 - 9		2-4A A1360 12 - 13		2-50B A1341 3 - 4	
		Background ¹	OCC Cat. II ²	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
	General Parameters (mg/l)												
	Total Petroleum Hydrocarbons		500	340		110		61		99			
	Metals (mg/kg)												
	Arsenic	23		1.1	N	2.3						2.5	
	Barium	1,770		97	N*	370	N*	160	N*	870	N*	160	N
	Cadmium	0.58				0.68						0.47	
	Chromium	34		15		14		10		6.3		11	
	Lead	26		4.7	N	13		3.5		2.0		7.6	
	Zinc	52		15		21		10		5.4		17	
	Semi-Volatiles (mg/kg)												
	2-Methylnaphthalene			3.3				0.92		4.9			
	Acenaphthene			0.24	J					0.04	J		
	Anthracene			0.085	J								
	Dibenzofuran			0.16	J								
	Fluorene			0.35						0.03	J		
	Naphthalene			1.3				0.96		4.4			
	Phenanthrene			0.95						0.07	J		
	Pyrene			0.07	J								
	bis(2-Ethylhexyl)phthalate												
	Volatiles (µg/kg)					0.18	J	0.07	J				
	2-Butanone			20	JB	200	JB	16	JB	5100	JB	7.3	JB
	Acetone			110	B	600	B	28	JB			11	JB
	Benzene		5,000			87							
	Chlorobenzene									370	J		
	Ethylbenzene		150,000	250	D	110		240		18,000		0.8	J
	Methylene Chloride			5.9	JB			5.2	JB			1.0	JB
	Toluene		400,000			89	B	1.4	JB	12,000	B	1.0	J
	Xylenes (total)		1,000,000	44		270		1600		10,000	D	1.4	J

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

D = Compound identified at a secondary dilution factor

* = Duplicate analysis outside control limits

Metals:

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
 Contract No. F34650-93-D-0107-5006
 Revision 0
 October 10, 1995
 Page 5-25

Well Number: Sample Number: Depth:	Parameters	Background/Cleanup		2-50B AI342 9 - 10		2-50B AI343 10 - 12		2-51A AI350 1 - 1.5	
		Background ¹	OCC Cat. II ²	Result	QFR	Result	QFR	Result	QFR
	General Parameters (mg/kg)								
	Total Petroleum Hydrocarbons		500	44		11		30	
	Metals (mg/kg)								
	Arsenic	23		1.8		2.8		2.1	N
	Barium	1,770		92	N	230	N	110	
	Cadmium	0.58				1.4			
	Chromium	34		19		24		14	
	Lead	52		3.2		6.0		7.4	N
	Zinc	79		24		29		14	
	Semi-Volatiles (mg/kg)								
	2-Methylnaphthalene			0.62		0.55			
	Di-n-butylphthalate					0.049	J		
	Naphthalene			0.44		0.36			
	bis(2-Ethylhexyl)phthalate							0.047	J
	Volatiles (µg/kg)								
	2-Butanone			83	JB	33	JB		
	Acetone			290	JB	170	JB	6.2	JB
	Benzene		5,000					1.0	JB
	Ethylbenzene		150,000	250		64			
	Methylene Chloride							2.7	JB
	Toluene		400,000	100		12			
	Xylenes (total)		1,000,000	1200		440			

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

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 Qualifier (QFR) Codes

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Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
 Contract No. F34650-93-D-0107-5006
 Revision 0
 October 10, 1995
 Page 5-26

Well Number: Sample Number: Depth:	Background/Cleanup		2-51A A1351 6 - 6.5		2-51A A1352 12 - 12.5		2-51A A1353 18 - 18.5		2-51B A1334 6 - 7		2-51B A1335 9 - 10	
	Parameters	Background ¹	OCC Cat. II ²	Result	QFR	Result	QFR	Result	QFR	Result	QFR	
General Parameters (mg/kg)												
Total Petroleum Hydrocarbons												
Metals (mg/kg)												
Arsenic	23			4.9	N	1.9	N	1.5	N	14	N	5.5
Barium	1,770			810		62		180		280	N	5000
Cadmium	0.58			0.73						1.6		0.58
Chromium	34			12		16		12		16		16
Lead	26			8.2	N	6.2	N	4.1	N	22		9.0
Selenium	8.2									16		
Zinc	52			16		17		12		23		23
Semi-Volatiles (mg/kg)												
Di-n-octylphthalate										0.38	B	0.27
Volatiles (µg/kg)												
2-Butanone				7.4	JB	5.2	JB	5.8	JB			
Acetone				20	JB	13	JB	11	JB	5.1	JB	32
Benzene			5,000	1.0	JB							
Chlorobenzene										0.5	J	
Ethylbenzene			150,000							0.2	J	
Methylene Chloride				2.4	JB	2.2	JB	13	B	6.6	JB	13

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
 Contract No. F34650-93-D-0107-5006
 Revision 0
 October 10, 1995
 Page 5-27

Well Number: Sample Number: Depth:	Background/Cleanup		2-51B A1336 11 - 12		2-52A A1347 1 - 2		2-52A A1348 8 - 9		2-52A A1349 10 - 10.5		2-52B A1338 4 - 5	
	Background	OCC Cat. II ¹	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
General Parameters (mg/kg)												
Total Petroleum Hydrocarbons		500	84						19			
Metals (mg/kg)												
Arsenic	23				2.4	N	4.4	N	1.8	N	2.8	N
Barium	1,770		63	N	160	N	120	N	120	N	260	
Cadmium	0.58		0.58								1.0	
Chromium	34		12		12	*	13	*	19	*	15	
Chromium VI	0.16										0.42	
Lead	26		5.5		11	N	7.1	N	6.7	N	8.0	N
Zinc	52		14		21	*	15	*	19	*	25	
Semi-Volatiles (mg/kg)												
2-Methylnaphthalene			0.19	J					1.1			
Di-n-octylphthalate			0.24	JB							0.07	JB
Naphthalene			0.13	J					0.88			
Volatiles (µg/kg)												
2-Butanone			21	JB	3.1	JB			40	JB		
Acetone			76	JB	12	JB	17	JB	100	B		
Benzene		5,000			4.8	J			47			
Ethylbenzene		150,000	4.9	J					92			
Methylene Chloride			0.9	JB	2.9	JB	3.2	JB	4.8	JB	8.3	JB
Xylenes (total)		1,000,000	65	B					71			

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit
¹Background metals concentration developed by IT Corporation (1995b)
²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes
 N = Sample is outside of Matrix Spike QC limit
 * = Duplicate analysis outside control limits

Metals:
 VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample
 J = Concentration is an estimated value

Table 5-9 (continued)
Analytical Results for Soil Samples
1993/94 Investigation
Area A Service Station

Investigation for Soil and Groundwater Cleanup Report
 Contract No. F34650-93-D-0107-5006
 Revision 0
 October 10, 1995
 Page 5-28

Well Number: Sample Number: Depth:	Background/Cleanup		2-52B A1339 5.5 - 7		2-52B A1340 12 - 13		
	Parameters	Background	OCC Cat. II ¹	Result	QFR	Result	QFR
	Metals (mg/kg)						
	Arsenic	23		2.9	N	1.5	N
	Barium	1,770		320		76	
	Cadmium	0.58		0.79		1.1	
	Chromium	34		16		16	
	Lead	26		6.8	N	5.3	N
	Zinc	52		22		18	
	Semi-Volatiles (mg/kg)						
	Di-n-octylphthalate			0.15	JB	0.31	JB
	Volatiles (µg/kg)						
	Acetone			17	JB	10	JB
	Methylene Chloride			7.6	JB	7.6	JB

Source: IT Corporation, 1995c; Sampling conducted October 1993 through January 1994

Note: Appendix IX constituents are listed where the analytical results are above any of the listed action levels or the method quantitation limit

¹Background metals concentration developed by IT Corporation (1995b)

²Oklahoma Corporation Commission (OCC) Category II Clean-up Levels

Qualifier (QFR) Codes

N = Sample is outside of Matrix Spike QC limit

VOCs/SVOCs: B = Analyte is found in the associated blank as well as in the sample

J = Concentration is an estimated value

TAFB Area A Fluid Production

	Amount of Fluid Recovered (Gallons)		
	VEP Wells	EW Wells	Total
June 1997	134,690	0	134,690
July 1997	226,135	0	226,135
August 1997	182,525	0	182,525
September 1997	275,998	56,063	332,061
October 1997	242,642	48,288	290,930
November 1997	264,115	9,621	273,736
December 1997	285,520	109,347	394,867
January 1998	279,607	151,615	431,222
February 1998	220,986	153,169	374,155
March 1998	210,147	175,912	386,059
April 1998	144,744	89,201	233,945
May 1998	176,323	70,654	246,977
Grand Total	2,643,432	863,870	3,507,302

Table 5-2
Slug Test Results
Area A Service Station

Upper Saturated Zone

Well No.	Thickness (ft)	Cooper et al.				Bouwer&Rice			
		T (ft ² /min)	K(cm/sec)	K(ft/min)	K(ft/day)	K(cm/sec)	K(ft/min)	K(ft/day)	
2-50B			Method not applicable				1.3E-03	0.0025	3.6
2-51B			Method not applicable				1.4E-05	0.000028	0.04
2-52B			Method not applicable				1.9E-04	0.00038	0.55
Average Value			Method not applicable				4.9E-04	0.00097	1.4

Lower Saturated Zone

Well No.	Thickness (ft)	Cooper et al.				Bouwer&Rice		
		T (ft ² /min)	K (cm/sec)	K (ft/min)	K (ft/day)	K (cm/sec)	K (ft/min)	K (ft/day)
2-2A	12.5	0.0069	2.8E-04	0.00055	0.79	1.9E-04	0.00037	0.53
2-4A	8	0.065	4.1E-03	0.0081	11	7.0E-04	0.0014	2.0
2-51A(slug in)	17	0.097	2.9E-03	0.0057	8.2	6.9E-04	0.0014	1.9
2-51A(slug out)	16.5	0.064	2.0E-03	0.0038	5.5	6.7E-04	0.0013	1.9
2-52A(slug in)	24.3	0.069	1.4E-03	0.0028	4.0	5.3E-04	0.0010	1.5
2-52A(slug out)	16	0.022	6.9E-04	0.0013	1.9	5.1E-04	0.0010	1.4
Average Value		5.4E-02	1.9E-03	3.7E-03	5.3E+00	5.5E-04	1.1E-03	1.6E+00

Analysis performed with AQTESOLV software

T - Transmissivity (based on Cooper et al methodology for confined aquifers)

K - Hydraulic Conductivity (based on Bouwer-Rice and Cooper et al.)

ft - feet; cm - centimeters; sec - seconds; min - minutes

Project: Tinker AFB - Area A

Project Number: F9 6522

Boring Location: NW corner of the Civil Engineer Bldg.
(Bldg 400)

Log of Boring VEP-09

Sheet 1 of 1

Date(s) Drilled	3-26-97	Logged By	G. Papinako (WCC)	Checked By	
Drilling Method	HSA	Auger Bit Size/Type (in. I.D.)	4-inch-ID HSA 6-inch-ID HSA	Approx. Surface Elevation (feet, MSL)	
Drill Rig Type	Mobile B-80	Drilled By	Craig Tucker	Total Depth Drilled (feet)	28.5
Groundwater Elevation (feet, MSL)		Number of Samples Collected:		Analyzed:	
Diameter of Hole (inches)	10.0	Diameter of Well (inches)	4.0	Type of Well Casing	4-inch-ID PVC, 4-inch-ID SS
Type of Sand Pack	20/40 Silica Sand	Type/Thickness of Seal(s)	2-2 bentonite pellets	Screen Perforation	0.01
Comments					Top of Well Casing Elevation (feet, MSL)

Depth, feet	Elevation, feet	SAMPLES			Unified Soil Classification	Graphic Log	MATERIAL DESCRIPTION	Head Space Well Completion Log FID/PD	FID (ppm)	REMARKS
Type	Number	Recovery, %								
0		CS	100%		FILL		LEAN CLAY (CL) w/ 10% of coarse angular gravel, dk grayish brown, dk brown and reddish brown (intermixed) w/ abundant root hairs	55/5.4	80	Boring advanced w/ 4-inch-ID HSA
		CS	100%				25% of fine grained sand - FILL			7.0 ppm - borehole opening (FID)
5		CS	100%				LEAN CLAY (CH) olive brown (2.5 Y - 4/6) moist, firm to hard - becoming dk reddish brown (2.5 YR - 3/4) w/ calcareous nodules, w/ root channels	49/6.9	362	
		CS	100%				POORLY GRADED SAND (SP) fine grained, gray to brownish gray (2.5 Y - 6/2), moist, dense	35/0	110	
10		CS	100%				SILTY SAND (SM) fine grained, poorly graded, yellowish red (5 YR - 4/6) and red (2.5 YR - 4/6) moist, dense	8.0	56	
		CS	100%				w/ 20% silt in fines		25	
15		CS	80%				w/ several thin zones of weak cementation	145/4.5	0.0	
		CS	80%				w/ occasional seams and partings of hard ferruginated sandstone - becoming wet but zones of cementation remain dry	344/37	62	Water detected ATD
20		CS	100%				w/ calcareous veinlets		8.2	
		CS	100%				w/ thin zones of hard sandy breccia (clay pebbles and sand in ferruginated cement)	78/65	62	
		CS	100%				becoming laminated	263/71	70	
25		CS	100%				CLAYEY SAND (SC) fine grained, poorly graded, dusky red (10R - 3/4) moist, dense, laminated w/ abundant horizontal calcareous seams		0.0	Borehole reached to 20.0 ft depth w/ 6-inch-ID HSA
		CS	100%				[GRADATIONAL CONTACT]	0.0/0.4	0.0	B.O.B. 28.5 ft
30		CS	100%				FAT CLAY (CA) red (2.5 YR - 4/6) moist, very hard			Well VEP-09 ft installed upon completion

Woodward-Clyde

SPECIFICATIONS

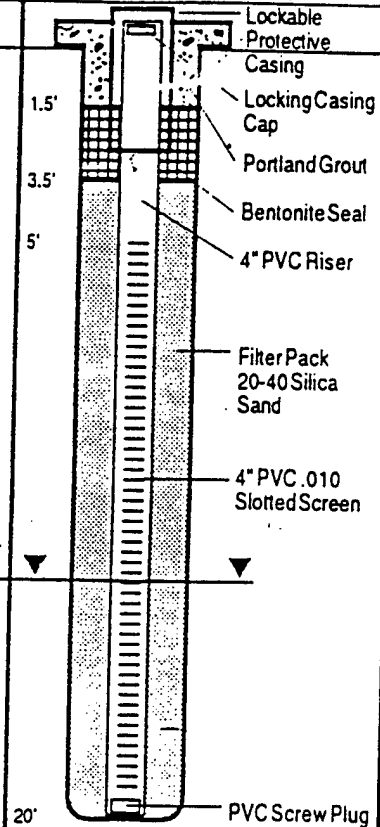
OPTIONAL FORM 99 (7-90)

of pages ►

WELL NUMBER: VEP - 09
JOB NAME/NUMBER: Area A
LOCATION: Tinker AFB
INSTALLATION DATE: 3-26-97
REG REPRESENTATIVE: Gene Papinako
DRILLING CONTRACTOR: AW Pro
DRILLING METHOD: NSA

BORING LOG

Depth (feet)	Lithology Description	Graphic Log	USCS Class.	Well Construction	Remarks
0					PID READING
— — 2	Fill material			1.5' Lockable Protective Casing	
— — 5	Clay; silty; mottled gray; soft			3.5' Locking Casing Cap	3' 0 ppm
— — 7				5' Bentonite Seal	5' 32 ppm
— — 10	Silt; very clayey; red brown; crumbly			4" PVC Riser	7' 4 ppm
9.5				Filter Pack 20-40 Silica Sand	8' 3 ppm
— — 12	Silt to fine sand; red brown; loosely to well cemented			4" PVC .010 Slotted Screen	10' 362 ppm
— — 15	Silt to fine sand; red brown; alternating thin zones of loosely and well cemented material				12' 745 ppm
— — 16	Sandstone; fine grained; red brown; thinly laminated; water saturated at top				14' 437 ppm
— — 20	Auger refusal at 16' - drilled without core barrel to 20'				15' 563 ppm
— — 25	T.D. 20'				16' 566 ppm
— — 30	Note: Water level in boring at 14.5' after 20 minutes with thin floating layer of free product.				



MONITOR WELL #2-4

Top Fuel - 12.67'
Top Water - 17.12'
Effective Static Water Level - 13.83'

Project Number: 90-164	Client: USAF - POL SITE "A"	Driller: A. W. Pool, Inc.
Boring Number: SB-4	Date Drilled: 20 May 1991	Drill Type: Hollow Stem Auger
Logged By: DLW	Elevation: 1243.22 Feet	

BORING LOG

Depth (feet)	Lithology Description	Graphic Log	USCS Class.	Well Construction	Remarks
0				Lockable Protective Casing	PID READING
.67	Top soil; clay			Locking Casing Cap	1.5' 0 ppm
2.3	Fill material; red brown clay			Portland Grout	4.1' 0 ppm
5	Clay; plastic; brown			Bentonite Seal	6.5' 0 ppm
5.9	Clay; plastic; brown red			4" PVC Riser	7.5' 4 ppm
10				Filter Pack	9.2' 512 ppm
10.2	Clay; gray			20-40 Silica Sand	10.3' 25 ppm
10.4	Silt; clayey; soft; red brown				11' 406 ppm
12	Silt; some fine sand; clayey; red brown; thinly laminated				12' 3 ppm
15				4" PVC .010 Slotted Screen	14' 48 ppm
17	Siltstone; red brown; thinly laminated				15' 12 ppm
17.5	Clay; plastic; firm; red brown				17' 14 ppm
19	Sandstone; fine-medium grained; red brown; water saturated				17.5' 4 ppm
20	Siltstone; red brown; thinly laminated				19.5' 5 ppm
21.5	Sand; fine grained; red brown; wet; auger refusal at 23'			PVC Screw Plug	21' 0 ppm
23					21.75' 1 ppm
25	T.D. 23'				22.5' 0 ppm
30					

MONITOR WELL #2-2

Static Water Level - 12.69'

Project Number: 90-164	Client: USAF - POL SITE "A"	Driller: A. W. Pool, Inc.
Boring Number: SB-7	Date Drilled: 20 May 1991	Drill Type: Hollow Stem Auger
Logged By: DLW	Elevation: 1242.34 Feet	

BORING LOG

Depth (feet)	Lithology Description	Graphic Log	USCS Class.	Well Construction	Remarks
0				Lockable Protective Casing	PID READING
2	No samples			Locking Casing Cap	
5	Clay; slightly silty; plastic; mottled dark brown to red			Portland Grout	3' 0 ppm
6	Clay; plastic; brown red			5.5'	6' 0 ppm
7	Clay; plastic; red; thin bedded and alternating with thin bedded, red brown clayey silt			7.5'	7' 582 ppm
10				9.5'	8' 315 ppm
12	Silt; very clayey; brown red			Filter Pack 20-40 Silica Sand	9' 11 ppm
14	Clay; silty; brown red				10' 9 ppm
15			14.86'		13' 577 ppm
17	Siltstone; gray green			4" PVC .010 Slotted Screen	14' 157 ppm
20	Sand; fine grained; silty; brown red; massive bedded in upper 2', thin bedded below; top water saturation occurs at 19' - 20'				15' 15 ppm
24				PVC Screw Plug	16' 452 ppm
25	Sand; fine grained; light gray			Hole Cavings	17' 217 ppm
	T.D. 25'				18' 17 ppm
30					20' 5 ppm
					23' 16 ppm
					24.5' 0 ppm
					25'
				MONITOR WELL #2-3	
				Static Water Level - 14.86'	

Project Number: 90-164	Client: USAF - POL SITE "A"	Driller: A. W. Pool, Inc.
Boring Number: SB-8	Date Drilled: 23 May 1991	Drill Type: Hollow Stem Auger
Logged By: JLT	Elevation: 1242.60 Feet	

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A

SURFACE ELEV.(FT): 1241.24 NGVD

TOTAL DEPTH(FT.): 25

Logged By: P. SCHUMANN, K. HERRINGTON

Date Started: 10/21/93

Drilled By: D. EYLER

Date Completed: 10/22/93

NESCO

Drill Rig Type: RODGERS 760

Drilling Method: HOLLOW STEM AUGER

Sampling Method: 5" I.D. CONTINUOUS SAMPLER

Notes: 8" DIAMETER BOREHOLE

COORDINATES—NAD 27: N 158461.461, E 2180256.673

DESCRIPTION										SAMPLE TYPE SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	FID	USCS	GRAPHIC LOG
<u>CLAY</u> - moderately plastic; firm; dark reddish brown (5YR-3/3); dry - hard; (5YR-3/2)										A 1167	60	0	0	ch	
- reddish brown (5YR-4/6) - occasional pebbles; dark red (2.5YR-4/6)											60	0	0	ch	
<u>SILTY CLAY</u> - nonplastic; 50% silt; stiff; light blueish gray (5B-7/1); dry										A 1168	60	0	0	cl	
<u>CLAY</u> - moderately plastic; hard; occasional pebbles; silty light blueish gray layers; dark red (2.5YR-4/6); dry - stiff; red (2.5YR-5/8)											60	0	0	ch	
<u>SILTY CLAY</u> - nonplastic; 20% silt; firm; 3" discolored layer; gray (N6); strong gasoline odor										A 1170	60	0	5	cl	
<u>CLAY</u> - moderately plastic; firm; occasional pebbles; red (2.5YR-5/8); dry											60	0	0	ch	
<u>SILTY CLAY</u> - nonplastic; 20% silt; soft; red (10R-4/8); dry										A 1171	60	0	0	cl	
<u>CLAY</u> - moderately plastic; hard; increasing fines; gray silty layers; red (10R-4/8); moist; on odor											60	0	6	cl	
<u>SAND</u> - very fine grained; poorly graded; loose; increasing clay content with depth; light gray to reddish yellow (5YR-6/6); moist to wet - 10% to 20% clay; moderately graded; reddish yellow (5YR-6/6); no odor										A 1172	60	0	0	ml	
<u>CLAY</u> - slightly plastic; hard; reddish brown (5YR-4/4); dry											60	0	0	ch	
<u>SILTY CLAY</u> - slightly plastic; 20% silt; soft; red (2.5YR-5/8); wet; on odor										A 1172	60	0	0	ch	
<u>CLAY</u> - plastic; soft; red (2.5YR-5/8); moist; on odor											60	0	0	ch	
<u>SAND</u> - very fine grained; 10% fines; moderately graded; loose; red (2.5YR-5/8); moist to wet; compact at 23'										A 1172	60	0	0	sc	
											48	0	0		
TOTAL DEPTH = 25.0 FEET															

DRAFT BY: 11/15/93
 RPS
 DRAFT CHK: 11/15/93

PROJ. CHK: 11/15/93
 APPRV. BY: 11/15/93

DWG. NO.: 409802-A2
 Sheet 1 of 1

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

SOIL BORING SB-0

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A
SURFACE ELEV.(FT): 1240.78 NGVD
TOTAL DEPTH(FT.): 20
Logged By: P. SCHUMANN, K. HERRINGTON
Date Started: 10/25/93
Drilled By: D. EYLER
Date Completed: 10/25/93
NESCO
Drill Rig Type: RODGERS 760
Drilling Method: HOLLOW STEM AUGER

Sampling Method: 5" I.D. CONTINUOUS SAMPLER

Notes: 8" DIAMETER BOREHOLE
COORDINATES-NAD 27: N 158291.785, E 2180348.712

DESCRIPTION							SAMPLE TYPE SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	FID	USCS	GRAPHIC LOG	
<u>SILTY CLAY</u> - slightly plastic; 20% silt; soft; small gravel layer at 1'; strong brown (2.5YR-4/6); dry - highly plastic; hard; yellowish red (5YR-4/6); moist - moderately plastic; firm; dark olive brown (2.5Y-3/3)							A 1173	60	0	0	ol		
								48	0	0			ch
								60	0	0			
<u>CLAY</u> - highly plastic; hard; dark olive brown (2.5Y-3/3); moist - stiff; olive brown streaks; yellowish red (5YR-5/6) - hard - some 1" greenish gray layers; strong odor - firm; dark red (2.5YR-4/8)							A 1174	60	0	5			
								48	0	12			
								60	0	60			
<u>SAND</u> - very fine grained; 20% fines; moderately graded; compact; some grayish green streaking; reddish yellow (5YR-6/8); moist; gasoline odor - 10% fines; poorly graded; loose; saturated with product (gasoline) - 15% fines; moderately graded; yellowish red (5YR-5/8); wet; slight product odor - sample lost during removal							A 1175 A 1176	52	30	80	sc		
								60	5	150			
								24		5000			
TOTAL DEPTH = 20.0 FEET													

DRAFT	RPS	DRAFT	PROJ.	APPRV.	DWG.	409802-A2
BY	11/16/93	CHK	CHK	BY	NO.	Sheet 1 of 1

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

SOIL BORING SB-0

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A

SURFACE ELEV.(FT): 1240.43 NGVD

TOTAL DEPTH(FT.): 18

Logged By: P. SCHUMANN, K. HERRINGTON

Date Started: 10/25/93

Drilled By: D. EYLER

Date Completed: 10/26/93

NESCO

Drill Rig Type: RODGERS 760

Drilling Method: HOLLOW STEM AUGER

Sampling Method: 5" I.D. CONTINUOUS SAMPLER

Notes: 8" DIAMETER BOREHOLE

COORDINATES-NAD 27: N 158257.819, E 2180317.691

DESCRIPTION		SAMPLE TYPE SAMPLE NO.	IN. DRIVEN	IN. RECOVERED	FID	USCS	GRAPHIC LOG
<u>CLAYEY SILT</u> - 30% clay; organics; moderately graded; loose; dark yellowish brown grading to yellowish red (10YR-4/4); dry		A 1177	60	0	0	ol	
<u>SILTY CLAY</u> - moderately plastic; 10% silt; stiff; brown (7.5YR-4/4); dry			0	0	0	ch	
<u>SAND</u> - very fine to medium grained; moderately graded; loose; red (2.5YR-5/8); moist - wet			0	0	0	sp	
<u>SILTY GRAVELLY CLAY</u> - highly plastic; 10% silt, 10% gravel; soft; dark gray (N4) streaking; red (2.5YR-5/8); moist - stiff - slightly plastic; 5% silt, 5% gravel; soft; red (2.5YR-6/8); dry; strong product odor		A 1178	40	2	6	ch	
<u>SILTY CLAY</u> - moderately plastic; 20% silt; soft; red (2.5YR-5/8); moist; strong product odor		A 1179	60	48	200	cl	
<u>SILTY GRAVELLY CLAY</u> - slightly plastic; 5% silt, 5% gravel; hard; dark gray streaks; red (2.5YR-5/8); dry; strong product odor		60	4000	2000	60	cl	
<u>SAND</u> - very fine grained; poorly graded; compact; red (2.5YR-5/8); moist		A 1180	60	20	20	sp	
<u>SILTY CLAY</u> - nonplastic; 10% silt; soft; red (2.5YR-5/8); moist; strong product odor			36	50	20	cl	
<u>SAND</u> - very fine grained; poorly graded; loose; red (2.5YR-5/8); moist - very fine to fine grained; wet			36	10	10	sp	
TOTAL DEPTH = 18.0 FEET							

DRAFT BY	RPS 11/16/93	DRAFT CHK	PROJ. CHK	APPRV. BY	DWG. NO.	409802-A22 Sheet 1 of 1

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

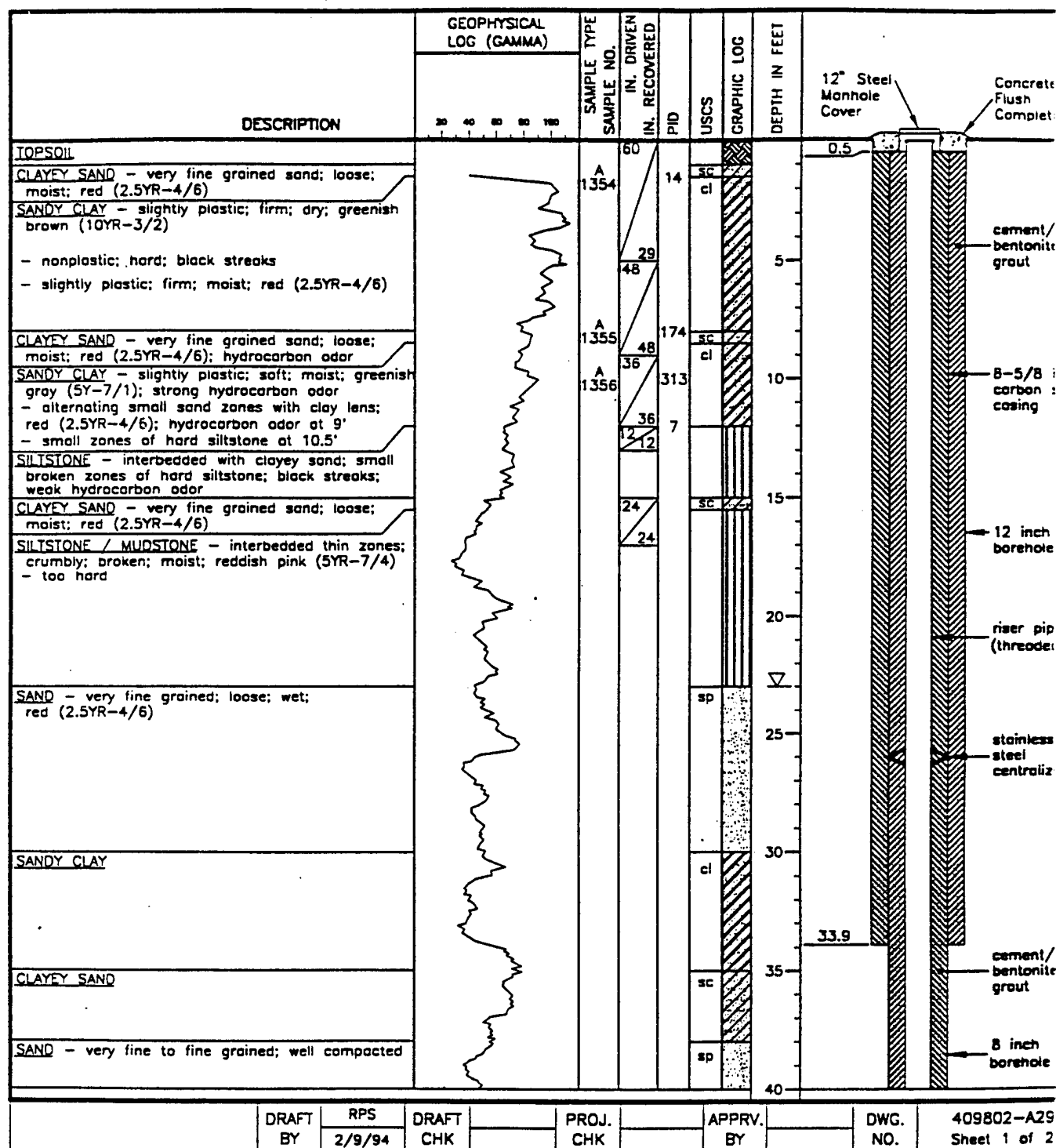
MONITORING WELL 2-

DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A
PAD ELEV.(FT): 1240.51
TOTAL DEPTH(FT.): 70.5
Logged By: V. CRNICH, P. SCHUMANN
Date Started: 11/9/93
Drilled By: T. PATTERSON, NESCO
Date Completed: 11/24/93
A. SORIANO, GPI
Drill Rig Type: SIMCO, MOBILE B-61
Drilling Method: HOLLOW STEM AUGER
AND MUD ROTARY
Sampling Method: CONTINUOUS SAMPLER
Notes: 6" AND 8" BOREHOLE; DESCRIPTIONS BELOW 40'
PARTIALLY BASED ON GAMMA LOG
COORDINATES--NAD 27: N 158259.233, E 2180356.152

WELL COMPLETION DATA

Elev--Top of Casing(ft.): 1242.96
Ref. Datum: NGVD
1. Surf Casing--I.D.(in.): 8-5/8
Depth(ft.): 33.9
Type: Carbon
Centralizers--Type:
Depths(ft.):
2. Riser Pipe--I.D.(in.): 2
Depth(ft.): 60.0
Type: S.Steel
Centralizers--Type: S.Steel
Depths(ft.): 26.0, 59.0
3. Screen Dia.(in.): 2
Type: S.Steel Millslotted
Depth Interval(ft.): 60.0-70.0
Slot Size(in.): .010
Centralizers--Type:
Depths(ft.):
4. Filter Pack Type: Silica Sand
Depth Interval(ft.): 58.0-70.5
Conc. Pad Size: 4'x4'x6'



Client: TINKER AFB

Project Location: TINKER AFB, OKLAHOMA

Project Name: TINKER 5000

Project Number: 409802

MONITORING WELL 2-

DRILLING AND SAMPLING INFORMATION

WELL COMPLETION DATA

Boring Location: AREA A PAD ELEV.(FT): 1240.51
 TOTAL DEPTH(FT.): 70.5
 Logged By: V. CRNICH, P. SCHUMANN Date Started: 11/9/93
 Drilled By: T. PATTERSON, NESCO Date Completed: 11/24/93
 A. SORIANO, GPI

Drill Rig Type: SIMCO, MOBILE B-61
 Drilling Method: HOLLOW STEM AUGER
 AND MUD ROTARY

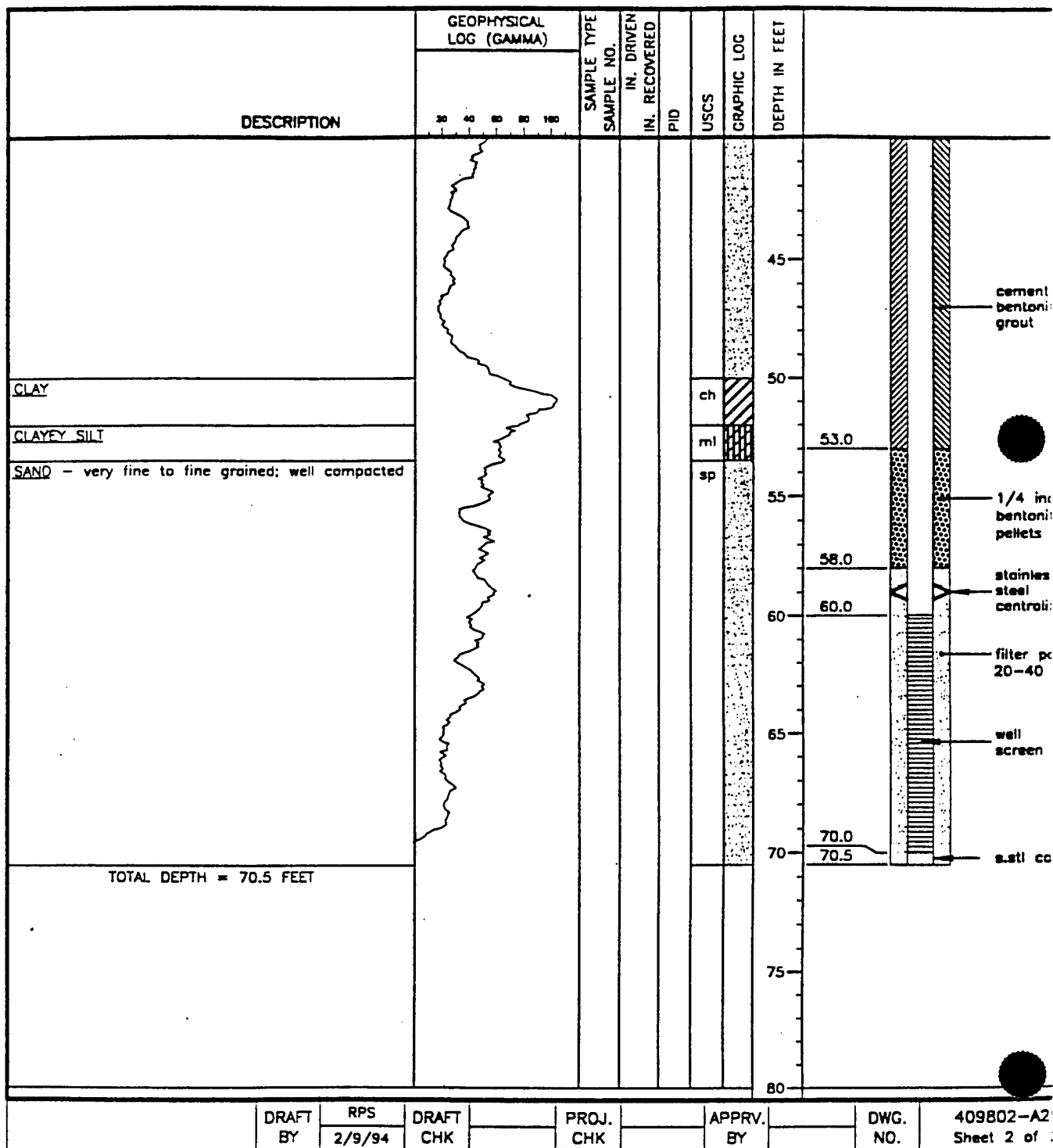
Sampling Method: CONTINUOUS SAMPLER

Notes: 6" AND 8" BOREHOLE; DESCRIPTIONS BELOW 40'

PARTIALLY BASED, ON GAMMA LOG

COORDINATES--NAD 27: N 158259.233, E 2180356.152

Elev-Top of Casing(FT.): 1242.96 Ref. Datum: NGVD
 1. Surf Casing-LD.(in.): 8-5/8 Depth(FT.): 33.9 Type: S.Steel
 Centralizers-Type: Depths(FT.):
 2. Riser Pipe-LD.(in.): 2 Depth(FT.): 60.0 Type: S.Steel
 Centralizers-Type: S.Steel Depths(FT.): 26.0, 59.0
 3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
 Depth Interval(FT.): 60.0-70.0 Slot Size(in.): .010
 Centralizers-Type: Depths(FT.):
 4. Filter Pack Type: Silica Sand Depth Interval(FT.): 58.0-70.5
 Conc. Pad Size: 4'x4'x5'



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-

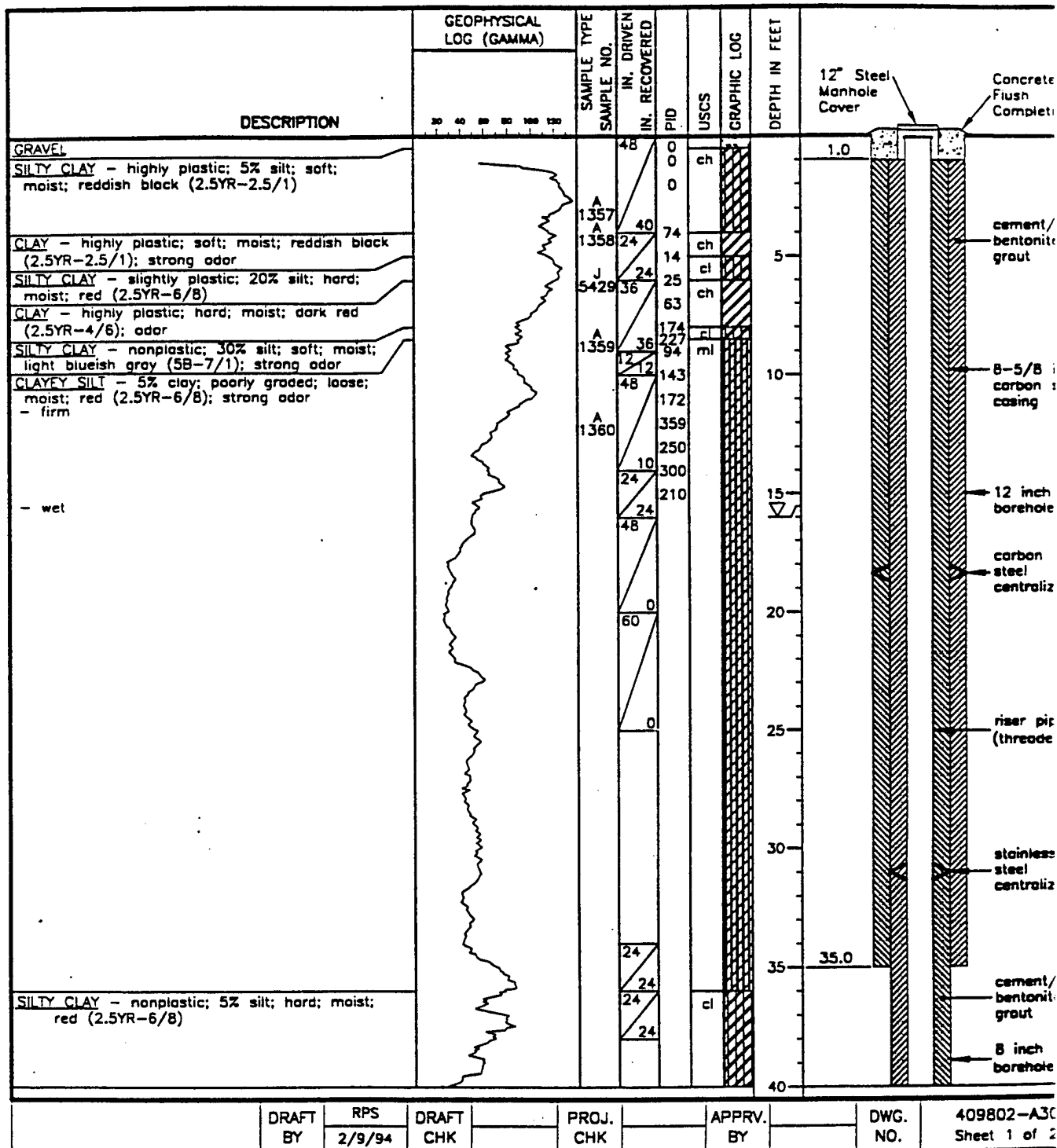
DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A PAD ELEV.(FT.): 1240.98
TOTAL DEPTH(FT.): 74.0
Logged By: P. SCHUMANN, V. CRNICH Date Started: 11/22/93
Drilled By: J. WALKER Date Completed: 12/29/93
GPI
Drill Rig Type: MOBILE B-61 AND TH-60
Drilling Method: HOLLOW STEM AUGER
AND MUD ROTARY
Sampling Method: 3" I.D CONTINUOUS SAMPLER

WELL COMPLETION DATA

Elev-Top of Casing(FT.): 1240.81 Ref. Datum: NGVD
1. Surf Casing-I.D.(in.): 8-5/8 Depth(FT.): 35.0 Type: Carbon
Centralizers-Type: C.Steel Depths(FT.): 18.4
2. Riser Pipe-I.D.(in.): 2 Depth(FT.): 61.0 Type: S.Steel
Centralizers-Type: S.Steel Depths(FT.): 31.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(FT.): 61.0-71.0 Slot Size(in.): .010
Centralizers-Type: S.Steel Depths(FT.): 60.4
4. Filter Pack Type: Silica Sand Depth Interval(FT.): 59.0-71.5
Conc. Pad Size: 4'x4'x6"

Notes: 8" BOREHOLE
COORDINATES-NAD 27: N 158368.779, E 2180374.657



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

2-4A
MONITORING WELL 2-

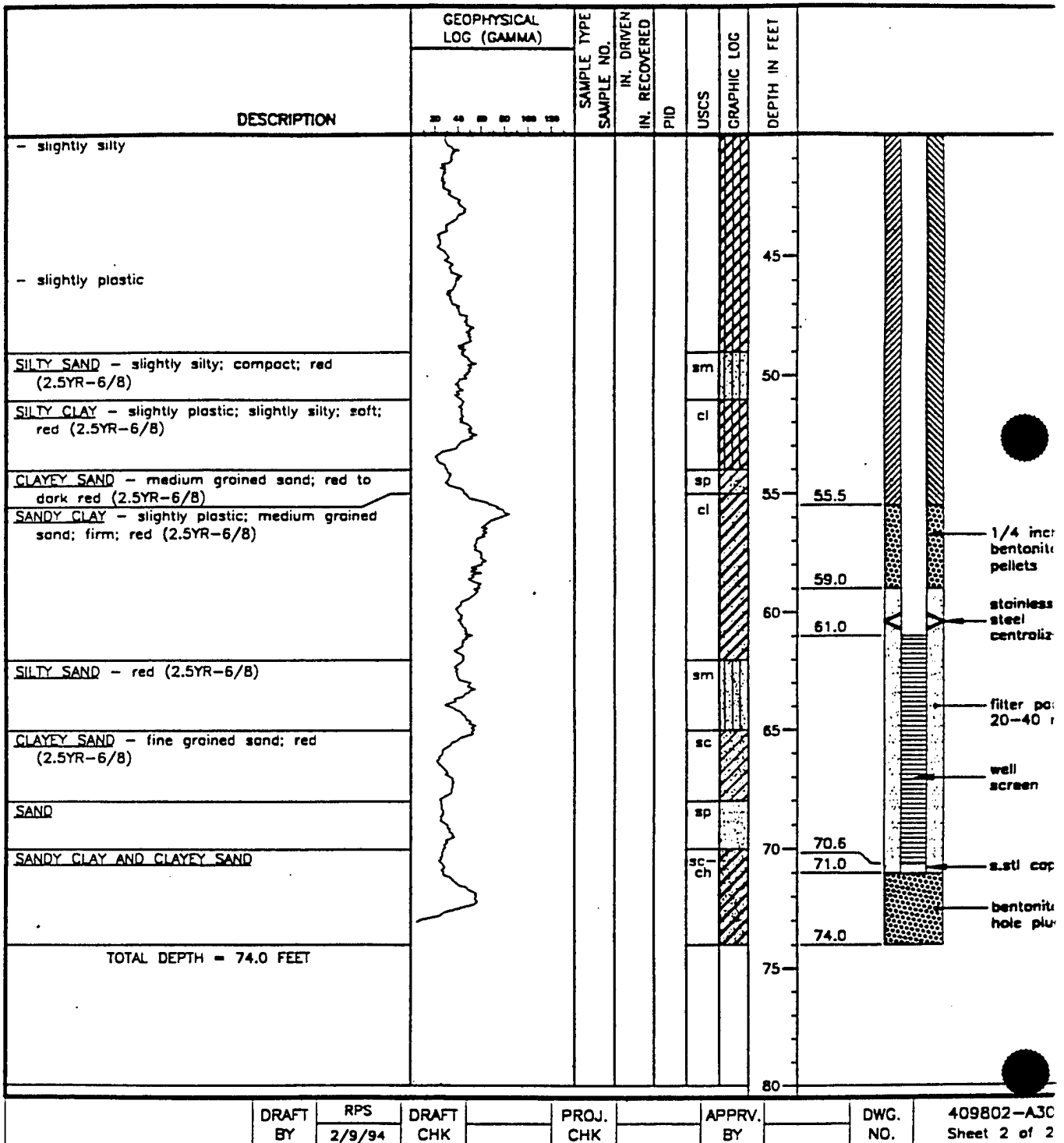
DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A PAD ELEV.(FT.): 1240.98
TOTAL DEPTH(FT.): 74.0
Logged By: P. SCHUMANN, V. CRNICH Date Started: 11/22/93
Drilled By: J. WALKER Date Completed: 12/29/93
GPI
Drill Rig Type: MOBILE B-61 AND TH-60
Drilling Method: HOLLOW STEM AUGER
AND MUD ROTARY
Sampling Method: 3" I.D CONTINUOUS SAMPLER

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 1240.81 Ref. Datum: NGVD
1. Surf Casing-LD.(in.): 8-5/8 Depth(ft.): 35.0 Type: C-Steel
Centralizers-Type: C-Steel Depths(ft.): 18.4
2. Riser Pipe-LD.(in.): 2 Depth(ft.): 61.0 Type: S-Steel
Centralizers-Type: S-Steel Depths(ft.): 31.0
3. Screen Dia.(in.): 2 Type: S-Steel Millslotted
Depth Interval(ft.): 61.0-71.0 Slot Size(in.): .010
Centralizers-Type: S-Steel Depths(ft.): 60.4
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 59.0-71.5
Conc. Pad Size: 4'x4'x6"

Notes: 8" BOREHOLE
COORDINATES-NAD 27: N 158368.779, E 2180374.657



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-51

DRILLING AND SAMPLING INFORMATION

Boring Location: SOUTHEAST OF
BUILDING 410

Logged By: V. CRNICH

Drilled By: J. WALKER

GPI

Drill Rig Type: TH-60, INGERSOL RAND

Drilling Method: HOLLOW STEM AUGER AND

MUD ROTARY

Sampling Method: 2'x2" CONTINUOUS SPLIT SPOON

PAD ELEV.(FT): 1241.77
TOTAL DEPTH(FT.): 74.0
Date Started: 11/8/93
Date Completed: 12/27/93

Elev-Top of Casing(ft.): 2141.65

1. Surf Casing-I.D.(in.): 8-5/8

Centralizers-Type: C.Steel

2. Riser Pipe-I.D.(in.): 2

Centralizers-Type: S.Steel

3. Screen Dia.(in.): 2

Depth Interval(ft.): 61.6-71.6

Centralizers-Type:

4. Filter Pack Type: Silica Sand

Conc. Pad Size: 4'x4'x6"

Ref. Datum: NGVD

Depth(ft.): 36.5 Type: Carbon Ste

Depths(ft.): 18.75

Depth(ft.): 61.6 Type: S.Steel

Depths(ft.): 30.4, 61.0

Type: S.Steel Millslotted

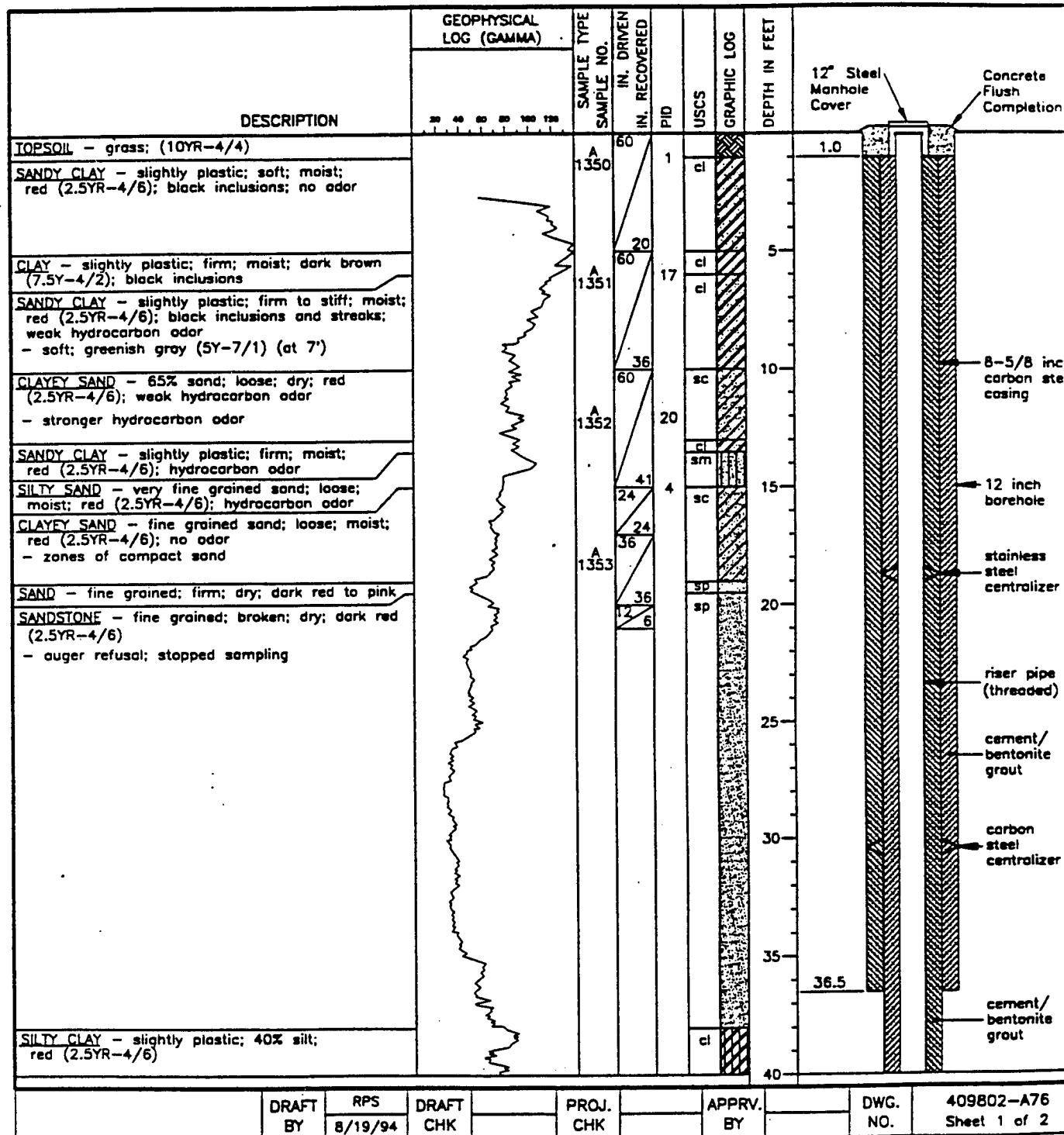
Slot Size(in.): .010

Depths(ft.):

Depth Interval(ft.): 60.1-74.0

Notes: 8" AND 12" BOREHOLE

COORDINATES-NAD 27: N 158317.014, E 2180427.678



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-51

DRILLING AND SAMPLING INFORMATION

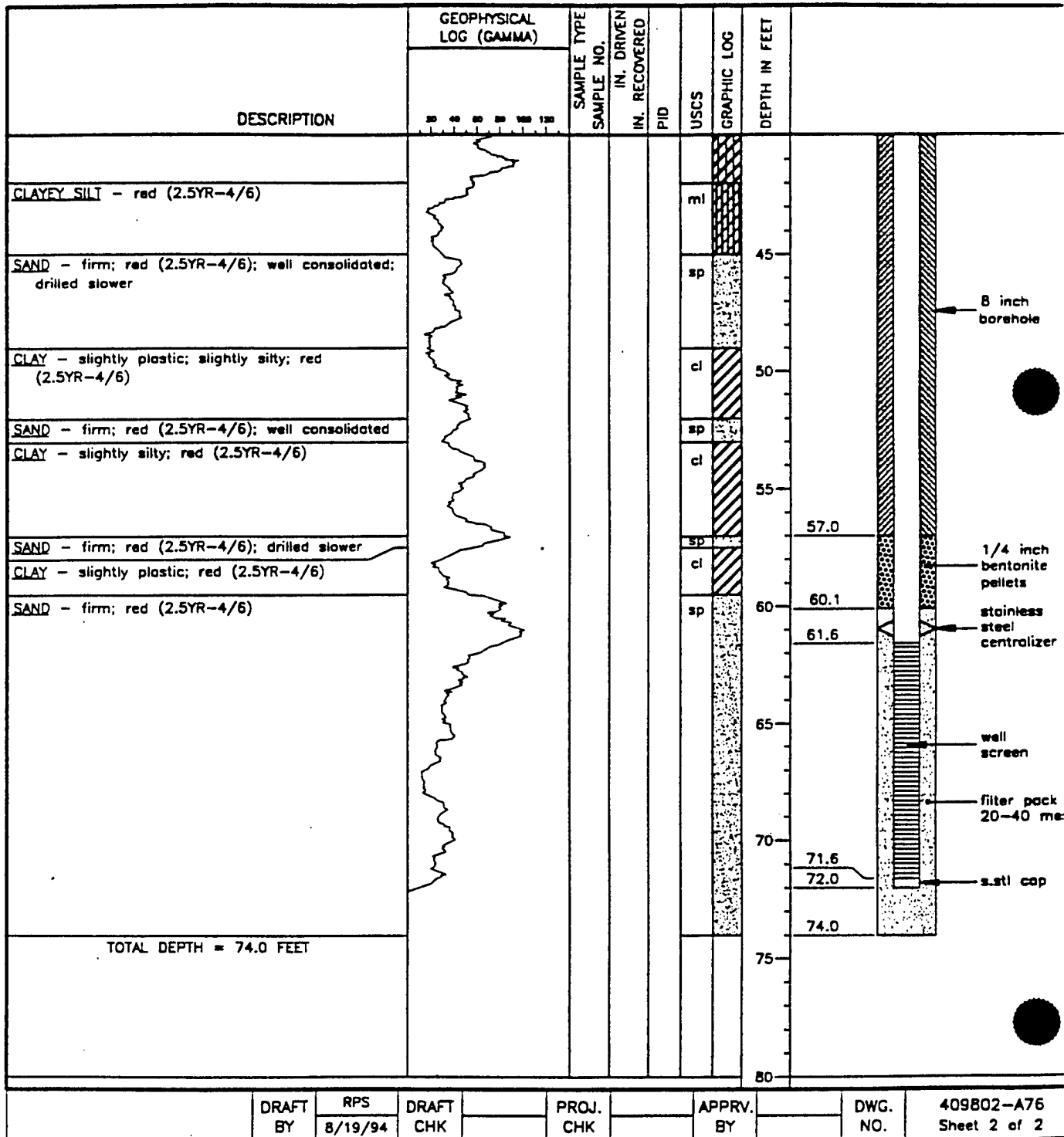
Boring Location: SOUTHEAST OF BUILDING 410
Logged By: V. CRNICH
Drilled By: J. WALKER
GPI
Drill Rig Type: TH-60, INGERSOL RAND
Drilling Method: HOLLOW STEM AUGER AND MUD ROTARY
Sampling Method: 2"x2" CONTINUOUS SPLIT SPOON

PAD ELEV.(FT.): 1241.77
TOTAL DEPTH(FT.): 74.0
Date Started: 11/8/93
Date Completed: 12/27/93

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 2141.65 Ref. Datum: NGVD
1. Surf Casing-L.D.(in.): 8-5/8 Depth(ft.): 36.5 Type: Carbon St.
Centralizers-Type: C.Steel Depths(ft.): 18.75
2. Riser Pipe-L.D.(in.): 2 Depth(ft.): 61.6 Type: S.Steel
Centralizers-Type: S.Steel Depths(ft.): 30.4, 61.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 61.6-71.6 Slot Size(in.): .010
Centralizers-Type: S.Steel
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 60.1-74.0
Conc. Pod Size: 4"x4"x6"

Notes: 8" AND 12" BOREHOLE
COORDINATES-NAD 27: N 158317.014, E 2180427.678



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

2-503
MONITORING WELL 2-5C

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST OF CIVIL ENGINEERING BLDG
Logged By: V. CRNICH
Drilled By: B. HYBER
NESCO

PAD ELEV.(FT): 1241.38
TOTAL DEPTH(FT.): 23
Date Started: 10/25/93
Date Completed: 10/26/93

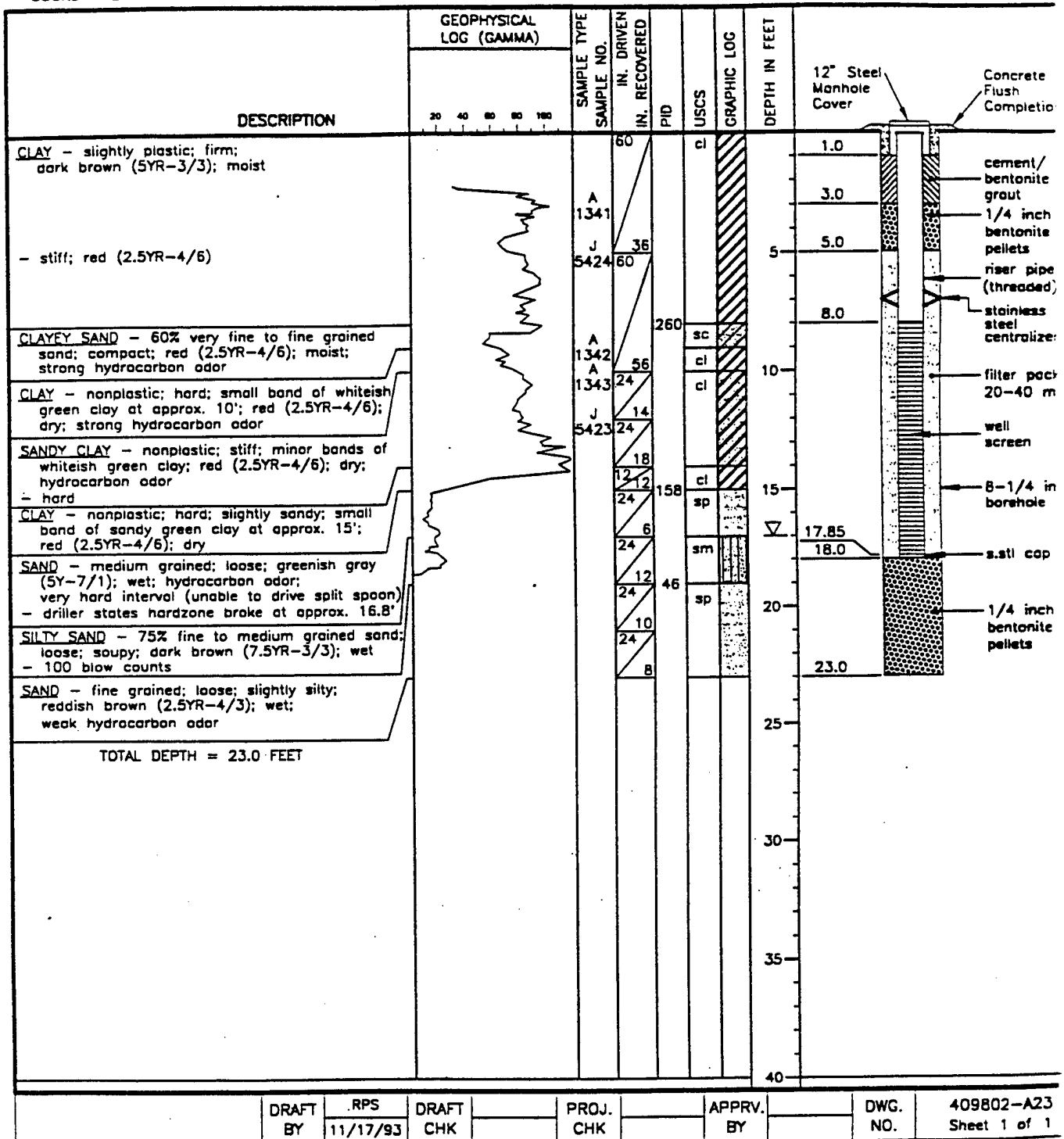
Drill Rig Type: B-61 HD
Drilling Method: 8-1/4" HOLLOW STEM AUGER

Sampling Method: 5'x4" CONTINUOUS SAMPLER AND
2'x2" SPLIT SPOON

Notes: GEOTECH SAMPLES COLLECTED FROM THE 5-7' AND THE 12-14' INTERVALS;
SPLIT SPOON HAMMERED TO 100 BLOW COUNTS BEFORE PULLING IT OUT OF HOLE
COORDINATES--NAD 27: N158461.793, E 2180201.105

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 2141.30 Ref. Datum: NGVD
1. Riser Pipe-LD.(in.): 2 Depth(ft.): 8.0 Type: S.Steel
Centralizers-Type: S.Steel Depths(ft.): 7.0
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 8.0-17.85 Slot Size(in.): .010
Centralizers-Type: Depths(ft.):
3. Filter Pack Type: Silica Sand Depth Interval(ft.): 5.0-18.0
Conc. Pad Size: 4'x4'x6"



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-5

DRILLING AND SAMPLING INFORMATION

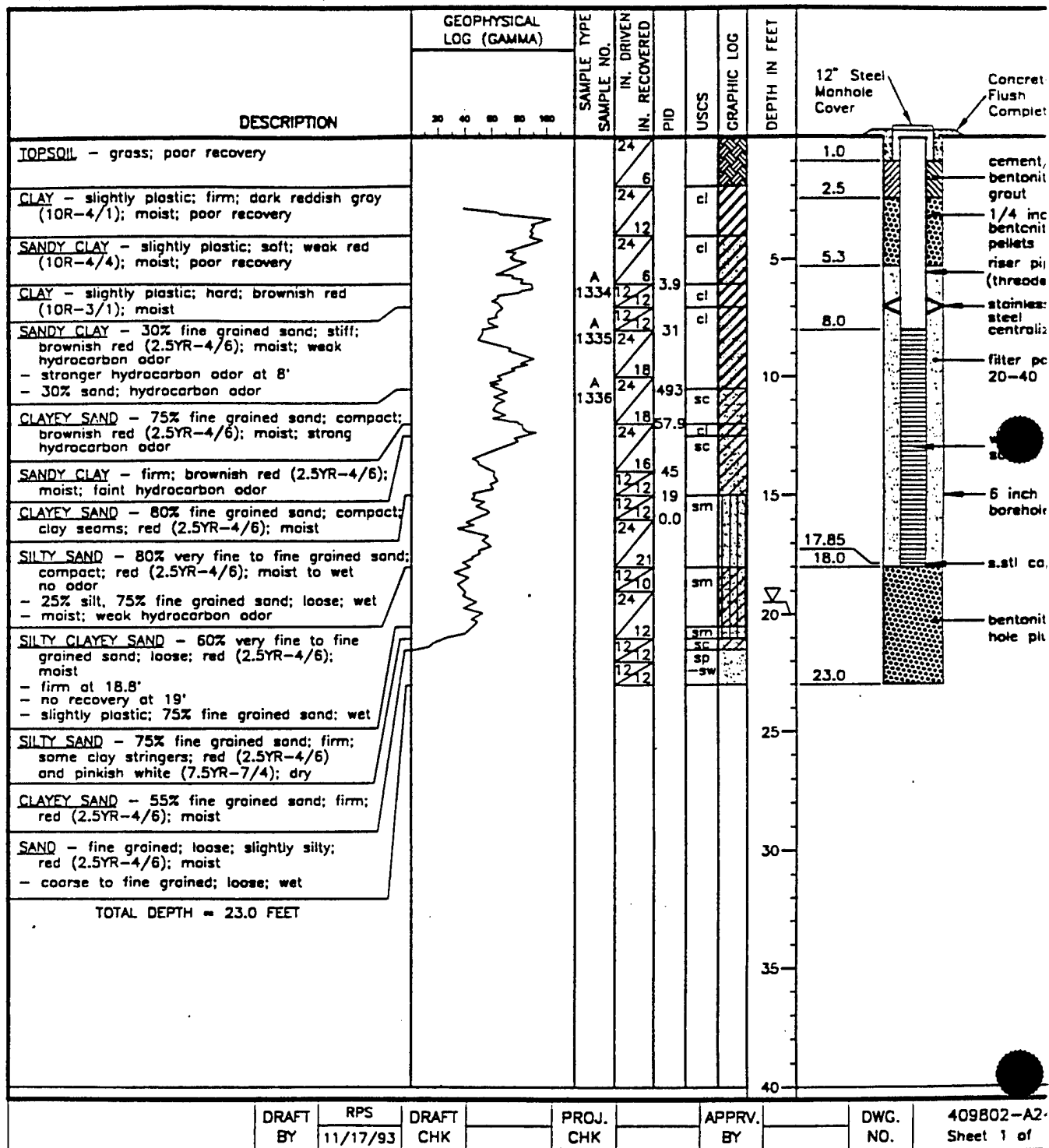
Boring Location: SOUTHEAST OF BUILDING 410
Logged By: V. CRNICH
Drilled By: T. PATTERSON
Drill Rig Type: SIMCO 2800 HS HT
Drilling Method: 6" HOLLOW STEM AUGER

Sampling Method: 2'x 2' SPLIT SPOON

Notes: CREW USING CRISCO AS LUBRICANT ON SPLIT SPOONS;
HIT WATER AT 16 FEET
COORDINATES-NAD 27: N 158301.112, E 2180427.530

WELL COMPLETION DATA

Elev-Top of Casing(FL): 1241.29 Ref. Datum: NGVD
1. Riser Pipe-LD.(in.): 2 Depth(ft.): 8.0 Type: S
Centralizers-Type: S.Steel Depths(ft.): 7.0
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 8.0-17.85 Slot Size(in.): .010
Centralizers-Type: Depths(ft.):
3. Filter Pack Type:Silica Sand Depth Interval(ft.): 5.3-18.0
Conc. Pad Size: 4'x4'x5'



DRAFT BY	RPS	DRAFT CHK	PROJ. CHK	APPRV. BY	DWG. NO.	409802-A2- Sheet 1 of
	11/17/93					

Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

2-52A
MONITORING WELL 2-5

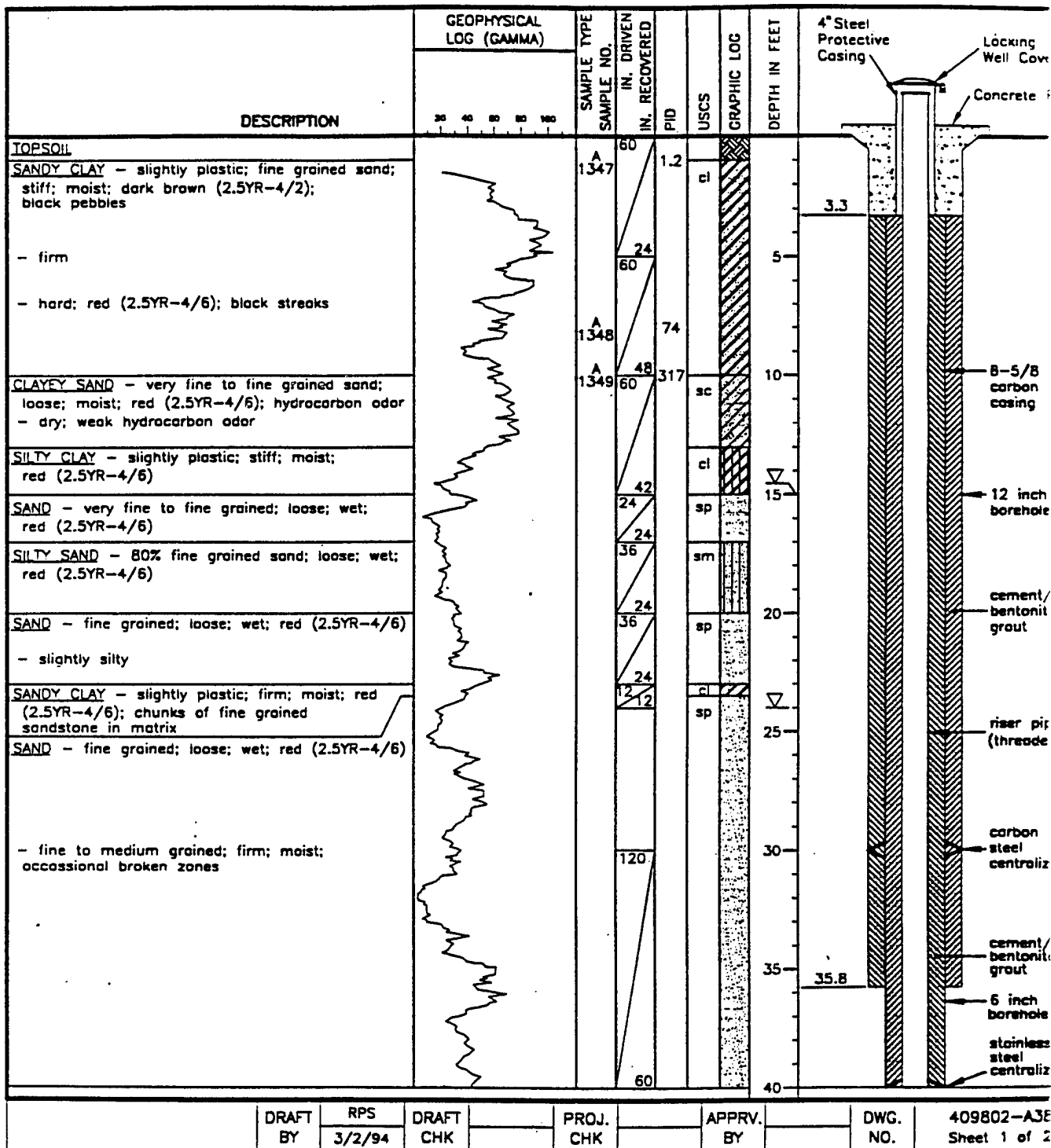
DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A PAD ELEV.(FT): 1239.83
TOTAL DEPTH(FT.): 72.0
Logged By: V. CRNICH Date Started: 11/3/93
Drilled By: T. PATTERSON, D. FORSTER Date Completed: 11/10/93
NESCO
Drill Rig Type: SIMCO, FAILING 1250
Drilling Method: HOLLOW STEM AUGER AND
MUD ROTARY
Sampling Method: 5'x2.5" CONTINUOUS SAMPLER

WELL COMPLETION DATA

Elev-Top of Casing(FT.): 1241.98 Ref. Datum: NGVD
1. Surf Casing-LD.(in.): 8-5/8 Depth(FT.): 35.8 Type: Carbon
Centralizers-Type: S.Steel Depths(FT.): 30.0
2. Riser Pipe-LD.(in.): 2 Depth(FT.): 56.8 Type: S.Steel
Centralizers-Type: S.Steel Depths(FT.): 40.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslottec
Depth Interval(FT.): 56.8-66.5 Slot Size(in.): .010
Centralizers-Type: S.Steel Depths(FT.): 60.4
4. Filter Pack Type: Silica Sand Depth Interval(FT.): 55.0-66.8
Conc. Pad Size: 4'x4'x5"

Notes: 6-1/4" BOREHOLE AND 12" BOREHOLE
COORDINATES-NAD 27: N 158283.581, E 2180247.928



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

MONITORING WELL 2-5:

DRILLING AND SAMPLING INFORMATION

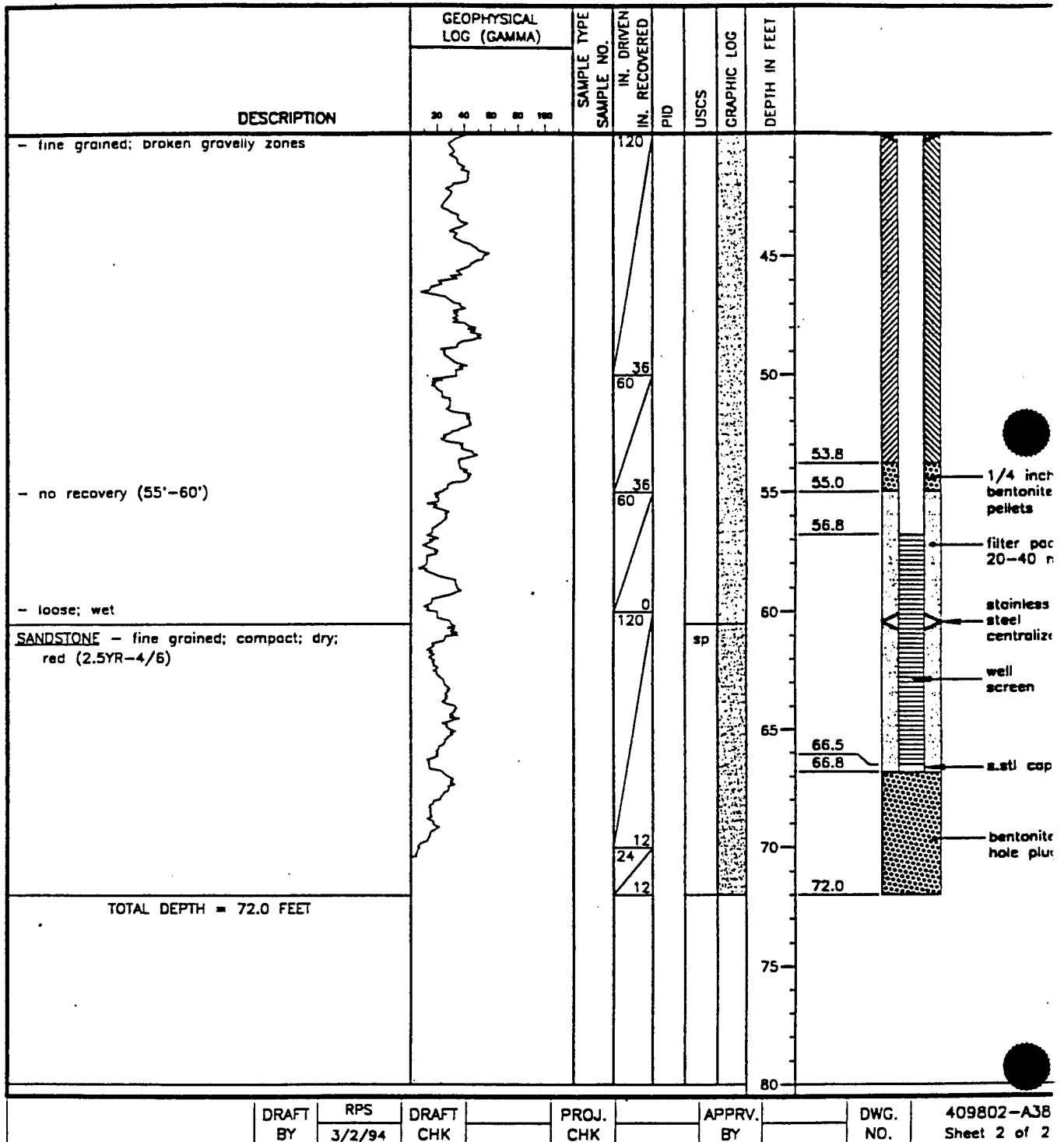
Boring Location: AREA A PAD ELEV.(FT): 1239.83
TOTAL DEPTH(FT.): 72.0
Logged By: V. CRNICH Date Started: 11/3/93
Drilled By: T. PATTERSON, D. FORSTER Date Completed: 11/10/93
NESCO

Drill Rig Type: SIMCO, FAILING 1250
Drilling Method: HOLLOW STEM AUGER AND
MUD ROTARY
Sampling Method: 5'x2.5" CONTINUOUS SAMPLER

Notes: 6-1/4" BOREHOLE AND 12" BOREHOLE
COORDINATES-NAD 27: N 158283.581, E 2180247.928

WELL COMPLETION DATA

Elev-Top of Casing(ft.): 1241.98 Ref. Datum: NGVD
1. Surf Casing-LD.(in.): 8-5/8 Depth(ft.): 35.8 Type: C
Centralizers-Type: S.Steel Depths(ft.): 30.0
2. Riser Pipe-LD.(in.): 2 Depth(ft.): 56.8 Type: S.Steel
Centralizers-Type: S.Steel Depths(ft.): 40.0
3. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(ft.): 56.8-66.5 Slot Size(in.): .010
Centralizers-Type: S.Steel Depths(ft.): 60.4
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 55.0-66.8
Conc. Pod Size: 4'x4'x6"



Client: TINKER AFB
Project Name: TINKER 5000

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409802

2-523
MONITORING WELL 2-5

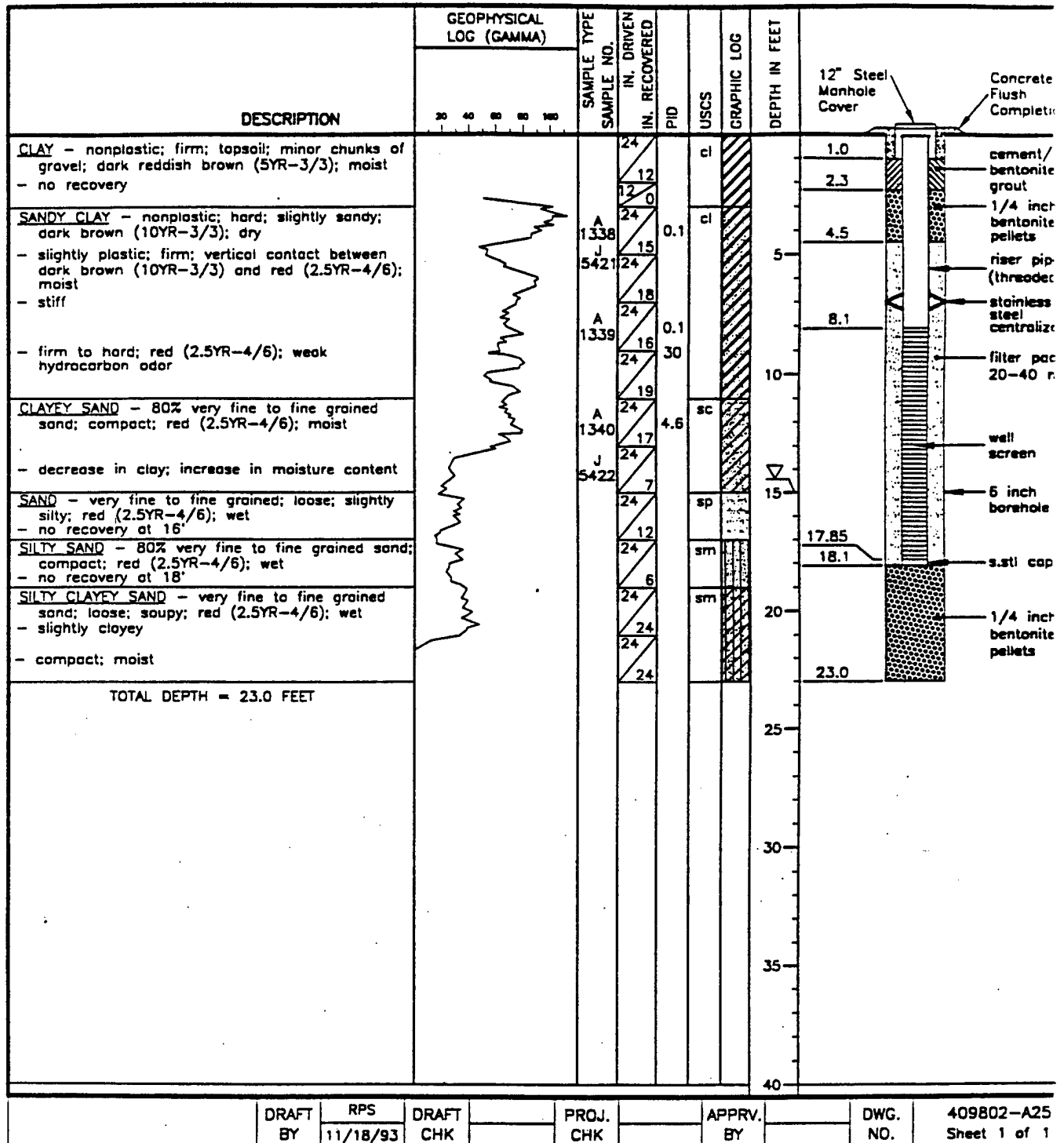
DRILLING AND SAMPLING INFORMATION

Boring Location: AREA A
PAD ELEV.(FT): 1239.95
TOTAL DEPTH(FT.): 23
Logged By: V. CRNICH
Date Started: 10/22/93
Drilled By: T. PATTERSON
Date Completed: 10/25/93
NECSO
Drill Rig Type: SIMCO 2800 HS HT
Drilling Method: 6" HOLLOW STEM AUGER
Sampling Method: 2'x 2" SPLIT SPOON

WELL COMPLETION DATA

Elev-Top of Casing(FT.): 1241.81 Ref. Datum: NGVD
1. Riser Pipe-ID.(in.): 2 Depth(FT.): 8.1 Type: S.Steel
Centralizers-Type: S.Steel Depths(FT.): 7.0
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
Depth Interval(FT.): 8.1-17.85 Slot Size(in.): .010
Centralizers-Type: Depths(FT.):
3. Filter Pack Type: Silica Sand Depth Interval(FT.): 4.5-18.1
Conc. Pad Size: 4'x4'x5'

Notes: CREW USING CRISCO AS LUBRICANT ON SPLIT SPOONS;
GEOTECH SAMPLES COLLECTED FROM THE 5-7' AND THE 13-15' INTERVAL
COORDINATES-NAD 27: N 158292.472, E 2180247.692



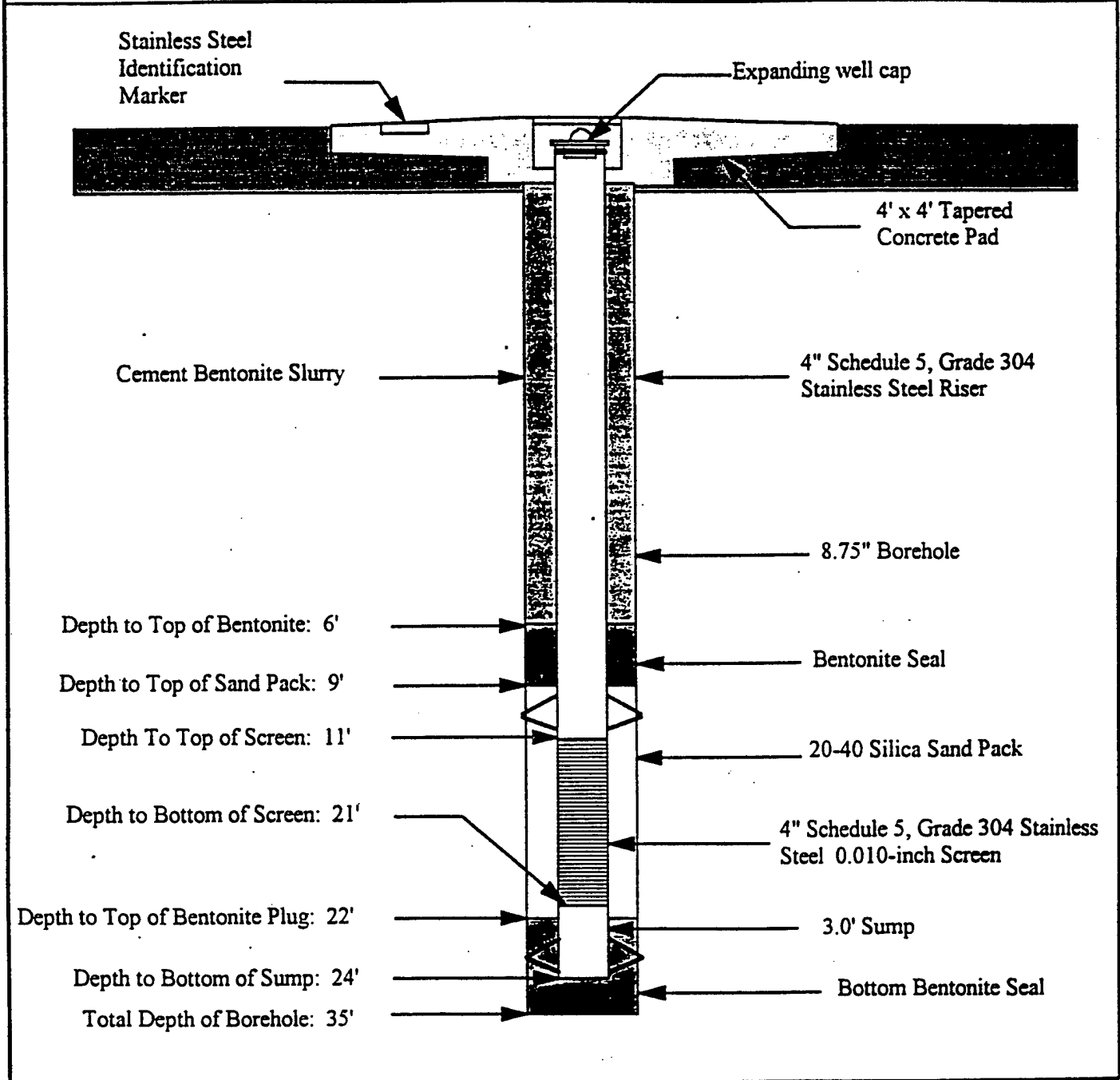


WELL CONSTRUCTION SCHEMATIC

(2)

Client: Tinker Air Force Base	Well ID: 2-145B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/14/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 3' thick top bentonite seal set.

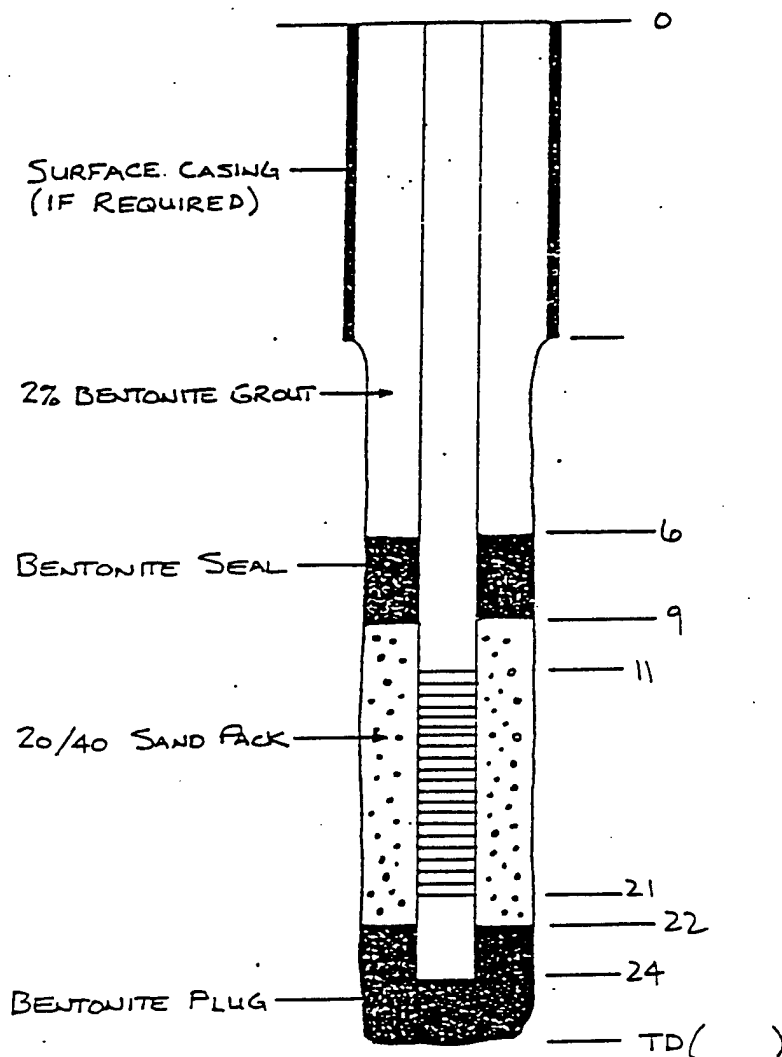


Drawing not to scale

< > Centralizers

R

Well ID	Recommended Construction		Comments
	Item	Depth	
2-145B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-6	
	Bentonite Seal (top)	6-9	
	Sand Pack	9-22	
	Bentonite Seal (bottom)	22-TD	
	Riser	0-11	
	Screen	11-21	
	Sumo	21-24	



Log Received

6-14-95

1 LOG RUN

2 LOG RUN

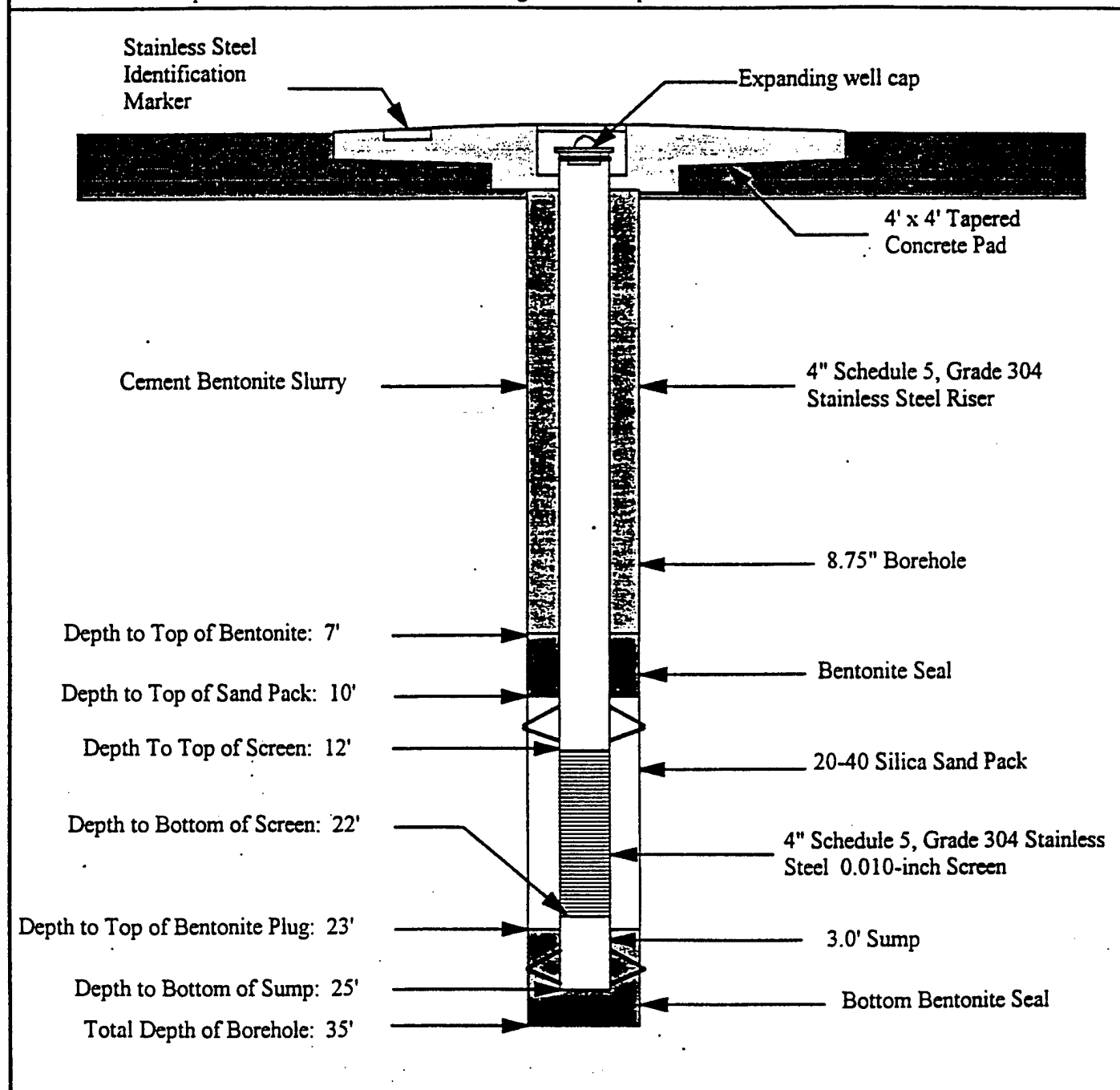
Well Design De

6-14-95

WELL CONSTRUCTION SCHEMATIC

(P)

Client: Tinker Air Force Base	Well ID: 2-146B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/13/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 3' thick top bentonite seal set.	

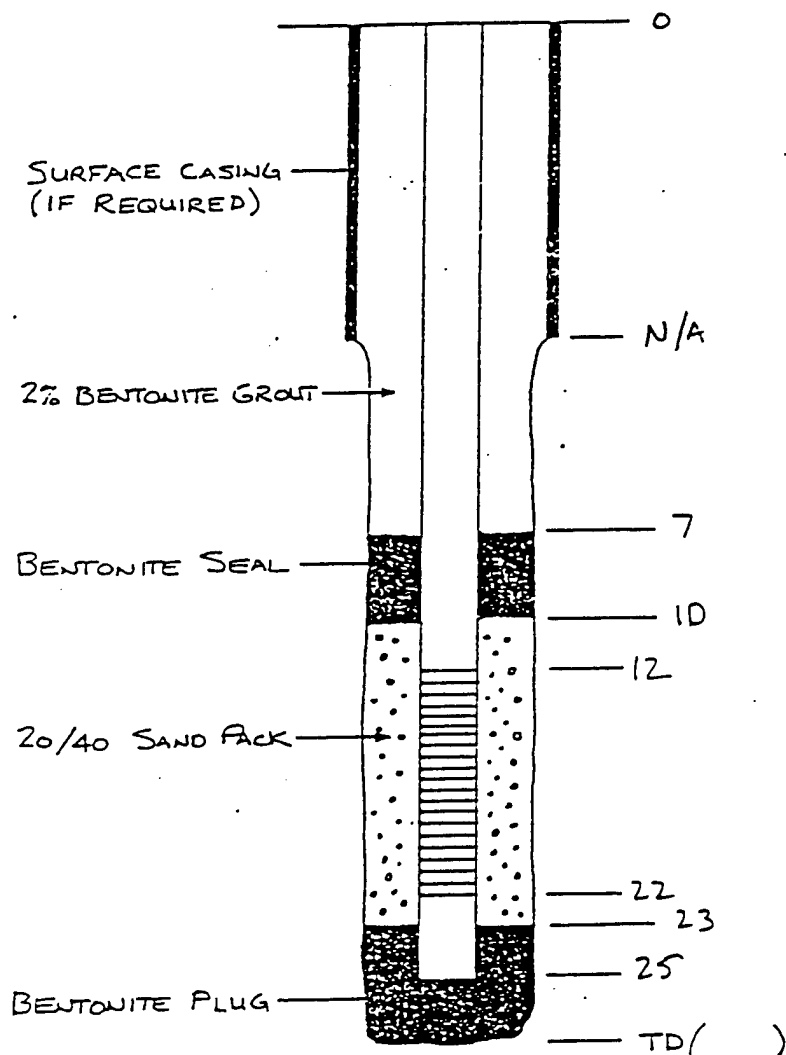


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< > Centralizers

2

Well ID	Recommended Construction		Comments
	Item	Depth	
2-146B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-7	
	Bentonite Seal (top)	7-10	
	Sand Pack	10-23	
	Bentonite Seal (bottom)	23-TD	
	Riser	0-12	
	Screen	12-22	
	Sump	22-25	



Log Received

Well Design De

12-14-95 2:27

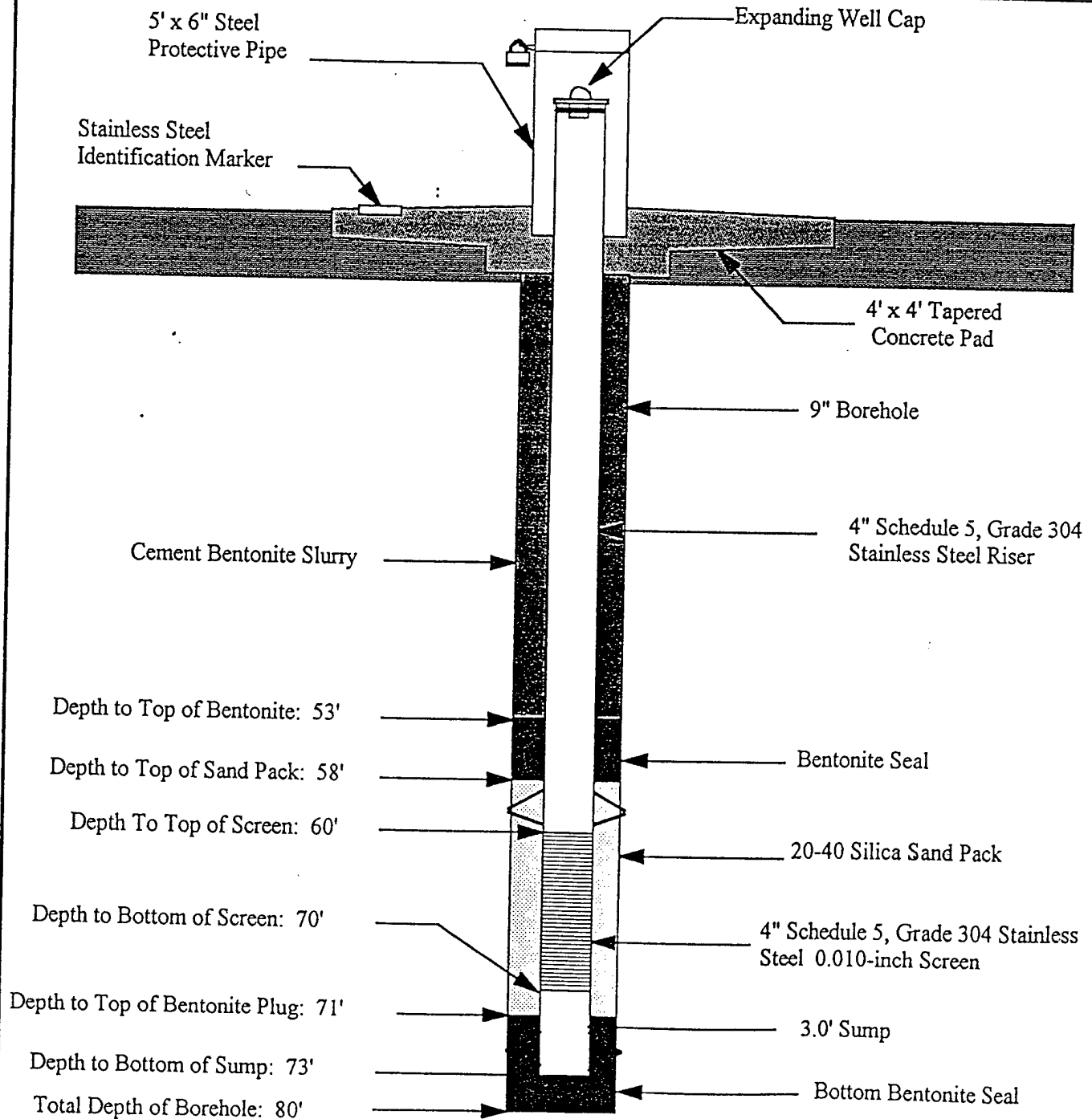
12-14-95 3:45

1 LOG RUN

2 LOG RUN

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-147A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 02/01/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1268.58'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1271.51'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Riser Casing.	

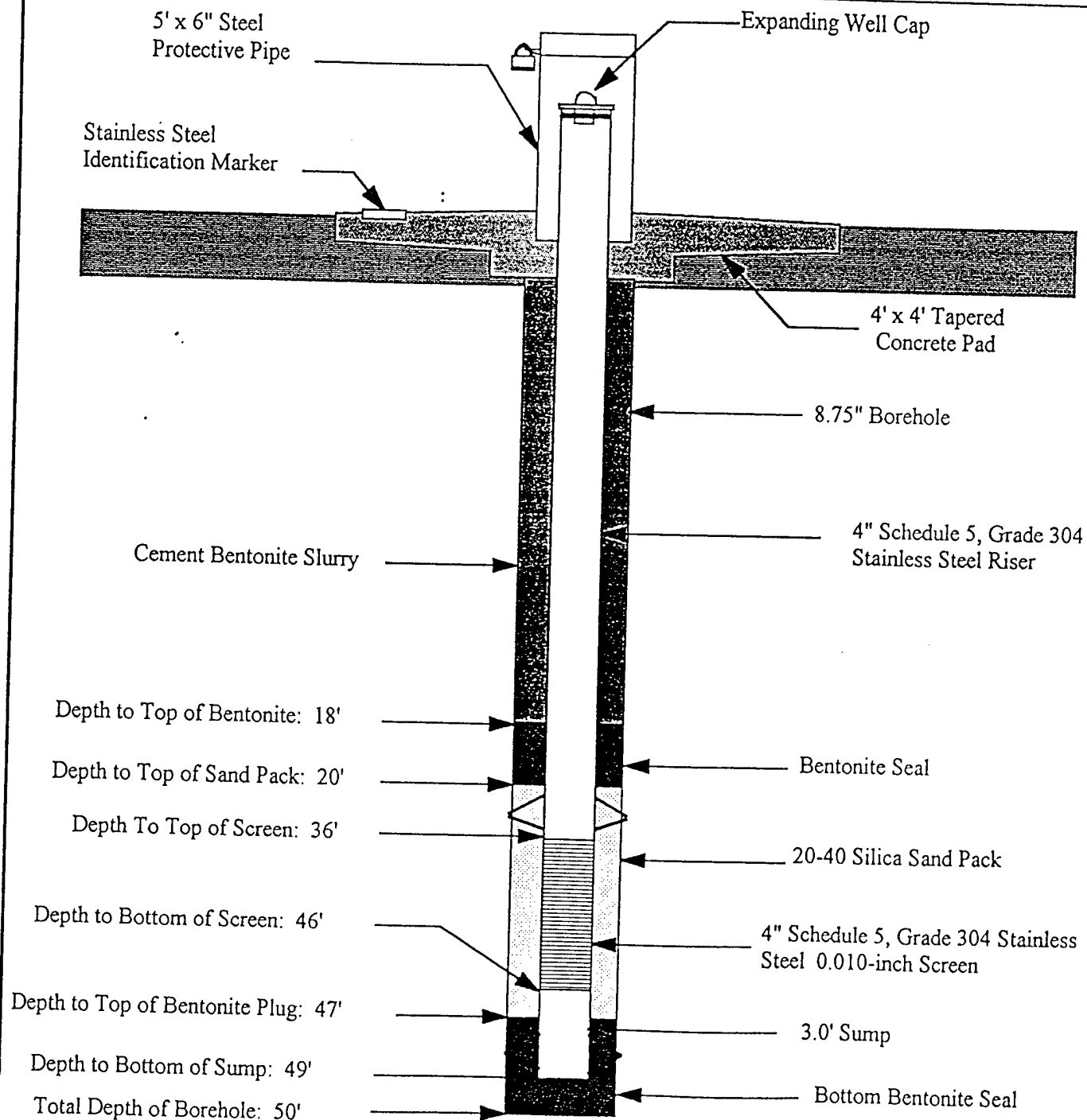


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-147B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 02/03/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1268.63'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1271.83'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Riser Casing. 2' thick top seal. Top of sand set 16' above screen.	

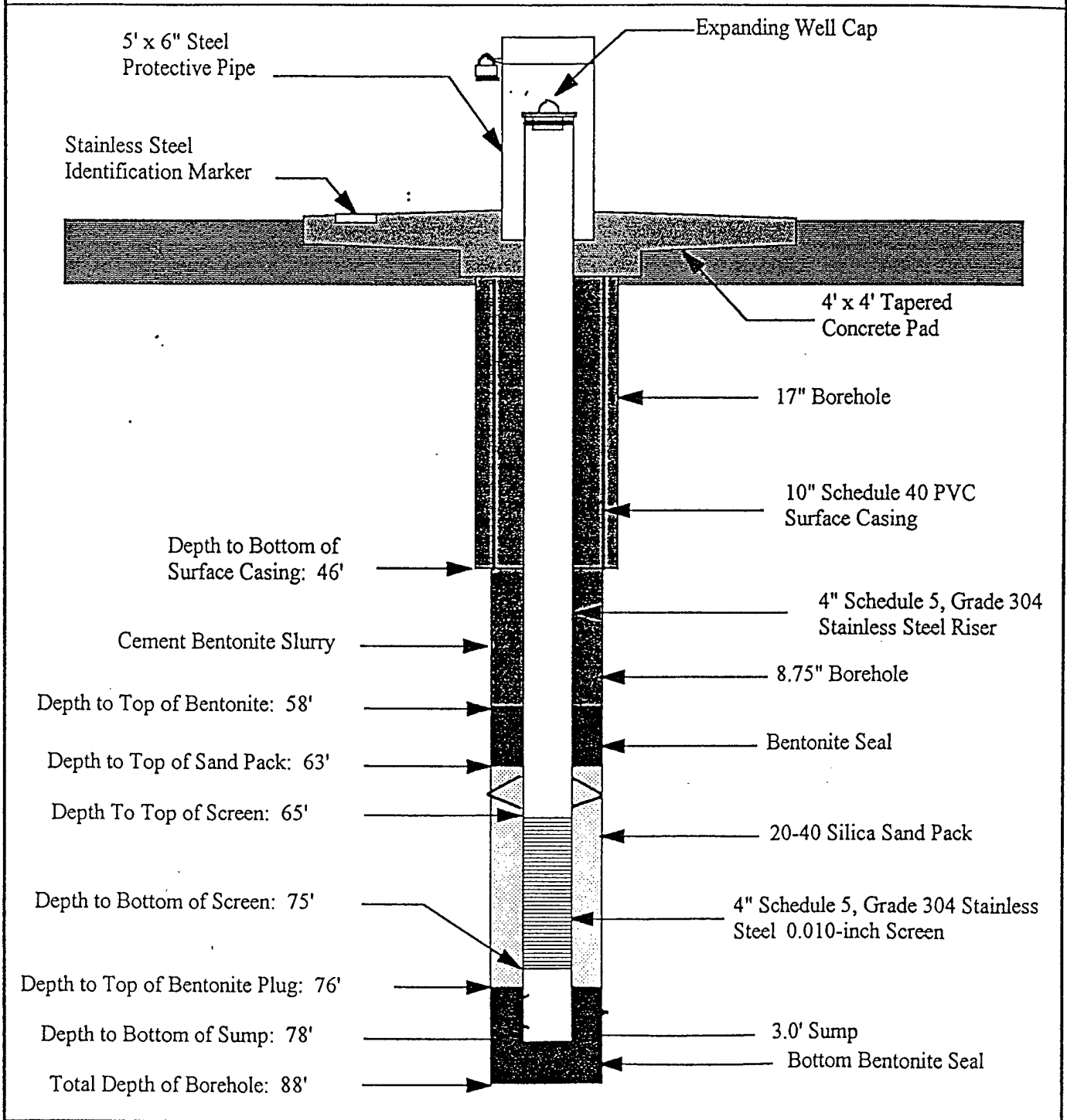


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< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-148A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/11/95
Contractor: Brown & Root Environmental	Drilling Method: Auger, 0'-46'; Mud Rotary, 46'-88'
Project Manager: David Parker	Ground Level Elev. (AMSL): 1247.45'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1250.11'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	



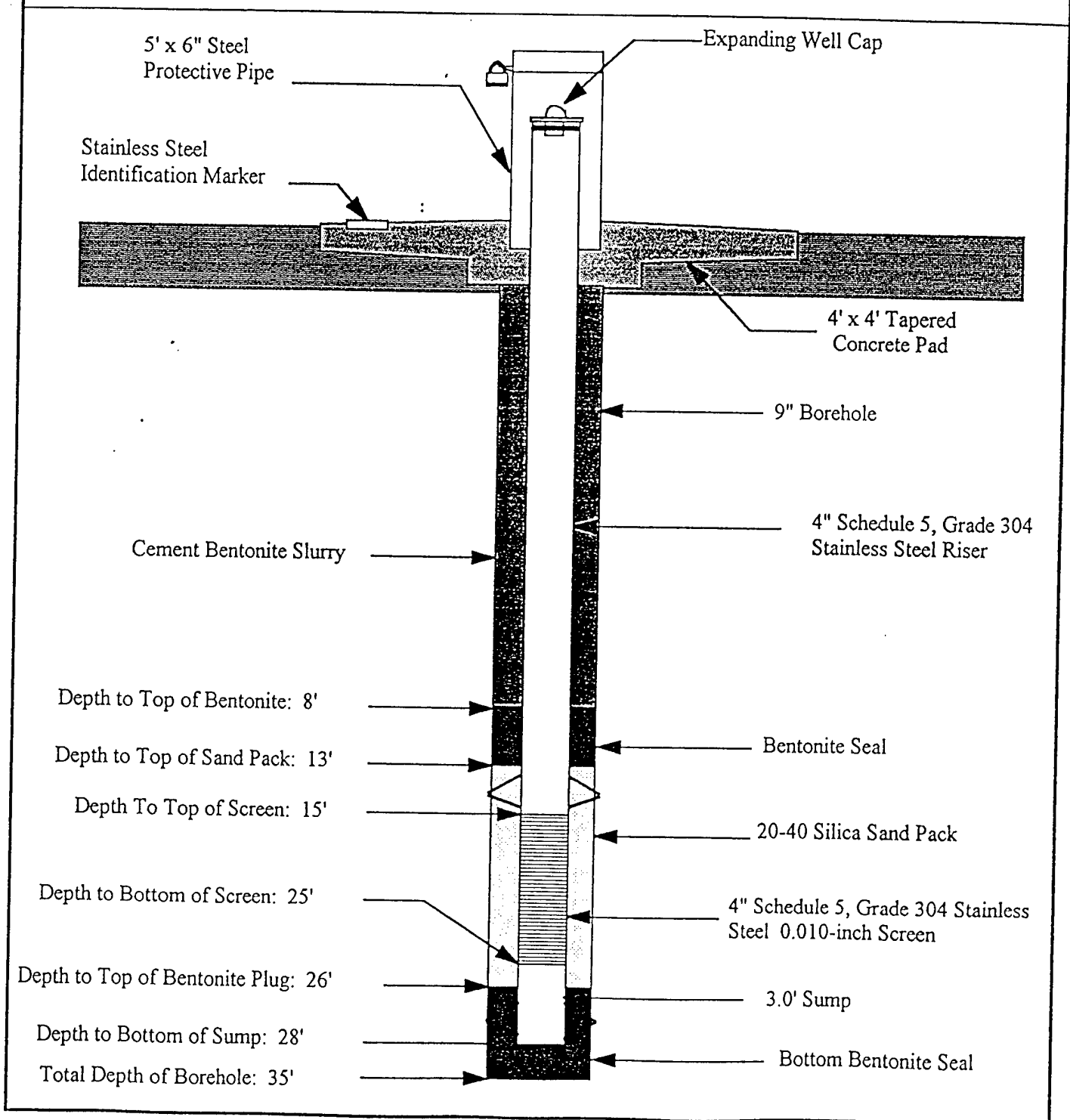
Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-148B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/20/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1247.46'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1250.12'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments:

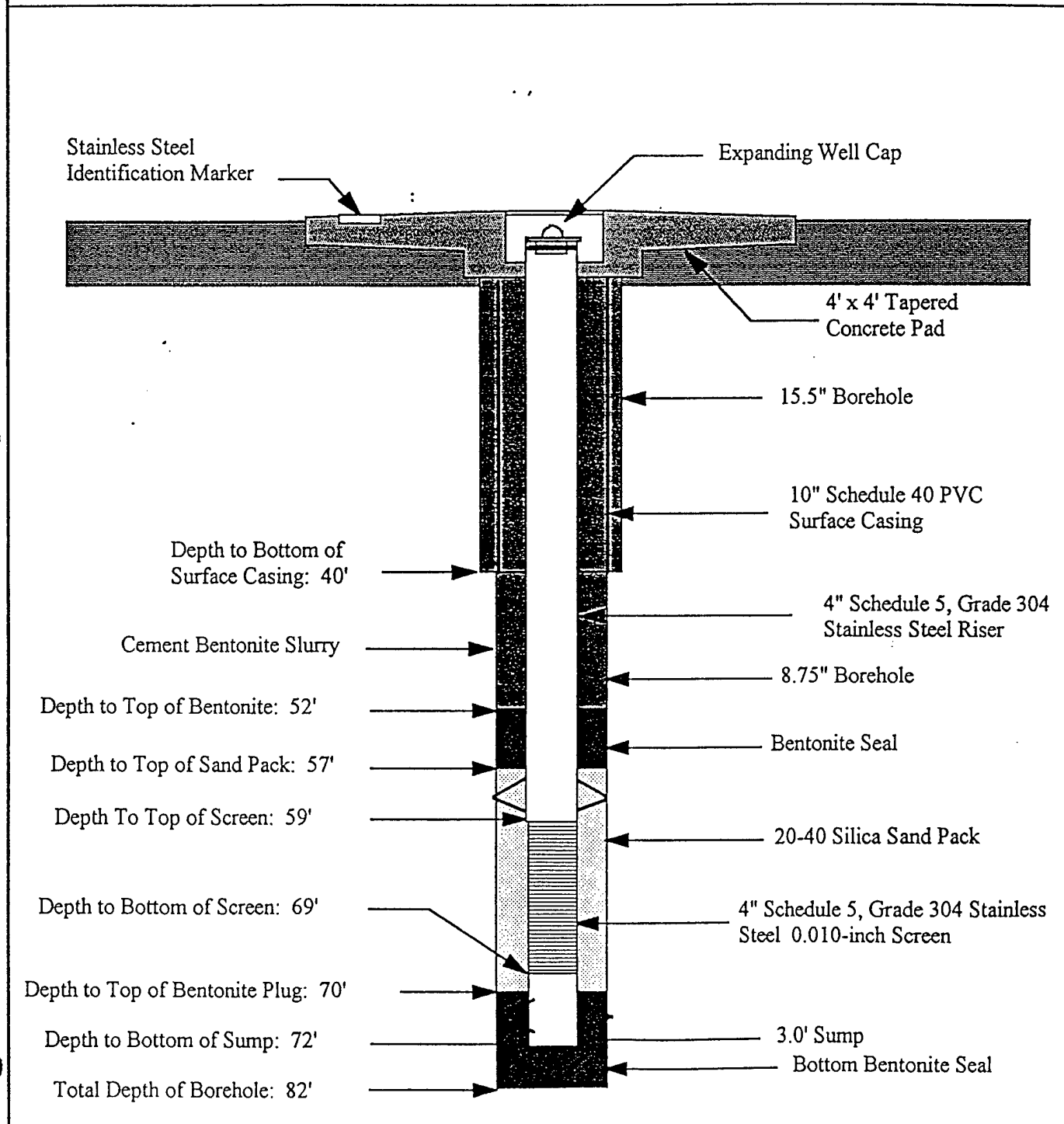


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< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-149A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/05/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1237.39'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1236.72'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

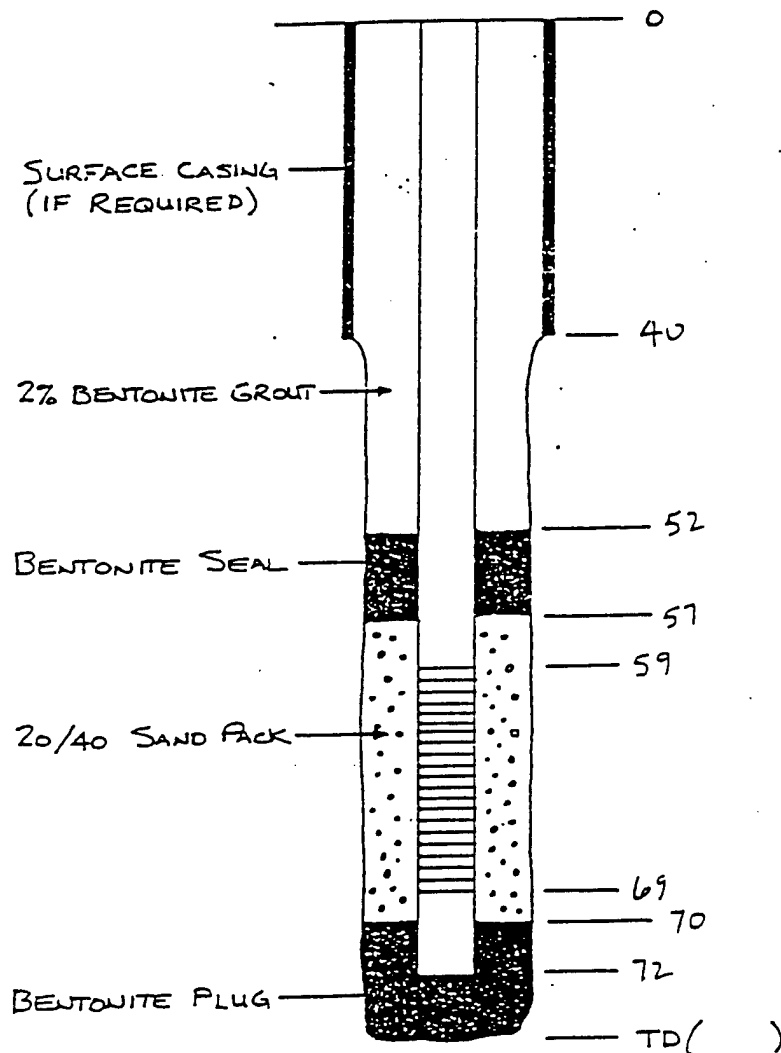


Drawing not to scale

< > Centralizers

12

Well ID	Recommended Construction		Comments
	Item	Depth	
2-149A	Surface Casing	0-40	
	Inner Casing	—	
	Grout	0-52	
	Bentonite Seal (top)	52-57	
	Sand Pack	57-70	
	Bentonite Seal (bottom)	70-TD	
	Riser	0-59	
	Screen	59-69	
	Sump	69-72	



Log Received

6-5-95 12:10

1 LOG RUN

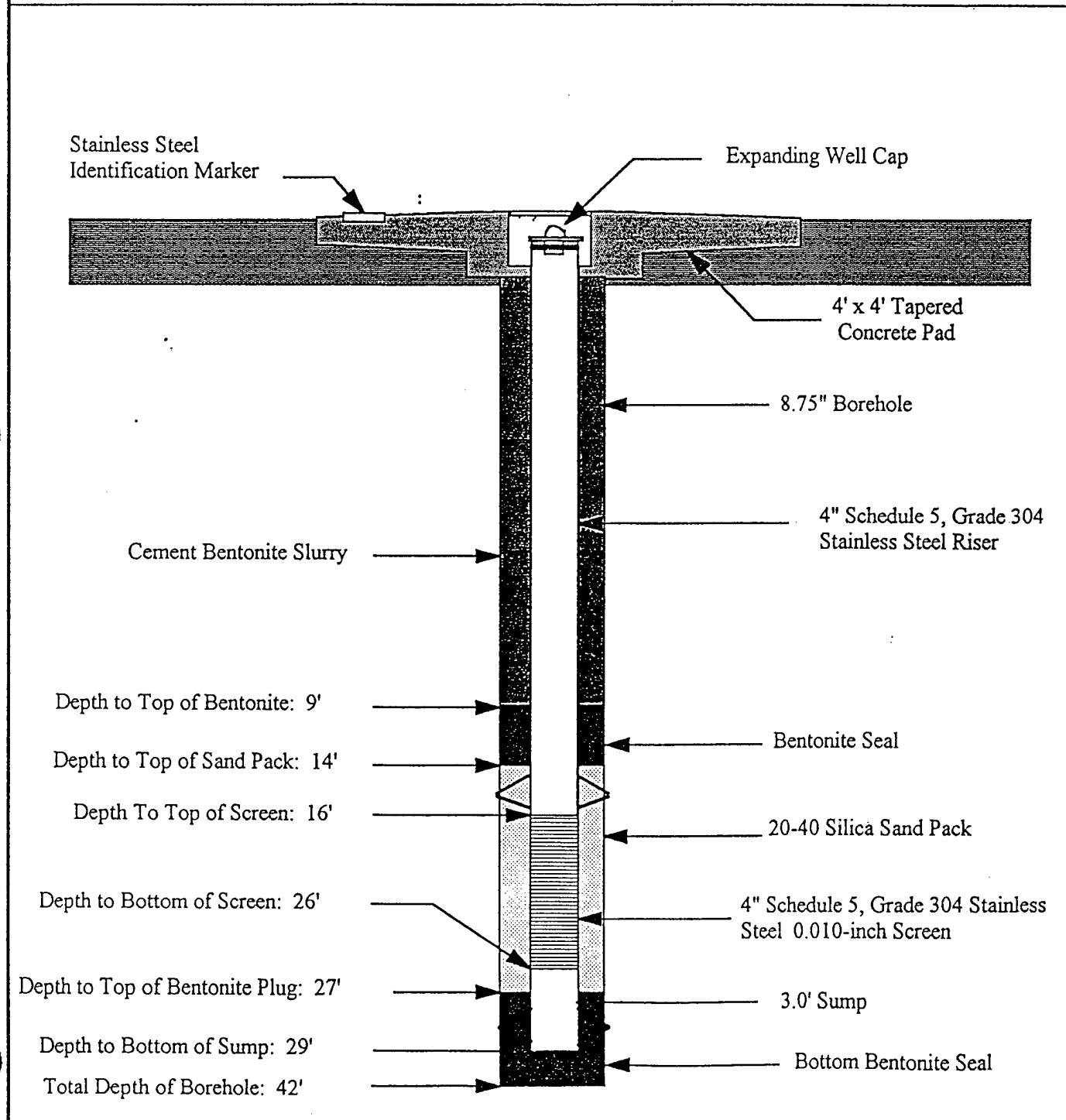
2 LOG RUN

Well Design De

6-5-95 12:10

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-149B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/07/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1237.08'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1236.55'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

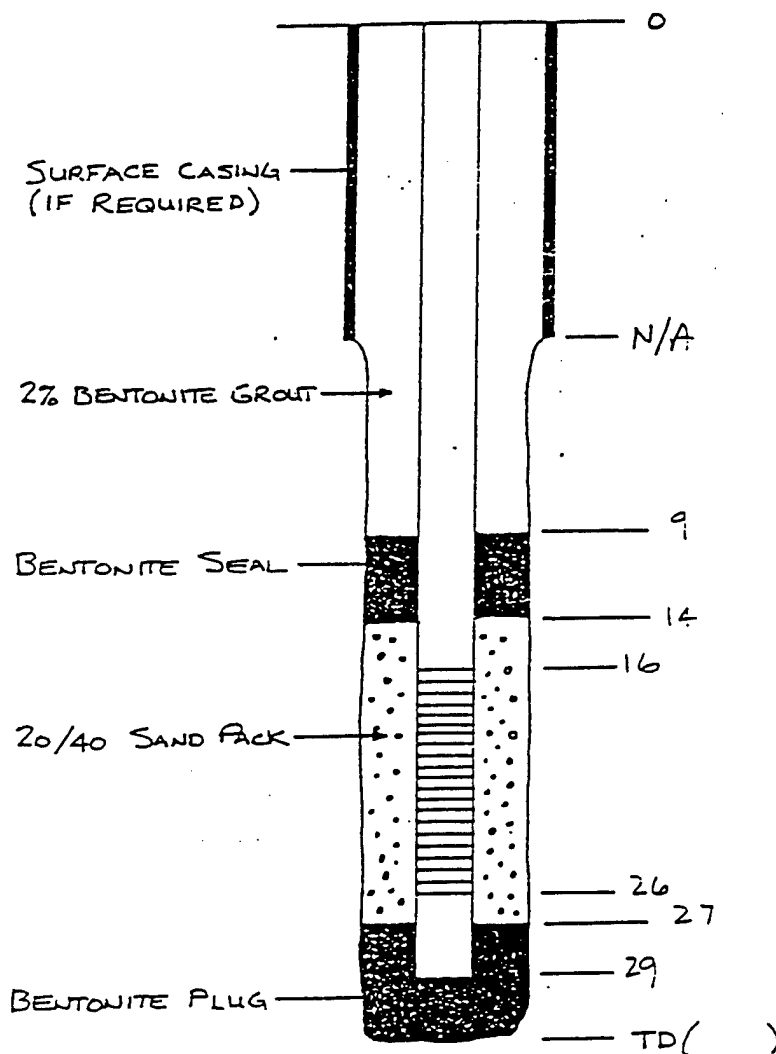


Drawing not to scale

< > Centralizers

12

Well ID	Recommended Construction		Comments
	Item	Depth	
Z-149B	Surface Casing	—	
	Inner Casing	—	
	Grout	0 - 9	
	Bentonite Seal (top)	9 - 14	
	Sand Pack	14 - 27	
	Bentonite Seal (bottom)	27 - TD	
	Riser	0 - 16	
	Screen	16 - 26	
	Sump	26 - 29	



Log Received

Well Design Del

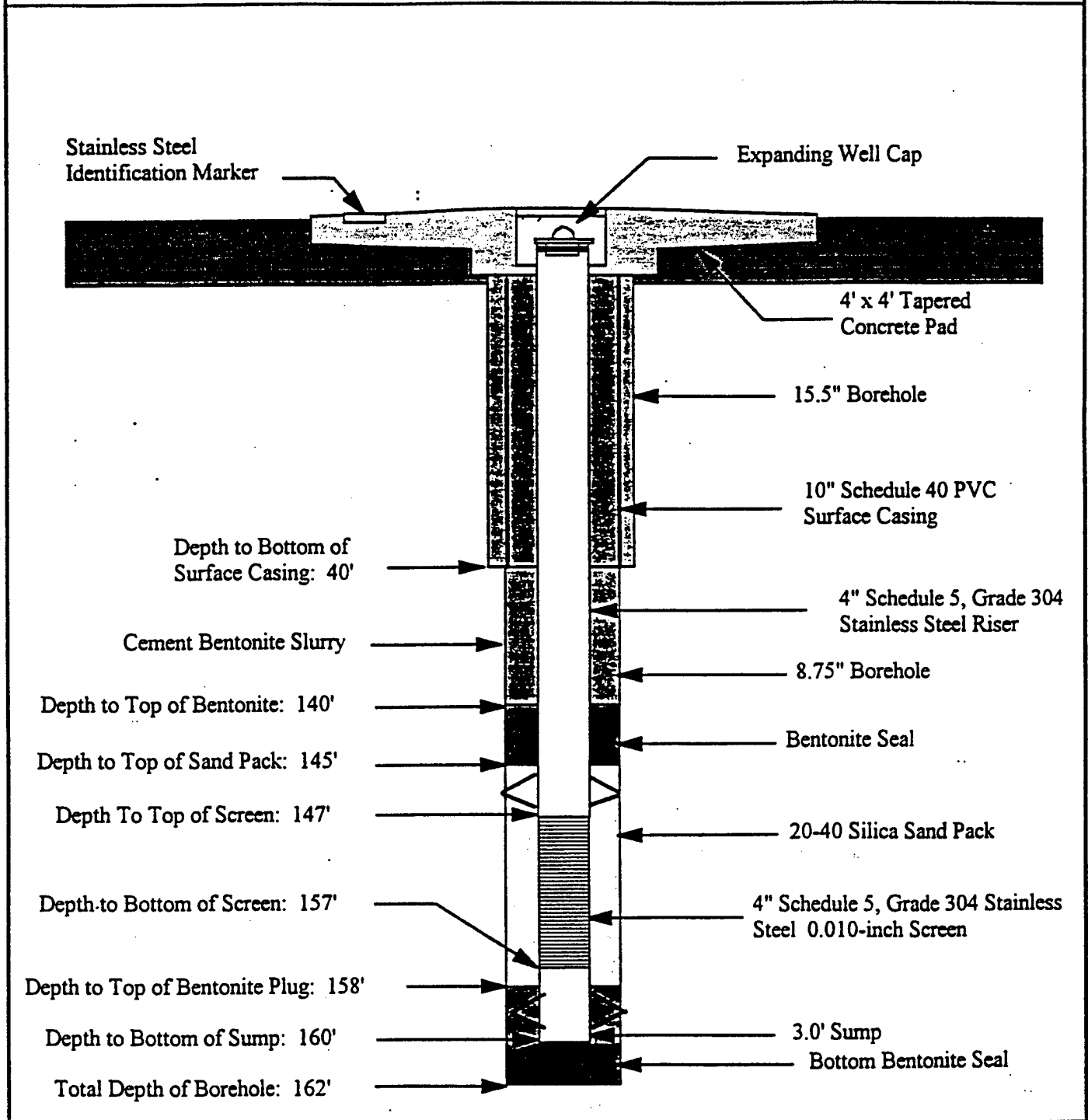
1 LOG RUN

2 LOG RUN

WELL CONSTRUCTION SCHEMATIC

(2)

Client: Tinker Air Force Base	Well ID: 2-149C
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/06/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): '
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): '
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

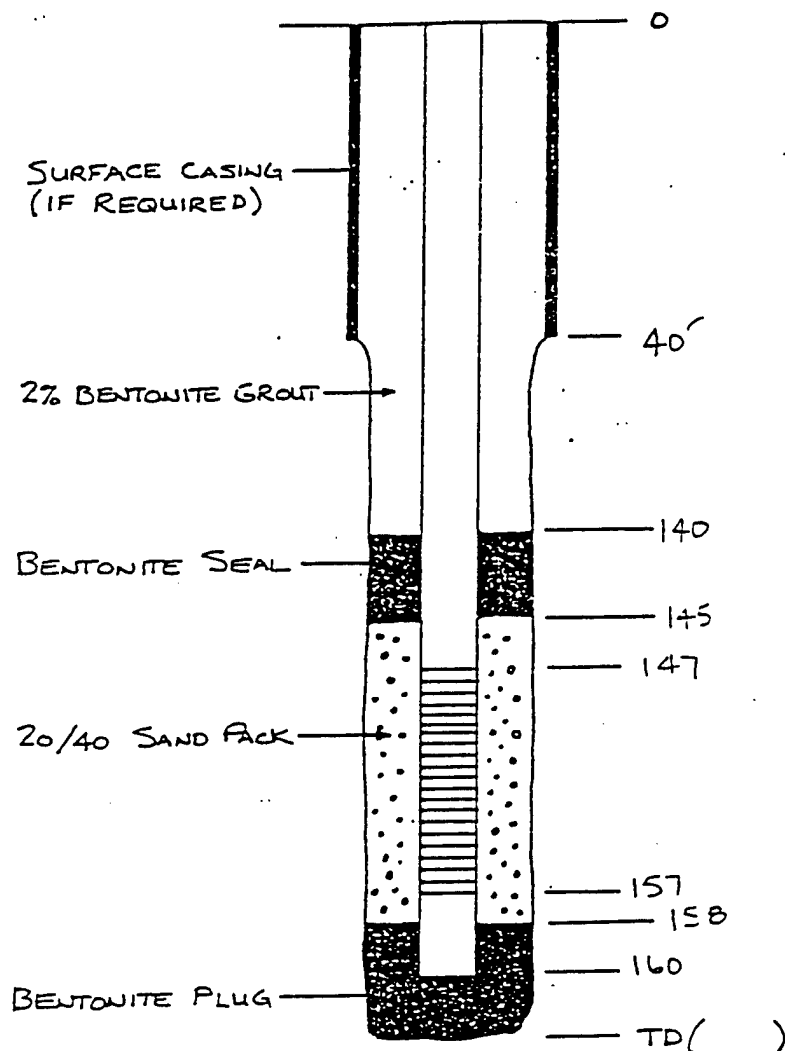


Drawing not to scale

< > Centralizers

2

Well ID	Recommended Construction		Comments
	Item	Depth	
2-149C	Surface Casing	0-40'	
	Inner Casing	—	
	Grout	0-140	
	Bentonite Seal (top)	140-145	
	Sand Pack	145-158	
	Bentonite Seal (bottom)	158-159	
	Riser	0-147	
	Screen	147-157	
	Sump	157-160	



Log Received
6-5-95 5:30

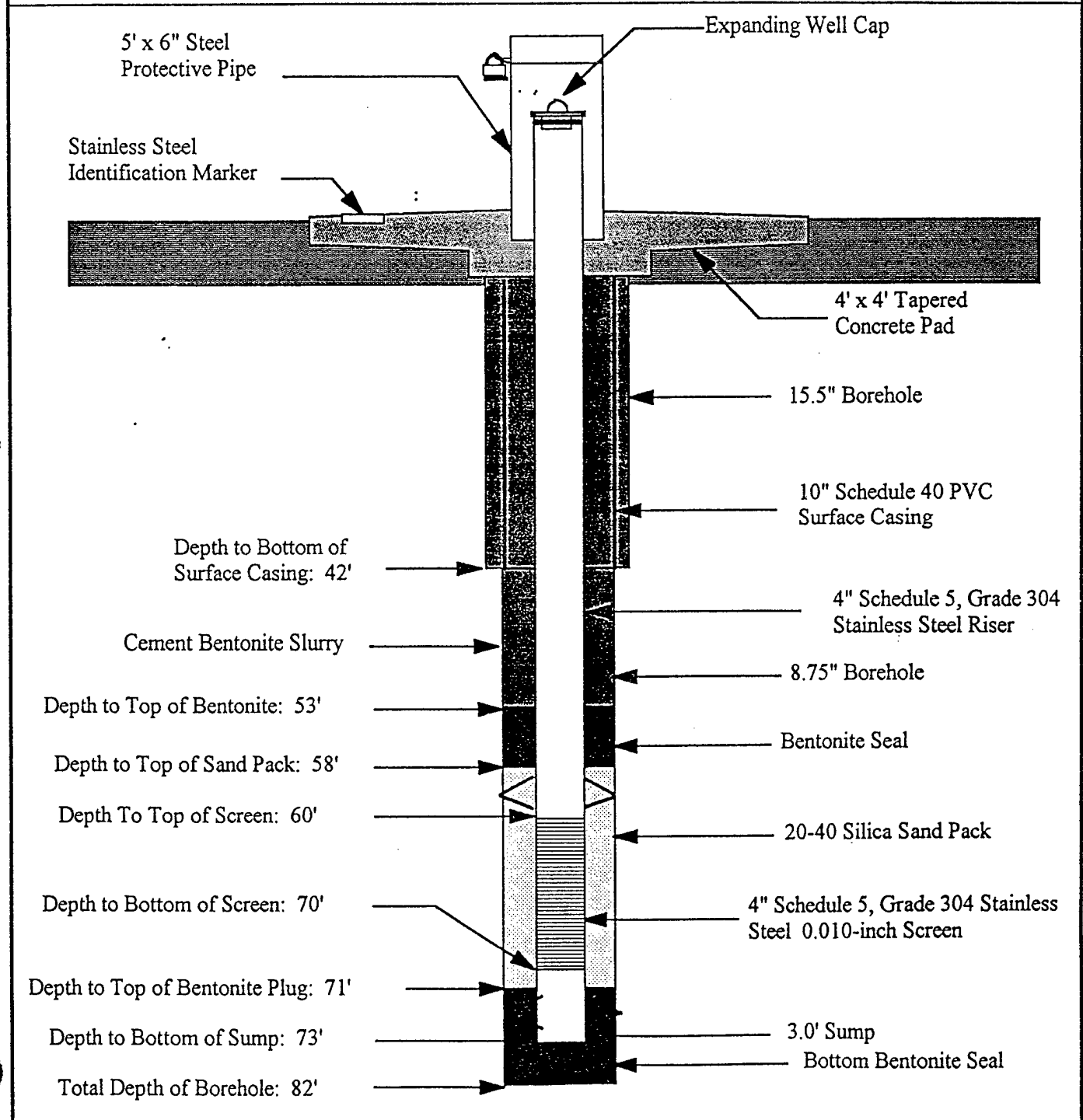
1 LOG RUN

2 LOG RUN

Well Design Del
6-5-95 5:40

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-150A
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/17/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1231.28'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1233.80'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	

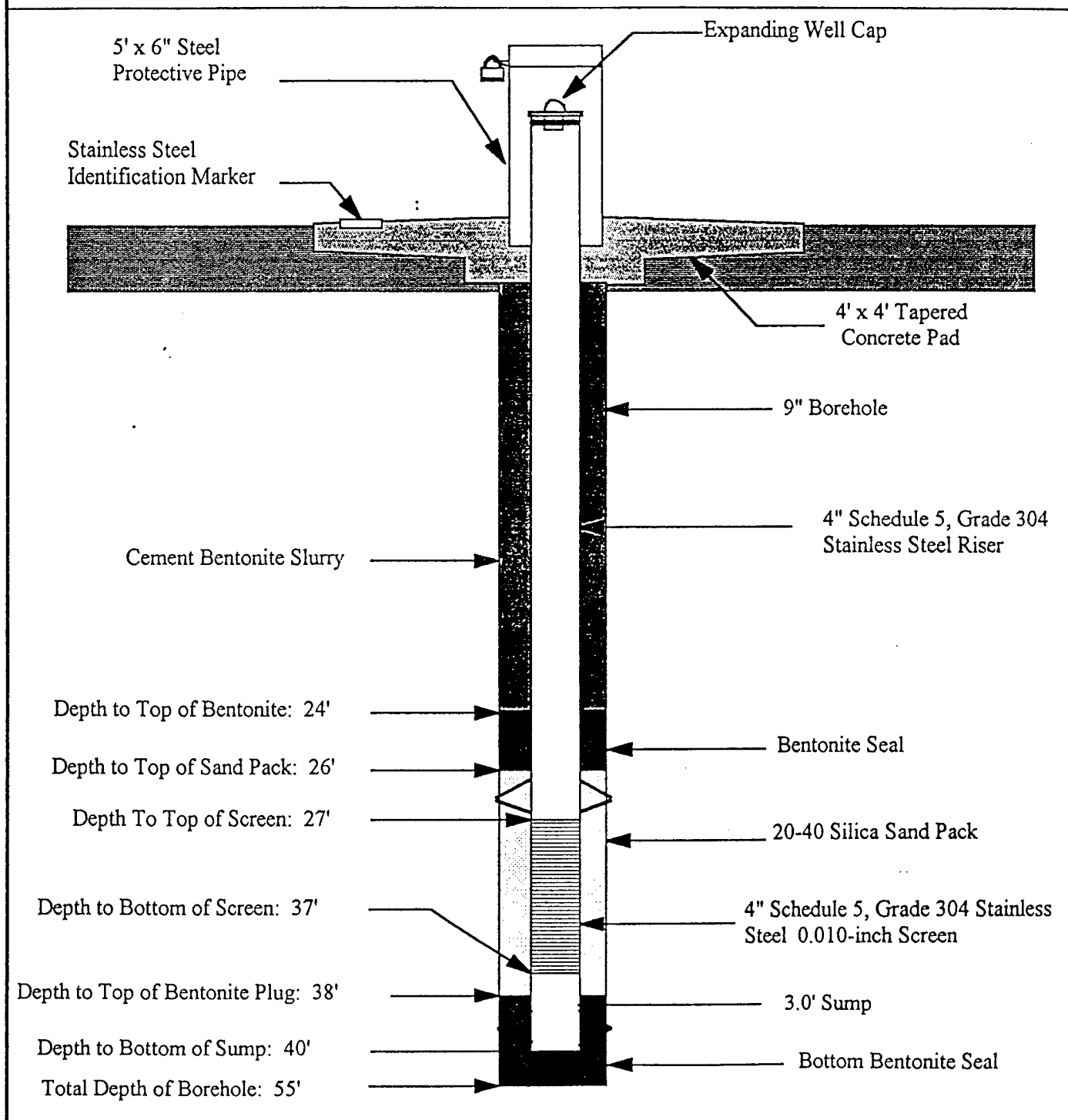


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< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-150B
Location: TAFB, Oklahoma	Site: PRM
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/10/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1231.40'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1234.03'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 2' thick top seal set. Top of sand placed 1' above screen.	

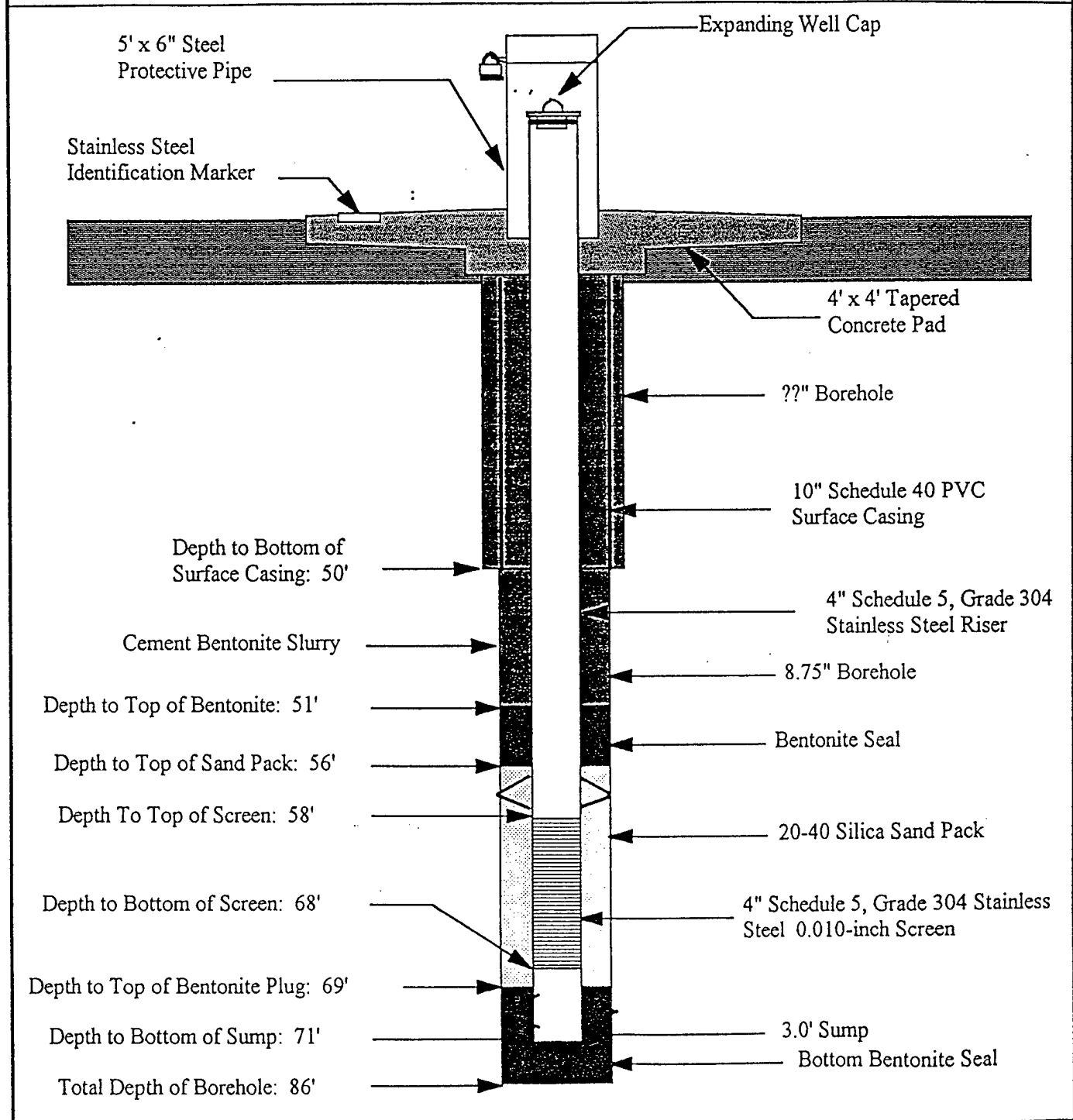


Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-152A
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/18/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1243.63'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1246.36'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing	

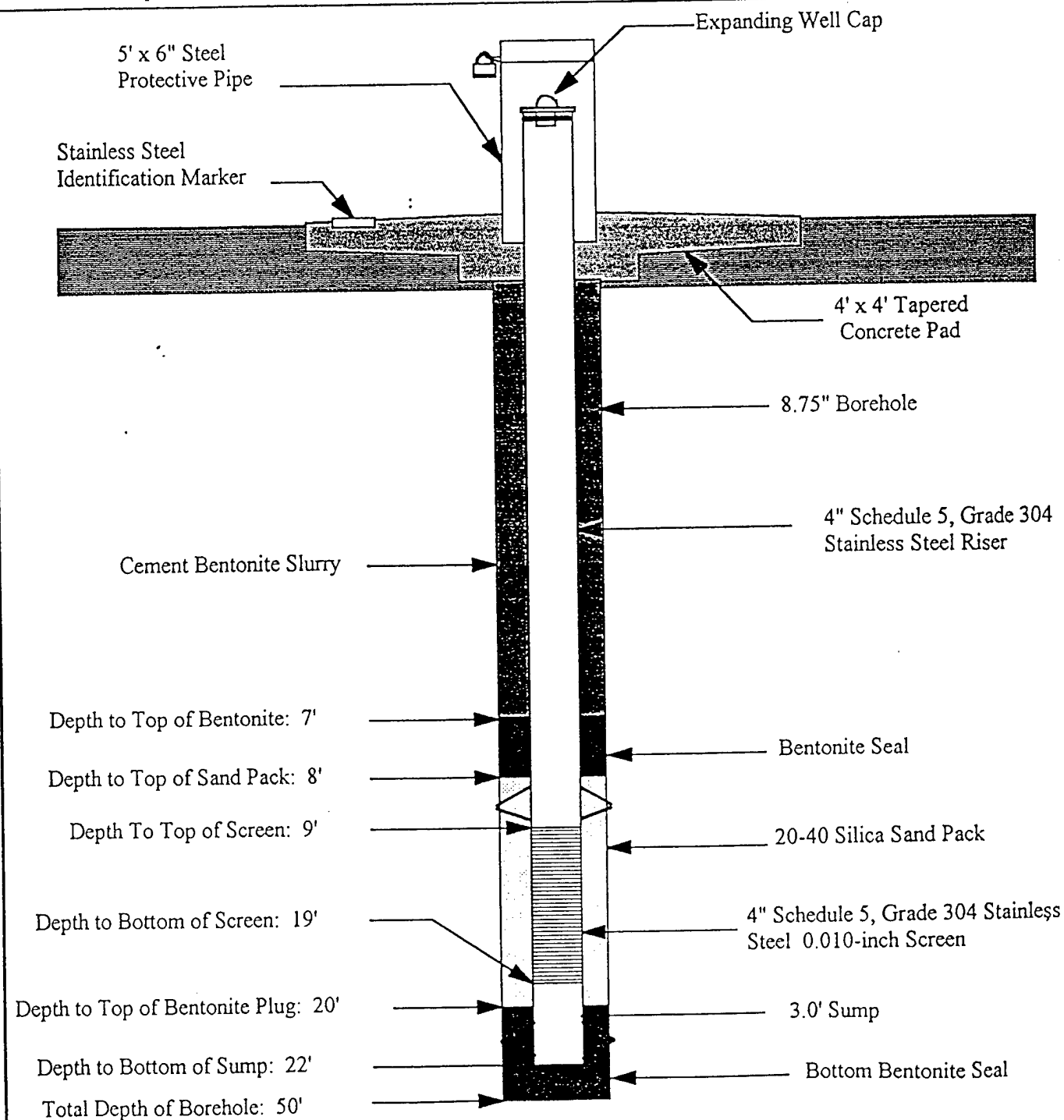


Drawing not to scale

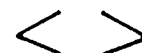
< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-152B
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/18/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1243.46'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1246.06'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 1' thick top seal set. Top of sand set 1' above screen.	



Drawing not to scale



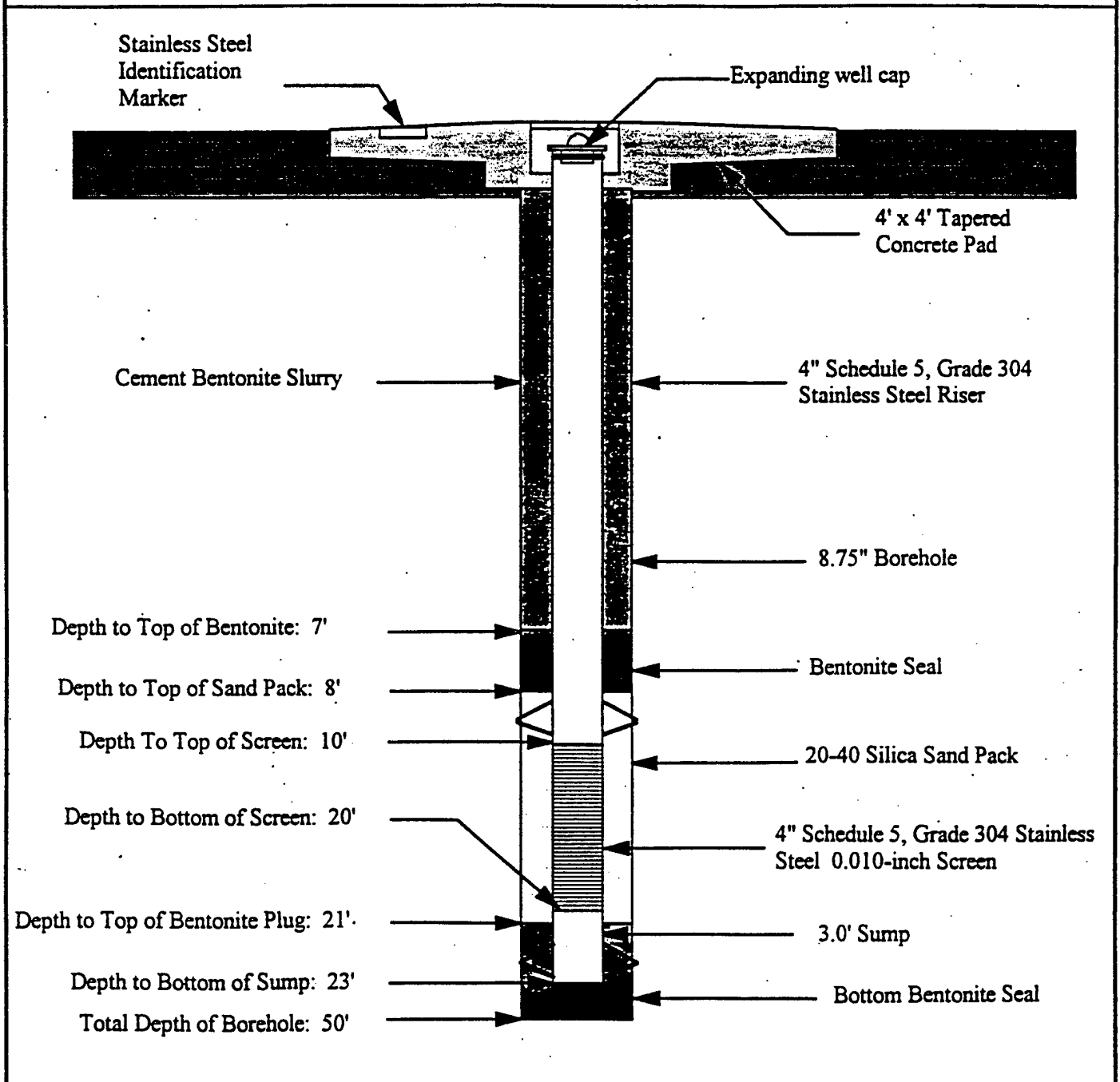
Centralizers

WELL CONSTRUCTION SCHEMATIC

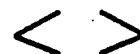
2

Client: Tinker Air Force Base	Well ID: 2-163B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/01/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 1' thick top bentonite seal set.



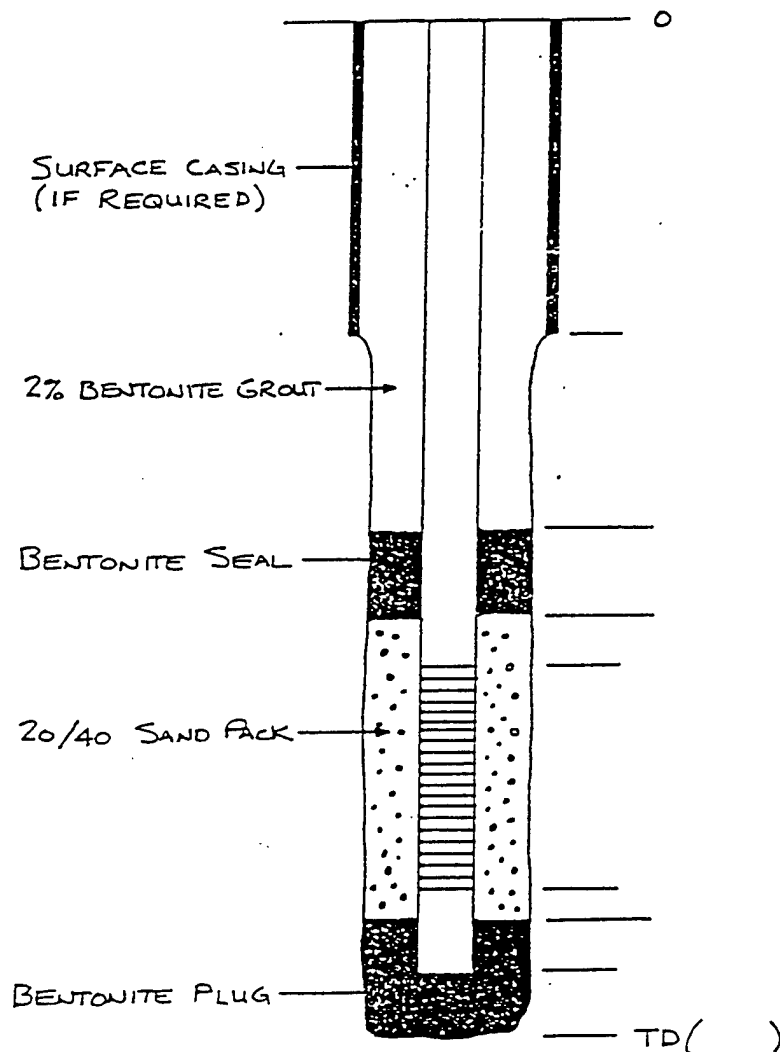
Drawing not to scale



Centralizers

(2)

Well ID	Recommended Construction		Comments
	Item	Depth	
2-1638	Surface Casing		
	Inner Casing		
	Grout	0-7	
	Bentonite Seal (top)	7-8	
	Sand Pack	8-21	
	Bentonite Seal (bottom)	21-TD	
	Riser	0-10	
	Screen	10-20	
	Sump	20-23	



Log Received
9:00 AM 6-1-95

1 LOG RUN

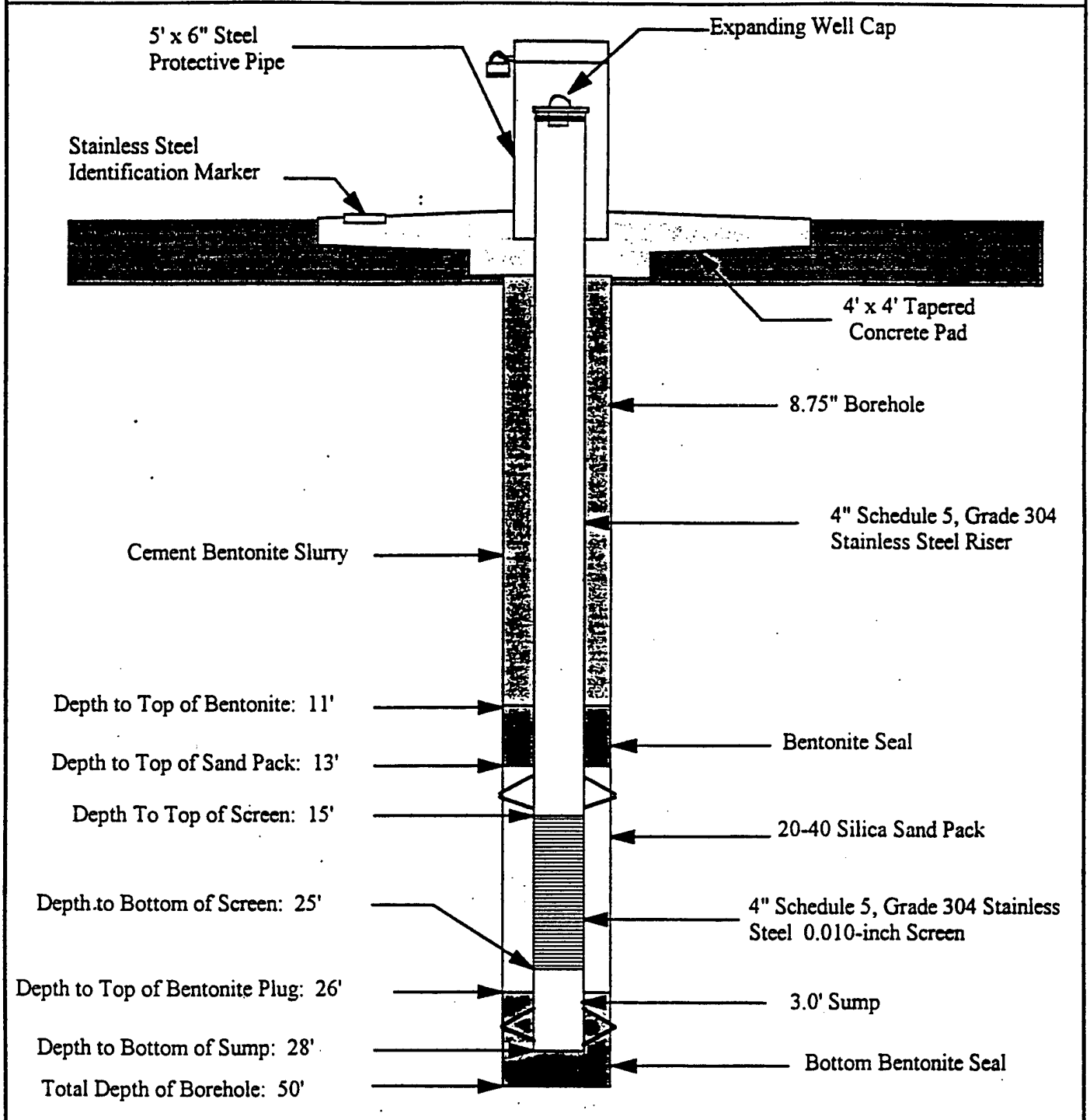
2 LOG RUN

Well Design Delivered
9:20 AM 6-1-95

WELL CONSTRUCTION SCHEMATIC

(2)

Client: Tinker Air Force Base	Well ID: 2-164B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/02/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): '
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): '
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 2' thick top seal set.	

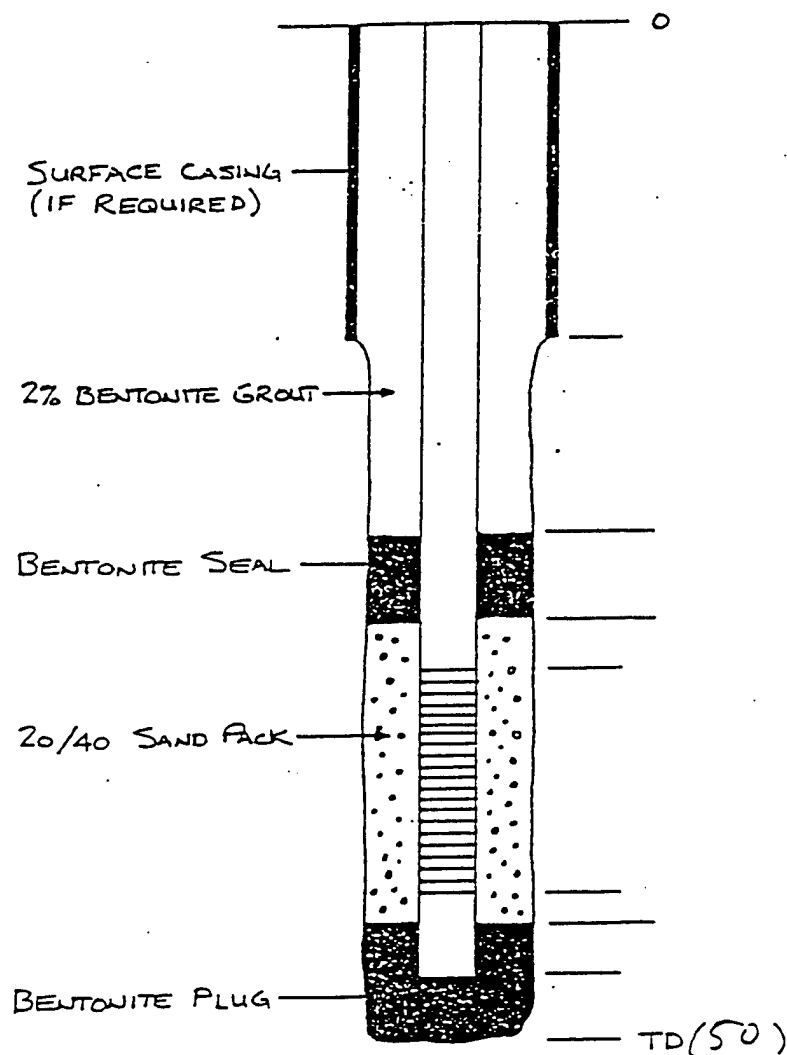


Drawing not to scale

< > Centralizers

2

Well ID	Recommended Construction		Comments
	Item	Depth	
2-16-B	Surface Casing	—	
	Inner Casing	—	
	Grout	0 - 11	
	Bentonite Seal (top)	11 - 13	(2')
	Sand Pack	13 - 26	
	Bentonite Seal (bottom)	26 - TD	
	Riser	0 - 15	
	Screen	15 - 25	
	Sump	25 - 28	



Log Received

6-2-95 4:10

1 LOG RUN

2 LOG RUN

well Design De

6-2-95 4:30

Stainless Steel Identification Marker

Expanding well cap

4' x 4' Tapered Concrete Pad

Cement Bentonite Slurry

4" Schedule 5, Grade 304 Stainless Steel Riser

8.75" Borehole

Depth to Top of Bentonite: 5'

Depth to Top of Sand Pack: 7'

Depth To Top of Screen: 9'

Depth to Bottom of Screen: 19'

Depth to Top of Bentonite Plug: 20'

Depth to Bottom of Sump: 22'

Total Depth of Borehole: 35'

Bentonite Seal

20-40 Silica Sand Pack

4" Schedule 5, Grade 304 Stainless Steel 0.010-inch Screen

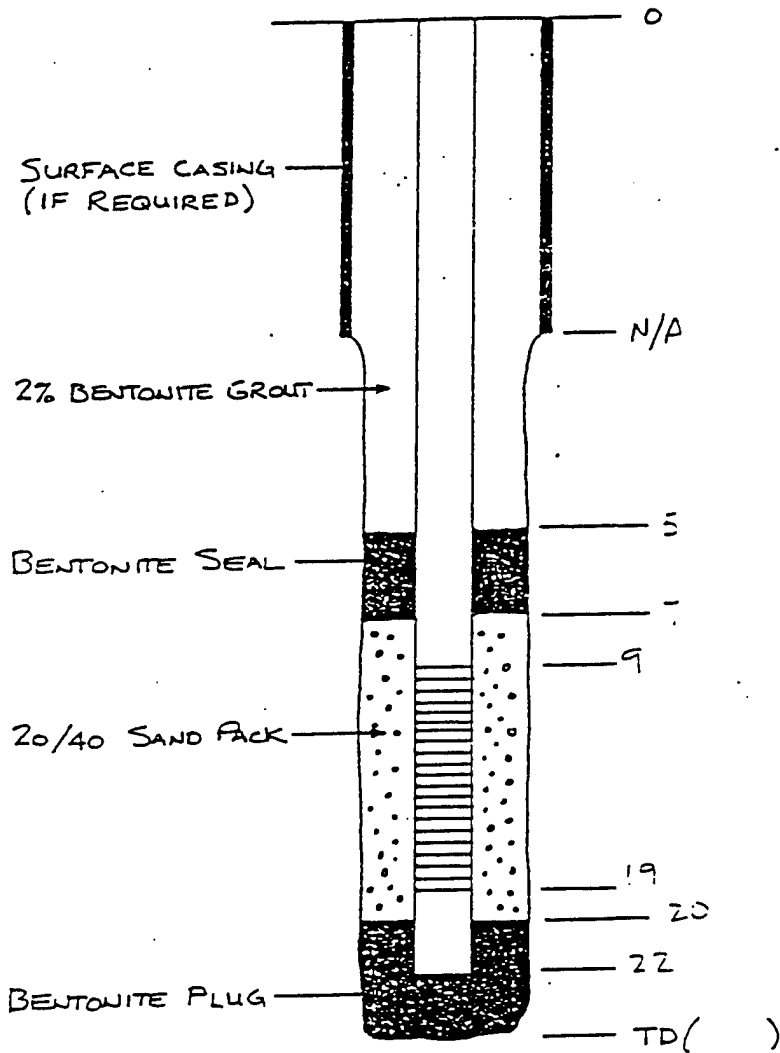
3.0' Sump

Bottom Bentonite Seal

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12

Well ID	Recommended	Construction	Comments
	Item	Depth	
2-165B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-5	
	Bentonite Seal (top)	5-7	
	Sand Pack	7-20	
	Bentonite Seal (bottom)	20-TD	
	Riser	0-9	
	Screen	9-19	
	Sump	19-22	



Log Received

1-27-95 2:00 PM

1 LOG RUN

2 LOG RUN

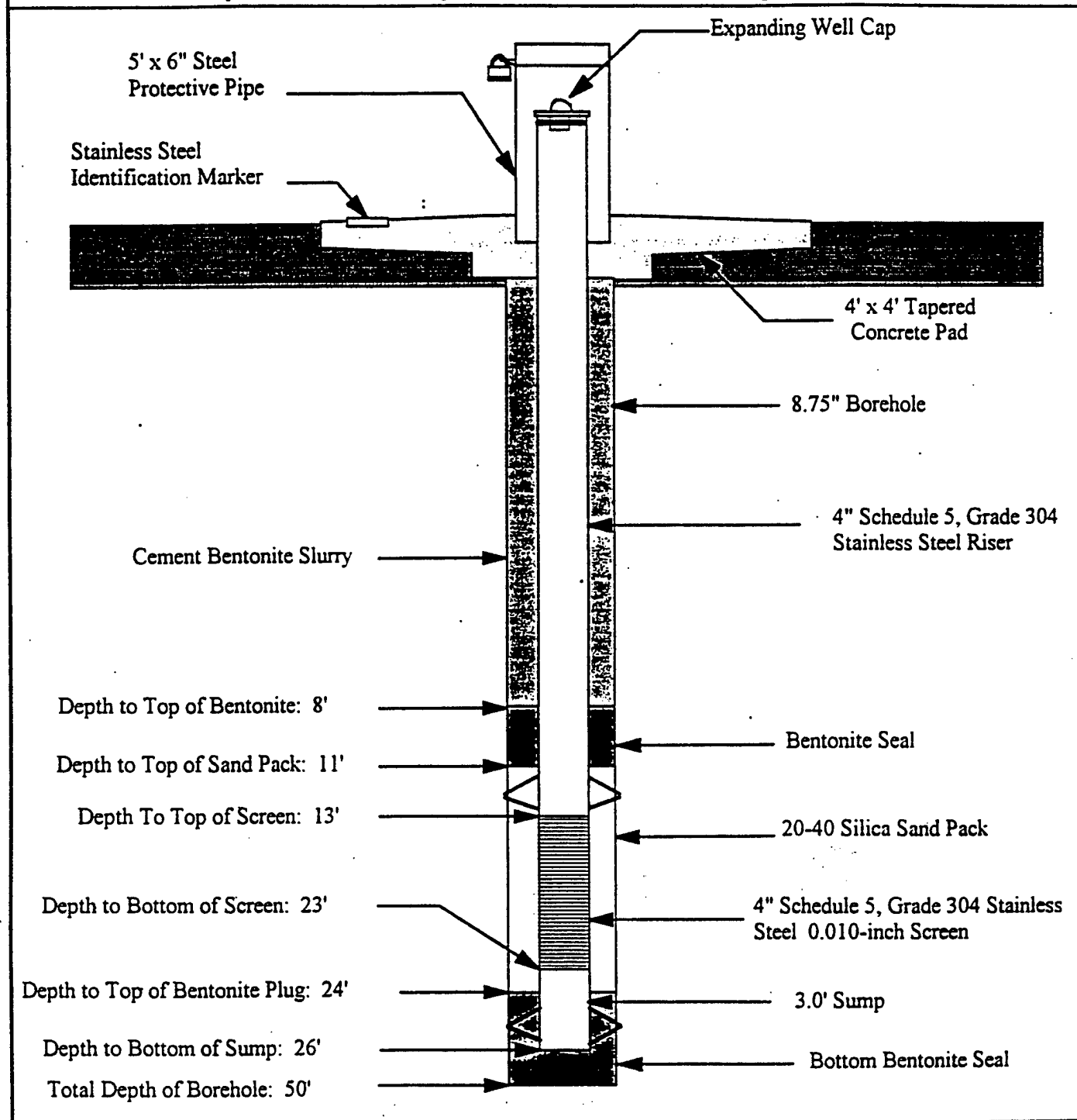
Well Design De

1-27-95 2:30 PM

WELL CONSTRUCTION SCHEMATIC

(12)

Client: Tinker Air Force Base	Well ID: 2-166B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/07/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): '
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): '
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: 3' thick top bentonite seal set. Top Riser: 4" Schedule 40 PVC Casing.	

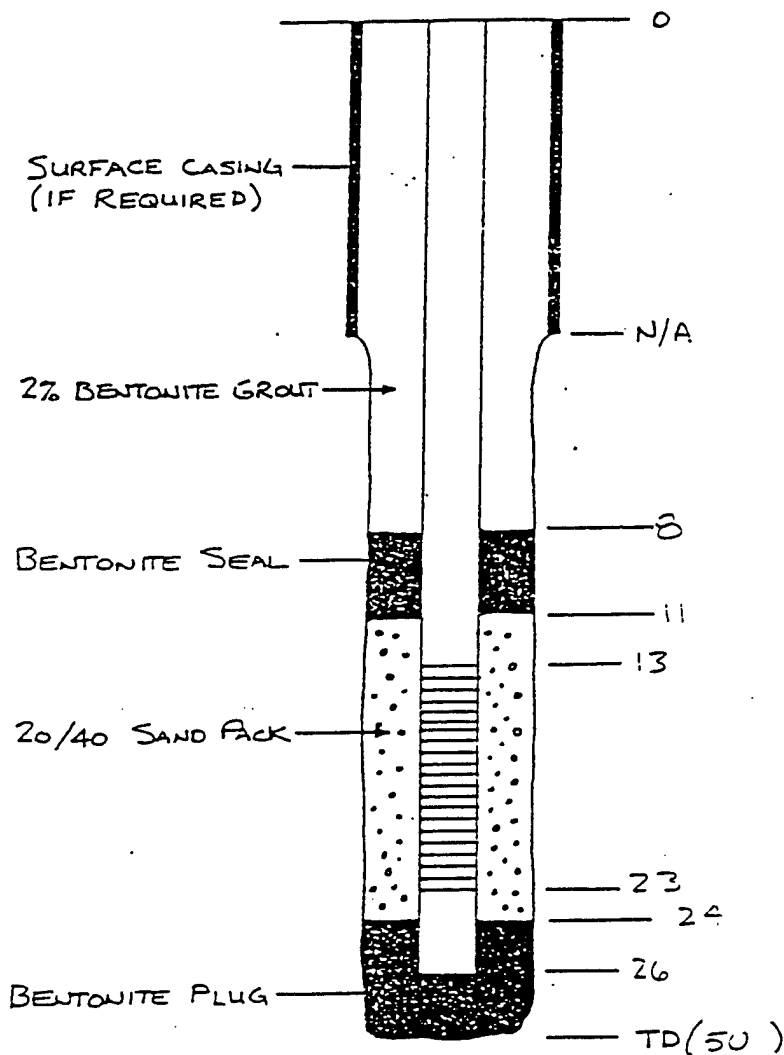


Drawing not to scale

< > Centralizers

72

Well ID	Recommended Construction		Comments
	Item	Depth	
Z-166B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-8	
	Bentonite Seal (top)	8-11	
	Sand Pack	11-24	
	Bentonite Seal (bottom)	24-TD	
	Riser	0-13	
	Screen	13-23	
	Sumo	23-26	



Log Received

5-6-95

1 LOG RUN

2 LOG RUN

Well Design Del

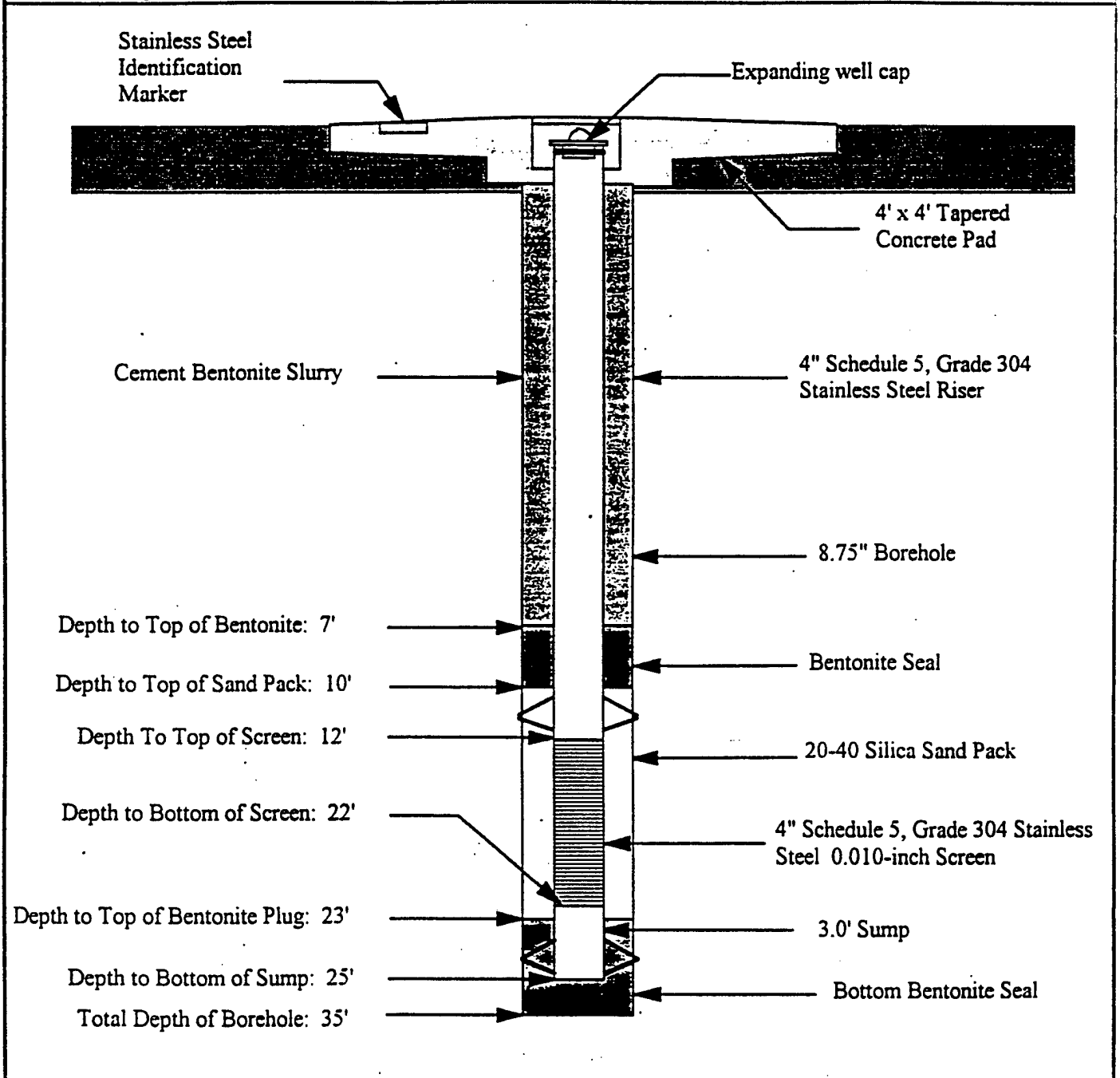
6-7-95 9:00 AM

WELL CONSTRUCTION SCHEMATIC



Client: Tinker Air Force Base	Well ID: 2-173B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 06/14/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL):
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL):
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Top Riser: 4" Schedule 40 PVC Casing. 3' thick top bentonite seal set.

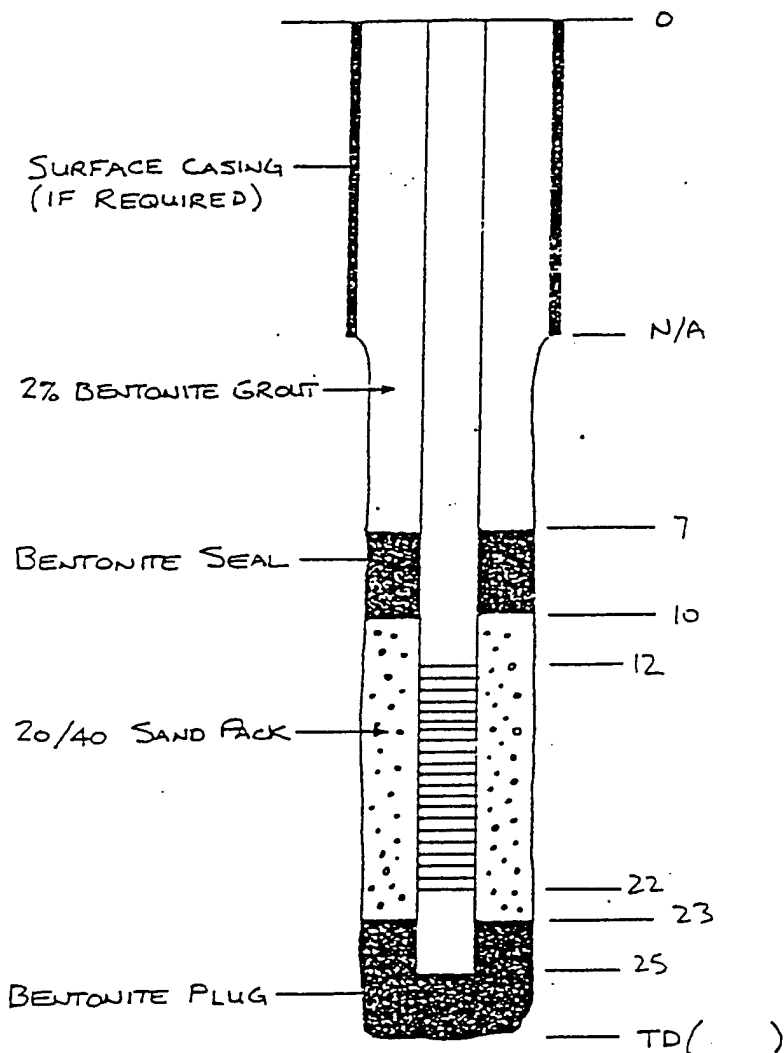


Drawing not to scale

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2

Well ID	Recommended Construction		Comments
	Item	Depth	
2-173B	Surface Casing	—	
	Inner Casing	—	
	Grout	0-7	
	Bentonite Seal (top)	7-10	
	Sand Pack	10-23	
	Bentonite Seal (bottom)	23-TD	
	Riser	0-12	
	Screen	12-22	
	Sump	22-25	



Log Received
5-14-95 3:45

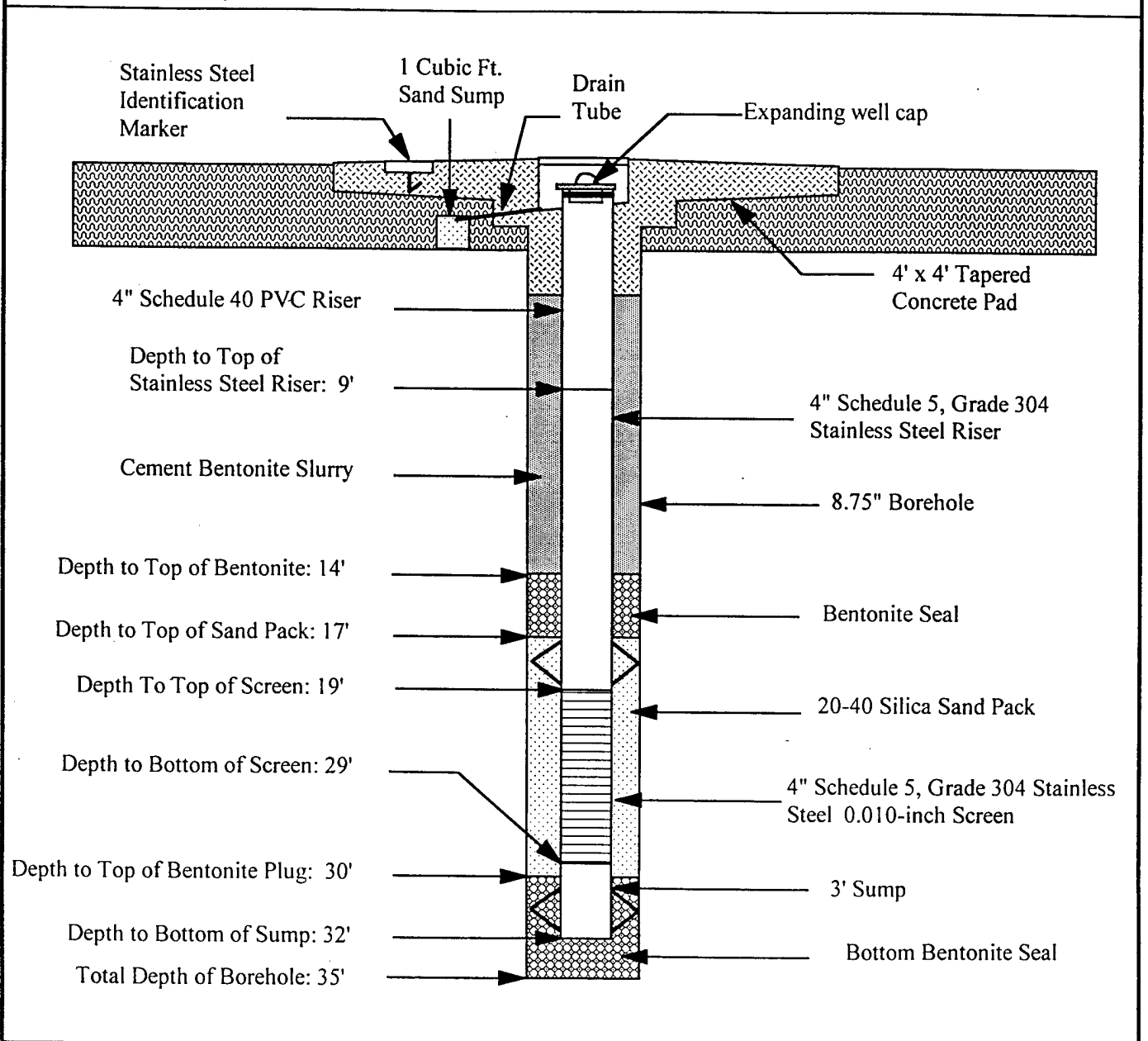
well Design Del.
5-14-95 3:45

1 LOG RUN

2 LOG RUN

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-264B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/12/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,235.08'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,234.86'
Project Geologist: Steve Kelly	Northing Coordinate: 158,467.86'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,179,427.90'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE53, PR11
Dedicated Pump: 2-inch Grundfos	Legal Description: NW/4 Section 15, T11N, R2W
Comments: 3' thick top bentonite seal set.	



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FRONTIER LOGGING CORP.

Oklahoma City, Oklahoma

405-787-3952

CLIENT: TINKER AIR FORCE BASE	PERM. DATUM : GL
HOLE #: 2-264B	DRILL MEAS FROM: GL
DATE : JUNE 12, 1996	LOG MEAS FROM : GL
FIELD : ST33	GL ELEVATION : NA
COUNTY: OKLAHOMA	DF ELEVATION : NA
STATE : OKLAHOMA	KB ELEVATION : NA

TD (DRILLER) : 35'	CASING : NONE
TD (LOGGER) : 35.0'	BIT SIZE : 8 3/4"
LOGGED INTERVAL: 0' TO 34.0'	WITNESS : STEVE WILHOIT
FLUID TYPE : WATER	Rm : -
DEN/VISCOSITY : -	Rmf : -
pH/FLUID LOSS : -	Rmc : -
TIME SINCE CIRC: -	Rm at BHT: -
MAX REC TEMP. : -	SAMPLE SOURCE : -
OTHER SERVICE : GR, SP, RES, CAL	SOURCE Rmf Rmc: -

OPERATOR: J. JUST

EQUIP/LOC: 116/OKLAHOMA CITY

REMARKS:

NW1/4 SEC. 15 T. 11N R. 2W
PROBE#104-12911, 1.25" DIA
DETECTOR: 1/2" X 2 1/2" SCINT XTAL
SOURCE CAL#276/200 API UNITS
AUGER DRILLED
RES. LOGRITH. CAL.

HOLE NUMBER: 2-264B

DATE: JUNE 12, 1996

POINT RES. (OHMS)

100.0

192

GAMMA API

3 ARM CALIPER

0.0

100.0

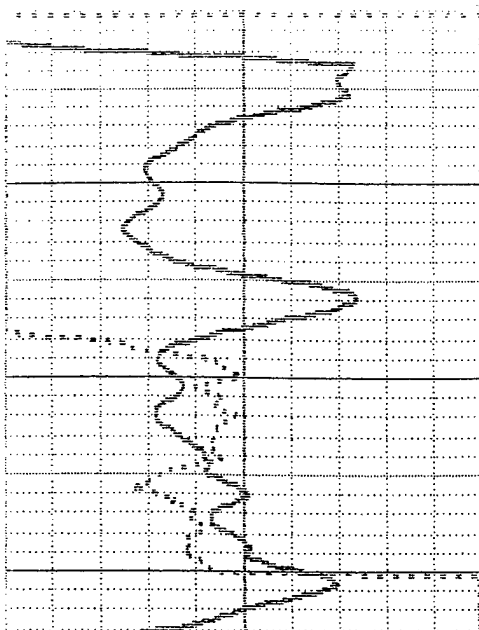
0.0

25

SP (MV)

-133.0

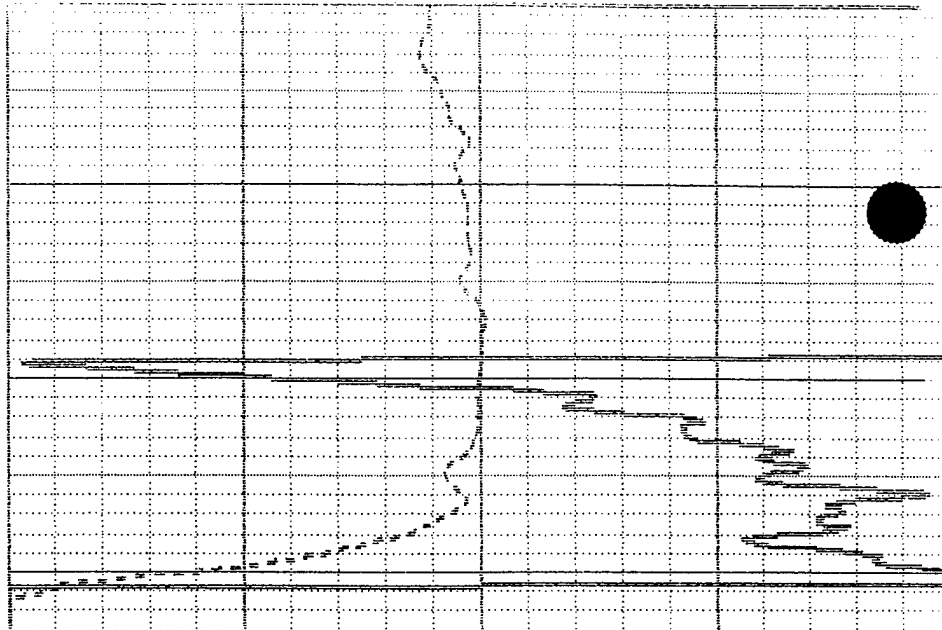
-130.0



10

20

30



HOLE NUMBER: 2-264B-REPEAT

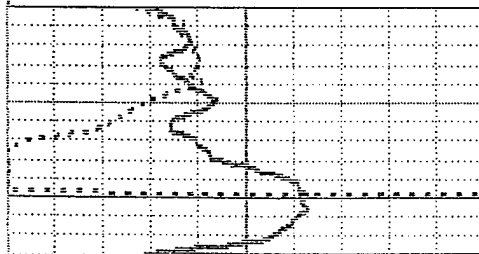
DATE: JUNE 12, 1996

GAMMA API

0.0 100.0

SP (MV)

-133.0 -130.0



30

POINT RES. (OHMS)

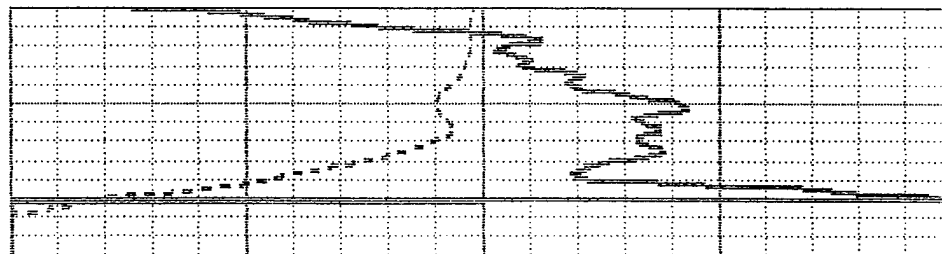
188.0

192.0

3 ARM CALIPER

0.0

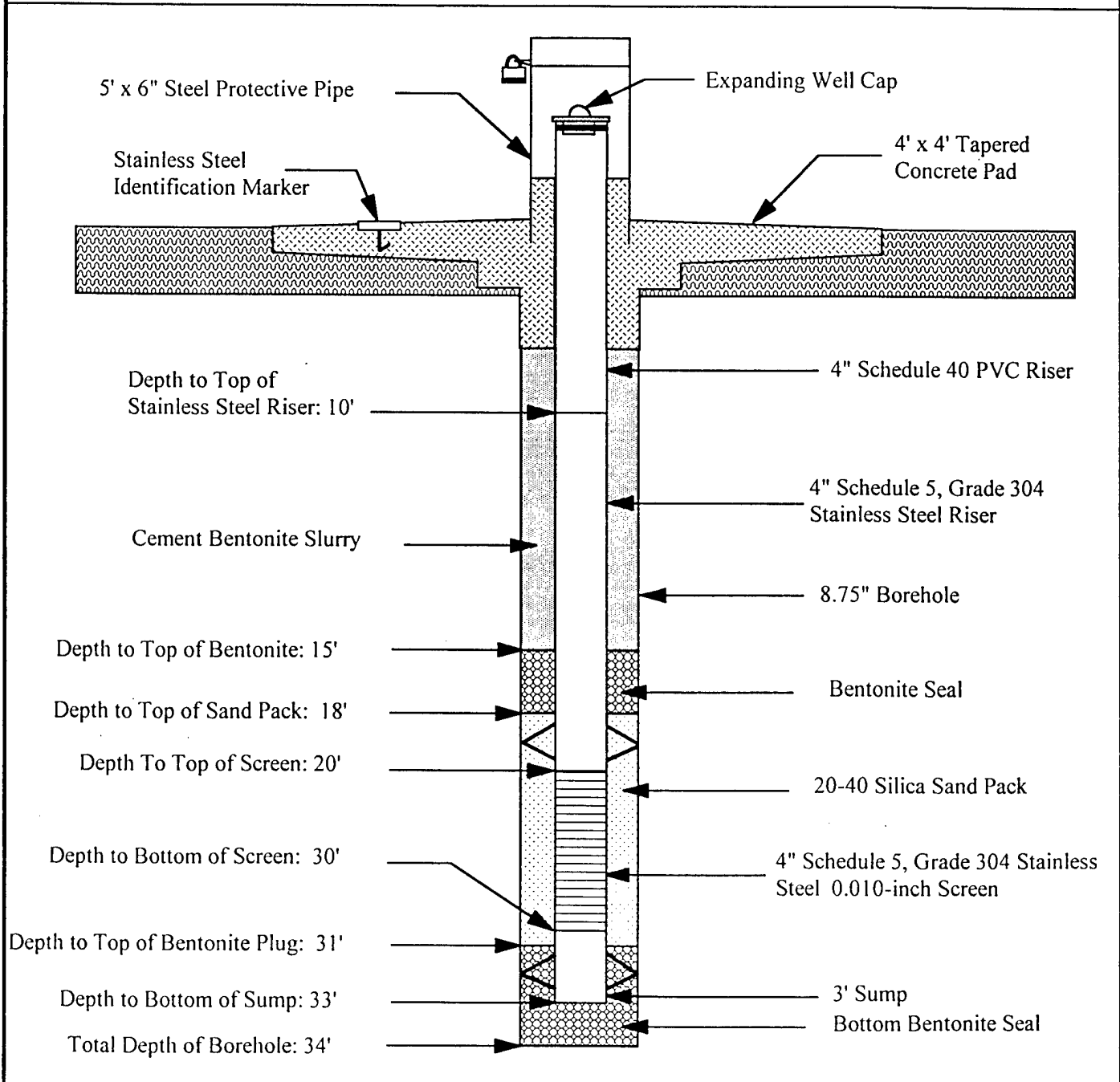
20.0



WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-265B
Location: TAFB, Oklahoma	Site: ST33
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/12/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,234.13'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,236.63'
Project Geologist: Steve Kelly	Northing Coordinate: 158,291.51'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,179,373.38'
Drilling Method: Hollow Stem Auger	Permanent Monuments used in Survey: SE53, PR11
Dedicated Pump: 2-inch Grundfos	Legal Description: NW/4 Section 15 T11N, R2W

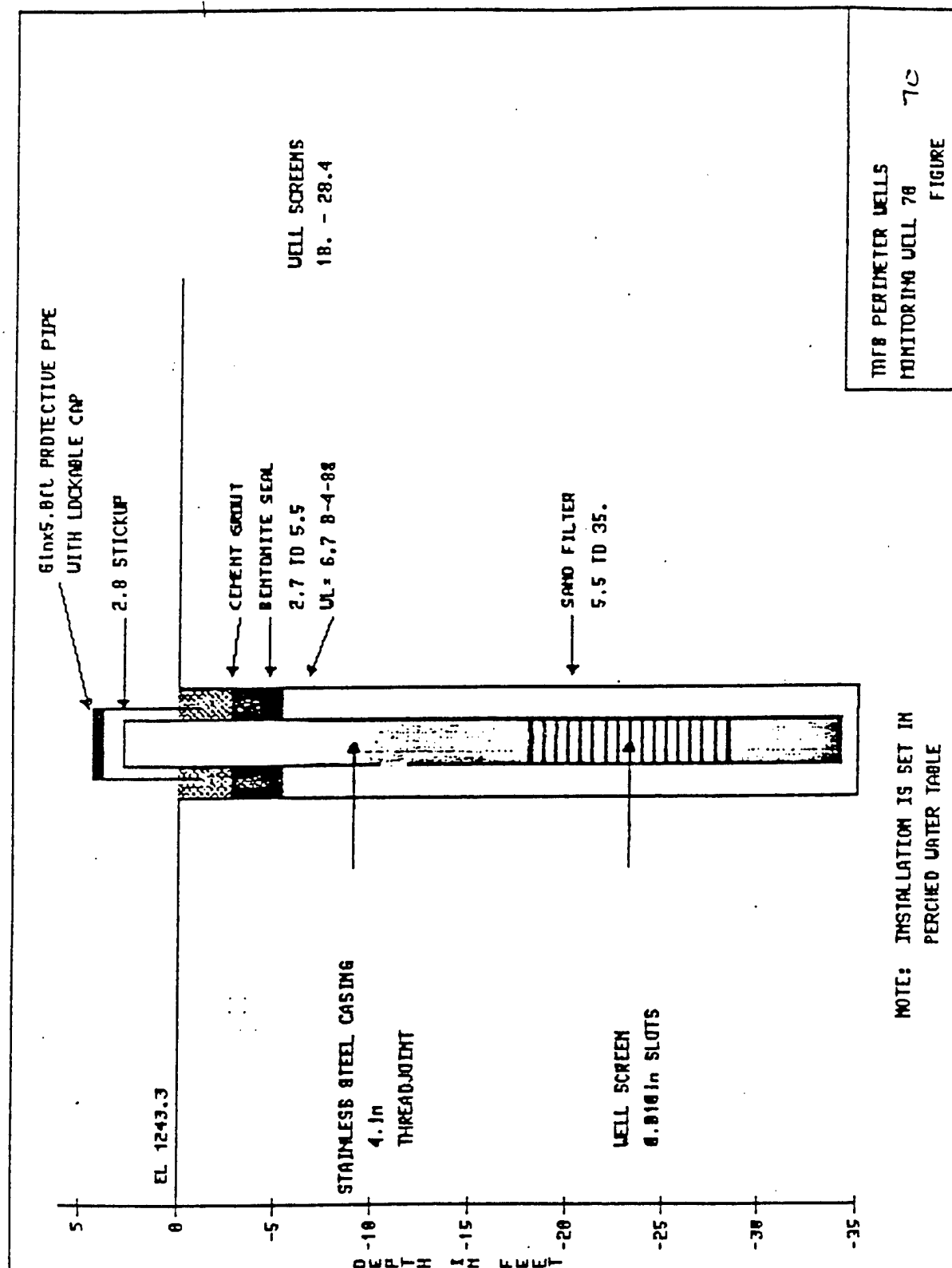
Comments: 3' thick top bentonite seal set.



Drawing not to scale

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DRILLING LOG		DIVISION		SOUTHWEST		INSTALLATION		TINKER AFB		SHEET 1 OF 1 SHEETS			
1. PROJECT				PERIMETER MONITORING WELLS				10. SIZE AND TYPE OF BIT				6" A 9.5" RB	
2. LOCATION (Coordinates or Station)				158-485.40 2180809.30				11. DATUM FOR ELEVATION SHOWN (TBM or MSL)				MSL	
3. DRILLING AGENCY				TULSA DISTRICT				12. MANUFACTURER'S DESIGNATION OF DRILL				CME	
4. HOLE NO. (As shown on drilling site and log number)				MW-70				13. TOTAL NO OF OVER-BURDEN SAMPLES TAKEN		DISTURBED 0		UNDISTURBED 0	
5. NAME OF DRILLER				JAMES WYATT				14. TOTAL NUMBER CORE BOXES		0			
6. DIRECTION OF HOLE				DD VERTICAL				15. ELEVATION GROUND WATER		7.0' (5 NOV 87)			
7. THICKNESS OF OVERBURDEN				8.0				16. DATE HOLE		STARTED 10/29/1987		COMPLETED 10/29/1987	
8. DEPTH DRILLED INTO ROCK				27.0				17. ELEVATION TOP OF HOLE		1243.3			
9. TOTAL DEPTH OF HOLE				35.0				18. TOTAL CORE RECOVERY FOR BORING		0.0		3	
				18. SIGNATURE OF INSPECTOR				CARL NARDIN					
ELEVATION	DEPTH	LEGEND	CLASSIFICATION OF MATERIALS (Description)	3 CORE RECOVERY	BOX OR SAMPLE NO.	REMARKS (Drilling time, water level, depth of casing, etc., if appropriate)							
1233.1			CLAY (CL) (0.0 - 0.4)			AUGERED W/6" BIT TO WATER @ 25.0', ROCKBIT TO 35.0' WITH 9 1/2" BIT. MEASURED WATER LEVEL AT 7.0' ON 5 NOV 87. SET 37.0' OF 4" STAINLESS STEEL CASING WITH SCREEN FROM 28.2 TO 17.8' AND A 5.8' SUMP. SAND FILTER TO 5.5'. SEAL TO 2.7'. BAILED INSIDE PIPE AND FLUSHED WITH FRESH WATER.							
1232.5			TOPSOIL, DK-BROWN, DRY										
			CONCRETE () (0.4 - 1.0)										
	2		CLAY (CL) (1.0 - 4.0)										
			SILTY, SOFT, LOW PLAST., RED-BROWN, SL. MOIST										
1229.5	4		SAND (SC) (4.0 - 8.0)										
			CLAYEY, V. FINE, LOOSE, GRAY-BROWN, SL. MOIST										
	6												
1225.5	8		SANDSTONE (SS) (8.0 - 35.0)										
			SHALEY, LOOSELY CEMENTED, V. FINE, RED-BROWN, OCCASIONALLY SPECKLED W/ GREEN-GRAY, SL. MOIST 8.0' TO 15.0' WET @ 15.0'										
	10												
	12												
	14												
	16												
	18												
1223.3	20		BOTTOM OF HOLE AT 35.0'										



GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/1/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-2

(number)

REASON FOR SAMPLING: [☒] Regular Sampling; [☐] Special Sampling;

DATE AND TIME OF SAMPLING: 5/1/97 at 1000 am/p.m.

SAMPLE COLLECTED BY: Tom H. FR of Persone EPA.

WEATHER: Clear - Cloudy, Breezy, 70°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of Access Port

MONITORING WELL CONDITION:

[☐] LOCKED:

[☒] UNLOCKED

WELL NUMBER (S) - IS NOT APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: OK

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

[☐] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

[☐] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [☒]

EQUIPMENT CLEANED BEFORE USE WITH Alcohol / Distilled Water

Items Cleaned (List): Probes / Sampling Equip.

2 [☒]

PRODUCT DEPTH NA

FT. BELOW DATUM

Measured with:

WATER DEPTH 12.0'

FT. BELOW DATUM

Measured with: TD = 23' Pure Vol. = 21 gal.

3 [☒]

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: Clear

Turbidity: Clear

Odor: None

Other Comments:

4 [☒]

WELL EVACUATION:

Method: Dedicated Circulator Pump

Volume Removed: ~12-15 gal. - Well Purged Dry - 10 gal. - Let Sit, Pump

Observations: Turbidity (clear) slightly cloudy very cloudy until readings

Water level (rose fell) no change - Pumped Dry / stable

Water odors: None sample.

Other comments:

Groundwater Sampling Record

Monitoring Well No. 2-2 (Cont'd)

5 ☒ SAMPLE EXTRACTION METHOD:

☐ Bailer made of: _____
☒ Pump, type: Dedicated Groutless Pump
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☒ ON-SITE MEASUREMENTS:

Time	10.03-11.12.0	12.0	12.0				Measured with
Temp (°C)	0948 17.7	0952 18.6	0954 19.0				Onion 840
pH	NA	NA	—				—
Cond (µS/cm)	2240	2250	2250				Onion 140
DO (mg/L)	0.4	0.4	0.4				Onion 840
Redox (mV)	10.59	10.68	10.72				Onion 250A
Salinity	—	—	—				—

7 ☒ SAMPLE CONTAINERS (material, number, size): Standard Set

8 ☒ ON-SITE SAMPLE TREATMENT:

☐ None Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☒ Preservatives added: HCl / Phosphate

Method VOCs Containers: VOCs
 Method D.C. Containers: Syrum Jers
 Method Fixed Inorg. Containers: 250 ml. Plastic
 Method _____ Containers: _____

9 ☒ CONTAINER HANDLING:

☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest } EPA

10 ☐ OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/7/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-3

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/7/97 at 1130 a.m./p.m.

SAMPLE COLLECTED BY: Smith, FB of Parsons/EPA

WEATHER: Cloudy, Breezy, 70-75°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top Access Port

MONITORING WELL CONDITION:

☒ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS) - IS NOT) APPARENT

STEEL CASING CONDITION IS: OK

INNER PVC CASING CONDITION IS: OK

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Alconer / DSC 624

Items Cleaned (List): Probes + Sampling Equip.

2 ☒

PRODUCT DEPTH NA

FT. BELOW DATUM

Measured with:

WATER DEPTH 14.08'

FT. BELOW DATUM

Measured with: T.D. = 24.5 Purge Vol. = 20 gallons

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: None

Turbidity: Clear

Odor: None

Other Comments:

4 ☒

WELL EVACUATION:

Method: Dedicated Groutless Pump

Volume Removed: 21 gallons

Observations: Turbidity (clear) slightly cloudy very cloudy

Water level (rose fell no change)

Water odors: None

Other comments:

Groundwater Sampling Record

Monitoring Well No. 2-3 (Cont'd)

5 [✓]

SAMPLE EXTRACTION METHOD:

[] Bailer made of: _____
 [✓] Pump, type: Reduced Gradient Pump
 [] Other, describe: _____

Sample obtained is [X] GRAB; [] COMPOSITE SAMPLE

6 [✓]

ON-SITE MEASUREMENTS:

	2.0	6.0	11.0	16.0	21.0		Measured with
Time	1045	1053	1102	1113	1123		
Temp (°C)	18.6	18.7	19.1	19.3	19.3		Orion 840
pH	—	—	—	—	—		—
Cond (µS/cm)	980	1080	1250	1420	1590		Orion 140
DO (mg/L)	0.3	0.3	0.1	0.1	0.1		Orion 840
Redox (mV)	10.73	10.87	11.13	11.14	10.60		Orion 250A
Salinity	—	—	—	—	—		—

7 [✓]

SAMPLE CONTAINERS (material, number, size): Standard Set

8 [✓]

ON-SITE SAMPLE TREATMENT:

[] None Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

[✓] Preservatives added: HCl / Phosphoric

Method WCS Containers: VOAs
 Method D.C. / Final Inert Containers: Syringe Jars / Zirconium Plastic
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [✓]

CONTAINER HANDLING:

[✓] Container Sides Labeled
 [] Container Lids Taped
 [] Containers Placed in Ice Chest } ERA

10 []

OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/7/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-2A

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/7/97 at 0815 am/p.m.

SAMPLE COLLECTED BY: FBIDE of EPA

WEATHER: Partly cloudy

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of well housing for grout for pump attachment

MONITORING WELL CONDITION:

☒ LOCKED:

☐ UNLOCKED

WELL NUMBER (2) IS NOT APPARENT

STEEL CASING CONDITION IS: OK

INNER PVC CASING CONDITION IS: OK

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Alconox Distilled H₂O

Items Cleaned (List): Pipes & Sampling Equip.

2 ☒

PRODUCT DEPTH NA

FT. BELOW DATUM

Measured with:

WATER DEPTH 47.0

FT. BELOW DATUM

Measured with: T.D. = 70'

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: None

Turbidity: Clear

Odor: None

Other Comments:

4 ☒

WELL EVACUATION:

Method: Dedicated Groutless Pump

Volume Removed: 20+ gal.

Observations: Turbidity (clear) slightly cloudy very cloudy

Water level (rose fell no change)

Water odors: None

Other comments:

Groundwater Sampling Record

Monitoring Well No. 2-2A (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

- ☐ Bailer made of: _____
☒ Pump, type: Grubbs permanent installation
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☒

ON-SITE MEASUREMENTS:

Time	0754	0800	0805	0810			Measured with
Temp (°C)	20.3	20.4	20.6	20.6			Omn 840
pH	na	na	na	na			-
Cond (µS/cm)	1234	1230	1235	1236			Omn 140
DO (mg/L)	5.2	4.8	4.8	5.0			Omn 840
Redox (mV)	107.2	85.1	72.3	70.1			Omn 250A
Salinity	na	na	na	na			-

7 ☒

SAMPLE CONTAINERS (material, number, size): Standard set

8 ☒

ON-SITE SAMPLE TREATMENT:

☒ NaOH Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☒ Preservatives added: HCL / Phosphate

Method VOCs Containers: VOCs
 Method D.C. Containers: Synm Jars
 Method Fixed Iron Containers: 250ml Plastic
 Method _____ Containers: _____

9 ☒

CONTAINER HANDLING:

- ☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest } EPA

10 ☐

OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/6/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-4A

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/6/97 at 1330 a.m./p.m.

SAMPLE COLLECTED BY: Bmill/FR of Parsens/EPA

WEATHER: Cloudy, Breezy, mild 75°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of Access Port

MONITORING WELL CONDITION:

☐ LOCKED:

☒ UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: OK

INNER PVC CASING CONDITION IS: OK

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Water in Well Box, Very Corroded Fittings

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Alconox / Distilled H₂O

Items Cleaned (List): Water Level & Sampling Equipment & Probes

2 ☒

PRODUCT DEPTH NA

FT. BELOW DATUM

Measured with:

WATER DEPTH 42.44'

TD=70

FT. BELOW DATUM

Measured with: Purge Vol. = 14 gallons

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: Brown

Turbidity: Murky

Odor: None

Other Comments: Very Poor Water Quality

4 ☐

WELL EVACUATION:

Method: Dedicated Boreholes Pump

Volume Removed: 15 gallons to clear

Observations: Turbidity (clear → slightly cloudy very cloudy)

Water level (rose fell no change)

Water odors: None

Other comments:

NOTE

1430 Water Level 2-51A

45.00' Top Access Cap

Pump Plugged off - Couldn't get to work.

Groundwater Sampling Record

Monitoring Well No. 2-4A (Cont'd)

NOTE 1545 2-4

Product = 9.67 Top Casing
Water = 10.93

5 [x]

SAMPLE EXTRACTION METHOD:

- ☐ Bailer made of: _____
☒ Pump, type: Dedicated circulation Pump
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 [x]

ON-SITE MEASUREMENTS:

Time	15.0	25.0	27.0				Measured with
Temp (°C)	1520	1528	1530				YSI-55
pH	NA	NA	NA				-
Cond (µS/cm)	1296	1296	1298				Orion 140
DO (mg/L)	4.75	4.67	4.70				YSI-51
Redox (mV)	113.8	87.5	83.4				Orion 250A
Salinity	NA	NA	NA				-

7 [x]

SAMPLE CONTAINERS (material, number, size): Standard Set

8 [x]

ON-SITE SAMPLE TREATMENT:

☒ Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☒ Preservatives added:

Method VOAs Containers: Phenoxide
 Method DC - Fixed Ineq. Containers: ITC
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [x]

CONTAINER HANDLING:

- ☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest } EPA

10 [x]

OTHER COMMENTS: Very muddy at start, Think str-
2" Wells are Silted In.

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/11/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-SCB

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/11/97 at 12:50 a.m./p.m.

SAMPLE COLLECTED BY: Bm11/FB of Parsons/EPA CMV/Parsons

WEATHER: Partly cloudy, Breezy, 70-75°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of SS Casing (North Side)

MONITORING WELL CONDITION:

☐ LOCKED:

☒ UNLOCKED

WELL NUMBER (IS - ~~IS NOT~~ APPARENT

STEEL CASING CONDITION IS: OK

INNER PVC CASING CONDITION IS: OK

WATER DEPTH MEASUREMENT DATUM (IS - ~~IS NOT~~ APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): North Side measurement

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Alconox / Distilled Water

Items Cleaned (List): Probes / Levels

2 ☒

PRODUCT DEPTH 13.23' FT. BELOW DATUM

Measured with: Kleck O/W Probe

WATER DEPTH 13.48' FT. BELOW DATUM

Measured with: Kleck O/W Probe T.D. = 17.85'

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: lt brown

Turbidity: slightly silty

Odor: —

Other Comments: —

Casing Volume = 0.7 gal. Pump Vol = 2.1 gal.

4 ☒

WELL EVACUATION:

Method: Peristaltic Pump

Volume Removed: 2.0 gal.

Observations: Turbidity (clear slightly cloudy very cloudy)

Water level (rose fell no change)

Water odors: None

Other comments: —

Monitoring Well No. 2-SCB (Cont'd)

[] Bailer made of: _____
 [x] Pump, type: Penetallite
 [] Other, describe: _____

6 [] ON-SITE MEASUREMENTS:

Time	12:18p	12:25p	12:30p	12:35p	12:40p	12:45p	Measured with
Temp (°C)	20.5	20.3	20.3	20.5	20.5	20.3	ORION 840
pH	NM	NM	NM	NM	NM	NM	onsite lab
Cond (µS/cm)	1500	1510	1510	1520	1530	1530	ORION 140
DO (mg/L)	0.5	0.3	0.2	0.2	0.2	0.1	ORION 840
Redox (mV)	-210	-222	-225	-229.5	-233	-243	ORION 250A
Salinity	NM	NM	NM	NM	NM	NM	NM

8 [✓] ON-SITE SAMPLE TREATMENT:

[] New Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

[✓] Preservatives added: 14C1 Phosphate

Method VOCs Containers: VOCs
 Method D.G Containers: Synum Jars
 Method Freeze Drying Containers: 250 ml. Plastic.
 Method _____ Containers: _____

9 ~~[-]~~ CONTAINER HANDLING:

☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest *3 EPA*

10 [] OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-51B

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/6/97 at 1520 h m p.m.

SAMPLE COLLECTED BY: Cindy Merrill of Parsons SS. and Don Kampbell of USEPA

WEATHER: partly cloudy, humid, hot

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" Ø flush mount w/ dedicated electric submersible pump

MONITORING WELL CONDITION:

☐ LOCKED:

☒ UNLOCKED bolted

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: Good

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water

Items Cleaned (List): probes

2 ☒

PRODUCT DEPTH NA FT. BELOW DATUM

Measured with: —

WATER DEPTH 9.2 FT. BELOW DATUM

Measured with: Geoprobe Water level meter

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: clear

Turbidity: clear

Odor: fuel odor

Other Comments: —

4 ☒

WELL EVACUATION:

Method: dedicated electric submersible pump

Volume Removed: —

Observations: Turbidity (clear slightly cloudy very cloudy)

Water level (rose fell no change)

Water odors: —

Other comments: —

Groundwater Sampling Record

Monitoring Well No. 2-51B (Cont'd)

5 [4]

SAMPLE EXTRACTION METHOD:

☐ Bailer made of: _____
☒ Pump, type: Electric Submersible
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 []

ON-SITE MEASUREMENTS:

Time	3:00	3:11	3:15				Measured with
Temp (°C)	21.1	22.0	23.3				ORION 840
pH	NM	NM	NM				on site lab
Cond (µS/cm)	560	3900	3910				ORION 140
DO (mg/L)	0.3	0.2	0.3				ORION 840
Redox (mV)	-204	-206	-215				ORION 250A
Salinity	NM	NM	NM				NM

7 [4]

SAMPLE CONTAINERS (material, number, size): 4 40ml VOA vials (HCl)
2 50 ml clear glass serum bottles (H2SO4)
1 125 ml plastic bottle (H2SO4)
1 125 ml plastic bottle (no preservatives)
2 250 ml plastic bottles (for on site analysis)

8 []

ON-SITE SAMPLE TREATMENT:

☐ Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

☐ Preservatives added: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 []

CONTAINER HANDLING:

☐ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest

10 []

OTHER COMMENTS: _____

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: _____

GROUNDWATER SAMPLING RECORD - MONITORING WELL MW 2-52A
(number)

REASON FOR SAMPLING: ☐ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: _____ at _____ a.m./p.m.

SAMPLE COLLECTED BY: _____ of _____.

WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:

☐ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: _____

INNER PVC CASING CONDITION IS: _____

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 ☐ EQUIPMENT CLEANED BEFORE USE WITH _____
Items Cleaned (List): _____

2 ☐ PRODUCT DEPTH _____ FT. BELOW DATUM
Measured with: _____

WATER DEPTH 46.24 FT. BELOW DATUM
Measured with: TD = 66.5' Purge Vol. = 10.0 gallons

3 ☐ WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: _____
Turbidity: _____
Odor: _____
Other Comments: _____

4 ☐ WELL EVACUATION:
Method: _____
Volume Removed: _____
Observations: Turbidity (clear slightly cloudy very cloudy)
Water level (rose fell no change)
Water odors: _____
Other comments: _____

Groundwater Sampling Record

Monitoring Well No. Z-S2A (Cont'd)

5 [] SAMPLE EXTRACTION METHOD:

[] Bailer made of: _____
[] Pump, type: _____
[] Other, describe: _____

Sample obtained is [X] GRAB; [] COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Time							Measured with
Temp (°C)							
pH							
Cond (µS/cm)							
DO (mg/L)							
Redox (mV)							
Salinity							

7 [] SAMPLE CONTAINERS (material, number, size): _____

8 [] ON-SITE SAMPLE TREATMENT:

[] Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

[] Preservatives added: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [] CONTAINER HANDLING:

[] Container Sides Labeled
[] Container Lids Taped
[] Containers Placed in Ice Chest

10 [] OTHER COMMENTS: _____

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/18/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL MW2-52B

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/17/97 at 0930 am/p.m.

SAMPLE COLLECTED BY: Bmit/DK of Persus/EPA

WEATHER: Partly Cloudy, Breezy, 70°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top SS casing - North Side

MONITORING WELL CONDITION:

☒ LOCKED:

☐ UNLOCKED

WELL NUMBER 18 - IS NOT APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: Good (SS)

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH

Items Cleaned (List):

2 ☒

PRODUCT DEPTH 12.485' TD=13' FT. BELOW DATUM

Measured with: Purge Volume = 2.7 gallons

WATER DEPTH 12.49' - True Product FT. BELOW DATUM

Measured with: ORS Oil/Water Probe

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: None

Turbidity: Clear

Odor: Slight

Other Comments:

4 ☒

WELL EVACUATION:

Method: Peristaltic Pump

Volume Removed: 30 gal.

Observations: Turbidity (clear) slightly cloudy very cloudy

Water level (rose fell no change)

Water odors: Slight gasoline odor

Other comments:

Groundwater Sampling Record

Monitoring Well No. 2-S2B (Cont'd)

5 [✓] SAMPLE EXTRACTION METHOD:

[] Bailer made of: _____
 [x] Pump, type: Peristaltic
 [] Other, describe: _____

Sample obtained is [X] GRAB; [] COMPOSITE SAMPLE

6 [✓] ON-SITE MEASUREMENTS:

	0.5	1.5	2.0	2.5	3.0		Measured with
Time	0845	0855	0905	0915	0925		
Temp (°C)	17.2	17.1	17.9	17.3	17.4		Omn 840
pH	NA	NA	—	—	—		—
Cond (µS/cm)	604	606	603	601	600		Omn 140
DO (mg/L)	1.4	1.2	0.7	0.4	0.3		Omn 840
Redox (mV)	97.8	107.3	-195.2	-250	-265		Omn 280A
Salinity	NA	NA	—	—	—		—

clear ————— clear ————— clear

7 [✓] SAMPLE CONTAINERS (material, number, size):

Standard Set
Inorganic Duplicates
Field Blank

8 [✓] ON-SITE SAMPLE TREATMENT:

[] None Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

[✓] Preservatives added: HCL / Phosphate

Method VOCS Containers: VOAs
 Method D.G. Containers: Syringe Jars
 Method Fixed Inorg Containers: 250 ml. Plastic
 Method _____ Containers: _____

9 [✓] CONTAINER HANDLING:

[✓] Container Sides Labeled
 [] Container Lids Taped
 [] Containers Placed in Ice Chest } EPA

10 [] OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: _____

GROUNDWATER SAMPLING RECORD - MONITORING WELL 170 (number)

REASON FOR SAMPLING: ☐ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/6/97 at 11:00 am p.m.

SAMPLE COLLECTED BY: Lindy Merrill of Parsons ES and Don Campbell of USEPA

WEATHER: sunny breezy & warm

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 4" Ø stickup with dedicated downhole pump

MONITORING WELL CONDITION:

☒ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS) IS NOT APPARENT

STEEL CASING CONDITION IS: good

INNER PVC CASING CONDITION IS: good

WATER DEPTH MEASUREMENT DATUM (IS) IS NOT APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water
Items Cleaned (List): probes

2 ☒

PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 9.4 FT. BELOW DATUM
Measured with: Geoprobe water level indicator

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):
TD = 35' Purge Vol 50 gal
Color: clear
Turbidity: none
Odor: none
Other Comments: —

4 ☒

WELL EVACUATION:
Method: dedicated downhole pump
Volume Removed: _____
Observations: Turbidity (clear) slightly cloudy very cloudy
Water level (rose fell no change)
Water odors: none
Other comments: —

Groundwater Sampling Record

Monitoring Well No. 70 (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

☐ Bailer made of:

☒ Pump, type: dedicated downhole submersible

☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐

ON-SITE MEASUREMENTS:

Time	10:39a	10:43a	10:46a	10:52a		Measured with
Temp (°C)	20.2	20.3	20.4	20.3		ORION 840
pH	NM	NM	NM	NM		on-site lab
Cond (µS/cm)	1330	1330	1340	1340		ORION 140
DO (mg/L)	1.9	1.5	0.0 ?	1.5 ?		ORION 840
Redox (mV)	19.8	8.7	3.4	1.3		ORION 250A
Salinity	NM	NM	NM	NM		NM

7 ☐

SAMPLE CONTAINERS (material, number, size): 4 40 ml vial vials (w/HCl)

2 50 ml glass serum bottles (w/sulfuric acid)

2 125 ml plastic bottles (one w/sulfuric acid)

2 750 ml plastic bottles (for on-site analysis)

8 ☒

ON-SITE SAMPLE TREATMENT:

☐ Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☐ Preservatives added: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 ☒

CONTAINER HANDLING:

☐ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest

10 ☒

OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-145 B

(number)

REASON FOR SAMPLING: ☐ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/6/97 at 9:15 a.m./p.m.

SAMPLE COLLECTED BY: Cindy Merrill of Parsons ES and Don Kampbell of USEPA

WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): 4" Ø flush mount w/ dedicated downhole pump

MONITORING WELL CONDITION:

☐ LOCKED:

☒ UNLOCKED bolted

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: good

INNER PVC CASING CONDITION IS: good

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water

Items Cleaned (List): probes

2 ☒

PRODUCT DEPTH NA FT. BELOW DATUM

Measured with: —

WATER DEPTH 9.5' FT. BELOW DATUM

Measured with: Geoprobe water level meter

TD = 24'

Purge Vol = 28 gal

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: clear to red brown

Turbidity: none

Odor: none

Other Comments: —

4 ☒

WELL EVACUATION:

Method: dedicated downhole submersible pump

Volume Removed: 30 gal

Observations: Turbidity (clear ☒ slightly cloudy ☐ very cloudy)

Water level (rose ☐ fell ☒ no change)

Water odors: none

Other comments: —

Groundwater Sampling Record

Monitoring Well No. 2-145B (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

☐ Bailer made of:

☒ Pump, type: dedicated downhole submersible

☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☒

ON-SITE MEASUREMENTS:

Time	8:47a	8:50a	8:53a	9:00a			Measured with
Temp (°C)	18.6	20.3	20.8	20.8			ORION 840
pH	NM	NM	NM	NM			on site lab
Cond (µS/cm)	1630	1640	1650	1660			ORION 140
DO (mg/L)	0.8	0.4	0.3	0.3			ORION 840
Redox (mV)	106.2	73.8	89.0	69.7			ORION 250A
Salinity	NM	NM	NM	NM			NM

7 ☒

SAMPLE CONTAINERS (material, number, size): 4 40ml vials w/ HCl

2 50ml glass serum bottles w/ sulphuric acid

2 125ml plastic bottles (1 w/ sulphuric acid)

2 150 ml plastic bottles (for on site analysis)

8 ☒

ON-SITE SAMPLE TREATMENT:

☐

Filtration:

Method _____

Containers: _____

Method _____

Containers: _____

Method _____

Containers: _____

☐

Preservatives added:

Method _____

Containers: _____

Method _____

Containers: _____

Method _____

Containers: _____

Method _____

Containers: _____

EPA

9 ☒

CONTAINER HANDLING:

☐ Container Sides Labeled

☐ Container Lids Taped

☐ Containers Placed in Ice Chest

EPA

10 ☒

OTHER COMMENTS:

EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/6/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-146B

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/6/97 at 11:30 a.m./p.m.

SAMPLE COLLECTED BY: B. Smith / FB of Persons / EPA.

WEATHER: Clear Sunny Hot 75-80°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of Access Port

MONITORING WELL CONDITION:

☐ LOCKED:

☒ UNLOCKED

WELL NUMBER (IS) IS NOT) APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: NA

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Alconox / DI water

Items Cleaned (List): Probes & Sampling Equip.

2 ☒

PRODUCT DEPTH NA FT. BELOW DATUM

Measured with:

WATER DEPTH 10.23 FT. BELOW DATUM

Measured with: T.D. = 22' Purge Vol. = 23 gallons

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: Clear

Turbidity: Clear

Odor: None

Other Comments:

4 ☒

WELL EVACUATION:

Method: Dedicated Circulator Pump

Volume Removed:

Observations: Turbidity (clear slightly cloudy very cloudy)

Water level (rose fell no change) Reddish Orange

Water odors: None

Other comments:

Groundwater Sampling Record

Monitoring Well No. 2-146B (Cont'd)

5 [✓] SAMPLE EXTRACTION METHOD:

[] Bailer made of: _____
 [✓] Pump, type: Dedicated Grundfos
 [] Other, describe: _____

Sample obtained is [X] GRAB; [] COMPOSITE SAMPLE

6 [✓] ON-SITE MEASUREMENTS:

	2.0	6.0	11.0	16.0	22.0		
Time	1028	1036	1050	1110	1122		Measured with
Temp (°C)	17.2	17.6	18.2	19.1	19.1		YSI-55
pH	NA	NA	NA	NA	NA		— (EPA)
Cond (µS/cm)	1229	1236	1242	1237	1216		Omn 140
DO (mg/L)	0.44	0.23	0.21	0.26	0.25		YSI-55
Redox (mV)	145.3	116.0	114.2	124.3	129.4		Omn ZSA
Salinity	NA	NA	NA	NA	NA		—

7 [✓] SAMPLE CONTAINERS (material, number, size): Standard Set

8 [✓] ON-SITE SAMPLE TREATMENT:

[] None Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

[✓] Preservatives added: HCl / phosphate

Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [✓] CONTAINER HANDLING:

[✓] Container Sides Labeled
 [] Container Lids Taped
 [] Containers Placed in Ice Chest } EPA

10 [] OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-148A

(number)

REASON FOR SAMPLING: ☐ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/6/97 at 2:15 a.m. (p.m.)

SAMPLE COLLECTED BY: Cynthia Herrick of Parsons ES and Don Kampbell of USEPA

WEATHER: sunny & warm

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 4" Ø sticking
with dedicated downhole submersible pump (electric)

MONITORING WELL CONDITION:

☒ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: Good

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water

Items Cleaned (List): probes

2 ☒

PRODUCT DEPTH NA FT. BELOW DATUM

Measured with: —

WATER DEPTH 51.0 FT. BELOW DATUM

Measured with: Geoprobe water level meter

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: clear

Turbidity: none

Odor: none

Other Comments: —

4 ☐

WELL EVACUATION:

Method: dedicated downhole submersible pump

Volume Removed: —

Observations: Turbidity (clear slightly cloudy very cloudy)

Water level (rose fell no change)

Water odors: —

Other comments: —

Groundwater Sampling Record

Monitoring Well No. 2-148A (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

☐ Bailer made of:

☒ Pump, type: dedicated electric downhole submersible

☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐

ON-SITE MEASUREMENTS:

Time	1:50p	1:56p	2:03p	2:08p		Measured with
Temp (°C)	22.6	23.3	23.6	23.8		ORION 840
pH	NM	NM	NM	NM		on-site lab
Cond (µS/cm)	1090	1080	1070	1070		ORION 14C
DO (mg/L)	5.7	5.6	5.4	5.7		ORION 840
Redox (mV)	NM	82	56.3	51.2		ORION 250A
Salinity	NM	NM	NM	NM		NM

7 ☒

SAMPLE CONTAINERS (material, number, size): 4 40 ml VOA vials (HCl)

2 125 ml plastic bottles (one w/ H₂SO₄)

2 250 ml plastic bottles

2 50 ml clear glass serum bottles (w/ H₂SO₄)

8 ☒

ON-SITE SAMPLE TREATMENT:

☐

Filtration:

Method _____

Containers: _____

Method _____

Containers: _____

Method _____

Containers: _____

☐

Preservatives added:

Method _____

Containers: _____

Method _____

Containers: _____

Method _____

Containers: _____

Method _____

Containers: _____

9 ☒

CONTAINER HANDLING:

☐ Container Sides Labeled

☐ Container Lids Taped

☐ Containers Placed in Ice Chest

10 ☒

OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-148B

(number)

REASON FOR SAMPLING: ☐ Regular Sampling; ☐ Special Sampling:

DATE AND TIME OF SAMPLING: 5/6/97 at 12:20 a.m./p.m.

SAMPLE COLLECTED BY: Lindy Merrill Parsonses & Don Campbell of USEPA

WEATHER: Sunny, warm

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 4"Ø stickup with dedicated downhole submersible pump

MONITORING WELL CONDITION:

☒ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS NOT) APPARENT

STEEL CASING CONDITION IS: good

INNER PVC CASING CONDITION IS: good

WATER DEPTH MEASUREMENT DATUM (IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water

Items Cleaned (List): probes

2 ☒

PRODUCT DEPTH NA FT. BELOW DATUM

Measured with: —

WATER DEPTH 7.9 FT. BELOW DATUM

Measured with: Geoprobe

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe): TD = 28' Purge Vol 40 gal

Color: red-brown

Turbidity: silty

Odor: none

Other Comments: —

4 ☒

WELL EVACUATION:

Method: dedicated downhole submersible

Volume Removed:

Observations: Turbidity (clear slightly cloudy very cloudy)

Water level (rose fell no change)

Water odors: none

Other comments: —

Groundwater Sampling Record

Monitoring Well No. 2-148B (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

- ☐ Bailer made of: _____
☒ Pump, type: dedicated downhole submersible
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐

ON-SITE MEASUREMENTS:

Time	12:00p	12:05p	12:10p	12:15p		Measured with
Temp (°C)	20.0	20.5	20.8	21.0		ORION 840
pH	NM	NM	NM	NM		~~ORION~~ ^{on site} lab
Cond (µS/cm)	2950	2950	2940	2940		ORION 140
DO (mg/L)	5.0	4.7	4.6	4.4		ORION 840
Redox (mV)	6.4	6.7	6.7	6.8		ORION 250A
Salinity	NM	NM	NM	NM		NM

7 ☒

SAMPLE CONTAINERS (material, number, size):

- 4 40 ml vial vials w/HCl
2 50 ml glass serum bottles w/H₂O₄
2 125 ml plastic bottles (one w/H₂O₄)
2 250 ml plastic bottles (for on-site analysis)

8 ☒

ON-SITE SAMPLE TREATMENT:

☐ Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☐ Preservatives added: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 ☒

CONTAINER HANDLING:

- ☐ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest

10 ☒

OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5-5/7/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL MW2-149A

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/5/97 at 1440 a.m./p.m.

SAMPLE COLLECTED BY: BMH / FS of Pursers / EPA

WEATHER: Clear, Sunny, Hot, Boff

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of metal well housing on pump lid

MONITORING WELL CONDITION:

☐ LOCKED:

☒ UNLOCKED

WELL NUMBER ~~(IS)~~ IS NOT APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: NA

WATER DEPTH MEASUREMENT DATUM (IS - ~~IS NOT~~) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Alcon / DI Water

Items Cleaned (List): Water level Indicator / Probes

2 ☒

PRODUCT DEPTH NA

FT. BELOW DATUM

Measured with:

WATER DEPTH 42.28'

FT. BELOW DATUM

Measured with: T.D. = 69' Casing Volume = 17 gal. x 3 = 53 gal.

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: Clear - Sl. Cloudy

Turbidity: Sl. Cloudy

Odor: None

Other Comments: Sl. brown.

4 ☒

WELL EVACUATION:

Method: Dedicated Groutbox Pump

Volume Removed: 53 gal.

Observations: Turbidity (clear) slightly cloudy very cloudy

Water level (rose fell no change) Not measured

Water odors: None

Other comments:

Groundwater Sampling Record

Monitoring Well No. MW2-144A (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

- ☐ Bailer made of: _____
☒ Pump, type: Dedicated Grundfos Pump
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☒

ON-SITE MEASUREMENTS:

	40 gal.	11.0	25.0	40.0	50.0		Measured with
Time	1405	1415	1425	1435	1440		
Temp (°C)	20.4	19.1	19.2°F	19.2°F	19.0°F		YSI 55
pH	NA	NA	9.28	9.38	NA		Orion 250A
Cond (µS/cm)	1110	815	370	561	576		Orion 140
DO (mg/L)	2.60	3.91	4.46	4.74	4.83		YSI 55
Redox (mV)	136.0	120	129.5	140.7	145		Orion 250A
Salinity	NA	NA	NA	NA	NA		NA

7 ☒

SAMPLE CONTAINERS (material, number, size): Standard Set

8 ☒

ON-SITE SAMPLE TREATMENT:

☐ None Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☐ Preservatives added:

Method VOCs Containers: Phosphate
 Method Dissolved Gases Containers: HCL
 Method Fixed Inorganics Containers: HCL
 Method _____ Containers: _____

9 ☒

CONTAINER HANDLING:

- ☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest } EDA

10 ☐

OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL MW - 2-149B (number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/5/97 at 3:40 a.m./p.m.

SAMPLE COLLECTED BY: Bruce F. S. of Parsons ES

WEATHER: Clear, Sunny, Warm, 80°F, Breezy

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of Steel - Water Level Access cap

MONITORING WELL CONDITION:

~~LOCKED~~:

UNLOCKED 15 min

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: Not Accessible

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe): NA

Check-off

1 ☒ EQUIPMENT CLEANED BEFORE USE WITH Alconox & DI Water
Items Cleaned (List): Level Probes / Meter Probes / Sampling Equipment

2 ☒ PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: _____

WATER DEPTH 18.02' TPVC FT. BELOW DATUM
Measured with: T: 20' -> 2.98' submersed (Thru was)

Casing W. = 5.2 gal.

3 ☒ WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: Clear - Orangeish Tint
Turbidity: Slightly Cloudy
Odor: None
Other Comments: _____

4 ☒ WELL EVACUATION:
Method: Dedicated Caster Pump
Volume Removed: 16 + gallons
Observations: Turbidity (clear slightly cloudy very cloudy)
Water level (rose fell no change) NA Clear - Orangeish
Water odors: None
Other comments: None

Groundwater Sampling Record

Monitoring Well No. MW 2-144B (Cont'd)

5 ☒ SAMPLE EXTRACTION METHOD:

☐ Bailer made of: _____
☒ Pump, type: Peristaltic pump
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☒ ON-SITE MEASUREMENTS:

	5.0 gal	10.0 gal	12.0	15.0	16.0		Measured with
Time	1309	1316	1320	1328	1330		
Temp (°C)	18.4	18.4	18.6	18.8	19.0		YSI-55
pH	NA	NA	NA	NA	NA		EPA
Cond (µS/cm)	1660	1542	1580	1576	1596		Omnion 140
DO (mg/L)	1.54	1.60	1.47	1.37 ~~1.47~~ (EPA)	1.40		YSI-55
Redox (mV)	462	365.6	369.6	370.8	365.9		Omnion 280A
Salinity	NA	NA	NA	NA	NA		NA

7 ☒ SAMPLE CONTAINERS (material, number, size): 4 x VGAs
2 x 250 ml Plastic
2 x Syring Jars
2 x 500 ml. Plastic.

8 ☒ ON-SITE SAMPLE TREATMENT:

☒ Filtration: Method _____ Containers: _____
NONE Method _____ Containers: _____
Method _____ Containers: _____

☒ Preservatives added:

Method HCL Containers: 1 - 250 ml. / Plastic / Syring Jars
Method Phosphate Containers: VGAs
Method _____ Containers: _____
Method _____ Containers: _____

9 ☒ CONTAINER HANDLING:

EPA { ☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest

10 ☐ OTHER COMMENTS: _____

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/6/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-152A

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/6/97 at 1240 a.m./p.m.

SAMPLE COLLECTED BY: BmH/FS of Persons/EPA

WEATHER: Partly Cloudy, Breezy, Hot, 80°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top Access Port.

MONITORING WELL CONDITION:

☒ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS) IS NOT APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: NA

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Alconox / Distilled H₂O

Items Cleaned (List): Water Level / Probes / Sampling Equip.

2 ☒

PRODUCT DEPTH NA FT. BELOW DATUM

Measured with:

WATER DEPTH 50.37' Top Access Port FT. BELOW DATUM

Measured with: T.D. = 68' Surge Vol. = 35 gal.

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: Clear to

Turbidity: sl. cloudy

Odor: None

Other Comments:

4 ☒

WELL EVACUATION:

Method: Dedicated Gravel Pump

Volume Removed: 35 gallons

Observations: Turbidity clear slightly cloudy very cloudy)

Water level (rose fell no change)

Water odors: None

Other comments:

Groundwater Sampling Record

Monitoring Well No. 2-152A (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

- ☐ Bailer made of: _____
☒ Pump, type: Dedicated Groutless Pump
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☒

ON-SITE MEASUREMENTS:

	<u>15 gal</u>	<u>25 gal</u>	<u>30 gal</u>				
Time	12:16	12:28	12:35				Measured with
Temp (°C)	-	20.6	20.6				YSI-55
pH	NA	NA	NA				-
Cond (µS/cm)	711	711	711				Orion 140
DO (mg/L)	6.31	6.42	6.65				YSI-55
Redox (mV)	173.3	217.7	233.4				Orion 252A
Salinity	NA	NA	NA				-

7 ☒

SAMPLE CONTAINERS (material, number, size): Stainless Steel

8 ☒

ON-SITE SAMPLE TREATMENT:

- ☐ None Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☒ Preservatives added: HCL, Phosphate

- Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 ☒

CONTAINER HANDLING:

- ☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest } EPA

10 ☐

OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/6/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL MWZ-152R

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/6/97 at 1330 a.m./p.m.

SAMPLE COLLECTED BY: BmH / FB of Davers / EPA

WEATHER: Partly Cloudy Breezy, Mild 75°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top Access Port

MONITORING WELL CONDITION:

☒ LOCKED: ☐ UNLOCKED

WELL NUMBER (15) - IS NOT APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: NA

WATER DEPTH MEASUREMENT DATUM (IS - ☒ NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒ EQUIPMENT CLEANED BEFORE USE WITH Alconox / Distilled Water
Items Cleaned (List): Probes / meters

2 ☒ PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH 12.85 Top Access Port FT. BELOW DATUM
Measured with: T.D. = 19' Purge Vol. = 12 gallons

3 ☒ WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: Sl-mod cloudy orangish brown
Turbidity: NA
Odor: None
Other Comments:

4 ☒ WELL EVACUATION:
Method: Dedicated Circulation Pump
Volume Removed: 13 gal.
Observations: Turbidity (clear slightly cloudy very cloudy)
Water level (rose fell no change) Orange Red
Water odors: None
Other comments:

Groundwater Sampling Record

Monitoring Well No. MW 2-152B (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

☐ Bailer made of: _____
☒ Pump, type: Dedicated controller
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐

ON-SITE MEASUREMENTS:

Well Purged Dry - 8.0 gal. Total Recovered
let sit 15 min., Sample

	2.0	6.0					
Time	1257	1310					Measured with
Temp (°C)	23.1	23.7					YSI-55
pH	NA	NA					-
Cond (µS/cm)	3650	3680					Orion 140
DO (mg/L)	0.93	1.90*					YSI-85
Redox (mV)	208.3	197					Orion 250A
Salinity	NA	NA					-

* Bubbling in Line - Poor DO measurements

7 ☒

SAMPLE CONTAINERS (material, number, size): Standard Set

8 ☒

ON-SITE SAMPLE TREATMENT:

☐ ~~None~~ Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☒ Preservatives added:

Method UVAs Containers: Phosphate
 Method DG / Inorg Containers: HCl
 Method _____ Containers: _____
 Method _____ Containers: _____

9 ☒

CONTAINER HANDLING:

☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest } EPA

10 ☐

OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5/97 -

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-163B

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/5/97 at 11:45 (a.m./p.m.)

SAMPLE COLLECTED BY: Cindy Merrill of Parsons ES

WEATHER: Sunny, breezy, warm

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC - covered with threaded 4" steel cap with openings for pump tubing & water depth measurement

MONITORING WELL CONDITION:

☐ LOCKED:

☒ UNLOCKED bolted

WELL NUMBER (IS) IS NOT APPARENT

STEEL CASING CONDITION IS: good

INNER PVC CASING CONDITION IS: good

WATER DEPTH MEASUREMENT DATUM (IS) IS NOT APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water

Items Cleaned (List): probes

2 ☒

PRODUCT DEPTH NA

FT. BELOW DATUM

Measured with: —

WATER DEPTH 12.91

FT. BELOW DATUM

Measured with: electronic water level indicator (slope indicator)

TD = 23' Purge Vol 20 gal

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: clear none

Turbidity: clear

Odor: none

Other Comments: —

4 ☒

WELL EVACUATION:

Method: pump (dedicated downhole submersible)

Volume Removed: 20 gal

Observations: Turbidity clear slightly cloudy very cloudy)

Water level (rose fell no change)

Water odors: none

Other comments: none

Groundwater Sampling Record

Monitoring Well No. 2-163B (Cont'd)

5 [] SAMPLE EXTRACTION METHOD:

[] Bailer made of: _____
☒ Pump, type: dedicated downhole submersible
 [] Other, describe: _____

Sample obtained is [X] GRAB; [] COMPOSITE SAMPLE

6 [] ON-SITE MEASUREMENTS:

Time	11:25	11:28	11:33	11:39			Measured with
Temp (°C)	20.8	21.5	22.4	22.6			ORION 840
pH	NM	NM	NM	NM			on site lab
Cond (µS/cm)	5150	3200	2920	2690			ORION 140
DO (mg/L)	0.5	0.4	0.5	0.5			ORION 840
Redox (mV)	-183	-183	-189	-172			ORION 250A
Salinity	NM	NM	NM	NM			NM

7 [] SAMPLE CONTAINERS (material, number, size): 4 40ml vials (HCl)

2 50ml glass serum bottles (H₂SO₄)

2 125ml plastic bottles (1 with H₂SO₄)

2 250 ml plastic bottles

8 [] ON-SITE SAMPLE TREATMENT:

[] Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

[] Preservatives added:

Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [] CONTAINER HANDLING:

[] Container Sides Labeled
 [] Container Lids Taped
 [] Containers Placed in Ice Chest

10 [] OTHER COMMENTS: EPA (DK) collected samples

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5/97 -

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-164B (number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/5/97 at 3:30 a.m./p.m.

SAMPLE COLLECTED BY: Cindy Merrill of Parsons ES and DK of USEPA

WEATHER: Sunny, Warm

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC stickup 4" Ø PVC w/cover w/holes for dedicated pump tubing and water level measurements

MONITORING WELL CONDITION:

☐ LOCKED:

UNLOCKED bolted

WELL NUMBER (IS) IS NOT) APPARENT

STEEL CASING CONDITION IS: good

INNER PVC CASING CONDITION IS: good

WATER DEPTH MEASUREMENT DATUM (IS) IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH isopropyl, distilled water

Items Cleaned (List): probes

2 ☒

PRODUCT DEPTH NA FT. BELOW DATUM

Measured with: —

WATER DEPTH 13.6 FT. BELOW DATUM

Measured with: Geoprobe electronic water level meter

3 ☒

TD 28'
WATER-CONDITION BEFORE WELL EVACUATION (Describe): Purge Vol 28 gal

Color: none

Turbidity: clear

Odor: none

Other Comments: —

4 ☒

WELL EVACUATION:

Method: downhole submersible pump (dedicated)

Volume Removed: 30 gal

Observations: Turbidity (clear) slightly cloudy very cloudy)

Water level (rose (fell) no change)

Water odors: none

Other comments: —

Groundwater Sampling Record

Monitoring Well No. 2-164B (Cont'd)

5 [✓]

SAMPLE EXTRACTION METHOD:

- ☐ Bailer made of: _____
☒ Pump, type: dedicated downhole submersible
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 [✓]

ON-SITE MEASUREMENTS:

Time	2:30p	3:00p	3:10p	3:20p			Measured with
Temp (°C)	18.6	20.9	22.2	22.9			ORION 840
pH	NM	NM	NM	NM			~~ORION~~ on site lab
Cond (µS/cm)	1640	1640	1620	1630			ORION 140
DO (mg/L)	0.1	0.2	0.1	0.2			ORION 840
Redox (mV)	87.2	90.1	74.7	70.2			ORION 250A
Salinity	NM	NM	NM	NM			NM

7 [✓]

SAMPLE CONTAINERS (material, number, size):

- 4 40 ml VOA vials (2 BTEX, 2 CL-VOA)
2 50 ml glass screw bottles (dissolved gases) (TOC on rep 2) + sulfuric acid preservation
2 125 ml plastic bottles (Inorganics - sulfates, chlorides) (2) Fixed - nitrate, ammonia
2 250 ml plastic bottles (PH, sulfides, alk, Fe²⁺, CO₂) + sulfuric acid preservation

8 [✓]

ON-SITE SAMPLE TREATMENT:

☐ Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

☐ Preservatives added: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 [✓]

CONTAINER HANDLING:

- ☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest } EPA handled

10 [✓]

OTHER COMMENTS: EPA collected samples (DK)

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/14/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-105B

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/16/97 at 0805 a.m./p.m.

SAMPLE COLLECTED BY: Bm4/FS of Persons/EPA

WEATHER: Clear, Breezy, mild 60-70°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): top of water level access port

MONITORING WELL CONDITION:

☐ LOCKED:

☒ UNLOCKED

WELL NUMBER 12 - IS NOT APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: NA

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Alconex/DI Water

Items Cleaned (List): Water level Indicator, Sample Equipment

2 ☒

PRODUCT DEPTH NA

FT. BELOW DATUM

Measured with:

WATER DEPTH 4.44'

FT. BELOW DATUM

Measured with: TD = 19' (Slope Indicator to Water Level Meter)

14.56' Saturated Thickness 3 x casing volume = 28 gallons.

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: Clear - becoming Orange Red

Turbidity: Clear - sl. clarity

Odor: None

Other Comments:

4 ☒

WELL EVACUATION:

Method: Dedicated Groundwater Pump

Volume Removed: 28-30 gallons

Observations: Turbidity (clear ← slightly cloudy very cloudy)

Water level (rose fell no change) NM

Water odors: None

Other comments:

Groundwater Sampling Record

Monitoring Well No. 2-165B (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

- ☐ Bailer made of: _____
☒ Pump, type: Dedicated Grundfos Pump
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☒

ON-SITE MEASUREMENTS:

	5.0	15.0	20.0	28.0			
Time	0730	0745	0755	0800			Measured with
Temp (°C)	16.3	16.4	16.5	16.4			YSI-55
pH	NA	NA	NA	NA			-
Cond (µS/cm)	1573	1565	1563	1562			Orion 140
DO (mg/L)	0.55	0.48	0.53	0.55			YSI-55
Redox (mV)	~~200.1~~ 200.1	195	188.5	181.9			YSI-55
Salinity	NA	NA	NA	NA			Orion 250A

7 ☒

SAMPLE CONTAINERS (material, number, size): Standard Set

8 ☒

ON-SITE SAMPLE TREATMENT:

☒ None Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☒ Preservatives added: HCl / Phosphate
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

9 ☒

CONTAINER HANDLING:

- ☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest } EPA

10 ☐

OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-166B

(number)

REASON FOR SAMPLING: ☐ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/6/97 at 8:00 (a.m.) p.m.

SAMPLE COLLECTED BY: Lindy Merrill of Parsons ES and Don Campbell of USEPA

WEATHER: Clear, breezy

DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 4" Ø stickup w/ dedicated downhole submersible pump

MONITORING WELL CONDITION:

☒ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS) IS NOT APPARENT

STEEL CASING CONDITION IS: good

INNER PVC CASING CONDITION IS: good

WATER DEPTH MEASUREMENT DATUM (IS) IS NOT APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water
Items Cleaned (List): probes

2 ☒

PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 17.8 FT. BELOW DATUM
Measured with: Geoprobe water level meter

3 ☒

TD = 26' Purge Vol = 16 gal
WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: clear

Turbidity: none

Odor: none

Other Comments: —

4 ☒

WELL EVACUATION:

Method: dedicated downhole submersible pump

Volume Removed: 20 gal

Observations: Turbidity (clear) slightly cloudy very cloudy)

Water level (rose (fell) no change)

Water odors: none

Other comments: —

Groundwater Sampling Record

Monitoring Well No. 2-166B (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

- ☐ Bailer made of: _____
☒ Pump, type: dedicated downhole submersible
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐

ON-SITE MEASUREMENTS:

Time	7:45a	7:50a	7:55a				Measured with
Temp (°C)	18.3	19.4	19.4				ORION 840
pH	NM	NM	NM				on site lab
Cond (µS/cm)	1330	1320	1320				ORION 140
DO (mg/L)	1.6	1.4	1.4				ORION 840
Redox (mV)	47	38	43.6				ORION 250A
Salinity	NM	NM	NM				NM

7 ☒

SAMPLE CONTAINERS (material, number, size): 4 40ml VOA vials (HCL)

- 2 50ml glass serum bottles (2 preserved) H₂SO₄
2 125ml plastic bottles (1 preserved) H₂SO₄
2 250ml plastic bottles (for on site analysis)

8 ☒

ON-SITE SAMPLE TREATMENT:

- ☐ Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

- ☐ Preservatives added: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 ☒

CONTAINER HANDLING:

- ☐ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest

10 ☒

OTHER COMMENTS: _____

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/6/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL MWZ-173B

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling; (number)

DATE AND TIME OF SAMPLING: 5/6/97 at 0945 am/p.m.

SAMPLE COLLECTED BY: BmH/FB of Dariusz/EPA

WEATHER: Clear, Sunny, Hot 78-80°F.

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of Access Port

MONITORING WELL CONDITION:

☒ LOCKED:

☐ UNLOCKED

WELL NUMBER (S) IS NOT APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: NA

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Alconex/DT Wash

Items Cleaned (List): Pneumatics meters

2 ☒

PRODUCT DEPTH NA

Measured with: _____ FT. BELOW DATUM

WATER DEPTH 13.13'

Measured with: T.D. = 22' Purge Vol. = 17.3 gal. FT. BELOW DATUM

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: Clear - sl. yellow

Turbidity: sl. cloudy

Odor: None

Other Comments: _____

4 ☒

WELL EVACUATION:

Method: Dedicated Grundfos Pump

Volume Removed: 18 gallons

Observations: Turbidity (clear slightly cloudy very cloudy)

Water level (rose fell no change) reddish orange

Water odors: None

Other comments: _____

Groundwater Sampling Record

Monitoring Well No. MW 2-1733 (Cont'd)

5 [4]

SAMPLE EXTRACTION METHOD:

- ☐ Bailer made of: _____
☒ Pump, type: Peristaltic Pump
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 [4]

ON-SITE MEASUREMENTS:

	1.0	5.0	11.0	16.0			
Time	0920	0930	0936	0942			Measured with
Temp (°C)	18.7	18.4	18.8	19.0			YSI-55
pH	NA	NA	NA	NA			
Cond (µS/cm)	461	958	953	953			Orion 140
DO (mg/L)	2.12	2.16	1.96	2.01			YSI-55
Redox (mV)	201.3	197.4	203.1	204.3			Orion 280A
Salinity	NA	NA	NA	NA			

7 [4]

SAMPLE CONTAINERS (material, number, size): Standard Set

8 [4]

ON-SITE SAMPLE TREATMENT:

- ☐ Mem Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☒ Preservatives added:

- Method UVR Containers: Phosphate
 Method D.G. / Fixed Inorg Containers: HCL
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [4]

CONTAINER HANDLING:

- ☒ Container Sides Labeled
☐ Container Lids Taped
☐ Containers Placed in Ice Chest } EPA

10 []

OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL MW2-264B

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;

DATE AND TIME OF SAMPLING: 5/5/97 at 1545 a.m./p.m.

SAMPLE COLLECTED BY: Bm4/FB of Parsons/ERA

WEATHER: Clear, Sunny, Hot 83°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top Water level Access Point

MONITORING WELL CONDITION:

☐ LOCKED:

☒ UNLOCKED

WELL NUMBER (IS) IS NOT APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: NA

WATER DEPTH MEASUREMENT DATUM (IS IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Water level Indicator / Probes

Items Cleaned (List): DI / Alconox

2 ☒

PRODUCT DEPTH NA

Measured with: (T.D. = 29') FT. BELOW DATUM

WATER DEPTH 14.77 Top casing

Measured with: Purge vol. = 285 gallons FT. BELOW DATUM

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: Clear - Yellowish Brown → Turbid Reddish Brown

Turbidity: Clear - Sl. Cloudy

Odor: None

Other Comments: None

4 ☒

WELL EVACUATION:

Method: Dedicated Grundfos Pump

Volume Removed: 15 ~~30~~ gallons (Bm4)

Observations: Turbidity (clear slightly cloudy → very cloudy)

Water level (rose fell no change) NA

Water odors: None

Other comments: Reddish Brown

Groundwater Sampling Record

Monitoring Well No. MW 2-2W1B (Cont'd)

5 ☒

SAMPLE EXTRACTION METHOD:

☐ Bailer made of: _____
☒ Pump, type: Dedicated Groutless Pump
☐ Other, describe: _____

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☒

ON-SITE MEASUREMENTS:

NOTE: Well Pumped dry, recovered ~ 112 gallon in 6-10 min., tried twice, let well sit 15 min. & sample.

Time	5.00	10.0	12.5	13.0			Measured with
Temp (°C)	15.05	15.15	15.27	15.35			YSI 55
pH	NA	NA	NA	NA			Orion 250A
Cond (µS/cm)	1908	1343	1560	NA			Orion 140
DO (mg/L)	0.47	1.77	3.15	NA			YSI 55
Redox (mV)	395	405.5	NA	NA			Orion 250A
Salinity	NA	NA	NA	NA			NA

(Reckon Bm)

Groutless Pumped dry 111 gallons

7 ☒

SAMPLE CONTAINERS (material, number, size): Standard set (2-4-2-2)

8 ☒

ON-SITE SAMPLE TREATMENT:

☐ None Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

☒ Preservatives added:

Method HCL Containers: 1-Incubator / 2x Syring (DC)
 Method Phosphate Containers: UBA
 Method _____ Containers: _____
 Method _____ Containers: _____

9 ☒

CONTAINER HANDLING:

☒ Container Sides Labeled
☒ Container Lids Taped
☒ Containers Placed in Ice Chest

10 ☐

OTHER COMMENTS:

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - Area A

Sampling Dates: 5/5 - 5/7/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-205B

(number)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;
DATE AND TIME OF SAMPLING: 5/6/97 at 0855 a.m./p.m.

SAMPLE COLLECTED BY: BMI+LEB of Darsons EPA

WEATHER: Clear, Sunny, Warm 75°F

DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of Access Port

MONITORING WELL CONDITION:

☒ LOCKED:

☐ UNLOCKED

WELL NUMBER (IS) IS NOT APPARENT

STEEL CASING CONDITION IS: Good

INNER PVC CASING CONDITION IS: NA

WATER DEPTH MEASUREMENT DATUM (IS - (IS NOT) APPARENT

☐ DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

☐ MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 ☒

EQUIPMENT CLEANED BEFORE USE WITH Alconox / DI Water

Items Cleaned (List): Probes / Water level

2 ☒

PRODUCT DEPTH NA

Measured with: _____ FT. BELOW DATUM

WATER DEPTH 15.60'

Measured with: 30' Purge Vol. = 30 gal. FT. BELOW DATUM

3 ☒

WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Color: Rusty Brown

Turbidity: Cloudy

Odor: None

Other Comments: _____

4 ☒

WELL EVACUATION:

Method: Dechlorated Granules Pump

Volume Removed: 30 gal.

Observations: Turbidity (clear slightly cloudy → very cloudy)

Water level (rose tell no change) Reddish Brown

Water odors: None

Other comments: _____

Groundwater Sampling Record

Monitoring Well No. 2-265B (Cont'd)

5 [✓]

SAMPLE EXTRACTION METHOD:

[] Bailer made of: _____
 [X] Pump, type: Dedicated Circulator
 [] Other, describe: _____

Sample obtained is [X] GRAB; [] COMPOSITE SAMPLE

6 []

ON-SITE MEASUREMENTS:

	8.0	16.0	22.0	28.0			
Time	0830	0840	0846	0855			Measured with
Temp (°C)	18.6	18.6	19.0	19.1			YSI-55
pH	NA	NA	NA	NA			
Cond (µS/cm)	1367	1353	1343	1345			
DO (mg/L)	2.63	2.83	2.50				Oxi 140
Redox (mV)	187.5	156.1	152.7	157.4			YSI-55
Salinity	NA	NA	NA	NA			Oxi 230A

* Checked ~ 12-13 gallons then washed a cloudy red rest for pump

7 [✓]

SAMPLE CONTAINERS (material, number, size): Standard Set

8 [✓]

ON-SITE SAMPLE TREATMENT:

[] ~~None~~ Filtration: Method _____ Containers: _____
 Method _____ Containers: _____
 Method _____ Containers: _____

[✓] Preservatives added:

Method WAs Containers: Phosphoric
 Method D.G. / Inorganic Containers: HCL
 Method _____ Containers: _____
 Method _____ Containers: _____

9 [✓]

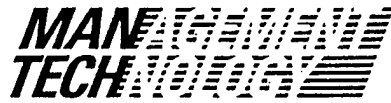
CONTAINER HANDLING:

[✓] Container Sides Labeled
 [] Container Lids Taped
 [] Containers Placed in Ice Chest } EPA

10 []

OTHER COMMENTS:

APPENDIX C
LABORATORY ANALYTICAL DATA



Ref: 97-LH15/vg

April 29, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

As requested in Service Request #SF-3-253, gas analysis was performed for methane, ethylene, and ethane on samples from Tinker AFB. The samples were received on April 24, 1997. The analyses were performed on April 25, 1997. These analyses were performed as per RSKSOP-194, and the calculations were done as per RSKSOP-175.

If you should have any questions, please feel free to contact me.

Sincerely,

A handwritten signature in black ink, appearing to read "Lisa Hopkins". The signature is fluid and cursive, with a long horizontal stroke extending to the left.

Lisa Hopkins

xc: R.L. Cosby
J.T. Wilson
G.B. Smith
J.L. Seeley *JS*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	Methane	Ethylene	Ethane
100ppm CH ₄	92.3	**	**
100ppm C ₂ H ₄	**	97.8	**
100ppm C ₂ H ₆	**	**	100.9
HPHe	**	**	**
Lab Blank	**	**	**
RW-10	0.682	**	0.027
RW-11	4.753	**	0.219
RW-12	1.268	**	0.013
RW-12	1.260	**	0.013
Lab Dup			
RW-13	3.074	0.268	0.112
RW-13	3.143	0.258	0.107
Field Dup			
10ppm CH ₄	10.2	**	**
100ppm CH ₄	100.0	**	**
100ppm C ₂ H ₄	**	91.4	**
100ppm C ₂ H ₆	**	**	96.6
Lower Limit of Quantitation			
	0.001	0.003	0.002

Units for the samples are in mg/L.

Units for the standards are parts per million.

** denotes None Detected.

* denotes Below Limit of Quantitation.



Ref: 97-BN27/vg

April 30, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

Please find attached the analytical results for Service Request #SF-3-253 requesting the analysis of field samples from Tinker AFB to be analyzed by purge-and-trap/GC-PID for Benzene, Toluene, Ethylbenzene, p-, m-, & o-xylene, 1,3,5-, 1,2,4-, & 1,2,3-Trimethylbenzene, and Total Fuel Carbon. We obtained the 4 samples in capped, 40 mL VOA autosampler vials April 24, 1997, and they were analyzed April 29, 1997. The samples were acquired and processed using the Millennium data system. A 5 place external standard curve (1-1000 ppb) was used to quantitate sample concentration for the compounds of interest.

RSKSOP-133, "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column-Dual Detector for Ground Water Samples" was used for these analyses. Autosampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Sincerely,

Bryan Newell

xc: R.L. Cosby
J.T. Wilson
G.B. Smith
J.L. Seeley *JS*
L. Black

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND
QC, OBSERVED, PPB	17	17	18	17	18	17	18	18	17
QC, TRUE VALUE, PPB	20	20	20	20	20	20	20	20	20
1 PPB	1	1	1	1	1	1	1	1	1
RW-10	50	6	11	6	2	5	1	4	1
RW-10 Field Dup	48	6	10	5	2	4	1	4	1
RW-11	18	4	8	4	1	3	1	2	1
RW-12	313	16	38	12	4	9	1	5	3
RW-13	3690	292	375	172	54	133	10	126	32
10 PPB	10	9	9	9	9	9	9	9	9
LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND
1 PPB	1	1	1	1	1	1	1	1	1

SampleName	TOTAL FUEL CARBON
RW-10	294
RW-10 Field Dup	280
RW-11	128
RW-12	1104
RW-13	6029



April 30, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

Attached are TOC results for 5 Tinker liquids submitted April 27, 1997 under Service Request #SF-3-253. Sample analysis was begun April 28, 1997 and completed April 28, 1997 using RSKSOP-102.

Blanks, duplicates, and AQC samples were analyzed along with your samples, as appropriate, for quality control. If you have any questions concerning this data, please feel free to ask me.

Sincerely,

Sharon Hightower
Sharon Hightower

xc: R.L. Cosby
G.B. Smith
J.L. Seeley *JS*

ManTech Environmental Research Services Corporation

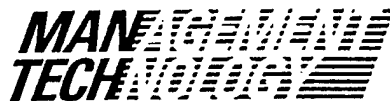
R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

KAMPBELL TINKER LIQUIDS SF-3-253

SAMPLE	MG/L TOC

RW-10	3.81
RW-11	3.77
RW-12	6.08
RW-13, REP 1	12.2
RW-13, REP 2	7.82
WSO 38 STD	5.23

WSO38 std t.v.=4.92



Ref: 97JAD27

May 12, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

As requested in Service Request # SF-3-253, headspace GC/MS analysis of 28 Tinker AFB water samples for chlorinated volatile organics was completed. The samples were received on April 24 & May 8, 1997 and analyzed on May 6 & 8, 1997. RSKSOP-148 (Determination of Volatile Organic Compounds in Water by Automated Headspace Gas Chromatography/Mass Spectrometry (Saturn II Ion Trap Detector) was used for this analysis.

An internal standard calibration method was established for the 15 compounds. The standard curves were prepared from 1.0 to 4000 ppb. The lower calibration limits were 1.0 ppb.

A dilution corrected quantitation report for the samples, lab duplicates, field duplicates, QC standards and lab blanks is presented in tables 1-2.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel
/John Allen Daniel

xc: R.L. Cosby
G.B. Smith
D.D. Fine
J.L. Seeley *JS*
J.T. Wilson

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Table 1. Quantitation Report for S.R. # SF-3-253 from Tinker AFB.

Concentration = ppb

Compound	RW-10	RW-11	RW-11 Lab Dup	RW-11 Field Dup	RW-12	RW-13	FIELD BLANK	2-2	2-2 Field Dup	2-2A
VINYL CHLORIDE	1.5	1.0	1.0	---	2.9	787	ND	ND	1.9	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	---	3.1	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	126	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	3.5	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	15.8	3.8	3.9	3.7	141	1680	ND	12.7	12.8	1.0
CHLOROFORM	2.1	ND	ND	ND	ND	9.5	12.9	ND	ND	---
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.3
1,2-DICHLOROETHANE	53.2	17.7	17.4	16.1	ND	ND	ND	ND	ND	1.4
TRICHLOROETHENE	252	5.5	5.7	5.6	13.9	ND	ND	37.0	37.6	54.8
TETRACHLOROETHENE	1.3	---	---	---	---	1.3	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	---	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	---	ND	ND	ND	ND
1,4-DICHLOROBENZENE	---	ND	ND	ND	---	1.2	ND	ND	ND	ND
1,2-DICHLOROBENZENE	---	ND	---	ND	---	7.6	ND	ND	ND	ND
	2-3	2-4A	2-50B	2-51B	2-52B	70	2-145B	2-145B Lab Dup	2-146B	2-148A
VINYL CHLORIDE	37.1	ND	64.0	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	---	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	158	---	407	---	---	---	ND	ND	ND	2.2
CHLOROFORM	11.9	---	ND	ND	ND	---	ND	ND	ND	1.6
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	---	ND	ND	ND	ND	ND	ND	ND	1.6
1,2-DICHLOROETHANE	ND	---	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	1120	39.9	ND	ND	ND	---	6.9	6.6	ND	17.3
TETRACHLOROETHENE	5.2	ND	ND	ND	ND	1.0	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = None Detected --- = Below Calibration Limit (1.0 ppb) Dup = Duplicate

Table 2. Quantitation Report for S.R. # SF-3-253 from Tinker AFB.

Concentration = ppb

Compound	2-148B	MW2-149A	MW2-149B	2-149B Field Dup	2-152A	2-152B	2-165B	2-173B	2-163B Lab Dup	2-265B	2-264B
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROFORM	4.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	83.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	2.3	ND	1.6	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	5.7	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
VINYL CHLORIDE	ND	ND	20.5	QC0506D 200 ppb	QC0508A 20 ppb	QC0508B 200 ppb	QC0508C 20 ppb	QC0508D 200 ppb	QC0508E 20 ppb	QC0508F 20 ppb	BL0508A
1,1-DICHLOROETHENE	ND	22.5	20.5	205	21.0	208	21.9	207	21.6	20.3	ND
T-1,2-DICHLOROETHENE	ND	25.1	233	233	23.7	236	24.8	240	24.8	24.2	ND
1,1-DICHLOROETHANE	ND	20.5	205	205	21.3	214	21.0	214	20.6	20.5	ND
C-1,2-DICHLOROETHENE	ND	20.4	213	213	21.2	212	20.6	214	20.7	21.7	ND
CHLOROFORM	ND	20.0	215	215	21.5	214	21.2	214	20.8	21.0	ND
1,1,1-TRICHLOROETHANE	ND	20.2	211	211	20.9	211	20.7	212	21.1	21.1	ND
CARBON TETRACHLORIDE	ND	21.1	208	208	20.5	210	22.0	209	21.6	20.6	ND
1,2-DICHLOROETHANE	ND	21.0	200	200	20.3	206	21.9	209	21.3	20.9	ND
TRICHLOROETHENE	ND	19.9	227	227	21.1	212	18.5	203	18.9	22.8	ND
TETRACHLOROETHENE	7.7	19.2	197	197	19.2	200	19.1	201	20.4	20.3	ND
CHLOROBENZENE	ND	20.6	203	203	19.8	208	20.8	207	21.0	19.9	ND
1,3-DICHLOROBENZENE	ND	20.5	223	223	21.7	224	21.2	225	21.6	20.5	ND
1,4-DICHLOROBENZENE	ND	20.7	228	228	21.3	225	21.5	223	21.1	20.1	ND
1,2-DICHLOROBENZENE	ND	20.2	234	234	21.5	236	22.3	233	21.6	20.6	ND
	ND	20.4	244	244	22.5	237	22.5	235	21.8	22.2	ND

ND = None Detected - - - = Below Calibration Limit(1.0 ppb) QC = Quality Control Std BL = Blank Dup = Duplicate



Ref: 97-LB29

May 13, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: Steve Vandegrift *SV*

Dear Don:

Please find attached the analytical results for the Tinker AFB Service Request SF-3-253 requesting the analysis of monitoring well samples to be analyzed for Benzene, Toluene, Ethylbenzene, p-, m-, and o-Xylene, 1,3,5-, 1,2,4-, and 1,2,3-Trimethylbenzene, and Total Fuel Carbon. We received your 24 samples, in duplicate, May 8, 1997 in capped, lead lined 40 mL VOA vials. The samples were analyzed on May 8-12, 1997. Samples were stored at 4°C until analyzed. All samples were acquired and processed using the Millennium data system. A 5 point (1-500 ppb) external calibration curve was used to determine the concentration for all compounds.

RSKSOP-133 "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column/Dual Detector Gas Chromatography in Ground Water Samples" was used for these analyses. Autosampling was performed using a Dynatech-Precision autosampler in-line with a Tekmar LSC 2000 sample concentrator.

Sincerely,

Lisa R. Black

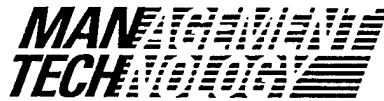
xc: R.L. Cosby
G.B. Smith
J.L. Seeley *JS*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
100 PPB	106	105	104	102	103	103	102	101	102	N/A
QC, OBSERVED, PPB	19.9	19.7	19.6	20.1	20.1	20.2	20.1	19.8	19.8	N/A
QC, TRUE VALUE, PPB	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	N/A
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
FIELD BLANK	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
2-2	453	12.3	136	12.0	16.2	7.2	2.9	1.5	13.1	1800
2-3	476	10.8	96.5	24.9	4.9	4.5	2.0	3.3	17.0	2600
2-51B	182	2.5	25.8	19.0	6.0	11.2	1.5	15.0	12.6	1800
2-52B	0.9	ND	2.2	ND	ND	ND	BLQ	ND	6.5	1000
2-52B Duplicate	BLQ	ND	2.7	BLQ	ND	ND	0.9	ND	7.0	1250
70	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-145B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-146B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-148A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10 PPB	10.0	9.3	10.1	9.5	9.4	9.6	9.5	9.3	10.4	N/A
2-148B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW2-149A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-149B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-152A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-152B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-163B	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
2-163B Duplicate	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
2-164B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-165B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-166B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-173B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1 PPB	1.0	0.9	1.0	1.0	1.0	0.9	0.9	1.0	1.0	N/A
2-264B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-265B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-265B Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-50B	14169	17535	1800	1934	4461	2840	355	1265	407	46000
2-2A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-4A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
100 PPB	104	104	103	103	103	103	103	102	103	N/A

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed



Ref: 97-LH17/vg

May 14, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

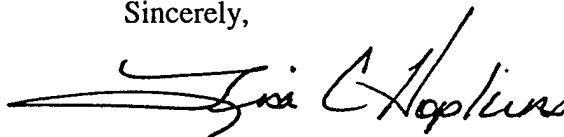
THRU: S.A. Vandegrift 

Dear Don:

As requested in Service Request #SF-3-253, gas analysis was performed for methane, ethylene, and ethane on samples from Tinker AFB. The samples were received on May 8, 1997. The analyses were performed on May 12 and 13, 1997. These analyses were performed as per RSKSOP-194, and the calculations were done as per RSKSOP-175.

If you should have any questions, please feel free to contact me.

Sincerely,

A handwritten signature in black ink, appearing to read "Lisa C. Hopkins". The signature is fluid and cursive, with a long horizontal stroke at the beginning.

Lisa Hopkins

xc: R.L. Cosby
J.T. Wilson
G.B. Smith
J.L. Seeley 

Sample	Methane	Ethylene	Ethane
100ppm CH ₄	90.0	**	**
100ppm C ₂ H ₄	**	95.4	**
100ppm C ₂ H ₆	**	**	96.4
HPHe	**	**	**
Lab Blank	**	**	**
2-2.	4.153	**	0.016
2-2A	0.001	**	**
2-3.	4.409	0.033	0.063
2-4A	0.001	**	**
2-50B	3.283	0.234	0.086
2-50B	3.153	0.223	0.082
Lab Dup			
2-51B	1.030	*	0.043
2-52B	0.531	**	**
70	**	**	**
2-145B	**	**	**
2-146B	*	**	**
2-146B	*	**	**
Field Dup			
10ppm CH ₄	9.7	**	**
100ppm CH ₄	97.6	**	**
100ppm C ₂ H ₄	**	88.6	**
100ppm C ₂ H ₆	**	**	96.0

Lower Limit of Quantitation

0.001	0.003	0.002

Units for samples are in mg/L.

Units for standards are parts per million.

** denotes None Detected.

* denotes Below Limit of Quantitation.

Sample	Methane	Ethylene	Ethane
100ppm CH ₄	89.4	**	**
100ppm C ₂ H ₄	**	93.5	**
100ppm C ₂ H ₆	**	**	102.7
HPHe	**	**	**
Lab Blank	**	**	**
2-148A	**	**	**
2-148B	**	**	**
MW2-149A	**	**	**
2-152A	**	**	**
2-149B	0.005	**	**
2-149B	0.004	**	**
Lab Dup			
2-152B	*	**	**
2-163B	3.410	**	0.166
2-164B	0.378	**	*
2-165B	**	**	**
2-166B	**	**	**
2-166B	**	**	**
Field Dup			
10ppm C ₂ H ₄	**	9.4	**
KLM-3	9.534	**	**
2-173B	**	**	**
2-264B	*	**	**
2-265B	**	**	**
100ppm CH ₄	91.7	**	**
100ppm C ₂ H ₄	**	91.7	**
100ppm C ₂ H ₆	**	**	97.8

Lower Limit of Quantitation

0.001 0.003 0.002

Units for the samples are in mg/L.

Units for the standards are parts per million.

** denotes None Detected.

* denotes Below Limit of Quantitation.



Ref: 97-DF24

May 14, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

As requested in Service Request SF-3-253, GC/MS analysis for phenols and aliphatic/aromatic acids was done on one groundwater sample from Tinker AFB. This sample was labeled RW-13. This sample was received on April 24, 1997. Amy Zhao extracted and derivatized the sample on April 30, 1997. The extract was analyzed by GC/MS on May 3, 1997. RSKERL SOP 177 was used for the extraction, derivatization and GC/MS analysis of the sample.

Table I provides the concentrations of the phenols and aliphatic/aromatic acids found in sample RW-13. Derivative and extraction blanks and recoveries of 50 ppb blank spiked samples and 100 ppb check standards are also included in the table.

If you should have any questions, please feel free to contact me.

Sincerely,

Dennis D. Fine
Dennis D. Fine

xc: J. Seeley *JS*
G. Smith
R. Cosby
D. Fine

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Table I. Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids
in Water Samples from Tinker AFB Service Request RE-3-247.

Concentration ppb						% Recovery			
File Name: 912RW13.TXT 891MTHBL.TX 913MTHBL.TX 923EXTBL.TX 911EXTBL.TX 910EXTRE.TX 922EXTRE.TX 906100AA.TXT 921100AA.TXT									
Compound	Sample Name: (VEP-9) RVV-13	Method Blank	Method Blank	Extraction Blank	Extraction Blank	50 ppb Extr. % Recovery	50 ppb Extr. % Recovery	100 ppb Std. % Recovery	100 ppb Std. % Recovery
Propanoic Acid	***	***	***	7	13	29	30	94	211
2-Methylpropanoic Acid	***	***	***	***	***	39	41	93	100
Trimethylacetic Acid	***	***	***	***	***	91	104	92	101
Butyric Acid	***	***	***	***	***	39	46	90	96
2-Methylbutyric Acid	***	***	***	***	***	76	91	90	99
3-Methylbutyric Acid	***	***	***	***	***	72	89	91	98
3,3-Dimethylpropanoic Acid	***	*	*	***	***	93	126	92	101
Pentanoic Acid	***	***	***	4	6	75	96	87	92
2,3-Dimethylbutyric Acid	***	***	***	***	***	92	132	92	102
2-Ethylbutyric Acid	***	***	***	***	***	91	135	94	104
2-Methylpentanoic Acid	***	***	***	***	***	91	136	91	100
3-Methylpentanoic Acid	***	*	*	*	***	88	130	90	98
4-Methylpentanoic Acid	***	*	*	***	***	88	130	89	97
Hexanoic Acid	9	***	***	9	14	103	143	89	93
2-Methylhexanoic Acid	***	*	*	*	*	103	127	91	100
Phenol	16	***	*	***	*	100	109	87	88
Cyclopentanecarboxylic Acid	***	*	*	*	*	86	101	89	96
5-Methylhexanoic Acid	*	*	*	*	*	103	138	89	98
o-Cresol	*	***	*	***	***	89	134	94	101
2-Ethylhexanoic Acid	64	*	***	***	***	111	144	90	96
Heptanoic Acid	***	***	*	4	8	111	143	89	92
m-Cresol	***	***	*	*	***	92	132	92	98
p-Cresol	*	*	*	*	***	83	130	94	100
1-Cyclopentene-1-carboxylic Acid	*	*	*	***	***	79	88	88	93
o-Ethylphenol	***	*	*	*	*	85	143	96	103
Cyclopentaneacetic Acid	*	***	*	*	***	94	130	89	95
2,6-Dimethylphenol	***	*	*	*	*	60	139	99	109
2,5-Dimethylphenol	*	*	*	*	*	70	136	95	103
Cyclohexanecarboxylic Acid	***	***	***	***	***	96	131	90	96
3-Cyclohexene-1-carboxylic Acid	*	*	*	*	*	81	111	89	92
2,4-Dimethylphenol	***	*	*	*	*	39	116	97	106
3,5-Dimethylphenol & m-Ethylphenol	***	*	*	*	*	87	141	95	102
Octanoic Acid	***	***	***	6	*	111	155	88	92
2,3-Dimethylphenol	*	*	*	*	*	73	140	95	104
p-Ethylphenol	*	*	*	*	*	84	132	95	98
Benzoic Acid	11	***	***	31	45	127	187	89	93
3,4-Dimethylphenol	*	*	*	***	*	71	137	98	105
m-Methylbenzoic Acid	***	*	*	*	*	81	142	89	89
1-Cyclohexene-1-carboxylic Acid	*	*	*	*	*	91	105	109	93
Cyclohexaneacetic Acid	*	*	*	*	*	94	158	111	95
2-Phenylpropanoic Acid	*	*	*	*	*	97	109	106	95
o-Methylbenzoic Acid	***	*	*	*	***	98	133	106	96
Phenylacetic Acid	7	*	*	***	***	94	131	96	95
m-Tolylacetic Acid	11	*	*	*	*	106	130	98	90
o-Tolylacetic Acid	***	*	*	*	*	105	122	99	92
2,6-Dimethylbenzoic Acid	***	*	*	***	*	128	129	135	96
p-Tolylacetic Acid	12	*	*	*	*	130	145	122	90
p-Methylbenzoic Acid	***	*	*	*	***	94	136	99	92
3-Phenylpropanoic Acid	*	*	*	*	*	89	125	89	91
2,5-Dimethylbenzoic Acid	6	*	*	*	*	99	119	97	95
Decanoic Acid	***	***	*	3	8	99	134	84	88
2,4-Dimethylbenzoic Acid	18	*	*	*	*	95	143	97	94
3,5-Dimethylbenzoic Acid	***	*	*	*	*	97	137	95	94
2,3-Dimethylbenzoic Acid	***	*	*	*	*	99	128	97	94
4-Ethylbenzoic Acid	***	*	*	*	*	97	128	101	92
2,4,6-Trimethylbenzoic Acid	25	*	*	*	***	100	129	107	96
3,4-Dimethylbenzoic Acid	10	*	*	*	*	92	134	92	88
2,4,5-Trimethylbenzoic Acid	***	*	*	*	*	96	127	94	87

*** indicates concentration of extract was below lowest calibration standard (3 ppb)
* indicates not found.



Ref: 97-DK15/vg

May 14, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Dr. Kampbell:

This report contains the results of my GC/MSD analysis of floating product sample "2-4 Product" from Tinker AFB for compound identification by mass spectral library searching and TIC chromatograms. The work was performed under Service Request #SF-3-253.

Chromatographic separation for purposes of mass spectral library identification was performed using a 30m X 0.25mm Restek "Stabilwax" capillary column in series with a 100m X 0.25mm J&W DB-1 "Petrocol" capillary column (total length = 130m, both 0.5um film). A 0.1 µl volume was injected on-column. The mass spectral scan range was m/z=39-350. The sample was diluted 1:20 with methylene chloride prior to analysis. Many sample peaks identified by mass spectral library search were verified using the following petroleum compound mixtures: n-paraffins (11 compounds), isoparaffins (35 compounds), naphthenes (29 compounds), aromatics (37 compounds), olefins (25 compounds), PNAs (3 compounds).

The sample was received on May 8, 1997 and analyzed on May 10, 1997.

If you require further information, please feel free to contact me.

Sincerely,

David A. Kovacs

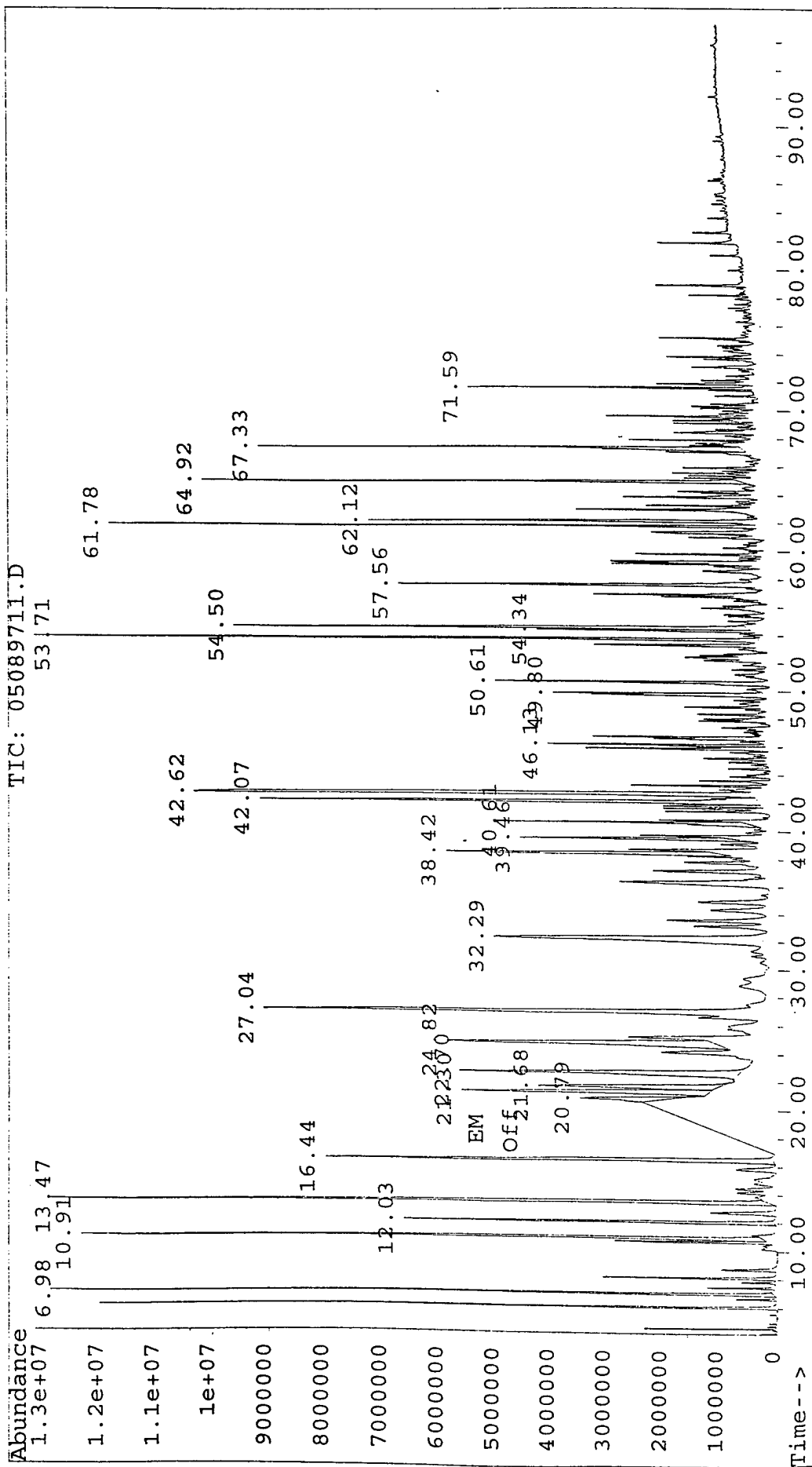
xc: R.L. Cosby
G.B. Smith

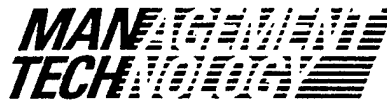
J.L. Seeley *JS*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

File : E:\05089711.D
 Operator :
 Acquired : 10 May 97 12:27 am using AcqMethod 253B
 Instrument : GC/MS
 Sample Name: 2-4 PRODUCT 1:20
 Misc Info :
 Vial Number: 9





May 19, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift^{SV}

Dear Don:

Attached are TOC results for 24 Tinker liquids submitted May 14, 1997 under Service Request #SF-3-253. Sample analysis was begun May 19, 1997 and completed May 19, 1997 using RSKSOP-102.

Blanks, duplicates, and AQC samples were analyzed along with your samples, as appropriate, for quality control. If you have any questions concerning this data, please feel free to ask me.

Sincerely,


Sharon Hightower

xc: R.L. Cosby
G.B. Smith
J.L. Seeley 

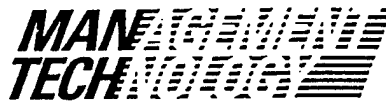
ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

KAMPBELL TINKER LIQUIDS SF-3-253

SAMPLE	MG/L TOC
KLM-3	85.2
2-2	24.9
2-2A	.776
2-3	5.47
2-4A	6.87
2-50B	157
2-51B	34.1
2-52B	2.03
2-145B	5.42
2-146B	6.50
DUP	6.96
2-148A	1.71
2-148B	2.66
2-149B	5.78
2-152A	5.69
2-152B	4.70
2-163B	6.40
2-164B	4.56
2-165B	6.87
2-166B	2.02
2-173B	1.77
DUP	1.67
2-264B	2.94
2-265B	2.62
MW2-149A	2.60
70	1.79
WSO 38 STD	4.61

WSO38 std t.v.=4.92



Ref: 97-LP50/vg

May 19, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SV*

Dear Don:

Attached are the results of 26 Tinker AFB samples submitted to MERSC as part of Service Request #SF-3-253 Mod. 3. The samples were received May 8 and analyzed May 9, 1997. The methods used for analysis were EPA Methods 353.1 for NO₂ and NO₃ and 350.1 for NH₃ and Waters capillary electrophoresis Method N-601 for Cl and SO₄. Quality assurance measures performed on this set of samples included spikes, duplicates, known AQC samples and blanks.

If you have any questions concerning these results, please feel free to contact me.

Sincerely,

Lynda Pennington
Lynda Pennington

xc: R.L. Cosby

G.B. Smith

J.L. Seeley *JL*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

<u>Sample</u>	<u>mg/L Cl⁻</u>	<u>mg/L SO₄⁼</u>	<u>mg/L NO₂⁻ + NO₃⁻(N)</u>	<u>mg/L NH₃</u>
2-2	361	<.5	<.05	<.05
2-2A	179	12.6	4.31	<.05
2-3	224	25.4	<.05	<.05
2-4A	195	18.0	3.69	<.05
2-4A Dup	-----	-----	-----	<.05
2-50B	188	<.5	<.05	<.05
2-51B	931	<.5	<.05	<.05
2-51B Dup	905	<.5	-----	-----
2-52B	15.9	13.2	<.05	<.05
2-52B Field Dup	15.6	12.7	<.05	<.05
70	123	78.9	2.38	<.05
70 Dup	-----	-----	2.40	-----
2-145B	94.0	197	2.79	<.05
2-146B	41.0	36.7	0.99	<.05
2-148A	134	21.1	2.35	<.05
2-148B	555	329	2.27	<.05
2-149A	NO SAMPLE RECEIVED		2.31	<.05
2-149B	168	30.6	17.0	<.05
2-152A	60.6	6.78	1.32	<.05
2-152A Dup	60.6	6.96	-----	-----
2-152B	938	251	3.13	<.05
2-152B Field Dup	941	248	3.28	<.05
2-163B	49.9	9.67	<.05	0.59
2-163B Dup	-----	-----	<.05	-----
2-164B	269	12.6	14.2	<.05
2-165B	156	46.6	1.33	<.05
2-165B Dup	-----	-----	-----	<.05
2-166B	119	155	5.01	<.05
2-173B	93.4	126	8.51	<.05
2-173B Dup	92.8	126	-----	-----
2-264	18.0	18.1	9.96	<.05
2-265	156	89.4	2.90	<.05
2-156A	176	21.2	NO SAMPLE RECEIVED	
Blank	<.5	<.5	<.05	<.05
AQC	34.9	42.7	2.06	10.2
AQC T.V.	34.8	44.0	2.10	10.0
Spike Rec.	100%	91%	98%	101%

TINKER AIR FORCE BASE
Field Data

Sample	Date	pH	Total Alkalinity mg/l C aCo ₃	Carbon Dioxide mg/l	Ferrous Iron	Hydrogen Sulfide mg/l
2-163B	5-5-95	6.9	560	344	2.0	<.1
2-149B	5-5-97	6.9	520	340	<.05	
2-149A	5-5-97	9.5	184	4	<.05	
2-164B	5-5-97	6.9	475	204	<.05	
2-264B	5-5-97	7.1	555	---	<.05	
2-166B	5-6-97	7.2	395	230	<.05	
2-165B	5-6-97	6.9	510	300	<.05	
2-145B	5-6-97	7.2	540	230	<.05	
2-265B	5-6-97	7.1	390	---	<.05	
2-173B	5-6-97	6.9	433	185	<.05	
70	5-6-97	7.2	425	230	<.05	
2-146B	5-6-97	7.1	565	240	<.05	
2-152A	5-6-97	7.4	287	170	<.05	
2-148B	5-6-97	7-1	372	230	<.05	
2-152B	5-6-97	7-2	431	250	<.05	
2-148A	5-6-97	7.3	302	186	<.05	
2-4A	5-6-97	7.2	348	226	.4	<.1
2-51B	5-6-97	7.0	632	440	4.0	<.1
2-2B	5-7-97	7.2	335	110	<.05	
2-52B	5-7-97	7.4	275	104	.2	.1
2-2	5-7-97	7.0	678	180	3.7	<.1
2-3	5-7-97	7.1	535	330	2.1	<.1
2-50B	5-7-97	7.1	539	282	1.9	.5

TINKER AIR FORCE BASE
FIELD DATA

Sample	Date	Redox	pH	Cond	Hydrogen Sulfide mg/l	Carbon Dioxide mg/l	Alkalinity Total mg/CaCO ₃	Ferrous Iron
RW-13	4-23-97	-113	7.0	2050	.1	432	625	7.4
RW-12	4-23-97	15	7.0	1540	<.1	314	520	.8
RW-10	4-23-97	>5	6.9	2240	<.1	400	526	<.05
RW-11	4-23-97	-36	7.1	1660	---	300	525	1.3



Ref: 97-DF25

May 19, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

As requested in Service Request SF-3-253, GC/MS analysis for semi-volatile compounds was done on one water sample from Tinker AFB. This sample was labeled: RE-13. The sample was received on April 24, 1997. Base/neutral extractions of the water sample was completed on April 25, 1997. The GC/MS analysis of the sample was completed on May 14, 1997. EPA method 8270A with the modifications listed below was used for this analysis.

The liquid/liquid extraction was done by Brad Scroggins according to the standard operating procedure for base/neutral extraction. After the pH of one liter of each water sample was adjusted to slightly above 11.0 with 10N NaOH, the water sample was extracted three times with 60 ml of methylene chloride. After the methylene chloride fraction was passed through a Na_2SO_4 column, it was concentrated using the Savant Evaporation Station to a final volume near 1.0 ml.

For quantitative analysis, 5 μl of a 400 ppm internal standard mixture of benzene- d_6 , toluene- d_8 , ethylbenzene- d_{10} , p-xylene- d_{10} , o-xylene- d_{10} , p-dichlorobenzene- d_2 , naphthalene- d_8 , acenaphthene- d_{10} , phenanthrene- d_{10} , chrysene- d_{12} and perylene- d_{12} in methylene chloride was added to 200 μl of each standard or sample. The Hewlett Packard 7673 autoinjector delivered 1.0 μl of the methylene chloride extract with a split flow of 20 ml/min to a 60 meter, 0.25 mm DB5-MS capillary column with 0.5 μm film thickness. The column was temperature programmed from -10°C to 60°C at $30^\circ\text{C}/\text{min}$ and then to 300°C at $6^\circ\text{C}/\text{min}$. The Finnigan 4615 GC/MS was scanned from 42 to 650 m/z in 0.5 sec.

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Chromatograms of the extract of the sample and an extraction blank are attached. Peaks which were tentatively identified in the extract include: Prometon, an isomer of Prometon and numerous amides. The mass spectral library search and information about Prometon from the Farm Chemicals Handbook are attached. A semi-quantitative estimate of the concentration of Prometon is 1 ppb. This is based on relative peak areas of Prometon and the internal standard, phenanthrene which was present in the extract at 10 ppm.

If you should have any questions, please feel free to contact me.

Sincerely,

Dennis D. Fine

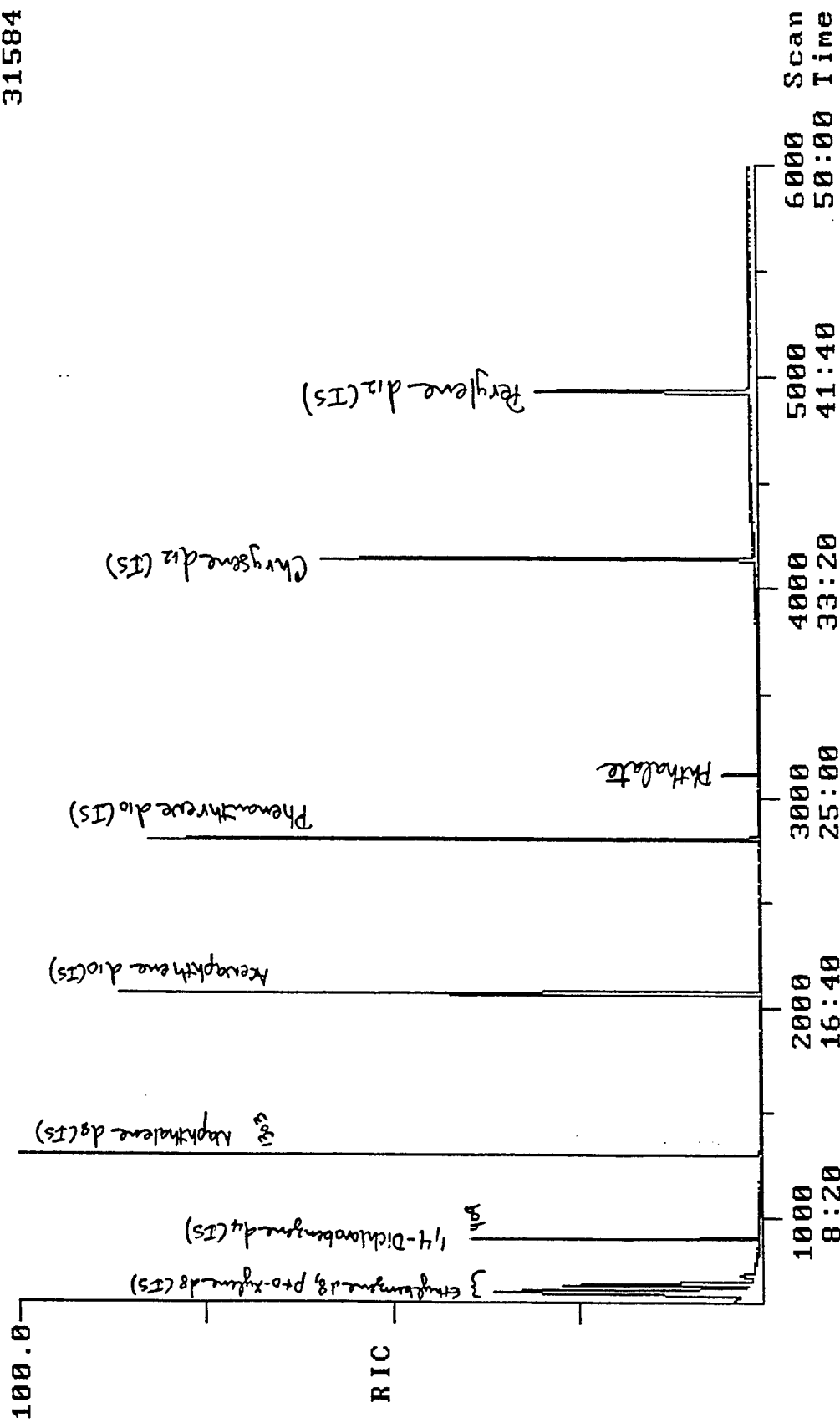
Dennis D. Fine

xc: J. Seeley *JS*
G. Smith
R. Cosby
D. Fine
J. Wilson

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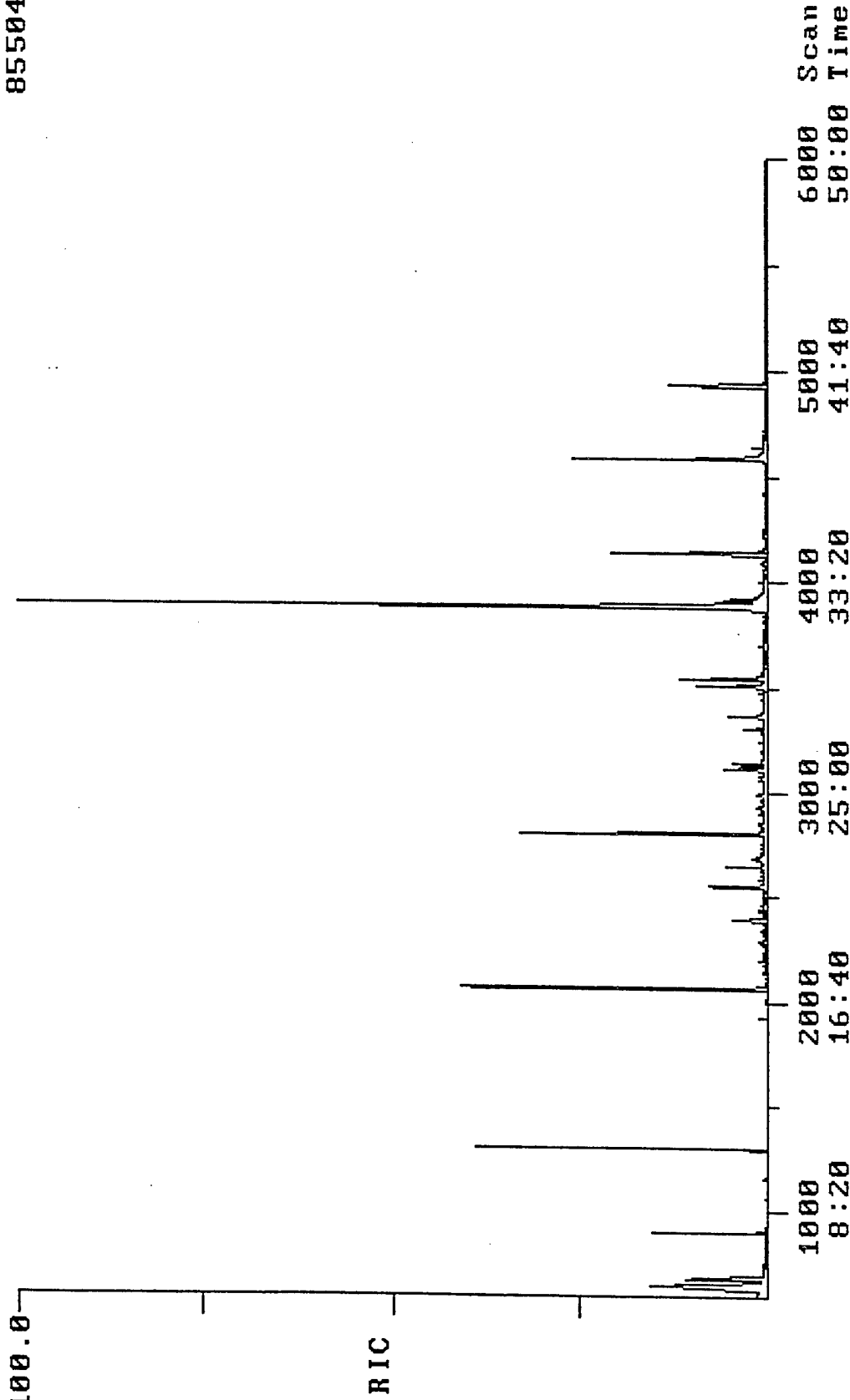
RIC
05/14/97 18:42:00 Data: 112MTHBLK #1 Scans 600 to 6000
Cal: CAL57 #3
Sample: 1UL SEMIVOL EXT LIQ/LIQ METHOD BLANK
Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
100 0- 31584.

```



CHRO:

RIC 05/14/97 19:46:00 Data: 113RW13 #1 Scans 600 to 6000
05/14/97 19:46:00 Cali: CAL57 #3
Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
100.0 85504.



CHRO:

Scans 600 to 1000

Data: 113RW13 #1

Cal: CAL57 #3

Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13

Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25

Range: G 1.6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3

100.0 658 692 837 940 1000 Scan 5:00 5:50 6:40 7:30 8:20 Time

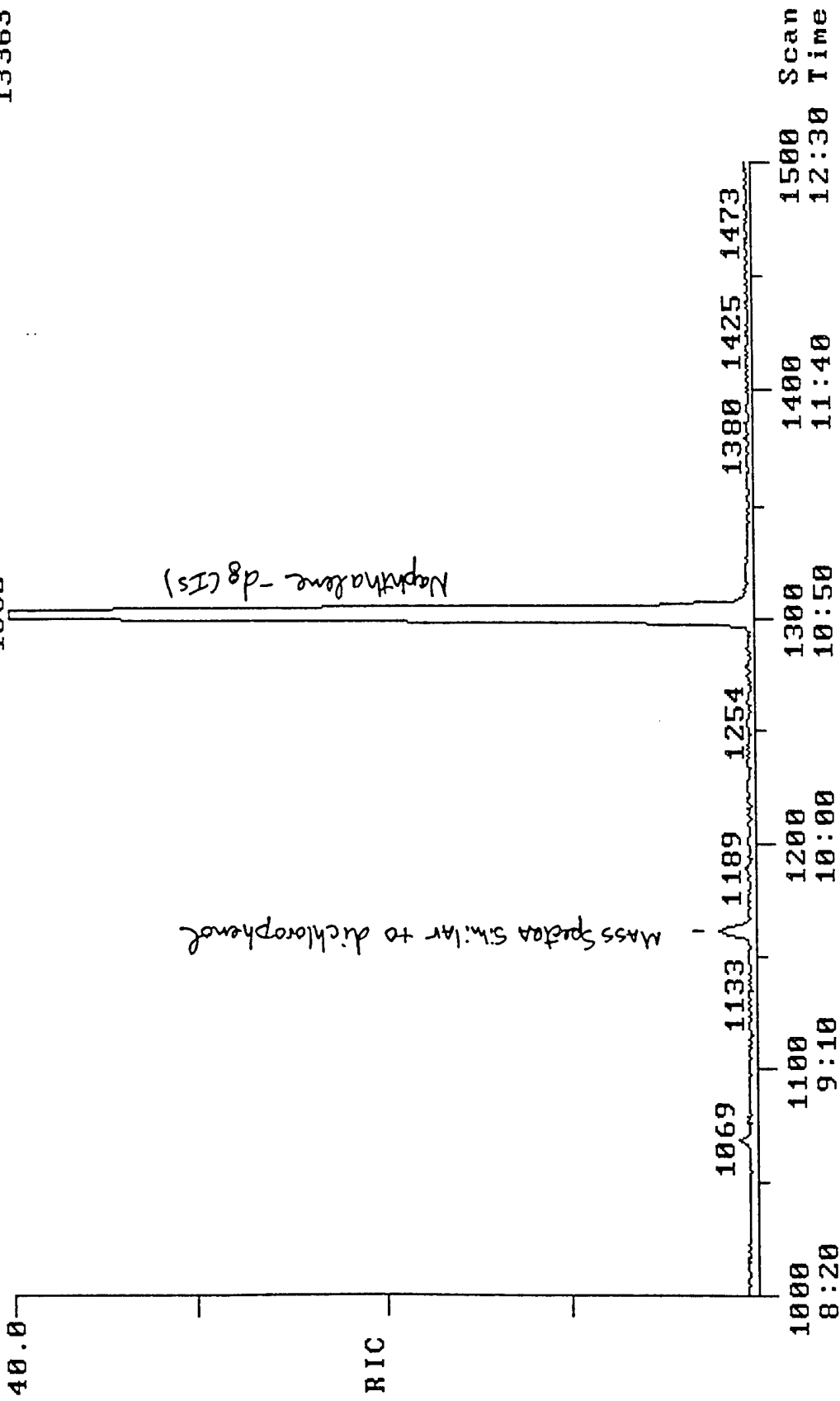
13456.

Deactivated
ethylbenzene
+ p-o-xylene
(Is)
692
837
940
1,4-Dichlorobenzene d4 (Is)

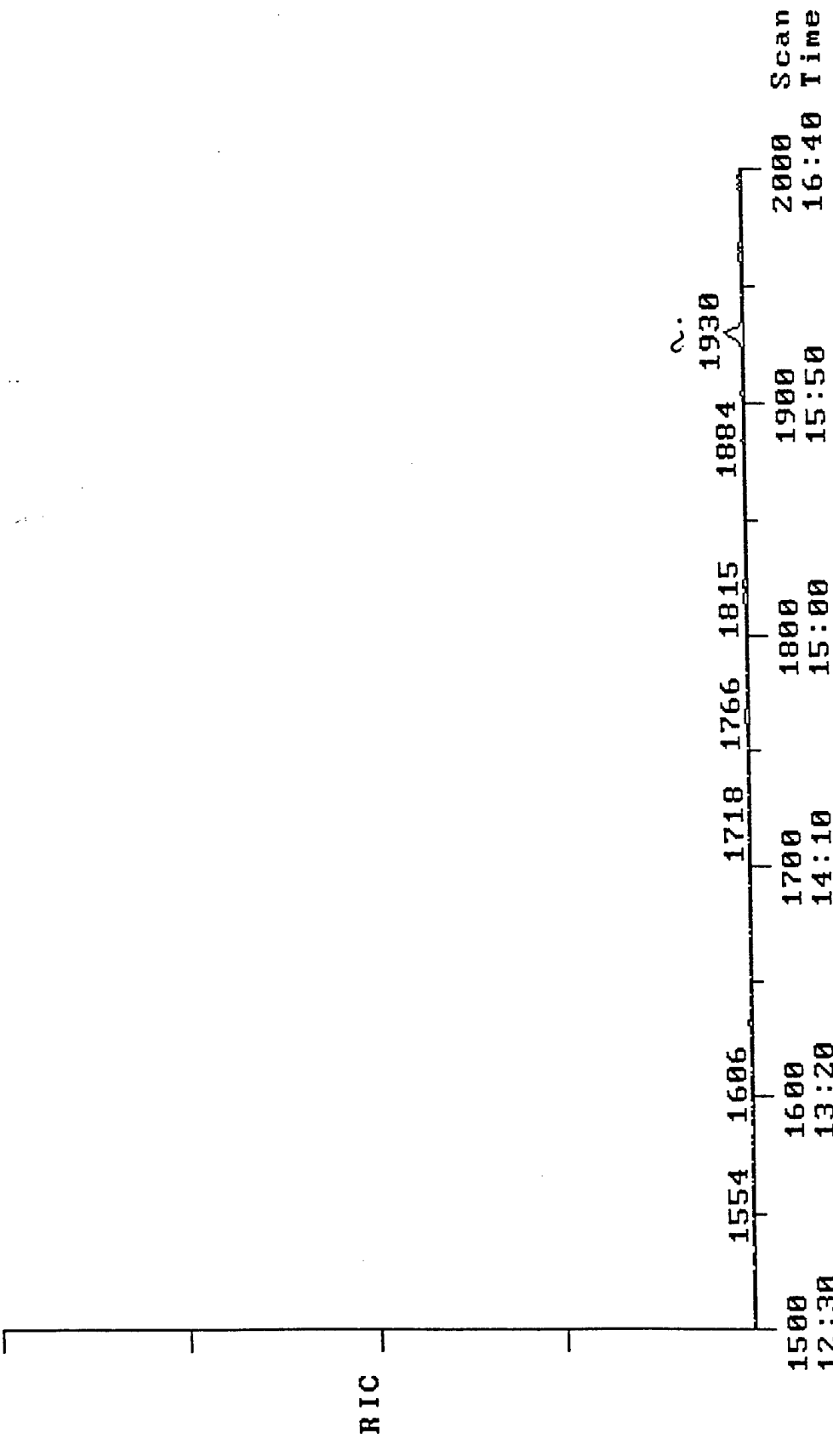
RIC

CHRO:

RIC
 05/14/97 19:46:00
 Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
 Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
 Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 40.0
 Data: 113RW13 #4580
 Cali: CAL57 #3
 Scans 1000 to 1500
 1302
 13363.



RIC
 05/14/97 19:46:00
 Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
 Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
 Range: G 1.6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 Data: 113RW13 #1
 Cali: CAL57 #3
 Scans 1500 to 2000
 33434.



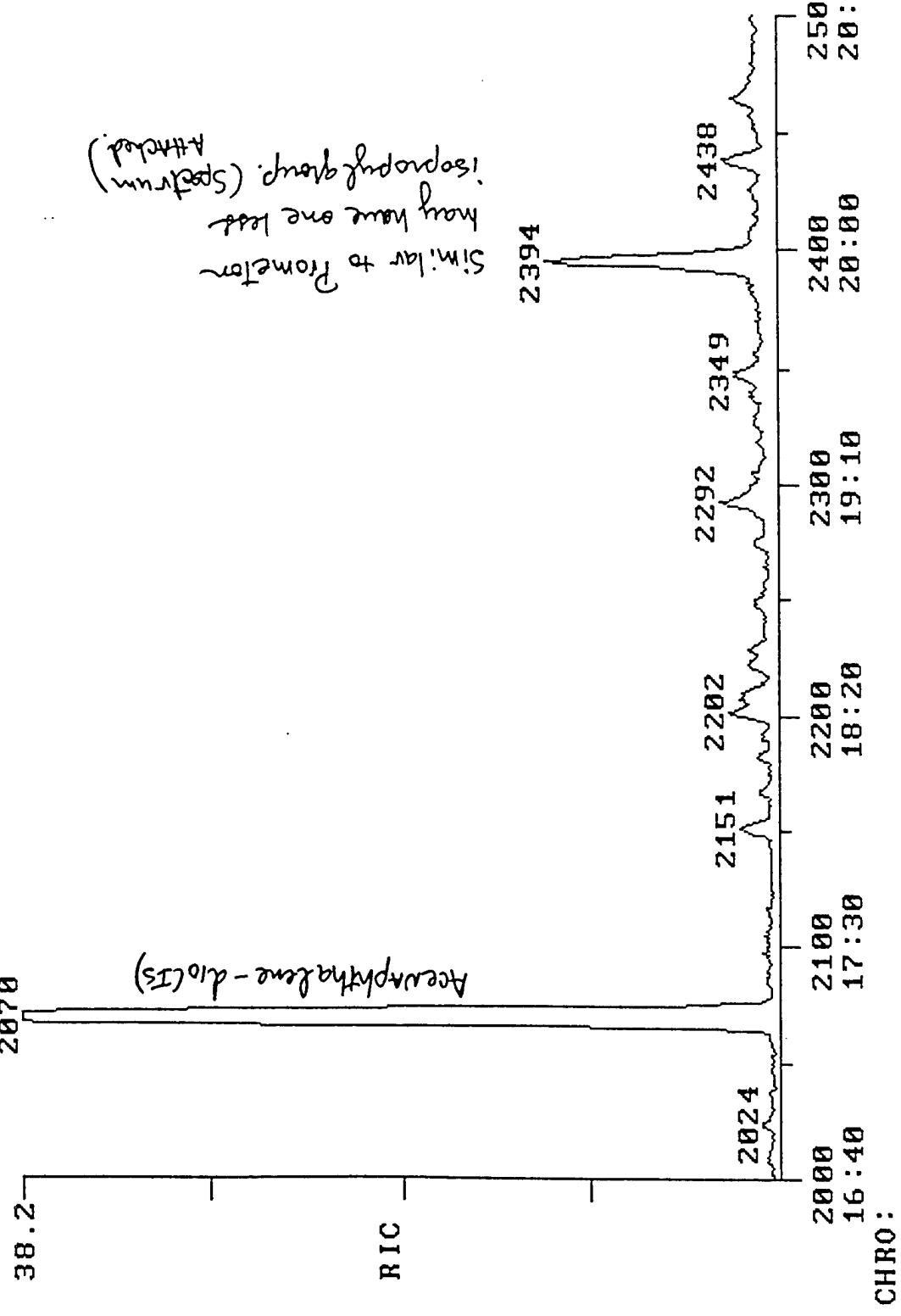
CHRO:

RIC
 05/14/97 19:46:00
 Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
 Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
 Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 38.2 2070 13454.

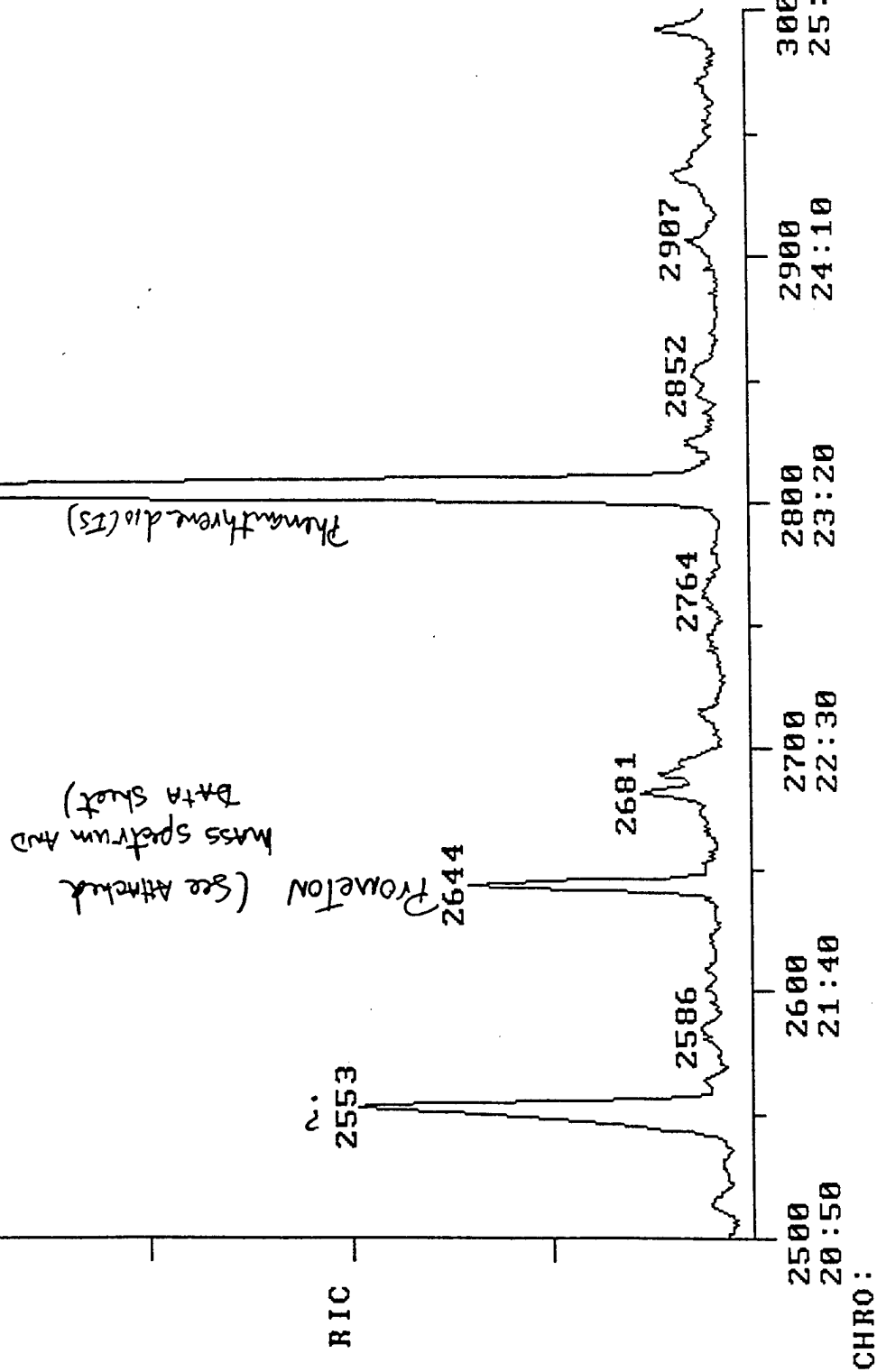
Data: 113RW13 #4580
 Cali: CAL57 #3

Scans 2000 to 2500

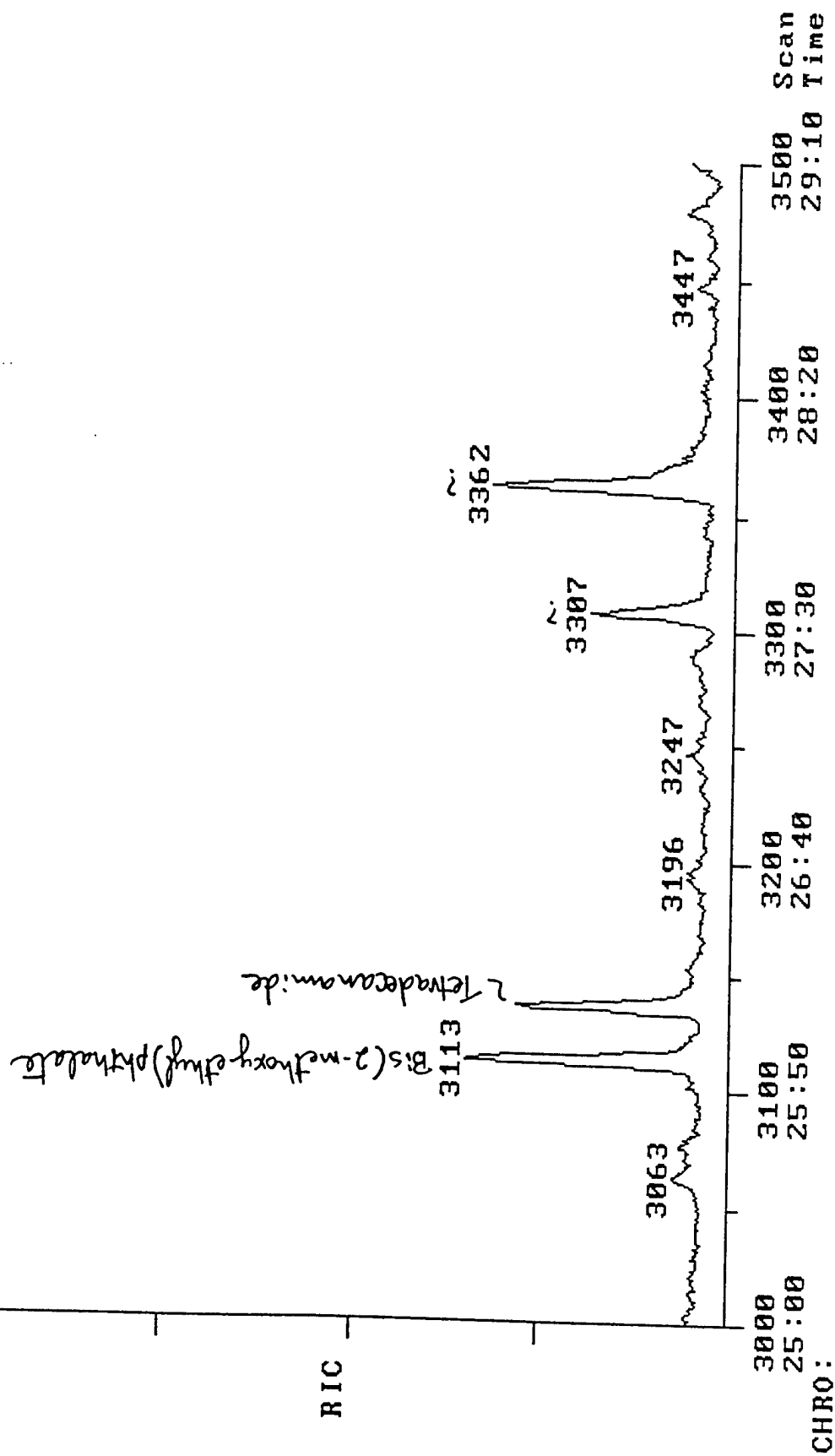
Similar to Prometon
 may have one less
 isopropyl group (Spectrum
 Attached)



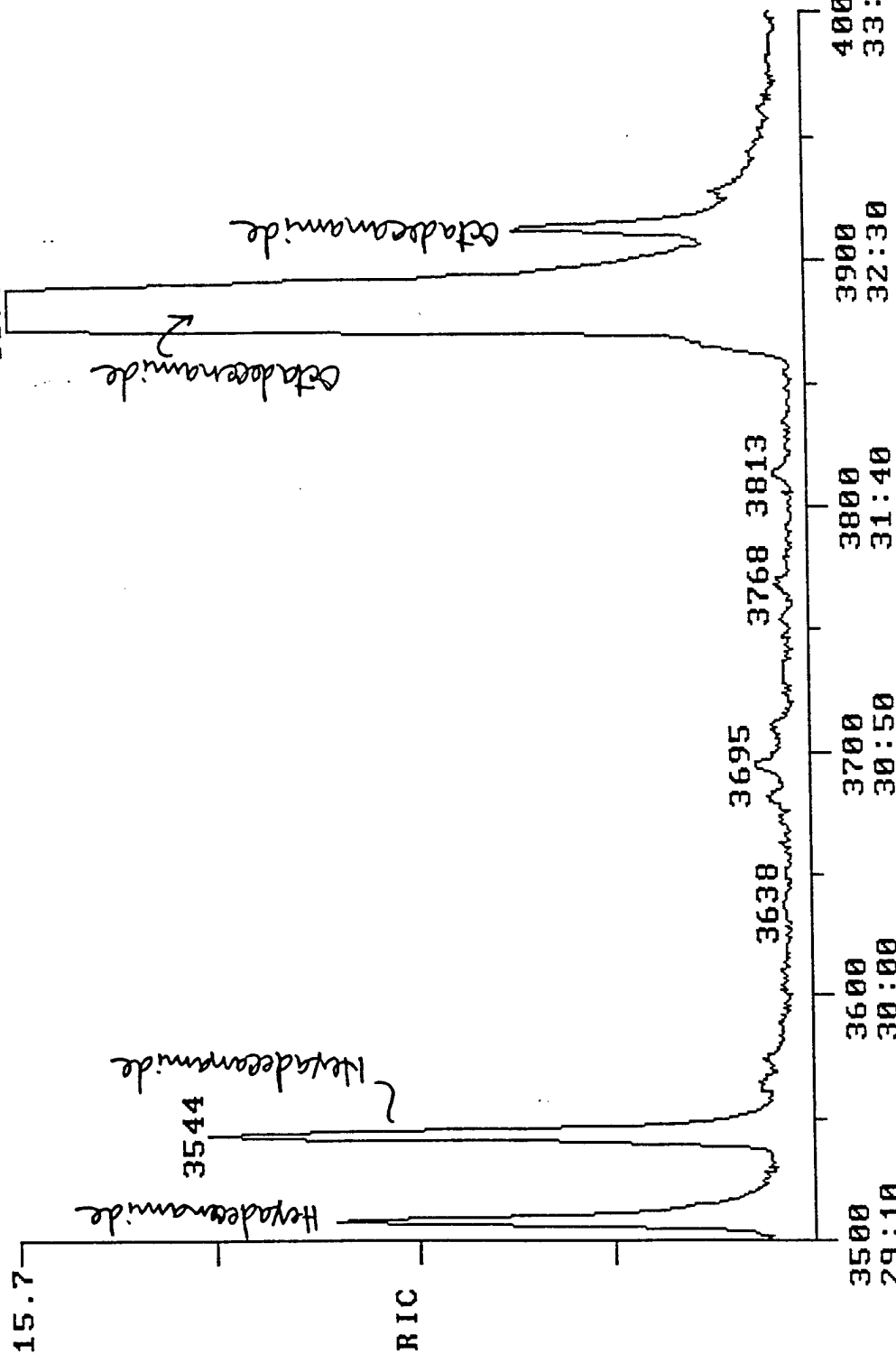
RIC
 05/14/97 19:46:00
 Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
 Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
 Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 47.7
 Data: 113RW13 #1
 Cali: CAL57 #3
 Scans 2500 to 3000
 2805
 13457.



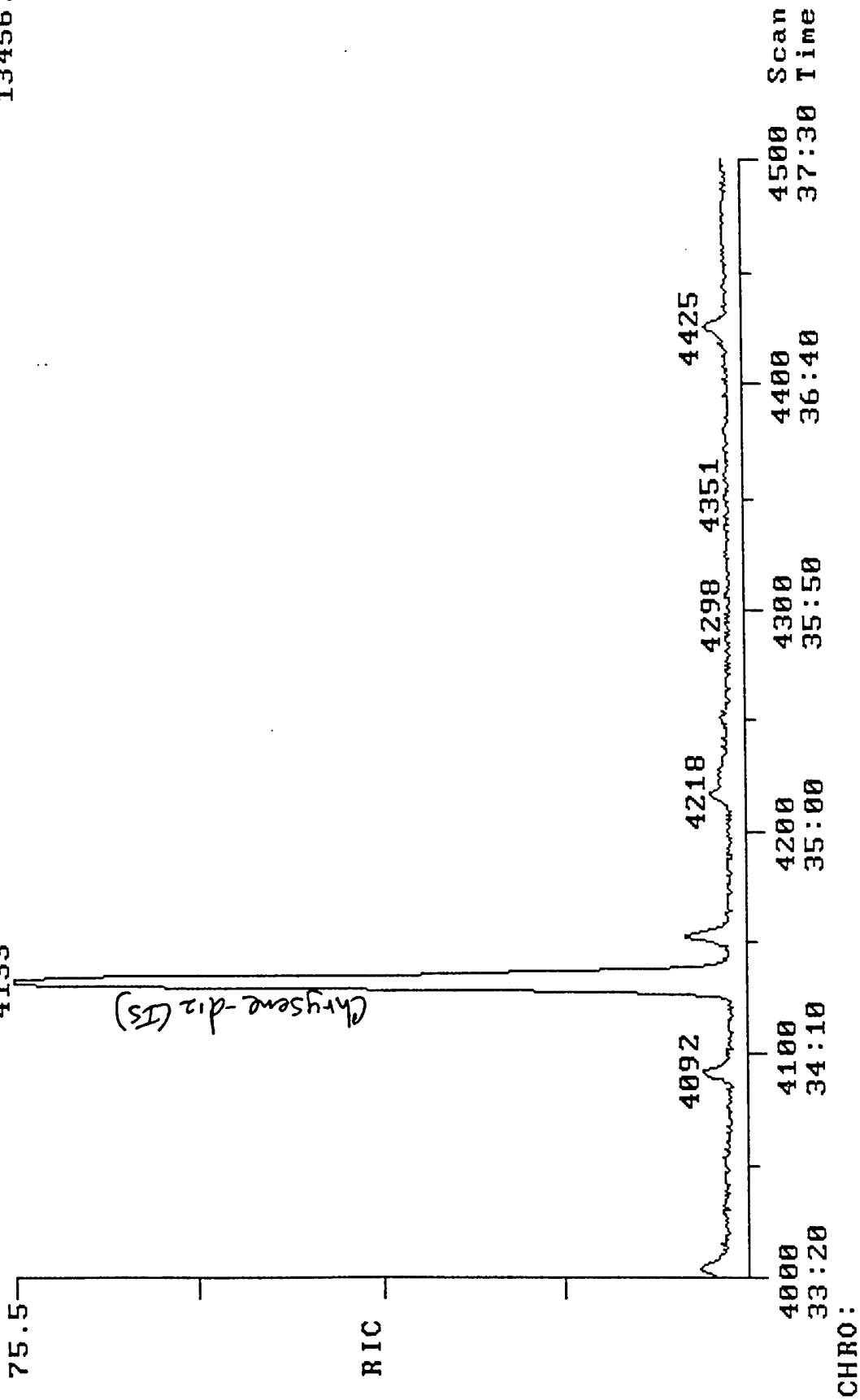
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 05/14/97 19:46:00
 Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
 Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
 Range: G 1.6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 284.4
 Data: 113RW13 #3136 Scans 3000 to 3500
 Cali: CAL57 #3
 14221.



RIC
05/14/97 19:46:00
Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
Data: 113RW13 #4580
Cal: CAL57 #3
Scans 3500 to 4000



RIC
 05/14/97 19:46:00
 Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
 Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
 Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 75.5
 Data: 113RW13 #1
 Cali: CAL57 #3
 Scans 4000 to 4500
 13456.



RIC
05/14/97 19:46:00
Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
100.0 4580

Data: 113RW13 #3913
Cali: CAL57 #3

Scans 4500 to 5000

C₂₂ Amide

Perylene d₁₂ (I.S.)

RIC

4637

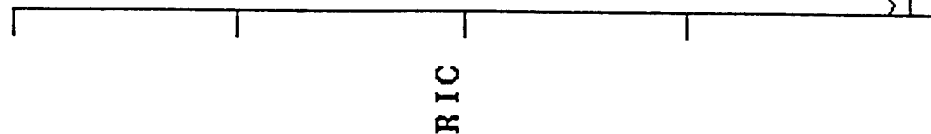
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4895

4930

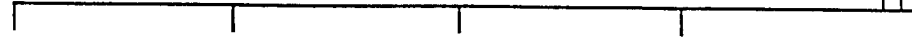
CHRO:
4500 37:30
4600 38:20
4700 39:10
4800 40:00
4900 40:50
5000 41:40 Scan Time

RIC
 05/14/97 19:46:00
 Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
 Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
 Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 Scans 5000 to 5500
 Data: 113RW13 #1
 Cali: CAL57 #3
 13448.

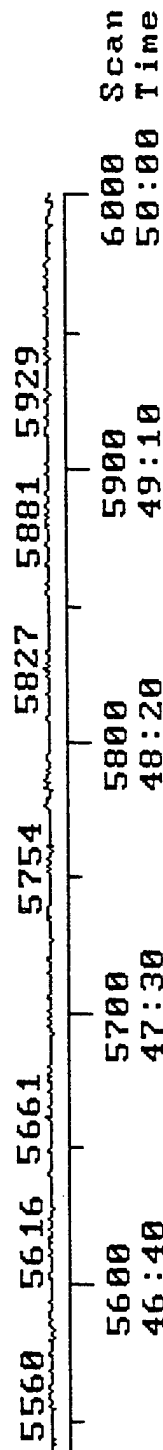


5000	5100	5135	5192	5294	5352	5403	5477	5500
41:40	42:30		43:20	44:10		45:00		45:50
Scan								Time

RIC
 05/14/97 19:46:00
 Sample: 1UL LIQ/LIQ EXTR TINKER AFB SAMPLE RE-13
 Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
 Range: G 1,6000 Label: N 0, 4.0 Quan: A 0, 1.0 J 0 Base: U 20, 3
 Scans 5500 to 6000
 Data: 113RW13 #1
 Cali: CAL57 #3
 13372.



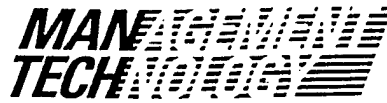
RIC



5500
45:50

6000 Scan
50:00 Time

CHRO:



Ref: 97-DF28

May 21, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift ↙✓

Dear Don:

As requested in Service Request SF-3-253, GC/MS analysis for phenols and aliphatic/aromatic acids was done on three groundwater sample from Tinker AFB. These sample were labeled 2-51B, 2-3 and 2-163B. These samples were received on May 8, 1997. Amy Zhao extracted and derivatized the samples on May 16, 1997. The extracts were analyzed by GC/MS on May 20, 1997. RSKERL SOP 177 was used for the extraction, derivatization and GC/MS analysis of the samples.

Table I provides the concentrations of the phenols and aliphatic/aromatic acids found in samples. Derivative and extraction blanks and recoveries of 50 ppb blank spiked samples and 100 ppb check standards are also included in the table.

If you should have any questions, please feel free to contact me.

Sincerely,

Dennis D. Fine

xc: J. Seeley ✕
G. Smith 67
R. Cosby
J. Wilson
D. Fine

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

**Table I. Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids
In Water Samples from Tinker AFB Service Request SF-3-353.**

Concentration ppb							
File Name: 942251B.TXT 94323.TXT 9442163B.TXT 924MTHBL.TX 941EXTBL.TXT 940EXTRE.TXT 939100AA.TXT							
Compound	Sample Name:	2-51B	2-3	2-163B	Method Blank	Extraction Blank	50 ppb Extr. % Recovery
							100 ppb Std. % Recovery
Propanoic Acid		3	3	***	***	10	94
2-Methylpropanoic Acid		***	4	***	***	***	93
Trimethylacetic Acid		***	***	***	***	***	94
Butyric Acid		***	4	***	***	***	89
2-Methylbutyric Acid		***	3	***	***	***	94
3-Methylbutyric Acid		***	12	***	***	***	91
3,3-Dimethylpropanoic Acid		***	4	***	*	***	90
Pentanoic Acid		***	***	***	***	4	91
2,3-Dimethylbutyric Acid		***	***	***	***	***	91
2-Ethylbutyric Acid		*	***	***	*	***	87
2-Methylpentanoic Acid		***	***	***	***	***	89
3-Methylpentanoic Acid		***	4	***	***	***	89
4-Methylpentanoic Acid		***	*	***	***	***	91
Hexanoic Acid		5	3	4	***	8	90
2-Methylhexanoic Acid		***	***	*	***	***	88
Phenol		5	15	***	***	***	91
Cyclopentanecarboxylic Acid		***	18	*	*	***	92
5-Methylhexanoic Acid		*	***	***	*	***	88
o-Cresol		***	9	***	***	*	94
2-Ethylhexanoic Acid		47	32	28	***	***	92
Heptanoic Acid		***	***	***	***	5	89
m-Cresol		***	5	***	***	*	94
p-Cresol		***	8	*	***	*	95
1-Cyclopentene-1-carboxylic Acid		***	***	*	***	***	91
o-Ethylphenol		***	7	*	*	*	93
Cyclopentaneacetic Acid		***	***	***	*	***	91
2,6-Dimethylphenol		***	12	*	*	*	97
2,5-Dimethylphenol		***	9	*	*	*	90
Cyclohexanecarboxylic Acid		***	7	***	***	***	90
3-Cyclohexene-1-carboxylic Acid		***	***	*	*	***	90
2,4-Dimethylphenol		*	6	*	*	*	98
3,5-Dimethylphenol & m-Ethylphenol		3	6	*	*	*	97
Octanoic Acid		3	***	***	***	8	91
2,3-Dimethylphenol		***	4	*	*	*	95
p-Ethylphenol		*	***	*	*	*	93
Benzoic Acid		11	23	5	***	67	92
3,4-Dimethylphenol		***	***	*	*	*	95
m-Methylbenzoic Acid		***	27	*	*	*	91
1-Cyclohexene-1-carboxylic Acid		***	*	*	*	***	92
Cyclohexaneacetic Acid		***	***	*	*	*	93
2-Phenylpropanoic Acid		***	***	*	*	*	93
o-Methylbenzoic Acid		***	9	*	***	***	94
Phenylacetic Acid		***	3	***	***	***	93
m-Tolylacetic Acid		3	7	*	*	*	106
o-Tolylacetic Acid		***	***	***	*	***	110
2,6-Dimethylbenzoic Acid		***	***	***	***	***	111
p-Tolylacetic Acid		8	6	*	*	*	110
p-Methylbenzoic Acid		***	7	*	***	***	91
3-Phenylpropanoic Acid		*	***	3	*	*	92
2,5-Dimethylbenzoic Acid		***	5	*	*	*	93
Decanoic Acid		***	***	***	***	5	90
2,4-Dimethylbenzoic Acid		33	9	*	***	*	93
3,5-Dimethylbenzoic Acid		*	4	*	***	***	90
2,3-Dimethylbenzoic Acid		***	4	*	***	*	93
4-Ethylbenzoic Acid		***	3	*	***	*	92
2,4,6-Trimethylbenzoic Acid		53	9	***	***	***	95
3,4-Dimethylbenzoic Acid		***	10	*	***	*	91
2,4,5-Trimethylbenzoic Acid		12	4	*	***	*	92

*** indicates concentration of extract was below lowest calibration standard (3 ppb)
* indicates not found.

APPENDIX D

MODEL INPUT PARAMETERS, RELATED CALCULATIONS, AND SENSITIVITY ANALYSIS RESULTS

MODFLOW Input Form: Area A

MODEL RUN : PL-CAL8
 FLOW RMS: 0.5083
 TCE RMS: 8.09
 HDS FILE: INPUT.HDS

SOLVER: WHS
 ADVECTION: Modified MOC w/ 1st Order Euler

GRID (see map)

# rows	<u>40</u>	# layers	<u>1</u>
# columns	<u>62</u>	top of layer elev.	<u>1240 ft. msl</u>
source area cell size	<u>10-20 sq ft</u>	bottom of layer elev.	<u>1205 ft. msl</u>
total area of model	<u>930,160 sq ft</u>	grid thickness	<u>35 feet</u>
# cells	<u>2480</u>	total size	<u>770' X 1208'</u>

PUMPING WELL (see map)

Grid Coordinates

Well Name	Row	Column
RW-1	23	48
RW-2	23	51
RW-3	24	50

Pumping Schedule (yr)

Pumping Rate (gpm)

FROM:	TO:	RW-1	RW-2	RW-3
0	5	0	0	0
5	10	0	0	0
10	15	0	0	0
20	25	0	0	0
25	30	0	0	0
30	35	0	0	0
35	40	0	0	0
40	45	0	0	0
45	50	0	0	0
50	50.5	0	0	0
50.5	52	-0.1	-5	-0.5
52	53	-0.1	-5	-0.5
53	53.5	-0.1	-5	-0.5
53.5	53.75	-0.1	-5	-0.5
53.75	54.6	-0.1	-5	-0.5
54.6	55.3	0	0	0

CONDUCTIVITY (see map)

Zone #	K _x	K _y	K _z	Color
1	1.0	1.0	0.1	white
2	0.1	0.1	0.01	blue
3	5.0	5.0	0.5	green
4	10.0	10.0	1.0	red/teal
5	15	15	1.5	purple

STORAGE

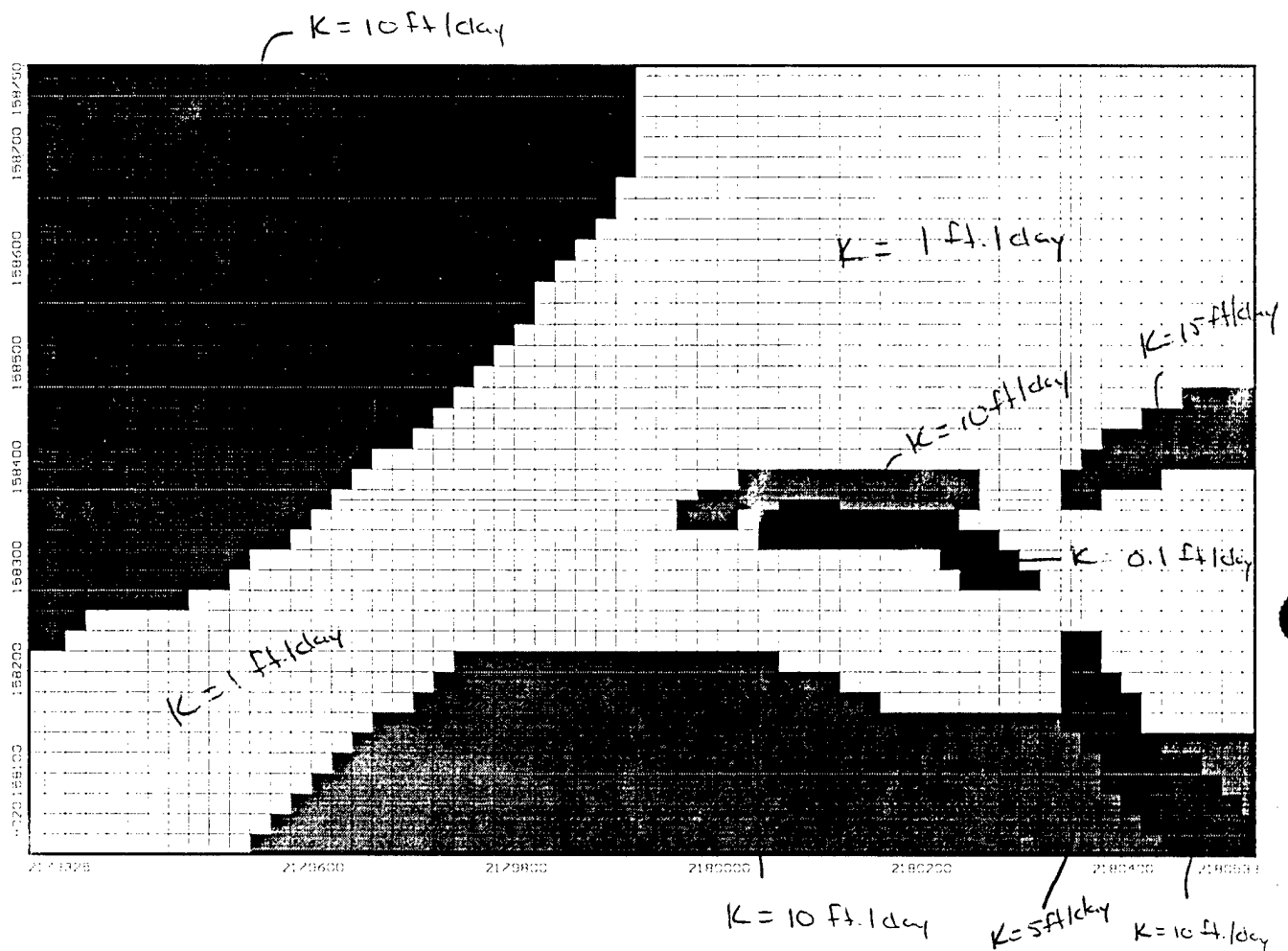
S _s	S _y	n _e	n _{total}
.0004 ft-1	0.2	0.2	0.3

-

Source Terms for 3% Weathering

Time	Conc. - A		Conc. - B	
55	1100		250	
56	1067		243	
57	1035		235	
58	1004		228	
59	974		221	
60	945	1005	215	228
61	916		208	
62	889		202	
63	862		196	
64	836		190	
65	811	863	184	196
66	787		179	
67	763		173	
68	740		168	
69	718		163	
70	697	741	158	168
71	676		154	
72	655		149	
73	636		144	
74	617		140	
75	598	636	136	145
76	580		132	
77	563		128	
78	546		124	
79	530		120	
80	514	546	117	124
81	498		113	
82	483		110	
83	469		107	
84	455		103	
85	441	469	100	107
86	428		97	
87	415		94	
88	403		91	
89	391		89	
90	379	403	86	92
91	367		84	
92	356		81	
93	346		79	
94	335		76	
95	325	346	74	79
96	316		72	
97	306		70	
98	297		67	
99	288		65	
100	279	297	63	68
101	271		62	
102	263		60	
103	255		58	
104	247		56	
105	240	255	55	58

HYDRAULIC CONDUCTIVITY

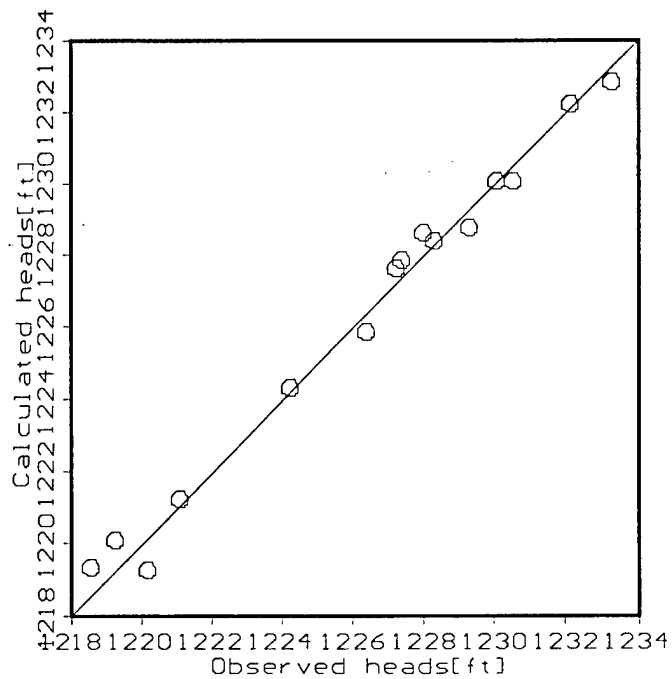


Parsons Eng Science, Inc - Denver, CO
 Project: Tinker AFB Area A
 Description: Model PL-CALB.VMF
 Modeller: Conductivity
 30 Mar 99

Visual MODFLOW v.2.50, (C) 1995-1997
 Waterloo Hydrogeologic Software
 NC: 62 NR: 40 NL: 1
 Current Layer: 1

FLOW CALIBRATION DATA
AREA A RNA TS
TINKER AFB, OKLAHOMA

Observation Name	Observed Heads (feet)	Calculated Heads (feet)	Residual Residual
2-2	1230.09	1230.06	0.03
2-3	1228.36	1228.33	0.03
2-4	1232.78	1233.28	-0.50
2-50B	1228.59	1228.02	0.57
2-51B	1232.23	1232.16	0.07
2-52B	1228.75	1229.32	-0.57
2-146B	1230.07	1230.54	-0.47
2-149B	1219.35	1218.60	0.75
2-163B	1224.31	1224.26	0.05
2-164B	1225.85	1226.37	-0.52
2-165B	1220.11	1219.23	0.88
2-166B	1227.58	1227.24	0.34
2-173B	1227.85	1227.35	0.50
2-264B	1219.29	1220.16	-0.87
2-265B	1221.24	1221.10	0.14



Period: 17
Step: 10

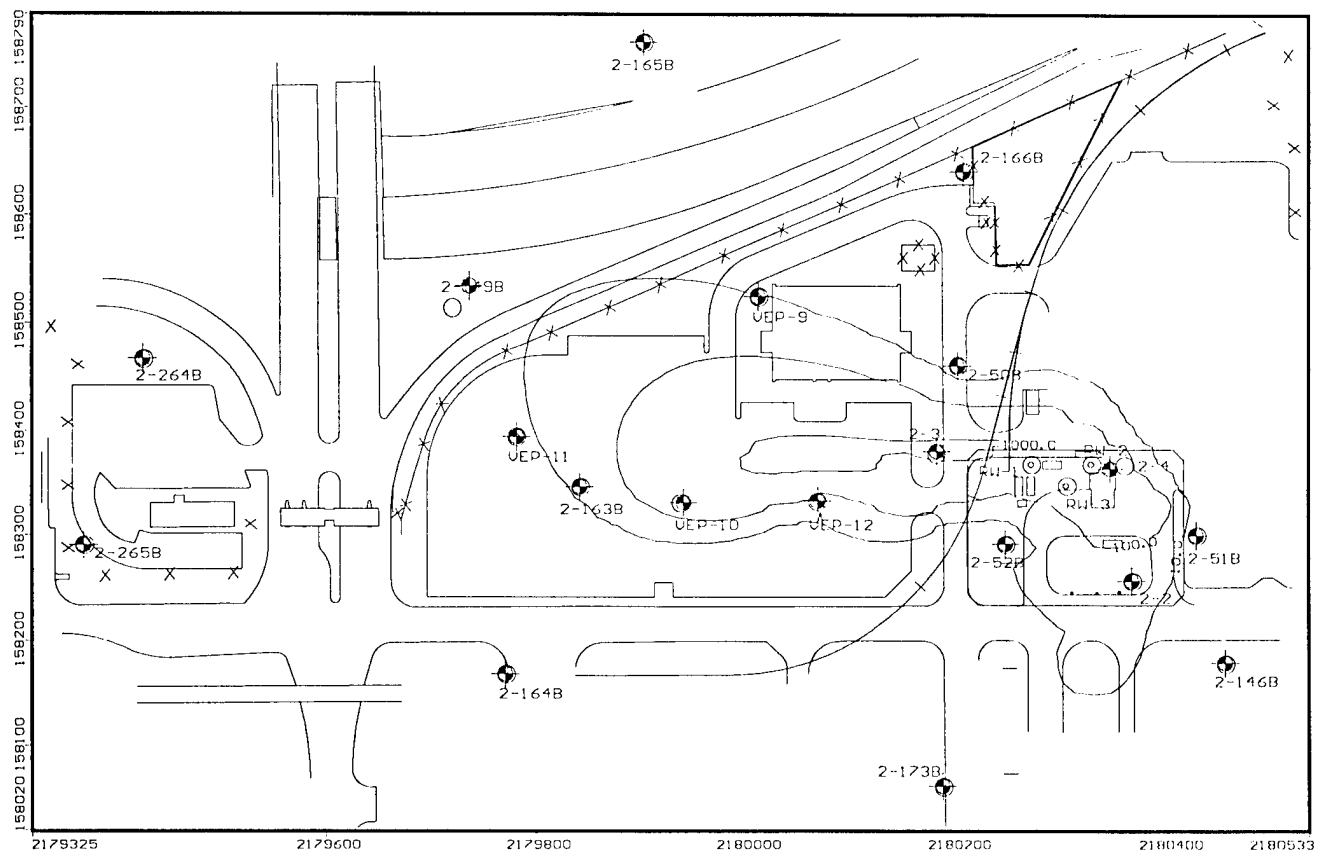
Mean error: 0.0297214

Mean abs. err: 0.419217

RMS error: 0.508348

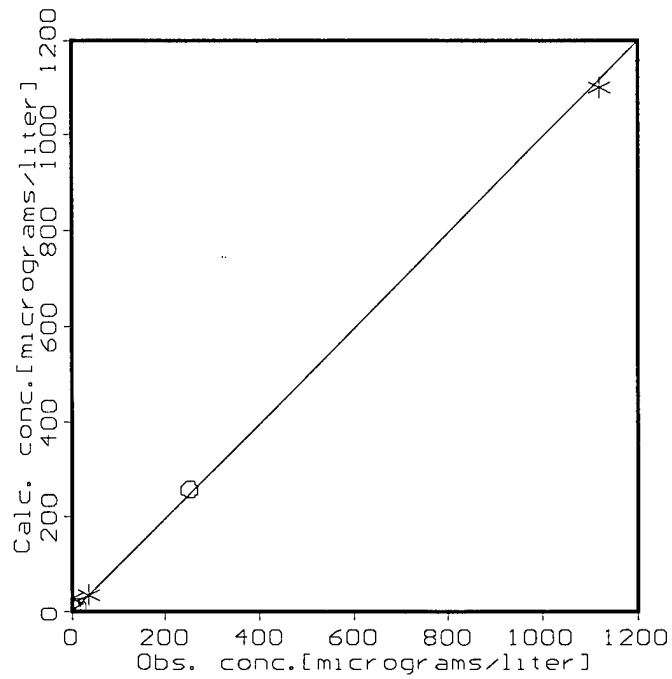
Parsons Eng Science, Inc - Denver, CO
Project: Tinker AFB Area A
Description: Model PL-CAL8.VMF
Modeller: Flow Calibration
20 Dec 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 62 NR: 40 NL: 1
Current Layer: 1



Parsons Eng Science, Inc - Denver, CO
 Project: Tinker AFB Area A
 Description: Model PL-CALB.VMF
 Modeller: Calibrated TCE Plume
 30 Mar 99

Visual MODFLOW v.2.50, (C) 1995-1997
 Waterloo Hydrogeologic Software
 NC: 62 NR: 40 NL: 1
 Current Layer: 1



Period: 17

Step: 10

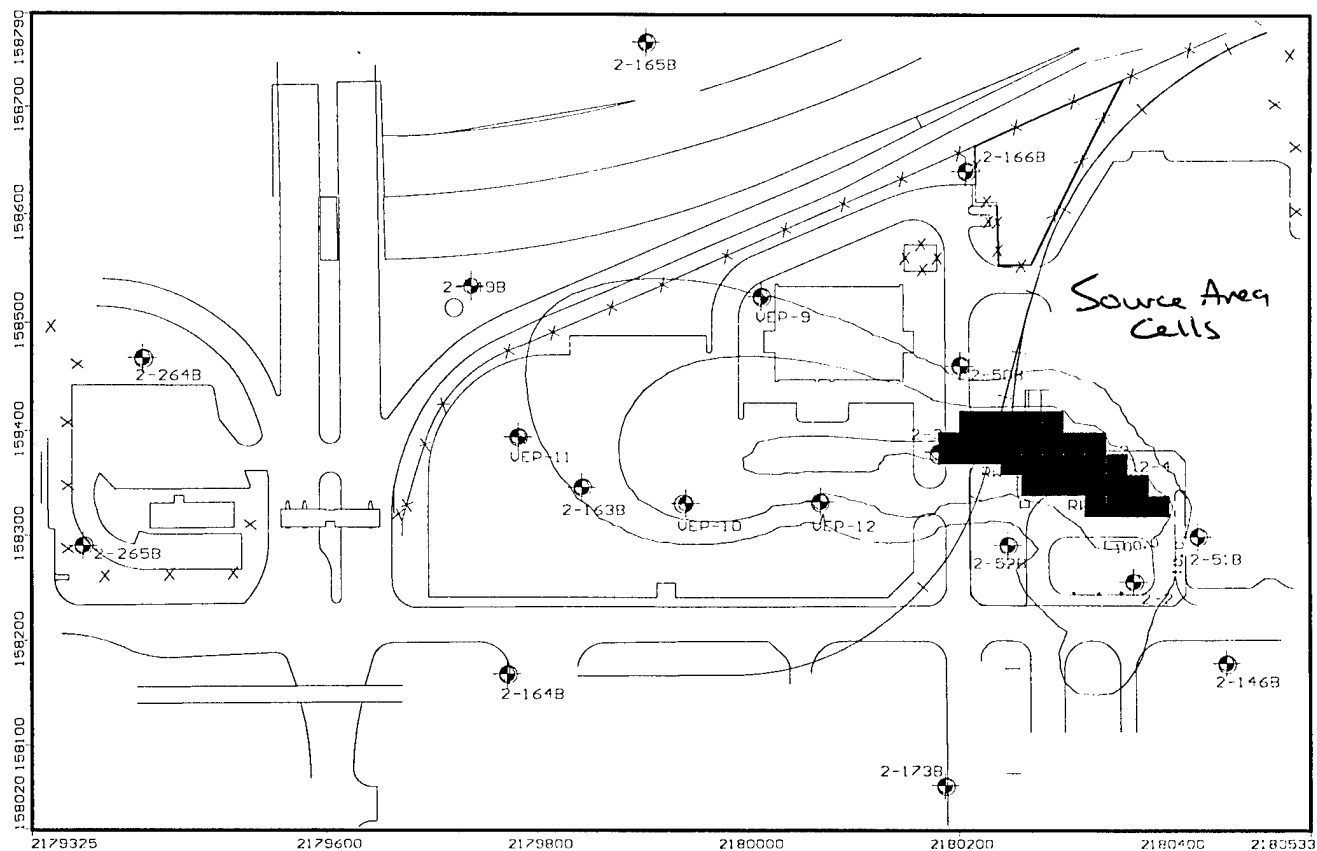
Mean error: 1.21813

Mean abs. err: 4.40757

RMS error: 8.09088

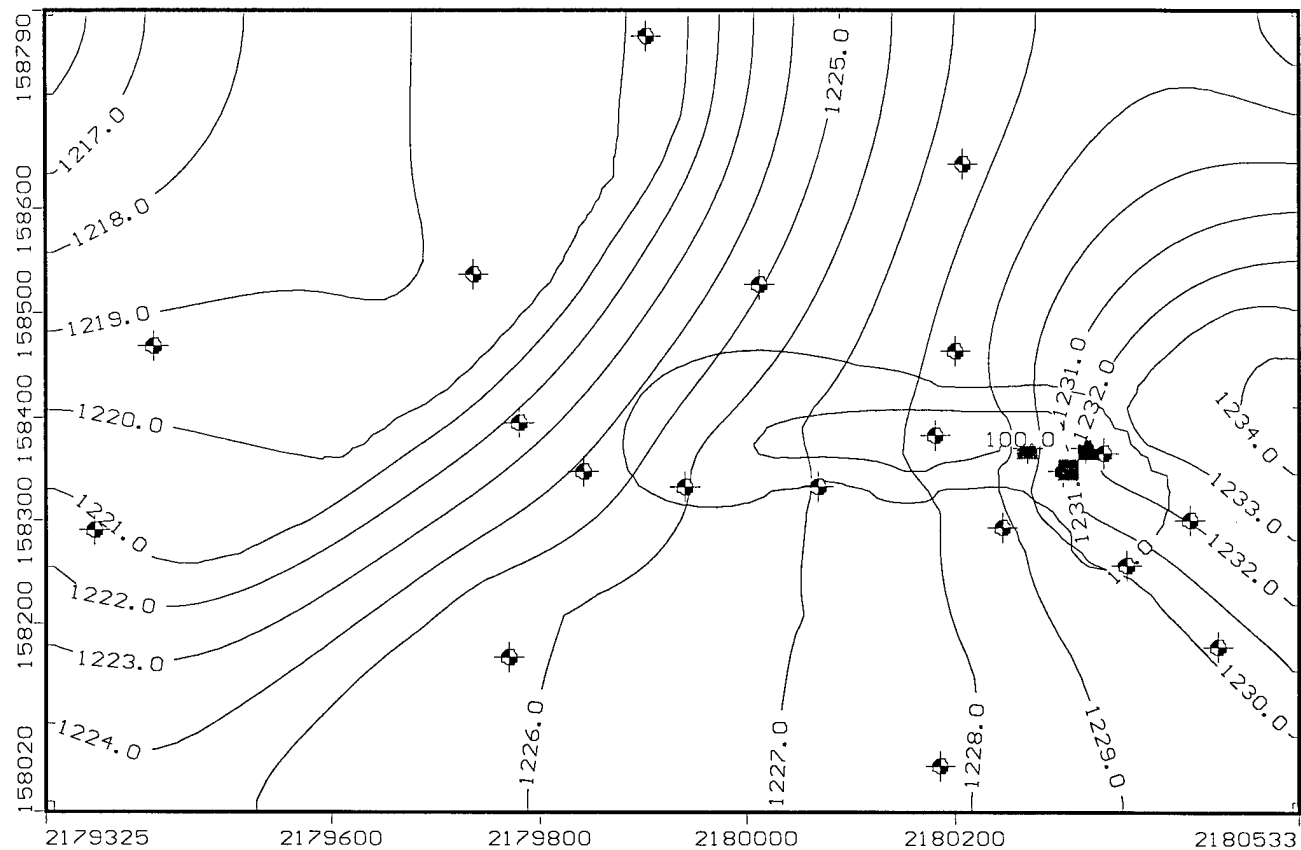
Parsons Eng Science, Inc - Denver, CO
 Project: Tinker AFB Area A
 Description: Model PL-CALB.VMF
 Modeller: TCE Calibration
 6 Apr 99

Visual MODFLOW v.2.50, (C) 1995-1997
 Waterloo Hydrogeologic Software
 NC: 62 NR: 40 NL: 1
 Current Layer: 1



Parsons Eng Science, Inc - Denver, CO
 Project: Tinker AFB Area A
 Description: Model PL-CAL8.VMF
 Modeller: Calibrated TCE Plume
 30 Mar 99

Visual MODFLOW v.2.50, (C) 1995-1997
 Waterloo Hydrogeologic Software
 NC: 62 NR: 40 NL: 1
 Current Layer: 1



Parsons Eng Science, Inc - Denver, CO
Project: Tinker AFB Area A
Description: Model PL-CALB.VMF
Modeller: TCE after 50 Years
6 Apr 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 62 NR: 40 NL: 1
Current Layer: 1

TCE CONCENTRATIONS AFTER 50 YEARS

Observation Nam	Obs conc.[µg/L]	Calc conc.[µg/L]
2-2	37.00	7.04
2-3	1120.00	255.00
2-50B	0.00	0.45
2-51B	2.50	0.35
2-52B	0.00	0.35
2-146B	0.00	0.01
2-149B	0.00	0.23
2-163B	0.00	2.47
2-164B	0.00	0.08
2-165B	0.00	0.00
2-173B	0.00	0.19
2-264B	0.00	0.00
2-265B	0.00	0.00
VEP-9	0.00	0.63
VEP-10	252.00	26.41
VEP-11	5.50	0.58
VEP-12	13.90	1.79

TABLE 5.3
SUMMARY OF SENSITIVITY ANALYSIS RESULTS
AREA A RNA TS
TINKER AFB, OKLAHOMA

Well	Observed Concentration (µg/L)	Calibrated Concentration (µg/L)	A (µg/L)	B (µg/L)	C (µg/L)	D (µg/L)	E (µg/L)	F (µg/L)	G (µg/L)	H (µg/L)	I (µg/L)	J (µg/L)
2-2	37.0	33.8	48.1	7.3	28.1	41.3	40.5	31.9	0.2	122.7	67.6	16.9
2-3	1,120	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	2,200	550
2-50B	ND	2.9	4.3	0.2	1.9	4.6	19.8	0.8	0.0	44.3	5.9	1.5
2-51B	2.5	1.7	3.2	0.4	1.4	2.1	13.5	0.1	0.0	5.8	3.4	0.9
2-52B	ND	2.2	12.9	0.0	1.1	4.7	8.9	1.0	0.0	163.5	4.5	1.1
2-146B	ND	0.0	0.0	0.0	0.0	0.1	1.1	0.0	0.0	0.4	0.1	0.0
2-149B	ND	3.5	110.0	0.0	1.0	12.8	5.9	2.8	0.0	803.1	6.9	1.7
2-163B	ND	23.8	84.3	0.5	13.2	44.6	37.2	14.4	0.0	382.7	47.7	11.9
2-164B	ND	0.4	8.1	0.0	0.1	1.1	0.6	0.3	0.0	38.2	0.7	0.2
2-165B	ND	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.6	0.0	0.0
2-173B	ND	1.0	0.8	0.0	0.6	1.9	2.7	0.6	0.0	15.6	2.1	0.5
2-264B	ND	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
2-265B	ND	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
VEP-9	ND	8.8	83.2	0.1	3.9	21.0	24.0	5.6	0.0	525.9	17.5	4.4
VEP-10	252	257	372	27	187	351	331	132	0	1170	513	128
VEP-11	5.5	6.0	52.7	0.0	2.6	14.9	10.9	3.9	0.0	296.7	12.1	3.0
VEP-12	13.9	10.8	108.0	0.4	5.8	22.4	64.9	2.1	0.0	279.8	21.5	5.4
Flow RMS	--	0.51	0.63	0.50	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
TCE RMS	--	8.09	55.53	55.32	17.18	27.62	26.44	29.84	62.03	351.91	269.90	141.60

Column: A : Hydraulic Conductivity x 3.

B: Hydraulic Conductivity /3.

C: Retardation = 3.0.

D: Retardation = 1.0.

E: Dispersivity x 4.

F: Dispersivity /4.

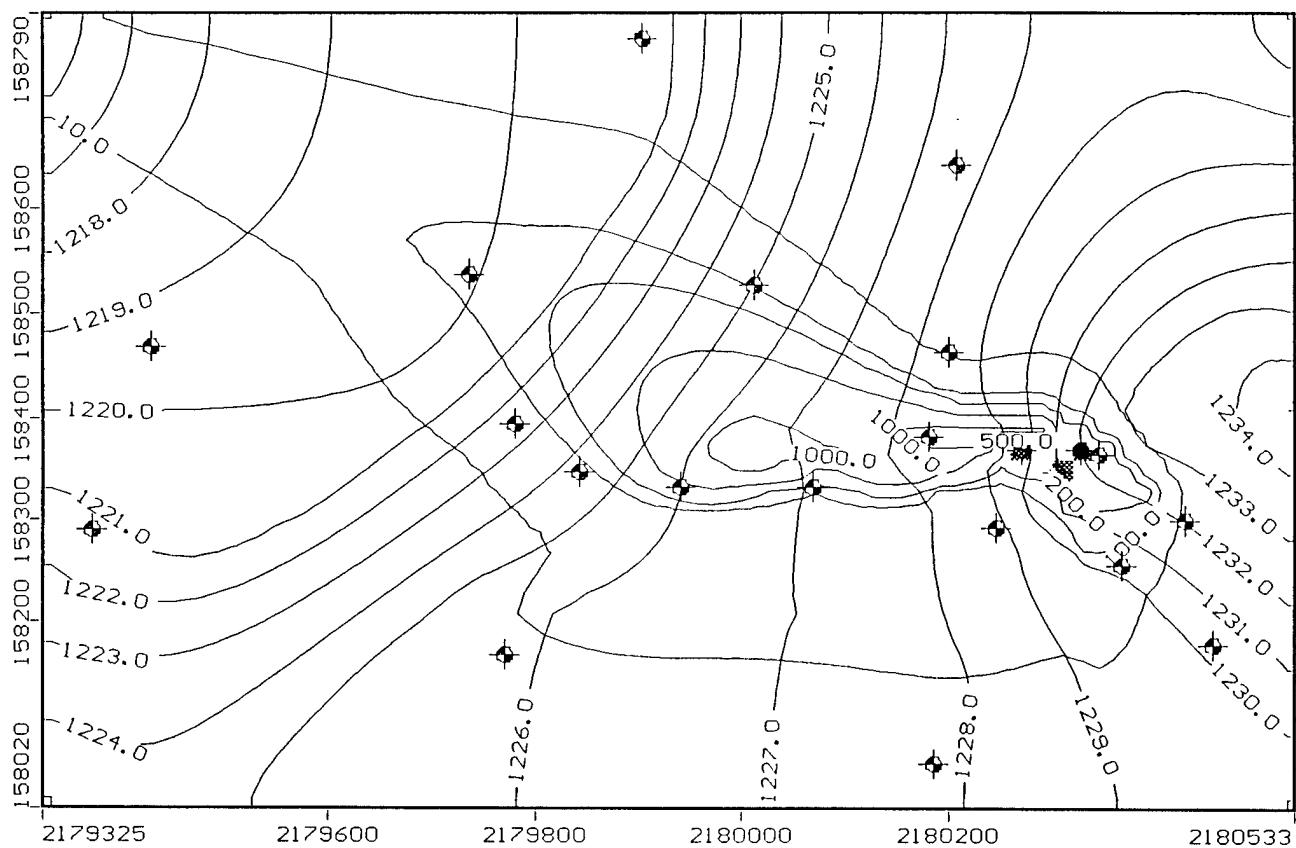
G: Decay rate increased one order-of-magnitude.

H: Decay rate decreased one-order-of-magnitude.

I: Source concentration x 2.

J: Source concentration /2.

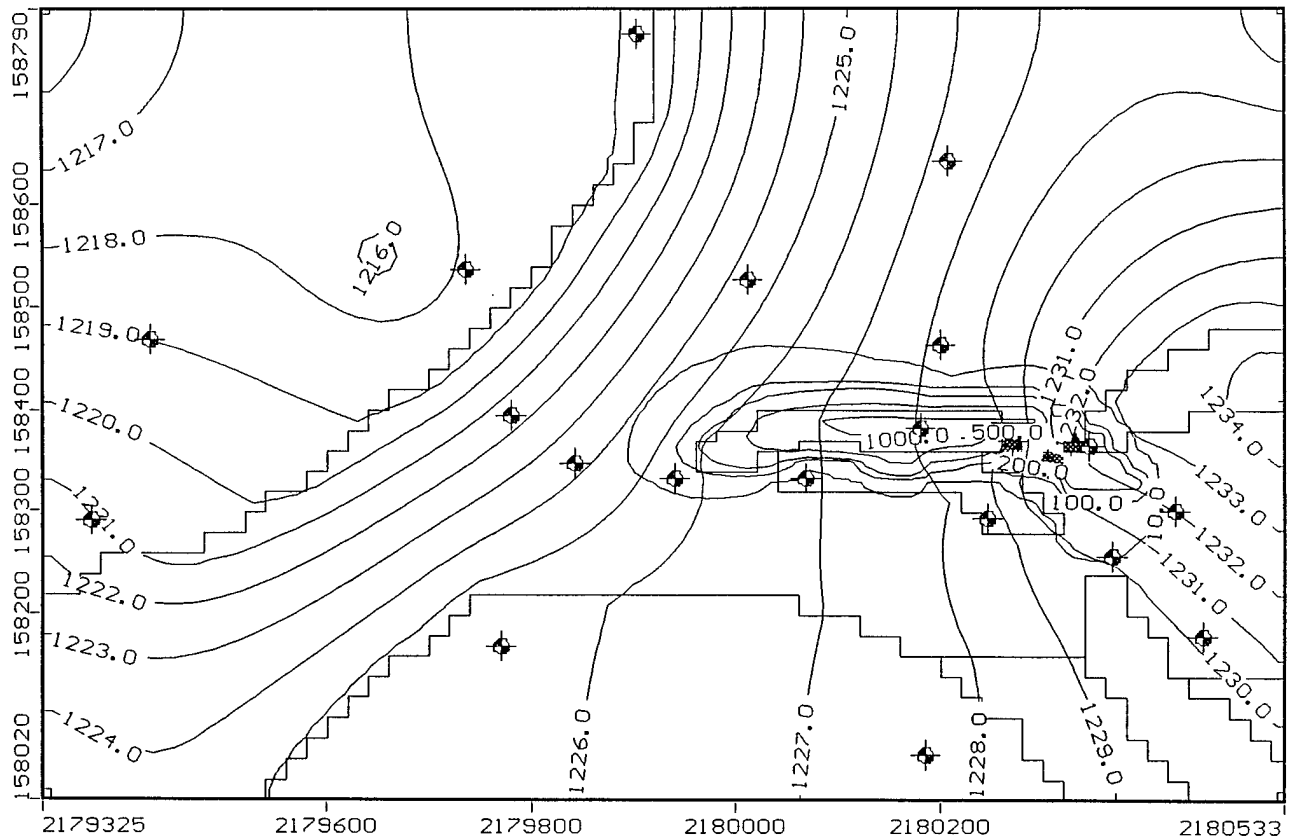
Sensitivity Analysis - A



Parsons Eng Science, Inc - Denver, CO
Project: Tinker AFB Area A
Description: Model PL-CAL8.VMF
Modeller: TCE Plume K=3X
17 Jan 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 62 NR: 40 NL: 1
Current Layer: 1

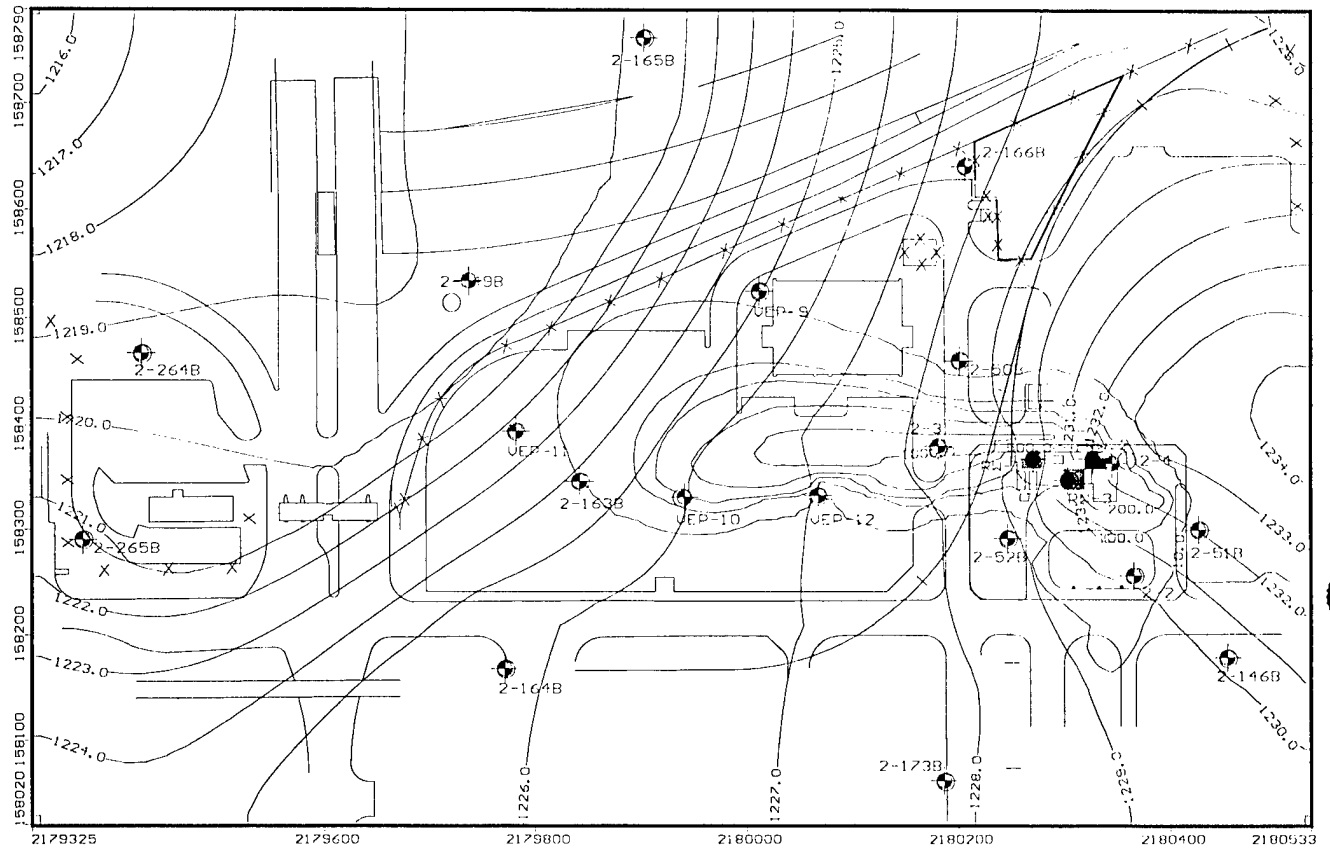
Sensitivity Analysis - B



Parsons Eng Science, Inc - Denver, CO
 Project: Tinker AFB Area A
 Description: Model PL-CALB.VMF
 Modeller: TCE Plume K= /3
 17 Jan 99

Visual MODFLOW v.2.50, (C) 1995-1997
 Waterloo Hydrogeologic Software
 NC: 62 NR: 40 NL: 1
 Current Layer: 1

Sensitivity Analysis - c

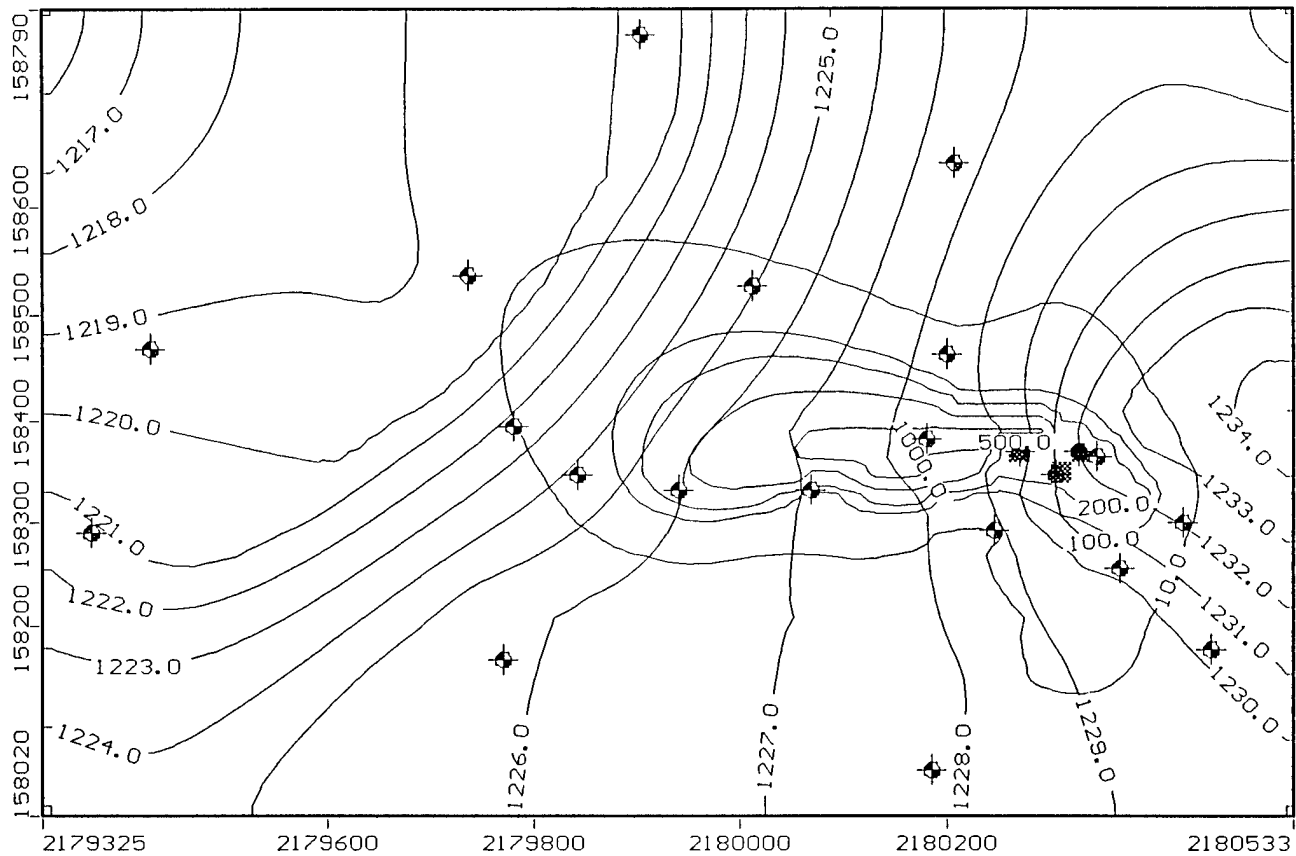


Parsons Eng Science, Inc - Denver, CO
 Project: Tinker AFB Area A
 Description: Model PL-CAL8.VMF
 Modeller: TCE Plume R=3.0
 6 Apr 99

Visual MODFLOW v.2.50, (C) 1995-1997
 Waterloo Hydrogeologic Software
 NC: 62 NR: 40 NL: 1
 Current Layer: 1

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 62 NR: 40 NL: 1
Current Layer: 1

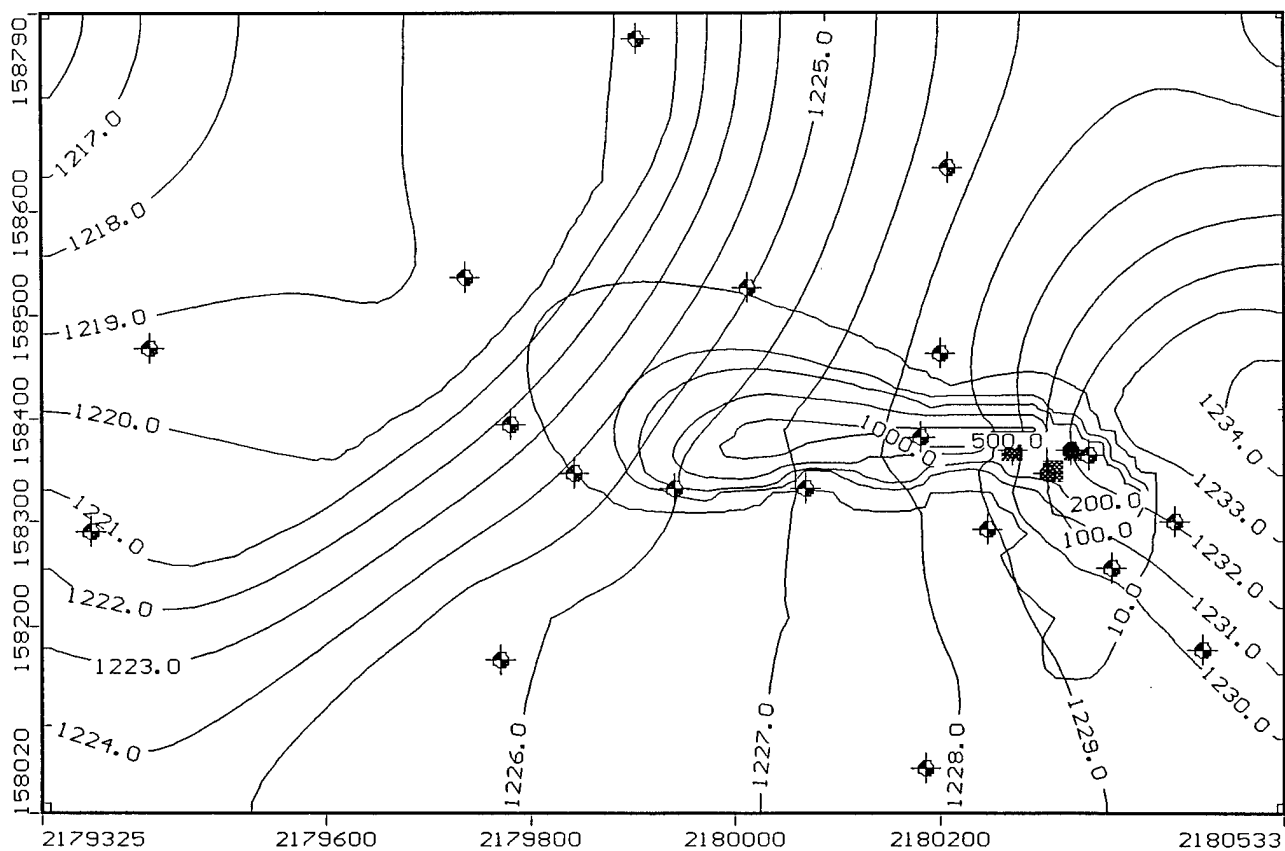
Sensitivity Analysis - F



Parsons Eng Science, Inc - Denver, CO
Project: Tinker AFB Area A
Description: Model PL-CALB.VMF
Modeller: TCE Plume D= X4
17 Jan 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 62 NR: 40 NL: 1
Current Layer: 1

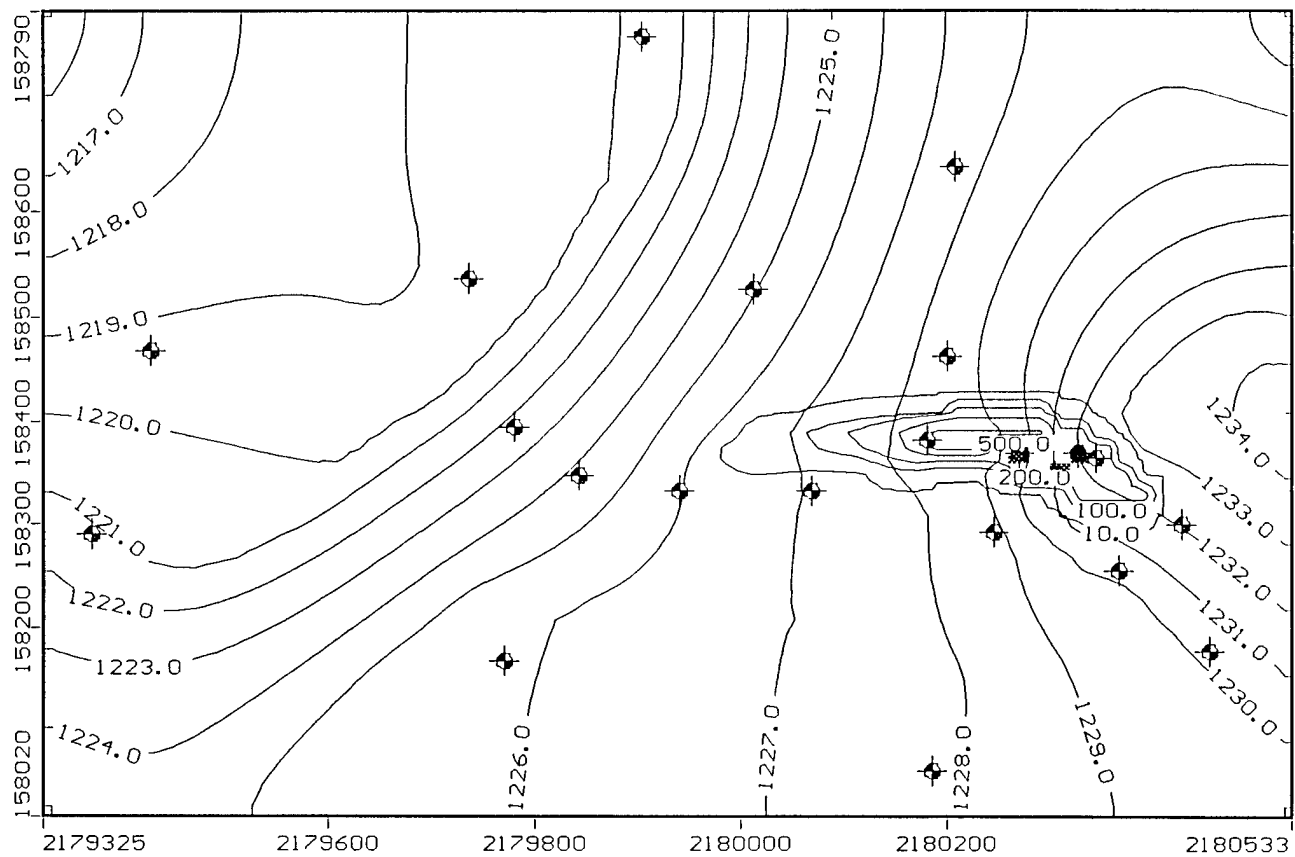
Sensitivity Analysis - F



Parsons Eng Science, Inc - Denver, CO
Project: Tinker AFB Area A
Description: Model PL-CAL8.VMF
Modeller: TCE Plume D= /4
17 Jan 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 62 NR: 40 NL: 1
Current Layer: 1

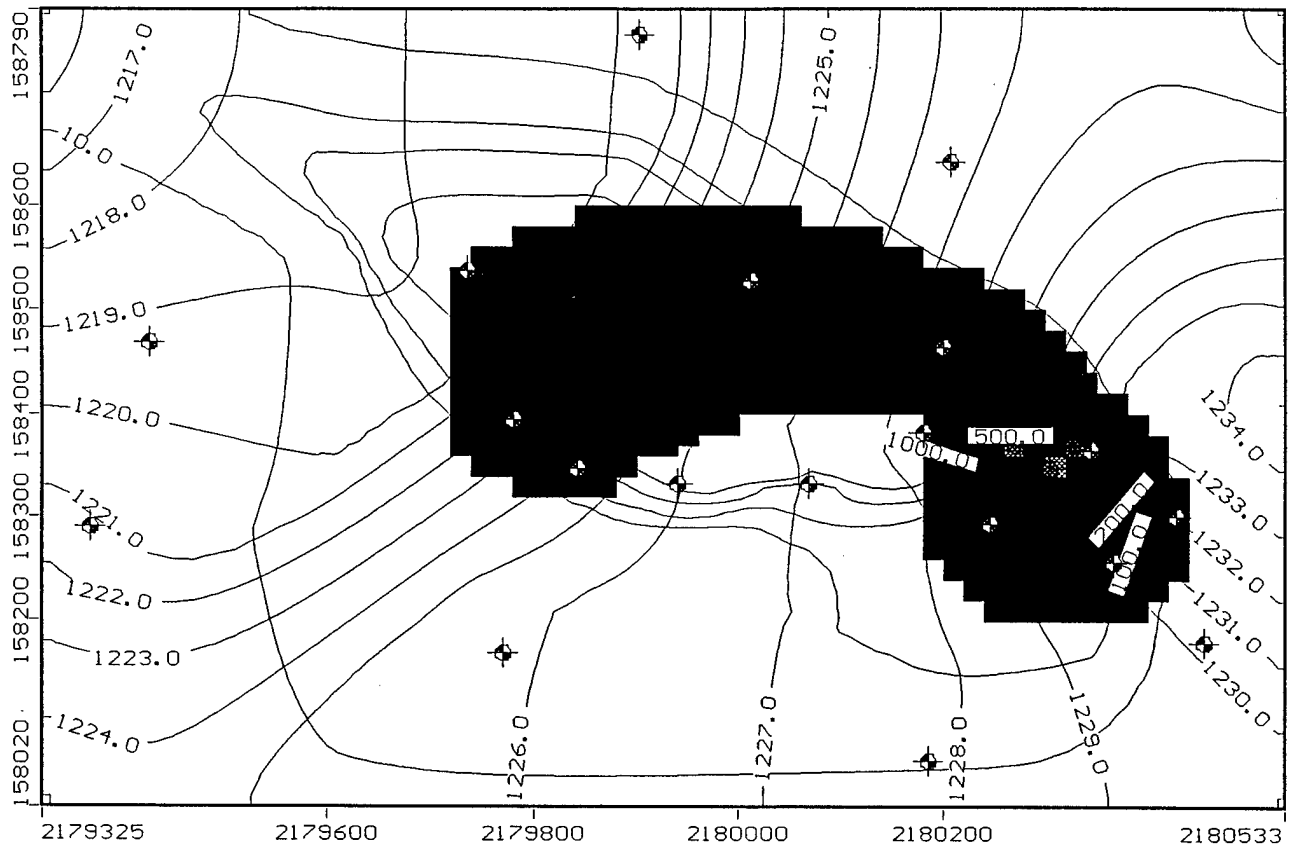
Sensitivity Analysis - G



Parsons Eng Science, Inc - Denver, CO
Project: Tinker AFB Area A
Description: Model PL-CAL8.VMF
Modeller: TCE Plume Decay = 10X
17 Jan 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 62 NR: 40 NL: 1
Current Layer: 1

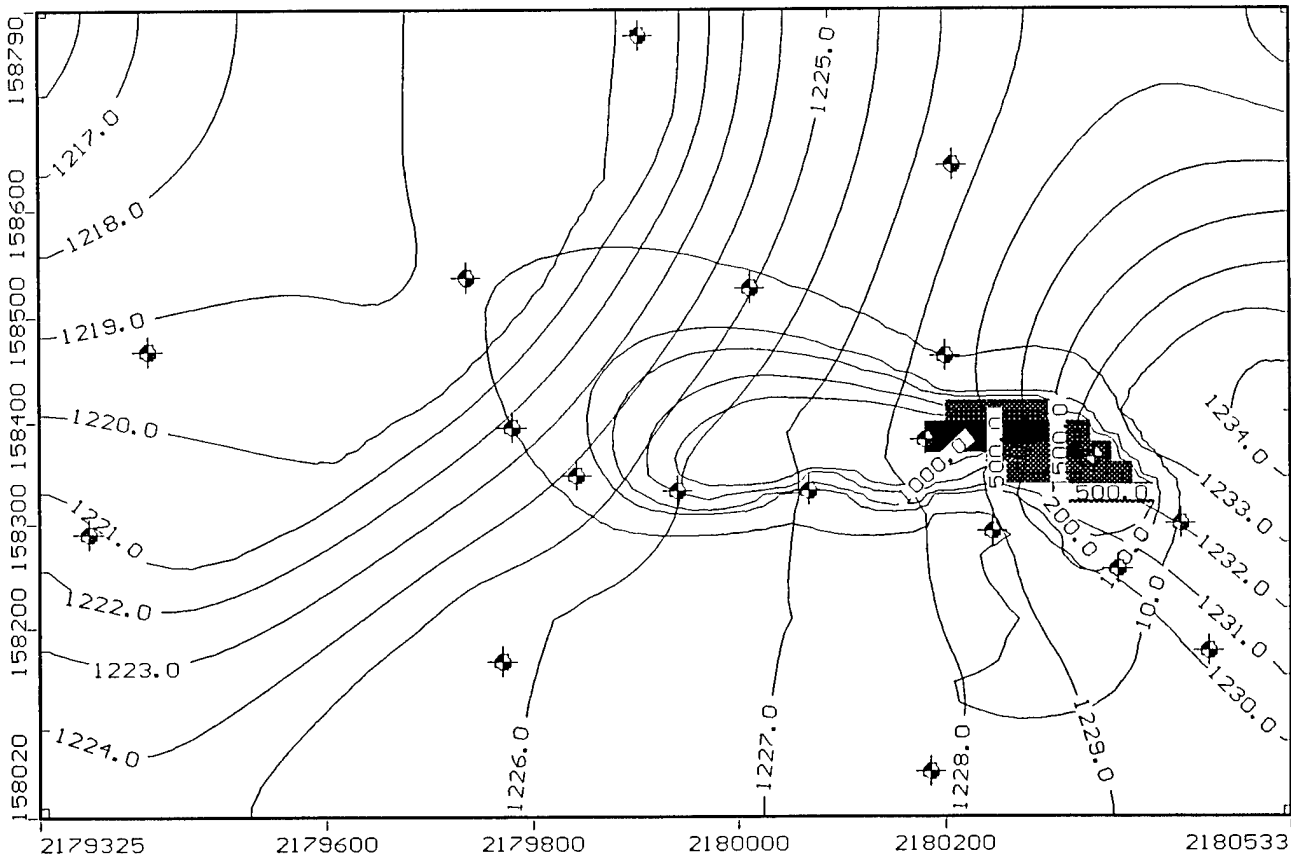
Sensitivity Analysis - H



Parsons Eng Science, Inc - Denver, CO
Project: Tinker AFB Area A
Description: Model PL-CALB.VMF
Modeller: TCE Plume Decay = /10
17 Jan 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 62 NR: 40 NL: 1
Current Layer: 1

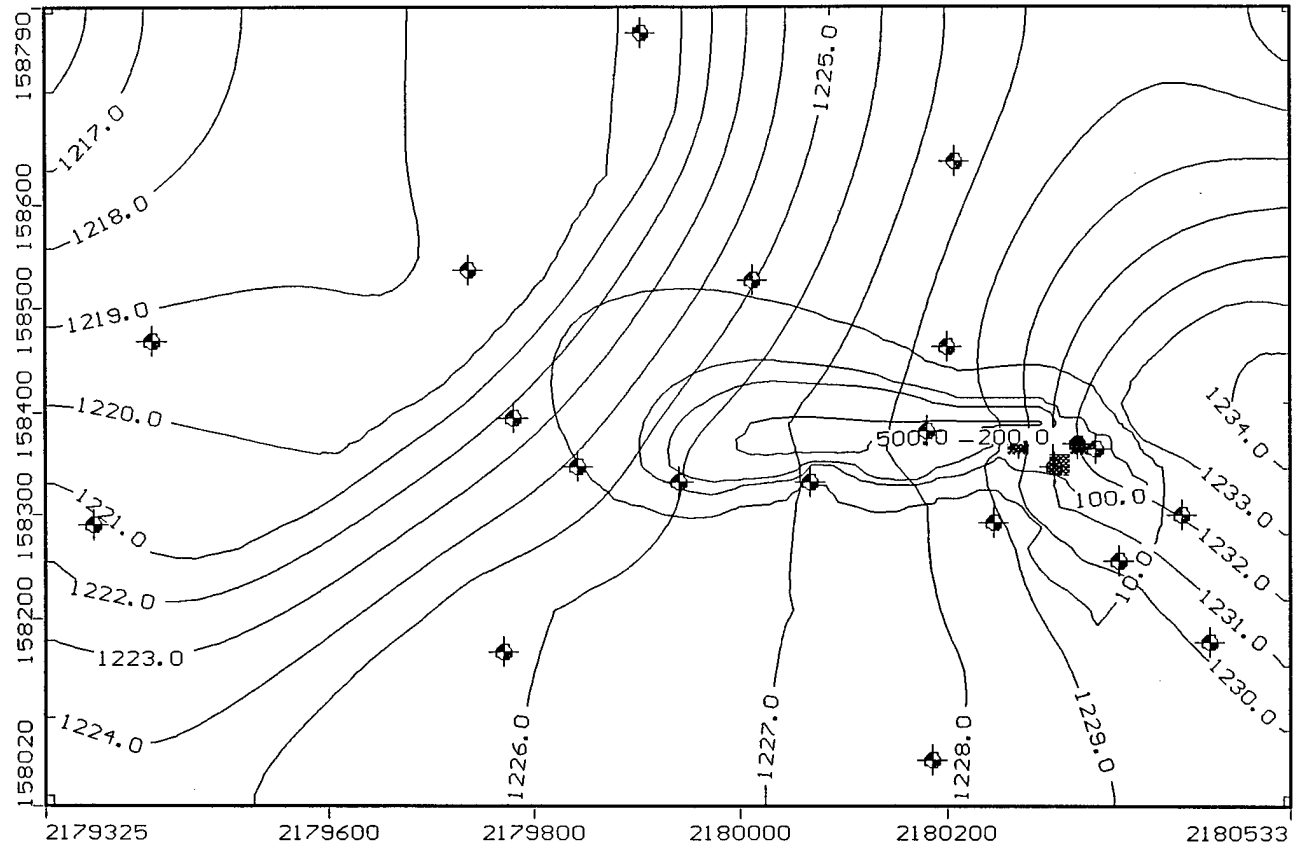
Sensitivity Analysis - I



Parsons Eng Science, Inc - Denver, CO
Project: Tinker AFB Area A
Description: Model PL-CALB.VMF
Modeller: TCE Plume Conc = 2X
17 Jan 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 62 NR: 40 NL: 1
Current Layer: 1

Sensitivity Analysis - J



Parsons Eng Science, Inc - Denver, CO
Project: Tinker AFB Area A
Description: Model PL-CALB.VMF
Modeller: TCE Plume Conc = /2
17 Jan 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 62 NR: 40 NL: 1
Current Layer: 1

TABLE 4.10
DECAY RATE SUMMARY
AREA A RNA TS
TINKER AIR FORCE BASE, OKLAHOMA

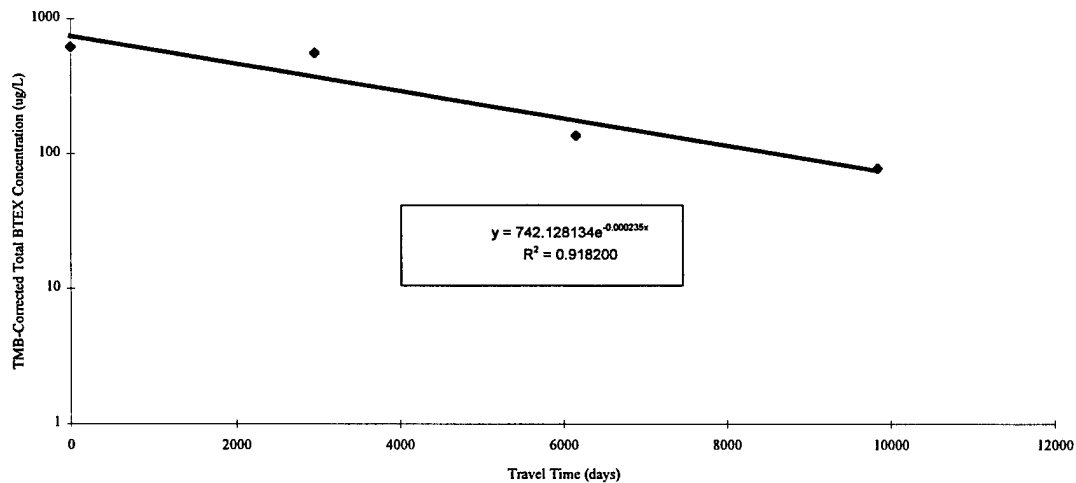
CONTAMINANT	METHOD	FLOW PATH	RATE (1/yr)	Half-Life (yr)
Total BTEX	Buscheck and Alcantar	2-3, VEP-12, VEP-10, VEP-11	0.36	1.91
Total BTEX	Conservative Tracer	2-3, VEP-12, VEP-10, VEP-11	0.09	8.08
Total BTEX	Conservative Tracer	2-50B, VEP-9	0.11	6.42
Benzene	Buscheck and Alcantar	2-3, VEP-12, VEP-10, VEP-11	0.43	1.60
Benzene	Conservative Tracer	2-3, VEP-12, VEP-10, VEP-11	0.20	3.41
Benzene	Conservative Tracer	2-50B, VEP-9	0.12	5.64
TCE	Buscheck and Alcantar	2-3, VEP-12, VEP-10, VEP-11	0.63	1.09
TCE	Buscheck and Alcantar	2-3, VEP-9	2.65	0.26
TCE	Conservative Tracer	2-3, VEP-10, VEP-11	0.27	2.53
<i>cis</i> -1,2-DCE	Buscheck and Alcantar	2-3, VEP-12, VEP-10, VEP-11	0.51	1.36
VC	Buscheck and Alcantar	2-3, VEP-12, VEP-10, VEP-11	0.45	1.55
Total Chlorinated Ethenes	Buscheck and Alcantar	2-3, VEP-10, VEP-11	0.21	3.32
Total Chlorinated Ethenes	Moutoux	2-3, VEP-10, VEP-11	0.04	15.75

**FIRST-ORDER RATE CONSTANT CALCULATION FOR TOTAL BTEX
USING TOTAL TMB AS A CONSERVATIVE TRACER
AREA A RNA TS
TINKER AFB, OKLAHOMA**

Point	Distance Downgradient (ft)	Travel Time Between Upgradient and Downgradient Point (days)	Measured Total BTEX Concentration (µg/L)	Measured Total TMB Concentration (µg/L)	$c(i-1,corr)^*$ ($c_i/c(i-1)$)	$r(c)/r(t)^*$ [$1-t(i)/t(i-1)$]	TMB Corrected Total BTEX Concentration (µg/L)
2-3	0	0	618	22	--	--	618
VEP-12	120	2952	392	9	392	0.2928	554
VEP-10	250	6150	80	6	113	0.1637	135
VEP-11	400	9840	38	4	64	0.1637	77

$v_x = 0.10$ advective groundwater velocity (ft/day)
 $R(btex) = 2.46$ BTEX retardation coefficient (average for all BTEX compounds)
 $R(tmb) = 5.01$ TMB retardation coefficient (average for all TMB compounds)

PLOT OF TMB-CORRECTED TOTAL BTEX CONCENTRATION VERSUS TIME



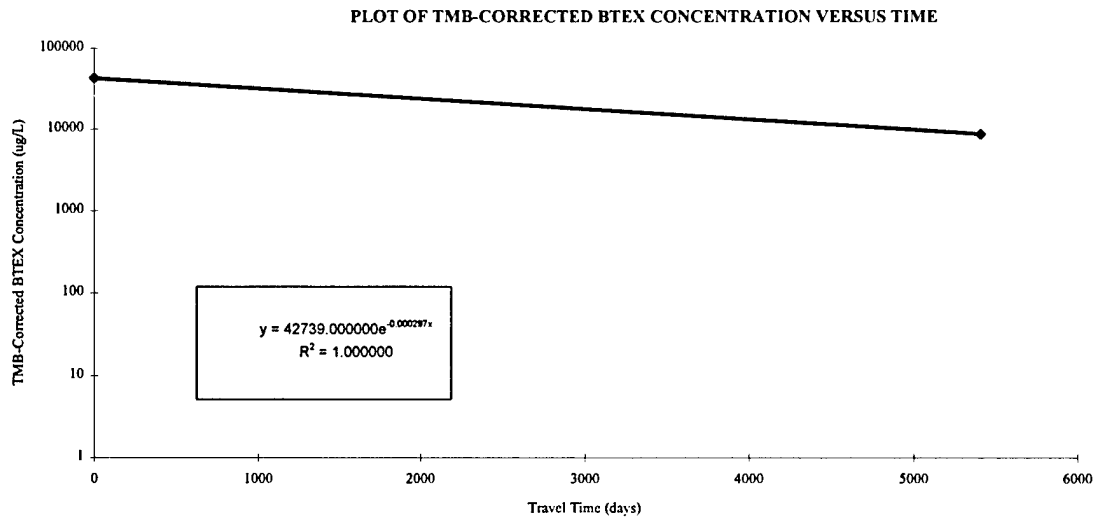
therefore rate = $2.35E-04$ 1/day
 rate = $8.58E-02$ 1/year
 rate = $2.35E-02$ %/day

 Half-life = 2948.94 days
 8.08 years

**FIRST-ORDER RATE CONSTANT CALCULATION FOR BTEX
USING TOTAL TMB AS A CONSERVATIVE TRACER
AREA A RNA TS
TINKER AFB, OKLAHOMA**

Point	Distance Downgradient (ft)	Travel Time Between Upgradient and Downgradient Point (days)	Measured BTEX Concentration (µg/L)	Measured Total TMB Concentration (µg/L)	$c(i-1, \text{corr})^*$ ($c_i/c(i-1)$)	$r(c)/r(t)^*$ [$1-t(i)/t(i-1)$]	TMB Corrected BTEX Concentration (µg/L)
2-50B	0	0	42739	2027	--	--	42739
VEP-9	220	5412	4716	168	4716	0.4503	8580

$v_x = 0.10$ advective groundwater velocity (ft/day)
 $R(\text{btex}) = 2.46$ TCE retardation coefficient
 $R(\text{tmb}) = 5.01$ TMB retardation coefficient (average for all TMB compounds)



therefore rate = $2.97E-04$ 1/day
 rate = $1.08E-01$ 1/year
 rate = $2.97E-02$ %/day

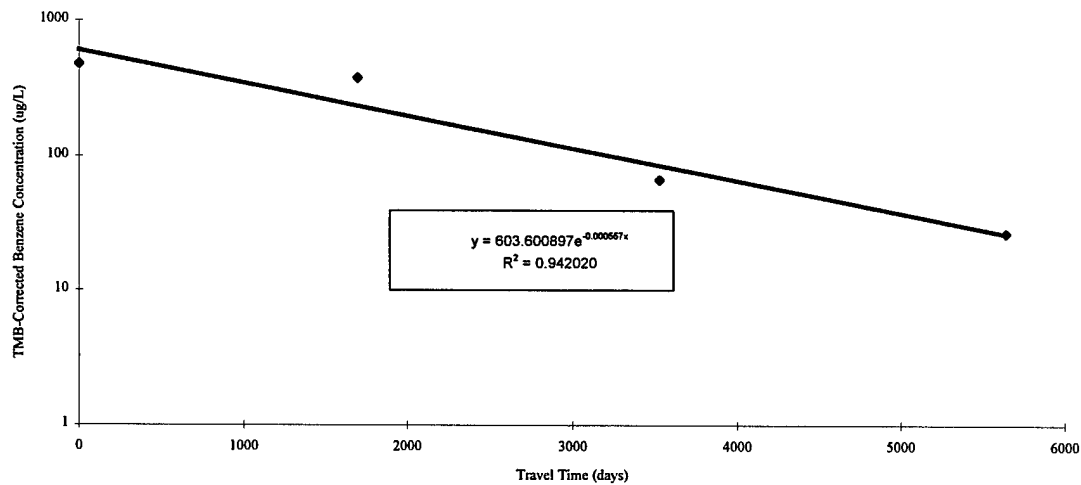
 Half-life = 2333.33 days
 6.39 years

**FIRST-ORDER RATE CONSTANT CALCULATION FOR BENZENE
USING TOTAL TMB AS A CONSERVATIVE TRACER
AREA A RNA TS
TINKER AFB, OKLAHOMA**

Point	Distance Downgradient (ft)	Travel Time Between Upgradient and Downgradient Point (days)	Measured Benzene Concentration (µg/L)	Measured Total TMB Concentration (µg/L)	$c(i-1, \text{corr})^*$ ($c_i/c(i-1)$)	$r(c)/r(t)^*$ [$1-t(i)/t(i-1)$]	TMB Corrected Benzene Concentration (µg/L)
2-3	0	0	476	22	--	--	476
VEP-12	120	1692	313	9	313	0.1679	376
VEP-10	250	3525	50	6	60	0.0938	66
VEP-11	400	5640	18	4	24	0.0938	26

$v_x = 0.10$ advective groundwater velocity (ft/day)
 $R(\text{benzene}) = 1.41$ Benzene retardation coefficient
 $R(\text{tmb}) = 5.01$ TMB retardation coefficient (average for all TMB compounds)

PLOT OF TMB-CORRECTED BENZENE CONCENTRATION VERSUS TIME



therefore rate = $5.57E-04$ 1/day
 rate = $2.03E-01$ 1/year
 rate = $5.57E-02$ %/day

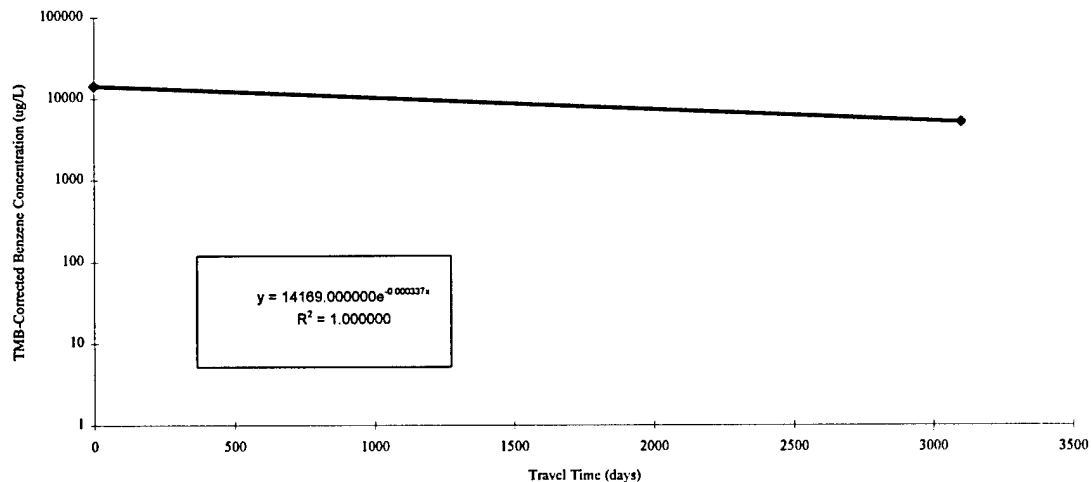
 Half-life = 1244.17 days
 3.41 years

**FIRST-ORDER RATE CONSTANT CALCULATION FOR BENZENE
USING TOTAL TMB AS A CONSERVATIVE TRACER
AREA A RNA TS
TINKER AFB, OKLAHOMA**

Point	Distance Downgradient (ft)	Travel Time Between Upgradient and Downgradient Point (days)	Measured Benzene Concentration (µg/L)	Measured Total TMB Concentration (µg/L)	$c(i-1,corr)^*$ ($c_i/c(i-1)$)	$r(c)/r(t)^*$ [$1-t(i)/t(i-1)$]	TMB Corrected Benzene Concentration (µg/L)
2-50B	0	0	14169	2027	--	--	14169
VEP-9	220	3102	3690	168	3690	0.2581	4974

$v_x =$ 0.10 advective groundwater velocity (ft/day)
 $R(\text{benzene}) =$ 1.41 TCE retardation coefficient
 $R(\text{tmb}) =$ 5.01 TMB retardation coefficient (average for all TMB compounds)

PLOT OF TMB-CORRECTED BENZENE CONCENTRATION VERSUS TIME



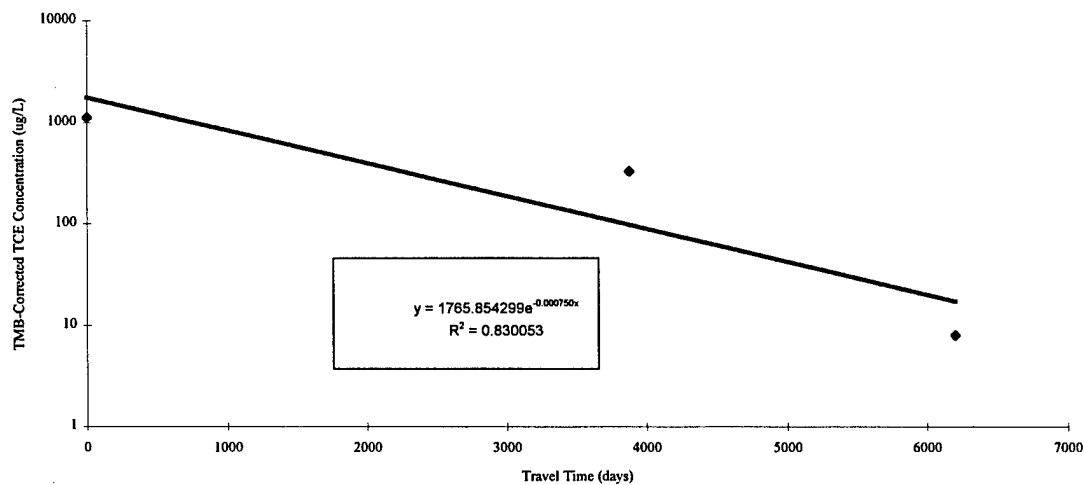
therefore rate = 3.37E-04 1/day
 rate = 1.23E-01 1/year
 rate = 3.37E-02 %/day
 Half-life = 2056.38 days
 5.63 years

**FIRST-ORDER RATE CONSTANT CALCULATION FOR TCE
USING TOTAL TMB AS A CONSERVATIVE TRACER
AREA A RNA TS
TINKER AFB, OKLAHOMA**

Point	Distance Downgradient (ft)	Travel Time Between Upgradient and Downgradient Point (days)	Measured TCE Concentration (µg/L)	Measured Total TMB Concentration (µg/L)	$c(i-1, \text{corr})^*$ ($c_i/c(i-1)$)	$r(c)/r(i)^*$ [$1-t(i)/t(i-1)$]	TMB Corrected TCE Concentration (µg/L)
2-3	0	0	1120	22	--	--	1120
VEP-10	250	3875	252	6	252	0.2261	326
VEP-11	400	6200	6	4	7	0.1031	8

$v_x =$ 0.10 advective groundwater velocity (ft/day)
 $R(\text{tce}) =$ 1.55 TCE retardation coefficient
 $R(\text{tmb}) =$ 5.01 TMB retardation coefficient (average for all TMB compounds)

PLOT OF TMB-CORRECTED TCE CONCENTRATION VERSUS TIME

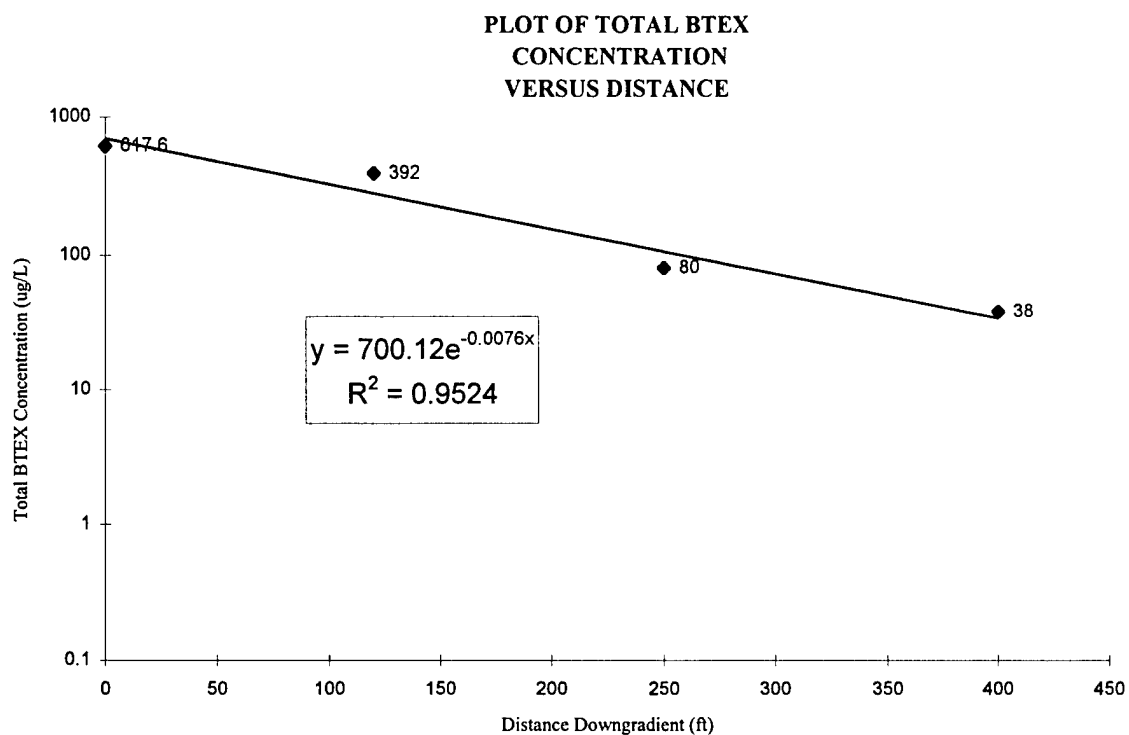


therefore rate = 7.50E-04 1/day
 rate = 2.74E-01 1/year
 rate = 7.50E-02 %/day

 Half-life = 924.00 days
 2.53 years

**FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)**

Point	Distance (ft) Downgradient	BTEX May-97
2-3	0	617.6
VEP-12	120	392
VEP-10	250	80
VEP-11	400	38



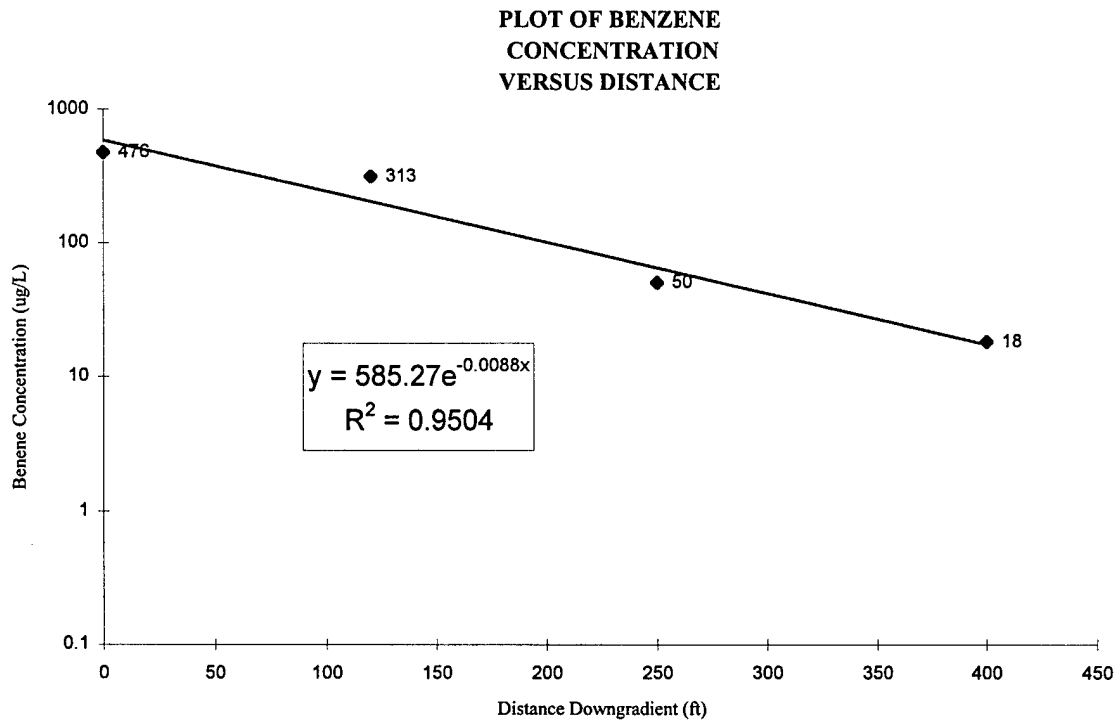
$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where $v_c = 0.1$ ft/day
 $\alpha_x = 40$ feet
 $k/v = 0.0076$

therefore $\lambda = 9.91E-04$ days⁻¹
 $3.62E-01$ years⁻¹

**FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)**

Point	Distance (ft) Downgradient	Benzene May-97
2-3	0	476
VEP-12	120	313
VEP-10	250	50
VEP-11	400	18



$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

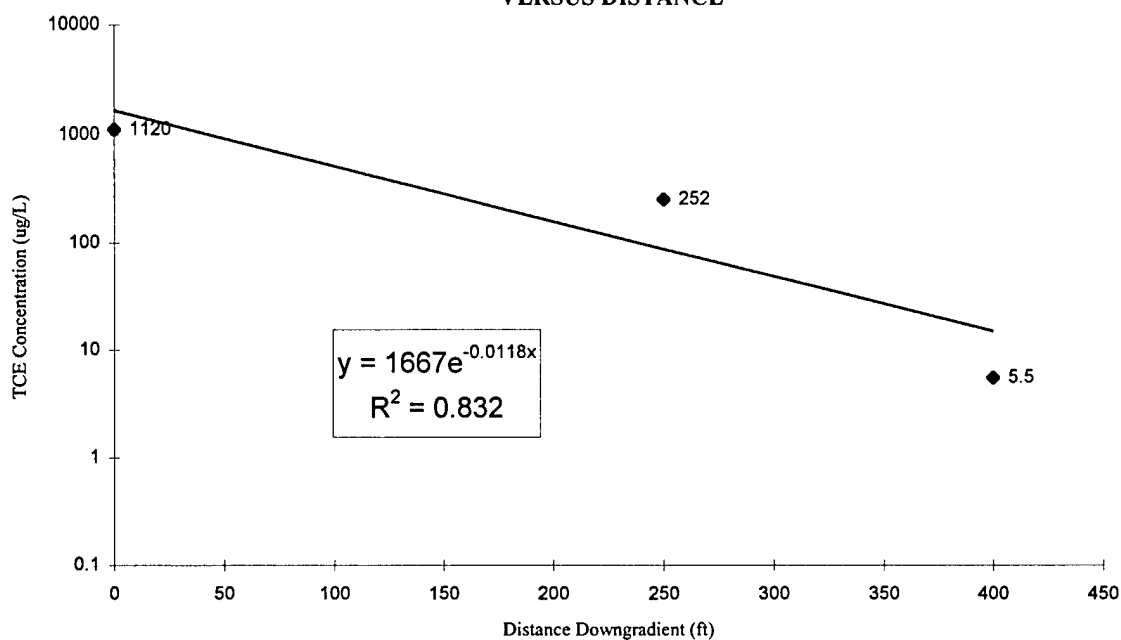
where $v_c = 0.1$ ft/day
 $\alpha_x = 40$ feet
 $k/v = 0.0088$

therefore $\lambda = 1.19E-03$ days⁻¹
 $4.34E-01$ years⁻¹

**FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)**

Point	Distance (ft) Downgradient	TCE May-97
2-3	0	1120
VEP-12	120	
VEP-10	250	252
VEP-11	400	5.5

**PLOT OF TCE
CONCENTRATION
VERSUS DISTANCE**



$$\lambda = v_e / 4\alpha_x ([1 + 2\alpha_x (k/v_x)]^2 - 1)$$

where $v_e = 0.1$ ft/day

$\alpha_x = 40$ feet

$k/v = 0.0118$

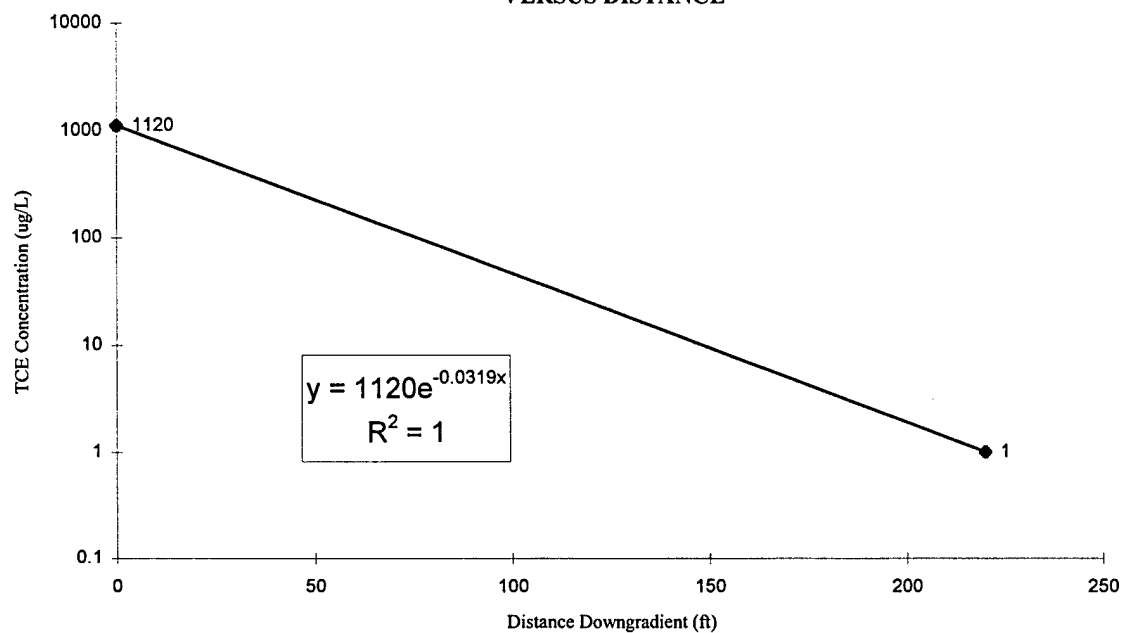
therefore $\lambda = 1.74E-03$ days⁻¹

6.34E-01 years⁻¹

**FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)**

Point	Distance (ft) Downgradient	TCE May-97
2-3	0	1120
VEP-9	220	1

**PLOT OF TCE
CONCENTRATION
VERSUS DISTANCE**



$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

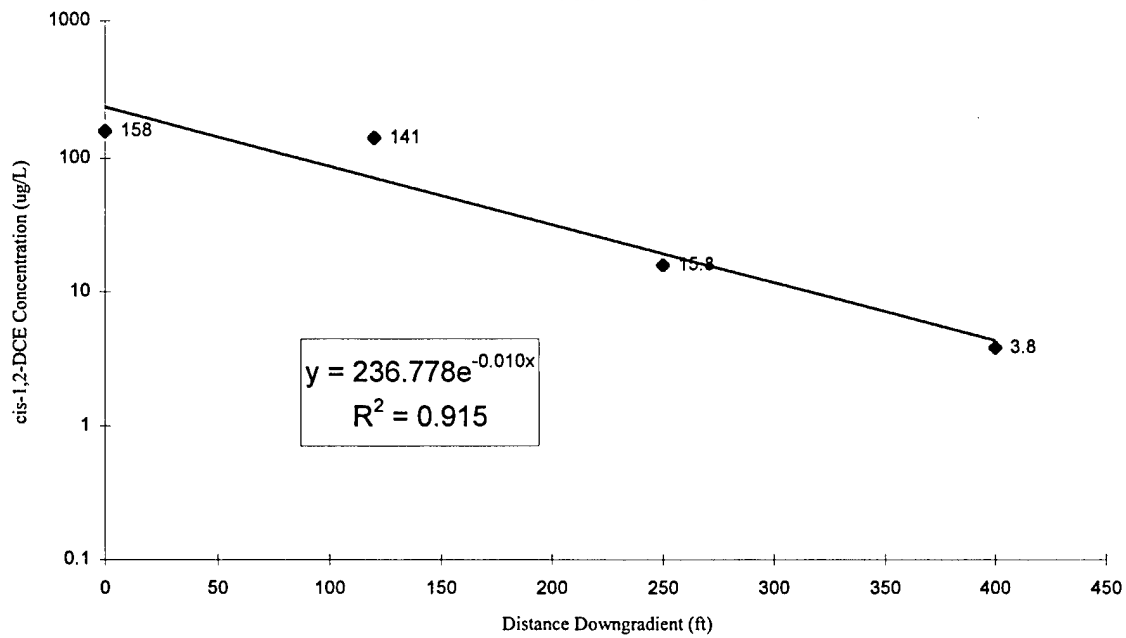
where $v_c = 0.1$ ft/day
 $\alpha_x = 40$ feet
 $k/v = 0.0319$

therefore $\lambda = 7.26E-03$ days⁻¹
 $2.65E+00$ years⁻¹

**FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)**

Point	Distance (ft) Downgradient	cis-1,2-DCE May-97
2-3	0	158
VEP-12	120	141
VEP-10	250	15.8
VEP-11	400	3.8

**PLOT OF cis-1,2-DCE
CONCENTRATION
VERSUS DISTANCE**



$$\lambda = v_c / 4\alpha_x ([1 + 2\alpha_x (k/v_x)]^2 - 1)$$

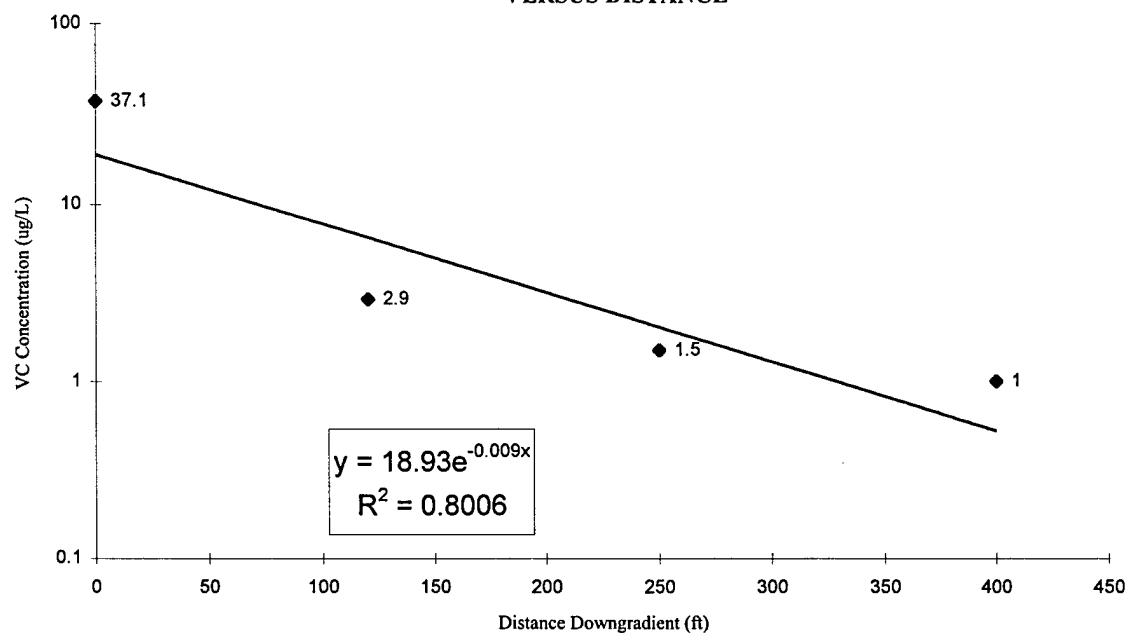
where $v_c = 0.1$ ft/day
 $\alpha_x = 40$ feet
 $k/v = 0.01$

therefore $\lambda = 1.40E-03$ days⁻¹
 $5.11E-01$ years⁻¹

**FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)**

Point	Distance (ft) Downgradient	VC May-97
2-3	0	37.1
VEP-12	120	2.9
VEP-10	250	1.5
VEP-11	400	1

**PLOT OF VC
CONCENTRATION
VERSUS DISTANCE**



$$\lambda = v_c / 4\alpha_x ([1 + 2\alpha_x (k/v_x)]^2 - 1)$$

where $v_c = 0.1$ ft/day

$\alpha_x = 40$ feet

$k/v = 0.009$

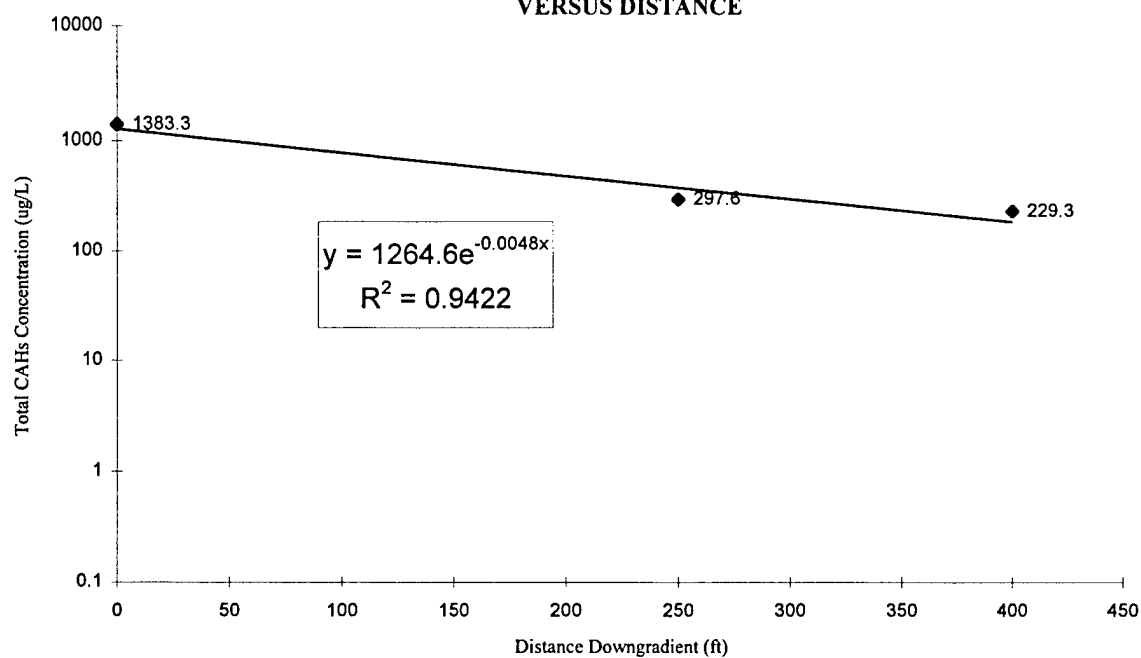
therefore $\lambda = 1.22E-03$ days⁻¹

4.47E-01 years⁻¹

**FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)**

Point	Distance (ft) Downgradient	CAHs May-97
2-3	0	1383.3
VEP-12	120	
VEP-10	250	297.6
VEP-11	400	229.3

**PLOT OF TOTAL CHLORINATED ETHENES
CONCENTRATION
VERSUS DISTANCE**



$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where $v_c = 0.1$ ft/day
 $\alpha_x = 40$ feet
 $k/v = 0.0048$

therefore $\lambda = 5.72E-04$ days⁻¹
 $2.09E-01$ years⁻¹

Corrected CAH Concentrations to Simulate Reductive Dechlorination As the Sole Attenuation Process
Moutoux Method (1995)

Step 1: Enter Observed Contaminant Concentration (µg/L)

Well	PCE	TCE	DCE	VC	Ethene	Total CAHs
2-3	5.2	1120	158.0	37	63	1383.3
VEP-10	1	252	15.8	2	27	297.6
VEP-11	0	6	3.8	1	219	229.3

Step 2: Compute Molar Concentrations (micromoles/Liter)

Well	M _{PCE}	M _{TCE}	M _{DCE}	M _{VC}	M _{Ethene}	Total M _{CAHs}
2-3	0.03	8.52	1.63	0.38	0.65	11.22
VEP-10	0.01	1.92	0.16	0.02	0.28	2.38
VEP-11	0.00	0.04	0.04	0.01	2.26	2.35

Step 3: Compute Carbon Equivalents

Well	Total M _{CAHs}	x 2	= Ceq _i
2-3	11.22		22.44
VEP-10	2.38		4.77
VEP-11	2.35		4.70

Step 4: Compute Chlorine Equivalents

Well	M _{PCE} x 4	M _{TCE} x 3	M _{DCE} x 2	M _{VC}	Σ = C _{leq} _i
2-3	0.13	25.57	3.26	0.38	29.34
VEP-10	0.03	5.75	0.33	0.02	6.13
VEP-11	0.00	0.13	0.08	0.01	0.21

Step 5: Compute Corrected CAH Concentrations

$$C_{i,corr} = C_{i-1,corr} \times (C_{leq}_i / C_{leq}_{i-1}) \times (C_{eq}_{i-1} / C_{eq}_i)$$

Well	C _{i-1,corr}	C _{leq} _i / C _{leq} _{i-1}	C _{eq} _{i-1} / C _{eq} _i	C _{i,corr}
2-3	1383.30			1383.30
VEP-10	1383.30	0.21	4.71	1359.90
VEP-11	1359.90	0.03	1.01	48.22

Step 6: Calculate Contaminant Travel Time

Well	K (ft/day)	gradient	n _e	v (ft/day)	R	v _c (ft/day)
2-3	1.40	1.50E-02	0.20	0.105	1.50	0.070
VEP-10	1.40	1.50E-02	0.20	0.105	1.50	0.070
VEP-11	1.40	1.50E-02	0.20	0.105	1.50	0.070

Step 7: Plot Exponential Trendline of Contaminant Concentration vs. Time

Well	Distance From Source (ft)	CAH velocity (ft/day)	CAH Travel Time (day)	C _{i,corr}
2-3	0	0.070	0	44032.40
VEP-10	250	0.070	3571	25407.89
VEP-11	400	0.070	5714	22415.30

Reductive Dechlorination Rate

$$C = C_0 e^{-kt} \quad \text{where:}$$

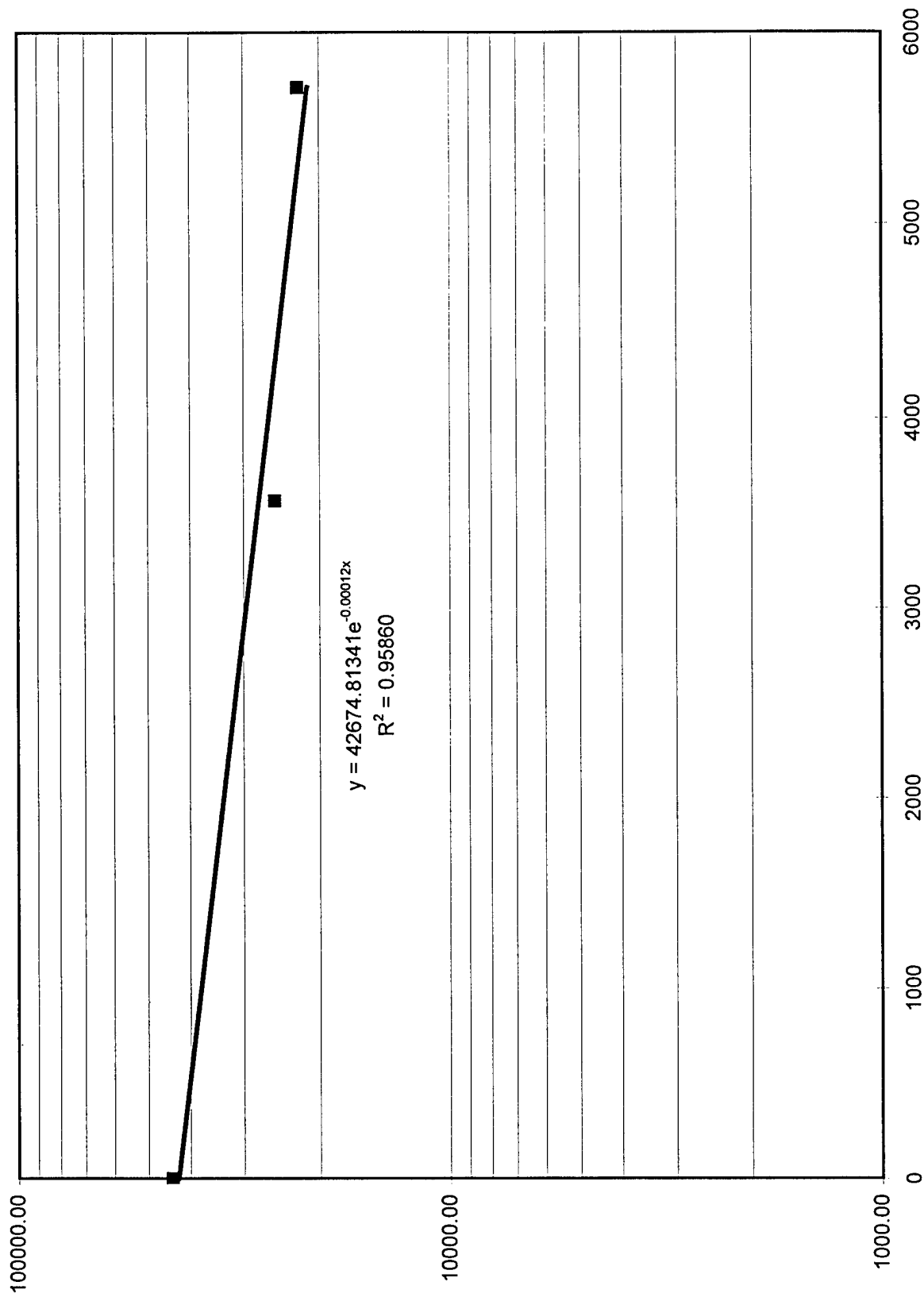
C = Corrected Contaminant Concentration (µg/L) at time t (days)

C₀ = Initial Contaminant Concentration (µg/L)

k = Reductive Dechlorination Rate (days⁻¹)

from plot: $y = 42675e^{-0.00012x}$ $k = \begin{matrix} 0.00012 & \text{days}^{-1} \\ 0.044 & \text{years}^{-1} \end{matrix}$

CORRECTED CAH CONCENTRATION VS. TRAVEL TIME
(Moutoux, 1995)



APPENDIX E
MODEL INPUT AND OUTPUT FILES

APPENDIX E
MODFLOW/MT3D MODEL
INPUT AND OUTPUT FILES

<u>Filename</u>	<u>Description</u>
AREAAIN.ZIP	Area A Model Calibration Input Files
AREAAOUT.ZIP	Area A Model Calibration Output Files
PKUNZIP.EXE	PKUNZIP utility executable

To decompress these file, type the following at the c:\> prompt:

A:\pkunzip a:*.zip c:\

This will create the input and output files for each model run in uncompressed ASCII format. The model files generated and the data contained therein are listed on the attached pages. All applicable input files are included. The general output MODFLOW *.LST and the MT3D *.OT and *.MAS output files are included.

Translated Inputs for Numerical Models

The following files are generated by Visual MODFLOW during translation:

Translated MODFLOW Files

MODFLOW.IN	List of translated files that Visual MODFLOW creates for MODFLOW.
<i>filename.BAS</i>	Translated MODFLOW file containing data for the BASIC Package.
<i>filename.BCF</i>	Translated MODFLOW file containing data for the Block-Centred Flow Package.
<i>filename.CH</i>	Translated MODFLOW file containing data for the transient constant head package.
<i>filename.DRN</i>	Translated MODFLOW file containing data for the Drain Package.
<i>filename.EVP</i>	Translated MODFLOW file containing data for the Evapotranspiration Package.
<i>filename.GHB</i>	Translated MODFLOW file containing data for the General Head Boundary Package.
<i>filename.OC</i>	Translated MODFLOW file containing data for the output control options.
<i>filename.PCG</i>	Translated MODFLOW file containing data for the PCG2 solver.
<i>filename.RCH</i>	Translated MODFLOW file containing data for the Recharge Package.
<i>filename.RIV</i>	Translated MODFLOW file containing data for the River Package.
<i>filename.SIP</i>	Translated MODFLOW file containing data for the SIP solver.
<i>filename.SOR</i>	Translated MODFLOW file containing data for the SOR solver.
<i>filename.WAL</i>	Translated MODFLOW file containing data for the Horizontal Flow Boundary Package.
<i>filename.WEL</i>	Translated MODFLOW file containing data for the Well Package.
<i>filename.WHS</i>	Translated MODFLOW file containing data for the WHS Solver.

Translated MT3D Files

<i>filename.AD3</i>	Translated MT3D file containing Advection data
<i>filename.BT3</i>	Translated MT3D file containing Basic Transport data
<i>filename.DP3</i>	Translated MT3D file containing Dispersion data
<i>filename.RC3</i>	Translated MT3D file containing Chemical Reaction data
<i>filename.SS3</i>	Translated MT3D file containing Source / Sink data
MT3D.IN	Translated MT3D file containing the list of files that Visual MODFLOW creates for use in MT3D

Visual MODFLOW Output Files

After running the model, a number of result files will be generated. Some of the files generated by Visual MODFLOW may be very large (more than 100 Mbytes) especially the .BGT and the .UGN files. These files are typically in ASCII format, but some are in binary format to save disk space. These files are described below. The files marked with an asterisk (*) can get quite large especially with a transient simulation.

General

<i>filename.ASC</i>	Visual MODFLOW output file containing data to be used by plotting programs, such as Surfer (Golden Software) - ASCII format
* <i>filename.LST</i>	Visual MODFLOW output file containing the listing information and messages from MODFLOW - ASCII format
<i>filename.PS</i>	Visual MODFLOW output file containing the POSTSCRIPT graphics file - ASCII format
<i>filename.DXF</i>	Visual MODFLOW output file containing the DXF graphic file - ASCII format

MODFLOW

<i>filename.DDN</i>	MODFLOW output file containing drawdown X, Y, Z heads for each node - Binary format
<i>filename.DVT</i>	MODFLOW output file containing drawdown versus time results - Binary format
* <i>filename.FLO</i>	MODFLOW output file containing output for input to MT3D cell-by-cell flow terms (See MT3D manual for format) - Binary format
* <i>filename.HDS</i>	MODFLOW output file containing equipotential results - Binary format;
<i>filename.HVT</i>	Contains MODFLOW head versus time results - Binary format;

MT3D

* <i>filename.OT</i>	MT3D output file containing listing information and messages from MT3D - ASCII format;
* <i>filename.UCN</i>	MT3D output file containing unformatted concentration information - Binary format;
* <i>filename.MAS</i>	MT3D output file containing mass balance file - ASCII format
* <i>filename.CNF</i>	MT3D output file containing model grid configuration file - ASCII format

APPENDIX F

REMEDIAL ALTERNATIVE COST CALCULATIONS

				Job Number		Page 1 of 2	
Calculation Page				729691.34050			
Rev	Date	By	Ck	Subject:	Cost Calculations for Alternative 1		
	4/7/99	MLP			RNA + LTM		
					Area A, Tinker AFB		
Groundwater Sampling - Years 1999 - 2048							
17 Long-Term Monitoring Wells							
9 QA/QC (2 dupl, 1 field blank, 2 trip blank, 2 MS, 2 MSD)							
26 Total Samples							
Sampling Labor		100 hours x		\$60 /hour		\$6,000	
Analytical Subcontractor							
		26 VOCs ^{a/}		\$160 /each		\$4,160	
		19 TPH GRO		\$70 /each		\$1,330	
		19 TPH DRO		\$85 /each		\$1,615	
		19 Methane/Ethane/Ethene		\$101 /each		\$1,919	
		26 Nitrate/Nitrite		\$30 /each		\$780	
		18 Field Parameters		\$20 /each		\$360	
Supplies				\$700 lump sum		\$700	
Travel				\$800 lump sum		\$800	
Per Diem		10	days x	\$88 /day		\$880	
Data Management		40	hours x	\$60 /hr		\$2,400	
Data Validation		20	hours x	\$60 /hr		\$1,200	
Reporting/Project Management Labor							
Word Processing		10	hours x	\$25 /hour		\$250	
CADD		15	hours x	\$50 /hour		\$750	
Reproduction		8	hours x	\$20 /hour		\$160	
Staff Level		50	hours x	\$60 /hour		\$3,000	
Proj. Manager		20	hours x	\$80 /hour		\$1,600	
Editor		5	hours x	\$60 /hour		\$300	
Reporting/Project Management ODCs				\$400 lump sum		\$400	
				Total for 1 Sampling Event		\$28,604	

^{a/} VOC analysis includes BTEX, CAHs, napgthalene, and MTBE.

Summary of Capital and Present Worth Costs

Capital Costs

None

Monitoring Costs

Annual Monitoring of 17 wells, 1999-2048 (10 events)

Cost per Event		\$28,604
P/A i=7%, n=0	1999	\$28,604.00
P/A i=7%, n=1	2000	\$26,732.71
P/A i=7%, n=2	2001	\$24,983.84
P/A i=7%, n=3	2002	\$23,349.38
P/A i=7%, n=4	2003	\$21,821.85
P/A i=7%, n=5	2004	\$20,394.26
P/A i=7%, n=6	2005	\$19,060.05
P/A i=7%, n=7	2006	\$17,813.13
P/A i=7%, n=8	2007	\$16,647.79
P/A i=7%, n=9	2008	\$15,558.68
P/A i=7%, n=10	2009	\$14,540.82

 PARSONS		Calculation Page		Job Number 729691.34050	Page 2 of 2
Rev	Date 4/7/99	By MLP	Ck	Subject: Cost Calculations for Alternative 1 RNA + LTM Area A, Tinker AFB	
		P/A i=7%, n=11	2010	\$13,589.55	
		P/A i=7%, n=12	2011	\$12,700.52	
		P/A i=7%, n=13	2012	\$11,869.64	
		P/A i=7%, n=14	2013	\$11,093.12	
		P/A i=7%, n=15	2014	\$10,367.41	
		P/A i=7%, n=16	2015	\$9,689.16	
		P/A i=7%, n=17	2016	\$9,055.29	
		P/A i=7%, n=18	2017	\$8,462.89	
		P/A i=7%, n=19	2018	\$7,909.24	
		P/A i=7%, n=20	2019	\$7,391.82	
		P/A i=7%, n=21	2020	\$6,908.24	
		P/A i=7%, n=22	2021	\$6,456.30	
		P/A i=7%, n=23	2022	\$6,033.92	
		P/A i=7%, n=24	2023	\$5,639.18	
		P/A i=7%, n=25	2024	\$5,270.26	
		P/A i=7%, n=26	2025	\$4,925.48	
		P/A i=7%, n=27	2026	\$4,603.25	
		P/A i=7%, n=28	2027	\$4,302.10	
		P/A i=7%, n=29	2028	\$4,020.66	
		P/A i=7%, n=30	2029	\$3,757.63	
		P/A i=7%, n=31	2030	\$3,511.80	
		P/A i=7%, n=32	2031	\$3,282.06	
		P/A i=7%, n=33	2032	\$3,067.34	
		P/A i=7%, n=34	2033	\$2,866.67	
		P/A i=7%, n=35	2034	\$2,679.13	
		P/A i=7%, n=36	2035	\$2,503.86	
		P/A i=7%, n=37	2036	\$2,340.06	
		P/A i=7%, n=38	2037	\$2,186.97	
		P/A i=7%, n=39	2038	\$2,043.90	
		P/A i=7%, n=40	2039	\$1,910.19	
		P/A i=7%, n=41	2040	\$1,785.22	
		P/A i=7%, n=42	2041	\$1,668.43	
		P/A i=7%, n=43	2042	\$1,559.28	
		P/A i=7%, n=44	2043	\$1,457.27	
		P/A i=7%, n=45	2044	\$1,361.94	
		P/A i=7%, n=46	2045	\$1,272.84	
		P/A i=7%, n=47	2046	\$1,189.57	
		P/A i=7%, n=48	2047	\$1,111.75	
		P/A i=7%, n=49	2048	\$1,039.01	
		Total Present Worth Cost			\$422,389.51
Site Management every year (50 years)					
		Annual Cost	\$6,000		
		P/A i=7% n=50	PWF = 13.8007463		
		Present Worth Cost			\$82,804
Total Capital and Present Worth Costs of LTM Program					\$505,194

 PARSONS				Job Number 729691.34050		Page 1 of 1	
Calculation Page							
Rev	Date 4/7/99	By MLP	Ck	Subject:	Cost Calculations for Alternative 2 RNA + LTM Area A, Tinker AFB		
Groundwater Sampling - Years 1999 - 2003							
17 Long-Term Monitoring Wells							
9 QA/QC (2 dupl, 1 field blank, 2 trip blank, 2 MS, 2 MSD)							
26 Total Samples							
Sampling Labor		100 hours x		\$60 /hour	\$6,000		
Analytical Subcontractor							
		26 VOCs ^{a/}		\$160 /each	\$4,160		
		19 TPH GRO		\$70 /each	\$1,330		
		19 TPH DRO		\$85 /each	\$1,615		
		19 Methane/Ethane/Ethene		\$101 /each	\$1,919		
		26 Nitrate/Nitrite		\$30 /each	\$780		
		18 Field Parameters		\$20 /each	\$360		
Supplies				\$700 lump sum	\$700		
Travel				\$800 lump sum	\$800		
Per Diem		10	days x	\$88 /day	\$880		
Data Management		40	hours x	\$60 /hr	\$2,400		
Data Validation		20	hours x	\$60 /hr	\$1,200		
Reporting/Project Management Labor							
Word Processing		10	hours x	\$25 /hour	\$250		
CADD		15	hours x	\$50 /hour	\$750		
Reproduction		8	hours x	\$20 /hour	\$160		
Staff Level		50	hours x	\$60 /hour	\$3,000		
Proj. Manager		20	hours x	\$80 /hour	\$1,600		
Editor		5	hours x	\$60 /hour	\$300		
Reporting/Project Management ODCs				\$400 lump sum	\$400		
				Total for 1	Sampling Event	\$28,604	

^{a/} VOC analysis includes BTEX, CAHs, napgthalene, and MTBE.

Summary of Capital and Present Worth Costs

Capital Costs

None

Monitoring Costs

Annual Monitoring of 17 wells, 1999-2003

(10 events)

Cost per Event

\$28,604

P/A i=7%, n=0

1999

\$28,604.00

P/A i=7%, n=1

2000

\$26,732.71

P/A i=7%, n=2

2001

\$24,983.84

P/A i=7%, n=3

2002

\$23,349.38

P/A i=7%, n=4

2003

\$21,821.85

Total Present Worth Cost

\$125,491.79

Site Management every year (5 years)

Annual Cost

\$6,000

P/A i=7% n=5

PWF = 4.100197436

Present Worth Cost

\$24,601

Total Capital and Present Worth Costs of LTM Program

\$150,093

APPENDIX G
RESPONSES TO COMMENTS

PARSONS

Parsons Engineering Science, Inc. • A Unit of Parsons Infrastructure & Technology Group Inc.

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14 September 1999

Mr. Jerry Hansen
Technical Program Manager
AFCEE/ERT
3207 North Road, Bldg. 532
Brooks AFB, TX 78235-5363

Subject: Responses to Comments on the Draft Treatability Study in Support of Remediation by Natural Attenuation for Groundwater at Area A, Tinker Air Force Base, Oklahoma (Contract F41624-92-D-8036-0025)

Dear Mr. Hansen:

This letter provides responses to comments received on the Draft Treatability Study (TS) in Support of Remediation by Natural Attenuation (RNA) for Groundwater at Area A, Tinker Air Force Base (AFB), Oklahoma. The draft TS was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) and Tinker AFB. The intent of the report was to summarize the results of a natural attenuation TS for the remediation of groundwater contaminated with fuel hydrocarbons and chlorinated solvents at the former Base service station (Area A), Tinker AFB, Oklahoma. The draft TS was submitted to AFCEE in April 1999. Comments on the draft report were received from AFCEE as reviewed by Mr. Jon Atkinson of AFCEE, dated 28 June 1999. Responses to these comments were prepared by Parsons ES and are attached this letter.

If you have any questions or require additional information, please call me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.


Bruce M. Henry, P.G.
Project Manager

Enclosures

**Responses to AFCEE Comments on the Draft Treatability Study in Support
of Natural Attenuation for Groundwater at Area A, Tinker AFB, Oklahoma**

Comment 1) Page v, Table of Contents: Suggest adding a list of appendices.

Parsons ES Response: *A list of appendices will be added to the final treatability study (TS).*

Comment 2) Page 1-12, Sec 1.3, Sent 3: Briefly describe or define "eductor wells."

Parsons ES Response: *The text will be amended to indicate that Eductor wells are groundwater recovery wells designed to recover groundwater via a jet pump-type system. The Eductor wells were installed to capture lower zone chlorinated solvent contamination and for vertical control of any fuel contaminants which may seep through the confining layer which separates the upper saturated zone (USZ) and lower saturated zone (LSZ).*

Comment 3) Pages 2-4 and 2-5, Sec 2.1.3.3, Line 8: A flow-through cell, by definition, is closed to the atmosphere, but an Erlenmeyer flask is not. Consequently, suggest referring to this sampling apparatus as a "quasi-flow-through cell."

Parsons ES Response: *The sampling apparatus will be referred to as a "quasi-flow-through cell."*

Comment 4) Page 3-16, Sec 3.3.2, Para 1, Last Sent: Geologic boring logs and monitoring well completion records appear in Appendix B, not Appendix A. Slug test data/graphs do not appear in any appendix, and should be added to Appendix B.

Parsons ES Response: *The text will be changed to indicate that geologic boring logs and monitoring well completion records are contained in Appendix B. As indicated in Section 3.3.2 and Table 3.3, values for hydraulic conductivity were obtained from the Investigation for Soil and Groundwater Cleanup Report (IT Corporation, 1996). Parsons ES did not perform slug tests at Area A. Available slug test data/graphs from IT, 1996 will be added to Appendix A, Pertinent Tables and Figures from Previous Reports.*

**Responses to AFCEE Comments on the Draft Treatability Study in Support
of Natural Attenuation for Groundwater at Area A, Tinker AFB, Oklahoma
(Continued)**

Comment 5) Page 4-19, Sec 4.2.3, Para 2, Line 11: Recommend reporting all analytical results to no more than three significant figures, to properly reflect accuracy/certainty of these results. This comment applies to the remainder of Section 4.0.

Parsons ES Response: *All analytical results will be reported to no more than three significant figures as recommended.*

Comment 6) Pages 4-33 and 4-35, Figs 4.11 and 4.12: Suggest adding the logarithmic scale to the right-hand y-axis, to enhance readability.

Parsons ES Response: *A logarithmic scale will be added to the right-hand y-axis on Figures 4.11 and 4.12 as requested.*

Comment 7) Page 4-59, Table 4.7: Recommend reporting BTEX assimilative capacity values to no more than three significant figures, to properly reflect accuracy/certainty of these calculated values.

Parsons ES Response: *All BTEX assimilative capacity values will be reported to no more than three significant figures as recommended.*

Comment 8) Pages 4-62 through 4-64, Figs 4.20 through 4.22: Suggest adding the logarithmic scale to the right-hand y-axis, to enhance readability.

Parsons ES Response: *A logarithmic scale will be added to the right-hand y-axis on Figures 4.20 through 4.22 as suggested.*

Comment 9) Pages 5-9 and 5-10, Sec 5.4.2.5, Last Sent: In MODFLOW, the drain discharge cannot be assigned directly; rather, the elevation of the drain bottom and the hydraulic conductivity of the aquifer/drain interface is specified in the input file. Recommend, consequently, that this sentence be revised accordingly.

Parsons ES Response: *The last two sentences in Section 5.4.2.5, Paragraph 1 will be revised to read: "The elevation of the drain bottom and the hydraulic conductivity (conductance) of the aquifer/drain interface were specified and varied in the model until the simulated drain discharge accurately simulated the observed water table elevation in the underpass area. The drain elevation was set to the approximate topographic elevation at the base of the underpass (1,210 feet MSL), and the conductance was set to 10,000 ft²/yr."*

**Responses to AFCEE Comments on the Draft Treatability Study in Support
of Natural Attenuation for Groundwater at Area A, Tinker AFB, Oklahoma
(Continued)**

Comment 10) Pages 5-12 and 5-13, Sec 5.4.3.3, Last Sent: Retardation coefficients are not assigned to MT3D as stated here; rather, values for bulk density, effective porosity and K_d are input to the model, and MT3D calculates the retardation coefficient.

Parsons ES Response: *The last sentence of Section 5.4.3.3, Paragraph 1 will be revised to read: "Initially, a bulk density of 1.72 kg/L, an effective porosity of 0.20, and an average K_d value of 0.1177 L/kg were specified in the model to simulate a retardation coefficient of 2.0 for TCE (Table 5.2)."*

Comment 11) Page 5-15, Sec 5.5.1, Para 1, Last Sent:

- a. Recommend adding to Appendix D a list of these 15 calibration target wells and the observed, simulated and residual head values for each target well.
- b. A map in Appendix D titled Calibrated Flow Model depicts 19 monitoring well. Recommend depicting only the 15 target calibration wells on this map.

Parsons ES Response: *a. A list of the 15 calibration target wells and the observed, simulated, and residual head values for each target well will be added to Appendix D as recommended.*

b. The Calibrated Flow Model map in Appendix D will be modified to show only the 15 target calibration wells for the flow model.

Comment 12) Page 5-19, Sec 5.5.2.1:

- a. Sent 6: Source concentrations were increased steadily until 1977, not 1992, according to the text in Section 5.4.31 (p. 5-12) and a spreadsheet in Appendix D titled "MT3D Input Form: Area A." This discrepancy should be corrected.
- b. Sent 8: According to a spreadsheet in Appendix D titled "MT3D Input Form: Area A," source cell concentrations increased until 1957, not 1992 as stated here. This discrepancy should be corrected.

Parsons ES Response: *a. The text will be revised in Sentence 6 to indicate that the source concentrations for the nine cells immediately upgradient from well 2-3 were steadily increased until 1977, and then held constant from 1977 until 1992.*

**Responses to AFCEE Comments on the Draft Treatability Study in Support
of Natural Attenuation for Groundwater at Area A, Tinker AFB, Oklahoma
(Continued)**

b. The text will be revised in Sentence 8 to indicate that concentrations for the remaining source cells were steadily increased until 1977, and then held constant from 1977 until 1992.

Comment 13) Page 5-29, Sec 5.7, Para 2, Sent 1: Would not prediction of the TCE plume 50 years into the future as measured from 1997 end at 2047, not 2049?

Parsons ES Response: *The text will be corrected to indicate that the 50-year plume ends in the year 2047.*

Comment 14) Page 56-4, Sec 6.2.1, Para 2, Line 4: Here, and throughout Subsection 6.2.1, suggest reporting BTEX values to no more than three significant figures (e.g., 26,200 ug/L) to better reflect accuracy/certainty of the analytical results.

Parsons ES Response: *All BTEX concentration values will be reported to no more than three significant figures as suggested.*

Comment 15) Page 6-18, Sec 6.3, Line 5: Recommend inserting "to" in front of "further."

Parsons ES Response: *The text will be changed as recommended.*

Comment 16) Page 7-7, Sec 7.2.3, Sent 2 and Page 7-10, Table 7.3: Suggest reporting total estimated costs to three significant figures (\$505,000) to better reflect accuracy/certainty of these estimates. This comment also applies to Subsection 7.3.2.

Parsons ES Response: *Total estimated costs will be reported to three significant figures throughout the report as suggested.*