FINAL

Demonstration of Remediation by Natural Attenuation for Groundwater at Site FTA-2

Tinker Air Force Base
Oklahoma City, Oklahoma

Prepared For

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

and

Tinker Air Force Base
Oklahoma City Oklahoma

20011030 090

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December 1999

FINAL
TREATABILITY STUDY IN SUPPORT OF REMEDIATION BY NATURAL ATTENUATION FOR GROUNDWATER AT SITE FTA-2

at

TINKER AIR FORCE BASE
OKLAHOMA

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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 remediation by natural attenuation treatability study (RNA TS) performed by Parsons Engineering Science, Inc. (Parsons ES) at Fire Training Area 2 (FTA-2), Tinker Air Force Base (AFB), Oklahoma. The RNA TS was performed to evaluate the use of natural attenuation with long-term monitoring (LTM) as a remedial option for dissolved chlorinated aliphatic hydrocarbon (CAH) contamination in the upper saturated zone (USZ). The presence of groundwater contamination and soil contamination at the site was documented during remedial investigations performed by International Technology Corporation (IT) (1994) and Tetra Tech (TT) (1996). This TS focused on the impact of dissolved CAHs, primarily trichloroethene (TCE), on the USZ groundwater system at, and downgradient from, the site. Site history and the results of soil and groundwater investigations conducted previously also are summarized in this report.

It is likely that contaminants were first introduced into groundwater at this site when the FTA-2 fire pit was initially used for fire training exercises in 1962. TT (1996) reported the FTA-2 pit was operational until 1966, although aerial photos indicate the pit was present as late as 1970. Fire training exercises at Air Force bases typically use contaminated or uncontaminated jet fuel. Solvents, fuels, and other liquid wastes may have been used for training exercises or cleaning, or dumped in the general fire training area. Aerial photographs show numerous dirt access roads crossing the area through the mid-1970s, indicating unknown activities continued in the area after use of the FTA-2 pit was discontinued. Analytical data indicate that the highest concentrations of CAHs occur in the vicinity of well 2-62B, located approximately 100 to 120 feet upgradient from the former fire pit along an access road. The presence of a secondary source, located further upgradient from well 2-62B and the former fire pit along another access road near the flightline (well 2-65B), also is suggested by increasing concentrations of CAHs at that location.

Temporal data for concentrations of TCE and *cis*-1,2-dichloroethene (*cis*-1,2-DCE) in groundwater at FTA-2 indicate that concentrations in the potential source area(s) are stable or gradually increasing. Given the available data, it appears that the plume is expanding downgradient from the suspected primary FTA-2 source, and also at an upgradient location, based on increased concentration data. An increase in concentrations within the center of the CAH plume further indicate the presence of another secondary source, and/or expansion of the CAH plume in this area. Conversely, decreasing CAH concentration data for wells along the plume axis at the most northern portion of the plume indicate the plume extent may be either decreasing or approaching equilibrium in this area.

Several lines of chemical and geochemical evidence indicate that, although dissolved CAHs are undergoing biologically facilitated reductive dehalogenation, the occurrence of this process is limited and localized to the source area(s). The presence of daughter products *cis*-1,2-DCE and vinyl chloride (VC) provides strong evidence that parent solvents (TCE and/or tetrachloroethene [PCE]) are being reductively dehalogenated. However, a relative lack of VC and ethene indicates that the process does not

significantly proceed past the initial step of TCE to DCE. Molar fractions of chlorinated ethenes along the apparent CAH plume axis indicates little, if any, degradation of TCE to DCE outside the immediate source area(s). At well 2-65B, an overall decrease in the molar fraction of TCE, with an increase in molar fraction of DCE and the presence of VC indicates that TCE is degrading to DCE, and DCE to VC at that location. Geochemical data indicate that biodegradation of native or anthropogenic carbon is occurring via aerobic respiration and methanogenesis in suspected source areas; but that nitrate, ferric iron, and sulfate reduction are not significant anaerobic degradation processes at the site. Furthermore, there are an abundance of alternate electron acceptors that may inhibit use of CAHs as electron acceptors. Away from the suspected source areas, dissolved oxygen (DO) concentrations and oxidation-reeduction potentials (ORPs) indicate that environmental conditions are not sufficiently reducing for dehalogenation of CAH compounds.

An important component of this study was an assessment of the potential for groundwater contamination to migrate from the source area to potential receptors at concentrations above regulatory levels intended to be protective of human health and the environment. To accomplish this objective, the numerical model codes MODFLOW and MT3D were used to estimate the impacts of RNA and potential engineered remedial actions on the future migration and persistence of dissolved TCE within the USZ under the influence of advection, dispersion, sorption, and biodegradation. Input parameters for the numerical model were obtained from existing site characterization data, supplemented with data collected during the RNA TS. Model parameters that were not measured at the site were estimated using reasonable literature values.

The results of this study suggest that, even with the implementation of all evaluated remedial actions (Alternatives 1 through 3), dissolved TCE contamination present in groundwater north and west of the FTA-2 fire pit has the potential to migrate at least 1,000 feet beyond the August 1997 plume toe within 35 years unless geochemical conditions are encountered along the plume flowpath that promote increased biodegradation rates. In addition, the model suggests that dissolved TCE concentrations in excess of the US Environmental Protection Agency (USEPA) maximum contaminant level (MCL) groundwater quality standard of 5 micrograms per liter (µg/L) have the potential to persist for more than 100 years (the duration of the numerical model predictive period). The model predicts that source characterization and removal could potentially cause the maximum dissolved TCE concentrations at downgradient observation points during the 35-year simulation period to be reduced by approximately one-half to one-fourth.

It should be noted that the numerical model constructed for this TS is reasonably conservative; therefore, plume migration and persistence may be less than that predicted by the model. Factors that could cause plume migration and persistence to differ from model predictions include the following:

- The calibrated model is not necessarily unique, and different combinations of input parameters could potentially have been used to achieve an acceptable calibration;
- The calibrated model is limited in accuracy by inadequate characterization of the source, preferential flowpaths, and aquifer anisotropy;

- The model does not account for the potential occurrence of abiotic degradation and volatilization of TCE; and

- Hydrogeologic and/or geochemical conditions that could slow or halt plume migration may exist downgradient from the investigated area.

This report presents a conceptual model where the primary source of TCE was near the FTA-2 fire pit and well 2-62B, and the TCE plume migrated toward the northwest due to a preferential flow path and anisotropy of the aquifer matrix. This conceptual model was primarily based on the plume configuration in 1997, which suggests linear contaminant transport in a northwest direction. Fate and transport modeling results indicate that dissolved TCE contamination present in groundwater north and west of the FTA-2 fire pit has the potential to migrate significantly. However, concentrations for wells located at the northern toe of the TCE plume decreased substantially from 1997 to 1999. Alternately, the TCE plume may be migrating in the direction of maximum hydraulic gradient (west-southwest) from multiple sources. The presence of multiple TCE "hotspots" does not support a conceptual model of a single source; rather, the "hotspots" suggest multiple sources. Increases in the concentration of TCE in 1999 at wells located downgradient of suspected TCE sources suggest a more westerly migration in the direction of maximum hydraulic conductivity. Therefore, the numerical model presented in this TS should be considered as only one of multiple possible interpretations.

Natural attenuation with source characterization and source reduction (Alternative 2) is recommeded for the FTA-2 Site. Additional site characterization is necessary to accurately predict the future behavior of dissolved contaminants at FTA-2, and may include a soil gas survey, a geophysical survey, aquifer testing, and tracer tests. Future exposure to potential receptors at the site can be minimized by land use restrictions, because access to the Base (and hence the site) is controlled by Base security. The beneficial affects of natural attenuation are included in Alternative 2. The degree to which RNA will continue to control significant downgradient migration of the plume is not known with certainty, but will become more apparent as successive LTM sampling events are performed.

Regular sampling of 22 existing and 8 new LTM wells, and 2 surface water stations, is recommended to monitor the long-term migration and degradation of the dissolved CAH plumes. The plumes should be progressively tracked in the downgradient direction, and additional downgradient sentry wells should be installed/sampled as required. Regular sampling and analysis of groundwater from these wells will allow the effectiveness of RNA and engineered remedial actions to be monitored, and should allow assessment of whether additional engineering controls should be implemented. Likewise, the model can be adjusted to reflect additional source and hydrogeologic characterization.

Contaminant fate and transport model results indicate that sampling should continue on an annual basis for approximately 15 years (the anticipated maximum duration of engineered remedial actions), followed by less frequent (e.g., every other year) sampling. The LTM plan should be periodically reevaluated and modified as necessary on the basis of newly obtained data and calibration of the numerical model.

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ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
°C	degrees centigrade
°F	degrees Fahrenheit
ΔG°r	Gibbs free energy of the reaction
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
µs/cm	microsiemens per centimeter
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AEI	Associated Environmental Industries
AOC	Area of Concern
ASCII	American Standard Code for Information Exchange
bgs	below ground surface
BR	Brown and Root
BTEX	benzene, toluene, ethylbenzene, and xylenes
btoc	below top of casing
$CaCO_3$	calcium carbonate
CB	chlorobenzene
DCA	dichloroethane
DCB	dichlorobenzene
DCE	dichloroethene
DO	dissolved oxygen
DOD	Department of Defense
FTA-2	Fire Training Area 2
ft/day	feet per day
ft/ft	feet per foot
ft/mile	feet per mile
ft/yr	feet per year
gpm	gallons per minute
GWTP	groundwater treatment plant
HDPE	high density polyethylene
HWBZ	Hennessey Water-Bearing Zone
ID	inside diameter
iron (II)	ferrous iron
iron (III)	ferric iron
IRP	Installation Restoration Program

IT	International Technology Corporation
K_d	soil distribution coefficient
K_{oc}	soil sorption coefficient
kg/L	kilograms per liter
L/kg	liters per kilogram
LSZ	lower saturated zone
LTM	long-term monitoring
MCL	maximum contaminant level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mm Hg	millimeters of mercury
MOC	method of characteristics
mV	millivolts
N	nitrogen
NAPL	non-aqueous phase liquid
NGVD	National Geodetic Vertical Datum
NR	not recorded
NRMRL	National Risk Management Research Laboratory
ORD	Office of Research and Development
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
PA/SI	preliminary assessment/site inspection
Parsons ES	Parsons Engineering Science, Inc.
PCA	tetrachloroethane
PCE	tetrachloroethene
PID	photoionization detector
POC	point of compliance
PVC	polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
redox	reduction-oxidation
RFI	RCRA facility investigation
RMS	root mean squared
RNA	remediation by natural attenuation
SAP	sampling and analysis plan
SVOC	semivolatile organic compound
SWMU	Solid Waste Management Unit
TCA	trichloroethane
TCE	trichloroethene
TeCB	tetrachlorobenzene

TMB	trimethylbenzene
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TS	Treatability Study
TT	Tetra Tech, Inc.
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
USZ	upper saturated zone
VC	vinyl chloride
VOC	volatile organic compound

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) at the former Fire Training Area 2 (FTA-2) 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 benzene, toluene, ethylbenzene, and xylenes (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 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, which is relatively toxic. Under certain geochemical conditions, vinyl chloride may accumulate in the environment rather than being 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 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 for the use of the Base and its prime environmental contractor(s) as information to be used for 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 FTA-2.

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), separated by a regional clay-silt aquitard from the lower saturated zone (LSZ);

- Develop an understanding of the current contaminant distribution in the USZ and LSZ;

- 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) 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 dissolved CAH plume expansion 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 asses the effect of current or planned future remedial actions on the TCE plume; 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-contaminated groundwater. Site characterization activities in support of RNA included static groundwater level measurement and groundwater sample collection and analysis from preexisting and recently installed site monitoring wells, and from monitoring wells and monitoring points installed by Parsons ES during the field program. Additional groundwater sampling was performed by the USEPA NRMRL in April 1999. Data for this event were not available for analysis in preparation of this TS, but have been evaluated in an addendum to this TS (Appendix H). Results of the addendum have been incorporated into the Executive Summary and Section 8, Conclusions and Recommendations.

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 CAH plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation. Results of the model were used to assess the potential for completion of exposure pathways involving groundwater, and to identify whether RNA with LTM is an appropriate and defensible remedial option for contaminated groundwater. 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 eight 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 predicted effects of potential future remedial actions on the TCE plume. Section 7 presents a LTM plan for the site. Section 8 presents a summary and conclusions, and Section 9 lists the references used to develop this document. Appendix A contains pertinent figures and tables from previous reports such as the Phase I Resource Conservation Recovery Act (RCRA) facility investigation report (RFI) for FTA-2 [IT Corporation (IT), 1994], and the Draft RCRA RFI for FTA-2 [Tetra Tech, Inc.(TT), 1996]. Appendix B contains well development and sampling records, borehole logs, well construction diagrams, geophysical logs for newly installed monitoring wells, and survey data. Appendix C presents groundwater analytical results for samples collected as a part of this TS. Appendix D contains cost calculations for remedial alternatives. Appendix E contains model input parameters and supporting calculations. Appendix F contains model input and output in American Standard Code for Information Interchange (ASCII) format on a diskette. Appendix G contains responses to comments on the draft TS, and Appendix H contains the Final Addendum to the TS report.

1.2 BASE AND FTA-2 BACKGROUND

Tinker AFB covers approximately 5,000 acres in the southeastern Oklahoma City metropolitan area (Figure 1.1). The Base has supported air operations since its founding as the Midwest Air Depot in July 1941. The Base was formally activated by the Air Force in March 1942 and serves as an international repair depot for a variety of aircraft, weapons, and engines.

Tinker AFB currently operates under a 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 FTA-2, and to perform corrective action at those sites identified as posing a 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).

Site FTA-2 is located in the south-central portion of the Base, west of Tower Road and south of the main northwest to southeast runway (Figure 1.2). FTA-2 was established as a temporary, unlined pit and was used infrequently for fire training exercises between 1962 and 1966. Standard operating procedures reportedly included adding water to the pit to saturate the soil and reduce fuel infiltration. Fuel was then brought in by tank truck, placed on top of the water, ignited, and extinguished using water and foam. Any residues were left in the pit to evaporate and infiltrate until the next fire training exercise. Available aerial photographs indicate that the site is currently a gently sloping, open grassy area with no visible evidence of former training practices. Records for facility operation do not exist. Therefore, data on composition, frequency, and quantity of fuel or extinguishing agents are not available.

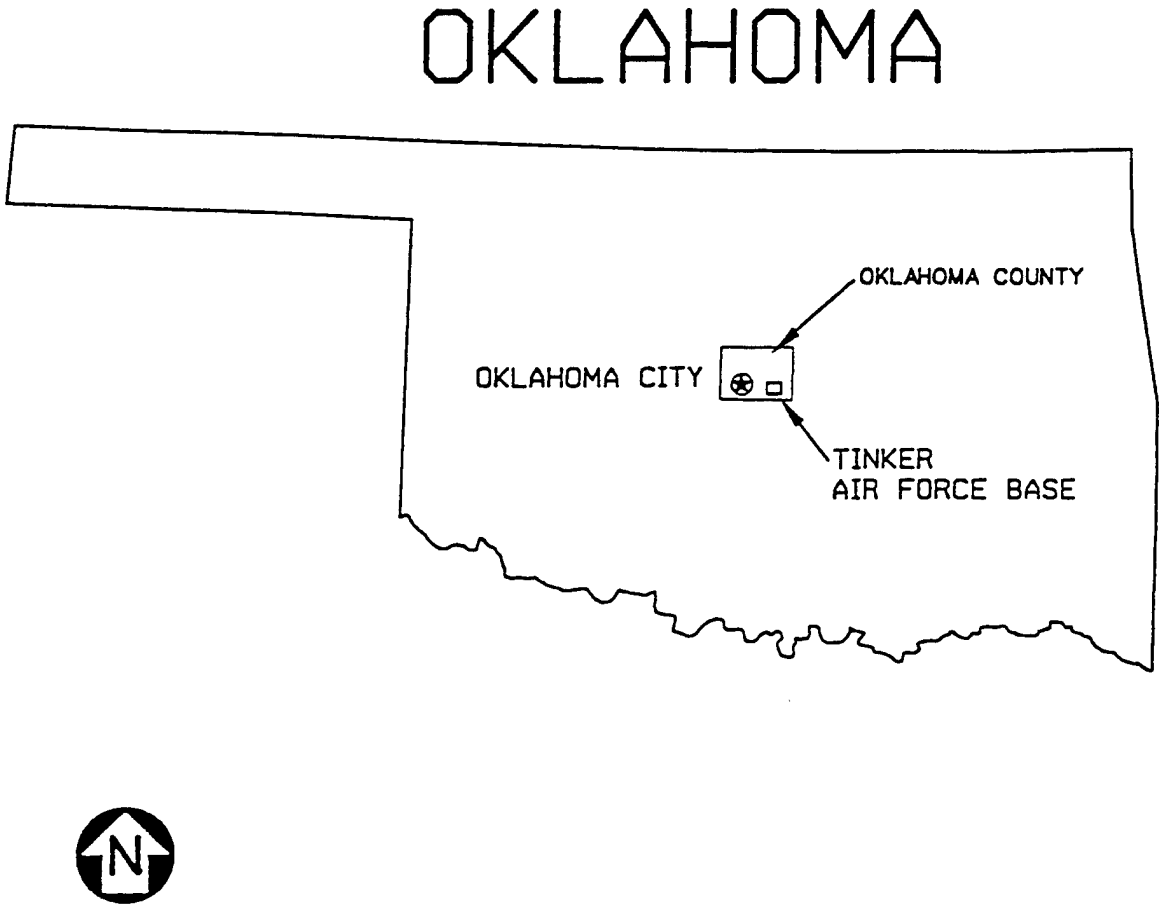


FIGURE 1.1

LOCATION OF TINKER AIR FORCE BASE

Site FTA 2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

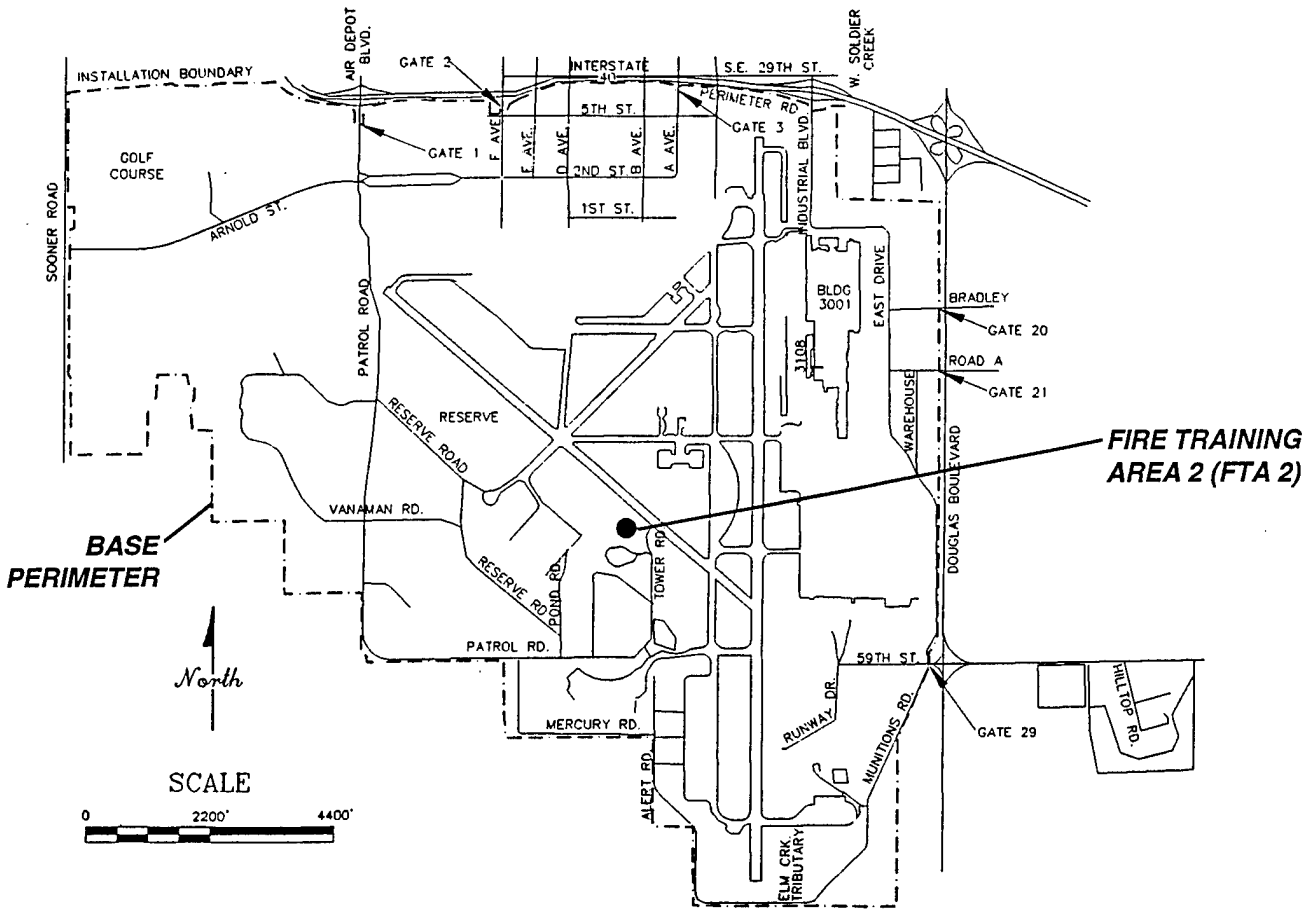


FIGURE 1.2

LOCATION OF FIRE TRAINING AREA 2

Site FTA 2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

Source: Tetra Tech. Inc., 1996.

In 1981, a Phase I study similar to a preliminary assessment/site inspection (PA/SI) was conducted at the Base by Engineering Science, Inc. (ES, 1982) as part of the Air Force IRP. The study identified 14 potentially contaminated sites, including Site FTA-2. Based on the findings of this study, the following tasks have been completed at Site FTA-2:

- An IRP Response Action was performed by the United States Army Corps of Engineers (USACE) in 1987 (USACE, 1988). Soil samples from seven boreholes, drilled to a maximum depth of 7 feet below ground surface (bgs), were analyzed for volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and total metals.

- IT conducted a Phase I RCRA RFI from October through December 1993, including soil sampling and the installation of four monitoring well pairs (IT, 1994). Soil and groundwater samples were analyzed for VOCs, SVOCs, and metals.

- A Phase II RFI was performed by TT, in 1995 (TT Draft Report, 1996). Soil samples were collected from five soil boreholes and two additional boreholes constructed for monitoring wells. Soil analytical results were included in the Draft Report. The monitoring wells were subsequently completed and sampled by Tinker AFB.

- Since 1995, six additional monitoring wells have been installed at FTA-2 and sampled for groundwater quality by Tinker AFB.

Twenty six groundwater monitoring wells and monitoring points (2-62A, 2-62B, 2-63A, 2-63B, 2-64A, 2-64B, 2-65A, 2-65B, 2-142A, 2-142B, 2-167B, 2-168B, 2-271B, 2-272B, 2-273B, 2-274A, 2-274B, 2-301B, 2-355B, 2-356B, 2-392B, 2-393B, BCG39-B97-41, CG39-B97-43S, CG39-B97-43D, and CG39-B97-45) were utilized for the RNA TS (Figure 1.3). No soil or groundwater remediation has been performed at FTA-2.

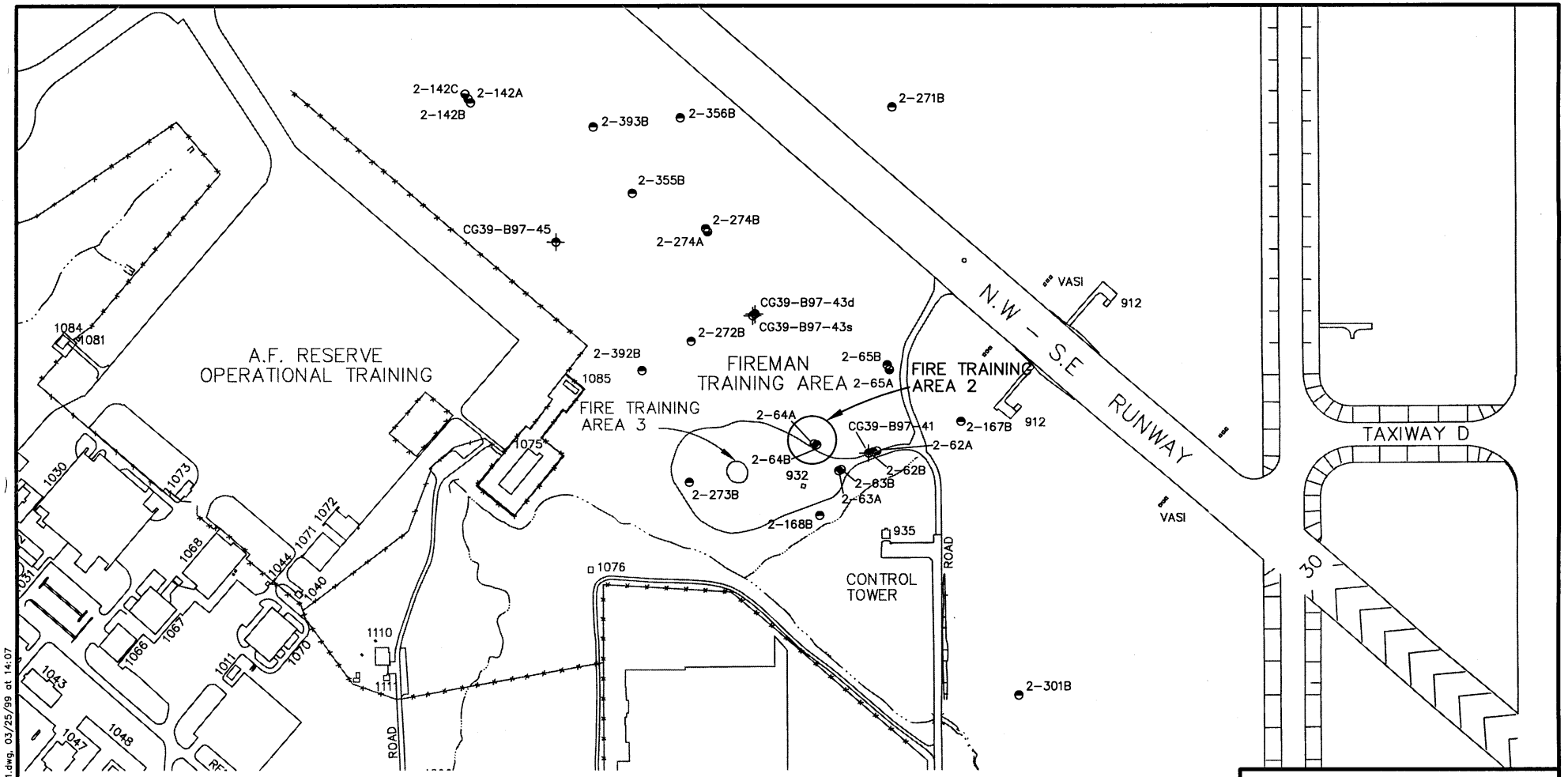


FIGURE 1.3

SAMPLING LOCATIONS
FIRE TRAINING AREA 2

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

S:\ES\cad\AFC...\29691\TINKER\98dn0201.dwg, 03/25/99 at 14:07

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

This section presents the methods used by Parsons ES personnel to collect site-specific data at FTA-2, Tinker AFB, Oklahoma. To meet the requirements of the RNA demonstration, additional data were required to evaluate near-surface geology and geochemistry, aquifer properties, and the extent of soil, surface water, and groundwater contamination. Site characterization activities involved using a hollow stem auger drill rig for soil sample collection and groundwater monitoring well and monitoring point installation. Groundwater samples were collected during this investigation from both newly installed and previously installed monitoring wells and points. Hydraulic conductivity (slug) tests were conducted at selected site monitoring wells and points. Previously collected data and data collected under this program were integrated to develop the conceptual hydrogeologic site model and to aid with interpretation of the physical setting (Section 3) and contaminant distribution (Section 4).

Sampling locations for the RNA TS are shown on Figure 1.3, and a summary of activities conducted during the RNA TS by location is provided in Table 2.1. The following subsections summarize the procedures followed when collecting site-specific data for this TS. Additional details regarding investigative activities are presented in the work plan (Parsons ES, 1997).

Two monitoring wells (2-392B and 2-393B), and four temporary well points (CG39-B97-41, CG39-B97-43s, CG39-B97-43d, and CG39-B97-45) were installed by Parsons ES during the field program. A summary of monitoring well and monitoring point construction is presented in Table 2.2. Boring logs, well construction diagrams, geophysical logs and well development forms for the six new monitoring wells and points are presented in Appendix B. In addition to the new RNA TS sampling locations, three monitoring wells (2-274A, 2-355B, and 2-356B) were installed by Brown and Root consultants (BR) at FTA-2. Construction details for the BR wells and all wells sampled as part of the TS are provided in Table 2.2.

2.1 SOIL SAMPLE COLLECTION AND GROUNDWATER MONITORING WELL/POINT INSTALLATION

2.1.1 Pre-Drilling Activities

All subsurface utility lines or other man-made subsurface features were located, and proposed borehole locations were cleared and approved by the Base prior to drilling activities.

TABLE 2.1
SUMMARY OF TREATABILITY STUDY ACTIVITIES
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Location	Monitoring Well/Point Installation	Slug Test Analysis	Soil Analyses		Groundwater Analyses														
			TOC[a] Analysis	TCE/PCE[b] Analysis	CAHs[c]	Fuel Hydrocarbons and Fuel Carbon	TOC	Well Head Analyses[d]	Mobile Lab Analyses[e]	Methane, ethane, and ethene	Cl^-[f]	NH_3[g]	$NO_2^- + NO_3^-$[h]	SO_4^{2-}[i]	H^+[j]	CO_2[k]	Total Phenols	Fatty Acids	Phenols
Upper Saturated Zone																			
CG39-B97-41	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		
CG39-B97-43s	X	X			X	X		X	X	X	X	X	X	X	X	X	X	X	X
CG39-B97-43d	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X		
CG39-B97-45	X	X			X	X		X	X	X	X	X	X	X	X	X	X		
2-392B	X	X	X		X	X		X	X	X	X	X	X	X	X	X	X		
2-393B	X	X	X		X	X		X	X	X	X	X	X	X	X	X	X		
2-62B					X	X		X	X	X	X	X	X	X	X	X	X		
2-63B					X	X		X	X	X	X	X	X	X	X	X	X		
2-64B					X	X		X	X	X	X	X	X	X	X	X	X		
2-65B					X	X		X	X	X	X	X	X	X	X	X	X		
2-167B					X	X		X	X	X	X	X	X	X	X	X	X		
2-168B					X	X		X	X	X	X	X	X	X	X	X	X		
2-271B					X	X		X	X	X	X	X	X	X	X	X	X		
2-272B					X	X		X	X	X	X	X	X	X	X	X	X		
2-273B					X	X		X	X	X	X	X	X	X	X	X	X		
2-274B					X	X		X	X	X	X	X	X	X	X	X	X		
2-355B		X			X	X		X	X	X	X	X	X	X	X	X	X		
2-356B[m]					X														
2-142B					X	X		X	X	X	X	X	X	X	X	X	X		
Lower Saturated Zone																			
2-62A					X	X		X	X	X	X	X	X	X	X	X	X		
2-63A					X	X		X	X	X	X	X	X	X	X	X	X		
2-64A					X	X		X	X	X	X	X	X	X	X	X	X		
2-65A					X	X		X	X	X	X	X	X	X	X	X	X		
2-142A					X	X		X	X	X	X	X	X	X	X	X	X		
2-274A					X	X		X	X	X	X	X	X	X	X	X	X		

a/ TOC = Total organic carbon.

b/ TCE/PCE = Trichloroethylene and Tetrachloroethylene.

c/ CAHs = Chlorinated Aliphatic Hydrocarbons.

d/ Well head analyses include dissolved oxygen, reduction-oxidation potential, pH, temperature, and conductivity.

e/ Mobile lab analyses include total alkalinity, ferrous iron, manganese, carbon dioxide, total phenols, and hydrogen sulfide.

f/ Cl^- = Chloride.

g/ NH_3 = Ammonia.

h/ $NO_2^- + NO_3^-$ = Nitrate + nitrite (as nitrogen).

i/ SO_4^{2-} = Sulfate.

j/ H^+ = Dissolved Hydrogen.

k/ CO_2 = Carbon dioxide.

l/ X indicates that the analysis was completed.

m/ Monitoring well 2-356B was sampled by Brown and Root on September 4, 1997.

TABLE 2.2
MONITORING WELL SUMMARY AND
AUGUST 1997 GROUNDWATER ELEVATIONS
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Well/Borehole Identification	Site Code	Completion Date	Well Diameter (Inches)	Screened Interval (Feet bgs)[a/]	Elevation Datum (Feet msl)[b/]	Elevation Datum	Ground Surface Elevation	Survey Northing (State Plane)	Survey Easting (State Plane)	Depth to Water August-1997 (Feet btoc)[c/]	Elevation of Water Table - August 1997 (Feet msl)
New Monitoring Points and Monitoring Wells - Upper Saturated Zone											
CG39-B97-41	FT22	7/28/1997	2.0	34 - 39	1245.20	Top PVC	1245.57	150440.90	2182126.70	12.33	1232.87
CG39-B97-43s	FT22	7/30/1997	2.0	30 - 35	1252.42	Top PVC	1252.72	150861.52	2181770.08	19.90	1232.52
CG39-B97-43d	FT22	7/29/1997	2.0	44.5 - 49.5	1252.54	Top PVC	1252.56	150866.94	2181777.04	20.19	1232.35
CG39-B97-45	FT22	7/31/1997	2.0	36.5 - 41.5	1241.82	Top PVC	1242.24	151085.60	2181167.63	12.11	1229.71
2-392B	FT22	7/29/1997	4.0	36 - 46	1244.99	Top PVC	1245.30	150696.27	2181430.89	15.43	1229.56
2-393B	FT22	7/30/1997	4.0	35 - 45	1245.97	Top PVC	1246.19	151434.08	2181280.87	15.86	1230.11
Existing Monitoring Wells - Upper Saturated Zone											
2-62B	FT22	11/9/1993	2.0	14-24	1245.94	Top PVC	1245.94	150444.52	2182140.56	14.51	1231.43
2-63B	FT22	11/8/1993	2.0	18-23	1243.28	Top PVC	1243.28	150386.11	2182035.36	12.06	1231.22
2-64B	FT22	11/9/1993	2.0	16-26	1245.59	Top PVC	1245.59	150467.40	2181967.76	14.11	1231.48
2-65B	FT22	11/5/1993	2.0	37-47	1250.81	Top PVC	1250.81	150712.88	2182183.20	17.10	1233.71
2-167B	FT22	8/8/1995	4.0	19-29	1250.70	Top PVC	1247.70	150539.81	2182408.35	16.03	1234.67
2-168B	FT22	8/8/1995	4.0	10-20	1243.00	Top PVC	1240.10	150249.00	2181976.69	12.55	1230.45
2-271B	FT22	8/8/1996	4.0	36-46	1252.13	Top PVC	1252.41	151494.42	2182196.43	18.35	1233.78
2-272B	FT22	8/9/1996	4.0	25-35	1248.91	Top PVC	1249.38	150784.70	2181581.74	17.79	1231.12
2-273B	FT22	6/18/1996	4.0	17-27	1238.42	Top PVC	1238.92	150351.11	2181576.36	8.26	1230.16
2-274B	FT22	7/25/1996	4.0	37-42	1248.32	Top PVC	1248.77	151126.23	2181625.92	16.67	1231.65
2-355B	FT22	7/9/1997	4.0	19.9-29.9	1245.92	Top PVC	1246.61	151233.46	2181400.66	15.73	1230.19
2-356B	FT22	7/10/1997	4.0	27.8-37.8	1249.30	Top PVC	1249.75	151462.29	2181548.00	18.24	1231.06
2-142B	BW	5/19/1995	4.0	32-42	1242.09	Top PVC	1242.45	NA	NA	13.31	1228.78
2-301B	LF15	6/17/1996	4.0	16-26	1244.00	Top PVC	1244.00	149701.00	2182586.00	10.14	1233.86
Existing Monitoring Wells - Lower Saturated Zone											
2-62A	FT22	11/29/1993	2.0	54-64	1246.21	Top PVC	1246.21	150447.89	2182152.17	57.32	1188.89
2-63A	FT22	11/23/1993	2.0	53-63	1243.39	Top PVC	1243.39	150389.96	2182043.02	54.70	1188.69
2-64A	FT22	11/22/1993	2.0	56-66	1246.05	Top PVC	1246.05	150470.21	2181959.37	57.34	1188.71
2-65A	FT22	11/19/1993	2.0	66-76	1250.98	Top PVC	1250.98	150698.28	2182189.88	61.48	1189.50
2-274A	FT22	7/17/1997	4.0	76-81	1248.75	Top PVC	1249.10	151115.88	2181631.94	59.20	1189.55
2-142A	BW	5/19/1995	4.0	72-82	1241.76	Top PVC	1242.30	NA	NA	53.03	1188.73

[a/] Feet bgs indicates elevation in feet below ground surface.

[b/] Feet msl indicates elevation in feet above mean sea level.

[c/] Feet btoc indicates depth measured below top of well casing.

[d/] NA indicates the data are not currently available.

2.1.2 Hollow Stem Auger Drill Rig Field Activities

Two new monitoring wells and four new monitoring points were installed in boreholes advanced by Associated Environmental Industries Corporation (AEI) using a Failing F10 hollow stem auger rig from July 28 through July 31, 1997. All boreholes for the proposed monitoring points/wells were drilled to the top of the USZ/LSZ aquitard. Geophysical logs (including gamma ray, spontaneous-potential, and resistivity) were run from the total depth of the borehole to the ground surface. Geophysical logs were a requirement of Base installation protocols and enhance resolution of lithologic contacts. Boring logs, monitoring well installation records, and geophysical logs for the two newly installed monitoring wells and the four newly installed monitoring points are provided in Appendix B.

2.1.2.1 Equipment Decontamination

Prior to arriving at the site and after each soil boring, draw works, augers, and push rods were cleaned with a steam-cleaning system. Water used in equipment cleaning was obtained from an on-Base potable water supply. Equipment cleaning was performed at a lined decontamination pad constructed of concrete at the Base former drying beds/sewage plant area. Rinseate drained from the pad was disposed of at the Base Groundwater Treatment Plant (GWTP).

2.1.2.2 Soil Sample Collection and Analysis

The hollow stem auger rig was used to collect soil samples for visual description, VOC headspace screening, VOC analyses, and total organic carbon (TOC) analysis during the installation of monitoring wells and points. The samples were collected from multiple depths using a decontaminated continuous California sampler.

At each soil borehole location, soil samples were collected and logged continuously to the total depth of the borehole. After visual examination, selected soil samples were transferred to analyte-appropriate jars, and submitted to NRMRL for TOC analysis using methods RSKSOP-102 and RSKSOP-120, or for TCE/ and tetrachloroethene (PCE) analyses using a modification of RSKSOP-124. A portion of the soil sample from each five-foot interval was placed in an unused, clean, glass jar for photoionization detector (PID) headspace measurements of ionizable VOCs. Soil remaining in the sampler was used for stratigraphic logging. Jars containing soil samples collected for the headspace screening procedure were quickly sealed with aluminum foil and stored for at least 15 minutes at the ambient temperature. Semiquantitative measurements were made by puncturing the jar seal with the PID probe and reading the concentration of the headspace gases. The PID relates the concentration of total VOCs in the sample to an isobutylene calibration standard. The PID was also used to monitor for VOCs in the worker breathing zone. The Parsons ES scientist maintained a descriptive log of subsurface materials recovered. Final geologic borehole logs with soil sampling intervals and PID screening are presented in Appendix B.

During monitoring well/point installation, the excess soils generated by drilling were temporarily stored in a portable bin. Soils were then transferred to an on-site 20 cubic yard rolloff bin after each well/point installation to await sampling, analysis, and

disposal. After laboratory analysis, the soils were approved for disposal at the Waste Management, Inc., East Oak Landfill.

2.1.2.3 Monitoring Well and Monitoring Point Installation

Using the hollow stem auger drill rig, Parsons ES and AEI staff installed two 4-inch inside diameter (ID) monitoring wells at 2-392B and 2-393B, and four 2-inch ID monitoring points at CG39-B97-41, CG39-B97-43s, CG39-B97-43d, and CG39-B97-45.

2.1.2.3.1 Materials

Monitoring wells were constructed of flush-threaded four-inch-ID stainless steel casing and screen. Polyvinyl chloride (PVC) casing was used above the water table to the surface completion. Installed screens were 10.0 feet in length and factory-slotted with 0.010-inch wire wrap openings. Monitoring points were constructed of flush-threaded two-inch-ID stainless steel casing and screen. PVC casing was used above the USZ water table to the surface completion. Monitoring point screens were 5.0 feet in length and factory-slotted with 0.010-inch wire wrap openings. Each monitoring well/point was fitted with a locking expandable cap. Well materials were inspected for cleanliness prior to use. No glue or solvents were used with monitoring well/point materials.

2.1.2.3.2 Installation

After geophysical logging, monitoring wells/points were installed in the open borehole. No difficulties related to borehole collapse were encountered. After the monitoring well screen and riser pipe were in place, the annular backfill materials were gradually added down the borehole. Monitoring wells/points were completed by filling the borehole around the well with 20-40 graded sand, bentonite chips and bentonite/cement grout. All monitoring wells/points were completed with surface flush mount protective casing in accordance with Base well installation standards. The tops of the wells/points were fitted with expandable, locking well caps. Monitoring well/point completion logs are included in Appendix B.

2.1.2.3.3 Development

Prior to sampling, newly installed monitoring wells and monitoring points were developed. Typically, well development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen. Monitoring well/point development was accomplished using a Grunfos® submersible pump with decontaminated high-density polyethylene (HDPE) tubing. The pump was lowered to the bottom of the well/point and surged so that fines were agitated and removed from the well/point in the development water. Development continued until at least ten casing volumes of water were removed from the monitoring well/point, the temperature, pH, oxidation-reduction potential (ORP), conductivity, and dissolved oxygen (DO) concentrations of the extracted groundwater had stabilized, and turbidity stabilized at less than 10 NTU, but with a limit of 300 gallons total developed water for individual monitoring points. Monitoring well/point development records are included in Appendix B. All development water was

contained in 500 to 1,000 gallon portable tanks and was disposed at the Base GWTP by AEI.

2.2 GROUNDWATER SAMPLING

The groundwater sampling procedures described in the site work plan (Parsons ES, 1997) and summarized in the following sections were followed. Groundwater sampling took place from July 31 to August 4, 1997, and consisted of collecting groundwater samples from sixteen previously installed wells (2-62A, 2-62B, 2-63A, 2-63B, 2-64A, 2-64B, 2-65A, 2-65B, 2-142A, 2-142B, 2-167B, 2-168B, 2-271B, 2-272B, 2-273B and 2-274B), two monitoring wells recently installed by BR (2-274A and 2-355B), four newly installed monitoring points (CG39B97-41d, CG39B97-43s, CG39B97-43d, and CG39B97-45), and two newly installed monitoring wells (2-393B and 2-393B). Refer to Table 2.1 for analyses conducted at each monitoring well and point.

2.2.1 Preparation and Equipment Cleaning

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

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

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

Prior to starting the sampling procedure, the area around the well or monitoring point was cleared of foreign materials, such as brush, rocks, and debris. These procedures prevented sampling equipment from inadvertently contacting debris around the monitoring wells and points. The integrity of the monitoring wells and points was also inspected, and any irregularities in the visible portions of the wells and points, protective covers, or concrete pads were noted.

2.2.2 Water Level and Total Depth Measurements

Prior to removing any water from the monitoring well or point, the static water level was measured. An electrical water level probe was used to measure the depth to groundwater below the well datum to the nearest 0.01 foot. After measurement of the

static water level, the water level probe was lowered to the bottom of the newly installed wells and points for measurement of total depth (recorded to the nearest 0.1 foot). The saturated casing volume for each well was calculated based on these measurements, or using total depths recorded on well construction.

2.2.3 Monitoring Well/Point Purging

Prior to sampling, each monitoring well or point was purged to remove stagnant water from the well casing. Where possible, the volume of water removed from each well/point 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/point was purged dry), the well/point was allowed to recharge until sufficient water was present to obtain the necessary sample quantity. Purging continued until the pH, DO concentration, ORP, conductivity, and temperature stabilized. Dedicated Grunfos® submersible pumps were used for existing wells. A decontaminated Grunfos® pump and tubing were used for newly or recently installed monitoring wells. All purge water from monitoring points and wells was collected in five-gallon buckets, transferred to a 500- or 1,000-gallon portable tank, and disposed at the Base GWTP.

2.2.4 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, dissolved hydrogen, and hydrogen sulfide. Analyses for BTEX, trimethylbenzenes (TMBs), fuel carbon, CAHs, nitrate and nitrite nitrogen, ammonia nitrogen, 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, and hydrogen sulfide, were analyzed at the USEPA mobile laboratory immediately after sample collection.

2.2.5 Sample Collection

Dedicated or decontaminated Grunfos® pumps and tubing were used to extract groundwater samples from monitoring points and wells. 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 BTEX, TMB isomers, total fuel carbon, CAHs, methane, ethane, ethene, and volatile fatty acids were filled so that there was no headspace or air bubbles within the container. Analytical methods are summarized in Table 2.3, and groundwater sampling records are provided in Appendix B.

2.3 SAMPLE HANDLING

The fixed-base analytical laboratory, NRMRL, provided pre-preserved sample containers where appropriate. The sample containers were filled as described in the previous sections. 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. Sample shipment to NRMRL and the associated chain-of-custody documentation was the responsibility of NRMRL field personnel.

2.4 AQUIFER TESTING

Slug tests were performed at FTA-2 by Parsons ES on August 5, 1997. Falling and rising head slug tests were performed at monitoring wells 2-355B, 2-393B, and 2-393B, and monitoring points CG39-B97-41, CG39-B97-43s, CG39-B97-43d, and CG39-B97-45. Parsons ES personnel used testing procedures similar to those described in the work plan (Parsons ES, 1997). Slug test data were analyzed using the AQTESOLV® software package (Geraghty and Miller, Inc., 1994) and the methods of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. Slug test results are presented in Section 3.3 and Appendix B of this document.

2.5 SURVEYING

After completion of field work, the locations and elevations of all new monitoring points and wells were surveyed by Lemke Land Surveying, an Oklahoma licensed land surveyor from Norman, Oklahoma. The horizontal locations and elevations of the measurement datum (i.e. top of PVC well casing) and the ground surface adjacent to the well casings were measured relative to existing control points referenced to the NAD 27 (horizontal) and National Geodetic Vertical Datum (NGVD) 29 (vertical) plane coordinate systems. Horizontal locations were surveyed to the nearest 0.1 foot. Measurement datum and ground surface elevations were surveyed to the nearest 0.01 foot. Survey data are presented in Appendix B.

TABLE 2.3
ANALYTICAL PROTOCOLS FOR
GROUNDWATER AND SOIL SAMPLES
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

MATRIX Analyte	METHOD	FIELD (F) OR ANALYTICAL LABORATORY (L)
WATER		
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
Ferrous Iron (Fe^{+2})	Titrimetric, Chemetrics Method	F
Manganese	Titrimetric, Chemetrics Method	F
Alkalinity (Carbonate [CO_3^{-2}] and Bicarbonate [HCO_3^{-1}])	Titrimetric, Hach Method 8221	F
Carbon Dioxide	Titrimetric, Hach Method 1436-01	F
Hydrogen Sulfide	Chemetrics Method	F
Total Phenols	Titrimetric, Chemetrics Method	F
Ammonia (NH_3)	E350.1	L
Nitrate + Nitrite	E353.1	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane, Ethane, Ethene	RSKSOP-194[a/] /RSKSOP-175	L
Total Organic Carbon	RSKSOP-102	L
VOCs (BTEX, TMBs, total fuel carbon)	RSKSOP-133	L
VOCs (CAHs, chloroform, chlorobenzenes)	RSKSOP-148	L
Phenols and Fatty Acids	RSKSOP-177	L
SOIL		
Total Organic Carbon	RSKSOP-102 & RSKSOP-120	L
VOCs (TCE and PCE)	RSKSOP-124, modified	L

[a/]RSKSOP = Robert S. Kerr Laboratory standard operating procedure.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

Existing site-specific data were reviewed and supplemented with data collected by Parsons ES in July and August 1997 to develop a synopsis of FTA-2 physical characteristics. In addition to field investigation results from this TS, data from the following sources are included:

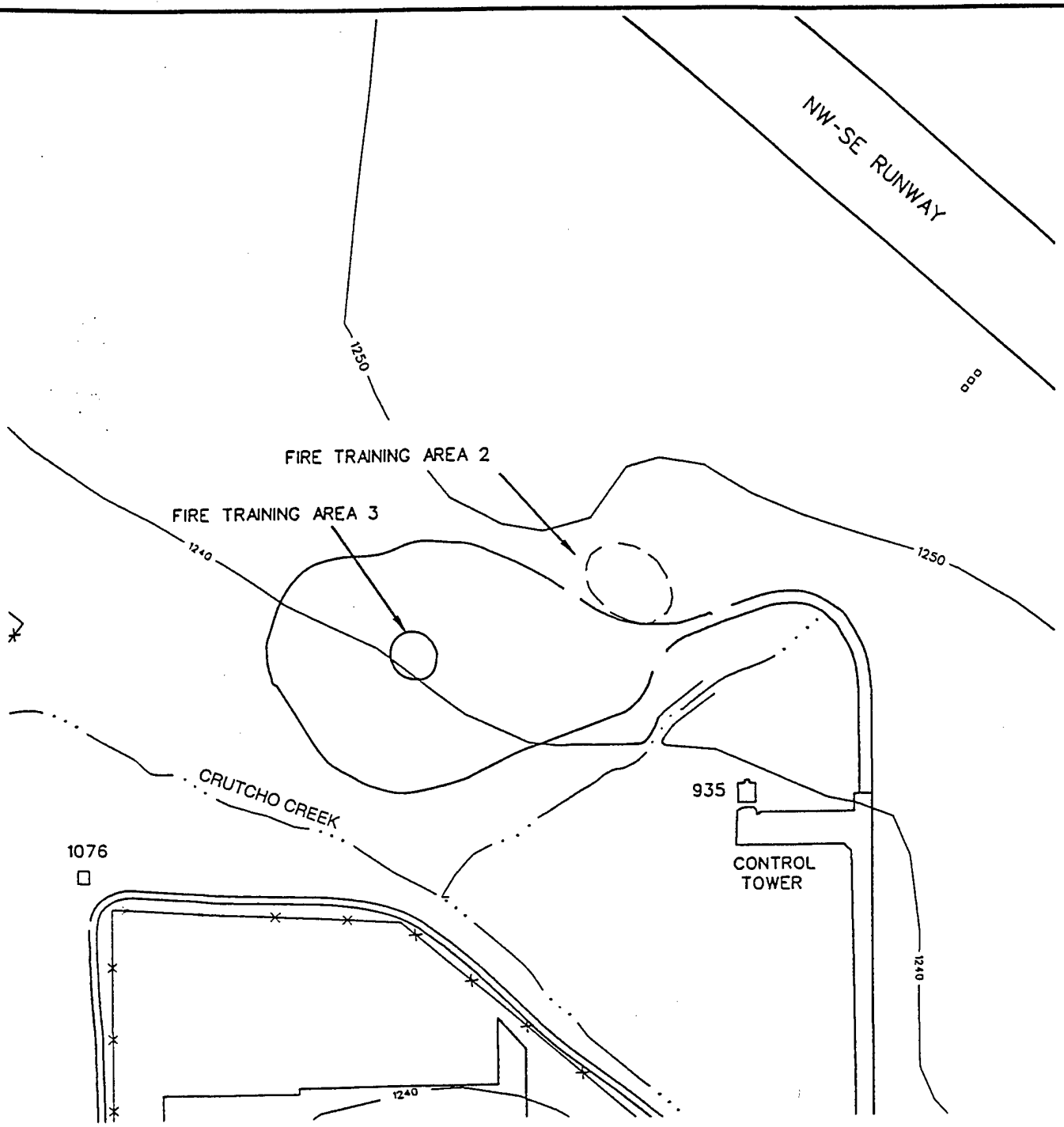
- Final Report, Phase I RCRA Facility Investigation Report for Appendix I Sites, SWMU-8, Fire Training Area 2, (IT, 1994); and
- Draft Report, RCRA Facility Investigation Report for Selected Appendix I Sites at Tinker Air Force Base, OK (TT, 1996).

3.1 TOPOGRAPHY, SURFACE HYDROLOGY, AND CLIMATE

Tinker AFB is located in central Oklahoma and topography varies from almost level to gently rolling. The local relief is a result of dissection by erosional activity and stream channel development. Ground surface elevations at Tinker AFB range from 1,190 feet above the NGVD near the northwest corner where Crutcho Creek intersects the Base boundary, to 1,320 feet NGVD at Area D, located east of the main installation. A topographic map of FTA-2 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 Crutcho Creek, a tributary of the North Canadian River. Kuhlman Creek also collects drainage from the northwest portion of the Base and discharges into Crutcho Creek north of the Base. The northeast portion of the Base is drained primarily by tributaries of Soldier Creek, which is also a tributary of Crutcho Creek. Two small unnamed intermittent tributaries of Elm Creek cross installation boundaries south of the main runway, and 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.

In the area of FTA-2, topography slopes gently to the southwest, towards Crutcho Creek, with elevations ranging from 1,240 to 1,250 feet NGVD. The sloping topography is modified by an incised channel of a southwest-flowing tributary to Crutcho Creek. The channel of this tributary is approximately 5 to 10 feet below the grade of the surrounding terrain. Surface water run-off at FTA-2 travels southeast to this southwest-draining tributary. The tributary emerges from a culvert located



Source: IT, 1994.

FIGURE 3.1

TOPOGRAPHIC MAP OF FIRE TRAINING AREA 2

Site FTA 2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

approximately 200 feet east of FTA-2, after draining an area occupied by industrial facilities on the east side of the airfield.

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, 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 (IT, 1994). Because of similar lithologies and 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 two 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 Crutcho 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

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
QUATERNARY	RECENT AND PLEISTOCENE	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
		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
PERMIAN	LOWER PERMIAN	Hennessey Group (includes Kingmen Siltstone and Fairmont Shale)	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.
		Garber Sandstone	500±	Deep-red to reddish-orange sandstone, massive and cross-bedded and interfingered with red shale and siltstone.	Poorly to moderately permeable. Important source of groundwater in Cleveland and Oklahoma counties. 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.
		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.

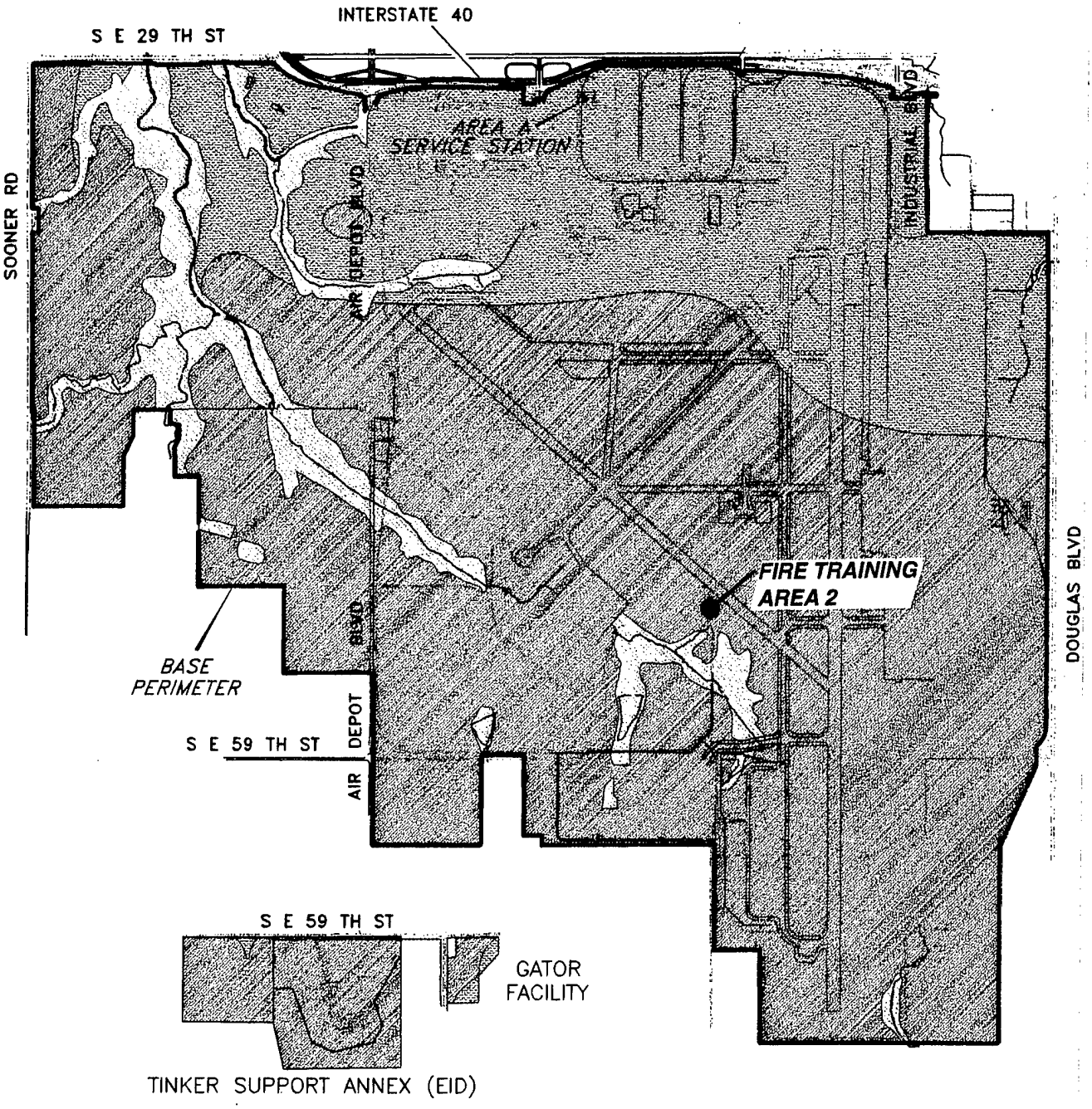


FIGURE 3.2

SURFACE GEOLOGIC MAP
TINKER AIR FOCE BASE

Site FTA 2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Source: Tinker AFB, 1991; IT, 1996.

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 structures. The Wellington Formation, underlying the Garber Sandstone, outcrops 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.

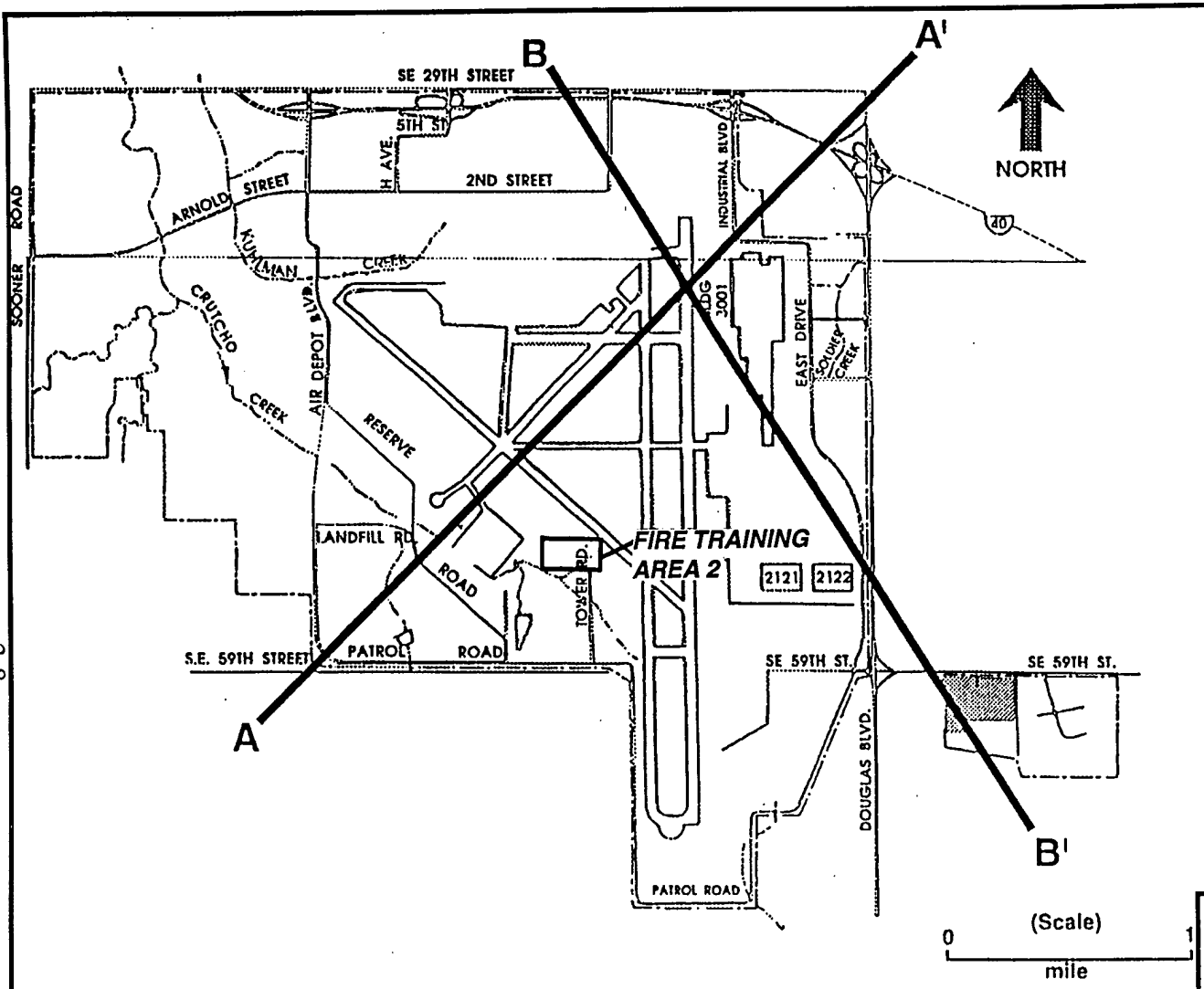
3.2.2 Regional Hydrogeology

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 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 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



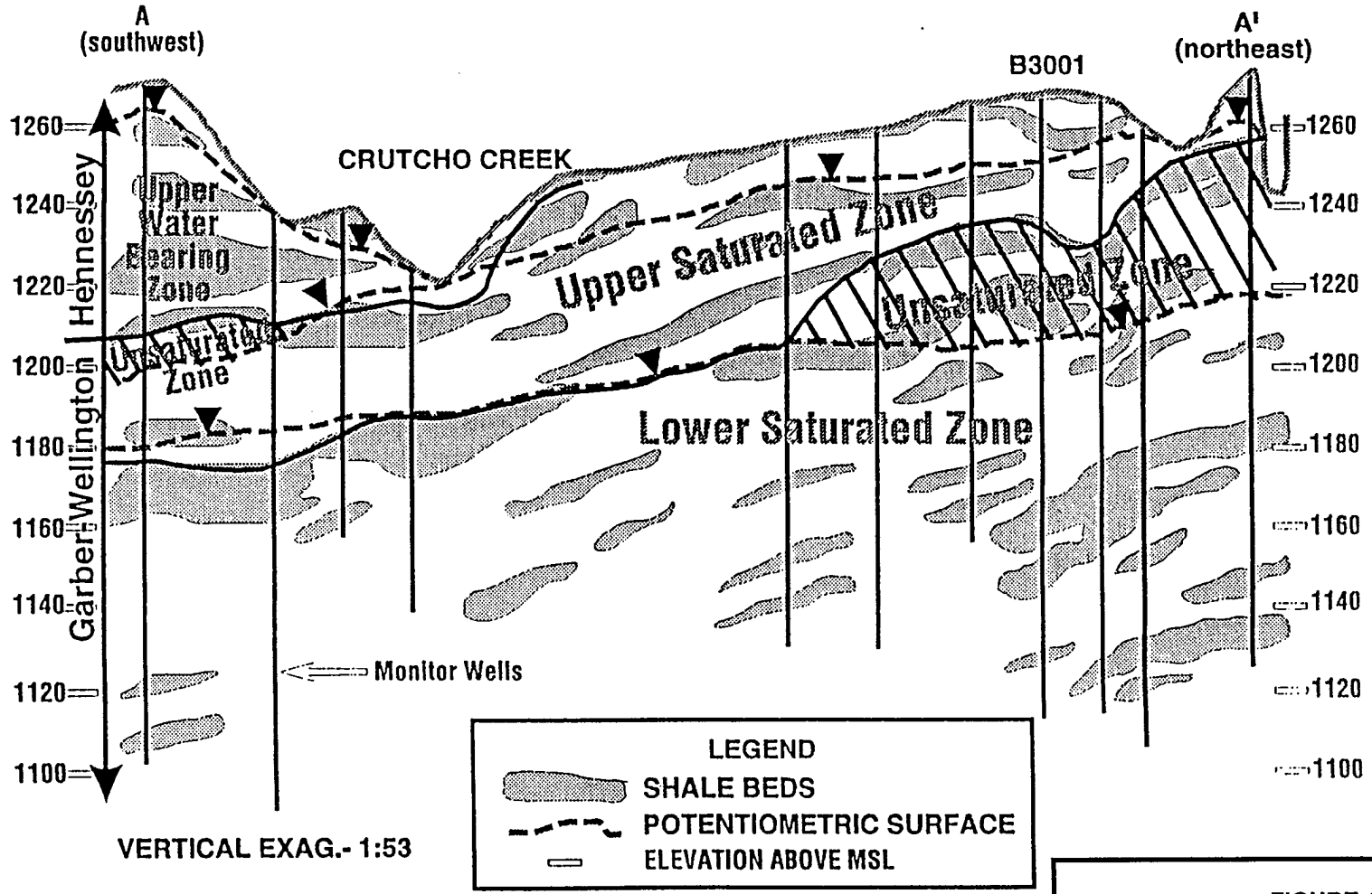
Source: IT, 1994.

FIGURE 3.3

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

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



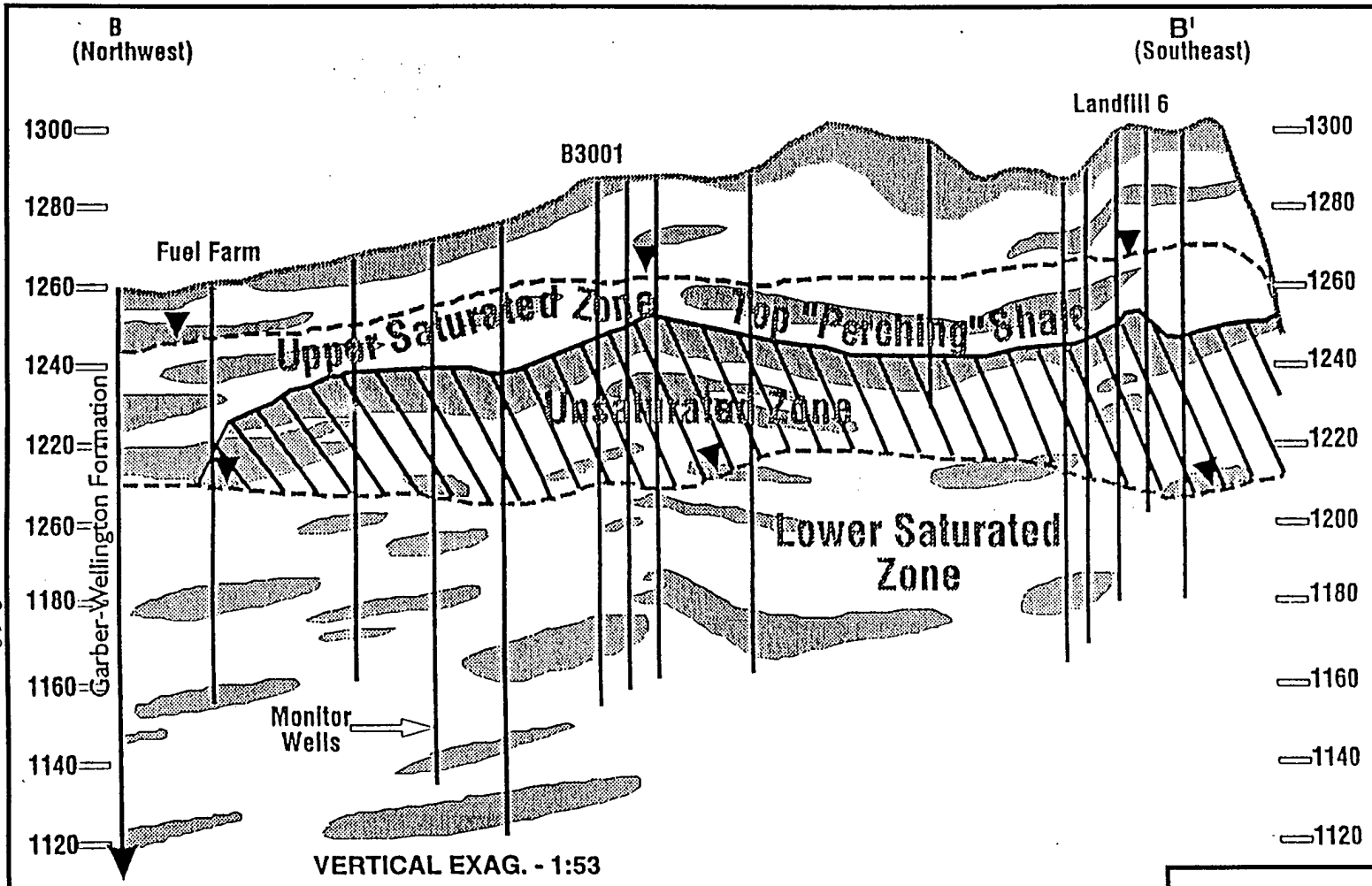
Source: IT, 1994.

FIGURE 3.4

HYDROGEOLOGIC CROSS-SECTION A-A'

Site FTA 2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



LEGEND

- SHALE BEDS
- POTENTIOMETRIC SURFACE
- Elevation above MSL

Source: IT, 1994.

FIGURE 3.5

HYDROGEOLOGIC CROSS-SECTION B-B'

Site FTA 2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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, 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 portions of the Base an unsaturated zone is present between the USZ/LSZ aquitard and the top of the LSZ potentiometric surface, 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 FTA-2 GEOLOGY AND HYDROGEOLOGY

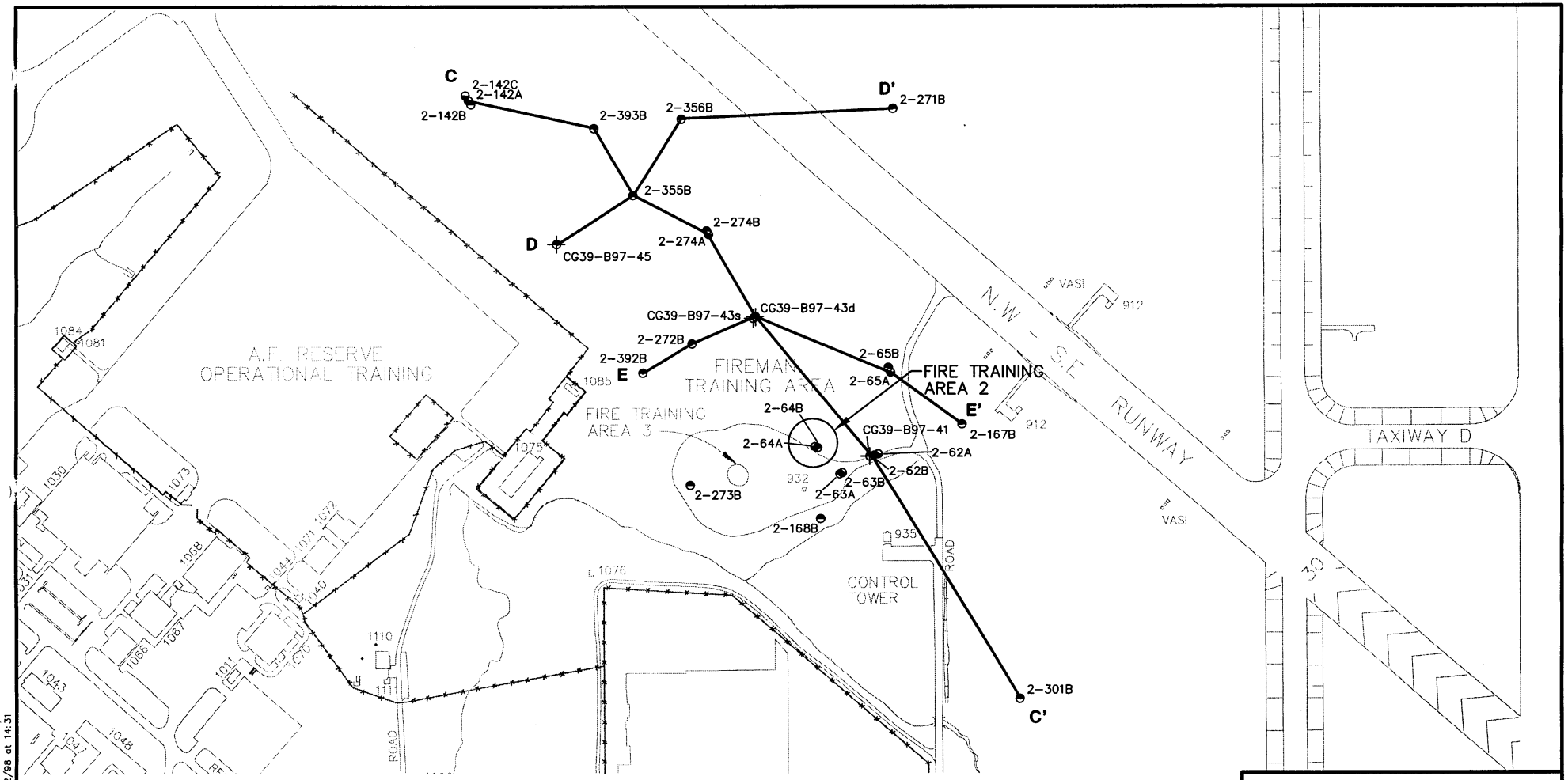
3.3.1 Site Geology

Stratigraphy through the center of the site is depicted in three hydrogeologic cross-sections through FTA-2 (Figure 3.6). Cross-section C-C' (Figure 3.7) is drawn in the approximate direction of groundwater flow, while Cross-sections D-D' (Figure 3.8), and E-E' (Figure 3.9) illustrate the stratigraphy perpendicular to Cross-section C-C' and the approximate direction of contaminant transport. Approximately 10 to 20 feet of reddish silty clay or clayey silt of the Hennessey Group overlies sands of the Garber Sandstone. The Garber Sandstone consists of fine-grained sands with silt and clay lenses. The USZ-LSZ aquitard occurs approximately 40 to 50 feet bgs and consists of a 6- to 12-foot thick interval with high clay content and cemented siltstone (Figure 3.7).

The USZ sands are primarily unconsolidated, with local lenses and intervals that are poorly to moderately cemented with silica or calcareous cement. In the southern and eastern portion of the study area a three- to six-foot thick interval of silt and clay separates the USZ into two separable sandstone intervals, herein referred to as the upper and lower USZ sand intervals (Cross-sections C-C' and E-E'). This intermediate clay and silt layer extends north and westward to well locations CG39-B97-43s,d and CG39-B97-45. To the north of these locations the intermediate clay and silt layer is discontinuous and less developed (Cross-section C-C' and D-D'). There are insufficient data to determine the extent or continuity of the intermediate clay and silt layer to the west of location CG39-B97-45.

3.3.2 Site Hydrogeology

The hydrogeology at FTA-2 is characterized by groundwater flow within the USZ and the LSZ as described for regional conditions. Groundwater elevations and



LEGEND

2-142B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-142A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
CG39-B97-41	TEMPORARY MONITORING POINT LOCATION/ UPPER SATURATED ZONE
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR

0 150 300 600
FEET

FIGURE 3.6

CROSS-SECTION LOCATION MAP

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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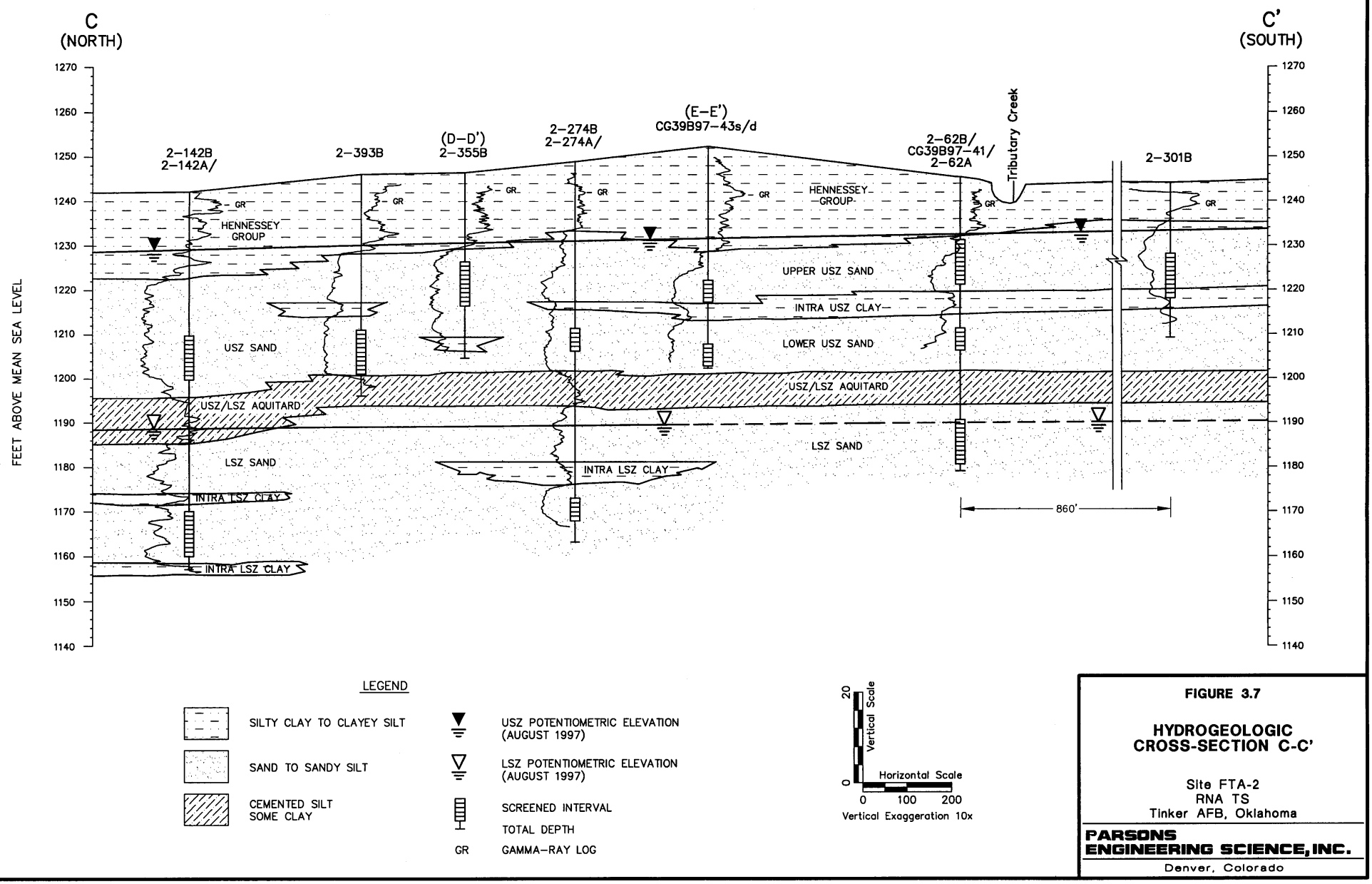

FIGURE 3.7

HYDROGEOLOGIC CROSS-SECTION C-C'

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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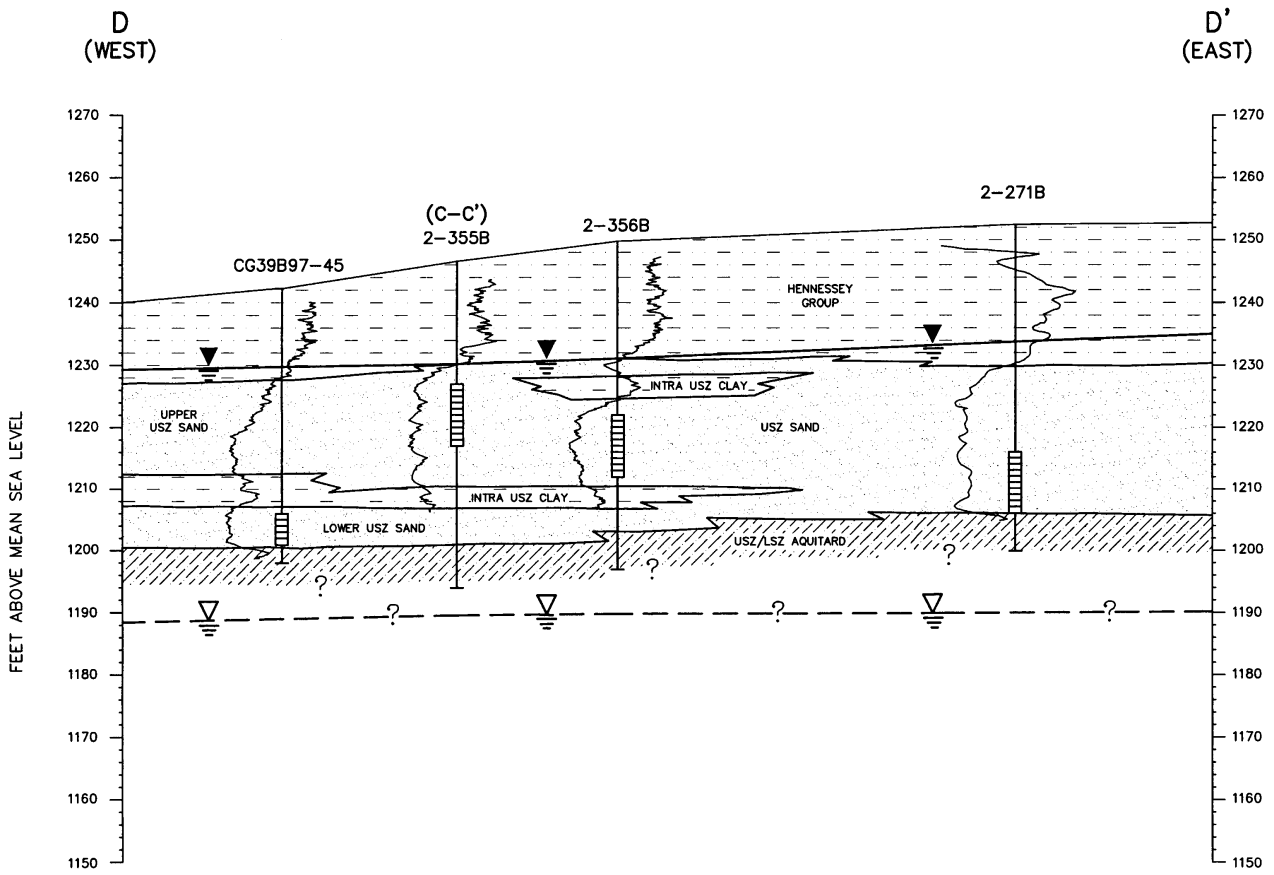

LEGEND

- SILTY CLAY TO CLAYEY SILT
- SAND TO SANDY SILT
- CEMENTED SILT SOME CLAY
- USZ POTENTIOMETRIC ELEVATION (AUGUST 1997)
- LSZ POTENTIOMETRIC ELEVATION (AUGUST 1997)
- SCREENED INTERVAL
- TOTAL DEPTH
- GR GAMMA-RAY LOG

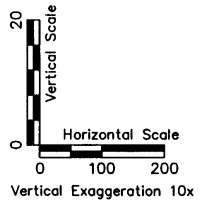

FIGURE 3.8

HYDROGEOLOGIC CROSS-SECTION D-D'

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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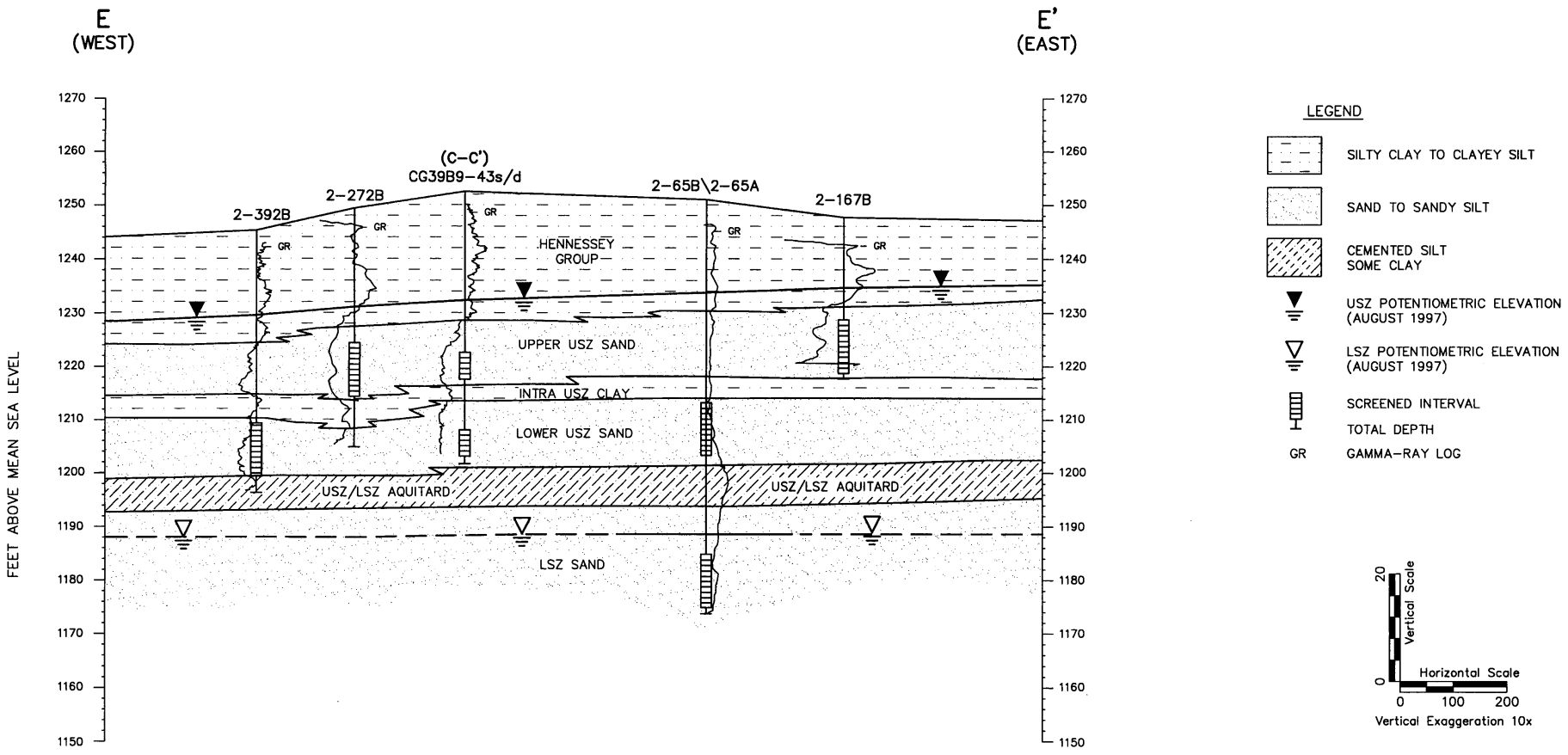

FIGURE 3.9

HYDROGEOLOGIC CROSS-SECTION E-E'

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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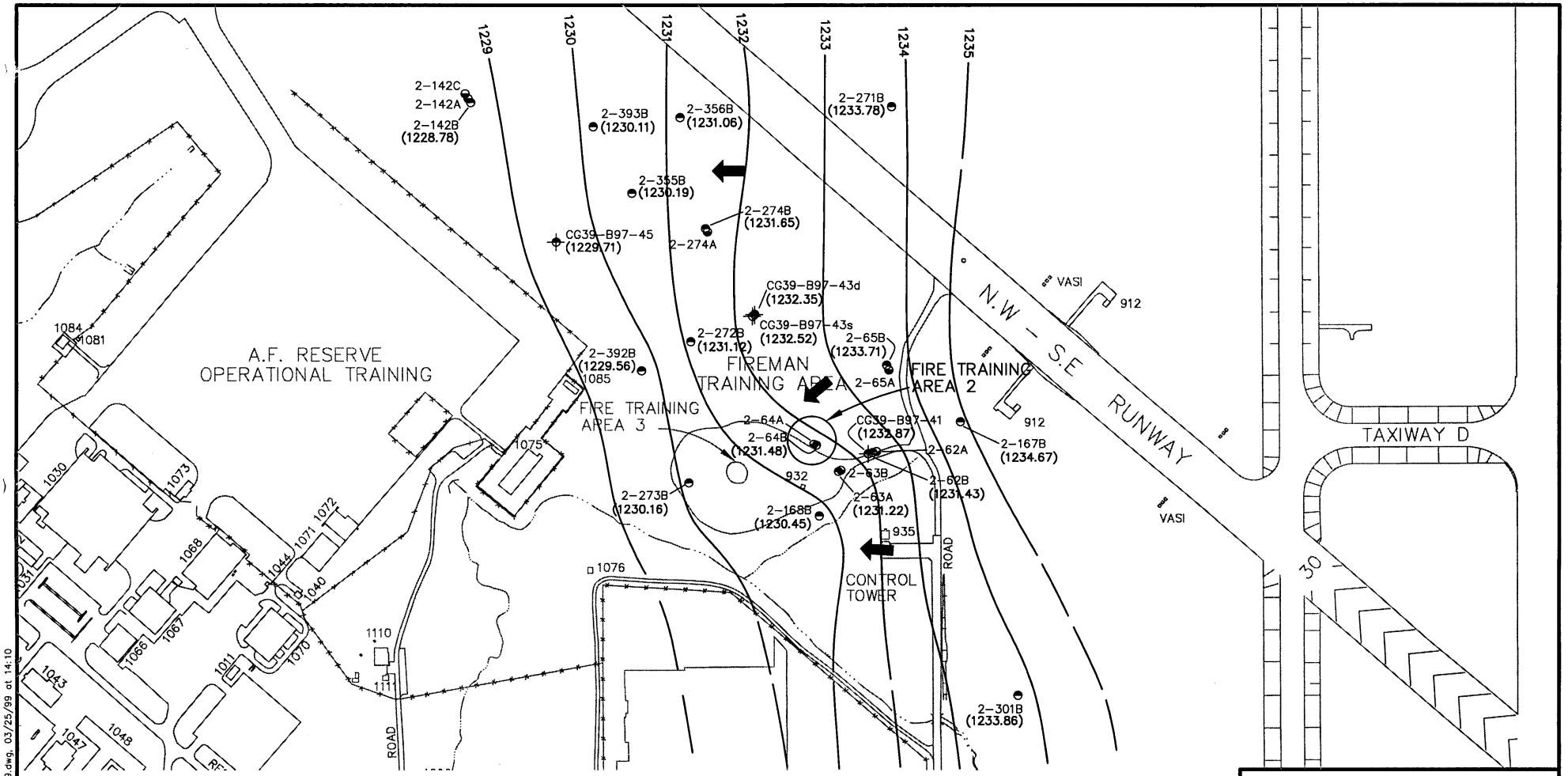
monitoring well completion data are listed in Table 2.2. Geologic boring logs, monitoring well completion records, geophysical logs, and slug test data for newly installed monitoring well/points at FTA-2 are included in Appendix B.

3.3.2.1 Upper Saturated Zone

The USZ potentiometric surface generally lies above the Hennessey Group/Garber Sandstone (USZ sands) contact approximately 9 to 18 feet bgs. Figure 3.10 is a groundwater potentiometric surface map for the USZ based on data from August 1997. The horizontal hydraulic gradient in the USZ is approximately 0.003 to 0.01 ft/ft. Assuming isotropic horizontal hydraulic conductivity, horizontal flow direction in the vicinity of FTA-2 is generally towards the west-southwest. However, based on contaminant transport direction, horizontal hydraulic conductivity in the USZ may be anisotropic, with the primary direction of contaminant transport to the northwest (see Section 4.2 for further discussion of contaminant transport). The direction of maximum horizontal hydraulic gradient in the USZ for 1997 is consistent with gradient data observed in 1994 (IT, 1994), and 1996 (Parsons ES, 1997). The base of the USZ is the USZ/LSZ aquitard, a layer of hard siltstone traceable across the area at a depth of approximately 40 to 50 feet bgs. Because the underlying LSZ exists primarily as an unconfined aquifer (following Section 3.3.2.2), the USZ in the vicinity of FTA-2 is primarily a perched aquifer.

Vertical hydraulic gradients between the upper and lower USZ sand intervals were calculated for monitoring well pair CG39-B97-43s and CG39-B97-43d, and well pair 2-62B and CG39-B97-41. The vertical gradients were calculated by dividing the water level elevation difference between two clustered wells by the distance between the midpoints of the saturated portions of the well screens. The vertical groundwater gradient at well pair CG39-B97-43s and CG39-B97-43d was 0.012 ft/ft in a downward direction, typical of an unconfined/perched aquifer. The vertical groundwater gradient at well pair 2-62B and CG39-B97-41 was 0.081 ft/ft in an upward direction, indicating semi-confined or confined conditions. While the USZ is regionally considered an unconfined aquifer, semi-confined to confined conditions may exist where the potentiometric surface intercepts overlying fine-grained deposits. At FTA-2 an upward USZ groundwater gradient within the source area at well pair 2-62B and CG39-B97-41 may impact source area contaminant transport.

Hydraulic conductivity in the USZ was estimated by performing slug tests in seven newly installed and developed monitoring wells (CG39-B97-41, CG39-B97-43s, CG39-B97-43d, CG39-B97-45, 2-392B, 2-393B, and 3-355B). Hydraulic conductivity results are shown in Table 3.2. Results are segregated to compare the upper USZ sand interval and the lower USZ sand interval. The estimated hydraulic conductivity values for the upper USZ sand interval ranged from 6.5 to 28 feet per day (ft/day), and averaged 14 ft/day. The estimated hydraulic conductivity values for the lower USZ sand interval ranged from 0.9 to 44 ft/day, and averaged 15 ft/day. While the lower USZ sand interval demonstrated a greater range of hydraulic conductivities, overall values for the upper and lower USZ sand intervals are similar, corresponding to accepted literature values for fine-grained unconsolidated sand (Spitz and Moreno, 1996).



LEGEND

2-142B (1228.78) — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER / GROUNDWATER ELEVATION IN FEET ABOVE MEAN SEA LEVEL	s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER	DIRECTION OF GROUNDWATER FLOW
CG39-B97-41 — MONITORING POINT LOCATION/ UPPER SATURATED ZONE	1231 — LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED

0 150 300 600
FEET

FIGURE 3.10

UPPER SATURATED ZONE POTENTIOMETRIC SURFACE AUGUST 1997

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 3.2
UPPER SATURATED ZONE HYDRAULIC CONDUCTIVITIES AND AVERAGE GROUNDWATER VELOCITIES
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Monitoring Well	Test Date	Screened Interval Elevation (ft bgs)[a/]	Test Number	Hydraulic Conductivity (K) (ft/day)[b/]	(cm/sec)[c/]	(gpd/ft^2)[d/]	Estimated Effective Porosity	Hydraulic Gradient (ft/ft)[e/]	Average Groundwater Velocity (ft/yr)[f/]
Upper USZ Sand Interval									
CG39-B97-43S	Aug-97	30.0-35.0	1	18	6.4E-03	135	0.20	0.006	198
			2	28	1.0E-02	212	0.20	0.006	311
			3	16	5.5E-03	117	0.20	0.006	171
			Average	21	7.3E-03	155	0.20	0.006	227
2-355B	Aug-97	19.9-29.9	1	7.7	2.7E-03	57	0.20	0.006	84
			2	6.5	2.3E-03	49	0.20	0.006	72
			Average	7.1	2.5E-03	53	0.20	0.006	78
Average of Upper USZ Sand Interval:				**14**	**4.91E-3**	**104**	**0.20**	**0.006**	**152**
Lower USZ Sand Interval									
CG39-B97-41	Aug-97	34.0-39.0	1	8.8	3.1E-03	66	0.20	0.006	97
			2	12	4.2E-03	89	0.20	0.006	131
			Average	10	3.7E-03	78	0.20	0.006	114
CG39-B97-43D	Aug-97	44.5-49.5	1	27	9.5E-03	202	0.20	0.006	295
			2	36	1.3E-02	272	0.20	0.006	398
			Average	32	1.1E-02	237	0.20	0.006	347
CG39-B97-45	Aug-97	36.5-41.5	1	44	1.5E-02	326	0.20	0.006	477
2-392B	Aug-97	36.0-46.0	1	1.2	4.4E-04	9.0	0.20	0.006	14
			2	0.9	3.2E-04	7.0	0.20	0.006	9.8
			Average	1.1	3.8E-04	8.0	0.20	0.006	12
2-393B	Aug-97	35.0-45.0	1	18	6.2E-03	132	0.20	0.006	193
			2	18	6.3E-03	134	0.20	0.006	196
			Average	18	6.3E-03	133	0.20	0.006	194
Average of Lower USZ Sand Interval:				**15**	**5.37E-3**	**114**	**0.20**	**0.006**	**167**

[a/] ft bgs = Feet below ground surface.
[b/] ft/day = Feet per day.
[c/] cm/sec = Centimeters per second.
[d/] gpd/ft^2 = Gallons per day per square foot.
[e/] ft/ft = Foot per foot.
[f/] ft/yr = Feet per year.

The effective porosity of a given lithology is a measure of the amount of void space available for fluid flow through the lithologic unit. Effective porosity for the USZ sand intervals is estimated to be approximately 20 to 25 percent, based on accepted literature values (Spitz and Moreno, 1996) and the high estimated hydraulic conductivities. However, effective porosity can reduced by localized intervals of cementation or fine-grained deposits. The effective porosity of the USZ/LSZ aquitard would be much less than that of the overlying USZ sands, with an estimated range of 0.5 to 5 percent based on a silt or cemented dense sandstone lithology (Spitz and Moreno, 1996).

Assuming isotropic horizontal hydraulic conductivity, the advective velocity of groundwater in the direction of maximum hydraulic gradient is given by:

$$\bar{v} = \frac{K}{n_e}\frac{dH}{dL}$$

Where: $\bar{v}$ = Average advective groundwater velocity (seepage velocity) [L/T]

K = Hydraulic conductivity [L/T]

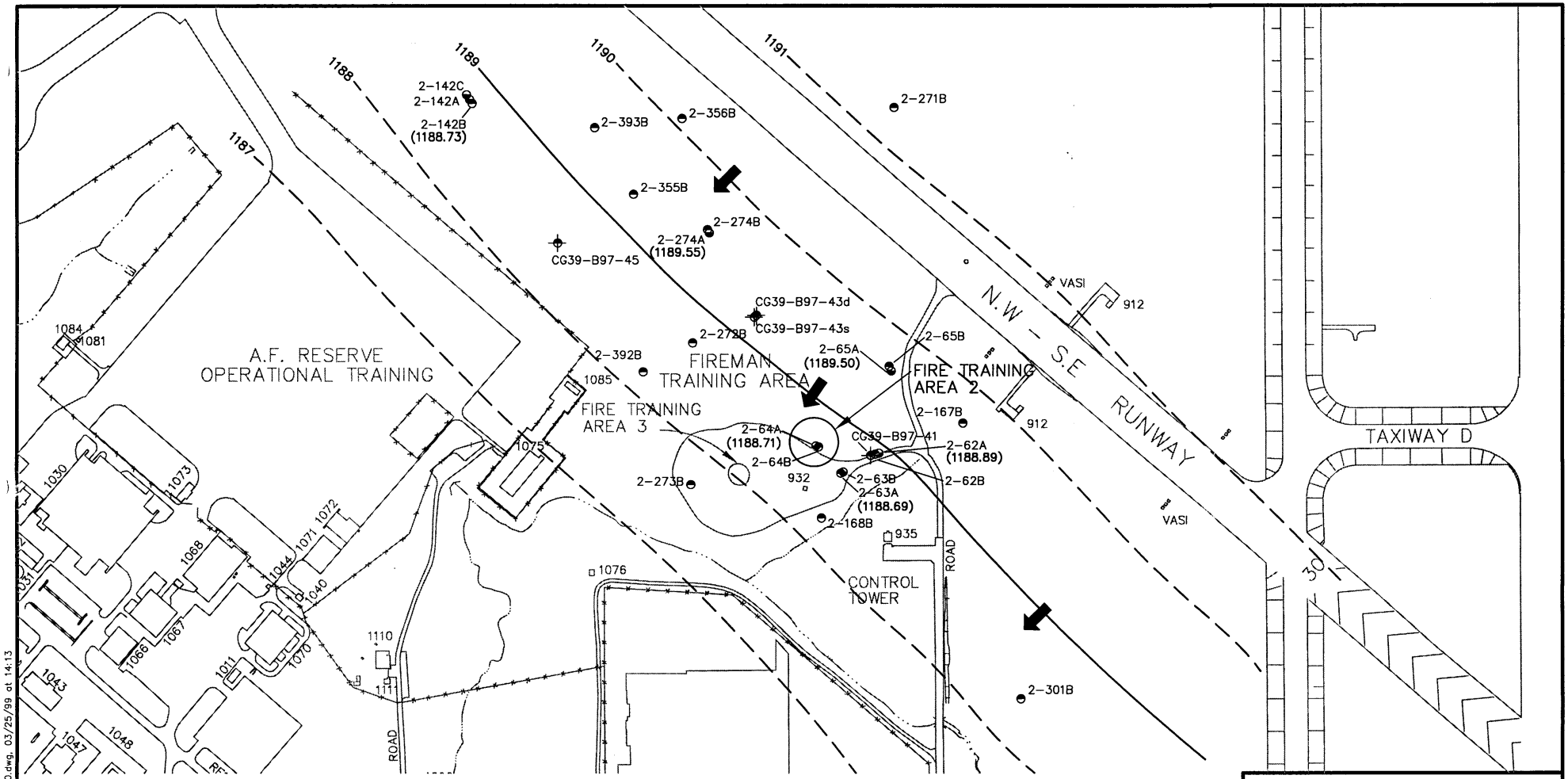
dH/dL = Lateral hydraulic gradient [L/L]

n_e = Effective porosity.

Using the range of hydraulic conductivity (0.9 to 44 ft/day), an average horizontal hydraulic gradient of 0.006 ft/ft, and an estimated effective porosity of 0.20 for fine-grained sand, the advective groundwater flow velocity in the USZ is calculated (Table 3.2) to be 0.027 to 1.305 ft/day [9.8 to 477 feet per year (ft/yr)]. Based on average hydraulic conductivites, the average advective groundwater flow velocity in the upper USZ sand interval is calculated to be 0.417 ft/day (152 ft/yr), and the average advective groundwater flow velocity in the lower USZ sand interval is calculated to be 0.456 ft/day (167 ft/yr). Advective groundwater velocities in flow directions other than the direction of maximum hydraulic gradient would be less than these computed values.

3.3.2.2 Lower Saturated Zone

The top of the LSZ coincides approximately with the base of the USZ-LSZ aquitard at a depth of approximately 50 to 60 feet bgs. In general, the LSZ potentiometric surface lies beneath the base of the USZ-LSZ aquitard under unconfined conditions. Locally the LSZ may be confined where the LSZ potentiometric surface rises above the USZ-LSZ aquitard (monitoring wells 2-142A and 2-65A, Cross-sections C-C' and E-E'). Figure 3.11 is a groundwater potentiometric surface map for the LSZ based on data from August 1997. The direction of maximum hydraulic gradient and groundwater flow (assuming isotropic horizontal hydraulic conductivity) in the LSZ is towards the southwest at an approximate horizontal hydraulic gradient of 0.0033 ft/ft. The flow direction and gradient in the LSZ for 1997 are consistent with groundwater flow direction and gradient data observed in 1994 (IT, 1994), and 1996 (Parsons ES, 1997).



LEGEND

2-142B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-142A (1188.73)	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER / GROUNDWATER ELEVATION IN FEET ABOVE MEAN SEA LEVEL
CG39-B97-41	MONITORING POINT LOCATION/ UPPER SATURATED ZONE
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
	DIRECTION OF GROUNDWATER FLOW
1190	LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED

FIGURE 3.11

LOWER SATURATED ZONE POTENTIOMETRIC SURFACE AUGUST 1997

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

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Denver, Colorado

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While the upper and lower USZ sand intervals are hydraulically connected, where it is developed the intermediate clay and silt interval may act as a significant vertical permeability barrier to local groundwater flow and contaminant transport.

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 deep (>400 feet) wells in the Garber-Wellington Formation, supplemented by water purchased from Oklahoma City. Midwest City also obtains potable water from deep wells screened in the Central Oklahoma Aquifer, including the Garber-Wellington Formation.

3.5 POTENTIAL PATHWAYS AND RECEPTORS AT FTA-2

Precipitation runoff at FTA-2 primarily flows to a tributary of Crutcho Creek or the Base storm sewer system. Groundwater at FTA-2 flows generally west-southwest, with local variations due to lithologic, topographic, or surface (tributary) features. A light industrial area is present west of FTA-2. Because the site is located near an industrial area on a secured military Base, Base workers are the most probable potential receptors that could be exposed to any site-related contamination. Other potential receptors include Tinker AFB water supply wells located on the western portion of the Base, over one mile away in a downgradient direction, and screened at a depth of over 400 feet bgs.

SECTION 4

CONTAMINANT DISTRIBUTION AND EVIDENCE FOR BIODEGRADATION

Soil and groundwater have been contaminated as a result of fire training activities at FTA-2. Work during the RFI (IT, 1994, and TT, 1996) focused on defining the nature and extent of contamination at the site, and annual groundwater monitoring is conducted (Tinker AFB, 1997). As needed, the data collected during those efforts are used to supplement the TS field investigation results presented in the following subsections. In particular, this section focuses on data useful for evaluating and modeling natural attenuation of CAHs dissolved in groundwater following a summary of hydrocarbon degradation.

4.1 OVERVIEW OF HYDROCARBON BIODEGRADATION

Primary mechanisms for natural attenuation of fuel hydrocarbons 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 ultimately 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.

To provide a foundation for site interpretations, the following subsections review the major bioremediation processes that act upon CAHs and fuel hydrocarbons. Chlorinated solvents are the primary groundwater contaminants at FTA-2. Total fuel carbon, benzene, toluene, and chlorobenzenes are generally limited to the FTA-2 source area (monitoring wells 2-62B, 2-63B, 2-64B, and 2-65B). Because the terminology of describing biodegradation of CAHs and fuel hydrocarbons is similar, a generalized review of the processes is first presented. Subsequent sections focus on the biodegradation of CAHs.

4.1.1 Review of Biodegradation Processes

Microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous reduction/oxidation (redox) reactions involving the transfer of electrons from electron donors to available electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors may be natural organic carbon, fuel hydrocarbon compounds (BTEX), and less-chlorinated solvents [e.g., vinyl chloride (VC), dichloroethene (DCE), dichloroethane (DCA), or chlorinated benzenes ranging from chlorobenzene (CB) to tetrachlorobenzene].

Fuel hydrocarbons or solvents are completely degraded or detoxified if they are utilized as the primary electron donor (i.e., as a primary substrate or carbon source) for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states, and include oxygen, nitrate, ferric iron, sulfate, manganese, carbon dioxide, and highly chlorinated solvents [e.g., PCE, TCE, tetrachloroethane (PCA), trichloroethane (TCA), and polychlorinated benzenes].

The driving force of biodegradation is electron transfer, which is quantified by the Gibbs free energy of the reaction ($\Delta G°_r$) (Stumm and Morgan, 1981; Bouwer, 1994; Godsey, 1994). The value of $\Delta G°_r$ represents the quantity of free energy consumed ($\Delta G°_r>0$) or yielded ($\Delta G°_r<0$) to the system during the reaction. Although thermodynamically favorable, most of the reactions involved in biodegradation of fuel hydrocarbons or CAHs cannot proceed abiotically due to a 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. $\Delta G°_r < 0$). Most reactions involving biodegradation of contaminants do yield energy to the microbes. However, specific geochemical conditions are often necessary for biodegradation reactions, which allow the appropriate microbial population to develop and grow.

Microorganisms preferentially utilize electron acceptors while metabolizing hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor where present. It is under aerobic conditions that fuel hydrocarbons and the less chlorinated solvents are most commonly used as electron donors. After the DO is consumed, anaerobic microorganisms use native electron acceptors (as available) in the following order of preference: nitrate, manganese, ferric iron hydroxide, sulfate, and finally carbon dioxide. Under anaerobic conditions, BTEX compounds and other fuel hydrocarbons are still used as electron donors. Chlorinated solvents that are amenable to reductive dehalogenation are generally used as electron acceptors when aquifer conditions are such that sulfate or carbon dioxide is the preferred electron acceptor. Because the biodegradation of fuel hydrocarbons and CAHs can deplete the concentrations of electron acceptors, examining the distribution of electron acceptor concentrations can provide evidence of whether biodegradation is occurring and the degree to which it is occurring.

The expected sequence of redox reactions in an aquifer is also a function of the ORP of the groundwater. ORP is a measure of the relative tendency of a solution or chemical reaction to accept or transfer electrons, and it can be used as an indicator of which redox reactions are operating at a site. As each subsequent electron acceptor is utilized, the groundwater becomes more reducing, and the redox potential of the water decreases. Microbial mediated redox reactions are the main driving force for ORP decreases.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, manganese reduction, 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. Vroblesky and Chapelle (1995) 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 Chlorinated Solvents

Chlorinated solvents can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Miller and Guengerich, 1982; Reineke and Knackmuss, 1984; Wilson and Wilson, 1985; de Bont *et al.*, 1986; Nelson *et al.*, 1986; Spain and Nishino, 1987; 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; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; Sander *et al.*, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; Chapelle, 1993; McCarty and Semprini, 1994; Vogel, 1994; Suflita and Townsend, 1995; Bradley and Chapelle, 1996; Klier *et al.*, 1996; Spain, 1996). Biodegradation of chlorinated solvents (or CAHs) and chlorinated benzenes results from the same general processes that bring about biodegradation of fuel hydrocarbons. However, a more complex series of processes often is involved, and CAHs and chlorinated benzenes may act as either substrates (electron donors) or electron acceptors depending upon what geochemical conditions prevail.

Whereas fuel hydrocarbons are biodegraded in essentially one step by acting as an electron donor/carbon source, CAHs and chlorinated benzenes may undergo several types of biodegradation involving multiple steps. 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 likely.

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, less-chlorinated CAHs, or chlorinated benzenes with four or fewer chlorines) is present, it may also be utilized as an electron donor. Most chlorinated solvents that can act as electron donors have thus far only been demonstrated to do so under aerobic conditions, with the notable exception of VC (Bradley and Chapelle, 1996). 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 also will provide evidence of the types of biodegradation processes acting at a site. A more complete description of the main types of biodegradation reactions affecting CAHs dissolved in groundwater 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 of chlorinated ethenes occurs by sequential dehalogenation from PCE to TCE to DCE to VC to ethene. An analogous pattern for chlorinated ethanes might be PCA to TCA to DCA to CA, and for chlorinated benzenes the pattern might be tetrachlorobenzene (TeCB) to trichlorobenzene (TCB) to dichlorobenzene (DCB) to CB. Depending upon environmental conditions, these sequences may be interrupted, with other processes (e.g., aerobic or abiotic degradation) then acting upon the products. 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. Of the ethenes, PCE is the most susceptible 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 the ethene compounds. Likewise, hexachlorobenzene is more susceptible to reductive dehalogenation than less-chlorinated benzenes. In general, the rate of reductive dehalogenation of chlorinated solvents 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 can also be controlled by the redox conditions of the site groundwater system. In general, reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of compounds, occur under methanogenic conditions (Bouwer, 1994). Dehalogenation of PCE and TCE to DCE can proceed under mildly reducing conditions such as nitrate reduction or ferric iron [iron (III)] reduction (Vogel *et al.*, 1987). However, the transformation of DCE to VC, or the transformation from VC to ethene requires more strongly reducing conditions (Freedman and Gossett, 1989; DeStefano *et al.*, 1991; De Bruin *et al.*, 1992).

Reductive dehalogenation of some compounds can also preferentially produce specific daughter compounds. For example, during reductive dehalogenation of TCE or PCE, all three isomers of DCE can theoretically 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.

When chlorinated 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/electron donors can include low-

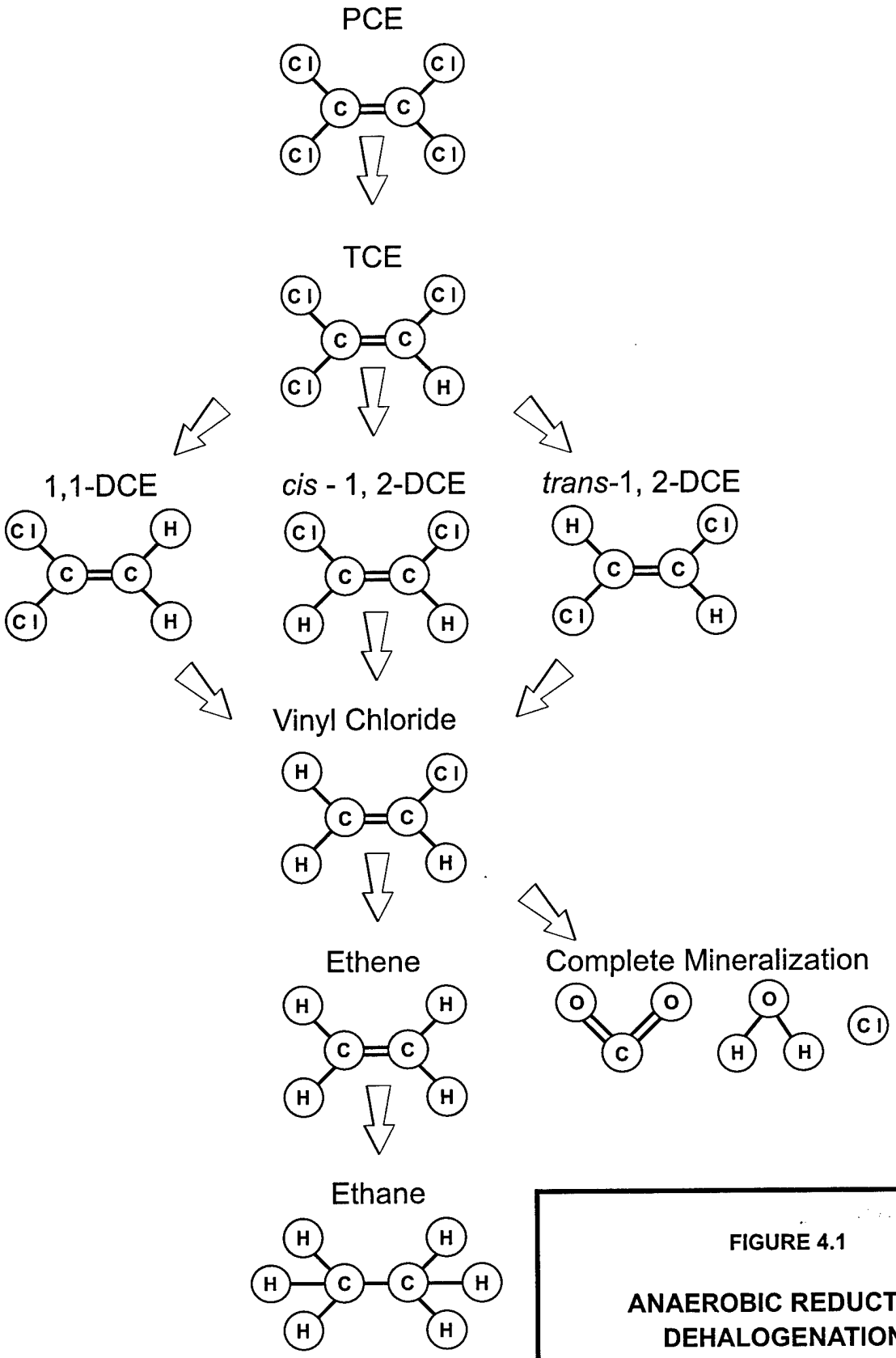

FIGURE 4.1

ANAEROBIC REDUCTIVE DEHALOGENATION

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molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, fuel hydrocarbons, or less-chlorinated solvents (as discussed below).

4.1.2.2 Electron Donor Reactions

Under aerobic conditions some CAHs 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 compound. In contrast to reactions in which the chlorinated compound is used as an electron acceptor, only the least oxidized chlorinated solvents (e.g., VC, DCE, or CB) may be utilized as electron donors in biologically mediated redox reactions. Also, chlorinated benzenes with up to four chlorines (i.e., CB, DCB isomers, TCB isomers, and TeCB isomers) can act as electron donors under aerobic conditions.

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). For example, Davis and Carpenter (1990) describe the aerobic oxidation of VC in groundwater, and McCarty and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates. Dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments (McCarty and Semprini, 1994), and all three DCE isomers can be mineralized under aerobic conditions (Klier *et al.*, 1996). In addition, Bradley and Chapelle (1996) show evidence of oxidation of VC under iron-reducing conditions as long as there is sufficient bioavailable iron (III). Aerobic metabolism of VC may be characterized by a loss of VC mass, a decreasing molar ratio of VC to other CAH compounds, and rarely, the presence of chloromethane.

CB and polychlorinated benzenes (up to and including TeCB) have been shown to biodegrade under aerobic conditions. Several studies have shown that bacteria are able to utilize CB (Reineke and Knackmuss, 1984), 1,4-DCB (Reineke and Knackmuss, 1984; Schraa *et al.*, 1986; Spain and Nishino, 1987), 1,3-DCB (de Bont *et al.*, 1986), 1,2-DCB (Haigler *et al.*, 1988), 1,2,4-TCB (van der Meer *et al.*, 1987; Sander *et al.*, 1991), and 1,2,4,5-TeCB (Sander *et al.*, 1991) as primary growth substrates in aerobic systems. Nishino *et al.* (1994) note that aerobic bacteria able to grow on chlorobenzene have been detected at a variety of chlorobenzene-contaminated sites but not at uncontaminated sites. Spain (1996) notes that this provides strong evidence that the bacteria are selected for their ability to derive carbon and energy from chlorobenzene degradation *in situ*. The pathways for all of these reactions are similar and are also similar to that of benzene (Chapelle, 1993; Spain, 1996). The only significant difference between aerobic oxidation of chlorobenzenes and benzene is the required elimination of chlorine. Anaerobic oxidation of chlorobenzenes has not been conclusively documented, although little work has been done on the subject (Spain, 1996).

4.1.2.3 Cometabolism

When a chlorinated solvent is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, an enzyme or cofactor that is fortuitously produced by organisms for other

purposes catalyzes the degradation of the compound. The organism receives no known benefit from degradation of the solvent; rather the cometabolic degradation of the solvent 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 for chlorinated ethenes in aerobic environments, although it potentially could occur with other chlorinated solvents or under anaerobic conditions. Aerobic degradation 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.

In the cometabolic process, bacteria indirectly transform TCE while they use BTEX or another carbon source to meet their energy requirements. TCE does not enhance the degradation of carbon sources, nor does its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. Given this relationship, it would follow that depletion of suitable substrates (BTEX or other organic carbon sources) likely limits cometabolism of CAHs.

4.1.2.4 Abiotic Degradation of Chlorinated Solvents

Chlorinated solvents dissolved in groundwater may also 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 halogen substituent 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 depends partly on the number of halogen substitutes, 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 substitutes increases. One common solvent for which abiotic degradation reactions are well documented is 1,1,1-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, 1985), and

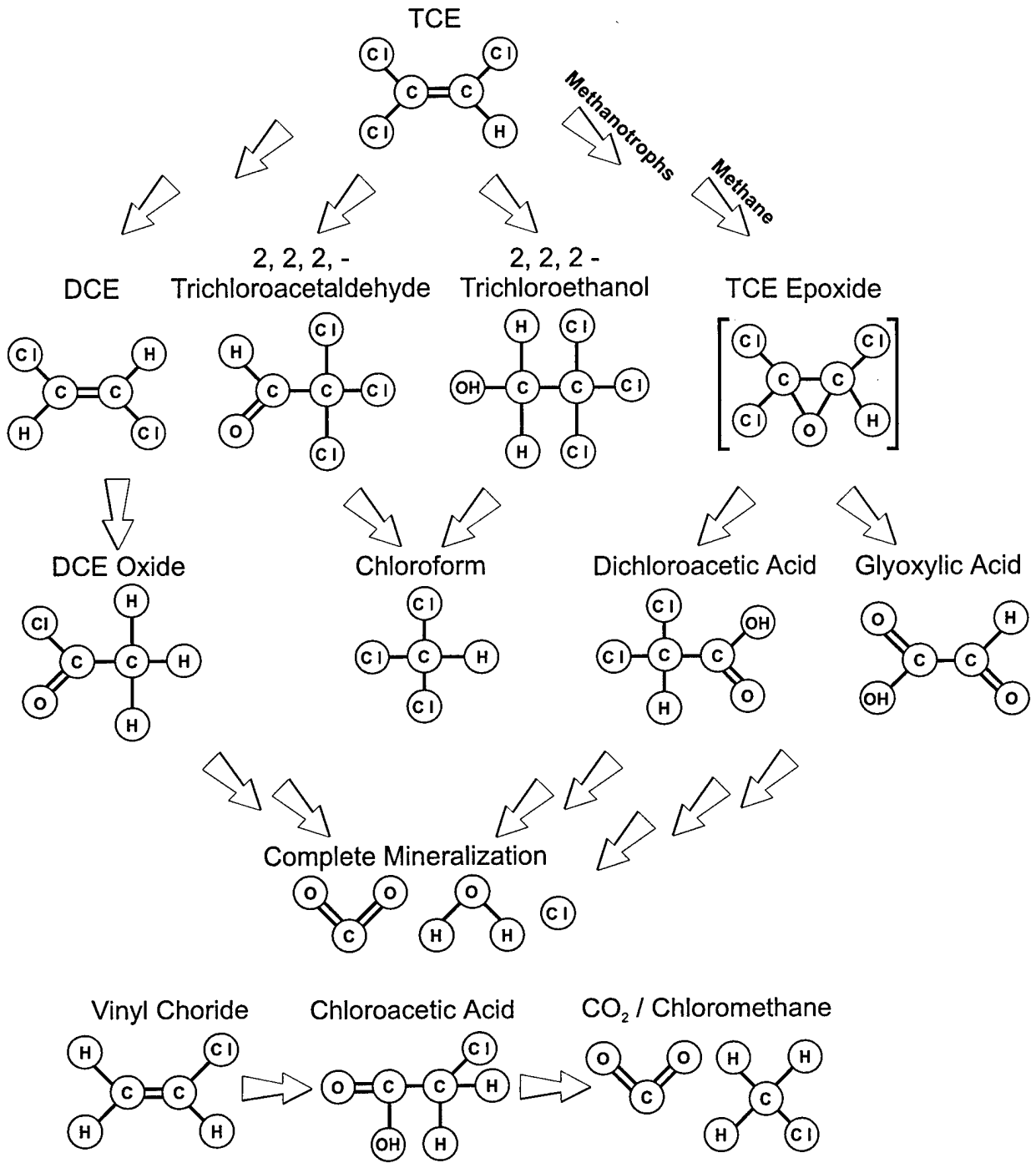

FIGURE 4.2

AEROBIC DEGRADATION PATHWAYS

FTA-2
RNA TS
Tinker AFB, Oklahoma

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Denver, Colorado

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, 1985) 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 dechlorination. When evaluating natural attenuation of a plume exhibiting Type 1 behavior the following questions must be answered:

1) Is the electron donor supply adequate to allow microbial reduction of the chlorinated organic compounds? In other words, will the microorganisms "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 (e.g., DO, nitrate, iron (III) and sulfate)?

3) Are VC and other less-chlorinated solvents being oxidized, or are they being reduced?

Type 1 behavior results in the rapid and extensive degradation of the highly chlorinated solvents such as PCE, TCE, or polychlorinated benzenes.

4.1.2.5.2 Type 2 Behavior

Type 2 behavior dominates in areas characterized by relatively high concentrations of biologically available native organic carbon. This natural carbon source drives reductive dehalogenation (i.e., the primary substrate for microorganism growth is native organic carbon). When evaluating natural attenuation of a Type 2 chlorinated solvent plume, the same questions as those posed in the description of Type 1 behavior must be answered. Type 2 behavior generally results in slower biodegradation of the highly chlorinated solvents than Type 1 behavior, but under the right conditions (e.g., areas with high natural organic carbon contents), this type of behavior also can result in rapid degradation of CAH compounds.

4.1.2.5.3 Type 3 Behavior

Type 3 behavior dominates in areas characterized by low concentrations of native and/or anthropogenic carbon, and concentrations of DO that are greater than 1.0 mg/L. Under these aerobic conditions reductive dehalogenation will not occur. Thus there is little or no removal of PCE and TCE. Biodegradation may proceed via the much slower process of cometabolism, but will be limited by the low concentrations of native or anthropogenic carbon. The most significant natural attenuation mechanisms for CAHs will be advection, dispersion, and sorption. However, VC can be rapidly oxidized under these conditions, DCE may be oxidized, CBs may be oxidized, and cometabolism also may occur.

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 CAH plume at Plattsburgh AFB, New York that exhibits Type 1 behavior in the source area and Type 3 behavior downgradient along the contaminant flowpath from the source. The best scenario involves a plume in which PCE, TCE, and DCE are reductively dehalogenated (Type 1 or Type 2 behavior), then VC is oxidized (Type 3 behavior), either aerobically or anaerobically (via iron reduction). VC is oxidized to carbon dioxide in this type of plume and does not accumulate. The following sequence of reactions occurs in a plume that exhibits mixed behavior:

$$\text{PCE} \rightarrow \text{TCE} \rightarrow \text{DCE} \rightarrow \text{VC} \rightarrow \text{Carbon Dioxide}$$

In general, the TCE, DCE, and VC may attenuate at approximately the same rate, and 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 under VC-reducing conditions.

A less desirable scenario, but one in which all contaminants may be entirely biodegraded, involves a plume in which all CAHs are reductively dehalogenated via Type 1 or Type 2 behavior. VC is reduced to ethene, which may be further reduced to ethane or methane. The following sequence of reactions occur in this type of plume:

$$PCE \rightarrow TCE \rightarrow DCE \rightarrow VC \rightarrow \text{Ethene or Ethane}$$

In a reductive plume, VC degrades more slowly than TCE, and tends to accumulate (Freedman and Gossett, 1989).

4.2 NATURE AND EXTENT OF CONTAMINATION

The first step for evaluating the occurrence and methods of CAH and fuel hydrocarbon biodegradation is to look at the distribution of contaminants and the biodegradation products of those compounds. At site FTA-2, dissolved groundwater contamination consists of a mixture of compounds, some of which may be electron donors, some of which may be electron acceptors, and some of which may be either donors or acceptors. It is therefore important to evaluate the distribution of all relevant compounds and the spatial relations between their distributions.

The following sections present contaminant and daughter product distributions at FTA-2, providing the initial evidence that dissolved fuels and chlorinated solvents are biodegrading. Geochemical data presented in later sections also provides evidence of contaminant biodegradation.

4.2.1 Contaminant Sources

Sources of dissolved groundwater contamination at FTA-2 are not clearly defined. It is likely that residues from fuel or extinguishing agents have leached into soil and groundwater at the fire training pit and are a primary source of groundwater contamination. However, the exact locations and nature of the releases is not clear from the available data. Residual non-aqueous phase liquid (NAPL) has not been identified during either previous or current subsurface investigations.

In a 1987 soil investigation by the USACE (USACE, 1988), seven soil boreholes were drilled to a maximum depth of 7 feet and soil samples were collected and analyzed for VOCs and metals. From October to December 1993, 21 soil samples were collected from four locations at depths from 2 to 30 feet bgs and analyzed for VOCs, SVOCs, total petroleum hydrocarbons (TPH), and metals (IT, 1994). In 1995, an additional 37 soil samples were collected from five soil boreholes and two monitoring well boreholes (TT, 1996). Low concentrations of TPH, VOC, and SVOC compounds were detected, including methylene chloride, 1,1,1-TCA, butybenzyphthalate, di-n-butylphthalate, and bis(2-ethylhexyl)phthalate. TCA was detected at concentrations ranging from 0.07J (estimated concentration) to 6.7 micrograms per kilogram (µg/kg). Metals detected at the site were within background concentration ranges.

A total of six soil samples were collected from four soil boreholes (CG39-B97-41, CG-B97-43d, 2-392B, and 2-393B) in July 1997. Two samples were analyzed for TCE and PCE, and all six samples were analyzed for TOC. The results are summarized in Table 4.1. TCE was detected at concentrations of 0.019 and 0.070 milligrams per kilogram (mg/kg) in the soil sample and its replicate collected at a depth of 18 to 19 feet bgs from the borehole for CG39-B97-41. PCE was not detected in either sample.

TABLE 4.1

PCE, TCE AND TOC IN SOIL[b/]

JULY 1997

FTA-2 RNA TS

TINKER AIR FORCE BASE, OKLAHOMA

Sample Location	Sample Date	Sample Depth (feet bgs)[a/]	Sample Replicate	TCE[b/] (mg/kg)[c/]	PCE[b/] (mg/kg)	TOC[b/] (percent)
CG39-B97-41	7/28/1997	18-19	Replicate 1	0.019	ND[d/]	0.952
CG39-B97-41	7/28/1997	18-19	Replicate 2	0.07	ND	0.816
CG39-B97-41	7/28/1997	18-19	Replicate 3	NA[e/]	NA	0.819
					Mean TOC:	**0.862**
CG39-B97-43d	7/29/1997	29-30	Replicate 1	ND	ND	0.894
CG39-B97-43d	7/29/1997	29-30	Replicate 2	ND	ND	0.832
CG39-B97-43d	7/29/1997	29-30	Replicate 3	NA	NA	0.869
					Mean TOC:	**0.865**
2-392B	7/29/1997	29-30	Replicate 1	NA	NA	0.969
2-392B	7/29/1997	29-30	Replicate 2	NA	NA	0.632
2-392B	7/29/1997	29-30	Replicate 3	NA	NA	0.888
					Mean TOC:	**0.830**
2-392B	7/29/1997	44-45	Replicate 1	NA	NA	0.806
2-392B	7/29/1997	44-45	Replicate 2	NA	NA	0.860
2-392B	7/29/1997	44-45	Replicate 3	NA	NA	0.790
					Mean TOC:	**0.819**
2-393B	7/30/1997	34-35	Replicate 1	NA	NA	0.857
2-393B	7/30/1997	34-35	Replicate 2	NA	NA	0.638
2-393B	7/30/1997	34-35	Replicate 3	NA	NA	0.697
					Mean TOC:	**0.731**
2-393B	7/30/1997	44-45	Replicate 1	NA	NA	0.684
2-393B	7/30/1997	44-45	Replicate 2	NA	NA	0.755
2-393B	7/30/1997	44-45	Replicate 3	NA	NA	0.873
					Mean TOC:	**0.771**
					Average of Mean TOC Values:	**0.813**

[a/] feet bgs = feet below ground surface.

[b/] PCE = tetrachloroethene, TCE = trichloroethene, and TOC = Total Organic Carbon.

[c/] mg/kg = milligrams per kilogram.

[d/] ND = not detected.

[e/] NA = compound was not analyzed for.

The presence of TCE and TCA in soil does suggest the use of chlorinated solvents at this site, though the low detected concentrations of TCE and TCA in soils do not confirm that the FTA-2 fire pit is the primary source for chlorinated solvents in groundwater. The presence of TCE in soil at borehole CG39-B97-41 coincides with the maximum concentrations of total fuel carbon, benzene, and TCE detected in USZ groundwater at monitoring well 2-62B, located immediately adjacent to CG39-B97-41. These wells are located approximately 75 feet upgradient from, and along the access road to, the site identified from aerial photographs as FTA-2 (Figure 1.3). Therefore, the source area for FTA-2 may be larger than estimated from the actual fire pit area identified from aerial photographs, or the access road may have been used for other purposes presenting additional sources (i.e., cleaning or dumping).

4.2.2 Total Organic Carbon in Soil

TOC concentrations 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 sorb to organic carbon in the aquifer matrix. Sorption results in retardation of the contaminant plume relative to the average advective groundwater velocity. In addition, TOC can be used as a gross indicator of organic compounds that are available as a source of carbon and electron donors (or substrate) for a microbial population.

Soil TOC concentrations were measured in six samples from four borehole locations in 1997 (Table 4.1). All samples were collected from below the water table. Soil TOC concentrations ranged from 0.632 to 0.969 percent, and average 0.813 percent. For most of the CAHs detected at FTA-2, contaminant retardation due to sorption is significant when TOC concentrations are greater than approximately 0.01 percent. Because TOC concentrations at FTA-2 are significantly greater than 0.01 percent, sorption of dissolved CAHs onto organic carbon may play an important role in contaminant retardation at FTA-2.

4.2.3 Fuel Hydrocarbons in Groundwater

Total fuel carbon was detected in two of eighteen groundwater samples collected from the USZ aquifer at FTA2. Total fuel was not detected in the LSZ aquifer. Results for fuel hydrocarbon analyses performed on samples collected in August 1997 are presented in Table 4.2. Total fuel carbon was detected at concentrations of 1,140 and 5.8 micrograms per liter (µg/L) for wells 2-62B and 2-168B, respectively. Compound specific fuel hydrocarbons detected in groundwater at FTA-2 are benzene and toluene. Benzene was detected at two locations, 2-62B and 2-168B, at concentrations of 6.0 and 2.5 µg/L, respectively. Only the detected concentration at 2-62B exceeds the USEPA maximum contaminant level (MCL) of 5 µg/L. Toluene was only detected at location 2-62B at a concentration of 1.2 µg/L.

Based on the location of fuel hydrocarbon detections in groundwater, the contamination source at FTA-2 is in a small isolated area near 2-62B and 2-168B. This area is located hydraulically upgradient and cross-gradient of the FTA-2 pit. Detection of fuel hydrocarbons at location 2-62B coincides with the highest detected concentration

TABLE 4.2
FUEL HYDROCARBONS IN GROUNDWATER
AUGUST 1997
FTA-2 RNA TS
TINKER AIR FORCE BASE, OKLAHOMA

Sample Location	Sample Date	Total Fuel Carbon (µg/L)[a/]	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
	MCL[b/]	--[c/]	5	1000	700	10,000[d/]	10,000[d/]	10,000[d/]	--	--	--
Upper Saturated Zone											
CG39-B97-41	8/4/1997	ND[e/]	ND	ND	ND	ND	ND	ND	ND	ND	ND
CG39-B97-43s	8/4/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CG39-B97-43d	8/4/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CG39-B97-45	8/4/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-392B	8/3/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-393B	8/4/1997	BLQ[f/]	BLQ	ND	ND	ND	ND	ND	ND	ND	ND
2-62B	7/31/1997	1140	6	1.2	ND	ND	ND	BLQ	BLQ	ND	ND
2-63B	7/31/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-64B	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-65B	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-167B	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-168B	7/31/1997	5.8	2.5	ND	ND	ND	ND	ND	ND	ND	ND
2-271B	8/3/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-272B	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-273B	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-274B	8/3/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-355B	8/3/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3-356B[g/]	9/4/1997	NA[h/]	ND	ND	ND	ND	ND	ND	ND	ND	NA
2-142B	8/2/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lower Saturated Zone											
2-62A	7/31/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-63A	7/31/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-64A	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-65A	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-274A	8/3/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-142A	8/2/1997	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a/] µg/L = micrograms per liter.

[b/] MCL = Maximum Contaminant Level, State of Oklahoma OAC 165:25-3-65+A21, or U.S. EPA Primary Drinking Water Regulations, May 14, 1996.

[c/] -- = no standard listed.

[d/] Standard listed is for total xylenes.

[e/] ND = Not Detected.

[f/] BLQ = below limit of quantification.

[g/] Monitoring well 3-356B was sampled on 9/4/97 by Brown and Root.

[h/] NA = not analyzed.

of TCE (Section 4.3.2), suggesting fuel hydrocarbons originated from the same source as CAHs at the site. Because of the limited occurrence and low concentrations of fuel hydrocarbons detected at the site, natural attenuation of benzene and toluene is not further analyzed. However, the presence of low levels of anthropogenic carbon (fuel hydrocarbons) within the source area may impact biodegradation of CAHs.

4.2.4 Dissolved Chlorinated Ethenes

Chlorinated ethenes detected in groundwater at FTA-2 include PCE, TCE, DCE, and VC. Data for chlorinated ethenes and other chlorinated compounds are presented in Table 4.3. Distributions of TCE, cis-1,2-DCE and trans-1,2-DCE for both the upper and lower USZ sand intervals are shown on Figures 4.3 through 4.5, respectively. Concentrations for PCE, 1,1-DCE and VC are shown on Figure 4.6.

As measured in August 1997, PCE was detected in three of the nineteen groundwater samples collected from the USZ aquifer at FTA-2 (Figure 4.6). PCE concentrations detected in groundwater ranged from 1.9 µg/L at 2-63B to 52 µg/L at 2-65B. PCE was also detected at a concentration of 6.1 µg/L at 2-62B. The detected concentration at monitoring well 2-65B is above the USEPA MCL for PCE of 5 µg/L. All three locations correspond to an area approximately 100-200 feet east and north of the FTA-2 fire pit area, in an USZ upgradient direction. Locations 2-62B and 2-63B are screened in the upper USZ sand interval, while location 2-65B is screened in the lower USZ sand interval. It is unclear whether the presence of PCE is directly associated with the former FTA-2 fire pit location.

As measured in August 1997, TCE was detected in thirteen of the nineteen groundwater samples collected from the USZ aquifer at FTA-2 (Figure 4.3). TCE concentrations detected in USZ groundwater ranged from 1.4 µg/L at 2-168B to 9,440 µg/L at 2-62B. Of these detections, 11 locations exceed the USEPA MCL of 5 µg/L. The highest detection of TCE at 2-62B suggests that there may be a source of TCE associated with the area located to the east of the FTA-2 fire pit in an upgradient direction. The concentration of TCE within the FTA-2 fire pit area was 914 µg/L at 2-64B. Based on the distribution of TCE, the source of CAHs (PCE and TCE) may be the FTA-2 fire pit, or upgradient locations near 2-62B and 2-65B located along access roads in the area. Although undocumented, the data suggest possible cleaning or dumping operations may also be potential sources in the general fire training area. TCE was detected in one of the six groundwater samples collected from the LSZ aquifer at FTA-2. At 2-62A, TCE was detected at 10.9 µg/L, which is above the USEPA MCL for TCE.

Cis-1,2-DCE was detected at several wells (Figure 4.4), with the highest concentration of 1,200 µg/L detected at 2-62B. Concentrations of *cis*-1,2-DCE exceed the USEPA MCL of 70 µg/L at four locations. The two locations with the highest concentrations of *cis*-1,2-DCE coincide with the highest TCE detections at 2-62B and CG3-B97-43s in the upper USZ sand interval. In addition, another apparent plume of *cis*-1,2-DCE was detected downgradient in the lower USZ sand interval extending from well 2-65B to 2-393B. The concentrations at 2-393B and 2-274B in the lower USZ sand interval were slightly higher than measured at 2-355B located between the two wells, suggesting the cis-1,2-DCE plume is migrating downward into the lower USZ

TABLE 4.3
CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER
AUGUST 1997
FTA-2 RNA TS
TINKER AIR FORCE BASE, 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)	1,1,1-TCA[a] (µg/L)	1,1-DCA[a] (µg/L)
	MCL[c]	5	5	7	70	100	2	200	--[d]
Upper Saturated Zone									
CG39-B97-41	8/4/1997	ND[e]	3.6	ND	---[f]	ND	ND	ND	ND
CG39-B97-43s	8/4/1997	---	1490	1.1	183	6.1	ND	ND	ND
CG39-B97-43d	8/4/1997	ND	169	ND	31.8	2.4	ND	ND	ND
CG39-B97-45	8/4/1997	ND	153	ND	22.6	---	ND	ND	ND
2-392B	8/3/1997	ND	---	ND	ND	ND	ND	ND	ND
2-393B	8/4/1997	ND	406	---	54.3	---	ND	ND	ND
3-393B-Dup[g]	8/4/1997	ND	425	---	54.5	---	ND	ND	ND
2-62B	7/31/1997	6.1	>2000	9.5	1200	76.2	1.7	ND	ND
2-62B-Dup	7/31/1997	---	9440	---	1110	77	ND	ND	ND
2-63B	7/31/1997	1.9	75.4	1	161	3.6	6.6	ND	4.6
2-64B	8/1/1997	---	914	---	154	17.6	---	ND	ND
2-65B	8/1/1997	52	90	---	37	2.5	1.3	ND	---
2-167B	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND
2-168B	7/31/1997	---	1.4	---	27.6	ND	ND	ND	1.2
2-271B	8/3/1997	ND	ND	ND	ND	ND	ND	ND	ND
2-272B	8/1/1997	ND	28.1	ND	2.1	ND	ND	ND	ND
2-273B	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND
2-274B	8/3/1997	---	518	---	51.7	2.2	ND	ND	ND
2-274B-Dup	8/3/1997	---	506	---	53.4	2.1	ND	ND	ND
2-355B	8/3/1997	ND	344	ND	50	---	ND	ND	ND
2-356B[h]	9/4/1997	ND	ND	ND	ND	ND	ND	ND	ND
2-142B	8/2/1997	ND	---	ND	ND	ND	ND	ND	ND
Lower Saturated Zone									
2-62A	7/31/1997	ND	10.9	ND	---	ND	ND	ND	ND
2-63A	7/31/1997	ND	---	ND	ND	ND	ND	ND	ND
2-64A	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND
2-65A	8/1/1997	ND	ND	ND	ND	ND	ND	ND	ND
2-274A	8/3/1997	ND	ND	ND	ND	ND	ND	ND	ND
2-142A	8/2/1997	ND	ND	ND	ND	ND	ND	ND	ND

(Continued)

TABLE 4.3 (Continued)
CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER
AUGUST 1997
FTA2 RNA TS
TINKER AIR FORCE BASE, OKLAHOMA

Sample Location	Sample Date	1,2-DCA (µg/L)	Chlorobenzene (µg/L)	1,2-DCB (µg/L)	1,3-DCB[a/] (µg/L)	1,4-DCB (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)
	MCL[c/]	5	100	600	600	75	5	--
Upper Saturated Zone								
CG39-B97-41	8/4/1997	---	ND	---	ND	ND	ND	ND
CG39-B97-43s	8/4/1997	2.4	1	ND	1.6	ND	ND	1
CG39-B97-43d	8/4/1997	---	ND	ND	---	ND	ND	ND
CG39-B97-45	8/4/1997	1.4	ND	ND	---	ND	ND	ND
2-392B	8/3/1997	ND	ND	ND	ND	ND	ND	ND
2-393B	8/4/1997	45.4	---	ND	---	ND	ND	---
2-393B-Dup	8/4/1997	49.2	---	ND	---	ND	ND	---
2-62B	7/31/1997	260	117	950	34.8	168	ND	5.3
2-62B-Dup	7/31/1997	239	104	969	25	123	ND	---
2-63B	7/31/1997	---	ND	---	ND	ND	ND	ND
2-64B	8/1/1997	1.3	---	---	1.2	---	ND	---
2-65B	8/1/1997	3.2	9.5	3.6	---	1.8	ND	ND
2-167B	8/1/1997	ND	ND	ND	ND	ND	ND	ND
2-168B	7/31/1997	ND	ND	ND	ND	ND	ND	ND
2-271B	8/3/1997	ND	ND	ND	ND	ND	ND	ND
2-272B	8/1/1997	---	ND	ND	ND	ND	ND	ND
2-273B	8/1/1997	ND	ND	ND	ND	ND	ND	ND
2-274B	8/3/1997	1.1	---	ND	---	ND	ND	---
2-274B-Dup	8/3/1997	1.4	---	ND	---	ND	ND	---
2-355B	8/3/1997	1.8	---	ND	---	ND	ND	---
2-356B	9/4/1997	ND	ND	ND	ND	ND	ND	ND
2-142B	8/2/1997	ND	ND	ND	ND	ND	ND	ND
Lower Saturated Zone								
2-62A	7/31/1997	ND	ND	---	ND	ND	ND	ND
2-63A	7/31/1997	ND	ND	---	ND	ND	ND	ND
2-64A	8/1/1997	ND	ND	ND	ND	ND	ND	ND
2-65A	8/1/1997	ND	ND	ND	ND	ND	ND	ND
2-274A	8/3/1997	ND	ND	ND	ND	ND	ND	ND
2-142A	8/2/1997	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.

[c/] MCL = Maximum Contaminant Level, U.S. EPA Primary Drinking Water Regulations, May 14, 1996.

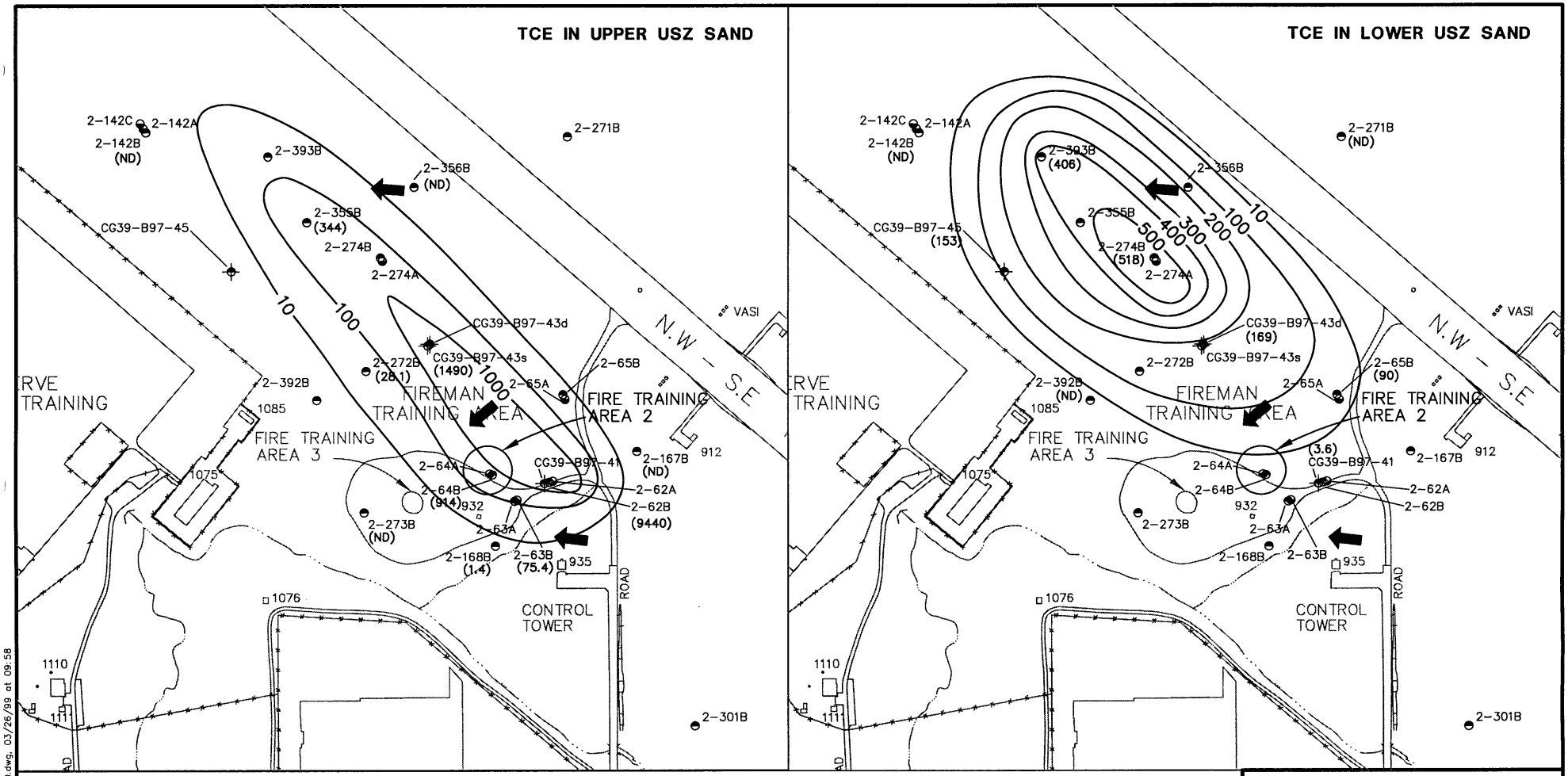
[d/] -- = no standard listed.

[e/] ND = not detected.

[f/] --- = below calibration limit (1 part per billion).

[g/] Dup = field duplicate of preceding sample.

[h/] Monitoring well 3-356B was sampled on 9/4/97 by Brown and Root.



LEGEND

- 2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- CG39-B97-41 — MONITORING POINT LOCATION/ UPPER SATURATED ZONE
- s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
- DIRECTION OF USZ GROUNDWATER FLOW
- ND — NOT DETECTED
- ALL CONCENTRATIONS IN MICROGRAMS PER LITER (ppb)
- 10 — LINE OF EQUAL TCE CONCENTRATION (ppb)

0 150 300 600
FEET

FIGURE 4.3

CONCENTRATION OF TCE IN USZ GROUNDWATER AUGUST 1997

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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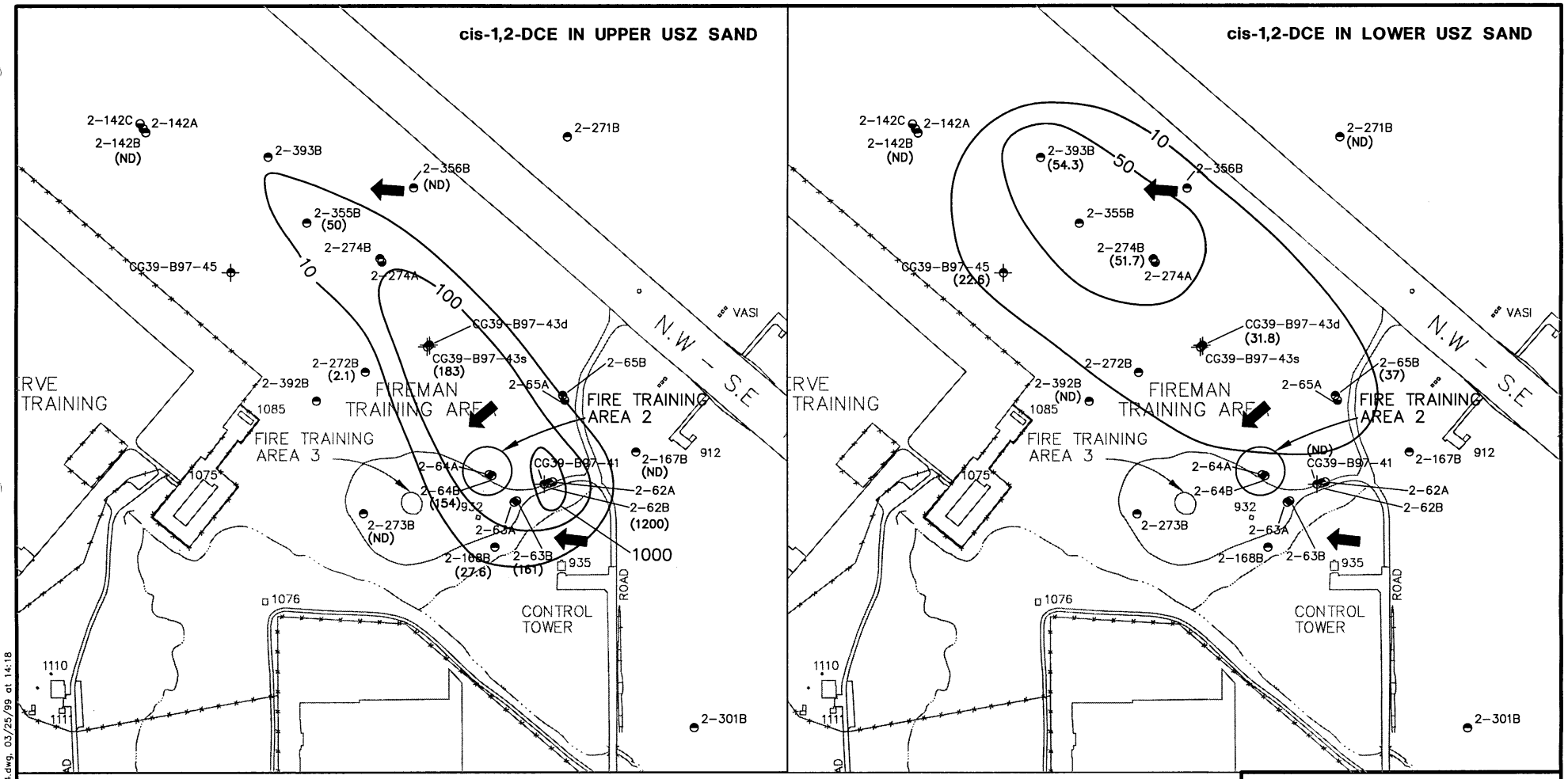

FIGURE 4.4

CONCENTRATION OF cis-1,2-DCE IN USZ GROUNDWATER AUGUST 1997

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

S:\ES\cad\AFCe...\29691\TINKER\98dn0194.dwg, 03/25/99 at 14:18

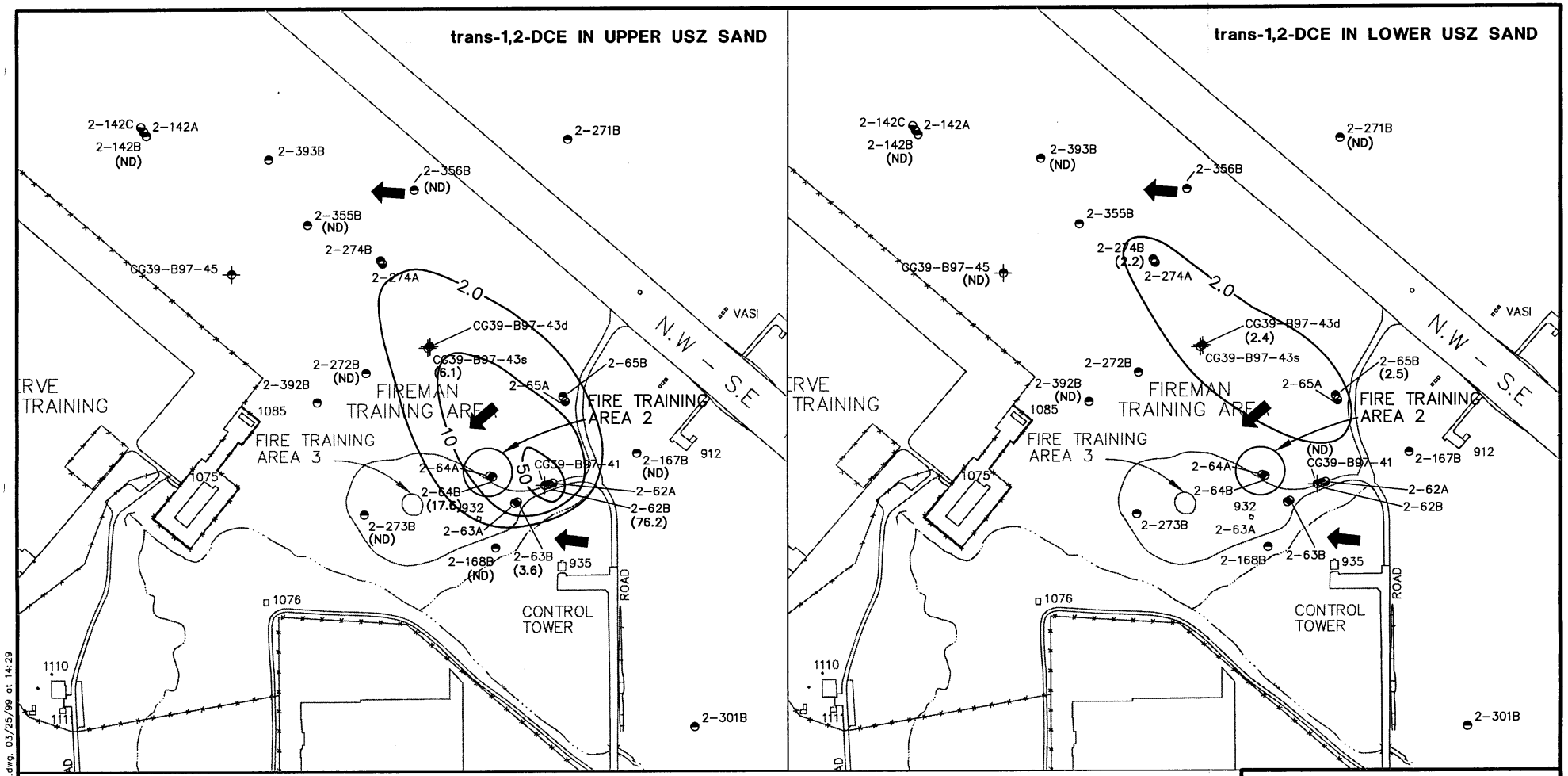

FIGURE 4.5

CONCENTRATION OF trans-1,2-DCE IN USZ GROUNDWATER AUGUST 1997

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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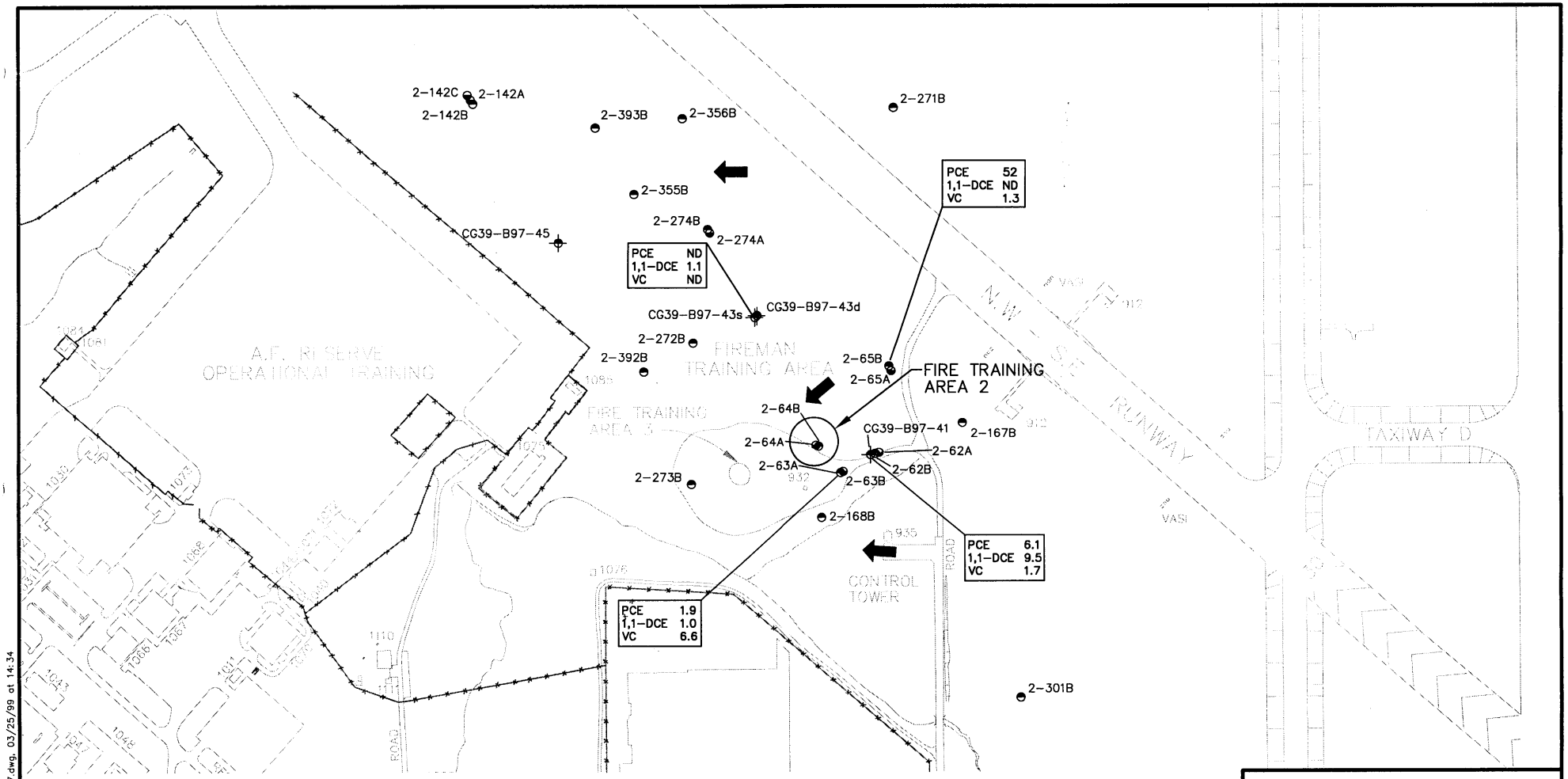

LEGEND

2-142B ●	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-142A ●	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
CG39-B97-41 ⊕	TEMPORARY MONITORING POINT LOCATION/ UPPER SATURATED ZONE
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
ND	NOT DETECTED
PCE	TETRACHLOROETHENE
1,1-DCE	1,1-DICHLOROETHENE
VC	VINYL CHLORIDE
ALL CONCENTRATIONS IN MICROGRAMS PER LITER (ppb)	
⬅	DIRECTION OF GROUNDWATER FLOW

0 150 300 600
FEET

FIGURE 4.6

DETECTED CONCENTRATIONS OF PCE, 1,1-DCE AND VC IN USZ GROUNDWATER AUGUST 1997

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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sand interval. The clay layer that separates the upper and lower USZ sands is thinner and less continuous in the area of well locations 2-274B, 2-355B, and 2-393B relative to the source area near well location 2-62B.

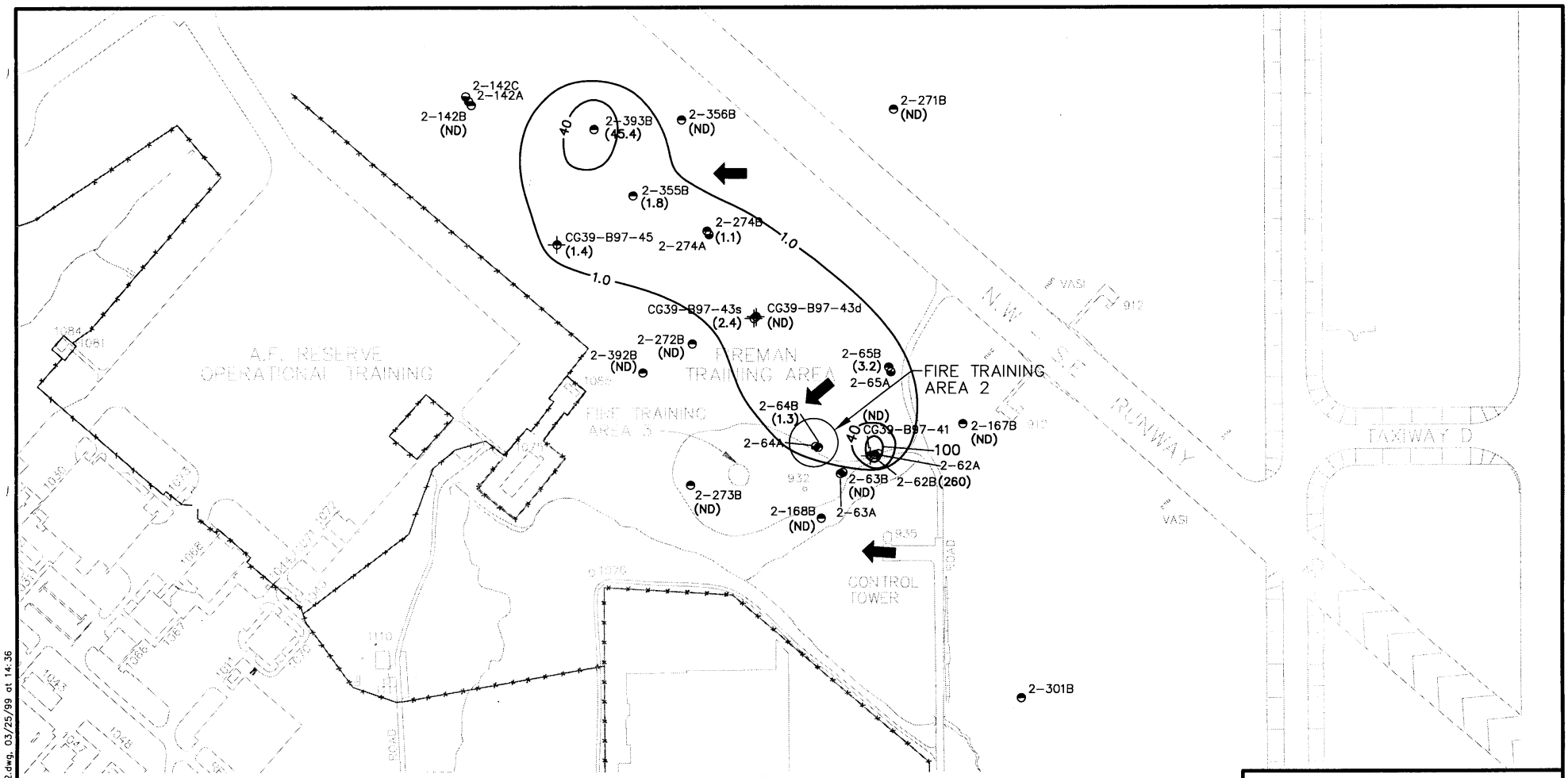
Trans-1,2-DCE was detected at seven locations at concentrations ranging from 2.1 to 77 µg/L (Figure 4.5). No concentrations exceeded the USEPA MCL of 100 µg/L. At all wells/points sampled, *trans*-1,2-DCE was detected at concentrations significantly lower than *cis*-1,2-DCE (Figures 4.4 and 4.5). This trend would be expected if TCE is being degraded to DCE via reductive dehalogenation. As noted before, under the influence of biodegradation, *cis*-1,2-DCE is a more common daughter product than the other DCE isomers. Furthermore, the *trans* isomer is more common when DCE is used for commercial applications. The presence of *cis*-1,2-DCE is therefore a good indicator that the initial step of TCE reductive dehalogenation is taking place in groundwater at FTA-2.

1,1-DCE was detected in samples from three of the 19 USZ groundwater monitoring wells at FTA-2 (Figure 4.6). Concentrations of 1.1 µg/L, 9.5 µg/L and 1.0 µg/L were detected in samples from wells CG39-B97-43s, 2-62B and 2-63B, respectively. Only the concentration detected at 2-62B exceeds the MCL of 7 µg/L. TCE and the other isomers of DCE were also detected in these wells suggesting that 1,1-DCE could have been produced by reductive dehalogenation of TCE.

VC was detected in samples from three of the 19 USZ groundwater monitoring wells sampled at FTA-2 (Figure 4.6). Concentrations of 1.7 µg/L, 6.6 µg/L and 1.3 µg/L were detected in samples from 2-62B, 2-63B and 2-65B, respectively. Only the concentration detected at well 2-62B exceeds the MCL of 2 µg/L. The distribution of VC is similar to that for PCE. In fact, VC was detected at all three locations where PCE was detected. The presence of VC in groundwater is also a good indicator of reductive dehalogenation. Because VC is typically a gas at most working temperatures [the boiling point of VC is about 13.5 degrees centigrade (°C) or 7 degrees Fahrenheit (°F) (Montgomery, 1996)], VC is used for plastic manufacturing instead of being used as a solvent. In addition, when liquid VC is spilled, most of the mass is likely to volatilize before reaching groundwater unless there is a large-volume release.

4.2.5 Dissolved Chlorinated Ethanes

Chlorinated ethanes detected in groundwater at FTA-2 include 1,1-DCA and 1,2-DCA (Table 4.3). Relatively low concentrations of 1,1-DCA were detected, with the maximum 1,1-DCA concentration of 4.6 µg/L occurring at well 2-63B. There is no USEPA MCL listed for 1,1-DCA. The distribution of 1,2-DCA is shown on Figure 4.7, with 1,2-DCA detected in eight of the 19 USZ groundwater samples analyzed. The maximum concentrations of 1,2-DCA were 260 µg/L at 2-62B and 49.2 µg/L at 2-393B, both exceeding the MCL of 5 µg/L. These two locations are at opposite ends of the overall CAH contaminant plume. Concentrations of 1,2-DCA in the intermediate area are substantially less, ranging from 1.1 to 3.2 µg/L. 1,1-DCA is not commonly used as a solvent, whereas 1,2-DCA is used as a solvent. Therefore, the presence of 1,2-DCA rather than 1,1-DCA suggests that 1,2-DCA is a result of source release, rather than a biodegradation byproduct. Furthermore, the data indicate the possibility


2-142C
2-142A
2-142B
(ND)
2-393B
(45.4)
2-356B
(ND)
2-271B
(ND)
40
2-355B
(1.8)
2-274B
(1.1)
CG39-B97-45
(1.4)
2-274A
1.0
1.0
CG39-B97-43s
(2.4)
CG39-B97-43d
(ND)
2-272B
(ND)
2-392B
(ND)
A.F. RESERVE
OPERATIONAL TRAINING
FIRE TRAINING
AREA 3
FIREMAN
TRAINING AREA
2-65B
(3.2)
2-65A
FIRE TRAINING
AREA 2
2-64B
(1.3)
(ND)
CG39-B97-41
2-167B
(ND)
2-64A
40
100
2-62A
2-63B
(ND)
2-62B(260)
2-273B
(ND)
2-168B
(ND)
2-63A
CONTROL
TOWER
2-301B
N.W. - S.E. RUNWAY
TAXIWAY D
VASI
912
932
935
1076
1051
1052
1053
1054
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of a secondary 1,2-DCA source located northwest of the FTA-2 fire pit in the vicinity of 2-393B.

4.2.6 Dissolved Chlorobenzenes

Chlorobenzenes detected in groundwater at FTA-2 include CB, 1,2-DCB, 1,3-DCB, and 1,4-DCB (Table 4.3, Figure 4.8). These compounds were detected in four wells associated with the general CAH source area (2-62B, 2-64B, and 2-65B), and the preferential plume migration pathway (CG39-B9743s). A CB and 1,2-DCB plume appears to be originating from the vicinity of 2-62B and migrating to the northwest. Detected CB concentrations ranged from 1.0 µg/L in CG39-B97-43s, to 117 µg/L in 2-62B. CB was also detected at a concentration of 9.5 µg/L in 2-65B. Only the highest CB concentration detected in 2-62B exceeds the MCL for CB of 100 µg/L. 1,2-DCB was detected in two wells at concentrations of 3.6 µg/L in 2-65B, and 969 µg/L in 2-62B. Only the 1,2-DCB concentration detected in 2-62B exceeds the MCL of 600 µg/L. Similarly, 1,4-DCB exceeded its MCL of 75 µg/L at well 2-62B. 1,3-DCB was not detected above its MCL of 600 µg/L.

4.2.7 Other Dissolved Chlorinated Compounds

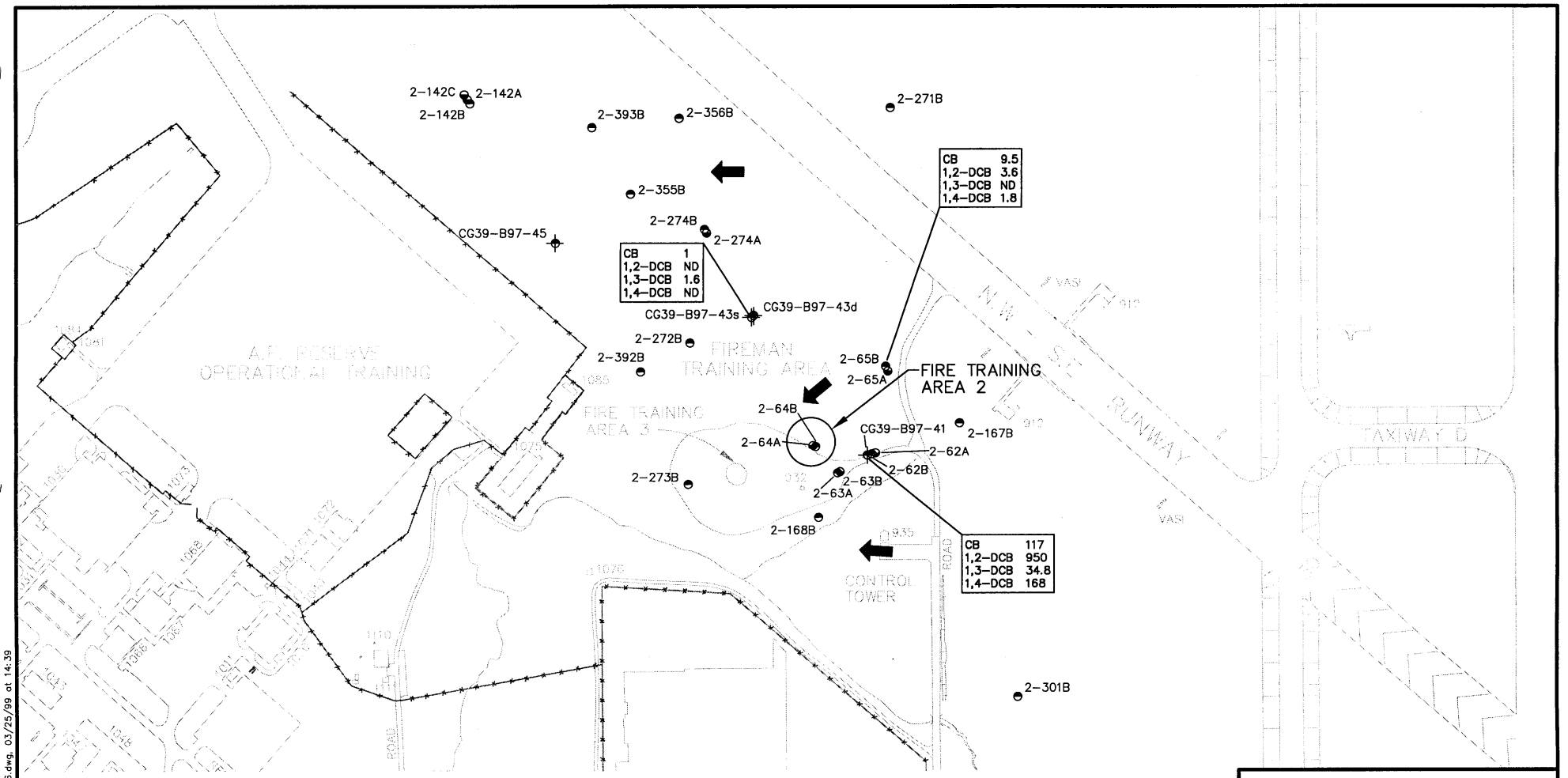
Chloroform was the only other chlorinated compound detected in groundwater at FTA-2. Chloroform was detected at concentrations of 1.0 µg/L in CG39-B97-43s, and 5.3 µg/L in 2-62B. These locations coincide with the maximum detected concentrations of TCE and cis-1,2-DCE. The detected concentrations do not exceed the MCL of 100 µg/L. Chloroform may form as the end product of aerobic degradation of TCE through intermediate byproducts of 2,2,2-trichloroacetaldehyde and 2,2,2-trichloroethanol (Figure 4.2). Therefore, the formation of chloroform in association with the presence of TCE may indicate an aerobic biodegradation pathway from TCE to chloroform.

4.2.8 LSZ Groundwater Quality

The only contaminant detected in LSZ groundwater was TCE at a concentration of 10 µg/L in the groundwater sample collected from monitoring well 2-62A. The TS sampling event is the first time CAHs have been detected in LSZ groundwater at FTA-2. Monitoring well 2-62A is located beneath the primary source area, immediately adjacent to well 2-62B, the USZ well with the highest detected concentration of TCE in USZ groundwater at FTA-2. TCE is the most mobile (lowest retardation) of the CAHs detected at FTA-2, and its detection indicates that CAH contamination is starting to migrate vertically through the USZ/LSZ aquitard to the LSZ.

4.3 ANALYSIS OF HYDROCARBON BIODEGRADATION

Available information indicates that the CAH plume primarily exhibits Type 1 behavior in the immediate source area delimited by monitoring wells 2-63B, 2-168B, 2-62B, and 2-64B. Fuel hydrocarbons and chlorobenzenes remain in this area, and the electron donor supply may be adequate to allow continued microbial reduction of CAHs. The role of competing electron acceptors (e.g., DO, nitrate, ferric iron, and sulfate) is described later in this subsection. The Type 1 conditions are resulting in



LEGEND

2-142B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-142A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
CG39-B97-41	TEMPORARY MONITORING POINT LOCATION/ UPPER SATURATED ZONE
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
ND	NOT DETECTED
CB	CHLORINATED BENZENE
1,2-DCB	1,2-DICHLORINATED BENZENE
1,3-DCB	1,3-DICHLORINATED BENZENE
1,4-DCB	1,4-DICHLORINATED BENZENE

ALL CONCENTRATIONS IN MICROGRAMS PER LITER (ppb)

DIRECTION OF GROUNDWATER FLOW

0 150 300 600
FEET

FIGURE 4.8

DETECTED CONCENTRATIONS OF CHLORINATED BENZENES IN USZ GROUNDWATER AUGUST 1997

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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extensive degradation of the highly chlorinated solvents PCE and TCE in the source area. Degradation of DCE may also be occurring, as evidenced by the presence of VC dissolved in groundwater in this area. The dehalogenation of DCE to VC and of VC to ethene occurs at progressively slower rates, because the rate of reductive dehalogenation decreases as the degree of chlorination decreases. DCE (particularly *cis*-1,2-DCE) is being produced from TCE and PCE faster than it can be dehalogenated to VC, explaining the abundance of DCE, the relative scarcity of VC, and the lack of ethene in site groundwater.

The downgradient portion of the CAH plume appears to primarily exhibit Type 3 behavior. There is little or no anaerobic reductive dehalogenation of TCE and DCE occurring; however, DCE may be aerobically degraded (oxidized). VC is being rapidly oxidized as it migrates into the more aerobic environment as evidenced by the general lack of VC detections north and west of the general source area. The rapid decrease, or lack of, chlorobenzenes in the downgradient portions of the plume may indicate that CB and DCB are being utilized as electron donors in the source or downgradient portion of the CAH plume.

In addition to the distribution of contaminants and daughter products, other evidence can be used to support the interpretation that biodegradation of fuel hydrocarbons and chlorinated solvents is ongoing at FTA-2. Analysis of temporal changes in contaminant concentrations over time may indicate field-scale contaminant mass loss as a result of biodegradation processes. By comparing concentrations and distributions of electron donors, electron acceptors, and byproducts of microbially mediated reactions, types of bidegradation processes operating at a site can be identified. Geochemical parameters, including redox potential, alkalinity, and other changes in groundwater chemistry can also provide supporting evidence and are presented in the following subsections.

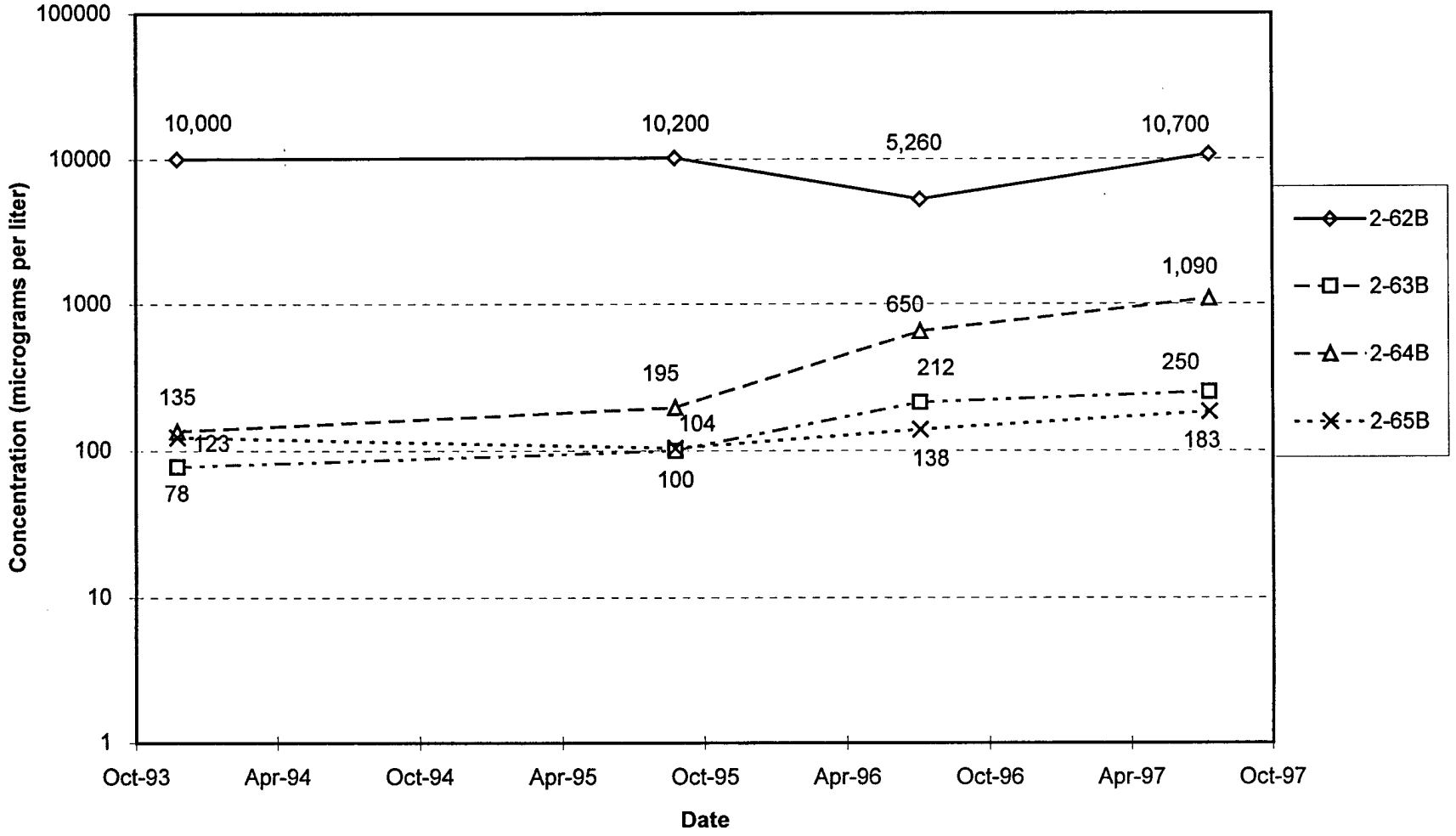
4.3.1 Field-Scale Contaminant Mass Loss

Groundwater quality data collected for four sampling events between December 1993 and August 1997 from monitoring wells 2-62B, 2-63B, 2-64B, and 2-65B were reviewed to assess temporal changes in contaminant concentrations over time. Decreasing contaminant concentration trends reflect natural attenuation trends. In a stable or attenuating contaminant plume, decreasing concentration trends may be used to support loss of contaminant mass through destructive processes such as biodegradation.

4.3.1.1 Chlorinated Ethenes Over Time

Available concentration-versus-time data for chlorinated ethenes in samples from source area wells 2-62B, 2-63B, 2-64B, and 2-65B were examined to reassess whether or not long-term trends in chlorinated ethene concentrations are apparent. Total chlorinated ethene concentrations at these wells are relatively stable (well 2-62B), or gradually increase over time (wells 2-63B, 2-64B, and 2-65B) (Figure 4.9). Review of this plot indicates that the source of the CAH contaminant plume has not attenuated over the period from 1993 to 1997.

FIGURE 4.9
TOTAL CHLORINATED ETHENES VERSUS TIME
Site FTA-2
RNA TS
Tinker AFB, Oklahoma



Concentrations of TCE, cis-1,2-DCE, trans-1,2-DCE, and VC versus time for well 2-62B are shown on Figure 4.10. Well 2-62B has consistently exhibited the highest detected concentrations at the site, and it is assumed to represent dissolved contaminant concentrations in the primary source area. Concentrations at well 2-62B do not show a discernible trend, indicating that the source of chlorinated ethenes at FTA-2 has not attenuated. TCE concentrations have increased from 9.0 to 28 µg/L, and from 260 to 518 µg/L, respectively, at two wells further down the plume migration pathway (2-272B and 2-274B) from August 1996 and August 1997. An accurate assessment regarding the degree to which the chlorinated ethene plume is at equilibrium (neither expanding nor receding) cannot be made on the basis of the available data. However, given the indications of increasing concentrations at several wells, it is probable that the plume is expanding.

4.3.1.2 Chlorinated Ethanes Over Time

Concentration-versus-time data for chlorinated ethanes detected in samples from wells 2-62B, 2-63B, 2-64B, and 2-65B were examined to reassess whether or not long-term trends in chlorinated ethanes concentrations are apparent. Total chlorinated ethane concentrations increase through time at wells 2-63B, 2-64B, and 2-65B; however, total chlorinated concentrations decrease through time at well 2-62B (Figure 4.11). Results of this analysis are inconclusive, but the data from source area well 2-62B may indicate slight attenuation of chlorinated ethanes over the period from 1993 to 1997.

4.3.1.3 Chlorobenzenes Over Time

Available concentration-versus-time data for chlorobenzenes in samples from source area wells 2-62B, 2-64B, and 2-65B were examined to reassess whether or not long-term trends in chlorobenzene concentrations are apparent. Total chlorobenzene concentrations at these wells are erratic (well 2-62B) or gradually increasing over time (wells 2-64B and 2-65B) (Figure 4.12). Results of this analysis indicate that the source of the chlorobenzene contaminant plume has not significantly attenuated over the period from 1993 to 1997.

4.3.2 Presence of Daughter Products and CAH Ratios

The presence of daughter products that were not used in Base operations, particularly *cis*-1,2-DCE and VC, provides strong evidence that the parent solvents (TCE and/or PCE) are being reductively dehalogenated. However, the anaerobic dehalogenation processes occurring in FTA-2 groundwater are limited to the primary source area.

If reductive dehalogenation of TCE were occurring along the contaminant flow path, then the mass fraction of TCE would be expected to decrease relative to that of DCE and VC. However, the molar ratio of TCE relative to *cis*-1,2-DCE does not decrease with distance from the source area (well 2-62B), remaining relatively constant at approximately 85 percent TCE of the TCE plus *cis*-1,2-DCE molar concentration (Figure 4.13). The rapid decrease in VC with distance from the source area (Table 2.3) indicates that, beyond the source area, VC is used as an electron donor and is aerobically degraded.

FIGURE 4.10
TCE, CIS-1,2-DCE, TRANS-1,2-DCE, AND VC VERSUS TIME AT 2-62B
Site FTA-2
RNA TS
Tinker AFB, Oklahoma

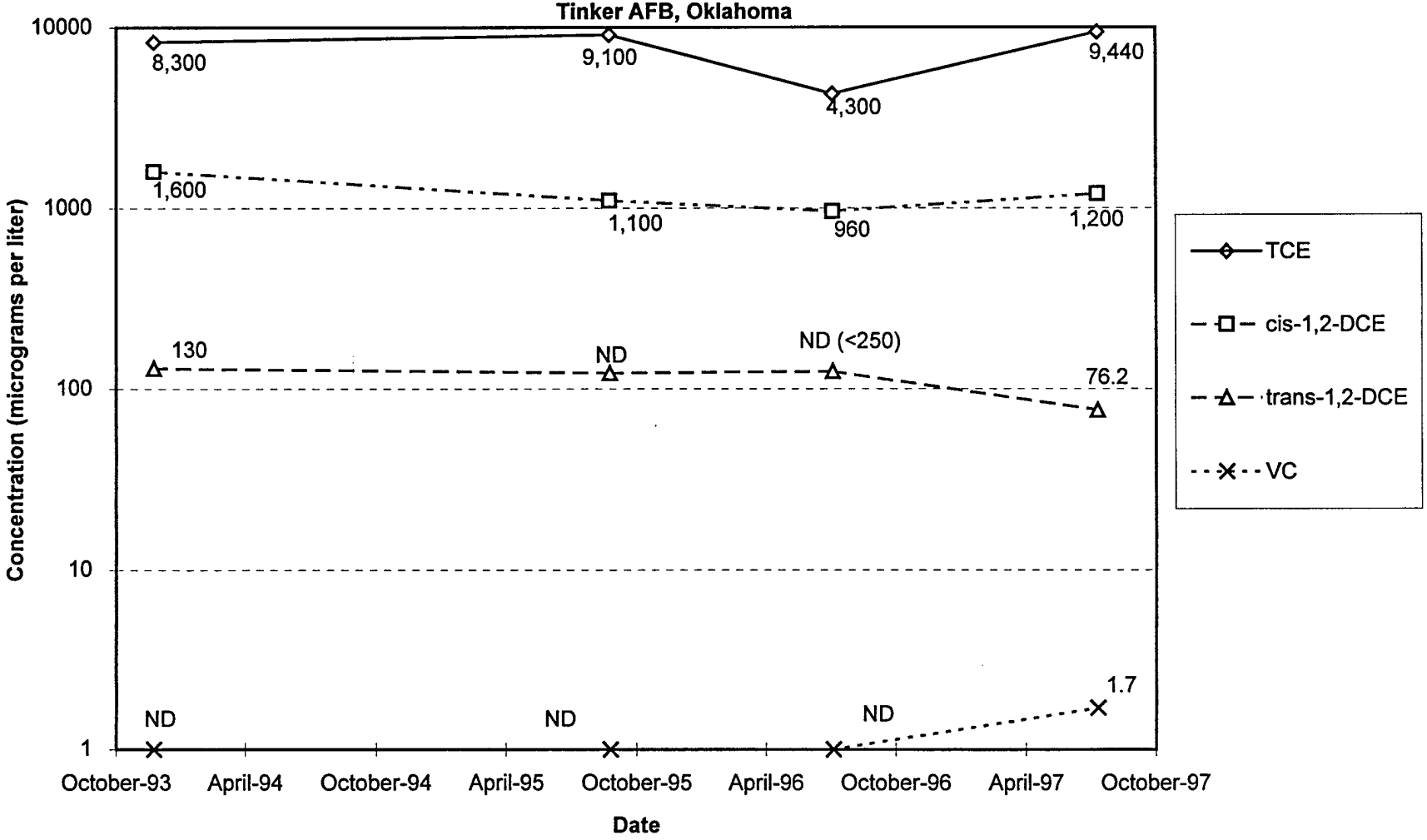


FIGURE 4.11
TOTAL CHLORINATED ETHANES VERSUS TIME
Site FTA-2
RNA TS
Tinker AFB, Oklahoma

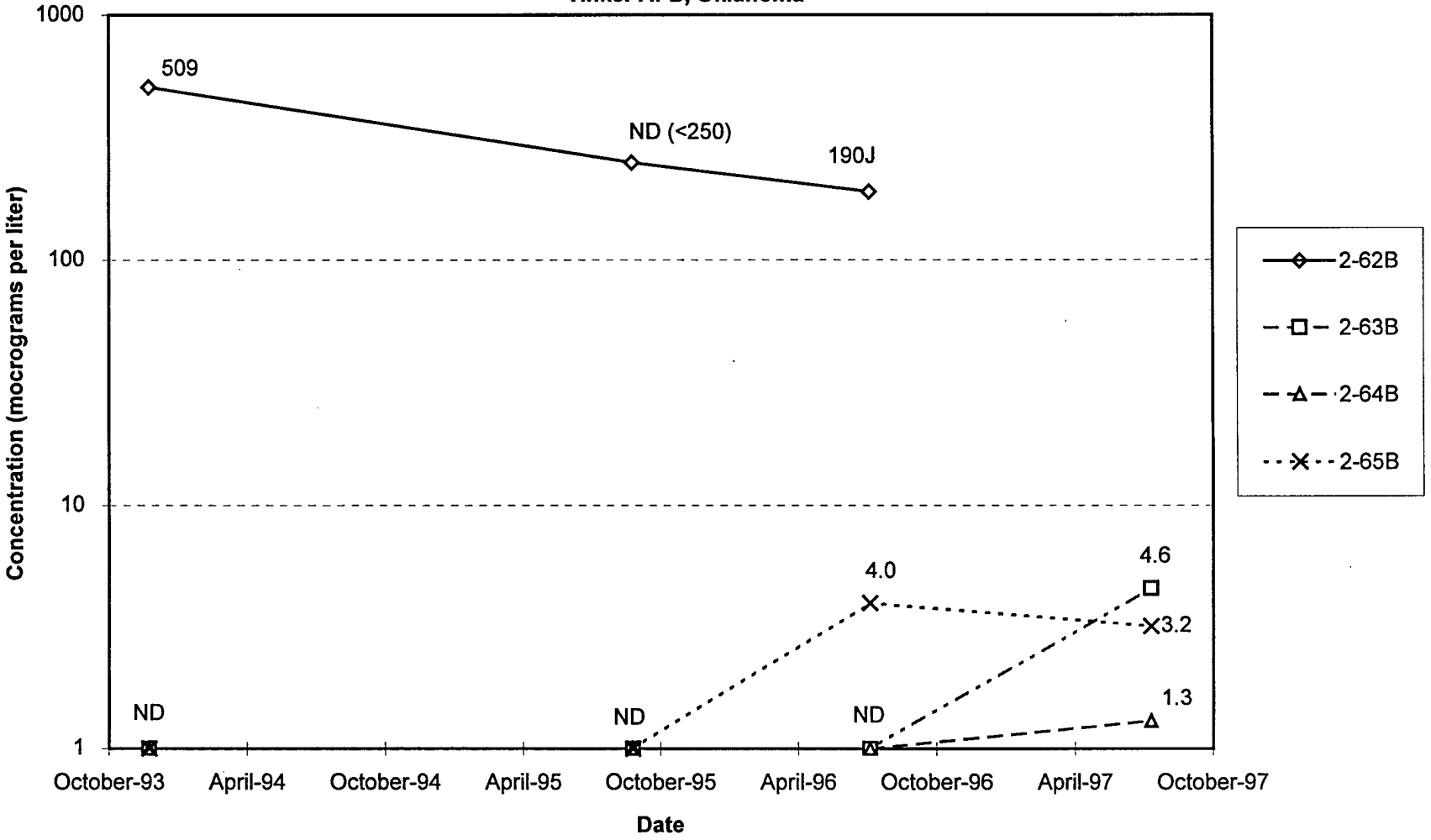


FIGURE 4.12
TOTAL CHLOROBENZENES VERSUS TIME
Site FTA-2
RNA TS
Tinker AFB, Oklahoma

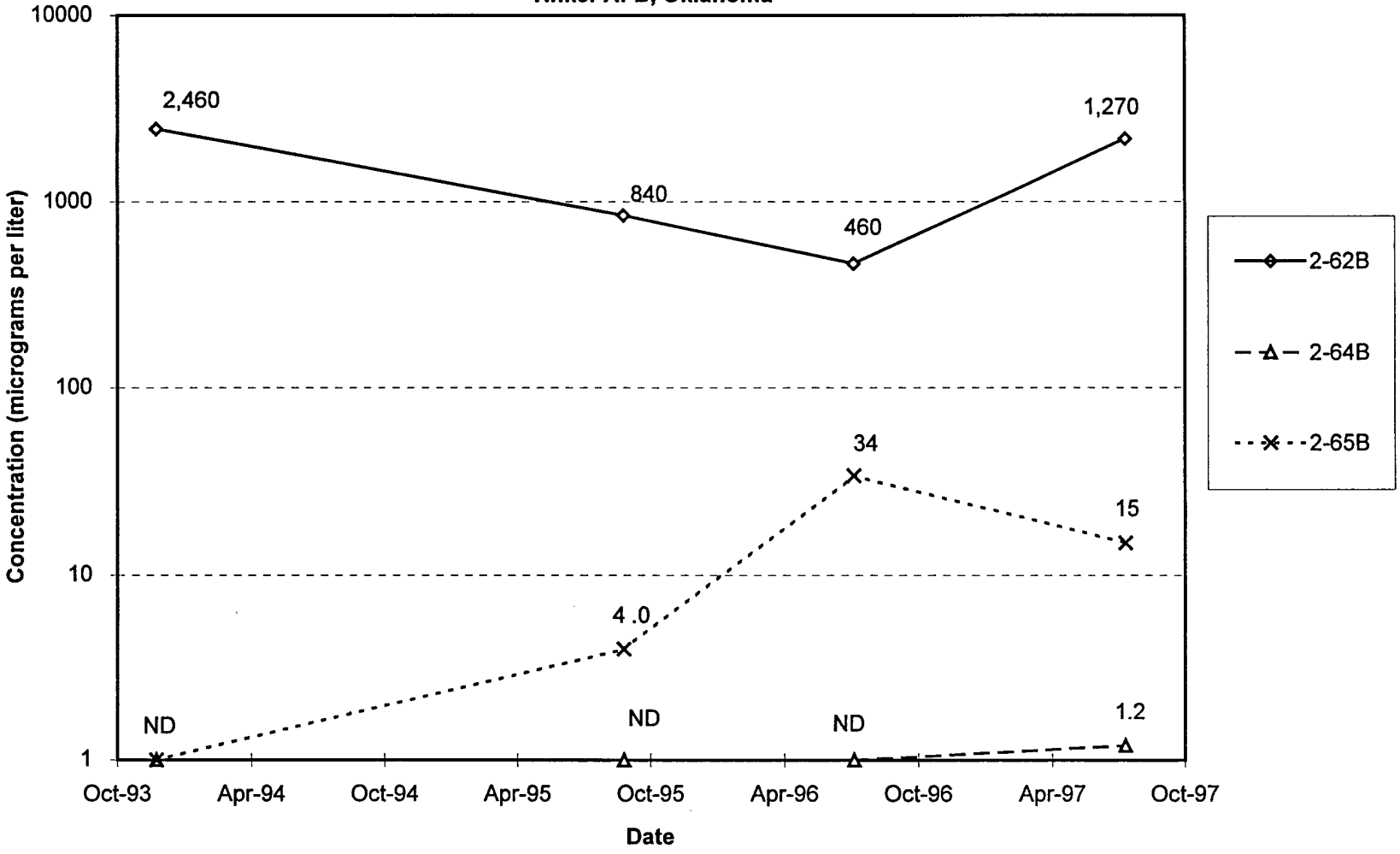
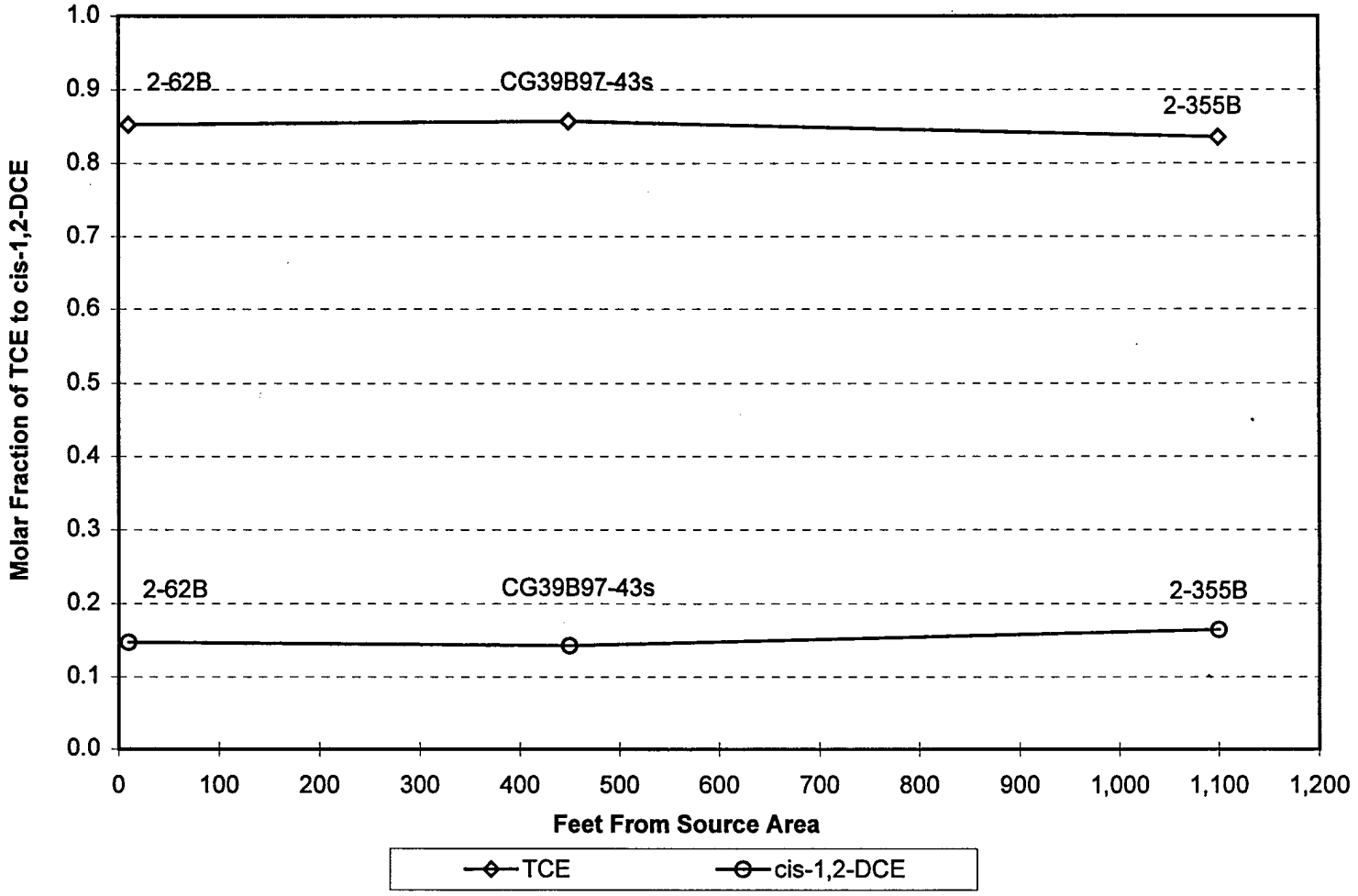


FIGURE 4.13
MOLAR FRACTION OF TCE TO cis-1,2-DCE VERSUS DISTANCE
Site FTA-2
RNA TS
Tinker AFB, Oklahoma



The geochemical conditions conducive to aerobic degradation of VC do not at the same time support anaerobic reductive dechlorination of TCE or DCE. DCE is most likely also aerobically degraded, but at a slower rate than VC.

Data from wells located near the source area (2-62B, 2-63B, 2-64B, and 2-65B), and along the approximate CAH plume axis (CG39B97-43s and 2-355B) were used to assess the magnitude of the *cis*-1,2-DCE to *trans*-1,2-DCE ratio throughout the CAH plume. Because the *cis*- isomer is preferentially produced by microbial reductive dehalogenation, the ratio of *cis*-1,2-DCE to *trans*-1,2-DCE should be relatively high, especially in areas where the parent solvent(s) is being transformed (source area). The reported concentrations of *trans*-1,2-DCE at well 2-355B were less than 1 µg/L, so the concentration was assumed to be 0.5 µg/L for calculation purposes. The magnitude of the *cis*-1,2-DCE to *trans*-1,2-DCE ratio varies from 8.75 at well 2-64B to approximately 100 at well CG39B97-43s, indicating that the *cis*- isomer predominates throughout the plume. These ratios are a strong indication that TCE is being reductively dehalogenated, at least in the source area. According to Weidemeier, *et al.* (1996), if *cis*-1,2-DCE is greater than 80 percent of total DCE present, then it is a likely daughter product of TCE. In all cases at FTA-2, *cis*-1,2-DCE is present at greater than 80 percent of total DCE.

4.3.3 Chloride as an Indicator of Dehalogenation

Chloride ions are removed from chlorinated solvents and enter solution during biodegradation, whether via reductive dehalogenation or aerobic oxidation. Therefore, chloride concentrations in groundwater should increase above background levels in areas where reductive dehalogenation or aerobic biodegradation are taking place. Chloride concentrations are presented in Table 4.4, and the distribution of chloride in USZ groundwater at the site is shown on Figure 4.14. Background chloride concentrations (measured in wells without contamination in USZ groundwater) range from about 4.49 milligrams per liter (mg/L) (2-167B) to about 17 mg/L (2-273B), with two exceptions being 117 mg/L at 2-271B and 218 mg/L at 2-142B. It is not clear why these higher chloride concentrations occur at wells 2-271B and 2-142B, although these wells are located farther to the north, and chloride concentrations may represent upgradient or cross-gradient water quality. Most background chloride concentrations are less than 20 mg/L.

Chloride concentrations within the boundaries of the chlorinated solvent plume are slightly elevated above background, with a maximum concentration of 187 mg/L at 2-355B. Within areas where biodegradation is indicated by other chemical data, most chloride concentrations are greater than 40 mg/L. The slightly elevated chloride concentrations observed at FTA-2 are a moderate indication that CAHs are undergoing microbially mediated degradation when reviewed in conjunction with the distributions of CAHs (Figures 4.4 through 4.6). Given the presence of daughter products such as *cis*-1,2-DCE, *trans*-1,2-DCE, and VC, it is likely that some of the chloride is a product of reductive dehalogenation, at least within the primary source area. Chloride concentrations within the dissolved CAH plume may also be related to aerobic degradation of DCE and VC.

TABLE 4.4
GROUNDWATER GEOCHEMICAL DATA
AUGUST 1997
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Sample Location	Temp (°C)[a/]	pH[b/]	Conductivity (µs/cm)[c/]	Dissolved Oxygen (mg/L)[d/]	Redox Potential (mV)[e/]	Total Alkalinity (mg/L)	Chloride (mg/L)	Ammonia (mg/L)	Ferrous Iron (mg/L)	Nitrite+ Nitrate (mg/L)	Sulfate (mg/L)	Hydrogen Sulfide (mg/L)	Manganese (mg/L)	Total Phenols (mg/L)	Carbon Dioxide (mg/L)	TOC (mg/L)	Methane (mg/L)	Ethane (mg/L)	Ethene (mg/L)
Upper Saturated Zone																			
CG39-B97-41	22.0	6.88	861	3.9	136.2	520	5.73	<0.05	<0.01	2.01	15.4	<0.01	<0.01	<0.01	60	<0.4	<0.001	<0.003	<0.002
CG39-B97-43s	21.5	6.80	1278	4.8	116.7	330	159	<0.05	<0.01	4.22	49.0	<0.01	<0.01	0.2	48	0.539	<0.001	<0.003	<0.002
CG39-B97-43d	18.4	7.07	1112	3.3	129.8	450	52.0	<0.05	<0.01	2.55	44.1	<0.01	<0.01	0.2	75	0.545	<0.001	<0.003	<0.002
CG39-B97-45	19.4	6.91	872	6.5	103.2	380	46.9	<0.05	<0.01	4.80	11.3	<0.01	<0.01	<0.01	75	<0.4	<0.001	<0.003	<0.002
2-392B	18.5	7.18	697	6.0	138.7	350	10.6	<0.05	<0.01	2.57	5.91	<0.01	<0.01	0.2	60	<0.4	<0.001	<0.003	<0.002
2-393B	18.2	7.23	1184	7.0	110.9	190	148	<0.05	<0.01	3.70	14.1	<0.01	<0.01	<0.01	110	<0.4	<0.001	<0.003	<0.002
2-62B	18.8	7.34	1441	0.2	50.7	260	173	<0.05	<0.01	3.92	127	<0.01	<0.01	<0.01	55	3.30	1.05	<0.003	<0.002
2-63B	19.9	7.35	1516	0.6	79.4	460	94.4	<0.05	<0.01	2.39	65.7	<0.01	<0.01	<0.01	75	11.2	0.002	<0.003	<0.002
2-64B	20.6	NR[f/]	848	1.8	123.5	260	49.3	<0.05	<0.01	3.42	27.0	<0.01	<0.01	<0.01	40	0.795	<0.001	<0.003	<0.002
2-65B	18.8	7.13	1166	2.3	91.2	350	78.5	<0.05	<0.01	3.18	44.4	<0.01	<0.01	<0.01	75	1.96	0.002	<0.003	<0.002
2-167B	17.3	7.11	1008	2.3	80.6	560	4.49	<0.05	0.1	0.27	18.1	<0.01	<0.01	0.1	75	0.488	0.022	<0.003	<0.002
2-168B	18.3	7.17	993	0.7	-21.7	380	14.4	<0.05	<0.01	0.58	42.4	<0.01	<0.01	<0.01	65	3.01	0.02	<0.003	<0.002
2-271B	16.9	7.19	1238	3.8	67.8	420	117	0.15	0.6	1.11	29.7	<0.01	<0.01	0.3	65	0.939	<0.001	<0.003	<0.002
2-272B	17.8	7.24	1075	4.1	30.2	280	130	<0.05	<0.01	1.95	37.6	<0.01	<0.01	<0.01	45	0.448	<0.001	<0.003	<0.002
2-273B	18.3	7.20	761	0.2	-105.1	280	16.5	<0.05	0.2	0.35	12.1	<0.01	<0.01	<0.01	45	0.638	0.005	<0.003	<0.002
2-274B	17.7	7.20	919	5.1	50.0	310	74.6	<0.05	0.2	3.08	24	<0.01	<0.01	0.2	45	<0.4	<0.001	<0.003	<0.002
2-355B	17.8	7.23	1490	7.9	116.7	380	187	<0.05	0.4	3.28	48.8	<0.01	<0.01	0.3	50	0.741	<0.001	<0.003	<0.002
2-142B	16.9	7.36	1480	3.1	52.6	380	218	<0.05	0.8	2.00	76.1	<0.01	<0.01	0.2	55	0.929	<0.001	<0.003	<0.002
Lower Saturated Zone																			
2-62A	21.5	7.42	782	5.6	97.2	310	7.54	<0.05	0.1	4.02	6.51	<0.01	<0.01	<0.01	45	1.53	<0.001	<0.003	<0.002
2-63A	18.9	7.31	654	7.2	47.8	380	20.5	<0.05	1.0	1.91	8.46	<0.01	<0.01	<0.01	50	0.745	<0.001	<0.003	<0.002
2-64A	20.2	7.69	666	6.1	121.9	270	21.5	<0.05	0.1	1.29	7.96	<0.01	<0.01	<0.01	45	0.152	<0.001	<0.003	<0.002
2-65A	19.9	7.67	576	4.2	-38.3	190	25.6	<0.05	0.3	0.72	9.89	<0.01	<0.01	<0.01	25	<0.4	<0.001	<0.003	<0.002
2-274A	20.1	7.60	516	7.4	63.1	210	18.0	<0.05	<0.01	0.62	10.4	<0.01	<0.01	0.4	25	<0.4	<0.001	<0.003	<0.002
2-142A	17.5	7.75	620	1.2	26.3	270	28.4	<0.05	<0.01	<0.05	9.72	<0.01	<0.01	0.2	45	2.14	<0.001	<0.003	<0.002

a/ °C = degrees Centigrade.

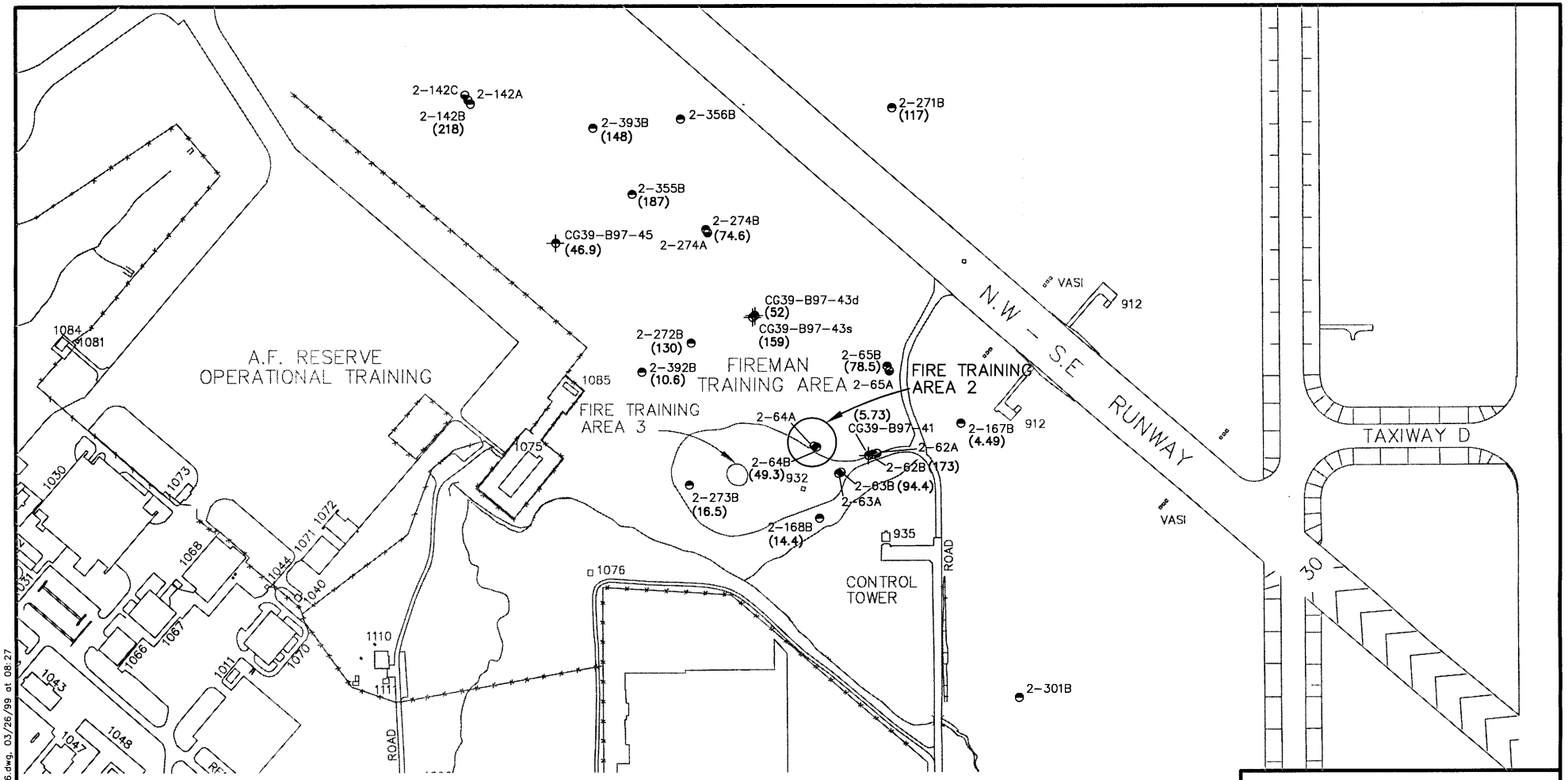
b/ well head measurement not made; value reported is measurement made in on-base field laboratory.

c/ µs/cm = microsiemens per centimeter.

d/ mg/L = milligrams per liter.

e/ mV = millivolts.

f/ NR = not recorded.



LEGEND

2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

CG39-B97-41 — MONITORING POINT LOCATION/ UPPER SATURATED ZONE

s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR

DIRECTION OF GROUNDWATER FLOW

ALL CONCENTRATIONS IN MILLIGRAMS PER LITER (mg/L)

0 150 300 600
FEET

FIGURE 4.14

CHLORIDE CONCENTRATIONS IN USZ GROUNDWATER

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4.3.4 ORP as an Indicator of Redox Processes

Redox potential is a measure of the relative tendency of a solution to accept or transfer electrons. The redox potential of a groundwater system depends on which electron acceptors are being reduced by microbes during oxidation of organic compounds. 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, ferric iron, sulfate, carbon dioxide, and possibly *cis*-1,2-DCE), which yields energy, the overall reaction will yield energy.

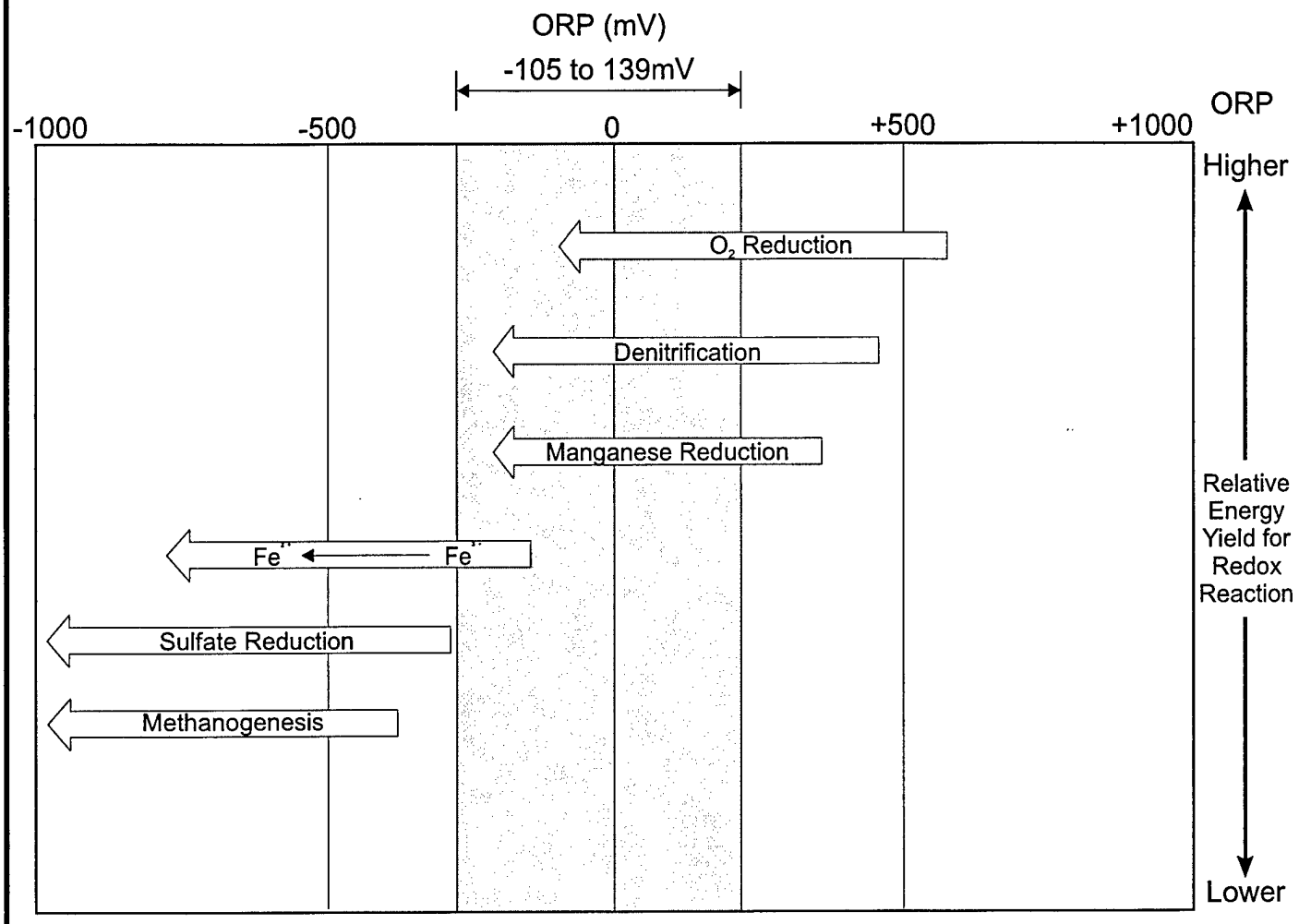
The sequence of microbially mediated redox processes and the approximate ranges of ORPs that are favorable for each process are presented in Figure 4.15. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981; Godsey, 1994; Reinhard, 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 DO 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), ferric iron (iron reduction), sulfate (sulfate reduction), and finally carbon dioxide (methanogenesis). Each successive redox reaction provides less energy to the system, and each step down in redox energy yield is paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

Redox potentials were measured at groundwater monitoring wells and points in August 1997. Redox potentials for USZ groundwater at the site range from 138.7 millivolts (mV) to -105.1 mV, and from 121.9 mV to -38.3 mV in the LSZ (Table 4.4 and Figure 4.16). In some locations, low redox potentials coincide with areas of elevated solvent concentrations, decreased DO, nitrate, and sulfate concentrations, and elevated ferrous iron (iron [II]) and methane concentrations. However, this is not always the case and the correlation between redox potential and geochemical indicators is not strong.

The lowest redox potentials were detected in the vicinity of 2-273B and 2-168B. The redox potentials measured at those two locations were -105.1 mV and -21.7 mV, respectively. This area is immediately downgradient of the FTA-2 fire pit and the CAH source area (2-62B). This area of low redox potential also coincides with Fire Training Area 3, and may reflect reducing conditions caused by biodegradation of hydrocarbons released by historical practices at either site.

4.3.5 Electron Donors

The distribution of potential electron donors (carbon sources) such as BTEX, native organic carbon, or CAHs themselves are useful for evaluating the feasibility of reductive dehalogenation, aerobic biodegradation, or cometabolism (i.e., biodegradation reactions involving another substrate).



Notes

ORP = Oxidation Reduction Potential

Range of ORP measured at FTA-2

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 reaction sequence is paralleled by an ecological succession of biological mediators.

Adapted from Stumm and Morgan, 1981.

FIGURE 4.15

SEQUENCE OF MICROBIALLY MEDIATED REDOX PROCESSES USZ GROUNDWATER

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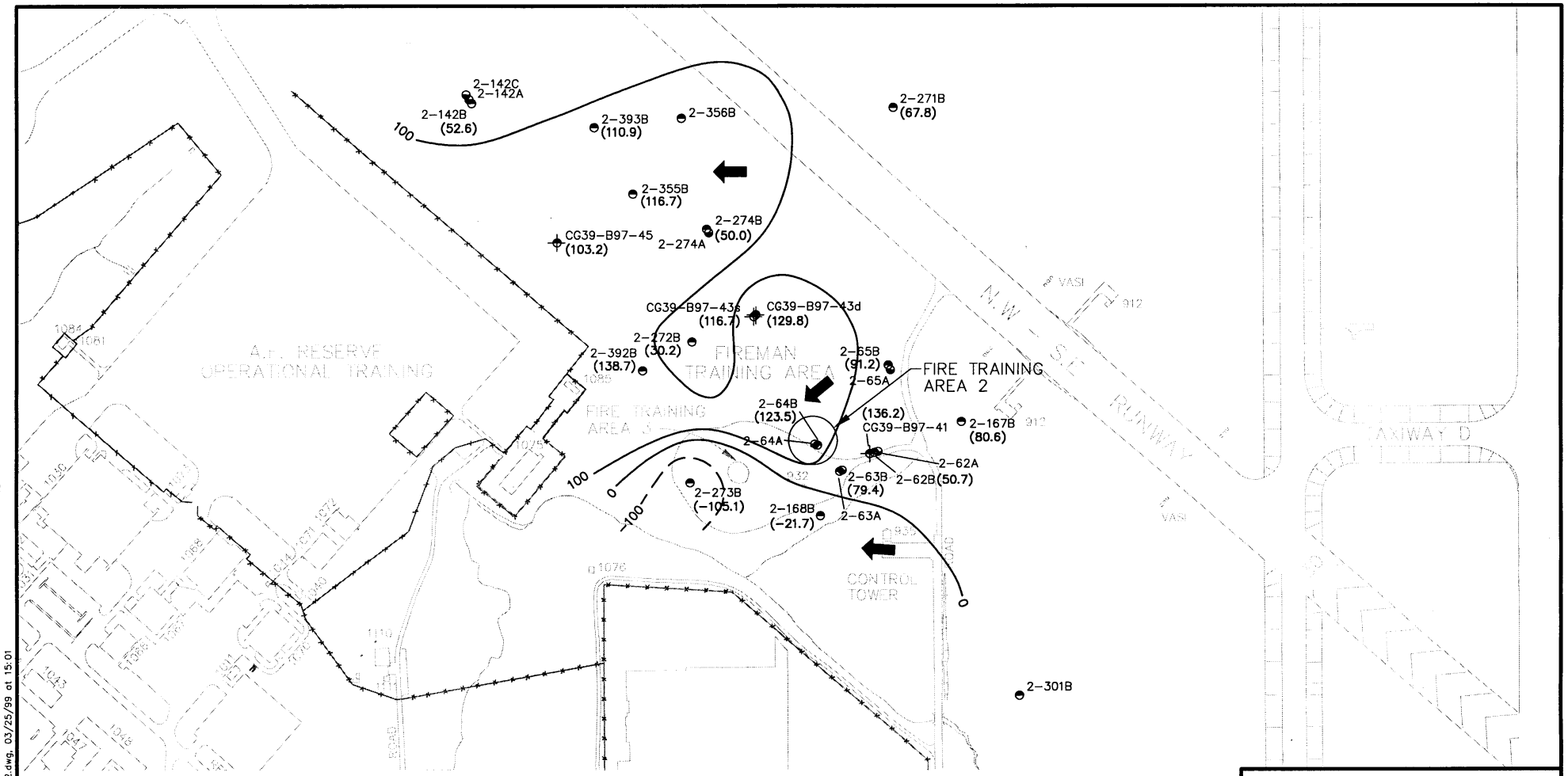

LEGEND

2-142B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-142A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
CG39-B97-41	TEMPORARY MONITORING POINT LOCATION/ UPPER SATURATED ZONE
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR

ALL POTENTIALS IN MILLIVOLTS (mv)

-100- LINE OF EQUAL REDOX POTENTIAL (mv)

DIRECTION OF GROUNDWATER FLOW

0 150 300 600
FEET

FIGURE 4.16

REDOX POTENTIAL OF USZ GROUNDWATER AUGUST 1997

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4.3.5.1 BTEX and Total Fuel Carbon in Groundwater

The presence of BTEX and fuel carbon in the same area as a CAH plume creates favorable conditions for reductive dehalogenation, because the petroleum compounds provide a source of electron donors and facilitate microbial reactions that lower the groundwater ORP. It is likely that the introduction of petroleum hydrocarbons due to fire training and other waste disposal activities stimulated microbial activity and reducing conditions ensued. Given these conditions, the presence of BTEX and fuel carbon in site groundwater is considered a favorable factor in the biodegradation of CAHs.

The coincidence of the dissolved BTEX and fuel carbon plumes with the highest concentrations of the reductive dehalogenation daughter products 1,1-DCE and VC (presented in Sections 4.3 and 4.4.1) establishes the importance of petroleum hydrocarbons in the effective reductive dehalogenation of chlorinated compounds near the general source area. However, BTEX and fuel carbon concentrations are much lower than CAH concentrations, and the extent and concentrations of the BTEX/fuel carbon plumes are such that detectable concentrations of these compounds do not appear to have significantly migrated beyond the general source area of the CAH contaminant plumes.

4.3.5.2 Organic Carbon in Groundwater

Dissolved organic carbon can also act as a source of electron donors 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 contamination (anthropogenic organic compounds, such as CAHs, petroleum hydrocarbons, or landfill leachate also are measured by the TOC analytical method). Dissolved TOC concentrations in excess of 20 mg/L are desirable to drive dehalogenation reactions (Wiedemeier et al., 1996a).

TOC dissolved in groundwater was measured in groundwater samples collected in August 1997 (Table 4.4). Dissolved TOC concentrations detected in shallow groundwater at FTA-2 range from less than 0.4 mg/L to 11.2 mg/L. The highest concentrations were measured in 2-63B and 2-62B, and may reflect the presence of contamination. Elsewhere, the TOC concentrations did not exceed 3.0 mg/L. Native organic carbon concentrations of this magnitude are insufficient to drive reductive dehalogenation of CAHs.

4.3.5.3 Use of CAHs as Electron Donors

Less-chlorinated CAHs (e.g., DCE and VC) can be used as electron donors in aerobic environments, resulting in biodegradation of CAHs. Shallow groundwater throughout most of the FTA-2 contaminant plume is relatively aerobic (DO >1 mg/L), and the silty to sandy alluvial sediments do not have a particularly high native organic carbon content (Table 4.1). In these areas, TCE, DCE, and VC are probably being degraded through use as electron donors in microbially mediated redox reactions.

4.3.6 Alternate Electron Acceptors and Metabolic Byproducts

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

Results of alternate electron acceptor and metabolic byproduct analyses for the TS are presented in Table 4.4. The following paragraphs discuss those parameters most useful in evaluating site biodegradation processes.

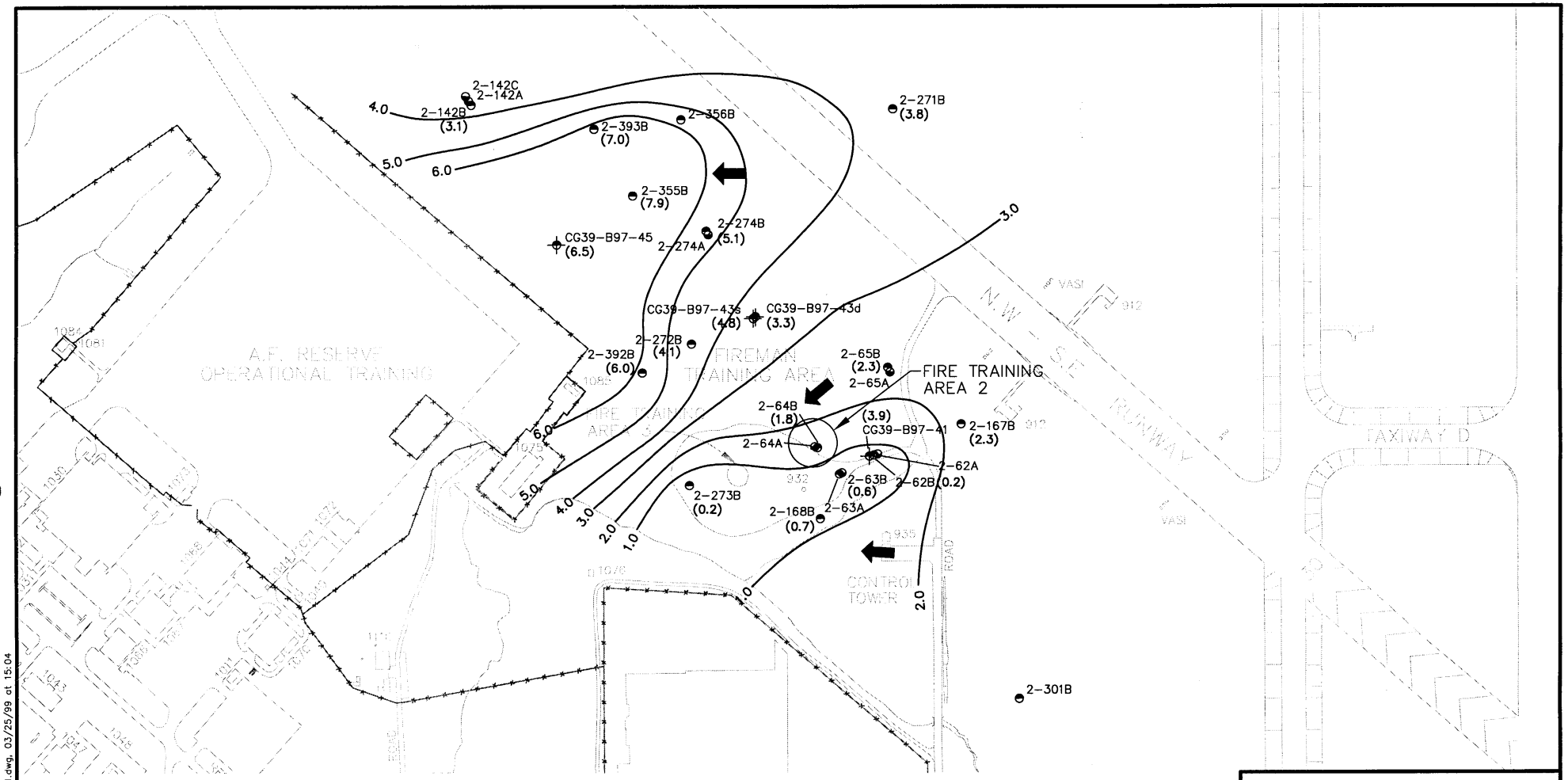
4.3.6.1 Dissolved Oxygen

DO concentrations were measured at monitoring wells and points during the August 1997 sampling event. Concentrations ranged from 0.2 to 7.9 mg/L (Table 4.4), with the highest concentrations measured in wells/points in the furthest downgradient portion of the USZ CAH contaminant plume, or outside of the area of the contaminant plumes. In the downgradient portion of the contaminant plume, DO concentrations in excess of 6.0 mg/L may be a result of extensive well development pumping in newly installed monitoring wells. Actual background DO concentrations may be on the order of 3 to 4 mg/L (2-271B and 2-148B). DO concentrations in the LSZ range from 1.2 to 7.4 mg/L. Within and immediately hydraulically downgradient of the source area, concentrations were generally below 1.0 mg/L (Figure 4.17). The low concentrations of oxygen in the plume source area relative to upgradient and crossgradient concentrations are a strong indication of biological activity. Depletion of DO within the CAH source area at FTA-2 indicates that microbial activity stimulated by the presence of anthropogenic hydrocarbons (e.g., fuel hydrocarbons, chlorobenzenes, VC, DCA, or DCE) is consuming DO and creating anaerobic conditions.

4.3.6.2 Nitrate/Nitrite

After DO has been depleted in the microbiological treatment zone, 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 nitrogen (N)] were measured in groundwater samples collected in August 1997. Measured nitrate/nitrite (as N) concentrations are summarized in Table 4.4, and the distribution of nitrate/nitrite (as N) concentrations in site groundwater is shown on Figure 4.18. Background concentrations in the USZ range from 0.27 mg/L to 4.8 mg/L. Within the plume, nitrate/nitrite concentrations are generally range from 2 to 3 mg/L. An area of reduced nitrate/nitrite concentrations exists immediately cross-gradient of the CAH plume source area (or hydraulically downgradient) at wells 2-168B and 2-273B, which also coincides with an area of low ORP and low DO concentrations. These observations may indicate that DO has been



LEGEND

2-142B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-142A	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
CG39-B97-41	TEMPORARY MONITORING POINT LOCATION/ UPPER SATURATED ZONE
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR

ALL CONCENTRATIONS IN MILLIGRAMS PER LITER (mg/L)

1.0 LINE OF EQUAL DISSOLVED OXYGEN CONCENTRATION (mg/L)

DIRECTION OF GROUNDWATER FLOW

0 150 300 600
FEET

FIGURE 4.17

CONCENTRATION OF DISSOLVED OXYGEN IN USZ GROUNDWATER AUGUST 1997

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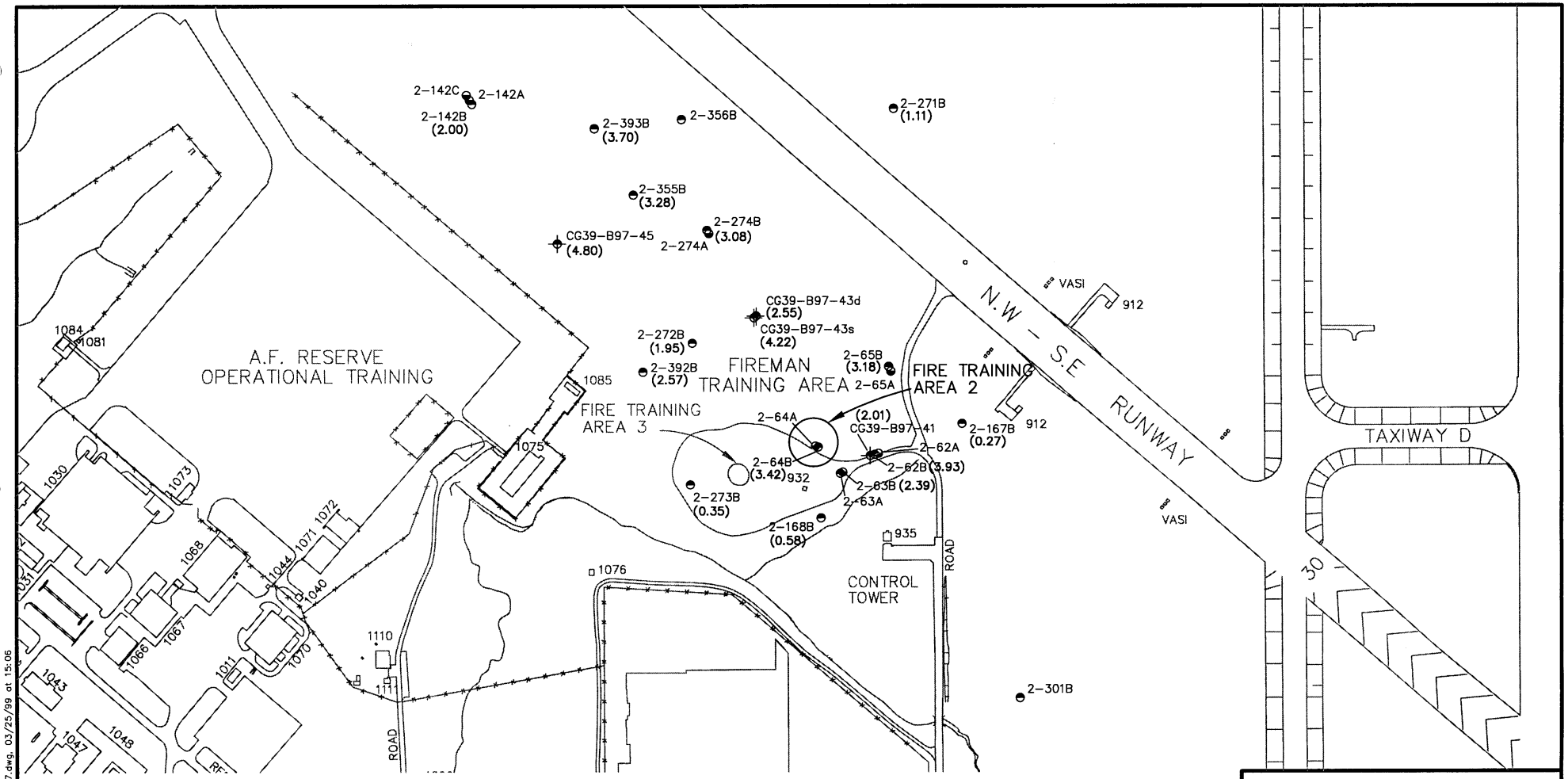

LEGEND

2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

CG39-B97-41 — MONITORING POINT LOCATION/ UPPER SATURATED ZONE

s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR

DIRECTION OF GROUNDWATER FLOW

ALL CONCENTRATIONS IN MILLIGRAMS PER LITER (mg/L)

0 150 300 600
FEET

FIGURE 4.18

CONCENTRATION OF NITRATE/NITRITE (as N) IN USZ GROUNDWATER AUGUST 1997

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consumed, and microbes are utilizing nitrate as an electron acceptor for degradation of organic material (such as fuel hydrocarbons or native organic carbon).

4.3.6.3 Ferrous Iron

The reduction of ferric iron [iron (III)] has been shown to be a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). The reduction of ferric iron results in the formation of ferrous iron [iron (II)], and elevated concentrations of iron (II) often are found in anaerobic groundwater systems. Ferrous iron concentrations once were attributed to the abiotic spontaneous and reversible reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as BTEX, TMB, and naphthalene. However, recent evidence suggests that the reduction of ferric iron 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 iron (II) under sterile laboratory conditions (Lovley *et al.,* 1991). This means that the reduction of ferric iron requires mediation by microorganisms with the appropriate enzymatic capabilities.

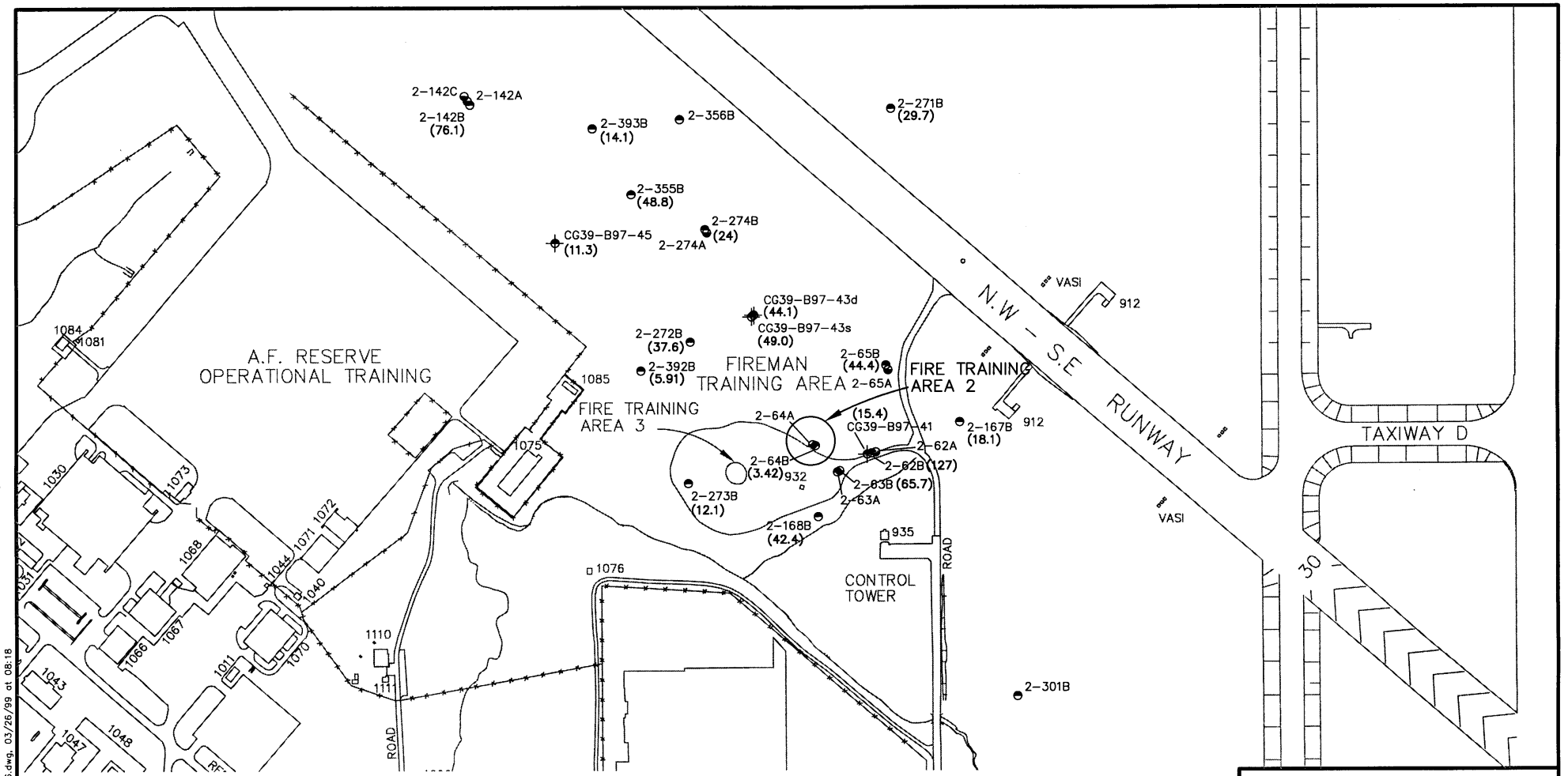
Iron (II) concentrations measured in groundwater samples collected in August 1997 are summarized in Table 4.4. Measured iron (II) concentrations in the USZ range from less than 0.01 mg/L to 0.8 mg/L, and from less than 0.01 mg/L to 1.0 mg/L in the LSZ. The highest iron (II) concentrations do not coincide with the solvent plume (2-271B, 2-142B, and 2-63A). This suggests that iron (III) hydroxide is not being reduced to iron (II) during biodegradation of native organic carbon, fuel hydrocarbons, or less-chlorinated solvents. Background levels of iron (II) in both the USZ and LSZ appear to range from below detection limits (0.01 mg/L) to about 1.0 mg/L, as measured at upgradient and cross-gradient wells.

4.3.6.4 Sulfate

Sulfate also may be used as an electron acceptor during microbial degradation of natural or anthropogenic organic carbon under anaerobic conditions (Grbic-Galic, 1990). This redox reaction is commonly called sulfate reduction. Sulfate concentrations were measured in groundwater samples collected in August 1997. Sulfate concentrations in USZ groundwater at the site ranged from 5.91 mg/L to 127 mg/L, and from 6.51 mg/L to 10.4 mg/L in the LSZ (Table 4.4). The highest sulfate concentration of 127 mg/L was detected in well 2-62B (Figure 4.19). Outside of the chlorinated solvent plume, sulfate concentrations ranged from 5.91 mg/L (2-392B) to 76.1 mg/L (2-242B). Within the plume area, nearly all sulfate concentrations ranged from 11.3 mg/L to 49 mg/L. Areas of decreased sulfate concentrations do not coincide with chlorinated solvent concentrations. It is therefore unlikely that sulfate reduction is an ongoing anaerobic biodegradation process at FTA-2.

4.3.6.5 Methane, Ethane and Ethene in Groundwater

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, ethane, and ethene



LEGEND

2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

CG39-B97-41 — MONITORING POINT LOCATION/ UPPER SATURATED ZONE

s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR

DIRECTION OF GROUNDWATER FLOW

ALL CONCENTRATIONS IN MILLIGRAMS PER LITER (mg/L)

0 150 300 600
FEET

FIGURE 4.19

CONCENTRATION OF SULFATE IN USZ GROUNDWATER AUGUST 1997

Site FTA-2
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concentrations were measured in groundwater samples collected in August 1997 (Table 4.4). Methane was detected at six locations, with concentrations ranging from less than 0.001 mg/L to 1.05 mg/L (2-62B). Ethane and ethene were not detected. The area of elevated methane concentrations coincides with the fuel hydrocarbon and chlorinated solvent source area. The presence of methane in the source area indicates highly reducing conditions favorable for oxidation of petroleum hydrocarbons and native organic matter as well as reductive dehalogenation of chlorinated solvents.

4.3.6.6 Ammonia/Ammonium

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 fixation of atmospheric nitrogen only occurs under reducing conditions [ORP less than -500 mV (Stumm and Morgan, 1981)], ammonia production via nitrate reduction is probably more common than by fixation of atmospheric nitrogen. In either case, the presence of ammonia in groundwater is a strong indication of microbial activity. Ammonia/ammonium was detected at one location (2-271B at 0.15 mg/L) in USZ groundwater at a concentration greater than 0.05 mg/L (Table 4.4). Because nitrate is not widespread in USZ groundwater or present at any significant concentrations, it is unlikely that biodegradation by nitrate reduction is occurring at the site outside of the source area. Therefore, ammonia/ammonium is not expected at elevated concentrations.

4.3.7 Additional Geochemical Indicators

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

4.3.7.1 Alkalinity and Carbon Dioxide Evolution

Carbon dioxide is produced during the biodegradation of fuel hydrocarbons and native organic carbon compounds. 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. An increase in alkalinity (measured as calcium carbonate [$CaCO_3$]) in an area with fuel hydrocarbons or chlorinated solvent (particularly less-chlorinated solvents) concentrations elevated above background conditions can be used to infer that fuel hydrocarbons, less-chlorinated solvents, or native organic carbon has been destroyed through aerobic and anaerobic microbial respiration.

Total alkalinity (as $CaCO_3$) was measured in groundwater samples collected in August 1997 (Table 4.4, Figure 4.20). Alkalinity is a measure of the ability of groundwater to buffer changes in pH. Total alkalinity in USZ groundwater at the site varied from 190 mg/L to 560 mg/L. Alkalinity within the plume area is highly variable, but appears to be sufficient to buffer potential changes in pH caused by biologically mediated reactions. The pH data for site groundwater (Section 4.3.7.2) suggest that groundwater pH decreases slightly at some locations within the plume.

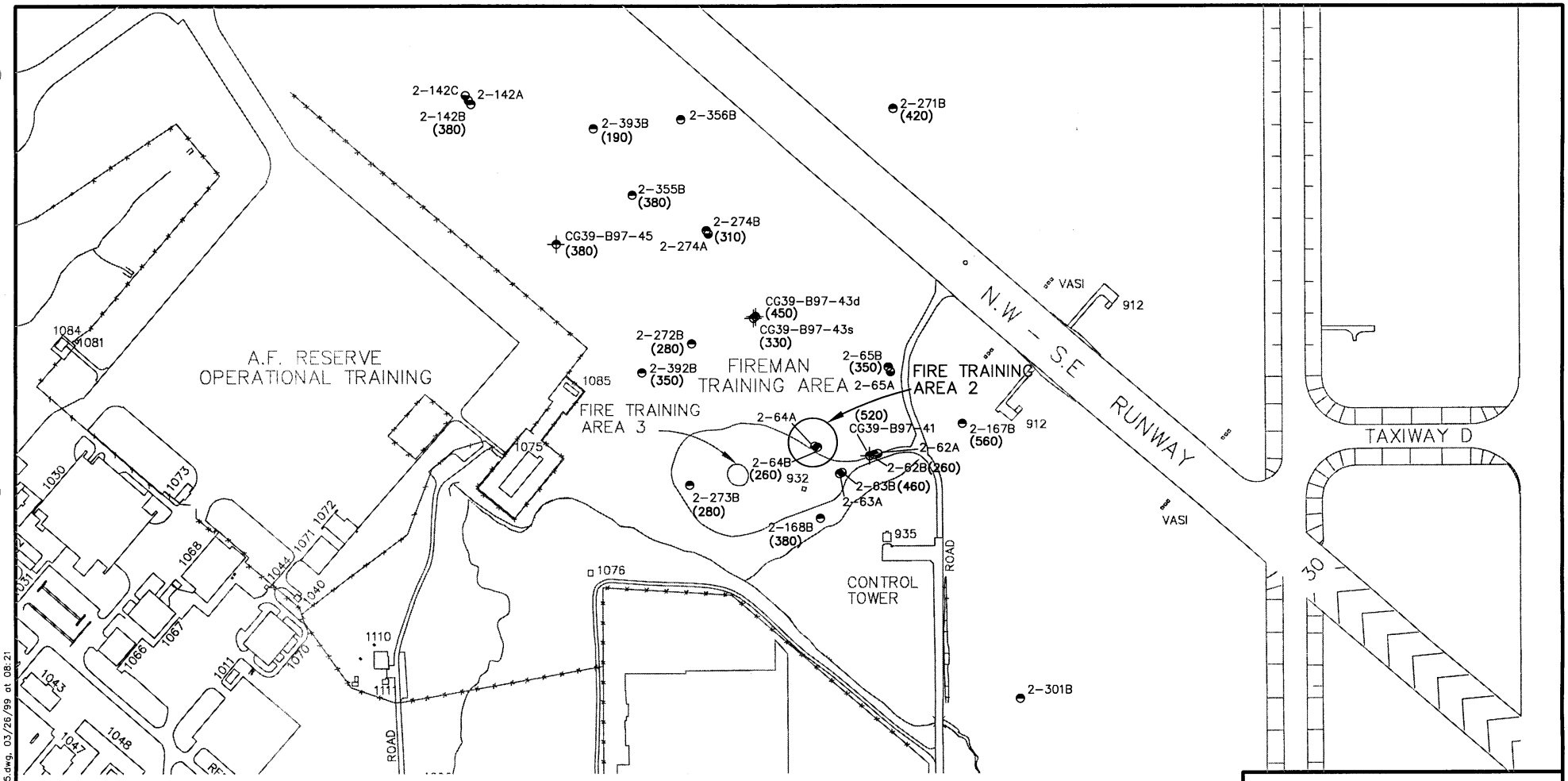

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FIGURE 4.20

CONCENTRATION OF TOTAL ALKALINITY IN USZ GROUNDWATER AUGUST 1997

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Free carbon dioxide concentrations also were measured in groundwater samples collected in August 1997 (Table 4.4). As shown on Figure 4.21, carbon dioxide concentrations within the full extent of the chlorinated solvent plume are not elevated noticeably above background concentrations. Background concentrations are about 50 to 65 mg/L, while within the plume area, concentrations are in the range of 40 to 110 mg/L. Carbon dioxide concentrations above background could result from both aerobic and anaerobic biodegradation processes as contaminants are ultimately converted to carbon dioxide and water.

4.3.7.2 pH

Groundwater pH was measured for samples collected from monitoring points and monitoring wells in August 1997 (Table 4.4). The pH of a solution is the negative logarithm of the hydrogen ion concentration [H^+]. USZ groundwater pH measured at the site ranges from 6.80 to 7.36 standard units, and from 7.31 to 7.75 standard units in the LSZ. This range of pH is within the optimal range for BTEX- and CAH-degrading microbes of 6 to 8 standard units.

4.3.7.3 Temperature

Groundwater temperature was measured at monitoring points and monitoring wells in August 1997 (Table 4.4). Temperature can affect the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures typically resulting in higher growth rates. Wiedemeier *et al.* (1996a) report that biochemical processes are accelerated at groundwater temperatures greater than 20°C. Groundwater temperatures at FTA-2 for the USZ varied from 16.9°C to 22.0°C, and from 17.5°C to 21.5°C for the LSZ. These are moderately warm temperatures for groundwater (but still within the optimal range), suggesting that bacterial growth rates should be high.

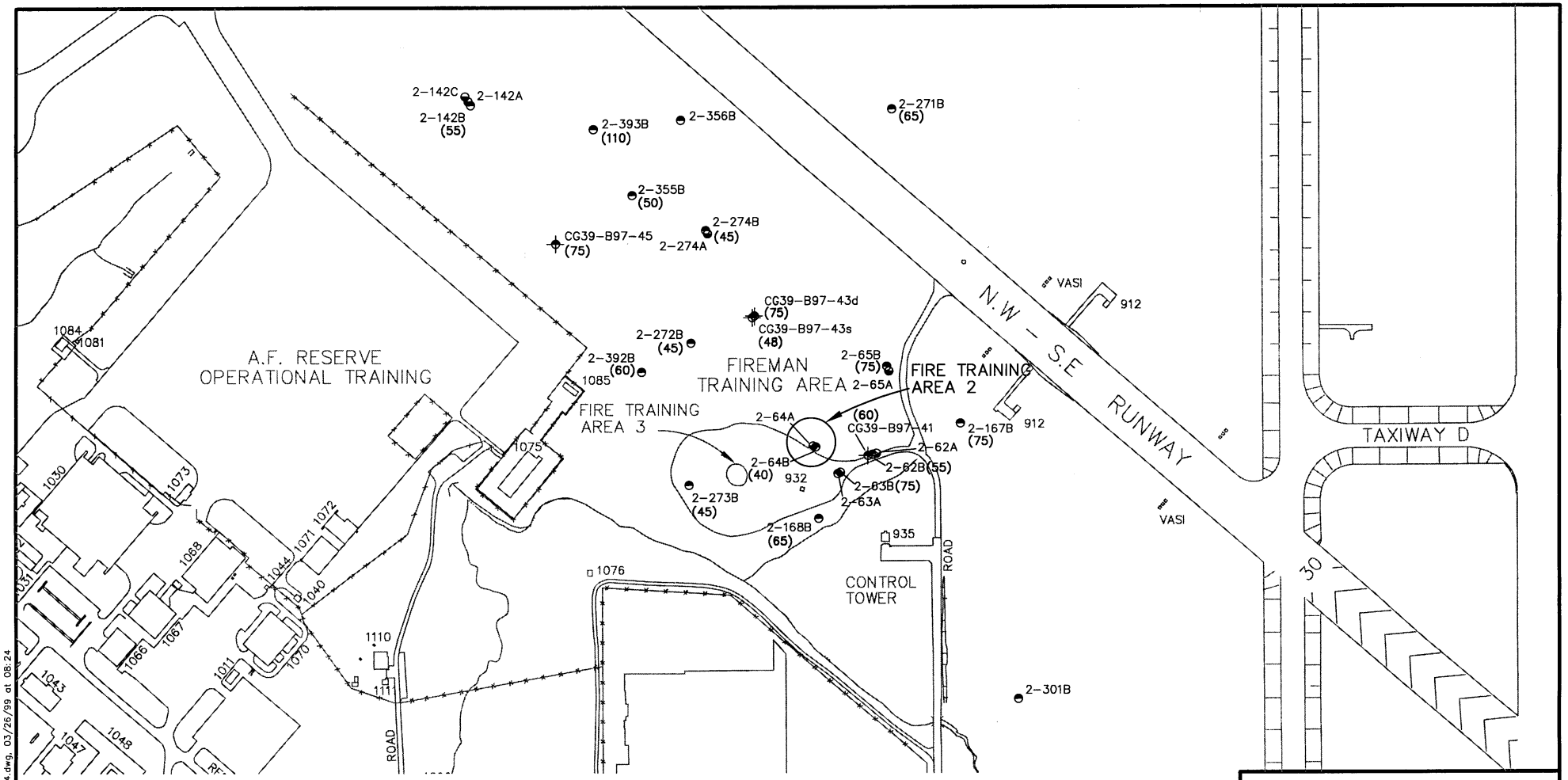
4.3.8 Screening Table for CAH Degradation

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 FTA-2, is included as Table 4.5. The interpretation of points awarded during the screening process outlined in Table 4.5 is shown in Table 4.6.

The score for FTA-2 computed using Table 4.5 is 9. Based on the evidence presented herein, there is limited evidence for biodegradation of CAHs at FTA-2.

4.4 APPROXIMATION OF BIODEGRADATION RATES

Biodegradation rate constants are necessary to accurately simulate the fate and transport of contaminants dissolved in groundwater. In many cases, biodegradation of contaminants can be approximated using first-order kinetics. First-order biodegradation rate constants may be calculated on the basis of field-scale data, or by using a small sample of the aquifer material and groundwater for microcosm studies. For reductive dehalogenation of chlorinated compounds, first-order rates are not necessarily an



LEGEND

2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER

CG39-B97-41 — MONITORING POINT LOCATION/ UPPER SATURATED ZONE

s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR

DIRECTION OF GROUNDWATER FLOW

ALL CONCENTRATIONS IN MILLIGRAMS PER LITER (mg/L)

0 150 300 600
FEET

FIGURE 4.21

CONCENTRATION OF CARBON DIOXIDE IN USZ GROUNDWATER AUGUST 1997

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

S:\ES\cad\AFCEE\729691\TINKER\98dn0244.dwg, 03/26/99 at 08:24

TABLE 4.5
ANALYTICAL PARAMETERS AND WEIGHTING FOR PRELIMINARY SCREENING
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value	FTA-2 Score
Oxygen	<0.5 mg/L >1 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations VC may be oxidized aerobically	3 -3	1
Nitrate	<1 mg/L	At higher concentrations may compete with reductive pathway	2	1
Iron II	>1 mg/L	Reductive pathway possible	3	0
Sulfate	<20 mg/L	At higher concentrations may compete with reductive pathway	2	0
Sulfide	>1 mg/L	Reductive pathway possible	3	0
Methane	<0.5 mg/L >0.5 mg/L	VC oxidizes Ultimate reductive daughter product, VC Accumulates	0 3	0 1
Oxidation Reduction Potential (ORP)	<50 millivolts (mV) <-100mV	Reductive pathway possible Reductive pathway likely	1 2	1 1
pH	5 < pH < 9 5 > pH >9	Optimal range for reductive pathway Outside optimal range for reductive pathway	0 -2	0 0
TOC	> 20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	2	0
Temperature	> 20°C	At T >20°C biochemical process is accelerated	1	1
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 <1 nM/L	Reductive pathway possible, VC may accumulate VC oxidized	3 0	--
Volatile Fatty Acids	> 0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	2	0
BTEX	> 0.1 mg/L	Carbon and energy source; drives dechlorination	2	0
PCE		Material released	0	0
TCE		Material released Daughter product of PCE	0 2[a/]	0
1,2-DCE		Material released Daughter product of TCE. If *cis* is greater than 80% of total DCE it is likely a daughter product of TCE	0 2[d/]	0 2
VC		Material released Daughter product of DCE	0 2[a/]	0 1
Ethene/Ethane	>0.01mg/L >0.1 mg/L	Daughter product of VC/ethene	2 3	0 0
Chloroethane		Daughter product of VC under reducing conditions	2	--

TABLE 4.5 (Continued)
ANALYTICAL PARAMETERS AND WEIGHTING FOR PRELIMINARY SCREENING
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value	FTA-2 Score
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[a/]	--
1,1-DCE		Daughter product of TCE or chemical reaction of 1,1,1-TCA	2[a/]	--
		TOTAL	**45**	**9**

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

TABLE 4.6
INTERPRETATION OF POINTS AWARDED DURING NATURAL ATTENUATION SCREENING
FTA-2 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

accurate representation because the degradation of CAHs depends on both concentration of electron donors (e.g., fuel hydrocarbons or native organic material) and the concentrations of electron acceptors (including inorganic acceptors and CAHs) (Moutoux *et al.*, 1996). Second-order rates would therefore allow more accurate modeling, but at this time there are no readily available groundwater contaminant transport models that can utilize such rates. Therefore, first-order rates must be estimated for use in a contaminant transport model.

Microcosm studies can be used to show that the microorganisms necessary for biodegradation are present and to help quantify rates of biodegradation. Because microcosm studies are time consuming and expensive, they should be undertaken only at sites where there is considerable uncertainty concerning the biodegradation of contaminants. Biodegradation rate constants determined by microcosm studies often are much higher than those observed in the field, and it may be inappropriate to use them to generate rate constants. The preferable method of contaminant biodegradation rate-constant determination is by use of field data, so no microcosm studies were conducted at the FTA-2 site.

In order to calculate first-order biodegradation rate constants on the field scale, the apparent degradation rate must be normalized for the effects of dilution, dispersion, and sorption. Two methods for determining first-order rate constants for BTEX compounds are described by Wiedemeier *et al.* (1996a). One method involves the use of a biologically recalcitrant compound found in the dissolved contaminant plume that can be used as a conservative tracer. One organic compound that can be used at some sites is TMB. However, TMB was not detected at FTA-2. For many chlorinated solvent plumes, chloride that is released to the groundwater during dehalogenation reactions also can serve as a tracer. Chloride was not used as a tracer for FTA-2 due to the similarity between background chloride concentrations and those in the CAH plume. The other method, proposed by Buscheck and Alcantar (1995), involves interpretation of a steady-

state contaminant plume and is based on the one-dimensional, steady-state analytical solution to the advection-dispersion equation presented by Bear (1979). Decay rates computed using this method account for chemical (abiotic) decay and biological (aerobic and anaerobic) decay. For an expanding plume, this first-order approximation can be viewed as an upper bound on the biodegradation rate. Use of this method overestimates biodegradation rate, 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. Both methods can be adapted to estimate rate constants for CAHs.

Another method for estimating reductive dehalogenation rates of CAHs is described by Moutoux *et al.* (1996). This method provides a total reductive dehalogenation rate for all dehalogenation steps. All rates (including the rapid TCE to DCE rate and the slow VC to ethene) are averaged together using the Moutoux *et al.* (1996) method. Because abiotic reactions and aerobic reactions that involve CAH compounds in the role of an electron donor are not included in this rate (and may in fact decrease the rate estimated by this method), the rate should be considered a lower bound on the destructive attenuation rate.

It should be noted that the magnitudes of the decay rates calculated using these methods are sensitive to the estimated migration velocity of the contaminant along the selected flowpath; therefore, inaccuracies in the estimated velocity will cause the decay rates to be less accurate. Overestimation of the groundwater velocity will result in overestimation of the decay rate, and vice versa.

The method of Buscheck and Alcantar (1995) was used to estimate first-order biodegradation rate constants for TCE, *cis*-1,2-DCE, *trans*-1,2-DCE and total chlorinated ethenes at FTA-2. The method of Moutoux *et al.* (1996) was also used to estimate a first-order biodegradation rate constant for total chlorinated ethenes at FTA-2. The decay rate calculations are summarized in Table 4.7 and Appendix E. Additional decay rate calculations for chlorinated ethanes and chlorobenzenes are also included and summarized in Appendix E. Rate constants were not calculated for BTEX compounds because of the relatively low remaining concentrations (Table 4.2).

The first-order, steady-state, TCE decay rate computed using data from the flowpath 2-62B, CG39B97-43S, and 2-355B and the method of Buscheck and Alcantar (1995) is 3.06E-04 day^{-1}, which corresponds to a half-life of 6.20 years. This flowpath extends from the inferred primary source area at well 2-62B to near the leading edge of the dissolved TCE plume. These wells are all screened within the upper USZ sand interval, and therefore may not be representative of decay rates in groundwater in the lower USZ sand interval. However, for purposes of modeling contaminant transport at the site, the wells used above are assumed to represent biodegradation for all of the USZ. For *cis*-1,2-DCE and *trans*-1,2-DCE, the calculated first order biodegradation rates are 4.08E-4 day^{-1} (half life of 4.65 years) and 7.58E-04 day^{-1} (half life of 2.51 years), respectively.

Total chlorinated ethene degradation was calculated by both the methods of Buscheck and Alcantar (1995) and Moutoux, *et al.*, (1996). The first-order, steady-

TABLE 4.7
SUMMARY OF CHLORINATED SOLVENT DECAY RATES
AUGUST 1997
FTA-2 RNA TS
TINKER AIR FORCE BASE, OKLAHOMA

Contaminant	Sample Date	Flow Path	Analysis Method	Decay Rate (day^{-1})	Half Life (years)
TCE	August-97	2-62B > CG39B97-43s > 2-355B	Buscheck and Alcantar[a/]	3.06E-04	6.20
cis -1,2-DCE	August-97	2-62B > CG39B97-43s > 2-355B	Buscheck and Alcantar	4.08E-04	4.65
trans -1,2-DCE	August-97	2-62B > CG39B97-43s	Buscheck and Alcantar	7.58E-04	2.51
Total Chlorinated Ethenes	August-97	2-62B > CG39B97-43s > 2-355B	Buscheck and Alcantar	2.96E-04	6.42
Total Chlorinated Ethenes	August-97	2-62B > CG39B97-43s > 2-355B	Reductive Dechlorination	1.86E-07	10,210

[a/] Method of Buscheck and Alcantar (1995) for steady-state plumes.

[b/] Reductive Dechlorination by method of Moutoux, et al., (1996), which gives decay rate attributable to reductive dechlorination.

state, total chlorinated ethene decay rate computed using data from the flowpath 2-62B, CG39B97-43s, and 2-355B and the method of Buscheck and Alcantar (1995) is 2.96E-04 day^{-1}, which corresponds to a half-life of 6.42 years. This rate is very similar to that calculated for TCE alone. As described above, the decay rates computed using this method can be viewed as an upper bound on the biodegradation rate if the plume is expanding. Data presented in Section 4.2 suggests that the plume is still expanding to a significant degree. Therefore, the computed decay rate should be considered an upper bound of the combined effects of both reductive dehalogenation occurring in the general source area and aerobic decay occurring downgradient.

An attempt was made to compute a lower bound dehalogenation rate along this same flowpath using the method of Moutoux *et al.* (1996). The corrected CAH concentration increased with distance along the flowpath between wells 2-62B and CG39B97-43s, although there was an overall decrease in corrected CAH concentration between 2-62B and 2-355B. The first-order, total reductive dehalogenation decay rate computed for total chlorinated ethenes using data from the flowpath 2-62B, CG39B97-43s, and 2-355B and the method of Moutoux (1996) is 1.86E-07 day^{-1}, which corresponds to a half-life of 10,210 years. The total reductive dehalogenation biodegradation rate calculated by the Moutoux method indicates that reductive dehalogenation along this flow path is not applicable. This is probably due to the occurrence of aerobic biodegradation of TCE and/or DCE, because the method assumes that both parent and daughter CAHs are conserved along the selected flowpath. The failure of this method indicates that other biodegradation processes besides reductive dehalogenation (e.g., aerobic processes) are occurring along this flowpath.

4.5 SUMMARY

Compounds detected in groundwater at FTA-2 include benzene, toluene, PCE, TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, 1,1-DCE, VC, 1,1-DCA, 1,2-DCA, 1,2-DCB, 1,3-DCB, 1,4-DCB, chloroform, and CB. Of these compounds, benzene, PCE, TCE, 1,1-DCE, *cis*-1,2-DCE, VC, 1,2-DCA, CB, 1,2-DCB and 1,4-DCB were detected at concentrations exceeding USEPA MCLs. Benzene exceeded the MCL of 5 µg/L at one location, monitoring well 2-62B at a concentration of 6.0 µg/L. Because concentrations of benzene rapidly attenuate to levels below detection outside of the primary source area (well 2-62B), benzene is not considered for further remedial action.

PCE was detected at a maximum concentration of 52 µg/L in well 2-65B, exceeding the MCL for PCE of 5 µg/L. PCE was also detected at a concentration of 6.1 µg/L in well 2-62B, and 1.9 µg/L in well 2-63B. The occurrence of PCE is limited to the general source area and attenuates to below detection limits with groundwater migration.

TCE was detected at concentrations ranging from non-detect to a maximum of 9,440 µg/L in well 2-62B, exceeding the MCL for TCE of 5 µg/L. The extent of the TCE plume extends northwest in the USZ to well 2-393B at a concentration of 406 µg/L. The distribution of TCE in USZ groundwater (Figure 4.3) suggests a vertical migration of TCE from the upper USZ sand to the lower USZ sand. The vertical migration of contaminants is the result of a discontinuous clay layer that pinches out northwest of the source area. Concentrations of TCE at source well 2-62B do not show any discernible decreasing trend (Figure 4.10). The increase of TCE concentration with time at two wells

along the contaminant flowpath (2-272B and 2-274B) suggests that the plume is expanding. TCE was also detected for the first time in the LSZ at a concentration of 10.9 µg/L in well 2-62A.

Cis-1,2-DCE was detected at a maximum concentration of 1,200 µg/L in 2-62B, exceeding the MCL for *cis*-1,2-DCE of 70 µg/L. The highest concentrations of *cis*-1,2-DCE coincide with the highest TCE detections at 2-62B and CG3-B97-43s in the upper USZ sand interval. The distribution of *cis*-1,2-DCE in USZ groundwater (Figure 4.4) suggests a vertical migration from the upper USZ sand interval to the lower USZ sand interval. The concentration of *cis*-1,2-DCE versus time at monitoring well 2-62B (Figure 4.10) does not show any discernible temporal trend. However, the relatively high ratio of *cis*-1,2-DCE to *trans*-1,2-DCE in the source area and the predominance of *cis*-1,2-DCE over *trans*-1,2-DCE throughout the plume indicate that TCE is being reductively dehalogenated in a limited source area.

1,2-DCA was detected at concentrations of 260 µg/L and 49.2 µg/L in 2-62B and 2-393B, respectively, both exceeding the MCL of 5 µg/L. The two detections of 1,2-DCE were at opposite ends of the overall CAH contaminant plume, suggesting two source release areas (Figure 4.7). The distribution of total chlorinated ethanes versus time (Figure 4.11) suggests that at monitoring well 2-62B chlorinated ethanes have slightly attenuated from 1993 to 1997.

CB was detected at a concentration of 117 µg/L in 2-62B, exceeding the MCL of 100 µg/L. In the sample from 2-65B, the CB concentration was only 9.5 µg/L. At every other sampling location CB was detected at 1 µg/L (CG39-B97-43S) or not-detected. Erratic concentrations of total chlorobenzenes in source area well 2-62B (Figure 4.12) suggest that the chlorobenzene source has not significantly attenuated with time. The lack of significant quantities of CB along the contaminant plume suggests that CB is being utilized aerobically as an electron donor/substrate in the same manner as BTEX compounds.

1,2-DCB was detected at a concentration of 950 µg/L in 2-62B, exceeding the MCL of 600 µg/L. 1,4-DCB was detected at a concentration of 168 µg/L in 2-62B, exceeding the MCL of 75 µg/L. The trends in 1,2-DCB and 1,4-DCB are similar to those in CB at FTA-2.

Data have been collected from several wells at the site since 1994, and changes in compound concentrations since 1994 are shown on Figures 4.9 through 4.12. Some concentrations have decreased slightly, but contaminant concentrations in single monitoring wells generally have fluctuated over time, with no clear overall trends of increasing or decreasing concentrations (i.e., some increase, some decrease, and some are relatively constant). This is likely a function of the low concentrations, mixing in wells during sampling, slight differences in sampling procedures, variations in plume concentrations due to water level/flow direction changes, and variable rates of desorption from aquifer solids.

The additional data collected for this effort also help to suggest alternative locations for sources of groundwater contamination in the FTA-2 area. These locations include the access road area immediately upgradient of the FTA-2 fire pit in the vicinity of well 2-

62B (TCE, 1,2-DCA, and CBs) and well 2-65B (PCE), and an area north of the FTA-2 pit at 2-393B (1,2-DCA). The nature of these sources of chlorinated solvents is not clear and no mobile NAPL has been detected. The lack of information on the sources presents a problem because contaminant mass loading cannot be accurately evaluated and the possibility of multiple releases cannot be discounted. However, the high concentrations detected at monitoring well 2-62B indicate a singular source area that dominates the occurrence of the dissolved contaminant plume.

Several lines of chemical and geochemical evidence indicate that the contaminants at FTA-2 are being biodegraded, either as substrates or as electron acceptors. Geochemical data indicate that DO and nitrate are being consumed and methane is produced near and hydraulically downgradient of the suspected source area (monitoring wells 2-273B and 2-168B). This evidence suggests that microbial consumption of anthropogenic and natural organic matter (carbon compounds) is taking place at FTA-2. Anthropogenic carbon compounds are present as petroleum hydrocarbons and less-chlorinated solvents (including, but not limited to, BTEX, chlorobenzene, VC, DCE, and DCA) that are dissolved in groundwater. Native carbon compounds include solid organic matter in the aquifer matrix and dissolved organic carbon in site groundwater. These compounds are electron donors in redox reactions that are also consuming electron acceptors (e.g., DO, iron (III), carbon dioxide, and chlorinated hydrocarbons) and creating byproducts [e.g., methane, iron (II), and carbon dioxide].

Concentration plots of contaminants, electron donors, electron acceptors, and biodegradation byproducts (Figures 4.3 through 4.21) provide some qualitative evidence of biodegradation processes. DO is depleted in the vicinity of the BTEX plume area, near monitoring wells 2-62B and hydraulically downgradient of the suspected source area. Nitrate is slightly reduced in this area, indicating microbial activity, however nitrate does not show a decreasing trend along the extent of the CAH contaminant plume. The highest iron (II) concentrations do not coincide with the solvent plume (2-271B, 2-142B, and 2-63A), suggesting that iron (III) hydroxide is not being reduced to iron (II) during biodegradation of native organic carbon, fuel hydrocarbons, or less-chlorinated solvents. Sulfate concentrations vary across the site, the areas of decreased sulfate concentrations do not correlate well with chlorinated solvent concentrations. It is therefore unlikely that sulfate reduction is an ongoing anaerobic biodegradation process at FTA-2. The area of elevated methane concentrations coincides with the fuel hydrocarbon and chlorinated solvent source area. The presence of methane in the source area indicates that conditions are sufficiently reducing the petroleum hydrocarbons and native organic matter and may be used to support methanogenesis. Further, the fact that methanogenesis is ongoing indicates that conditions in the plume area are highly reducing and therefore favorable for reductive dehalogenation of chlorinated solvents. Plots of additional indicators, such as carbon dioxide and ammonia concentrations, further indicate that biodegradation reactions are not rapidly occurring at FTA-2.

Elevated chloride concentrations within the solvent plumes also may indicate dehalogenation reactions, although chloride may also come from the oxidation of less-chlorinated compounds (i.e., utilization as a substrate). Because of other reductive dehalogenation evidence, it is likely that some fraction of the excess chloride is a result of chlorinated solvent degradation. In addition, the fact that *cis*-1,2-DCE is detected instead

of *trans*-1,2-DCE in wells where TCE or VC also are present is indicative of biologically mediated reductive dehalogenation.

Given the available evidence, the dissolved CAH plume at FTA-2 exhibits characteristics of both Type 1 and Type 3 behavior. Dissolved petroleum hydrocarbons and possibly some less-chlorinated solvents appear to act as carbon sources. It is likely that the introduction of petroleum hydrocarbons and solvents due to waste disposal activities stimulated microbial activity and created groundwater conditions reducing enough to allow reductive dehalogenation of TCE, DCE, 1,2-DCA and CBs. The TCE that is not transformed to DCE and that migrates away from the source area into more aerobic environments will not be readily degraded, and may be relatively persistent. VC has been created due to dehalogenation, but it is possible that it is being oxidized (as a substrate) once it enters aerobic groundwater. Likewise, it is possible that DCE and DCA are oxidized as well. However, conclusive evidence of these oxidation processes has not been gathered. It is possible that some microbial consumption of native organic matter is taking place outside the plume and within the plume, but the DO values measured outside of the immediate source area suggest this process is minor. Type 2 behavior is not discernible from consumption of contaminants.

As discussed in Section 4.4, rates of degradation of TCE, *cis*-1,2-DCE, *trans*-1,2-DCE, and total chlorinated ethenes, estimated from data collected for this investigation, calculated by the Buscheck and Alcantar (1995) method were 3.06E-04 day^{-1} (6.20 years), 4.08E-04 $days^{-1}$ (4.65 years), 7.58E-04 $days^{-1}$ (2.51 years), and 2.96E-04 day^{-1} (6.42 years), respectively. As petroleum hydrocarbons and native organic matter continue to be consumed, reductive dehalogenation of the chlorinated ethenes will continue; however, once BTEX compounds are completely degraded, the rate at which dehalogenation proceeds may slow as the microbes utilize less easily degradable fuel hydrocarbons or other organic matter. It also is conceivable that the plume may eventually come to display only Type 3 behavior, but this will depend on the concentrations and degradability of the remaining (non-BTEX) fuel hydrocarbon compounds relative to the native organic matter.

As the type of organic matter used during biodegradation changes, the redox conditions also may change and alter which reactions are favored. This could also affect the rates at which CAHs are reductively dehalogenated, and could cause dehalogenation of some compounds to cease. If and how this will happen is difficult to predict; the relative "degradability" of the native organic matter (or non-BTEX fuel hydrocarbons) and the effect of a changing electron donor source is not yet well-understood. If conditions become more oxidizing (but not aerobic), the dehalogenation of DCE may also cease or slow. However, aerobic and/or anaerobic mineralization of VC and DCE may become more important (i.e., Type 3 conditions may dominate).

SECTION 5

GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL

Computer simulations of USZ groundwater flow and the transport of dissolved TCE are used to evaluate the future migration and natural attenuation of TCE dissolved in groundwater at Tinker AFB FTA-2. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes.

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

The computer programs "A Modular Three-Dimensional Finite-Difference Ground-Water 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. MT3D96 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 FTA-2. 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 three primary objectives: 1) predict the future extent and concentrations of the dissolved TCE contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) assess the potential for downgradient receptors to be exposed to contaminants (TCE) at concentrations above regulatory levels of concern; and 3) if applicable, provide technical support for the natural attenuation remedial option at post-modeling regulatory negotiations. Specifically, the MT3D simulations for FTA-2 were constructed to address the following questions:

1. Does the observed distribution of TCE accurately reflect measured groundwater flow conditions or assumed source configuration?

2. What groundwater flow conditions (hydraulic conductivity, hydraulic anisotropy) would account for the observed distribution of TCE?

3. What source configuration can account for the observed distribution TCE?

4. To what extent is natural attenuation controlling the TCE plume at this site?

5. How will various remedial alternatives affect TCE plume migration and groundwater concentrations?

5.3 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

As discussed in Sections 3 and 4, groundwater flow in USZ groundwater at FTA-2 is toward the west-southwest; however, TCE transport is apparently toward the northwest from the FTA-2 source area (location of well 2-62B). This discrepancy between the direction of maximum hydraulic gradient and the primary direction of contaminant transport is not well understood, but could be caused by either anisotropic hydraulic conductivity in the USZ or multiple source areas to the northwest of the primary FTA-2 source area. Because there are no data to support a hypothesis of multiple source areas, the model presented herein assumes that the difference between groundwater flow and apparent contaminant transport directions is due to preferential flowpaths and anisotropic hydraulic conductivity in the USZ.

The TCE plume apparently migrates northwest from the FTA-2 source area through the upper USZ sand interval where it is underlain by and intra-USZ clay layer. This intra-USZ clay layer pinches out to the northwest providing direct hydraulic connection between the upper USZ sand interval and the lower USZ sand interval in the vicinity of wells 2-274B and 2-355B. The absence of the intra-USZ clay layer northwest of the FTA-2 source area also allows dissolved TCE in the upper USZ sand interval to migrate downward into the lower USZ sand interval in this area. Chlorinated solvents are not detected in the LSZ groundwater system downgradient of the FTA-2 source area. Based on the vertical distribution of TCE, the solute transport model for FTA-2 is composed of three layers. Layer 1 represents the upper USZ sand interval, layer 2 represents the intra-

USZ clay separating the upper and lower USZ sand intervals, and layer 3 represents the lower USZ sand interval. The base of the model domain represents the regional USZ/LSZ aquitard. Model layer properties are presented in detail in Section 5.4.2.

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 heterogeneities that cause 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 1,600 feet) and the documented presence of subsurface heterogeneities (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 suggest that both anaerobic and aerobic 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 FTA-2. 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 FTA-2 includes the FTA-3 source area and the downgradient area encompassing the TCE plume. The model domain for FTA-2 is represented using three layers, with a 63-cell by 69-cell horizontal grid (Figure 5.1). The long axis of the model grid is oriented east to west, parallel to the primary direction of maximum hydraulic gradient for the USZ. The model cells were varied in size, with dimensions of 50 feet (west-to-east) by 50 feet (north-to-south) in the general source area. Grid cell dimensions were expanded to a maximum of 175 feet (west-to-east) by 200 feet (north-to-south) outside of the general source area and measured TCE plume.

5.4.2 Model Layers

The TCE plume is migrating primarily through the upper and lower intervals of the USZ hydrogeologic unit. The model area was therefore designed with three layers. The upper layer represents the upper USZ sand interval, a middle layer represents the

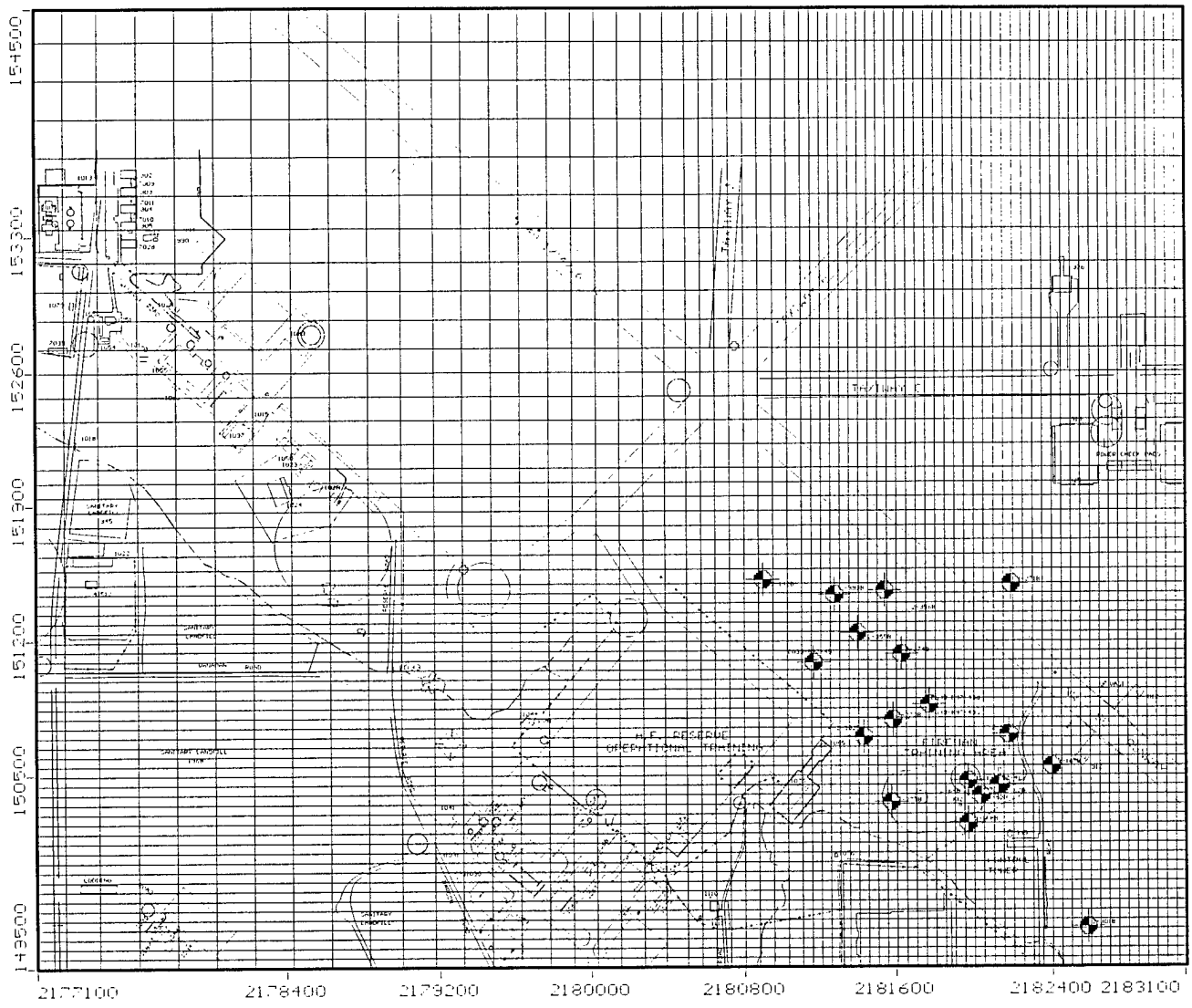


FIGURE 5.1

MODEL GRID SUPERIMPOSED ON FTA-2 SITE LOCATION

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

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intra-USZ clay horizon, and the lower layer represents the lower USZ sand interval. Where the intra-USZ clay horizon is not present, the upper and lower USZ sand intervals are in direct hydraulic connection, and the middle layer is assigned properties similar to those for the upper USZ sand interval.

The base of each layer was defined using borehole data and geophysical logs. The base of layer 1 represents the top of the intra-USZ clay layer. As a result, channels, pinch-outs and other features of that surface are represented in the model. Layer 2 was defined using borehole data, and was specified as clay with a minimal thickness of one foot in areas to the north and west beyond the pinch-out of the intra-USZ clay body. This maintained the spatial relationship between layers 1 and 3 while presenting negligible resistance to vertical contaminant transport between the layers. Borehole data indicate the presence of intra-USZ clay bodies other than the near-source body occupying layer 2. These do not appear to exert an effect on contaminant transport because of location and/or limited lateral extent. These bodies were excluded from the material distribution, resulting in considerable model simplification. The base of layer 3, or the lower boundary of the model, was defined using borehole data from geophysical logs to contour the top of the USZ/LSZ Aquitard. As a result, channels and other features of that surface are represented in the model. All three layers were assumed to be hydraulically connected, with the presence of vertical hydraulic gradients largely ignored. Regional stratigraphic and hydraulic gradients are similar, at approximately 40 ft/mile (0.0076 ft/ft). Therefore the layers were sloped to the west at this gradient, although local variations in stratigraphic gradient may exist.

5.4.3 Groundwater Flow Model

This section presents the initial input parameters used for the groundwater flow simulations. Contaminant transport input parameters are discussed in Section 5.4.4.

5.4.3.1 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.

TABLE 5.1
COMMON DESIGNATIONS FOR SEVERAL IMPORTANT BOUNDARY CONDITIONS
FTA-2 RNA TS
TINKER AIR FORCE BASE, 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)

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 model layer 1 (Appendix E). The specified heads were estimated by projecting heads from the August 1997 groundwater flow map. Although some vertical contaminant transport is indicated by the detection of TCE in well 2-62A (screened in the LSZ), a no-flow boundary was specified at the base of layer 3. The upper model boundary is defined by the simulated water table surface, although an arbitrary top of the model domain was set at 1,250 NGVD to accommodate potential water table fluctuations during the iterative head solution procedure.

5.4.3.2 Recharge and Evapotranspiration

No recharge to the water table was included in groundwater flow simulations because annual evaporation exceeds precipitation, and because a clay layer of the Hennessey Group occurs at ground surface which may inhibit direct recharge from precipitation. Evapotranspiration was also set to zero due to the depth of the USZ water table surface (10 to 20 feet) and the fine-grained nature of the surface formation.

5.4.3.3 Aquifer Properties

Hydraulic conductivity values were obtained from the results of slug and pumping tests performed during the TS. The calculated values are summarized in Table 3.2, and discussed in Section 3.3.2.1. Average hydraulic conductivities similar to those discussed in Section 3.3.2.1 were initially defined for each portion of the model domain (e.g., for each layer unit).

As mentioned previously, the TCE plume axis does not align with the downgradient groundwater flow direction determined from field-measured water elevations. If, as assumed, the source of TCE contamination is in the vicinity of well 2-62B, there must exist preferred pathways and/or significant anisotropy in horizontal hydraulic conductivity. The flow model developed for this exercise contains both a preferred pathway (a channel of sand more permeable than surrounding materials) and horizontal hydraulic conductivity anisotropy.

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 sand units within the model domain on the basis of grain-size observed in soil boreholes for the USZ aquifer sands (Spitz and Moreno, 1996). A lower effective porosity of 10 percent was assigned to the intra-USZ clay layer based on the fine-grained nature of the deposits observed in soil boreholes.

5.4.3.4 Aquifer Stresses

No groundwater supply or recovery wells are currently located in the model domain. Therefore no aquifer stresses were modeled and groundwater flow was assumed to be steady state for the 35-year model calibration simulations. Pumping wells are added to the model domain to evaluate a pump and treat remedial alternative for the site as discussed in Sections 6.3 and 6.4.

5.4.3.5 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.

5.4.4 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 represent both reductive dechlorination (source area) and aerobic oxidation. The TCE concentrations obtained from August 1997 laboratory analytical results for 19 monitoring wells/points were used as targets for model calibration. Table 4.3 presents dissolved TCE concentration data for August 1997, and Figure 4.3 shows the spatial distribution of dissolved TCE in August 1997.

5.4.4.1 Source

Transport models use boundary conditions to express the influence of contaminant sources such as mobile and residual 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 has suggested that this is currently the best available method for reproducing observed plumes. At FTA-2, the TCE is assumed to enter groundwater in the study area through contact between groundwater and residual NAPL at or below the water table. Partitioning of TCE from this source into groundwater was simulated by specifying source area dissolved concentrations in four model cells centered around well 2-62B (Appendix E).

It is likely that contaminants were first introduced into groundwater at this site when the FTA-2 fire pit was initially used for fire training exercises in 1962 (TT, 1996). TT (1996) reported the FTA-2 pit was operational until 1966, although aerial photos indicate the pit was present as late as 1970. Fire training exercises at Air Force bases typically use contaminated or uncontaminated jet fuel. Solvents, fuels, and other liquid wastes may have been used for training exercises or cleaning, or dumped in the general fire training area. Aerial photographs show numerous dirt access roads crossing the area through the mid-1970s, indicating unknown activities continued in the area after use of the FTA-2 pit was discontinued.

For the model it was assumed that contaminants first entered the groundwater upon fire training exercises in 1962, and that residual NAPL contamination associated with the

leached waste has acted as a continuous source. It was also assumed that after fire training operations in the source area ceased, the contaminant flux into the aquifer remained constant until August 1997. This is based on the observation that the concentration of TCE detected at well 2-62B has not decreased from 1993 to 1997, and that TCE concentrations do not appear to be significantly attenuating in the source area.

For predictive modeling after August 1997, it was assumed that the source will begin to weather (lose mass) due to processes such as volatilization, dissolution, and biodegradation, and that the mass of contaminants entering groundwater will begin to 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 FTA-2 will weather at about two percent per year. Thus, the model assumes that after 1997, the source loading rates decreased geometrically by two percent per year (each year's source strength was decreased by two percent from the previous year's strength).

5.4.4.2 Dispersivity

Published data summarized by Spitz and Moreno (1996) suggest that, as a rule of thumb, longitudinal dispersivity is approximately one-tenth the travel distance of the plume (from the source to the downgradient toe), which is equivalent to approximately 160 feet at FTA-2 (total plume length of 1,600 feet) (Figure 4.3). This was the initial value assigned to longitudinal dispersivity. The initial transverse dispersivity was estimated as one-tenth of the longitudinal dispersivity value, and vertical dispersivity was assumed to be one-hundredth of the longitudinal dispersivity (Domenico and Schwartz, 1990).

5.4.4.3 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 measured TOC concentrations near the water table at six locations across the site (see Table 4.1), an assumed bulk density of 1.65 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 each contaminant was calculated. The results of these calculations are summarized in Table 5.2. The lower the assumed coefficient of retardation, the faster the TCE plume will migrate downgradient. Initially, the average calculated retardation coefficient of 5.7 was assigned to the model.

5.4.4.4 Biodegradation

As discussed in Section 4.5, a first-order decay rate of approximately 3×10^{-4} day^{-1} was calculated for TCE using site-specific data. This rate was used as an upper bound to define an initial value for model input. An initial estimate of 2×10^{-4} day^{-1} was defined for the model domain.

TABLE 5.2
CALCULATION OF RETARDATION COEFFICIENTS
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Location	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) Maximum [c1/]	Minimum [c2/]	Average [c3/]	Bulk Density (kg/L) [d/]	Effective Porosity [d/]	Coefficient of Retardation Maximum	Minimum	Average
USZ Sand	PCE	209	0.00969	0.00632	0.00813	2.025	1.321	1.699	1.65	0.20	17.71	11.90	15.02
USZ Sand	TCE	87	0.00969	0.00632	0.00813	0.843	0.550	0.707	1.65	0.20	7.95	5.54	6.84
USZ Sand	1,1-DCE	64.6	0.00969	0.00632	0.00813	0.626	0.408	0.525	1.65	0.20	6.16	4.37	5.33
USZ Sand	cis-1,2-DCE	49	0.00969	0.00632	0.00813	0.475	0.310	0.398	1.65	0.20	4.92	3.55	4.29
USZ Sand	trans-1,2-DCE	36	0.00969	0.00632	0.00813	0.349	0.228	0.293	1.65	0.20	3.88	2.88	3.41
USZ Sand	VC	2.45	0.00969	0.00632	0.00813	0.024	0.015	0.020	1.65	0.20	1.20	1.13	1.16
USZ Sand	1,2-DCA	33	0.00969	0.00632	0.00813	0.320	0.209	0.268	1.65	0.20	3.64	2.72	3.21
USZ Sand	Chlorobenzene	83	0.00969	0.00632	0.00813	0.804	0.525	0.675	1.65	0.20	7.64	5.33	6.57
USZ Sand	1,2-DCB	272	0.00969	0.00632	0.00813	2.636	1.719	2.211	1.65	0.20	22.74	15.18	19.24
USZ Sand	1,3-DCB	293	0.00969	0.00632	0.00813	2.839	1.852	2.382	1.65	0.20	24.42	16.28	20.65
USZ Sand	1,4-DCB	273	0.00969	0.00632	0.00813	2.645	1.725	2.219	1.65	0.20	22.82	15.23	19.31
USZ Sand	Benzene	79	0.00969	0.00632	0.00813	0.766	0.499	0.642	1.65	0.20	7.32	5.12	6.30

[a/] From technical protocol (Wiedemeier *et al.*, 1996a)

[b/] From laboratory analyses of site soil samples

[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.

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 F. Due to the discrepancy noted previously between the direction of maximum hydraulic gradient and the distribution of the TCE contaminant plume, calibration of the groundwater flow model and solute transport model was a initially a simultaneous process. Final calibration of the solute transport model followed final calibration of the groundwater flow model.

5.5.1 Groundwater Flow Model

Groundwater elevation data collected in August 1997 and presented on Figure 3.10 were used to calibrate the flow model. Water level elevation data from 20 monitoring wells/points were used to compare measured and simulated heads for calibration. The selected locations are listed in Appendix E.

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 simulated heads approximated observed field values within a prescribed accuracy. In general, hydraulic conductivities were 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 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 for layer 1. Calibrated model horizontal hydraulic conductivities ranged between 0.01 and 36 ft/day. In general, the highest conductivity values (10 to 36 ft/day) were used for the USZ sands along the contaminant transport pathway (channels), a lower value (0.01 ft/day) was used for the intra-USZ clay layer, and intermediate values (1.5 to 2.25 ft/day) were used for the remainder of the medium. For all materials other than the layer 2 clay, the anisotropy ratio of y-direction (north-south) horizontal conductivity to x-direction horizontal conductivity was 2:1. Anistropy under the block-centered-flow option in MODFLOW also was set to 6.0 for layer 1 and 3.0 for layer 3. Hydraulic conductivity distributions for each layer are presented in Appendix E. For the majority of the medium, calibrated vertical hydraulic conductivities were in the range of 0.015 to 0.24 ft/day. To account for an apparent lack of vertical TCE mixing at some near-source locations, clay layer vertical conductivities were assigned negligible values. Similarly, to account for apparent downward TCE movement in certain downplume locations, vertical conductivities were increased (to 27 to 36 ft/day) in restricted zones for all three layers.

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:

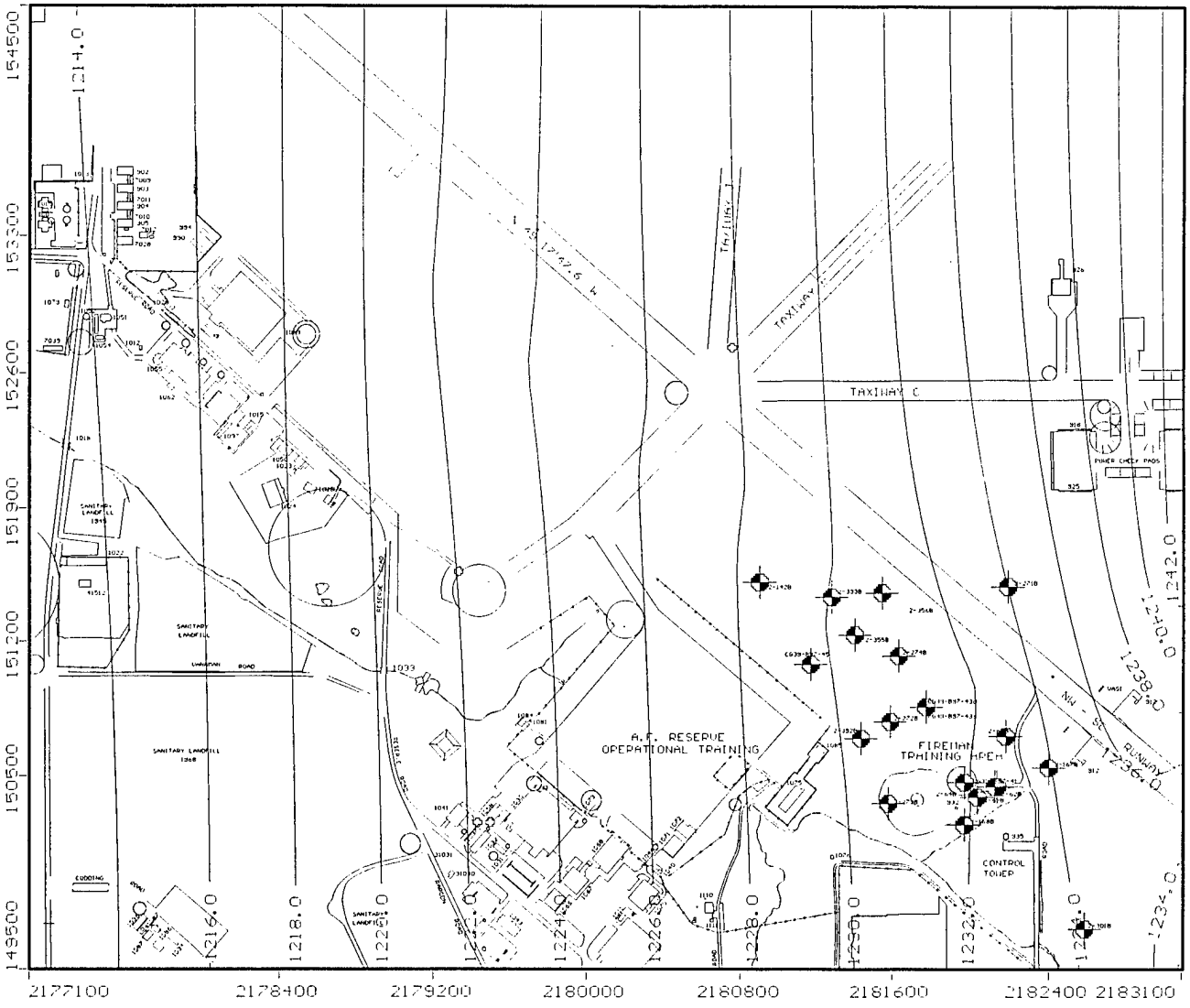

FIGURE 5.2

CALIBRATED GROUNDWATER SURFACE, LAYER 1

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

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Denver, Colorado

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

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 20 well locations was 0.67 feet, which corresponds to a calibration error of 11.1 percent. The calibration error is calculated using the change in relief for the area of the calibration wells only. 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 FTA-2 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 steady-state 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 (1978) indicates an error of less than 0.1 percent is ideal.

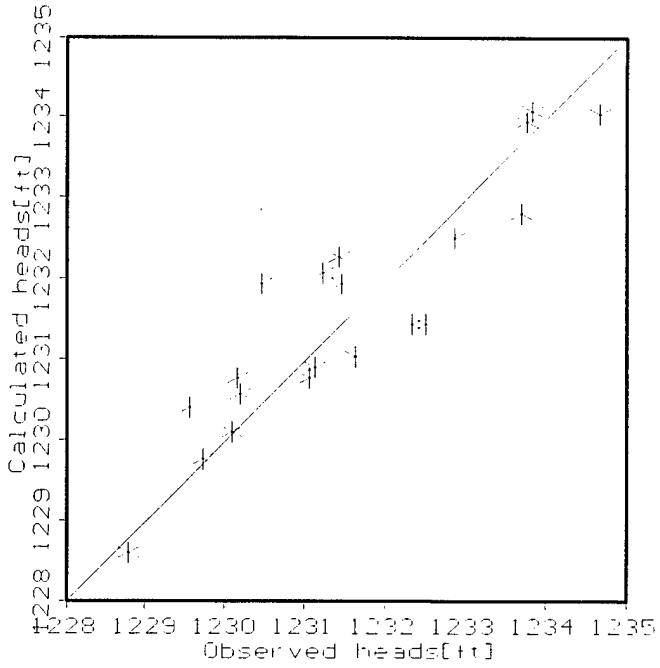
5.5.2 Plume Calibration

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 35-year period (1962 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 August 1997 laboratory analytical data from 20 monitoring wells/points were used to calibrate the contaminant transport model. Calibration sample locations and names are presented in Appendix E.

5.5.2.1 Source Concentrations

The 35-year time period was divided into five-year increments and the concentration history at each source cell was specified as a step function, with constant concentration specified for any given period. The four source cells are adjacent to each other and well 2-62B (Appendix E), where the highest TCE concentrations have been found (9,440 µg/L in 1997). The source cells lie along a line trending north-northeast from well 2-62B. Of the four cells, the major contributor of dissolved TCE was the third cell along this line (i.e., the second farthest from well 2-62B). At this cell, specified source concentrations steadily declined from a high of 75,000 µg/L in the first five-year



Period: 7
Step: 10

Mean error: 0.00233468 Mean abs. err: 0.558848 RMS error: 0.670091

FIGURE 5.3

CALIBRATED VERSUS OBSERVED GROUNDWATER ELEVATIONS

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

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period to 20,000 µg/L for the period 1993-1997 (years 30 through 35). The source cell farthest from well 2-62B was the next largest TCE contributor, remaining at a constant 9,500 µg/L concentration for the 35-year calibration period. The remaining two source cells began at zero concentration for the first five-year period, built steadily to a 9,500 µg/L concentration for years 16 through 20, and remained at that concentration for the rest of the calibration period. All specified source concentrations were at least an order of magnitude below the solubility limit for TCE in water (greater than 1,000,000 µg/L).

5.5.2.2 Dispersivity

The initial longitudinal dispersivity of 160 feet produced a simulated plume far longer and wider than that observed in 1997. This value was gradually decreased to 20 feet. For the great majority of the model domain, this is the value used to produce the calibrated plume. Local variations were specified to obtain a better match to the calibration target. These consisted of reducing dispersivity beneath the source area and adjacent downplume areas to further inhibit any vertical dispersion of TCE. Lateral-to-longitudinal and vertical-to-longitudinal dispersivity ratios were varied by layer. For layers 1, 2, and 3, respectively, the calibrated lateral anisotropy ratios were 0.1, 0.2, and 0.22, and calibrated vertical anisotropy ratios were 0.01, 0.02, and 0.05.

5.5.2.3 TCE Decay Rates

The decay rate was varied during plume calibration, and was important in controlling plume length and concentration distributions. Two major vertical zones of constant decay rate were defined for the calibrated model: layers 2 and 3 had a rate of 0.00003 day^{-1} (63-year half-life) and the majority of layer 1 had a 0.0001 day^{-1} rate (19-year half-life). Layer 1 was further refined by specifying a higher 0.00034 day^{-1} degradation rate (5.6-year half-life) for the near-source and plumes core area, and a surrounding zone at the intermediate rate of 0.0002 day^{-1} (9.5-year half-life). The distribution of these zones improved the transport calibration and is in agreement with conclusions reached in Section 4.5. The higher rates in the near-source and plume core area are reflective of Type 1 behavior, while more aerobic downplume environments exhibit Type 3 behavior and have lower rates. 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-linearities is highly problem-dependent and time-consuming. The rates obtained from the calibration process should be viewed as averages over the calibration period.

5.5.2.4 Sorption

During plume calibration, the retardation coefficient was varied, and the calibrated model used a value of 1.9 throughout the model domain. This value conservatively falls below the range estimated on the basis of observed TOC concentrations. However, sorption of any constituent can vary substantially among soils with similar organic content. Domenico and Schwartz (1990) and Pankow and Cherry (1996) 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 FTA-2) involve time scales of tens of years. While it was found that the retardation coefficients used in the model 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, particularly for layer 1. After examination of calibration results and iterative variation, it was found that assigning a slightly lower effective porosity of 0.15 to layer 3 improved the calibration in the lower USZ sand.

5.5.2.6 Transport Calibration Results

The calibrated layer 1 and 3 plumes calculated by the model (Figure 5.4) are similar, but not identical, to the observed August 1997 plumes (Figure 4.3). The overall shape and TCE concentration levels of the plumes are good. The RMS error of prediction over the 20 observations wells was 74.4 µg/L.

In general, simulated TCE concentrations are a relatively close match to measured concentrations along the plume axis to a downplume location between wells 2-355B and 2-393B. Beyond this point, predictions were low at well 2-393B (177 µg/L vs. 406 µg/L measured), and high further downplume at well 2-142B (13 µg/L vs. non-detect). Measured concentrations at well 2-393B were taken in the lower USZ sand and seem anomalously high, given the nearest upstream, downstream, and overlying measurements. It was found that no reasonable combination of transport parameters could reproduce the measured 406 µg/L concentration at well 2-393B while maintaining an adequate calibration elsewhere. This points to the possibility of TCE sources other than those included in the model, or perhaps faster transport along preferred pathways with less attenuation than indicated by the calibrated model.

In general, compared to the calibration targets, model predictions are slightly high in layer 1 and slightly low in layer 3. Prediction error is largest at the lateral plume margins where steep concentration gradients from the plume core to outlying undetectable levels exist. In layer 1, it appears that the predicted plume is slightly wider in the cross-plume direction than the measured plume. The inability to reproduce a narrower layer 1 plume while maintaining an accurate calibration overall may be due to numerical dispersion. Numerical dispersion is particularly evident when transport is in a direction diagonal to grid coordinates, as is the case here.

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. Modeling results also indicate a nonsteady-state plume.

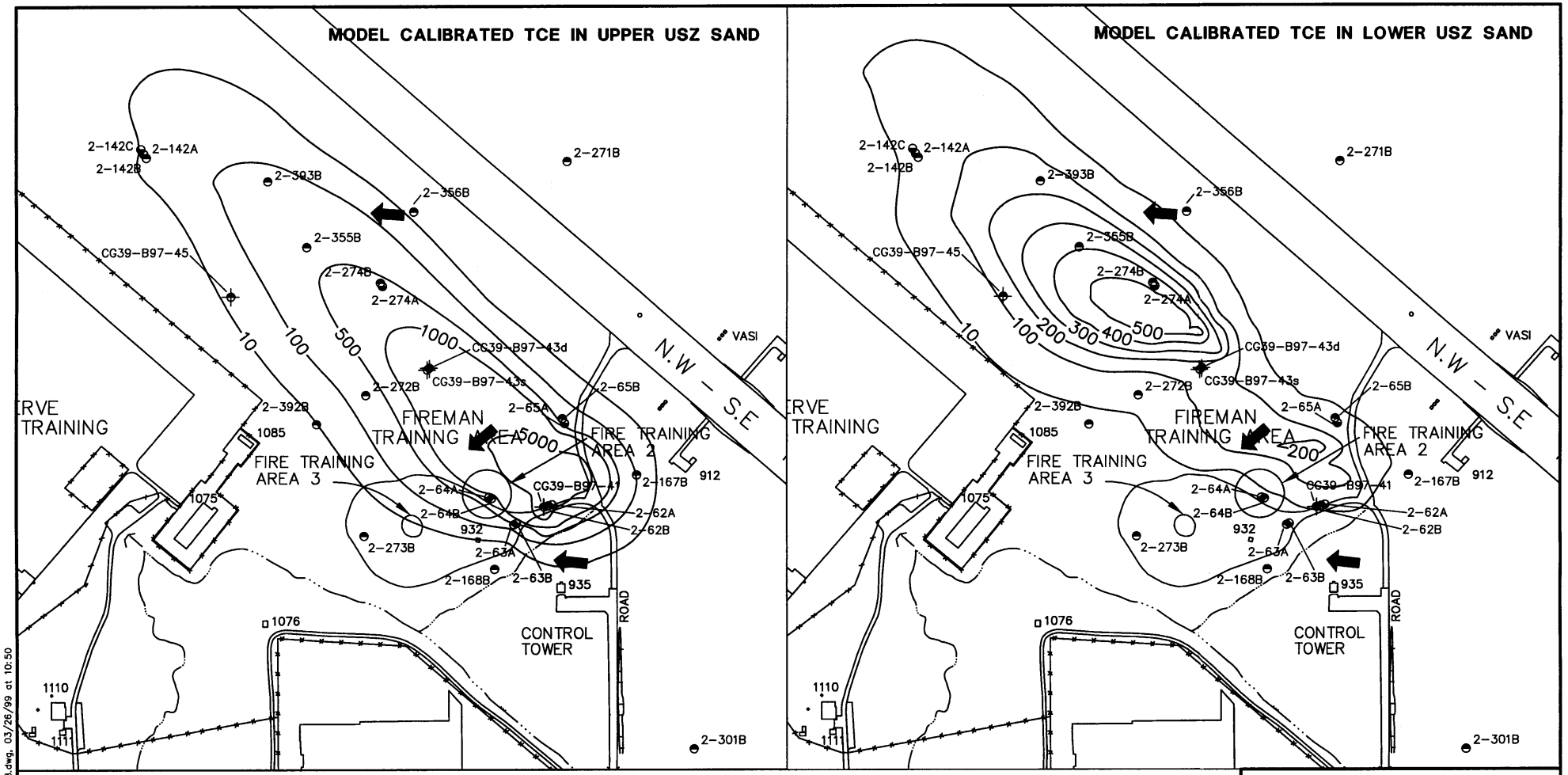

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FIGURE 5.4

CALIBRATED TCE PLUMES IN USZ GROUNDWATER

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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 sorption (i.e., the distribution coefficient K_d), the first-order decay rate, dispersivity, hydraulic conductivity, and effective porosity.

To perform the sensitivity analyses, the calibrated model was adjusted by systematically changing the aforementioned parameters individually, and then comparing the new simulations to the results of the calibrated model. The models were run for a 35-year period, just as the calibrated model was, so that 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 conductivities doubled;
2. All hydraulic conductivities halved;
3. Distribution coefficients doubled, which resulted in retardation coefficient set to 2.87;
4. Distribution coefficients halved, which resulted in retardation coefficient set to 1.4675;
5. Longitudinal dispersivities doubled;
6. Longitudinal dispersivities halved;
7. Decay rates doubled;
8. Decay rates halved;
9. Effective porosities doubled;
10. Effective porosities halved;

The results of the sensitivity analyses are discussed in the following subsections and summarized in Table 5.3. 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.

TABLE 5.3
SUMMARY OF SENSITIVITY ANALYSIS RESULTS
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Well	Observed Concentration (µg/l)	Calibrated Concentration (µg/l)	A	B	C	D	E	F	G	H	I	J
2-62B	9440	9500	9500	9500	9500	9500	9500	9500	9500	9500	9500	9500
CG39-B97-43s	1490	1581	2639	513	1250	1745	1559	1625	466	3178	680	2423
2-64B	914	924	2670	179	553	1196	1240	729	246	2066	270	2001
2-274B	518	470	897	60.2	290	552	536	423	127	974	131	816
2-393B	406	177	617	1.13	38.9	287	187	176	42.32	377	8.74	494
2-355B	344	417	1046	13.2	166	557	424	430	94.1	929	51.0	892
CG39-B97-43d	169	162	327	33.3	103	199	356	78.3	63.2	280	57.9	289
CG39-B97-45	153	115	1012	0.15	11.3	288	148	88.9	33.7	220	2.03	583
2-65B	90	18.1	30.2	4.78	11.8	21.7	99.4	2.61	10.1	25.1	7.50	27.1
2-63B	75	85.5	316	0.00	37.2	125	192	38.7	16.9	177	7.69	214
2-272B	28	211	1349	4.11	58.0	375	277	172	28.6	612	14.4	838
CG39-B97-41	4	8.39	30.6	1.57	3.87	13.3	45.4	1.60	6.28	9.86	2.61	18.5
2-168B	1	0.00	0.60	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.11
2-167B	ND	47.0	55.8	27.6	43.2	47.9	278	5.45	22.8	71.2	31.3	56.6
2-142B	ND	13.1	432	0.00	0.33	60.4	25.4	7.45	3.06	27.8	0.02	181
2-356B	ND	5.89	38.06	0.01	0.80	12.5	14.0	2.62	1.24	13.2	0.13	25.6
2-392B	ND	1.03	111	0.00	0.03	6.52	3.64	0.36	0.40	1.72	0.00	19.7
2-273B	ND	0.58	107	0.00	0.03	3.09	3.29	0.15	0.07	1.73	0.00	15.9
2-271B	ND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2-301B	ND	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RMS Error (µg/l)		76	627	319	149	135	134	92	307	506	275	410

Column: A : Hydraulic Conductivity x 2.
B: Hydraulic Conductivity ÷ 2.
C: Kd x 2, Retardation = 2.87.
D: Kd ÷ 2, Retardation = 1.4675.
E: Dispersivity x 2.
F: Dispersivity ÷ 2.
G: Decay Rate x 2.
H: Decay Rate ÷ 2.
I: Effective Porosity x 2.
J: Effective Porosity ÷ 2.

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 two greatly increased the extent of the plume so that the 10-μg/L isopleth reached approximately 1,100 feet further downstream than for the calibrated case, and the simulated concentrations downgradient of the source area were much higher than the calibrated model. In contrast, decreasing the hydraulic conductivity by a factor of two slowed overall plume migration, and resulted in a much 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 doubling K_d's increased the retardation factor R to 2.87. This increase produced shorter and slightly narrower plumes, with concentrations outside of the source area below those in the calibrated model. This reflects the increased mass of TCE sorbed to the soil matrix. Uniformly halving K_d resulted in a retardation factor of 1.47. 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, transverse, and vertical dispersivity were all varied for this analysis, as ratios of longitudinal-to-transverse dispersivity and longitudinal-to-vertical dispersivity were kept at their calibrated values. Doubling and halving longitudinal dispersivity then resulted in doubled and halved transverse components of dispersivity.

Doubling the dispersivity components lowered peak TCE concentrations and spread more of the contaminant to the margins of the plume. The result was a plume with a slightly larger footprint, lower peak values, and slightly smaller gradients. Accordingly, concentrations at all wells increased except at well CG39-B97-43s in the heart of the plume, which decreased from 1,581 to 1,559 μg/L.

Halving the dispersivity components had the opposite effect, resulting in a slightly smaller plume with higher peak concentrations, lower marginal concentrations, and slightly steeper gradients. Compared to the increased dispersivity case, and all other sensitivity cases, the effect of halving dispersivity produced the least amount of change from the calibrated case.

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 doubling decay rates resulted in rapid degradation of dissolved contaminants, producing a much smaller plume with lower concentrations everywhere outside the source. Uniformly halving the degradation rates resulted in a much larger plume with higher concentrations outside the source area than in the calibrated model.

5.6.5 Sensitivity to Variations in Effective Porosity

The results of doubling and halving effective porosity are summarized in columns I and J of Table 5.3. Doubling effective porosity halved the interstitial flow velocity and resulted in much slower transport. With more water in the system, dilution was increased and concentrations were lower than calibrated values everywhere outside the source. The opposite effect resulted from halving the effective porosity. Transport was sped up and dilution diminished, yielding a much larger plume with higher concentrations everywhere outside the source.

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 significant degradation in the goodness-of-fit between predictions and measurements. This suggests 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: hydraulic conductivity, degradation rate, effective porosity, distribution coefficient, and dispersivity. 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. Doubling hydraulic conductivity
2. Halving decay rate constant
3. Halving effective porosity
4. Halving hydraulic conductivity
5. Doubling decay rate constant
6. Doubling effective porosity
7. Doubling distribution coefficient
8. Halving distribution coefficient
9. Doubling dispersivity
10. Halving dispersivity

It should be kept in mind that typical percentage variations in field-measured values of these parameters are site-specific. For example, at a particular site effective porosity measurements may vary from the mean by less than a factor of two, while the distribution coefficient may vary over orders of magnitude. In this case, a model would be more sensitive to "typical" variations in distribution coefficient than to "typical" variations in

effective porosity, even if, for the same percentage change, the model were determined to be more sensitive to effective porosity.

5.7 DISCUSSION OF THE MODEL AND RECOMMENDATIONS TO REDUCE MODEL UNCERTAINTIES

Before discussing model predictions in Section 6, some points about the model should be emphasized. Most notably, the system that is modeled is very complex, and in many areas the relevant properties and parameters are not well defined. In addition, model computation time increases greatly as additional complexity or detail is added. Reasonable calibration results have been obtained, indicating that a proper balance was struck between model complexity, required model outputs, available input data, and numerical efficiency.

Given the underlying conceptual model of a compact TCE source near well 2-62B and downplume transport at an oblique angle to the downgradient hydraulic direction, the calibration exercise has yielded a useful tool for evaluation of future TCE transport under different remedial alternatives. However, large data uncertainties leave open the possibility that alternative conceptual models may explain the TCE plume as well or better. Among factors contributing to these uncertainties are 1) the unknown locations and history of CAH disposal at FTA-2; 2) inability to find any obvious contaminated soil "hot spots"; 3) the relatively wide range of distribution coefficients and degradation rates indicated by available field data; 4) apparent lack of subsurface structural features commonly associated with horizontal flow anisotropy; and 5) inability to discern the local change in water table gradient that would accompany preferred flow along permeable channels.

Given these facts, it is possible, that the observed TCE plume is the result of typical downgradient transport from multiple surface sources stretched along the plume length. In light of the plume's configuration and downgradient location, perhaps use of solvents to remove tire rubber from the NW-SE Runway has partially contributed to the plume. Releases responsible for the plume could have occurred in the 1960's, followed by downgradient transport with higher sorption, higher degradation rates, and/or higher effective porosities resulting in shorter migration distances in the southwest direction. Alternatively, such releases could have occurred more recently, with less time to migrate to the southwest.

Several approaches could be used to definitively answer the questions arising from data gaps at FTA-2. The first and most effective would be to conduct conservative tracer tests, injecting at well 2-62B and monitoring at wells 2-64A/B and 2-63A/B. Travel times between these wells are on the order of 100 days, and detection of significant amounts of tracer, particularly at 2-63A/B, would indicate transport to the southwest and call into question the current conceptual model. A similar tracer test could inject at CG39-B97-43s and monitor at 2-272B, although due to the distance involved a 200-day time frame would be involved. New or temporary wells could be placed to shorten the time frame and improve the spatial resolution of tracer tests.

Similarly, additional monitoring wells could be installed in hopes of detecting local gradient changes indicating the presence of preferred pathways. Soil gas surveys could

be performed, particularly upgradient of plume hot spots, in hopes of identifying previously unknown source areas. Finally, geophysical surveys could be used to attempt to identify structural features that might contribute to horizontal flow anisotropy. A combination of these approaches should provide enough evidence to clearly define the most appropriate conceptual model, and add confidence that model simulations of remedial alternatives are accurate.

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the development and comparative analysis of remedial alternatives for contaminated groundwater at Site FTA-2. The intent of this evaluation is to determine if RNA of groundwater is an appropriate and cost-effective remedial approach to consider when developing final remedial strategies for the study area, especially when combined with other remedial technologies.

Section 6.1 presents the criteria used to evaluate groundwater remedial alternatives. Section 6.2 discusses the development of remedial alternatives considered as part of this project. Section 6.3 provides a brief description of each of these remedial alternatives, and Section 6.4 provides a more detailed analysis of the remedial alternatives using the defined remedial alternative evaluation criteria. Results of this evaluation process are summarized in Section 6.5.

6.1 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

The evaluation criteria used to identify appropriate remedial alternatives for USZ groundwater contamination at the site were evaluated on the basis of (1) long-term effectiveness and permanence, (2) technical and administrative implementability, and (3) relative cost. The following sections briefly describe the scope and purpose of each evaluation criterion. This report focuses on the potential use of RNA to reduce dissolved chlorinated solvent concentrations in the USZ groundwater below MCLs.

6.1.1 Long-Term Effectiveness and Permanence

Each remedial alternative (which can be a combination of remedial approaches such as RNA and institutional controls) was analyzed to determine how effectively it would minimize groundwater plume expansion so groundwater quality standards can be achieved at a downgradient sentry well. The expected technical effectiveness based on case histories from other sites with similar conditions also is evaluated. The ability to minimize potential impacts on surrounding facilities and operations is considered. Also, the ability of each remedial alternative to protect both current and potential future receptors from potential risks associated with potentially completed exposure pathways is qualitatively assessed. The evaluation criterion also include permanence and the ability to reduce contaminant mass, toxicity, and volume. Long-term reliability for providing continued protection, including an assessment of potential technology failure and potential threats resulting from such a failure are also evaluated.

6.1.2 Implementability

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

6.1.3 Cost

The total cost (adjusted to present worth) of each remedial alternative was estimated for relative comparison. Estimates of capital costs and operating 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. The annual adjustment factor is the difference between the rate of inflation and the cost of money (USEPA, 1993).

6.2 FACTORS INFLUENCING ALTERNATIVES DEVELOPMENT

Several factors were considered during the identification and screening of remedial technologies for addressing USZ groundwater contamination at the site. Factors considered included the objectives of the AFCEE natural attenuation demonstration program; contaminant, groundwater, and soil properties; current and future land uses; and potential receptors and exposure pathways. The following section briefly describes each of these factors and how they were used to narrow the list of potentially applicable remedial technologies.

6.2.1 Program Objectives

The intent of the RNA demonstration program sponsored by AFCEE is to develop a systematic process for scientifically investigating and documenting natural subsurface attenuation processes that can be factored into overall site remediation plans. The objective of this program and the specific demonstration at Tinker AFB is to provide solid evidence of RNA of dissolved fuel hydrocarbons and chlorinated solvents so that this information can be used to develop an effective groundwater remediation strategy. A secondary goal of this multi-site initiative is to provide a series of regional case studies, which demonstrate natural processes of contaminant degradation can often reduce contaminant concentrations in groundwater to below acceptable cleanup standards before completion of potential receptor exposure pathways.

Because the objective of this program is to study natural processes in the saturated zone rather than all contaminated media (e.g., soil, soil gas, etc.), technologies have been evaluated based primarily on their potential impact to shallow groundwater and phreatic soils. Technologies that can reduce vadose zone contamination and partitioning of contaminants into groundwater also were evaluated. Many of the source removal technologies evaluated in this section will also reduce soil and soil gas contamination, but it is important to emphasize that the remedial alternatives developed in this document are

not intended to remediate all contaminated media. Additional program objectives set forth by AFCEE include cost effectiveness and waste minimization.

6.2.2 Contaminant Properties

Site-related groundwater contaminants exceeding USEPA MCLs and considered for remediation as part of this demonstration are PCE, TCE, 1,1-DCE, *cis*-1,2-DCE, VC, and 1,2-DCA. Benzene, CB, 1,2-DCB, and 1,4-DCB also exceed respective MCLs, but appear to rapidly attenuate away from the source area and are not considered as part of this remedial evaluation. The primary sources of contamination at FTA-2 are likely spills or dumping of waste scattered throughout the fire training area; however, the exact location and nature of these sources is unknown. The physiochemical characteristics of the individual compounds will greatly influence the effectiveness and selection of a remedial technology.

TCE was used as the target remediation compound at FTA-2. The summary of biodegradation rates in Table 4.7 by the method of Buscheck and Alcantar (1995) indicates that the transformation rate of TCE to daughter products and the transformation of total chlorinated ethenes to daughter products are nearly identical (halve-lives of 6.20 and 6.42 years, respectively). The maximum concentration of *cis*-1,2-DCE coincides with the maximum concentration of TCE, although at a concentration approximately seven to eight times lower than TCE. The relatively high TCE concentrations support its use as a surrogate for all CAH compounds at this site during the remedial alternative evaluation process. Modeling of TCE fate and transport (Section 5) also allows for comparative modeling of selected remedial alternatives.

All the CAH compounds (e.g., PCE, TCE, DCE, VC, and DCA) are generally volatile, relatively soluble in water, and do not adsorb strongly to soil particles. These characteristics allow the CAHs to leach readily from NAPL and contaminated soil into groundwater and to migrate as dissolved contamination (Lyman *et al.*, 1992). Many CAHs are amenable to *in situ* degradation by both biotic and abiotic mechanisms under certain geochemical conditions.

TCE is moderately volatile, with a vapor pressure ranging from 69 millimeters of mercury (mm Hg) to 74 mm Hg at 25°C (Mackay and Shiu, 1981; Klopffer *et al.*, 1988; Howard, 1990). Henry's Law Constants reported for TCE range from 0.0086 to 0.0102 atm-m^3/mol at 25°C (Ashworth *et al.*, 1988; Dewulf *et al.*, 1995). The solubility of pure TCE in water at 20°C has been reported to be 1,100 mg/L (Pearson and McConnell, 1975). TCE biodegradation products vary according to the prevailing groundwater geochemistry and are described in Section 4.1.

On the basis of these physiochemical characteristics, natural attenuation, soil vapor extraction, air sparging, and groundwater extraction and treatment could be effective options for collecting, destroying, and/or treating dissolved CAHs at Site FTA-2. In addition, *in situ* degradation of CAHs via permeable reaction walls (e.g., iron filings trenched) is a developing technology that holds promise for treatment of CAHs dissolved in groundwater. Some of these options are considered less desirable after considering site-specific conditions (Section 6.2.3) and program objectives (Section 6.2.1).

6.2.3 Site-Specific Conditions

Three general categories of site-specific characteristics were considered when identifying remedial approaches for comparative evaluation. The first category was physical characteristics such as groundwater depth, hydraulic conductivity, hydraulic gradient, flow direction, and soil type. The second category was the site geochemistry, or how the site contaminants are interacting with electron acceptors, microorganisms, and other site contaminants. Both of these categories influence the types of remedial technologies most appropriate for the site. The third category involved assumptions about future land use and potential receptor exposure pathways. Each of these site-specific characteristics has influenced the development of remedial alternatives included in the comparative evaluation.

6.2.3.1 Physical Characteristics

Site geology and hydrogeology have a profound effect on the transport of contaminants and the effectiveness and scope of required remedial technologies at a given site. Hydraulic conductivity is perhaps the most important aquifer parameter governing groundwater flow and contaminant transport in the subsurface. The velocity of the groundwater and dissolved contamination is directly related to the hydraulic conductivity of the saturated zone. The estimated average advective groundwater velocities at FTA-2 are 152 ft/yr (upper USZ sand) and 167 ft/yr (lower USZ sand) (Table 3.2).

Although the relatively high hydraulic conductivity of the study area can result in greater plume expansion and migration, this same characteristic also can enhance the effectiveness of other remedial technologies, such as groundwater extraction, air sparging, and intrinsic remediation. For example, it should be less expensive and time-consuming to capture and treat a contaminant plume using a network of extraction wells in an area of high hydraulic conductivity, because each well could envelope a larger area of influence and sustain a higher flow rate. The effectiveness of air sparging also may be increased in highly conductive and/or homogeneous aquifers because of reduced entry pressures and short-circuiting, and increased mixing of sparge air and groundwater. In addition, greater hydraulic conductivity would increase the amount of contaminant mass traveling through an air sparging network. Given a moderately high groundwater velocity, the effectiveness of natural attenuation can increase due to enhanced dilution and dispersion of the contaminant mass. The movement of contaminant mass within the subsurface away from the source area also can bring contaminants into contact with a larger mass of electron donors and acceptors, thereby increasing rates of biodegradation.

Like hydraulic conductivity, the organic carbon content of native phreatic zone soils can influence the effectiveness of remedial alternatives. Soils in the study area have a moderate organic carbon content (approximately 0.813 percent, Table 4.1), and therefore, the soils have a correspondingly moderate sorptive potential. Soil TOC values greater than 0.01 percent are typically sufficient to cause contaminant retardation due to sorption. The difference between contaminant and groundwater velocity increases the effectiveness of biodegradation in the source area because there are fresh electron acceptors flowing past the slower moving dissolved contaminant mass.

6.2.3.2 Geochemical Characteristics

To satisfy the requirements of indigenous microbial activity and RNA, the aquifer must also provide an adequate and available carbon or energy source (e.g., fuel hydrocarbon contamination or natural carbon), electron acceptors, essential nutrients, and proper ranges of pH, temperature, and redox potential. Data collected as part of this TS (Sections 3 and 4) indicate only the FTA-2 source area contains adequate and available carbon/energy sources to support reductive dehalogenation of CAH contamination by indigenous microorganisms. Dissolved oxygen, nitrate, ferric iron, sulfate, carbon dioxide and less chlorinated CAHs represent sources of significant electron acceptor capacity for the biodegradation of organic compounds at FTA-2.

The pH in USZ groundwater ranged between 6.80 and 7.36 standard units in August 1997, which is within the optimal range for biodegradation of 6 to 8 standard pH units (Wiedemeier *et al.*, 1995). Redox potentials ranged from -105 to 138.7 mV in August 1997 (Figure 4.15), and suggest a groundwater environment that is both oxidizing and reducing. The redox potentials at the site suggest that aerobic biodegradation, nitrate reduction, manganese reduction and iron (III) reduction could reduce contaminant concentrations in groundwater. Observed methane concentrations also indicate that methanogenesis could reduce contaminant concentrations in groundwater. Groundwater data presented in Section 4 strongly support the conclusion that aerobic and anaerobic processes may have reduced fuel hydrocarbon contamination given the current geochemical conditions. These same processes also appear to be acting upon chlorinated solvents within the general source area, both as electron donors and electron acceptors.

Microbe addition was not considered a viable remedial approach for this site on the basis of observed geochemical trends that suggest that significant microbial activity is likely occurring. Hydrocarbon-degrading microorganisms are ubiquitous in the subsurface, and a large number of hydrocarbon-degrading isolates (bacteria and fungi) have been discovered in different soil environments (see Wiedemeier *et al.*, 1995 and 1996a for a partial listing). Indigenous microorganisms have a distinct advantage over microorganisms injected into the subsurface to enhance biodegradation, because indigenous microorganisms are well adapted to the physical and chemical conditions of the subsurface in which they reside (Goldstein *et al.*, 1985).

6.2.3.3 Potential Receptor Exposure Pathways

A pathway analysis identifies the potential human and ecological receptors that could come into contact with site-related contamination and the pathways through which these receptors might be exposed. To have a completed exposure pathway, there must be a source of contamination, a potential mechanism(s) of release, a pathway of transport to an exposure point, an exposure point, and a receptor. If any of these elements do not exist, the exposure pathway is considered incomplete, and receptors will not come into contact with site-related contamination. Evaluation of the potential long-term effectiveness of any remedial technology or remedial alternative as part of this demonstration project includes determining the potential for pathway completion. If a completed exposure pathway exists, potential long-term remedial options may still be sufficient to maintain exposure concentrations below regulatory action levels. Establishing site-specific, risk-based cleanup levels is beyond the scope of this TS.

Assumptions about current and future land uses at a site form the basis for identifying potential receptors, potential exposure pathways, reasonable exposure scenarios, and appropriate remediation goals. USEPA (1991) advises that the land use associated with the highest (most conservative) potential level of exposure and risk that can reasonably be expected to occur should be used to guide the identification of potential exposure pathways and to determine the level to which a site must be remediated.

Groundwater beneath FTA-2 flows generally to the west, an area of light industrial use. Because the site is near industrial facilities for a secured military base, Base workers are the most probable potential receptors that could be exposed to any site-related contamination. Other receptors include Tinker AFB water supply wells located on the western portion of the Base.

6.2.3.4 Remediation Goals for USZ Groundwater

USEPA MCLs (1996) for compounds detected in FTA-2 groundwater that exceed these standards are presented in Table 6.1. For this TS, the primary remedial objective for evaluation of remediation technologies for shallow groundwater is to reduce contaminant concentrations in groundwater to below federal regulatory criteria at a downgradient point of compliance. To accomplish this, remedial alternatives focus on limiting migration of dissolved contaminant concentrations exceeding MCLs away from Site FTA-2. It is unlikely that groundwater from Site FTA-2 would be ingested by humans, because there are no current downgradient water supplies in close proximity to the site. However, the MCL of 5 μg/L for TCE will be used to evaluate the effectiveness, implementability, and cost of remedial alternatives in this TS.

Available data suggest there are no completed exposure pathways involving human and ecological receptors exposed to contaminated groundwater under current conditions. Site FTA-2 is part of a secured military base, so institutional controls can be incorporated to limit any future intrusive activity at the site. The required period of any groundwater and soil institutional controls associated with the selected remedial alternative is likely to expire before any anticipated future land use changes. Off-base migration of dissolved contaminants in concentrations exceeding MCLs appears unlikely, given the groundwater flow direction and distance to the western Base boundary (greater than one mile, Figure 1.2).

6.2.4 Summary of Remedial Option Screening

Several remedial options have been identified and screened for use in treating shallow groundwater at the site. Table 6.2 identifies the initial remedial technologies and approaches considered as part of this demonstration and those retained for detailed comparative analysis. Screening was conducted systematically by considering the

TABLE 6.1
GROUNDWATER QUALITY STANDARDS

FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Compound	USEPA MCL (µg/L)[a/]
Benzene	5
Tetrachloroethene	5
Trichloroethene	5
1,1-Dichloroethene	7
Cis-1,2-Dichloroethene	70
Vinyl Chloride	2
1,2-Dichloroethane	5
Chlorobenzene	100
1,2-Dichlorobenzene	600
1,4-Dichlorobenzene	75

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

program objectives of the AFCEE RNA demonstration, physiochemical properties of groundwater contaminants detected at FTA-2, and other site-specific characteristics such as hydrogeology, geochemistry, land use assumptions, potential receptor exposure pathways, and appropriate remediation goals. All of these factors will influence the technical effectiveness, implementation, and relative cost of technologies for remediating shallow groundwater underlying and migrating from the site. The remedial options retained for development of remedial alternatives and comparative analysis include institutional controls, natural attenuation, LTM, source characterization and removal, and groundwater extraction with air stripping for treatment of extracted groundwater.

TABLE 6.2
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Long-Term Monitoring	Periodic Groundwater Monitoring	Confirmation Wells	Many monitoring wells are available to confirm the progress of remediation. Sufficient space exists for additional wells.	Necessary for all remedia-tion strategies	Low	Yes
		Sentry Wells	Sufficient distance exists between the plume and point-of-compliance to locate several wells.	Necessary	Low	Yes
Institutional Controls	Groundwater Use Control	Land Use Control/Regulate Well Permits	The plume lies within the Base boundary, and land and groundwater use are under Base jurisdiction.	Necessary	Low	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the current or predicted plume area.	Not required at this site	Low	No
		Point-of-Use Treatment	No shallow groundwater is extracted from the plume area for any use.	Not required at this site	Moderate	No
	Public Education	Meetings/ Newsletters	Base public relations and environmental management offices have many information avenues through which to communicate to workers and residents.	Necessary	Low	Yes
Containment of Plume	Hydraulic Controls	Interceptor Trench Collection	Limited effectiveness and high cost due to depth of groundwater, depth to USZ/LSZ aquitard, and size of plume. Physical controls not required at this site.	Low	High	No
		Groundwater Extraction	Future migration and concentration of dissolved plume is projected to be significant. Does not comply with program objectives.	Moderate	Moderate	Yes
	Physical Controls	Slurry Walls/Grout Curtains	Limited effectiveness and high cost due to depth of groundwater, depth to USZ/LSZ aquitard, and size of plume. Physical controls not required at this site.	Low	High	No
		Sheet Piling	Limited effectiveness and high cost due to depth of groundwater, depth to USZ/LSZ aquitard, and size of plume. Physical controls not required at this site.	Low	High	No
	Reactive/ Semi-Permeable Barriers	Biologically Active Zones/ Iron Filings Trench	Degradation of CAHS may be stimulated by allowing groundwater to flow through a nutrient-rich zone or zero-valent zone. New, unproven technologies	Moderate	High	No

TABLE 6.2 (continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
In Situ Groundwater Treatment	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Nutrients and/or oxygen are injected within and/or downgradient of plume to limit plume migration by enhancing biodegradation and reducing CAH concentrations. Will inhibit anaerobic degradation of CAHs by oxygenating the groundwater. TCE not aerobically biodegradable. Would be most effective downgradient of the source area. Not proven to be more effective than natural attenuation.	Low	Low	No
	Chemical/ Physical	Natural Attenuation	A combination of natural biological, chemical, and physical removal mechanisms which occur to varying degrees on every site. Groundwater sampling at FTA-2 indicates that this is an ongoing remediation process.	High	Low	Yes
		Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of CAHs, specifically TCE, into air bubbles and vadose zone. Similar to biosparging in effectiveness; however, more mass is transferred rather than destroyed. Most effectively used downgradient of the source so as not to upset anaerobic conditions promoting reductive dechlorination in the source area.	Low	Low	No
Source Removal/ Groundwater Remediation	Groundwater Extraction	Vertical Pumping Wells	Source area of groundwater plume is pumped by installing submersible pumps in source area wells. Limited by contaminant mass transfer rates into the groundwater.	Moderate	Moderate	Yes
Aboveground Groundwater Treatment	Biological	Bioreactors	High flow rates require excessive retention times and large reactors. CAHs are often volatilized in these systems.	Moderate	High	No
	Chemical/ Physical	Air Stripping	Cost-effective technology for removing CAHs from groundwater at high flow rates. Potential permitting for air emissions.	High	Moderate	Yes
		Activated Carbon	Cost prohibitive for more concentrated Cahs. Creates a carbon disposal problem.	Moderate	High (O&M)	No
		Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)	Implementable option only when an IWWTP is readily available and capable of handling CAHs and hydraulic loading. IWWTP not available for this site.	High	Low	No
		UV/Ozone Reactors	High flow rates require lengthy retention times and large, costly reactors.	Moderate	High	No

TABLE 6.2 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Treated Groundwater Disposal	Discharge to IWWTP	IWWTP	Implementable option only when an IWWTP is available and capable of handling hydraulic loading. IWWTP is not available.	High	Low	No
	Discharge to Sanitary Sewer	Sanitary Sewer	Implementable option only when access to a sanitary sewer exists and hydraulic loading is acceptable.	High	Low	No
	Treated Groundwater Reinjection	Vertical Injection Wells	Injection wells subject to clogging, high maintenance, and permitting.	Moderate	Moderate	No
		Injection Trenches	Requires large trenches and can be subject to injection well permitting.	Moderate	Moderate	No
	Discharge to Surface Waters	Storm Drains or Surface Ditch	Generally requires NPDES or other discharge permit.	High	Low	Yes
Source Removal/Soil Remediation	Excavation/ Treatment	Landfilling	Some excavation may economically be feasible if it can be shown that source area is generally less than 4,000 cubic yards.	Moderate to High	Moderate	Yes
		Biological Landfarming	Some excavation may be feasible at this site. For reasons of risk and cost reduction, *in-situ* methods or landfilling preferable when possible.	Moderate to High	Moderate	No
		Thermal Desorption	Some excavation may be feasible at this site. For reasons of risk and cost reduction, *in-situ* methods or landfilling preferable when possible.	Moderate to High	High	No
	In Situ	Bioventing	Air injection/extraction to increase soil oxygen levels and stimulate biodegradation of fuel residuals. Conductivity of site soils to air movement would be greater than to water movement. Might stimulate cometabolism of CAHs during the biodegradation of fuel contamination.	Moderate to High	Low	No
		Soil Vapor Extraction	Air extraction to increase soil oxygen levels and extract VOCs from vadose zone. Conductivity of site soils to air movement would be greater than to water movement. May be subject to air emissions permitting.	High	Low to Moderate	No

TABLE 6.2 (Concluded)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
Source Removal/Soil Remediation (continued)	*In-Situ* (continued)	Soil Washing	Water and/or surfactant solution are forced through zones of residual contamination to enhance contaminant partitioning into the groundwater. Most effective in homogeneous sandy soils.	Low	High	No
	Mobile NAPL Recovery	Dual-Pump Systems	NAPL has not been detected at the site.	Moderate	High	No
		Skimmer Pumps, Bailers, Wicks	NAPL has not been detected at the site.	Moderate	Low to Moderate	No
		Total Fluids Pumping	NAPL has not been detected at the site.	Moderate	High	No
		Vacuum-enhanced extraction	NAPL has not been detected at the site.	Moderate to High	Moderate to High	Yes

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained from the screening process were combined into three remedial alternatives for the study area. Sufficient information on each remedial alternative is provided to facilitate a comparative analysis of effectiveness, implementability, and cost in Section 6.4.

6.3.1 Alternative 1 - RNA and Institutional Controls with Long-Term Groundwater Monitoring

RNA is achieved when natural attenuation mechanisms bring about a reduction in the total mass or concentration of a contaminant in the soil or dissolved in groundwater. RNA results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Destructive attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include sorption, dilution (caused by dispersion and infiltration), and volatilization. In some cases, RNA will reduce dissolved contaminant concentrations below numerical concentration goals intended to be protective of human health and the environment. As indicated by the evidence of RNA described in Section 4, these processes are occurring in the FTA-2 source area and will continue to reduce contaminant mass.

Implementation of Alternative 1 would require installation of additional monitoring wells, the use of institutional controls such as land use restrictions, and LTM. Land use restrictions may include placing long-term restrictions on groundwater well installations within and downgradient from the plume area. The intent of these restrictions would be to reduce potential receptor exposure to contaminants by legally restricting activities within areas affected by site-related contamination.

Long-term monitoring would be performed at a regular frequency and would consist of sampling a set of wells, including upgradient, source area, and plume extent (Section 7). Additional sentry wells may be required as the plume continues to expand. Due to uncertainty with site hydrogeology, sentry well locations should be selected after additional LTM data are available. For this site, it is assumed that 35 years of monitoring (consisting of annual monitoring for 15 years followed by biennial monitoring for 20 years) would be needed to establish plume behavior (i.e., expanding, stable, or shrinking) and that contaminant concentrations are decreasing. The recommended site-specific LTM strategy is provided in Section 7. On the basis of predictive contaminant fate and transport model results (Section 6.4), it is unlikely that contaminant concentrations exceeding groundwater MCLs would approach a potential receptor exposure point. Nevertheless, LTM is the technical mechanism used to evaluate the progress of natural attenuation processes and to ensure that remedial objectives are being met. Detection of TCE, *cis*-1,2-DCE, 1,2-DCA, or any other compounds listed in Table 6.1 in excess of their individual MCLs at a sentry well may require additional evaluation to assess contaminant migration, to determine the probable extent of migration, and to determine if additional corrective action is necessary. In either case, land use restrictions would require reevaluation.

Public education on the selected alternative would be developed to inform Base personnel and residents of the scientific principles underlying source reduction and RNA. This education could be accomplished through public meetings, presentations, press releases, and posting of signs where appropriate. Periodic site reviews could also be conducted annually using data collected from the LTM program. The purpose of these periodic reviews would be to evaluate the extent of contamination, assess contaminant migration and attenuation through time, document the effectiveness of source removal and/or institutional controls at the site, and reevaluate the need for additional remedial actions at the site.

6.3.2 Alternative 2 – Source Characterization and Removal, RNA, and Institutional Controls with Long-Term Groundwater Monitoring

Additional source and site characterization activities are recommended for site FTA-2 to further investigate the apparent discrepancy between the groundwater flow direction and distribution of dissolved TCE. The numerical model presented in Section 5 assumes anisotropic hydraulic parameters are responsible for the differences between groundwater flow and contaminant transport directions. However, additional sources of TCE and 1,2-DCA northwest of the primary FTA-2 source area also are suspected. Alternative 2 therefore includes additional source and site characterization activities including a soil gas survey, a geophysical survey, additional slug tests, and tracer tests, followed by source removal and LTM. As with Alternative 1, institutional controls and LTM would be required. Sentry and LTM wells would be the same as described for Alternative 1, and it is assumed that 35 years of monitoring would be needed to establish whether the plume is stable or shrinking and at contaminant concentrations are decreasing.

6.3.3 Alternative 3 - Groundwater Extraction and Treatment, Source Characterization and Removal, RNA, and Institutional Controls with Long-Term Groundwater Monitoring

Alternative 3 for FTA-2 includes groundwater extraction and treatment for plume containment in addition to the site characterization and source removal initiatives proposed for Alternative 2. Five 4-inch groundwater extraction wells would be completed in the upper USZ sand interval and located in the area with the highest TCE concentrations near well 2-62. Two additional 4-inch groundwater extraction wells would be completed in the lower USZ sand interval and located in the area near well 2-274B. A pumping rate of five gallons per minute (gpm) was assigned to each extraction well. The groundwater extraction system will prevent higher concentrations of contaminated groundwater from migrating downgradient and reduce the potential for completion of any potential receptor pathways. Given the relatively high natural hydraulic conductivity at the site, pumping should rapidly capture a significant portion of the water within the contaminant plume. It is estimated that the pumping system would operate for approximately ten years, a balance between the effectiveness of the system and the expected system lifespan.

Because groundwater extraction is not proposed for source reduction, it may not appreciably reduce the predicted length of time required for RNA to complete groundwater remediation upgradient of the extraction system. If contaminant concentrations drop rapidly, the system could be shut off, but monitoring would have to

continue to see if concentrations rebound after pumping ceases. In addition, because groundwater extraction potentially generates a large volume of waste requiring treatment (via air stripping) and disposal, the alternative does not comply with the objectives of this AFCEE initiative.

As with Alternatives 1 and 2, institutional controls and LTM would be required. LTM wells would be the same as described for Alternative 1. LTM should continue for an additional 25 years after pumping ceases (a total of 35 years) to verify that concentrations do not rebound above MCLs and to establish plume behavior patterns created by pumping.

6.4 EVALUATION OF ALTERNATIVES

This section provides a comparative analysis of each of the remedial alternatives based on the effectiveness, implementability, and cost criteria. A summary of this evaluation is presented in Section 6.5.

6.4.1 Alternative 1 - RNA and Institutional Controls with Long-Term Groundwater Monitoring

6.4.1.1 Effectiveness

Alternative 1 is based on the effectiveness of natural processes that minimize contaminant migration and reduce contaminant mass or concentrations over time as well as the effectiveness of institutional controls. To evaluate Alternative 1, the MODFLOW and MT3D numerical contaminant transport model presented in Section 5 was used to predict the future extent of TCE groundwater contamination. The Alternative 1 simulation assumes the TCE source from the calibrated model continues to contribute TCE to USZ groundwater for another 100 years (total simulation time of 135 years from initial source release). The TCE source is modeled with a conservative source weathering rate of two 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 two percent per year (each year's source strength was decreased by two percent from the previous year's strength).

The predicted extent of TCE in the upper and lower USZ sand intervals for Alternative 1 after 35 years (year 2033) is shown on Figure 6.1. A 35-year period was assumed for the TCE plume calibration in Section 5, so a 35-year time period is also used to predict plume behavior in the future. The predicted extent of TCE contamination after 35 years is also used as the basis for the long-term monitoring network and sentry well locations discussed in Section 7.

The model predicts maximum TCE concentrations of up to 10,500 µg/l in the upper USZ sand interval in the vicinity of well 2-62 after 35 years, and it predicts the plume will extend northwest of well 2-142 approximately 1,000 feet. For the lower USZ sand interval, the maximum predicted TCE concentration is approximately 350 µg/l in the vicinity of well 2-274B. The predicted plume shape and extent toward the northwest are similar for the upper and lower USZ sand intervals. Site data suggest that natural attenuation mechanisms are limited to the primary FTA-2 source area where anaerobic conditions are present.

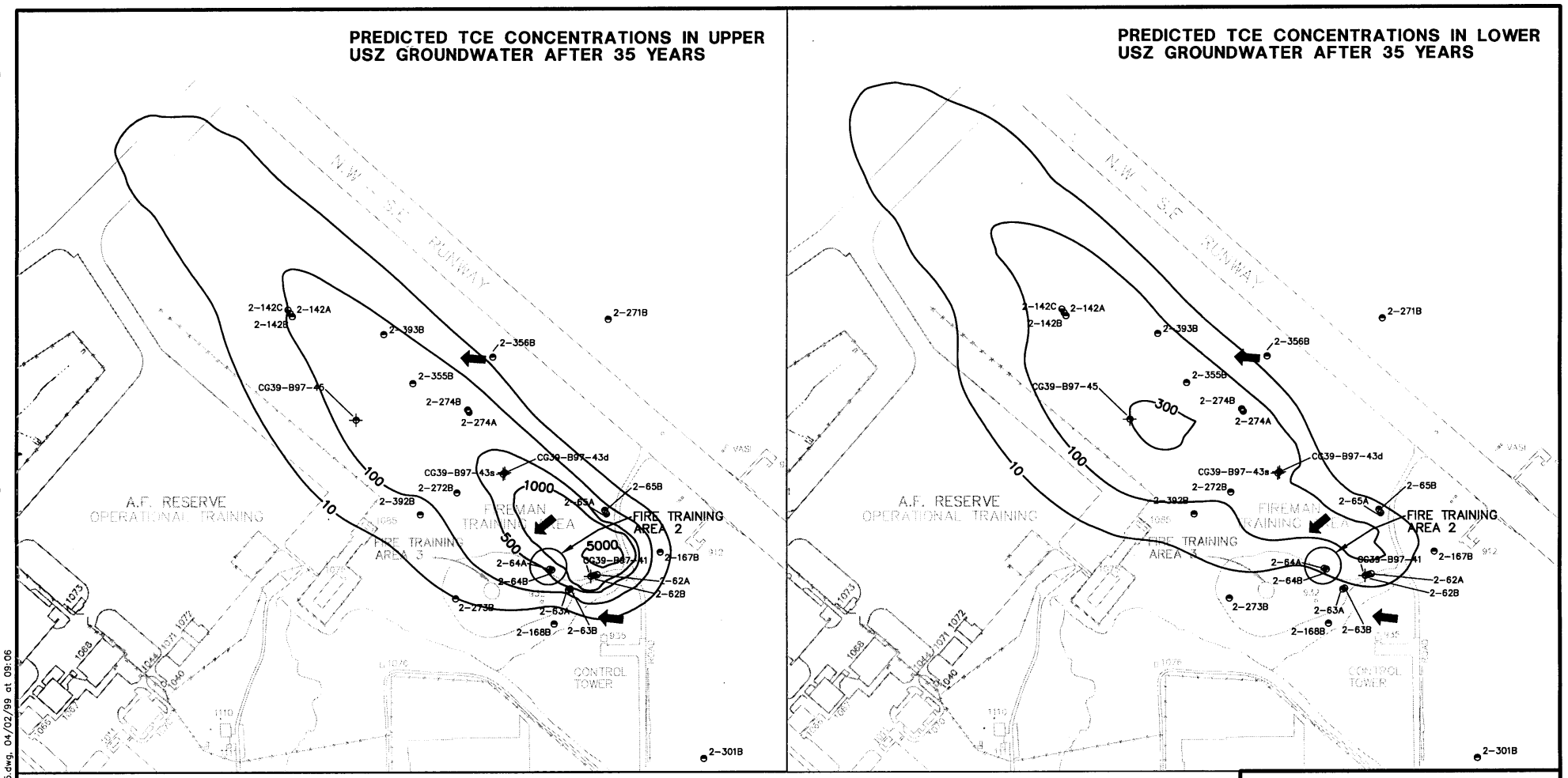

FIGURE 6.1

PREDICTED TCE CONCENTRATIONS IN USZ GROUNDWATER AFTER 35 YEARS FOR ALTERNATIVE 1

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TCE concentrations should exceed MCLs at the recommended LTM wells (Figure 7.1, Section 7). Speculative model predictions after 100 years indicate that the TCE plume may migrate approximately 1,400 feet northwest of well 2-142, with maximum TCE concentrations persisting in excess of 5,600 µg/L. Selection of additional sentry well locations should be made at a later date, when more data on plume behavior are available. Groundwater monitoring at the LTM wells will allow for continued evaluation of contaminant migration and ensure the safety of this alternative. While this alternative would not cease to be protective if the contaminant concentrations exceeding MCLs were detected in the LTM wells, such an instance would indicate that site conditions should be reevaluated.

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

Compliance with program goals is one component of the long-term effectiveness evaluation criterion. Alternative 1 would satisfy program objectives designed to promote RNA as a component of site remediation and to scientifically document natural processes. In addition, the alternative satisfies waste minimization goals, as only limited drill cuttings would be generated during construction of new monitoring wells. This alternative also satisfies the program goal for cost effectiveness.

Apart from the administrative concerns associated with the enforcement of long-term land use restrictions and long-term groundwater monitoring programs, this remedial alternative should provide reliable, continued protection. It is assumed that dissolved contaminant concentrations will exceed state and federal criteria throughout the plume for at least 35 years under Alternative 1. Furthermore, it is assumed that sampling will be performed every year for 15 years, and biennially for the remaining 20 years, to demonstrate that RNA is reducing dissolved contaminant concentrations and limiting plume migration.

6.4.1.2 Implementability

Alternative 1 is not technically difficult to implement. Installation of any additional LTM wells and monitoring of groundwater are standard procedures. Long-term management efforts would be required to ensure proper sampling 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. There also may be administrative concerns associated with long-term enforcement of groundwater use restrictions. Leaving contaminated soil and groundwater in place may impact future land use within the source area. However, with the exception of any subsurface work at the site, the risk for Base personnel of exposure to contaminants will be limited. If required, the public and the regulators would have to be informed of

the benefits and limitations of the RNA option. Educational programs are not difficult to implement. Where the effectiveness of this option has been supported, the initial regulatory reaction to this alternative has been positive.

6.4.1.3 Cost

The cost of Alternative 1 is summarized in Table 6.3, and cost calculations are included in Appendix D. Capital costs are limited to the construction of 8 new LTM wells (Section 7). Included in the $521,200 total present worth cost estimate for Alternative 1 are the costs of maintaining institutional controls and long-term monitoring at 30 LTM groundwater wells and 2 surface water stations for a total of 35 years. If the dissolved contaminant concentrations at the site decrease rapidly or drop below MCLs for consecutive sampling events, then monitoring may be reduced or eliminated. Conversely, significant increases for consecutive sampling events or a significant increase in plume extent could warrant an increase in sampling frequency or implementation of another remedial alternative.

TABLE 6.3
ALTERNATIVE 1 - COST ESTIMATE
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Capital Costs	Present Worth Cost
Design/Construct 8 LTM Wells	$38,840
Monitoring Costs (per Sampling Event)	**Present Worth Cost**
Conduct Annual Monitoring of 30 Groundwater Wells and 2 Surface Water Stations (1999 to 2013)	$336,200
Conduct Biennial Monitoring of 30 Groundwater Wells and 2 Surface Water Stations (2013 to 2033)	$68,470
Site Management (Maintain Institutional Controls/Public Education) and Reporting (35 years)	$77,690
Total Present Worth of Alternative 1 [a/]	**$521,200**

[a/] Based on an annual adjustment (discount) factor of 7 percent (USEPA, 1993).

6.4.2 Alternative 2 – Source Characterization and Removal, RNA, and Institutional Controls with Long-Term Groundwater Monitoring

6.4.2.1 Effectiveness

Alternative 2 includes additional source and site characterization activities including a soil gas survey, a geophysical survey, slug tests, and tracer tests, followed by source removal and LTM. Alternative 2 is based on locating and removing the source of TCE contamination as well as natural processes that minimize contaminant migration and reduce contaminant mass over time. To evaluate Alternative 2, the MODFLOW and MT3D numerical contaminant transport model presented in Section 5 was used to predict the future extent of TCE groundwater contamination after source removal. The Alternative 2 simulation assumes the TCE source from the calibrated model is reduced by 50 percent for 2 years, then is reduced by 2 percent per year as in Alternative 1.

The predicted extent of TCE in the upper and lower USZ sand intervals for Alternative 2 after 35 years (year 2033) is shown on Figure 6.2. The model predicts maximum TCE concentrations of up to 2,500 µg/l in the upper USZ sand interval in the vicinity of well 2-62 after 35 years, and it predicts the plume will extend northwest of well 2-142 approximately 1,000 feet. For the lower USZ sand interval, the maximum predicted TCE concentration is approximately 250 µg/l in the vicinity of well 2-274B. The predicted plume shape and extent toward the northwest are similar for the upper and lower USZ sand intervals. The predicted extent of TCE contamination after 35 years for Alternative 2 is also similar to the extent of TCE contamination after 35 years for Alternative 1. However, the maximum TCE concentrations in upper and lower USZ groundwater are significantly less for Alternative 2, particularly in the upper USZ sand where maximum TCE concentrations after 35 years are reduced approximately four-fold from Alternative 1.

Further delineation of TCE sources and hot spots at FTA-2 can be accomplished by implementing a soil gas survey of the upper USZ sand interval. Alternative 2 includes an initial soil gas survey on a relatively broad grid spacing of 50 feet, followed by a more focused investigation of areas identified as hot-spots on a tighter grid spacing of 20 ft. Results of the soil gas survey will be used to identify elevated concentrations of TCE in soil and upper USZ groundwater. Source removal by excavation will then be conducted based on results of the soil gas survey.

Two investigative techniques are recommended to further delineate anisotropic hydraulic conditions at FTA-2: an electromagnetic geophysical survey and a divergent radial flow, natural gradient tracer test. Electromagnetic (frequency domain) geophysical methods are recommended to further delineate paleochannels and/or zones of high hydraulic conductivity in the upper USZ sand interval. Geophysical methods can also be used to delineate the intra-USZ clay layer which separates the upper and lower USZ sand intervals and controls TCE groundwater transport from the upper to the lower USZ.

A conservative tracer test is proposed to evaluate contaminant transport rates and directions. For a radial flow, natural gradient tracer test, reagent grade lithium

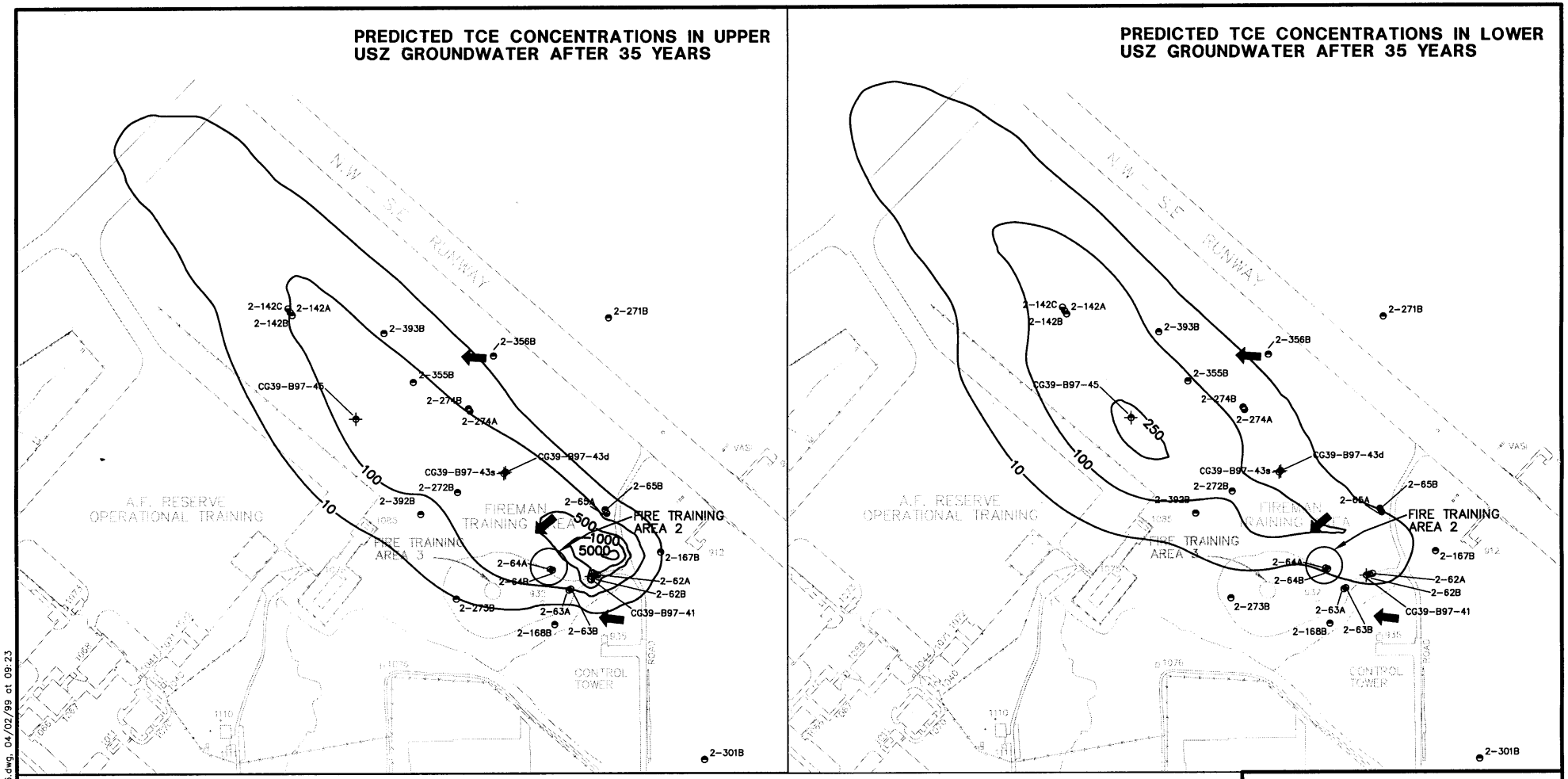

FIGURE 6.2

PREDICTED TCE CENCENTRATIONS IN USZ GROUNDWATER AFTER 35 YEARS FOR ALTERNATIVE 2

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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bromide is instantaneously injected into the source area well. With time, the bromide should be detected in downgradient wells at varying concentrations. The relative concentrations of bromide in downgradient wells can be used to define groundwater velocities, dispersivity, and contaminant transport rates and directions. Three new monitoring wells should be installed in conjunction with the tracer test for the determination of downgradient bromide concentrations.

Alternative 2 should provide reliable, continuous protection. This alternative complies with AFCEE program goals, because RNA remains the predominant remediation method for contaminants dissolved in groundwater at the site. This remedial alternative, however, will result in the generation of additional contaminated soil that may require treatment and/or disposal. The effectiveness of RNA and institutional controls with LTM is discussed for Alternative 1 in Section 6.4.1.1.

6.4.2.2 Implementability

Alternative 2 is not technically difficult to implement. Recommended site characterization activities as well as installation of additional LTM wells and monitoring of groundwater are standard procedures. The technical and administrative implementability concerns associated with the natural attenuation and LTM components of this remedial alternative are similar to those discussed for Alternative 1.

6.4.2.3 Cost

The estimated capital and operating costs of Alternative 2 are shown in Table 6.4. The total present worth cost of Alternative 2 is $1,058,000. The cost of Alternative 2 is increased from the costs of Alternative 1 by the addition of the soil gas survey, geophysical surveys, slug tests, tracer test, and source excavation. LTM is assumed to occur every year for 15 years, and biennially for an additional 20 years, to ensure that natural attenuation is reducing contaminant concentrations. The capital expense and annual costs for LTM and institutional controls are assumed to be the same as for Alternative 1.

6.4.3 Alternative 3 -Groundwater Extraction and Treatment, RNA, and Institutional Controls with Long-Term Groundwater Monitoring

6.4.3.1 Effectiveness

Alternative 3 includes groundwater extraction in addition to the source characterization and removal activities described for Alternative 2 and the long-term monitoring described for Alternative 1. Groundwater extraction is an established technology for controlling plume migration. The extraction of contaminated groundwater will prevent plume migration away from FTA-2, thereby preventing any completion of potential exposure pathways. A groundwater extraction system will also lower TCE concentrations in upper and lower USZ groundwater at FTA-2.

TABLE 6.4
ALTERNATIVE 2 - COST ESTIMATE
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

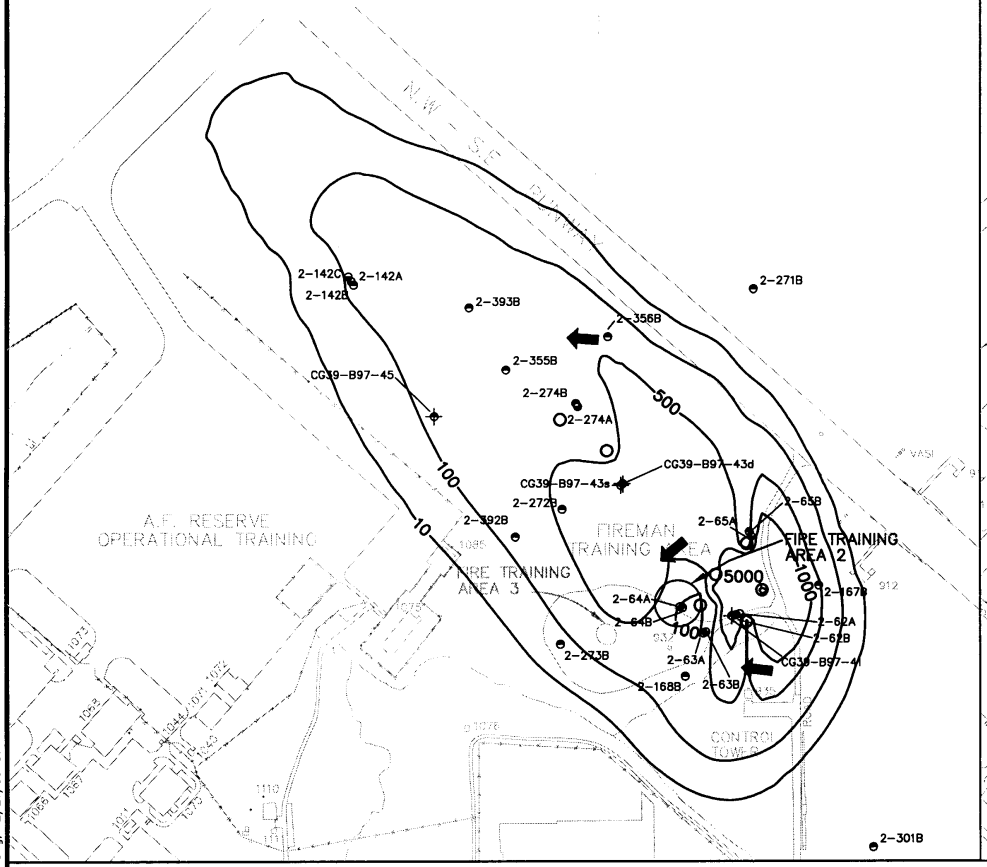
Capital Costs	Present Worth Cost
Perform Initial Soil Gas Investigation	$129,900
Perform Hot Spot Soil Gas Investigation	$78,000
Perform Geophysical Survey	$15,400
Perform Slug Tests	$1,980
Perform Tracer Test	$58,240
Soil Excavation and Disposal	$253,100
Present Worth of Alternative 1	**$521,200**
Subtotal for Present Worth of Alternative 2	**$536,600**
Total Present Worth of Alternative 2 [a/]	**$1,058,000**

[a/] Based on an annual adjustment (discount) factor of 7 percent (USEPA, 1993).

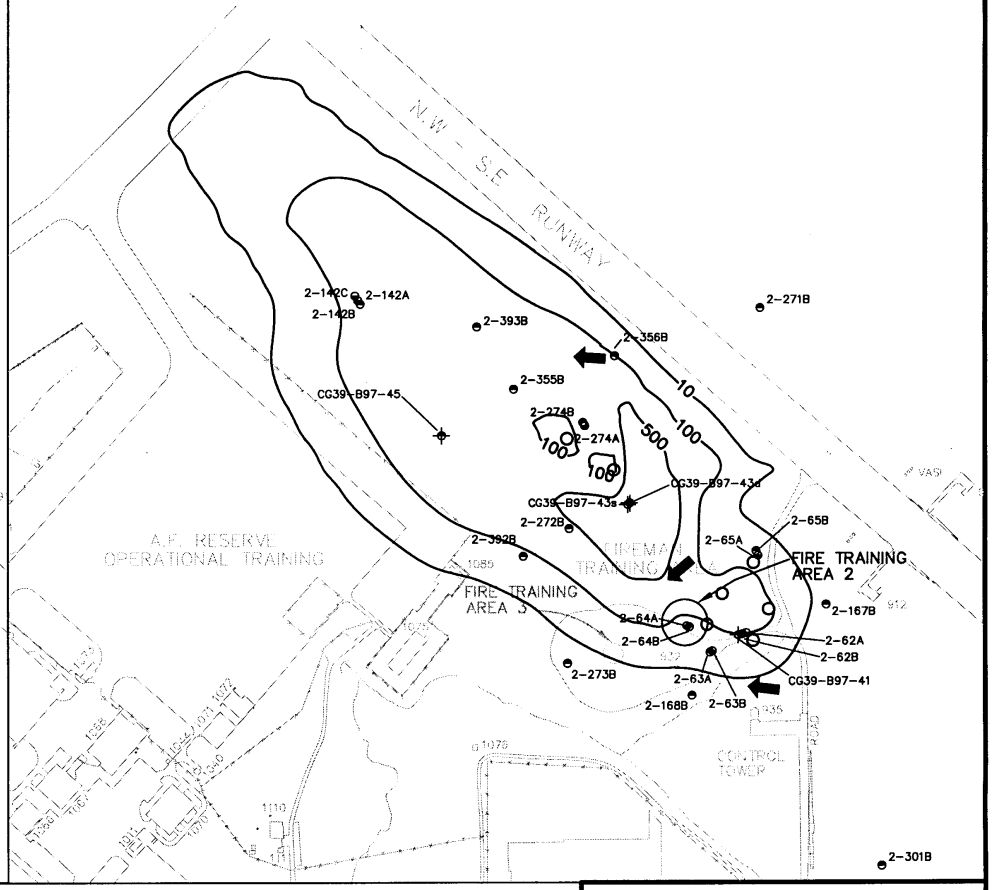
The MODFLOW and MT3D numerical contaminant transport model presented in Section 5 was used to estimate the number and locations of pumping wells in addition to the pumping rates needed to effect plume capture. The Alternative 3 simulations assume the TCE source is removed as in Alternative 2.

Containment of dissolved TCE concentrations greater than 1,000 µg/l in the upper USZ is obtained after ten years of pumping five gpm from each of seven groundwater extraction wells (Figure 6.3). Five extraction wells would be completed in the upper USZ sand interval near source area monitoring well 2-62B, and two extraction wells would be completed in the lower USZ sand interval near monitoring well 2-274B. In the lower USZ, containment of dissolved TCE concentrations greater than 500 µg/l is obtained after ten years of pumping (Figure 6.3).

PREDICTED TCE CONCENTRATIONS IN UPPER USZ GROUNDWATER AFTER 10 YEARS OF PUMPING



PREDICTED TCE CONCENTRATIONS IN LOWER USZ GROUNDWATER AFTER 10 YEARS OF PUMPING



LEGEND

- 2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- CG39-B97-41 — MONITORING POINT LOCATION/ UPPER SATURATED ZONE
- s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
- GROUNDWATER FLOW DIRECTION
- ALL CONCENTRATIONS IN MICROGRAMS PER LITER (µg/L)
- 10 — LINE OF EQUAL TCE CONCENTRATION (µg/L)
- PROPOSED GROUNDWATER EXTRACTION WELLS FOR ALTERNATIVE 3

0 200 400 800
FEET

FIGURE 6.3

PREDICTED TCE CONCENTRATIONS IN USZ GROUNDWATER AFTER 10 YEARS OF PUMPING FOR ALTERNATIVE 3

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Alternative 3 should provide reliable, continuous protection for downgradient receptors. This alternative, however, does not comply well with all of the AFCEE program goals because of the generation of soil and water waste requiring treatment and disposal. In addition, contaminants are not destroyed, but are instead transferred to another phase that may require further treatment. As with Alternatives 1 and 2, this alternative would rely on RNA with LTM and institutional controls to remediate the contaminated groundwater once the extraction system is shut down.

6.4.3.2 Implementability

Groundwater extraction would be labor intensive and expensive to implement. The option would require additional site investigation, design and engineering, installation, and a weekly commitment to operation and maintenance of the extraction and air stripper systems. An air emissions permit may need to be obtained for the air stripper prior to system start-up. A permit also may be needed for disposal of treated groundwater. The technical and administrative implementability concerns associated with the RNA, LTM, and institutional controls of this remedial alternative are similar to those discussed for Alternatives 1 and 2.

6.4.3.3 Cost

The estimated capital and operating costs of Alternative 3 are shown in Table 6.5. The total present-worth cost of Alternative 3 is $2,156,000. Despite the shorter operating time frame, the cost of Alternative 3 is comparable to the costs of Alternative 2 because it is more costly to design, install, operate, and maintain the groundwater extraction system. However, the cost could be significantly higher if off-gas treatment for the air stripper is required, if the system has to run for more than 10 years, or if treated groundwater cannot be easily disposed (e.g., discharged to a storm sewer). The annual costs for LTM and institutional controls are assumed to be the same as for Alternatives 1 and/or 2. The resulting present-worth cost for LTM and institutional controls are the same as for Alternative 1 because it is assumed that the groundwater extraction system merely contains the core of the contaminant plume without treating the source, and therefore, will operate for the same length of time.

6.5 RECOMMENDED REMEDIAL APPROACH

Three remedial alternatives have been evaluated for remediation of USZ groundwater at FTA-2. Components of the alternatives evaluated include RNA with LTM of groundwater, institutional controls, source characterization and removal, and groundwater extraction with ex-situ treatment. Table 6.6 summarizes the results of the evaluation based upon effectiveness, implementability, and cost criteria. Due to the risk of vertical contaminant migration and to the high cost and risk of engineered Alternative 3, the Air Force recommends Alternative 2 as a balanced and most cost-effective option for risk reduction at the study area.

All three alternatives make use of natural attenuation mechanisms to reduce plume migration and toxicity, although Alternative 3 relies more on capture of the plume with the extraction system. Alternatives 2 and 3 would use active *in situ* and *ex situ* techniques to limit contaminant migration. Implementation of Alternatives 2 and 3

TABLE 6.5
ALTERNATIVE 3 - COST ESTIMATE
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Capital Costs	Present Worth Cost
Install Groundwater Extraction System with Air Stripper	$708,000
Operation, Maintenance, and Monitoring Costs	**Present Worth Cost**
Operation and Maintenance for the Pump and Treat System (10 years)	$389,950
Subtotal Present Worth of Alternative 1	$521,200
Subtotal Present Worth of Alternative 2	$536,600
Subtotal Present Worth of Alternative 3	$1,098,000
Total Present Worth of Alternative 3 [a/]	**$2,156,000**

[a/] Based on an annual adjustment (discount) factor of 7 percent (USEPA, 1993).

would not substantially decrease the time frame for remediation, but both alternatives would require greater capital expenditures. Alternatives 2 and 3 are considered less favorable because in part they simply transfer contamination to a different medium rather than reducing contaminants to innocuous byproducts.

All three remedial alternatives are implementable and effectively reduce potential contaminant migration and toxicity in the groundwater. Under all three remedial alternatives, the plume is predicted to expand, but without impact to potential receptors (Figures 6.1, 6.2, and 6.3). All three 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, only Alternative 2 addresses soil (source) contamination. Implementation of any of the three alternatives will require land and groundwater use controls to be enforced. Groundwater monitoring would be required for the respective projected cleanup periods.

The 35-year remediation time for Alternative 1 is not considered conservative because the plume is likely expanding. Uncertainties about the nature and location of contaminant sources mean that site conditions could change during the LTM period and that additional contaminant mass could unexpectedly enter groundwater. However, this potential drawback would apply to all alternatives and would require reevaluation in all

TABLE 6.6
SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1 - Natural Attenuation - Long-Term Monitoring - Institutional Controls	Contaminant mass, volume, and toxicity will be slowly reduced over time, but the dissolved plume may persist for well over 100 years, necessitating a potentially lengthy period of LTM and institutional controls.	Readily implementable. Groundwater water quality monitoring required for an estimated minimum of 35 years, and potentially much longer. Institutional controls, including land and groundwater use controls, may be required for more than 100 years due to the persistance of elevated dissolved CAH concentrations. Minimal exposure to potential receptors if institutional controls are implemented. If significant plume migration occurs and completion of exposure pathways is possible, then additional remedial work may be required.	**$521,200**
Alternative 2 - Source Characterization - Source Removal - Tracer Test - Geophysical Survey - Natural Attenuation - Long-Term Monitoring - Institutional Controls	Similar to Alternative 1, with the addition of source characterization, source removal by excavation, and additional site characterization by tracer test and geophysical survey. Contaminant mass, volume, and toxicity will be reduced more rapidly than in Alternative 1. However, even if the source is substantially reduced, significantly elevated dissolved TCE concentrations may still persist for more than 50 years, and downgradient plume migration may exceed 750 feet, depending on the actual biodegradation rate.	Source reduction simulated by the numerical model should not pose significant implementability concerns. However, long-term site management, groundwater use controls, and monitoring would be required as elevated TCE concentrations may persist for more than 100 years. If significant plume migration occurs and completion of exposure pathways is possible, then additional remedial work may be required.	**$1,058,000**
Alternative 3 - Groundwater Pump and Treat - Source Characterization - Source Removal - Tracer Test - Geophysical Survey - Natural Attenuation - Long-Term Monitoring - Institutional Controls	Similar to Alternatives 1 and 2, with the addition of a multi-well pump and treat system to reduce the highest dissolved TCE concentrations. Contaminant mass, volume, and toxicity will be reduced more rapidly than in Alternative 1 and 2. However, even if the source and dissolved TCE concentrations are substantially reduced, significantly elevated dissolved TCE concentrations may still persist for more than 50 years, and downgradient plume migration may exceed 500 feet, depending on the actual biodegradation rate.	Installation/operation of the pump and treat system simulated by the numerical model should not pose significant implementability concerns. However, long-term site management, groundwater use controls, and monitoring would be required as elevated CAH concentrations may persist for more than 50 years. If significant plume migration occurs and completion of exposure pathways is possible, then additional remedial work may be required.	**$2,156,000**

cases. The proposed LTM period is not consistent with federal recommendations that proposed or implemented remedial activities at a site should not exceed 30 years in duration (USEPA, 1988), and even if site conditions require a change in the remedial strategy it is unlikely that this time limit would be met. The final evaluation criterion used to compare each of the remedial alternatives was cost; the additional costs of Alternative 3 does not justify the slightly reduced risk resulting from plume containment.

Alternative 2 will reduce the level of contamination and maintain the necessary degree of protection to potential receptors at or downgradient from the site, and is the recommended remedial alternative for USZ groundwater at FTA-2. Alternative 2 combines natural attenuation with source reduction, and provides for additional site characterization necessary to accurately predict the future behavior of dissolved contaminants at FTA-2. Future exposure to potential receptors at the site will be minimized by land use restrictions, because access to the Base (and hence the site) is controlled by Base security. A LTM plan for groundwater, including a generic SAP, is provided in Section 7.

SECTION 7

LONG-TERM MONITORING PLAN

7.1 OVERVIEW

In keeping with the requirements of the preferred remedial alternative for Tinker AFB Site FTA-2, a LTM plan was developed. The long-term groundwater and surface water monitoring plan for FTA-2 presented in this section describes a monitoring scheme for the next 35 years for planning and budgeting purposes. It should be noted that this plan was devised on the basis of currently available data; the LTM program may be progressively revised as new data are obtained during this 35-year period. The LTM plan consists of identifying the locations of LTM wells and surface water stations, and developing a groundwater and surface water sampling and analysis strategy to accomplish the following objectives:

- Monitor changes in site conditions, including plume magnitude and extent, over time;
- Assess the effectiveness of engineered remedial actions and naturally occurring processes at reducing contaminant mass and minimizing contaminant migration;
- Assess the degree to which site-specific remediation goals (Section 6.1) are being attained and facilitate the evaluation of the need for additional remediation; and
- Verify the predictions of the numerical contaminant fate and transport model.

The strategy described in this section is designed to monitor plume migration over time and to verify that natural and engineered remedial processes are adequately protecting potential receptors. Based on the presence of an upward vertical groundwater gradient at well location 2-62B, surface water sampling in the ditch to the south of well 2-62B (Figure 4.3) also is recommended to determine if the TCE plume is discharging to surface water. In the event that data collected under this LTM program indicate planned combination of naturally occurring processes and engineered remedial actions is insufficient to protect human health and the environment, contingency controls to more aggressively remediate the dissolved TCE plume would be necessary.

7.2 GROUNDWATER AND SURFACE WATER MONITORING NETWORK

LTM of a minimum of 18 existing USZ, 4 existing LSZ, and 8 proposed monitoring wells located upgradient from, within, and on the periphery of the primary TCE plume is recommended (30 total wells). Existing USZ wells include CG39-B97-41, CG39-B97-43s, CG39-B97-43d, CG39-B97-45, 2-62B, 2-63B, 2-64B, 2-65B, 2-142B, 2-167B, 2-

168B, 2-272B, 2-273B, 2-274B, 2-355B, 2-356B, 2-392B, and 2-393B (Figure 7.1). TCE was detected in LSZ monitoring well 2-62A during the August 1997 sampling event. Therefore, wells 2-62A, 2-63A, 2-64A, and 2-274 are recommended for monitoring in the LSZ. These wells are located beneath the USZ TCE plume axis (2-62A, 2-64A, and 2-274A), and downgradient of 2-62A (2-63A). In addition, eight proposed monitoring wells and two surface water stations also would be sampled as a part of the LTM for Site FTA 2.

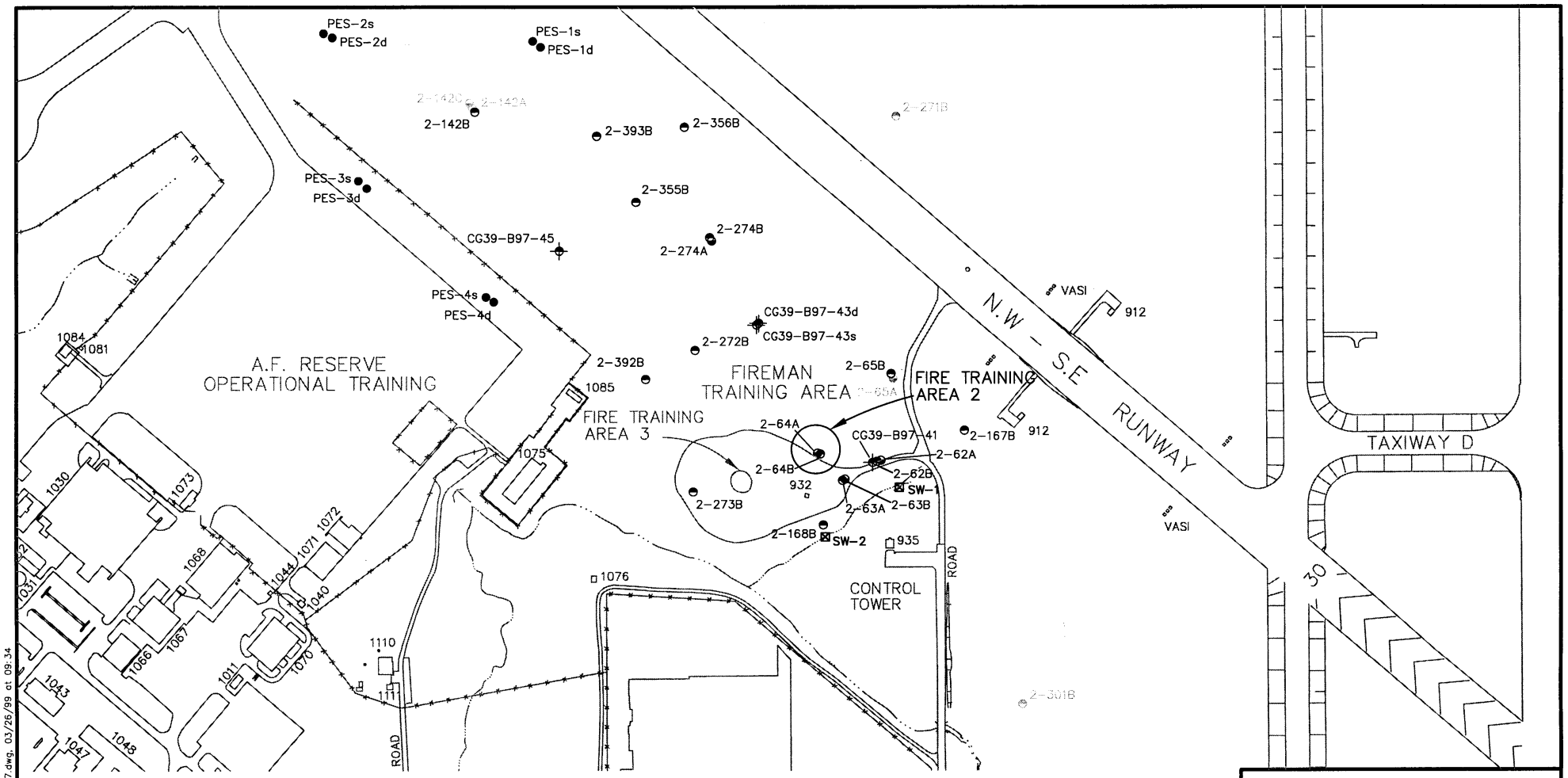
On the basis of the contaminant transport modeling results presented in Section 6, the TCE plume may migrate more than 1,000 feet past the current downgradient plume boundary over the next 35 years. Because the groundwater flow direction and subsurface properties in the area downgradient from the current plume boundary have not been investigated, installation of additional LTM wells approximately 300-500 feet downgradient of the current plume boundary is appropriate. Progressive tracking of the plume in the downgradient direction over time is recommended. In this way, the downgradient migration of the plume can be monitored. It is anticipated that additional sentry wells will be necessary to monitor the maximum plume extent before the 35-year monitoring period expires. The number and locations of these sentry wells cannot be accurately predicted at this time based on the limited hydrogeologic data for this site. Therefore these wells are not included or costed for this LTM plan.

The TCE plume in both the upper and lower USZ sands is not well defined to the north and west (Figure 4.3). The TCE plume in the upper USZ sand is only defined by non-detection in wells 2-356B (upgradient), 2-142B (downgradient), and 2-273B (downgradient). The TCE plume in the lower USZ sand is only defined by non-detection in wells 2-271B (upgradient), 2-142B (downgradient), and 2-392B (downgradient). Therefore, four well pairs screened in the USZ are recommended to monitor future plume expansion. The USZ well locations were selected to monitor USZ groundwater quality both horizontally and vertically in directions in front of the primary contaminant plume axis, and hydraulically downgradient of plume. Suggested locations for these wells are shown on Figure 7.1. If CAH contamination is detected in these wells in the future, then additional wells could be installed further downgradient. Estimates of the groundwater/CAH migration rate and direction should be progressively refined as new wells are installed to aid in locating additional LTM wells.

Prior to installation of the four LTM well pairs north and west of the current plume boundary, the stratigraphy at the well locations should be investigated to ensure that the wells are appropriately screened to intercept transmissive zones that may act as preferred contaminant migration pathways. This information could be obtained using a conventional hollow-stem auger (HSA) drilling rig and running borehole geophysical logs.

7.3 ANALYTICAL PROTOCOL

All LTM wells should be sampled and analyzed to determine compliance with chemical-specific remediation goals and to verify the effectiveness of remediation at the site. Groundwater level measurements should be made during each sampling event. Because natural attenuation is a component of the remedial strategy, appropriate geochemical parameters should also be analyzed in addition to target analytes.



LEGEND

- UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- CG39-B97-41 — MONITORING POINT LOCATION/ UPPER SATURATED ZONE
- s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
- PES-1s — PROPOSED UPPER SATURATED ZONE MONITORING WELL LOCATION
- SW-1 — PROPOSED SURFACE WATER SAMPLING LOCATION

FIGURE 7.1

LTM SAMPLING LOCATIONS
FIRE TRAINING AREA 2

Site FTA-2
RNA TS
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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Groundwater samples from LTM wells should be analyzed for the parameters listed in Table 7.1.

7.4 SAMPLING FREQUENCY

Under the current remedial strategy, dissolved TCE concentrations in excess of the 5 μg/L standard will be present for more than 35 years. Estimated LTM costs for a 35-year period beginning in 1999 are presented in Section 7.6. The 30 LTM wells (18 existing USZ, 4 existing LSZ, and 8 proposed) and 2 surface water stations would be sampled annually for 15 years beginning in 1999 (the duration of the engineered remedial actions evaluated), and every second year for the remaining 20 years of the 35-year period.

The LTM plan should be periodically reviewed and revised as appropriate on the basis of available groundwater quality data and the collection of additional source and hydrogeologic characterization data. For example, if the data collected during this time period indicate the plume has stabilized or is receding, and that CAH concentrations are diminishing, then the sampling frequency can be reduced. If sampling results indicate that geochemical conditions in the plume area are stable over time (e.g., nitrate, sulfate, and ferrous iron concentrations), then the sampling frequency for these parameters could be reduced. 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.

7.5 LTM COST ESTIMATE

The estimated present worth cost for the LTM program described in the preceding sections is shown in Table 7.2. Included in the total present worth cost of $502,900 are the estimated costs for installing four additional LTM wells, performing the recommended groundwater and surface water monitoring, maintaining institutional controls, public education, project management, and reporting.

TABLE 7.1
LONG-TERM MONITORING ANALYTICAL PROTOCOL FOR GROUNDWATER
FTA-2 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 7.1 (Concluded)
LONG-TERM MONITORING ANALYTICAL PROTOCOL FOR GROUNDWATER
FTA-2 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® SulfaVer 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 conditons 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 8260B	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.* (1995). Handbook refers to "AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigation/Feasibility Study (RI/FS).

TABLE 7.2
ESTIMATED LTM COSTS
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Capital Costs	Present Worth Cost
Design/construct eight LTM wells in 1999	$38,840

Monitoring Costs	Present Worth Cost
Conduct Annual Groundwater Monitoring of 30 Wells and Surface Water Monitoring of 2 Stations from 1999 to 2013.	$321,000
Conduct Biennial Groundwater Monitoring of 30 Wells and Surface Water Monitoring of 2 Stations from 2013 to 2033.	$65,370
Site Management (Maintain Institutional Controls/Public Education) and Reporting (35 years)	$77,690
Total Present Worth of LTM Program [a/]	**$502,900**

a/ Based on an annual inflation (discount) factor of 7 percent (USEPA, 1993).

Note: Cost assume that well installation and LTM are performed by local (Oklahoma City area) personnel.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a TS conducted to evaluate the use of natural attenuation for remediation of CAH-contaminated groundwater at FTA-2 at Tinker AFB, Oklahoma. The numerical models MODFLOW and MT3D were used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and biodegradation of CAHs dissolved in groundwater. To obtain the data necessary for the RNA demonstration, soil and 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.

It is likely that contaminants were first introduced into groundwater at this site when the FTA-2 fire pit was initially used for fire training exercises in 1962. TT (1996) reported the FTA-2 pit was operational until 1966, although aerial photos indicate the pit was present as late as 1970. Fire training exercises at Air Force bases typically use contaminated or uncontaminated jet fuel. Solvents, fuels, and other liquid wastes may have been used for training exercises or cleaning, or dumped in the general fire training area. Aerial photographs show numerous dirt access roads crossing the area through the mid-1970s, indicating unknown activities continued in the area after use of the FTA-2 pit was discontinued.

Analytical data indicate that the highest concentrations of CAHs occur in the vicinity of well 2-62B, located approximately 100 to 120 feet upgradient from the former fire pit along an access road. The presence of a secondary source, located further upgradient from well 2-62B and the former fire pit along another access road near the flightline (well 2-65B), also is suggested by increasing concentrations of CAHs at that location (Appendix H).

Contaminants observed in groundwater at concentrations greater than USEPA MCLs at FTA-2 include benzene, PCE, TCE, 1,1-DCE, *cis*-1,2-DCE, VC, 1,2-DCA, CB, 1,2-DCB, and 1,4-DCB. Temporal data (Appendix H) for concentrations of TCE and *cis*-1,2-DCE from monitoring wells/points at FTA-2 indicates that concentrations in the potential source areas are stable or gradually increasing. Given the available data, it appears that the plume is expanding downgradient from the suspected primary FTA-2 source and also at an upgradient location, based on increased concentration data for wells 2-63B, 2-64B, and 2-65B. An increase in concentrations within the center of the CAH plume at wells 2-72B and 2-274B further indicate the presence of secondary source(s) and/or expansion of the CAH plume in that area. Conversely, decreasing CAH concentration data for wells

2-355B and 2-393B along the plume axis at the most northern portion of the plume indicate the plume may be either decreasing or approaching equilibrium in this area.

Comparison of CAH, BTEX, TOC, electron acceptor, and byproduct data provides evidence that CAHs dissolved in groundwater at FTA-2 are being naturally degraded in limited areas. The presence of daughter products *cis*-1,2-DCE and VC provides strong evidence that parent solvents (TCE and/or PCE) are being reductively dehalogenated in an area limited to the general source area(s). However, a relative lack of VC and ethene indicates that the process does not significantly proceed past the initial step of TCE to DCE. TCE, DCE and DCA are reduced to a significantly lesser extent downgradient of the source area(s). Anaerobic conditions in the source area may be driven by low concentrations of anthropogenic fuel hydrocarbons. Downgradient of the source area, reductive dehalogenation ceases, and compounds such as DCE, VC, and chlorobenzenes likely are aerobically degraded or diluted. While VC and chlorobenzenes are reduced to non-detectable levels downgradient of the source area, DCE persists with TCE to the leading edge of both the upper and lower USZ plumes. 1,2-DCA also is present in elevated concentrations downgradient of the source area. It is not apparent whether elevated concentrations of 1,2-DCA have migrated downgradient from the FTA-2 source area, or whether an additional source of 1,2-DCA exists in that area.

Molar fractions (Appendix H) of chlorinated ethenes along the apparent CAH plume axis indicates little, if any, degradation of TCE to DCE outside the immediate source area(s). At well 2-65B, an overall decrease in the molar fraction of TCE, with an increase in molar fraction of DCE and the presence of VC indicates that TCE is degrading to DCE, and DCE to VC at that location. Geochemical data indicate that biodegradation of native or anthropogenic carbon is occurring via aerobic respiration and methanogenesis in suspected source areas, but that nitrate, ferric iron, and sulfate reduction are not significant anaerobic degradation processes at the site. Furthermore, there are an abundance of alternate electron acceptors that may inhibit use of CAHs as electron acceptors. Away from the suspected source areas, DO concentrations and ORPs indicate that environmental conditions are not sufficiently reducing for dehalogenation of CAH compounds.

Site-specific hydrogeologic and laboratory analytical data were used in the numerical groundwater model to simulate the effects of advection, dispersion, sorption, and biodegradation on the fate and transport of the TCE plume. TCE is used as an indicator compound in this report due to its relatively high concentration, low MCL, and persistence downgradient of the source area. During model calibration, model parameters that could not be obtained from existing site data were estimated using common literature values for aquifer materials similar to those found at the site. Model predictions were found to be very sensitive to hydraulic conductivity, anisotropy, dispersivity, and the magnitude of the first-order TCE decay rate assigned to the upper and lower USZ sands at FTA-2.

Remedial Alternative 1 incorporates natural attenuation, but does not include engineered remediation. The model used to simulate this alternative incorporates the assumption that dissolution from residual NAPL in the source area into groundwater will naturally decrease at a geometric rate of 2 percent per year (each concentration was decreased by a factor equal to 2 percent of the previous year's concentration) during the

35-year predictive period. The results of the model indicate that TCE will continue to migrate over the next 35 years an additional 1,000 feet from the present plume toe in both the upper and lower USZ sand intervals. Plume migration is too speculative to predict beyond 35 years based on limited hydrogeologic characterization of the site. Furthermore, TCE is predicted to persist in the source area at concentrations greater than 10,500 µg/L over the same 35 year period.

The model used to simulate remedial Alternative 2 assumes that partial source removal via application of engineered remedial technologies such as such as soil vapor source characterization and excavation would reduce TCE source mass. This model incorporates the assumption that the remediation will reduce the TCE source into groundwater by 50 percent per year over a 2 year period, followed by a 2 percent per year reduction due to natural weathering for the remainder of the 35 year model simulation. Results of these models indicate that source reduction at the assumed rates would result in decreases in dissolved TCE concentrations within the plume relative to Alternative 1. The Alternative 2 model predicts that maximum TCE concentrations would be reduced approximately four-fold in the upper USZ sand interval, and by approximately two-fold in the lower USZ sand interval over the 35-year model simulation. However, the overall plume extent would not be reduced, and TCE concentrations would continue to persist above USEPA MCLs.

A third groundwater model was used to simulate the potential effects of a groundwater extraction and treatment system. The Alternative 3 model was identical to Alternative 2, with the addition of seven pumping wells placed in the currently delineated TCE plume at areas of maximum TCE concentrations. The results of this model indicate that groundwater extraction and treatment would lower TCE concentrations in upper and lower USZ groundwater. On the basis of model simulations, the extraction system will contain groundwater with dissolved TCE concentrations in excess of 1,000 µg/L in the upper USZ after 10 years of pumping. In the lower USZ, the Alternative 3 model predicts containment of dissolved TCE concentrations in excess of 500 µg/L after 10 years of pumping.

It should be noted that the numerical model constructed for this TS is reasonably conservative; therefore, plume migration and persistence may be less than that predicted by the model. Factors that could cause plume migration and persistence to differ from model predictions include the following:

- The calibrated model is not necessarily unique, and different combinations of input parameters could potentially have been used to achieve an acceptable calibration;
- The calibrated model is limited in accuracy by inadequate characterization of the source, preferential flowpaths, and aquifer anisotropy;
- The model does not account for the potential occurrence of abiotic degradation and volatilization of TCE; and
- Hydrogeologic and/or geochemical conditions that could slow or halt plume migration may exist downgradient from the investigated area.

This report presents a conceptual model where the primary source of TCE was near the FTA-2 fire pit and well 2-62B, and the TCE plume migrated toward the northwest due to a preferential flow path and anisotropy of the aquifer matrix. This conceptual model was primarily based on the plume configuration in 1997, which suggests linear contaminant transport in a northwest direction. Fate and transport modeling results indicate that dissolved TCE contamination present in groundwater north and west of the FTA-2 fire pit has the potential to migrate significantly. However, concentrations for wells located at the northern toe of the TCE plume (2-355B in the upper USZ sand interval and 2-393B in the lower USZ sand interval) decreased substantially from 1997 to 1999 (Appendix H).

Alternately, the TCE plume may be migrating in the direction of maximum hydraulic gradient (west-southwest) from multiple sources. The presence of multiple TCE "hotspots" does not support a conceptual model of a single source; rather, the "hotspots" suggest multiple sources. Increases in the concentration of TCE in 1999 at wells located downgradient of suspected TCE sources or "hotspots" (wells 2-64B and 2-272B) suggest a more westerly migration in the direction of maximum hydraulic conductivity. Therefore, the numerical model presented in this TS should be considered as only one of multiple possible interpretations.

Alternative 2 is the recommended remedial alternative for USZ groundwater at FTA-2 because it will reduce the level of contamination while maintaining the necessary degree of protection to potential receptors at or downgradient from the site. Alternative 2 combines natural attenuation with source reduction, and provides for additional site characterization necessary to accurately predict the future behavior of dissolved contaminants at FTA-2. Source charactrization activities may include soil gas surveys, geophysical surveys, additional aquifer testing, and tracer tests. Future exposure to potential receptors at the site can be minimized by land use restrictions, because access to the Base (and hence the site) is controlled by Base security. The beneficial affects of natural attenuation are included in Alternative 2. The degree to which RNA will continue to control significant downgradient migration of the plume is not known with certainty, but will become more apparent as successive LTM sampling events are performed.

To assess the effectiveness of both naturally-occurring processes and source removal at reducing contaminant mass and minimizing contaminant migration, groundwater from a minimum of 22 existing monitoring wells and 8 proposed monitoring wells should be sampled annually for 15 years to build a historical groundwater quality database for the site. Two surface water stations also should be sampled annually during this 15-year period. Following completion of the 15-year annual LTM period, the LTM program should be reassessed, and sampling frequency may be reduced to biennial events. The number and location of additional sentry wells and surface water stations selected for continued monitoring should be determined on the basis of results from the initial 15-year LTM period. Likewise, the model can be adjusted to reflect additional source and hydrogeologic characterization.

The LTM plan should be periodically reviewed and revised as appropriate on the basis of available groundwater quality data. For example, if sampling results demonstrate that the plume is in equilibrium (not migrating downgradient) or is receding toward the source area, then the sampling frequency could be reduced appropriately. 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 and the appropriate remedial actions (e.g., groundwater extraction and treatment as described in Section 6) should be evaluated and implemented.

SECTION 9

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APPENDIX A

SELECTED FIGURES AND TABLES FROM THE PHASE I RCRA RFI FOR FTA-2 (IT, 1994), AND THE DRAFT RCRA RFI FOR FTA-2 (TT, 1996)

Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-62B

DRILLING AND SAMPLING INFORMATION

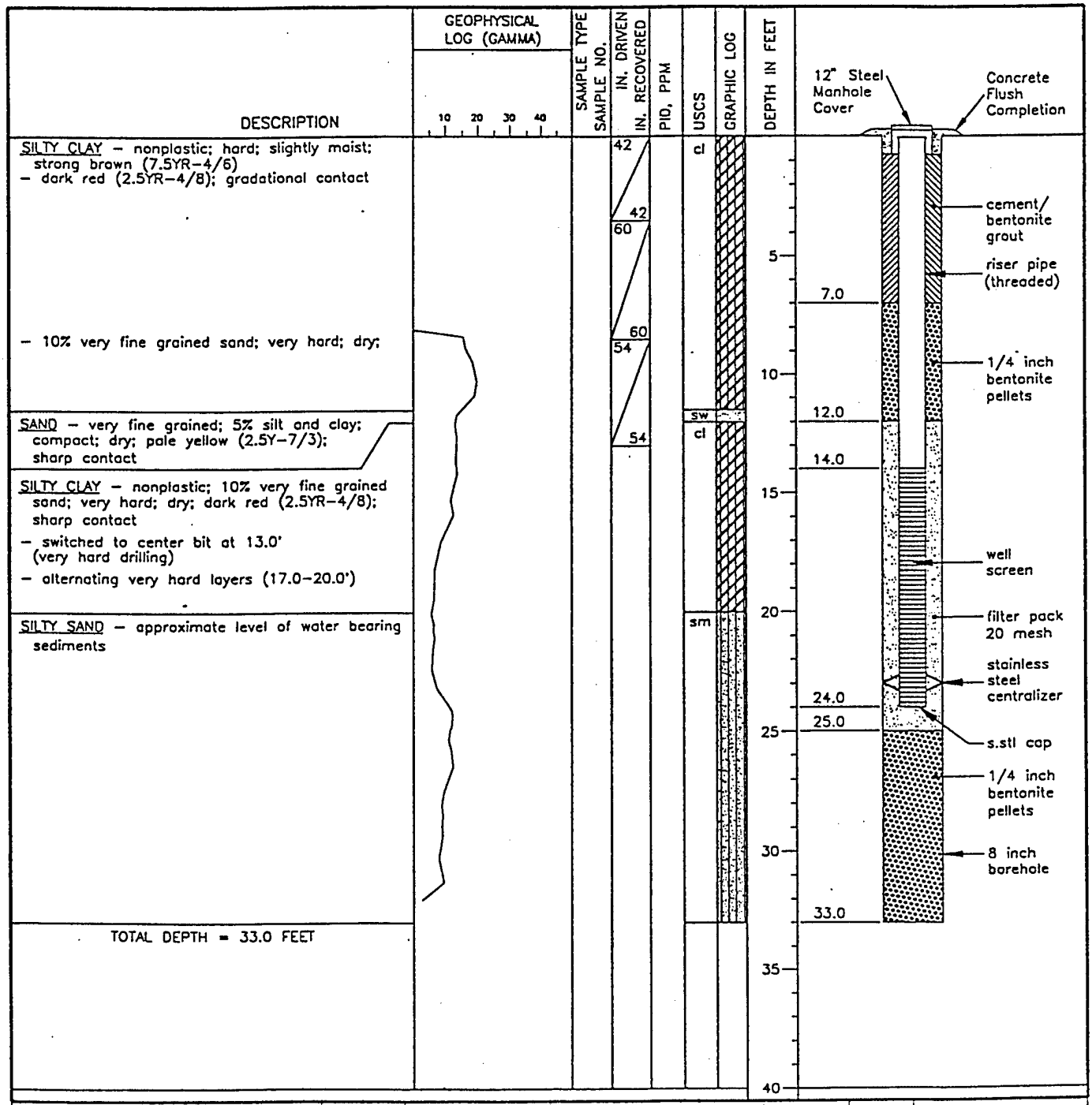
Boring Location: EAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT): 1245.940
TOTAL DEPTH(FT.): 33.0
Logged By: K. KIRSCHENMANN
Date Started: 11/9/93
Drilled By: P. GUERREIN GEOTECHNOLOGY. INC.
Date Completed: 11/9/93
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

Sampling Method: 3"x5' CONTINUOUS SAMPLER

Notes: N 150444.517, E 2182140.558

WELL COMPLETION DATA

Elev-Top of Casing(ft.): Ref. Datum: MSL
1. Riser Pipe-I.D.(in.): 2 Depth(ft.): 14 Type:S.Steel
   Centralizers-Type: Depths(ft.):
2. Screen Dia.(in.): 2 Type: S.Steel Millslotted
   Depth Interval(ft.): 14-24 Slot Size(in.): .010
   Centralizers-Type: S.Steel Depths(ft.):23
3. Filter Pack Type: Silica Sand Depth Interval(ft.): 12-25
   Conc. Pad Size: 4'x4'x6"



DRAFT BY	RPS	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A30 Sheet 1 of 1
	12/1/93								

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-63B

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT): 1243.284
TOTAL DEPTH(FT.): 29.0
Logged By: K. KIRSCHENMANN
Date Started: 11/8/93
Drilled By: P. GUERREIN
Date Completed: 11/8/93
GEOTECHNOLOGY. INC.
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

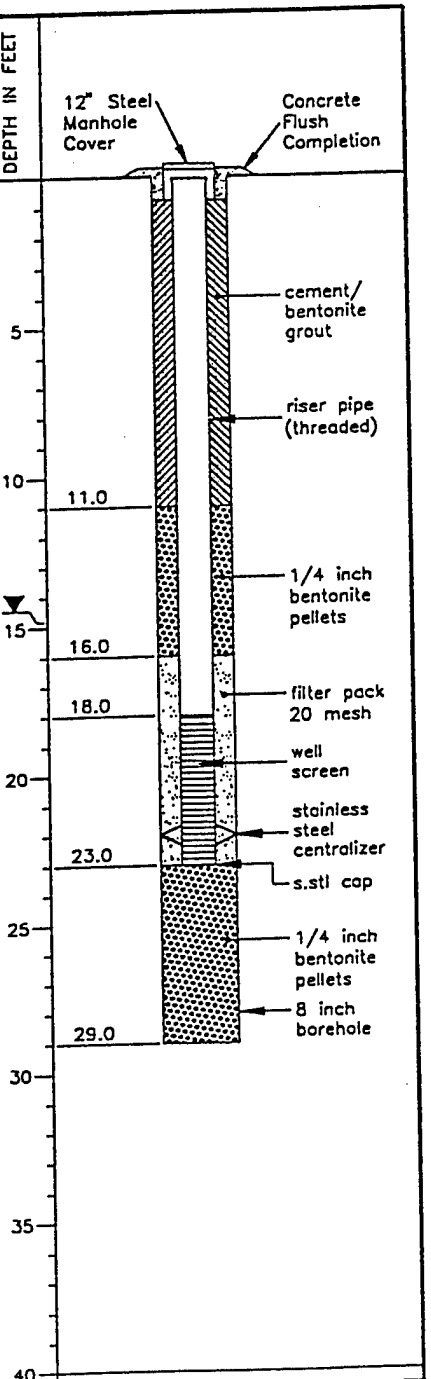
Sampling Method: 3"x5' CONTINUOUS SAMPLER

Notes: N 150386.113, E 2182035.358

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL
1. Riser Pipe-I.D.(in.): 2
   Depth(ft.): 18 Type:S.Steel
   Centralizers-Type:
   Depths(ft.):
2. Screen Dia.(in.): 2
   Type: S.Steel Millslotted
   Depth Interval(ft.): 18-23
   Slot Size(in.): .010
   Centralizers-Type: S.Steel
   Depths(ft.): 22
3. Filter Pack Type: Silica Sand
   Depth Interval(ft.): 16-23
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 10 20 30 40	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
SILTY CLAY - slightly plastic; <10% very fine grained sand; stiff; slightly moist; dark brown (7.5YR-3/4)			42 / 42		cl		0
- <5% to 10% very fine grained sand; dark red (2.5YR-4/8); gradational contact			60 / 60				5
- nonplastic; hard; dry							
SANDY SILTY CLAY - nonplastic; 10% to 20% fine grained sand; hard; dry; dark red (2.5YR-4/8); gradational contact			60 / 60		cl		10
SAND - very fine grained; compact; dry; pale yellow (2.5YR-8/2); sharp contact					sp		11.0
SILTY SAND - 40% clay and silt; 50% to 60% fine to very fine grained sand; firm; dry; dark red (2.5YR-4/8); sharp contact			60 / 48		sm		15
- 60% fine to medium grained sand; slightly moist; gradational contact							16.0
- alternating layers of siltstone and silty sand at 15'							18.0
- moist							20
- drill without sampling due to auger refusal			48				23.0
							25
							29.0
TOTAL DEPTH = 29.0 FEET							30
							35
							40



DRAFT BY	RPS 12/2/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A33 Sheet 1 of 1

Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-64B

DRILLING AND SAMPLING INFORMATION

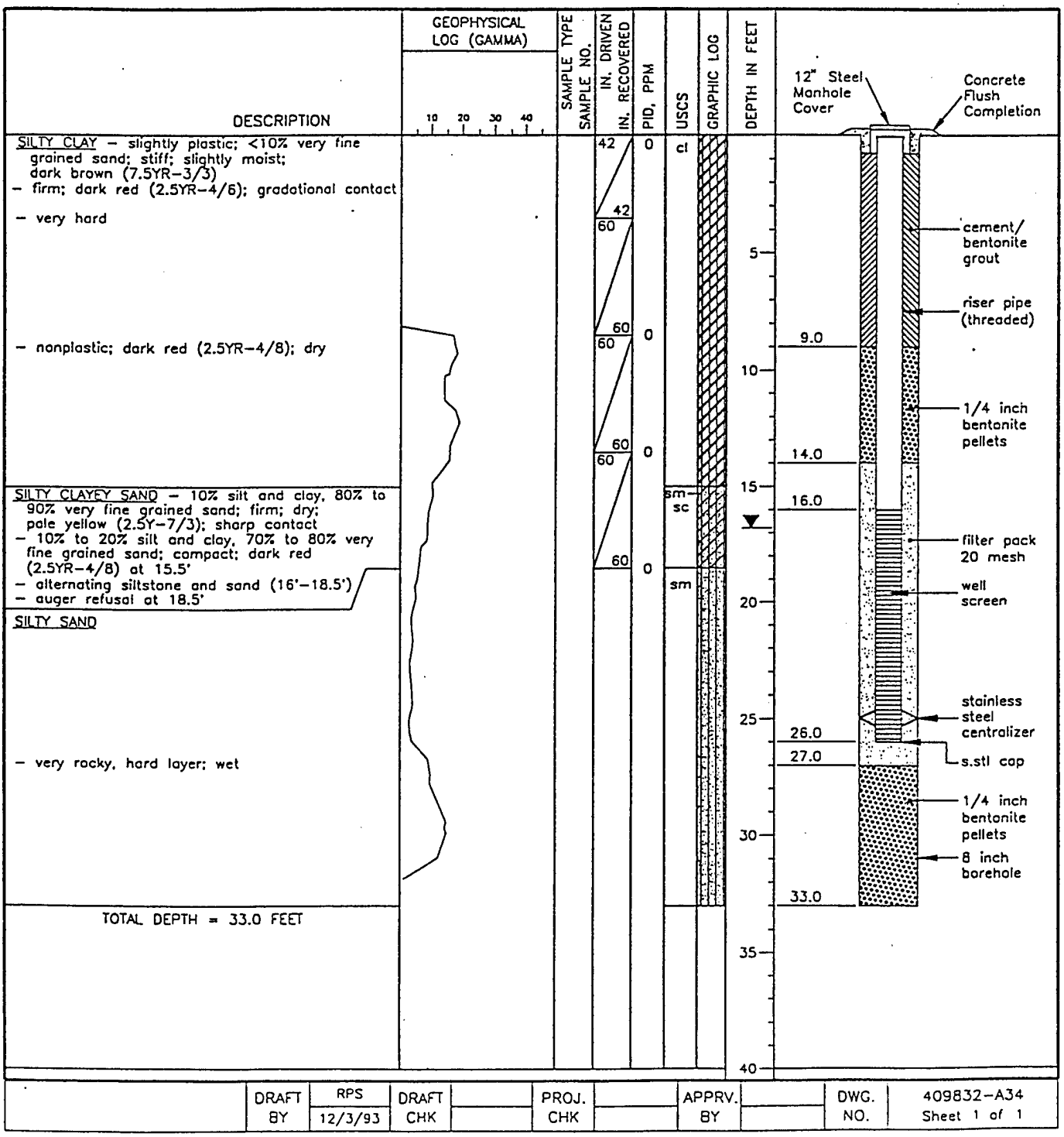
Boring Location: NORTHEAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT): 1245.586
TOTAL DEPTH(FT.): 33.0
Logged By: K. KIRSCHENMANN
Date Started: 11/9/93
Drilled By: P. GUERREIN GEOTECHNOLOGY, INC.
Date Completed: 11/9/93
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

Sampling Method: 3"x5' CONTINUOUS SAMPLER

Notes: N 150467.403, E 2181967.757

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL
1. Riser Pipe-I.D.(in.): 2
   Depth(ft.): 16 Type:S.Steel
   Centralizers-Type:
   Depths(ft.):
2. Screen Dia.(in.): 2
   Type: S.Steel Millslotted
   Depth Interval(ft.): 16-26
   Slot Size(in.): .010
   Centralizers-Type: S.Steel
   Depths(ft.): 25
3. Filter Pack Type: Silica Sand
   Depth Interval(ft.): 14-27
   Conc. Pad Size: 4'x4'x6"



DRAFT BY	RPS	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A34
	12/3/93								Sheet 1 of 1

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65B

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT): 1250.812
TOTAL DEPTH(FT.): 49.0
Logged By: K. KIRSCHENMANN
Date Started: 11/5/93
Drilled By: P. GUERREIN
Date Completed: 11/5/93
GEOTECHNOLOGY. INC.
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

Sampling Method: 3"x5' CONTINUOUS SAMPLER

Notes: NO ANALYTICAL SAMPLES TAKEN
N 150712.875, E 2182183.201

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL
1. Riser Pipe-I.D.(in.): 2
Depth(ft.): 37 Type:S.Steel
Centralizers-Type: S.Steel
Depths(ft.): 25
2. Screen Dia.(in.): 2
Type: S.Steel Millslotted
Depth Interval(ft.): 37-47
Slot Size(in.): .010
Centralizers-Type: S.Steel
Depths(ft.): 46
3. Filter Pack Type: Silica Sand
Depth Interval(ft.): 35-49
Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 10 20 30 40	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
SILTY CLAY - slightly plastic; <5% very fine grained sand; stiff; slightly moist; dark brown (7.5YR-3/4); organic rich			42		cl		
SILTY SANDY CLAY - slightly plastic; 10% fine grained sand; hard; slightly moist; dark red (2.5YR-4/6); gradational contact - black nodules			42 / 60		cl		5
SILTY CLAY - nonplastic; hard; dry; dark red (2.5YR-4/8); gradational contact			60		cl		
			60				10
			60				
			60				
			60				15
			60		sw		
SAND - very fine to fine grained; compact; slightly moist; pale yellow (2.5Y-8/2); sharp contact			60		cl		20
SILTY CLAY - nonplastic; very hard; dry; dark red (2.5YR-4/6); sharp contact			60		sm		
SILTY SAND - 30% silt and clay, 70% fine grained sand; compact; dry; dark red (2.5YR-4/6); gradational contact			60		cl		25
SANDY SILTY CLAY - nonplastic; 10% to 25% very fine to fine grained sand; stiff; dry; dark red (2.5YR-4/6); sharp contact			60				
SILTY SAND - 50% silt and clay, 50% fine grained sand; firm; dry; dark red (2.5YR-4/6); gradational contact			60		sm		30
			60				
			18 / 18				35
							40

12" Steel Manhole Cover
Concrete Flush Completion
riser pipe (threaded)
cement/ bentonite grout
8 inch borehole
stainless steel centralizer
33.0
35.0
37.0
1/4 inch bentonite pellets
filter pack 20 mesh
well screen

DRAFT BY	RPS 12/9/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A35 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65B

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA
SURFACE ELEV.(FT): 1250.812
TOTAL DEPTH(FT.): 49.0
Logged By: K. KIRSCHENMANN
Date Started: 11/5/93
Drilled By: P. GUERREIN
GEOTECHNOLOGY. INC.
Date Completed: 11/5/93
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER

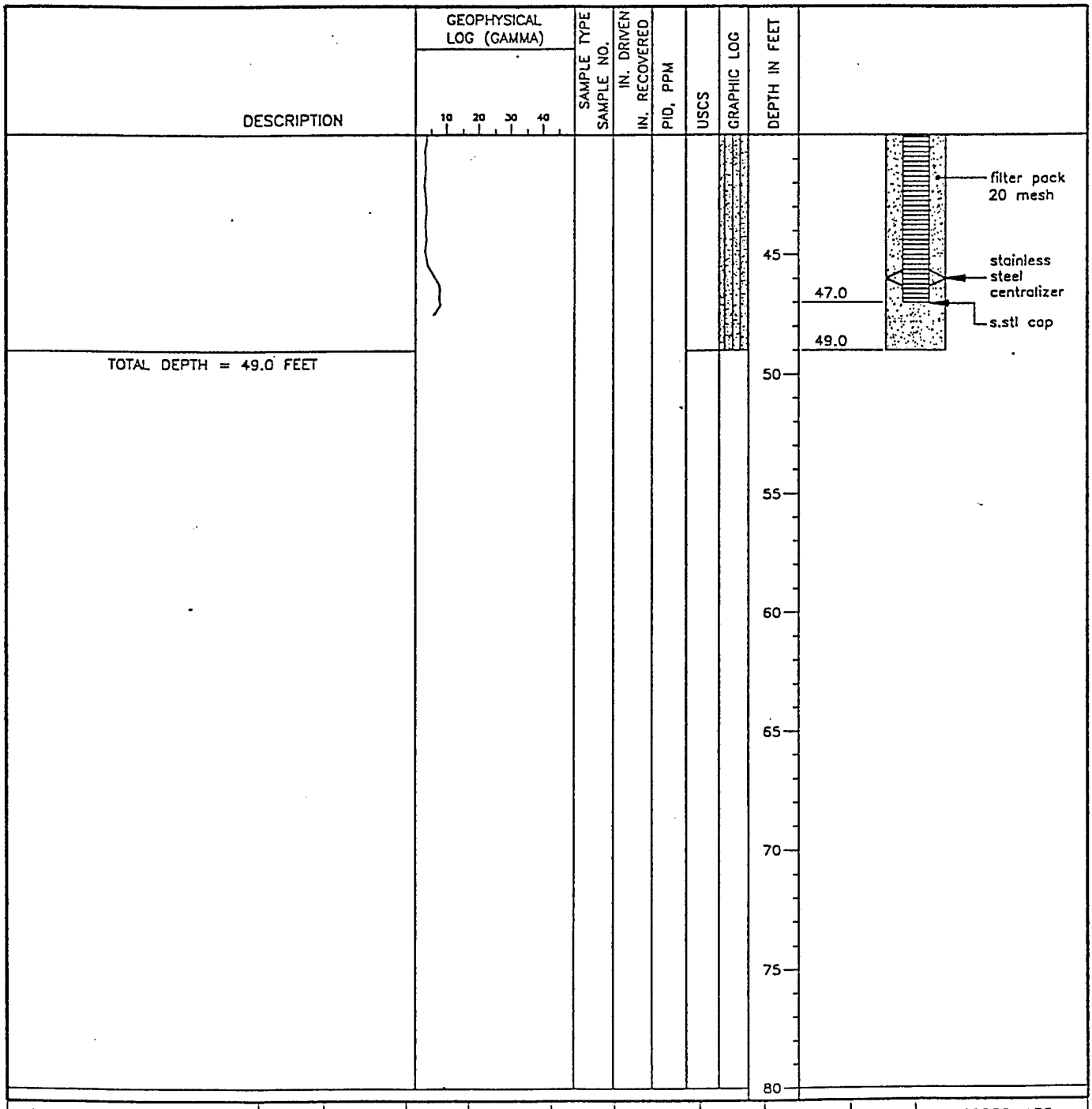
Sampling Method: 3"x5' CONTINUOUS SAMPLER

Notes: NO ANALYTICAL SAMPLES TAKEN
N 150712.875, E 2182183.201

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL

1. Riser Pipe-I.D.(in.): 2
   Depth(ft.): 37 Type:S.Steel
   Centralizers-Type: S.Steel
   Depths(ft.): 25
2. Screen Dia.(in.): 2
   Type: S.Steel Millslotted
   Depth Interval(ft.): 37-47
   Slot Size(in.): .010
   Centralizers-Type: S.Steel
   Depths(ft.): 46
3. Filter Pack Type: Silica Sand
   Depth Interval(ft.): 35-49
   Conc. Pad Size: 4'x4'x6"



	DRAFT BY	RPS 12/9/93	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A35 Sheet 2 of 2

SITE FTA2 BORING NUMBER 2-167B

PROJECT *TAFB Phase II RFI App. I Sites, Fire Train. Area 2*
DATE DRILLED *07 August 1995 (Drilled as MWI)*
DRILLING METHOD *6" Hollow-stem Augers; 5' Continuous Sampler*
DRILLING COMPANY *Associated Environmental Industries*
ELEVATION *1247.70 Feet msl, Ground Surface; 1,250.74 Feet msl, TOC*
TOTAL DEPTH *32 Feet*
DEPTH TO WATER *14.8 Feet (open hole)*
GEOLOGIST *R. Osgood*
X,Y COORD. *2182408.352, 150539.8117*

SAMPLE: Analytical	SAMPLE: Geotechnical	SAMPLE: Interval	SAMPLE: Recovery	DEPTH feet	PID (ppm)	MUNSELL	LITHOLOGY	GRAPHIC LOG	DESCRIPTION AND REMARKS
X							OL		Topsoil, silty, w/vegetation and subrounded, pebble-sized clasts.
					ND	2.5YR4/4			Clayey silt, reddisg brown, soft, slightly moist, low plasticity, some black organic speckling throughout.
					ND	2.5YR4/6			At 4 ft, grades to silt, red, firm, dry, a few small subrounded pebbles; light grey marbling at base.
				5			ML CL		Clayey silt, reddish brown, firm, dry, some black organic speckling, and trace of light grey marbling (mineralization?).
X					ND				
					ND	2.5YR4/4			
				10					Clayey silt, red, firm, dry, massive (homogeneous).
X					ND	2.5YR4/6			
									No Recovery
X				15			ML		Silt, light grey, stiff, moist for top 1", Interval grades from silt to sandy silt, red, moist, soft, massive. At 12 ft, moderately cemented sandstone clasts appx. 1" in diameter.
					ND	2.5YR4/6			
					ND				
									No Recovery
X				20			ML		Sandy silt (appx 75% silt), red, soft, very moist, few 1" moderately cemented sandstone fragments; lens of fine sand appx. 1" thick at 21.5 ft.
					ND	2.5YR4/6			
					ND				
									No Recovery
				25			SM		

JOB NUMBER: Tetra Tech, Inc. TC-7107

SITE FTA2 BORING NUMBER 2-167B

PROJECT *TAFB Phase II RFI App. I Sites, Fire Train. Area 2*
DATE DRILLED *07 August 1995 (Drilled as MW1)*
DRILLING METHOD *6" Hollow-stem Augers; 5' Continuous Sampler*
DRILLING COMPANY *Associated Environmental Industries*
ELEVATION *1247.70 Feet msl, Ground Surface; 1,250.74 Feet msl, TOC*
TOTAL DEPTH *32 Feet*
DEPTH TO WATER *14.8 Feet (open hole)*
GEOLOGIST *R. Osgood*
X,Y COORD. *2182408.352, 150539.8117*

SAMPLE: Analytical	SAMPLE: Geotechnical	SAMPLE: Interval	SAMPLE: Recovery	DEPTH feet	PID (ppm)	MUNSELL	LITHOLOGY	GRAPHIC LOG	DESCRIPTION AND REMARKS
X					ND	2.5YR4/4	SM		Silty sand (60%), reddish brown, soft, wet, very fine sand laminated throughout.
									No Recovery
X				30			SP		Sand, red, fine grained, poorly graded, wet, homogeneous color and massive texture.
									Completed as monitoring well 2-187 on 07 August 1995.
				35					
				40					
				45					
				50					

Tetra Tech Monitoring Well Construction Log

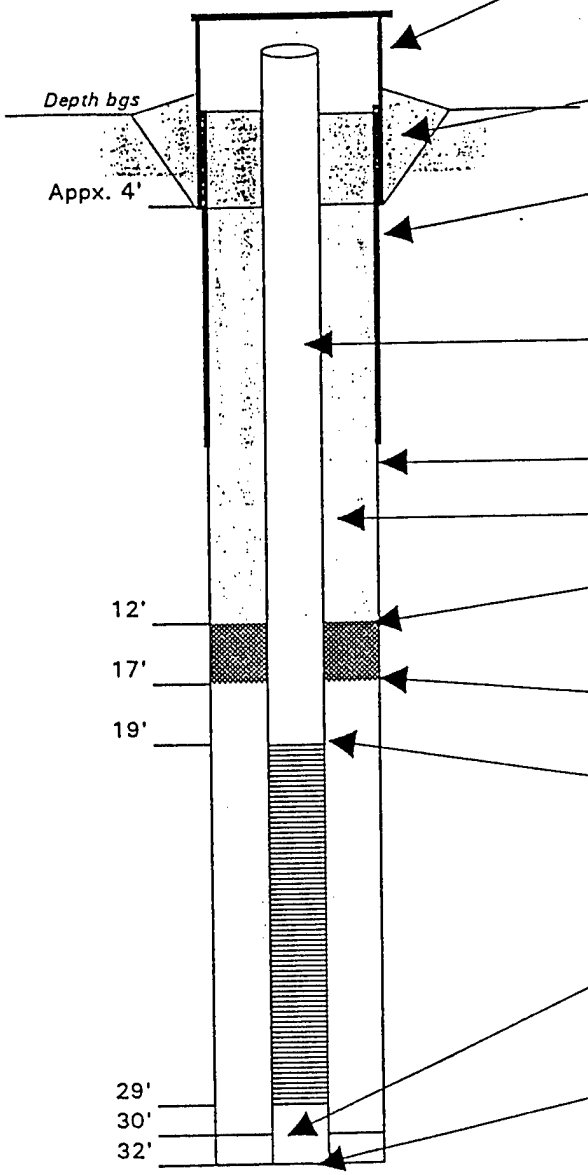
Project/Site Name: TAFB Phase II RFI, FTA2 Well No: 2-167 B Date: 08 Aug 95

Project No: 7107 Drilling Method: 8-3/4" Hollow-stem Augers

Geologist: R. Osgood

Elevation of Casing: 1250.7 Ft msl Drilling Contractor: Associated Environmental Industries

Surface Elevation: 1247.7 Ft msl Date Well Construction Completed: 08 Aug 95



Type of Protective Casing: Steel
Dimensions: 6"x6"x60"
Height of Stickup: 2.8 ft
Weep Hole: Y/N Cap Vent: Y/N Locking Cap: Y/N

Type of Surface Grout: Concrete to appx. 4 ft bgs.

Surface Casing(s) Diameter/Type/Length:
Not Applicable
Surface Casing Grouting Information:
Not Applicable

Riser Length Above Screen: 21.8 ft
Riser Inner Diameter/Type: 4" diameter
Schedule 304 Stainless Steel

Boring Diameter(s): 8-3/4"

Type of Annular Seal: Portland Type I, 2% Bentonite

Depth to Bentonite Seal: 12 ft
Type of Bentonite: Medium Chips
Length of Seal: 5 ft

Depth to Top of Filter Pack: 17 ft
Type of Filter Pack: 10/20 Sand

Depth to Screen: 19 ft
Screen Length and Type: 10 ft, 4" diameter
Schedule 304 Stainless Steel
Slot Size: 0.010"
Screened Interval: 19 to 29 ft

Length of Sediment Sump: 3 ft
Diameter/Type of Sediment Sump:
4" diameter Sch. 304 Stainless Steel

Original Boring Depth: 32 ft
Top of Bentonite Plug: 30 ft
Type of Backfill: Bentonite Chips

Centralizers: At appx. 18 ft and 30 ft.

SITE FTA2 BORING NUMBER 2-168B

PROJECT *TAFB Phase II RFI App. I Sites, Fire Train. Area 2*
DATE DRILLED *08 August 1995 (Drilled as MW2)*
DRILLING METHOD *6" Hollow-stem Augers; 5' Continuous Sampler*
DRILLING COMPANY *Associated Environmental Industries*
ELEVATION *1240.10 Feet msl, Ground Surface; 1,243.00 Feet msl, TOC*
TOTAL DEPTH *25 Feet*
DEPTH TO WATER *10.6 Feet bgs*
GEOLOGIST *R. Osgood*
X,Y COORD. *2181976.691, 150248.99500*

SAMPLE: Analytical	SAMPLE: Geotechnical	SAMPLE: Interval	SAMPLE: Recovery	DEPTH feet	PID (ppm)	MUNSELL	LITHOLOGY	GRAPHIC LOG	DESCRIPTION AND REMARKS
X				0	ND	2.5YR3/4			Topsoil, clayey silt, dark reddish brown, soft, slightly moist, root hairs extend to 1.5 ft. Clayey silt stiffens to base of core with trace of organic speckling from 2 to 5 ft.
					15				
					ND				
				5			ML CL		Clayey silt, reddish brown, soft to firm, slightly moist, massive, some black organic speckling and small nodules. Form 7 to 10 ft, some subangular pebbles and increase in the amount of black organics.
X					1.0	2.5YR4/4			
					ND				
				10	ND				Clayey silt as above to 10.8 ft.
X					21	2.5YR4/4	ML		Sandy silt, red, soft, moist to saturated at 13 ft, thin bedding (laminated), black organics from 11.5 to 12 ft.
					4/6	2.5YR4/6			
				15					No Recovery
X					20	2.5YR4/6	SM		Silty sand, red, wet, laminated layers (2-5 mm). From 17 to 17.5 ft, dark black organic lens with small (<3 mm) nodules. Some black speckles of organic matter to 19 ft.
					3				
					1				
									No Recovery
X				20	21	2.5YR4/6	SM		Silty sand, red, wet, laminated (appx. 2 mm), trace of black organic speckling throughout.
									No Recovery
				25					

JOB NUMBER: Tetra Tech, Inc. TC-7107

Tetra Tech Monitoring Well Construction Log

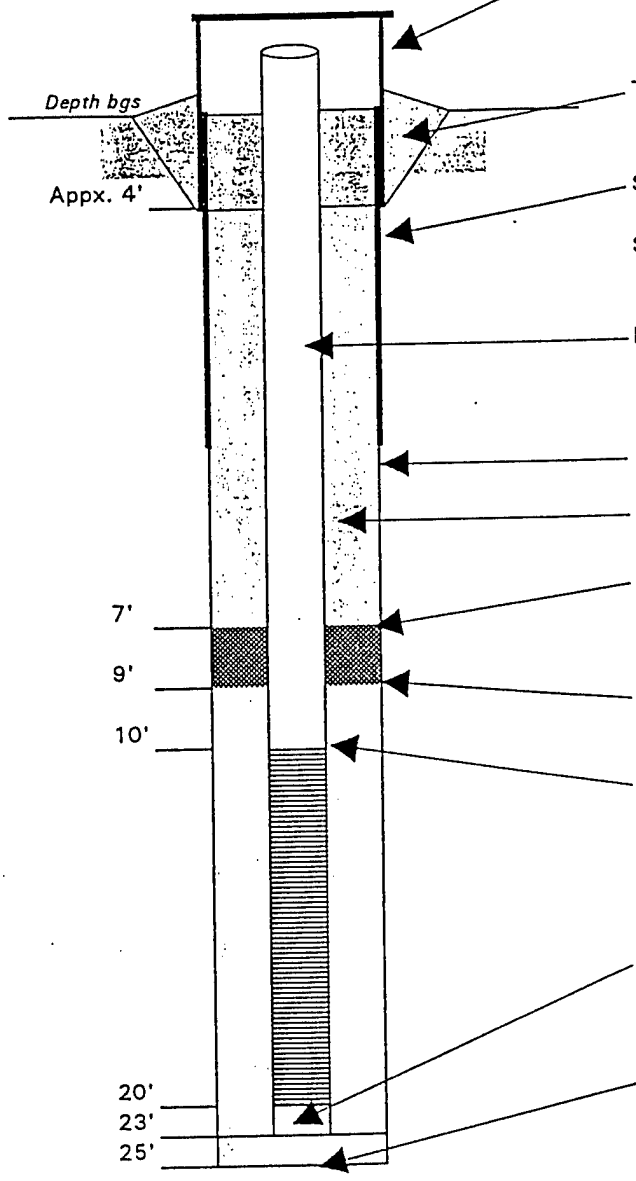
Project/Site Name: TAFB Phase II RFI, FTA2 Well No: 2-168 B Date: 08 Aug 95

Project No: 7107 Drilling Method: 8-3/4" Hollow-stem Augers

Geologist: R. Osgood

Elevation of Casing: 1243.0 Ft msl Drilling Contractor: Associated Environmental Industries

Surface Elevation: 1240.1 Ft msl Date Well Construction Completed: 08 Aug 95



Type of Protective Casing: Steel
Dimensions: 6"x6"x60"
Height of Stickup: 2.8 ft
Weep Hole: Y/N Cap Vent: Y/N Locking Cap: Y/N

Type of Surface Grout: Concrete to appx. 4 ft bgs

Surface Casing(s) Diameter/Type/Length:
Not Applicable
Surface Casing Grouting Information:
Not Applicable

Riser Length Above Screen: 12.8 ft
Riser Inner Diameter/Type: 4" diameter
Schedule 304 Stainless Steel

Boring Diameter(s): 8-3/4"

Type of Annular Seal: Portland Type I, 2% Bentonite

Depth to Bentonite Seal: 7 ft
Type of Bentonite: Medium Chips
Length of Seal: 2 ft

Depth to Top of Filter Pack: 9 ft
Type of Filter Pack: 10/20 Sand

Depth to Screen: 10 ft
Screen Length and Type: 10 ft, 4" diameter
Schedule 304 Stainless Steel
Slot Size: 0.010"
Screened Interval: 10 to 20 ft

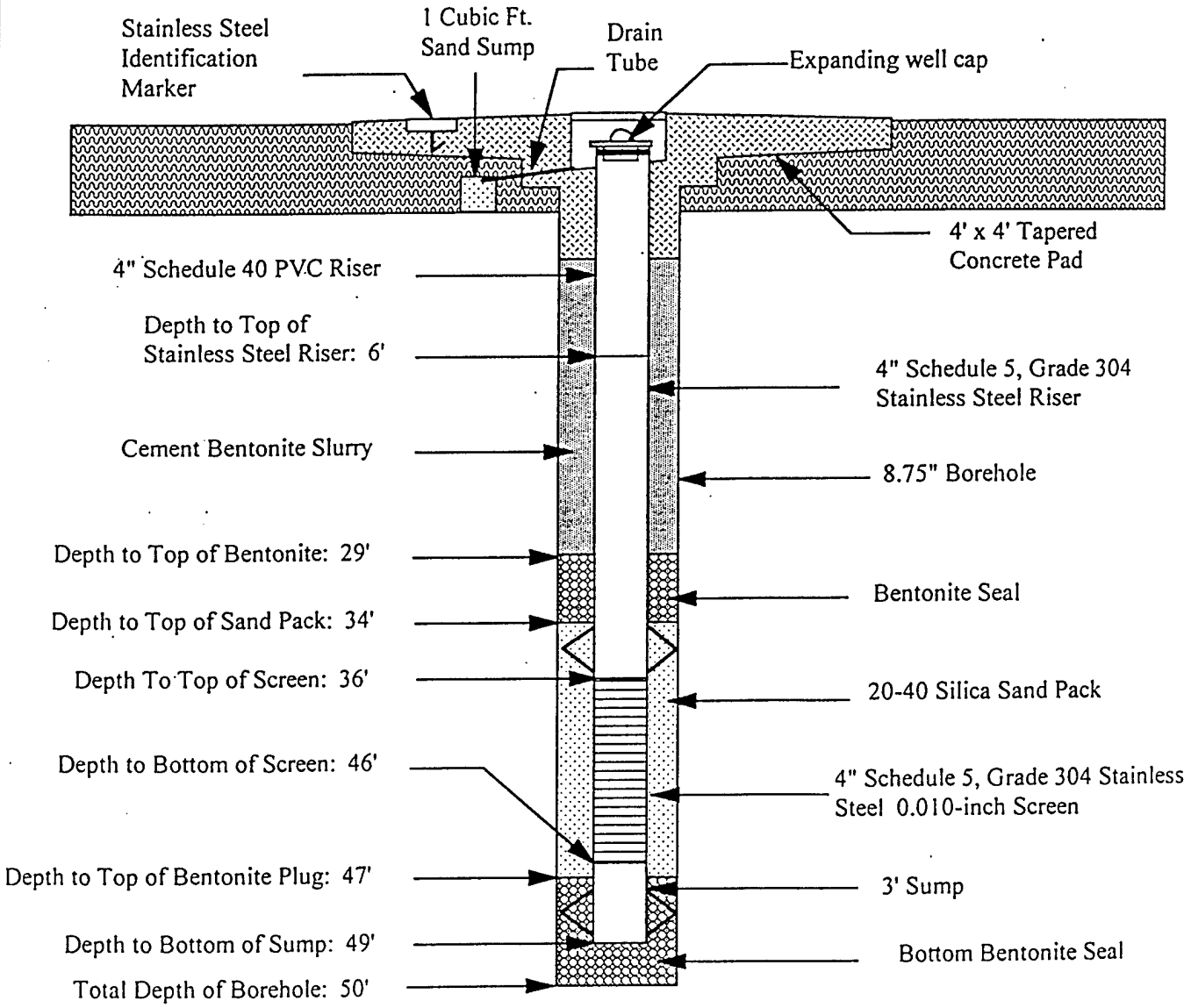
Length of Sediment Sump: 3 ft
Diameter/Type of Sediment Sump:
4" diameter Sch. 304 Stainless Steel

Original Boring Depth: 25 ft
Top of Bentonite Plug: 23 ft
Type of Backfill: Bentonite Chips

Centralizers: At appx. 9.5 ft and 21.5 ft

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-271B
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 08/08/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,252.41'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,252.13'
Project Geologist: Steve Kelly	Northing Coordinate: 151,494.42'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,182,196.43'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: NE/4 Section 22, T11N, R2W
Comments:	



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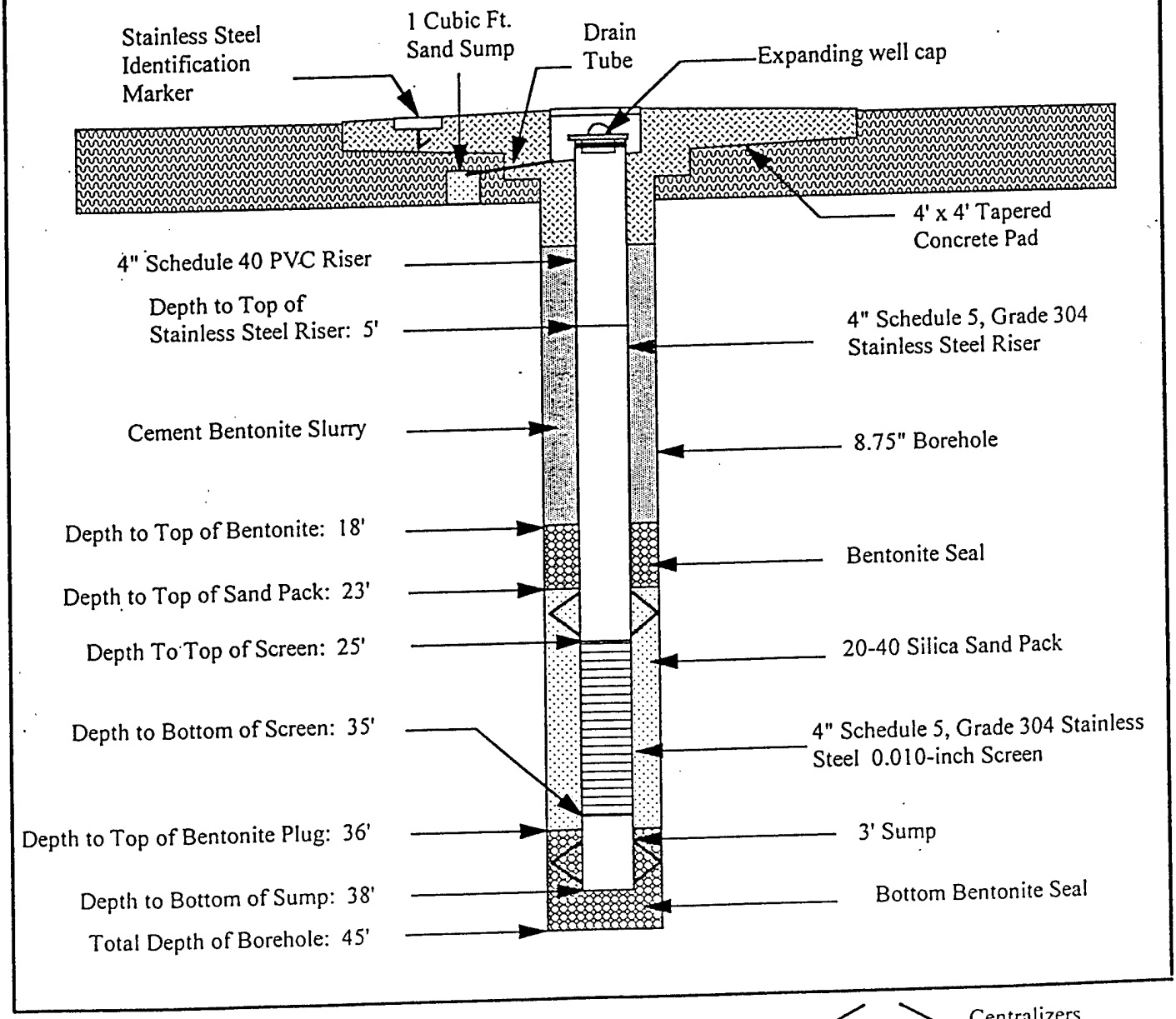
< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-272B**
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 08/09/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,249.38'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,248.91'
Project Geologist: Steve Kelly	Northing Coordinate: 150,784.70'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,181,581.74'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: SE/4 Section 22, T11N, R2W
Comments: Ground Level Elevation measured on identification plate rather than surveyor's pin.	



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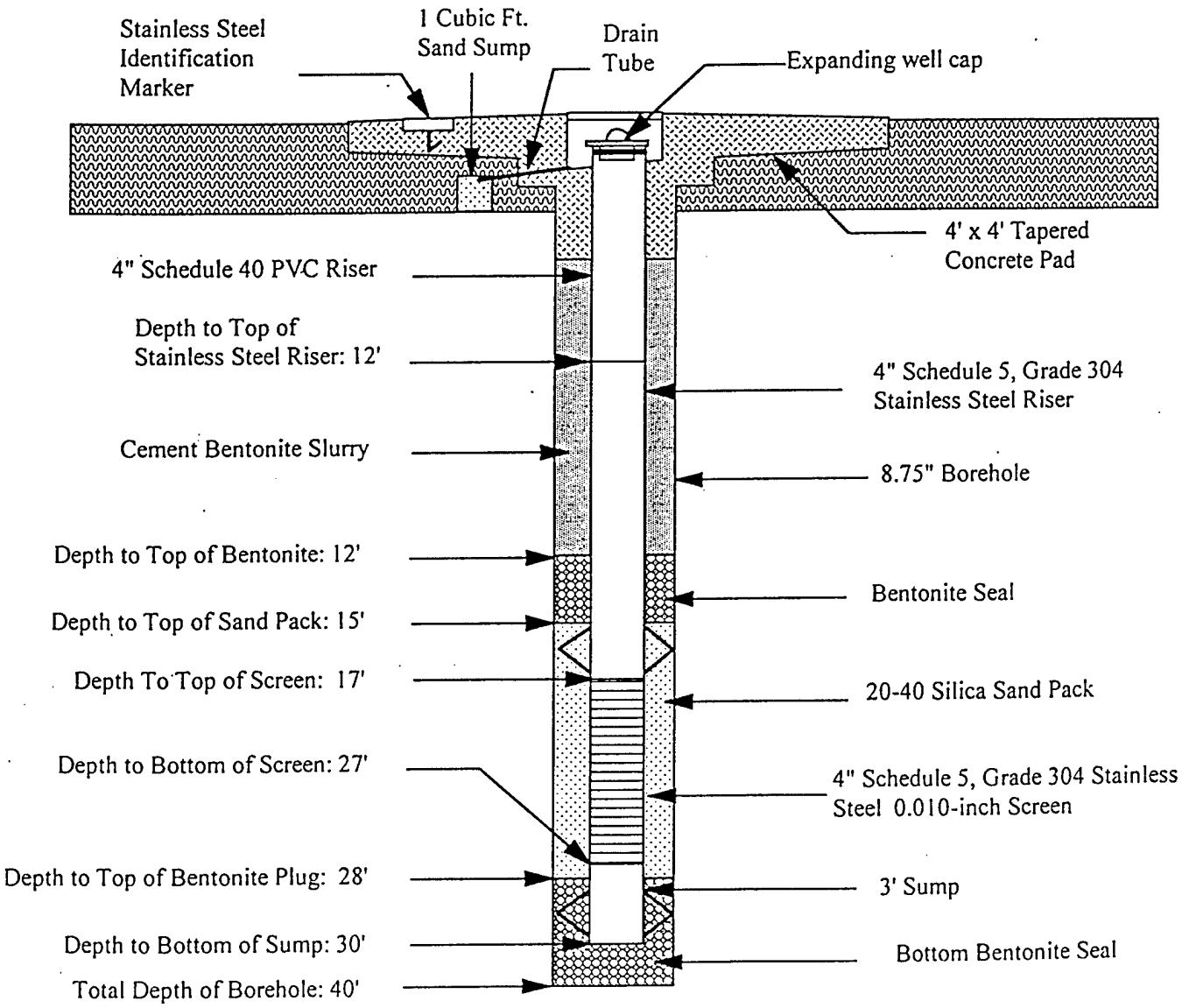
WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-273B**
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/18/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,238.92'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,238.42'
Project Geologist: Steve Kelly	Northing Coordinate: 150,351.11'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,181,576.36'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: SE/4 Section 22, T11N, R2W
Comments: Ground Level Elevation measured on identification plate rather than surveyor's pin. 3' thick top bentonite seal set.	



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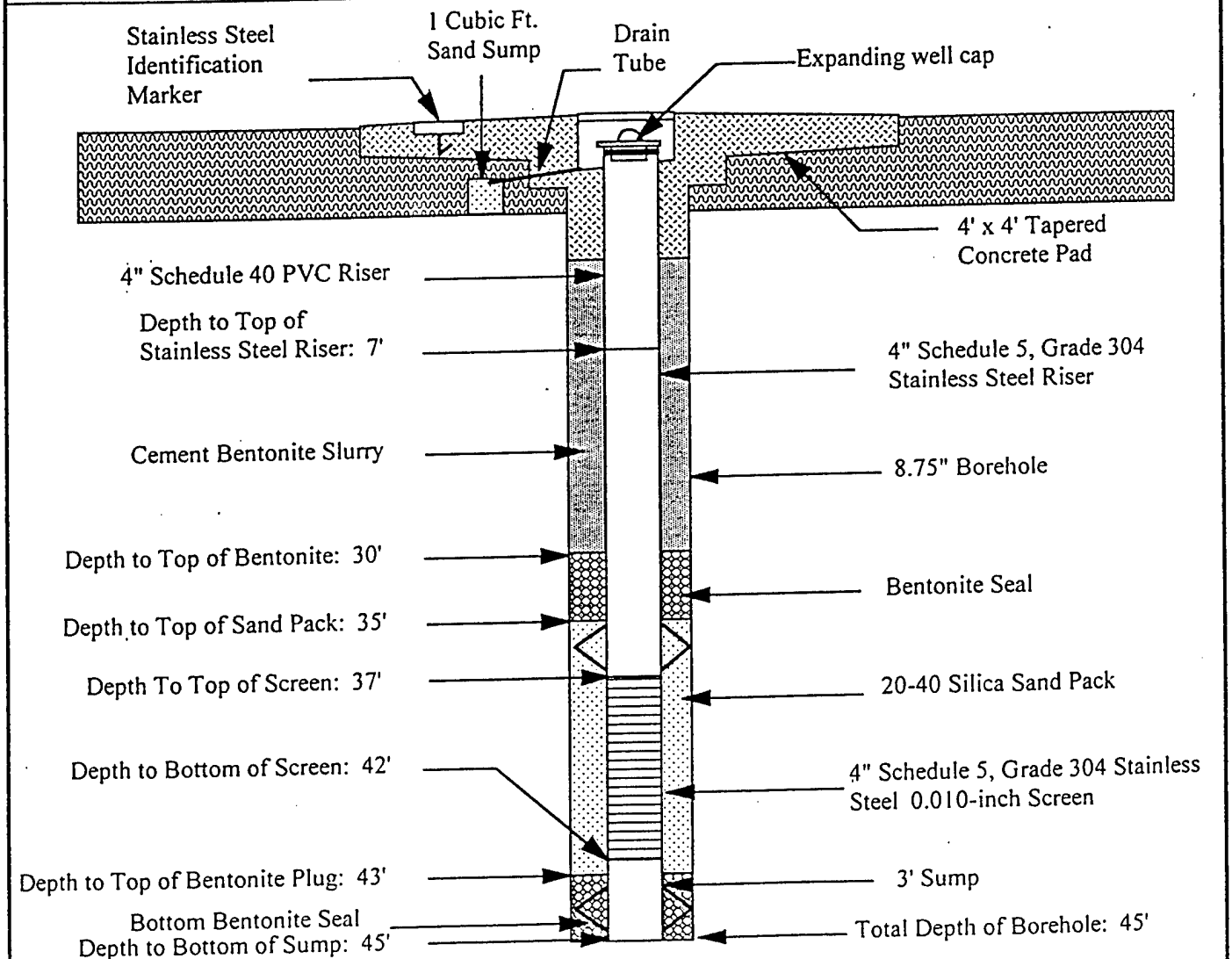
< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-274B**
Location: TAFB, Oklahoma	Site: FT22
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 07/25/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,248.77'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,248.32'
Project Geologist: Steve Kelly	Northing Coordinate: 151,126.23'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,181,625.92'
Drilling Method: Hollow Stem Auger	Permanent Monuments Used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: NE/4 Section 22 T11N, R2W
Comments: 5' long screen set. Well set at bottom of borehole. Ground Level Elevation measured on identification plate rather than surveyor's pin.	



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< > Centralizers

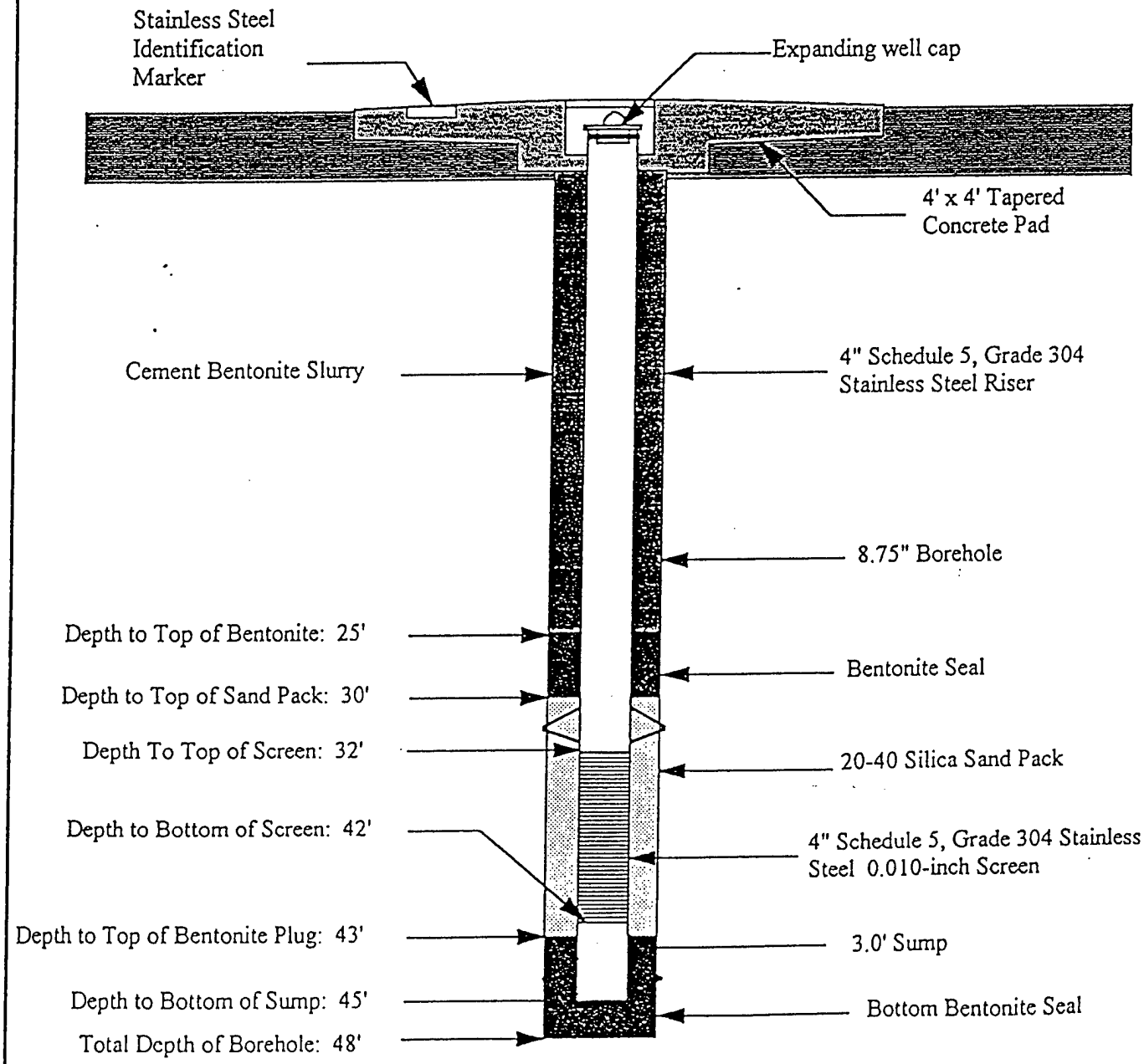
5/22/93

MW1-67B	RISER		0-34
	SCREEN		34-44
	SAND PACK		32-44
	BENTONITE		30-32
	GROUT		0-30
MW 1-67A	10"	SURFACE CASING	0-46
		RISER	0-75
		SCREEN	75-85
		SAND PACK	73-85
		BENTONITE	71-73
		GROUT	0-71
MW 1-67C	16"	SURFACE CASING	0-46
		10" CASING	0-90
		RISER	0-109
		SCREEN	109-119'
		SAND PACK	107-119
		BENTONITE	105-107
		GROUT	0-105

MW 1-67 WELL COMPLETION INFO.

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-142B**
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/19/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1242.45'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1242.09'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	



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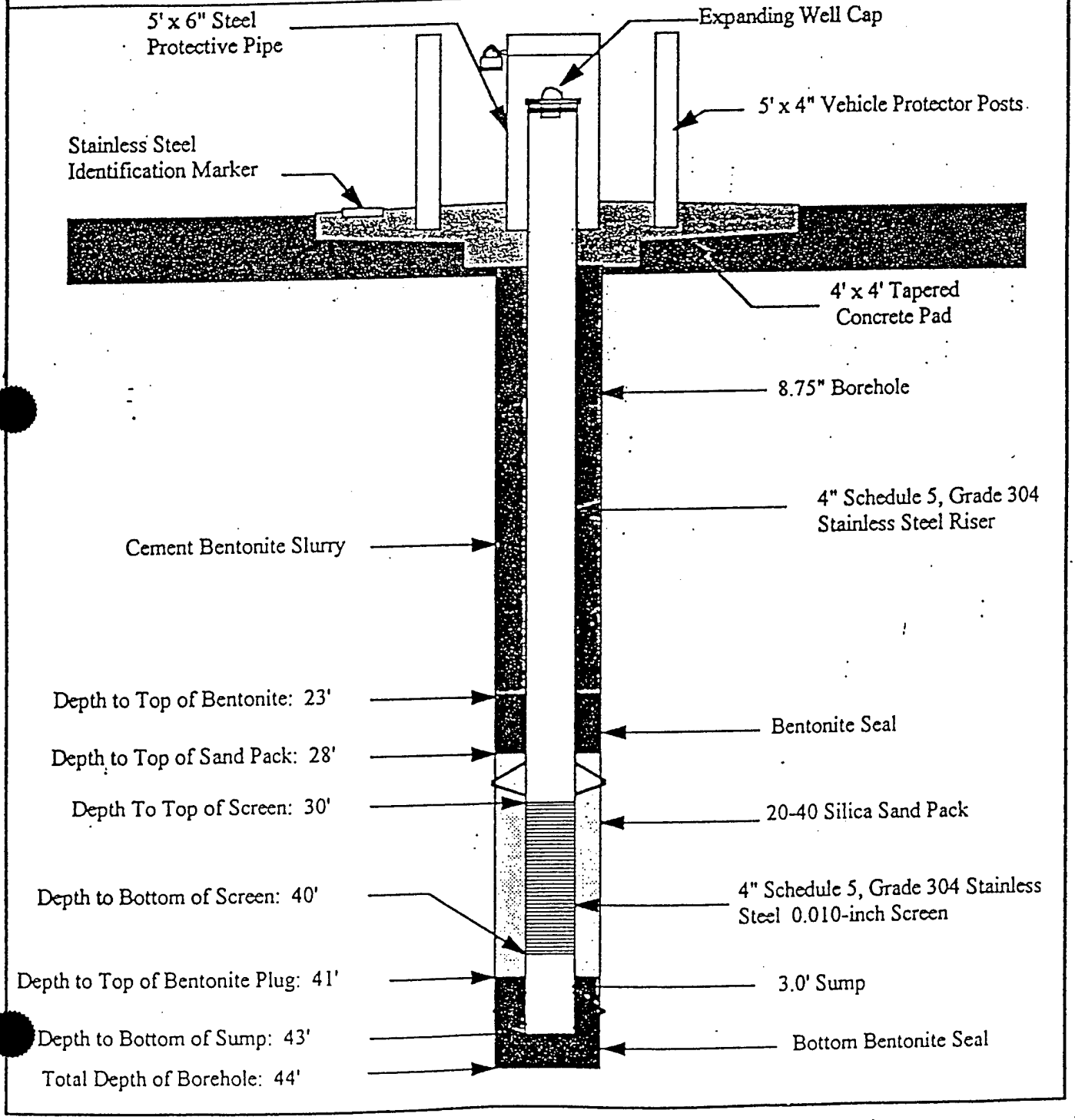
< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-112B
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 1/20/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1250.89'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1247.65'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser : 4" Schedule 40 PVC Casing.	



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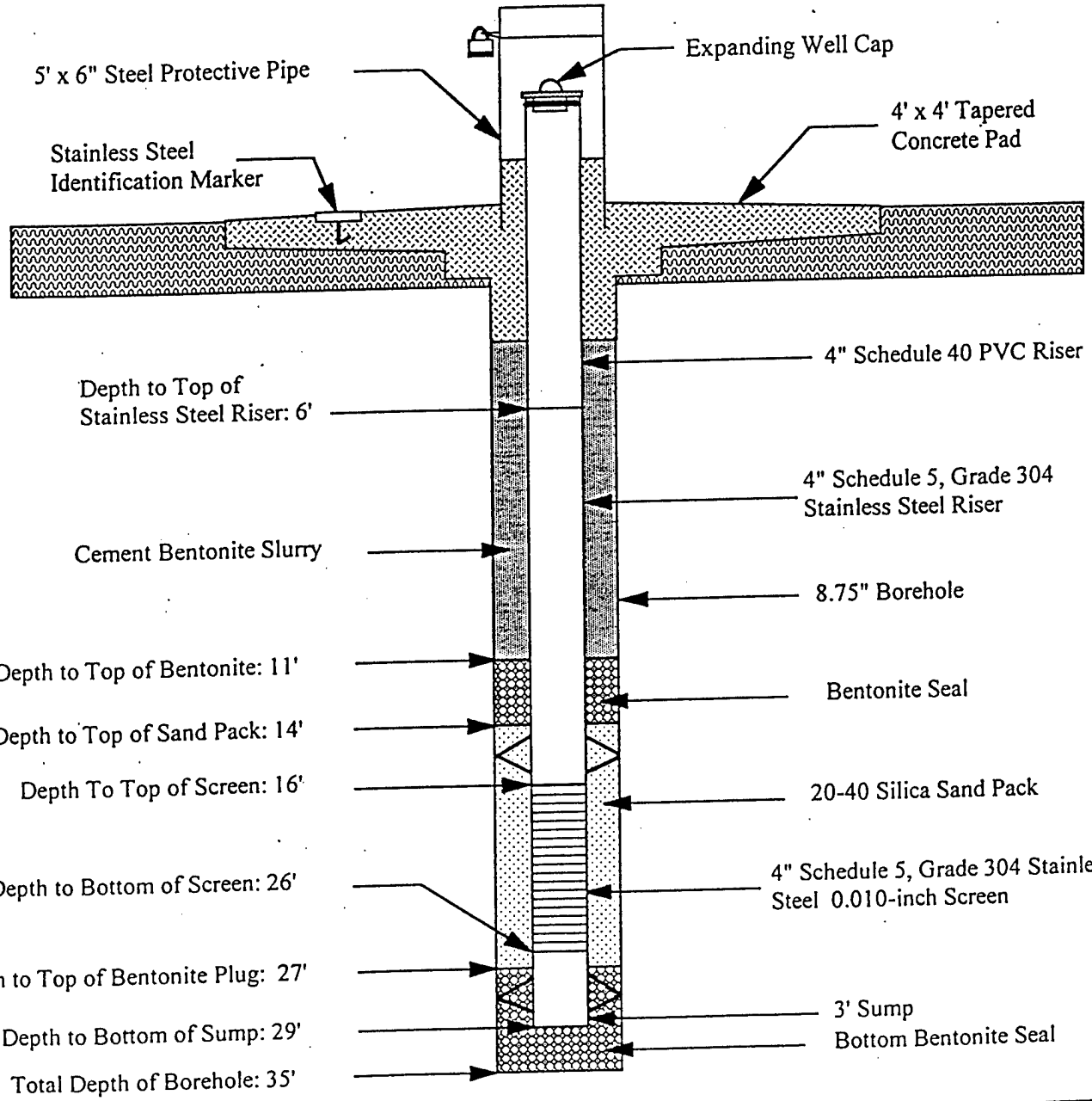
WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-301B**
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 06/17/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,263.19'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,265.71'
Project Geologist: Steve Kelly	Northing Coordinate: 150,500.39'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,176,072.65'
Drilling Method: Hollow Stem Auger	Permanent Monuments used in Survey: SE40, PR15
Dedicated Pump: 2-inch Grundfos	Legal Description: SW/4 Section 23, T11N, R2W
Comments: 3' thick top bentonite seal set..	



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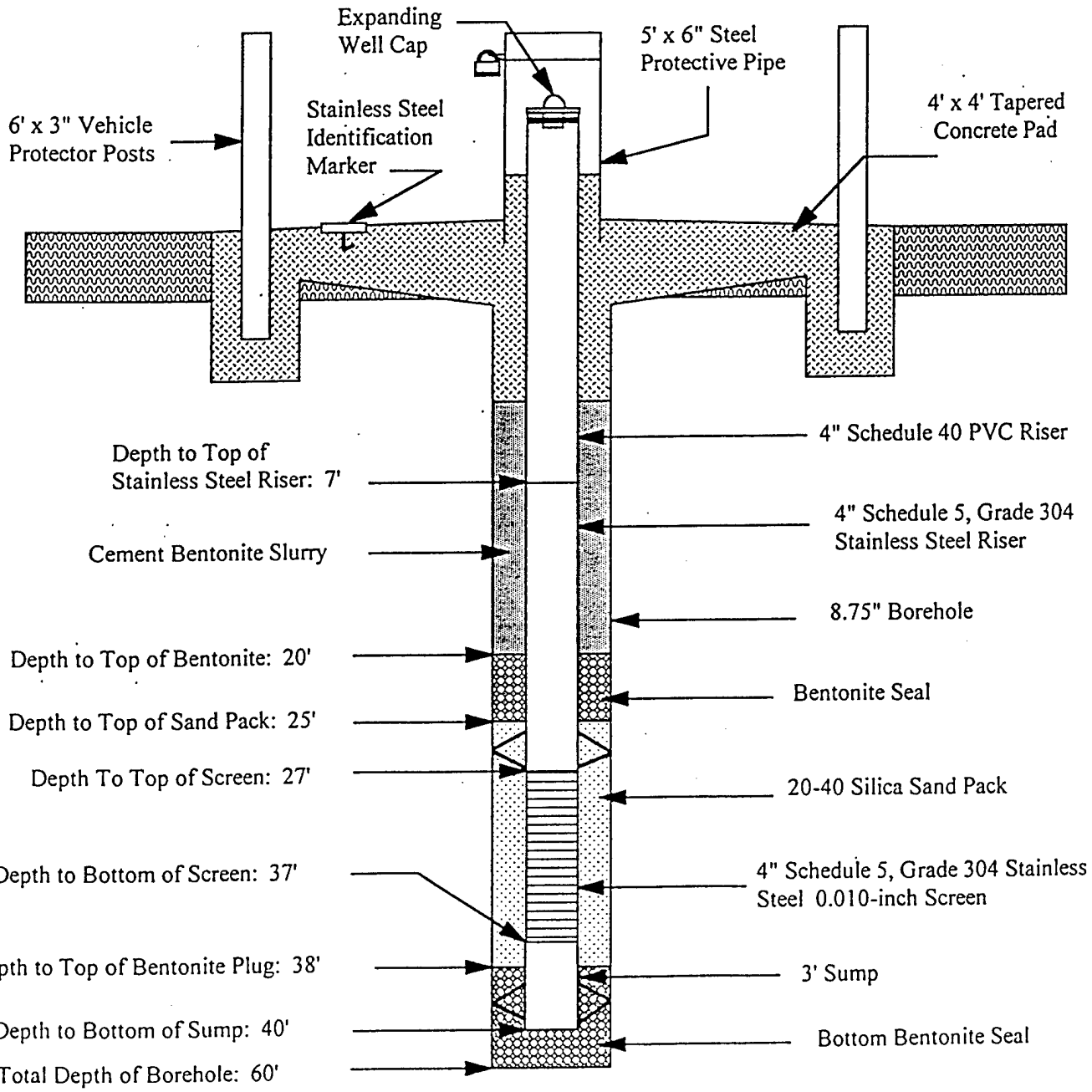
WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-302B**
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5017 (P&A #4)	Date 4-Inch Riser Set: 07/24/96
Contractor: Brown & Root Environmental	Ground Level Elevation (AMSL): 1,246.46'
Project Manager: David Parker	Top of Casing Elevation (AMSL): 1,249.15'
Project Geologist: Steve Kelly	Northing Coordinate: 149,491.80'
Drilling Contractor: Associated Environmental, Inc.	Easting Coordinate: 2,182,106.79'
Drilling Method: Hollow Stem Auger	Permanent Monuments used in Survey: SE32, SE28
Dedicated Pump: 2-inch Grundfos	Legal Description: SE/4 Section 22, T11N, R2W
Comments:	



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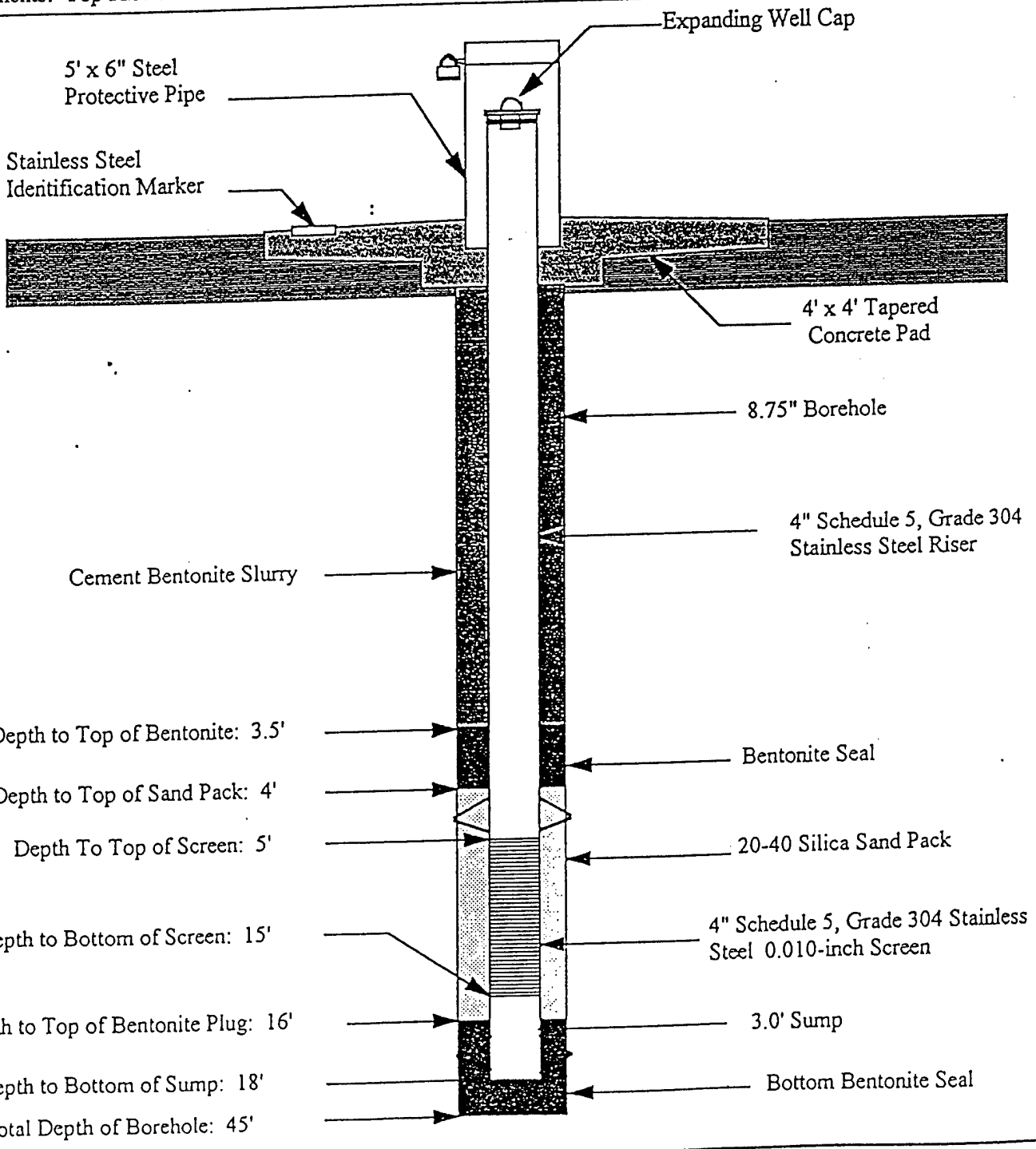
< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-160B**
Location: TAFB, Oklahoma	Site: ST07
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 06/05/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1250.99'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1253.56'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing. 6" thick top bentonite seal set. Sand set 1' above screen.	



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Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-62A

DRILLING AND SAMPLING INFORMATION

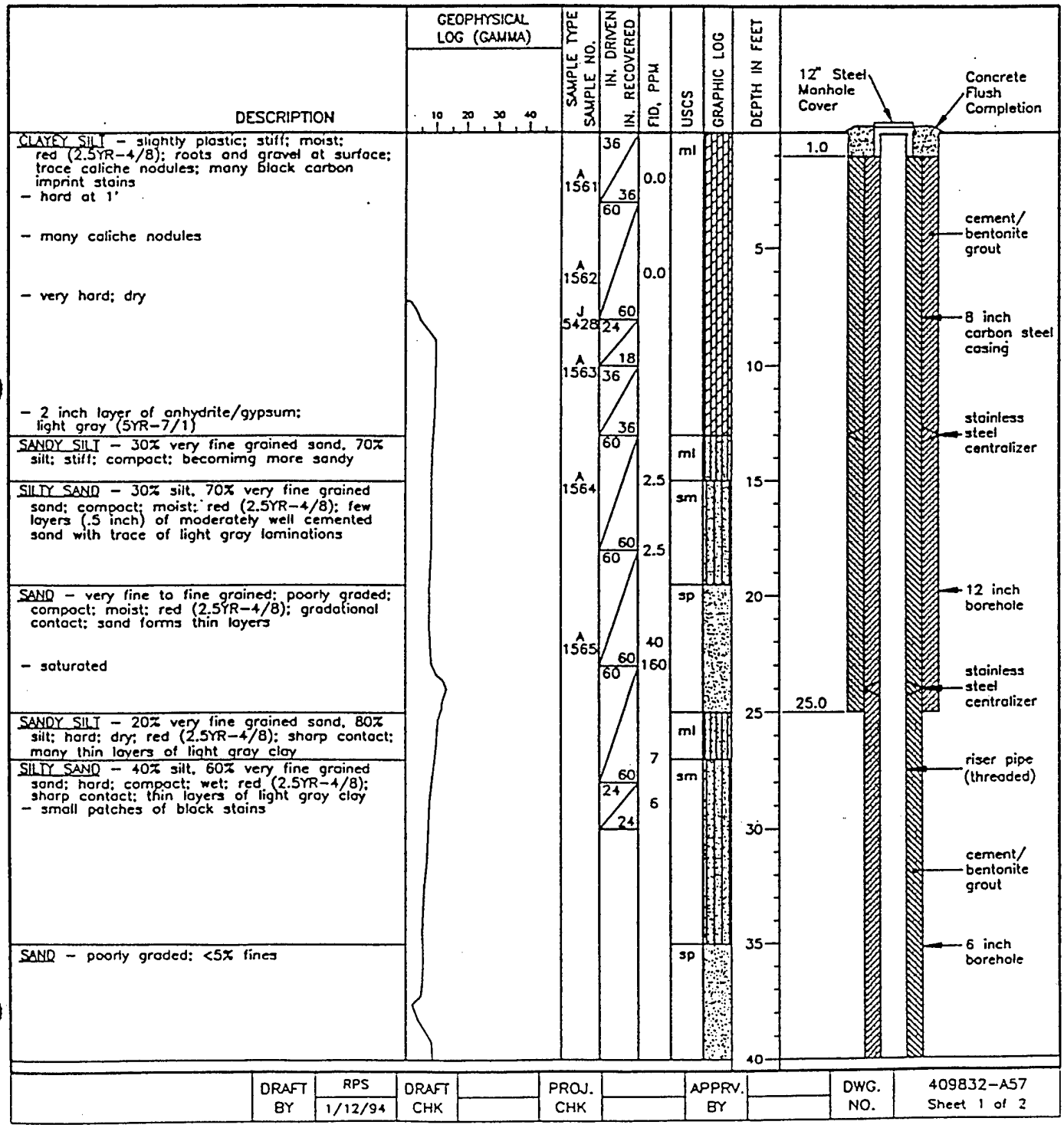
Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1246.213
TOTAL DEPTH(FT.): 70
Logged By: M. WILSON
Date Started: 11/22/93
Drilled By: D. MEYER
Date Completed: 11/29/93
GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER

Notes: N 150447.890, E 2182152.166

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL

1. Surf Casing-I.D.(in.): 8 — Depth(ft.): 25 — Type: Carbon Steel
   Centralizers-Type: S.Steel — Depths(ft.): 13
2. Riser Pipe-I.D.(in.): 2 — Depth(ft.): 53.8 — Type: S.Steel
   Centralizers-Type: S.Steel — Depths(ft.): 24, 53
3. Screen Dia.(in.): 2 — Type: S.Steel Wire Wound
   Depth Interval(ft.): 53.8-63.7 — Slot Size(in.): .010
   Centralizers-Type: — Depths(ft.):
4. Filter Pack Type: Silica Sand — Depth Interval(ft.): 52.0-65.0
   Conc. Pad Size: 4'x4'x6"



DRAFT BY	RPS 1/12/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A57 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-62A

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1246.213
TOTAL DEPTH(FT.): 70
Logged By: M. WILSON
Date Started: 11/22/93
Drilled By: D. MEYER
Date Completed: 11/29/93
GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER

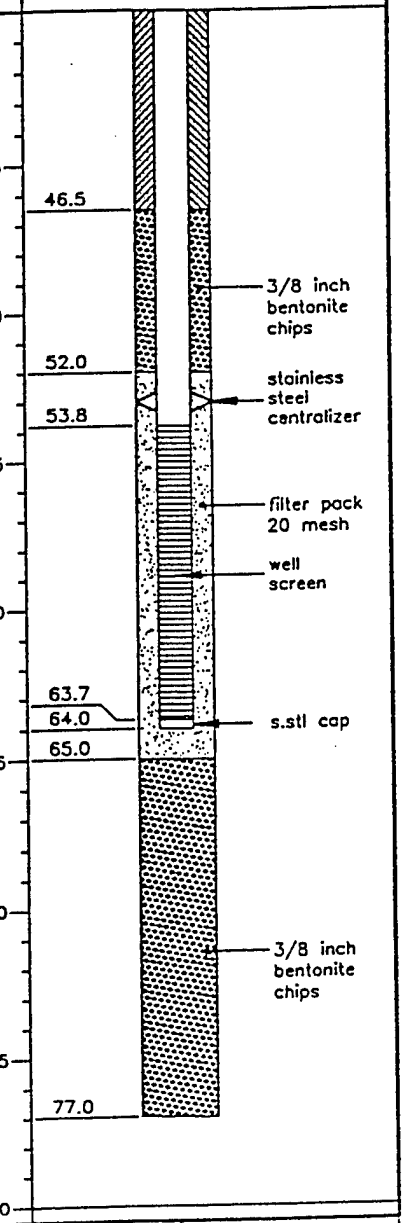
Notes: N 150447.890, E 2182152.166

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL

1. Surf Casing-I.D.(in.): 8 — Depth(ft.): 25 Type: Carbon Steel
   Centralizers-Type: S.Steel — Depths(ft.): 13
2. Riser Pipe-I.D.(in.): 2 — Depth(ft.): 53.8 Type: S.Steel
   Centralizers-Type: S.Steel — Depths(ft.): 24, 53
3. Screen Dia.(in.): 2 — Type: S.Steel Wire Wound
   Depth Interval(ft.): 53.8-63.7 — Slot Size(in.): .010
   Centralizers-Type: — Depths(ft.):
4. Filter Pack Type: Silica Sand — Depth Interval(ft.): 52.0-65.0
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 10 20 30 40	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	FID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
SILT - hard; dense					ml		45
SAND - thin layers of silt (46'-54'); clean sand (54'-63')					sp		50 55 60
SILT - hard; dense					ml		65
TOTAL DEPTH = 70.0 FEET							70 75 80



DRAFT BY	RPS 1/12/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A57 Sheet 2 of 2

Client: TINKER AFB
Project Location: TINKER AFB, OKLAHOMA
Project Name: TINKER 5001
Project Number: 409832

MONITORING WELL 2-63A

DRILLING AND SAMPLING INFORMATION

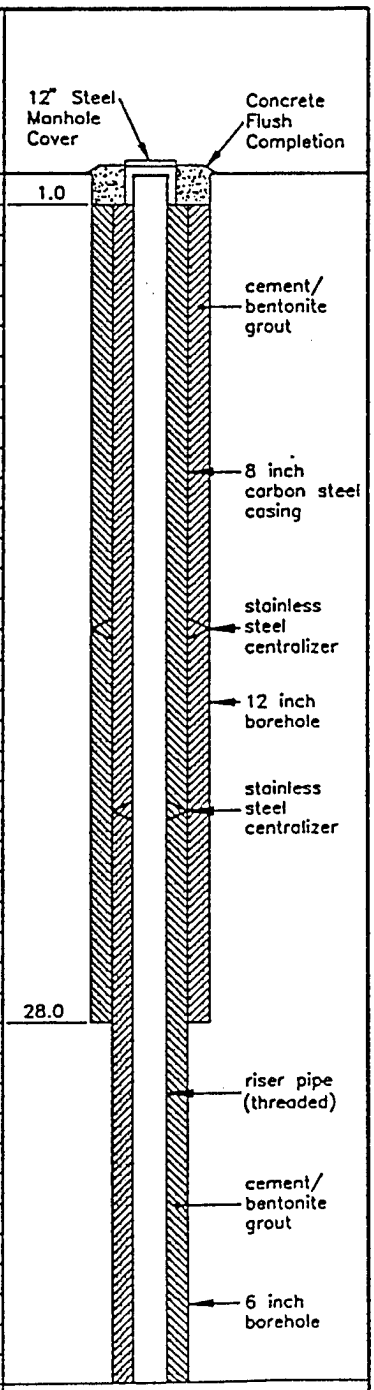
Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1243.387
TOTAL DEPTH(FT.): 67
Logged By: M. WILSON
Date Started: 11/19/93
Drilled By: D. MEYER
Date Completed: 11/23/93
GEOTECHNOLOGY. INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER AND 1-1/2"x2' SPLIT SPOON
Notes: N 150389.964, E 2182043.019

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL
1. Surf Casing-I.D.(in.): 8 — Depth(ft.): 28 — Type: Carbon Steel
   Centralizers-Type: S.Steel — Depths(ft.): 15
2. Riser Pipe-I.D.(in.): 2 — Depth(ft.): 53 — Type: S.Steel
   Centralizers-Type: S.Steel — Depths(ft.): 21, 51
3. Screen Dia.(in.): 2 — Type: S.Steel Wire Wound
   Depth Interval(ft.): 53.0-63.0 — Slot Size(in.): .010
   Centralizers-Type: — Depths(ft.):
4. Filter Pack Type: Silica Sand — Depth Interval(ft.): 51-64
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	FID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
CLAY - slightly plastic; firm; moist; dark grayish brown (10YR-3/2); black carbon imprints; small rootlets; small caliche nodules; gravel fill (0.0'-0.5') - gradational contact	A 1555	36 / 36	0.0	cl		0
CLAYEY SILT - moderately plastic; firm; moist; red (2.5YR-4/8); black carbon imprint stains		60		ml		5
- hard; dry; brittle	A 1556	60	0.0			
- very hard	2-63A	24				
- 6" anhydrite/gypsum layer; light gray (5YR-7/1)	A 1557	24 / 36	0.0			10
SILTY SAND - 20% silt, 80% very fine to fine grained sand; hard; compact; moist; sand forms thin (1-2mm) layers		36		sm		
- trace of thin laminations of anhydrite/gypsum; light gray (5YR-7/1)	A 1558	60	0.0			15
SAND - very fine to fine grained; <10% silt; mostly clean; poorly graded - saturated	A 1559	60 / 60	0.0	sp		
- some thin layers of sand; lighter red (2.5YR-5/6); poorly cemented		60				20
		36				
SILT - slightly plastic; hard; dry; red (2.5YR-4/8); sharp contact		36		ml		25
SAND - poorly graded; saturated		36		sp		
- silt layer						30
						35
SILT - hard; dense; several thin layers of sandy silt				ml		40

GEOPHYSICAL LOG (GAMMA) 10 20 30 40



	DRAFT BY	RPS 1/13/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A58 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

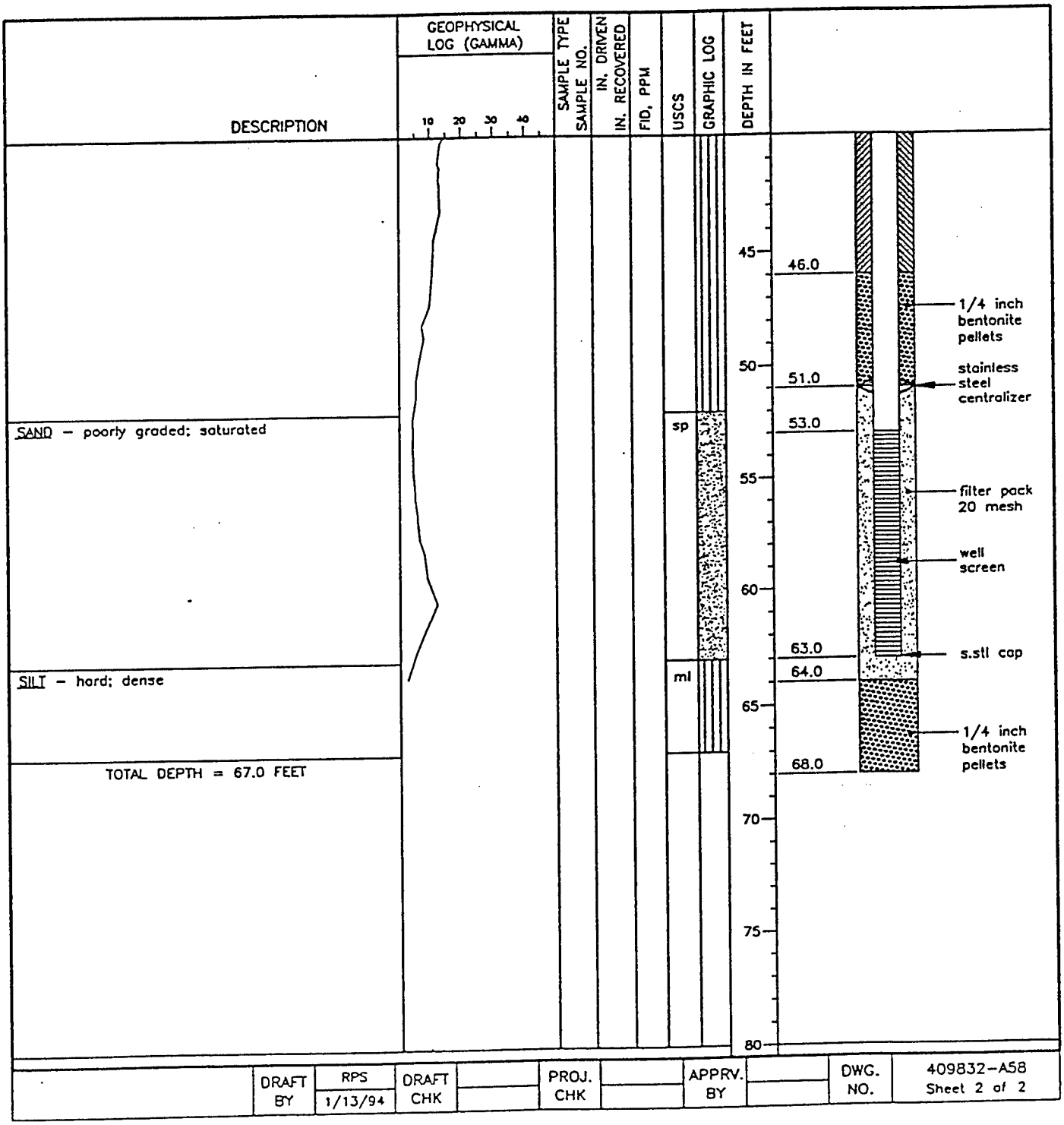
MONITORING WELL 2-63A

DRILLING AND SAMPLING INFORMATION

Boring Location: EAST SIDE OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1243.387
TOTAL DEPTH(FT.): 67
Logged By: M. WILSON
Date Started: 11/19/93
Drilled By: D. MEYER
Date Completed: 11/23/93
GEOTECHNOLOGY. INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER AND 1-1/2"x2' SPLIT SPOON
Notes: N 150389.964, E 2182043.019

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL
1. Surf Casing-I.D.(in.): 8 — Depth(ft.): 28 — Type: Carbon Steel
   Centralizers-Type: S.Steel — Depths(ft.): 15
2. Riser Pipe-I.D.(in.): 2 — Depth(ft.): 53 — Type: S.Steel
   Centralizers-Type: S.Steel — Depths(ft.): 21, 51
3. Screen Dia.(in.): 2 — Type: S.Steel Wire Wound
   Depth Interval(ft.): 53.0-63.0 — Slot Size(in.): .010
   Centralizers-Type: — Depths(ft.):
4. Filter Pack Type: Silica Sand — Depth Interval(ft.): 51-64
   Conc. Pad Size: 4'x4'x6"



DRAFT BY	RPS 1/13/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A58 Sheet 2 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-64A

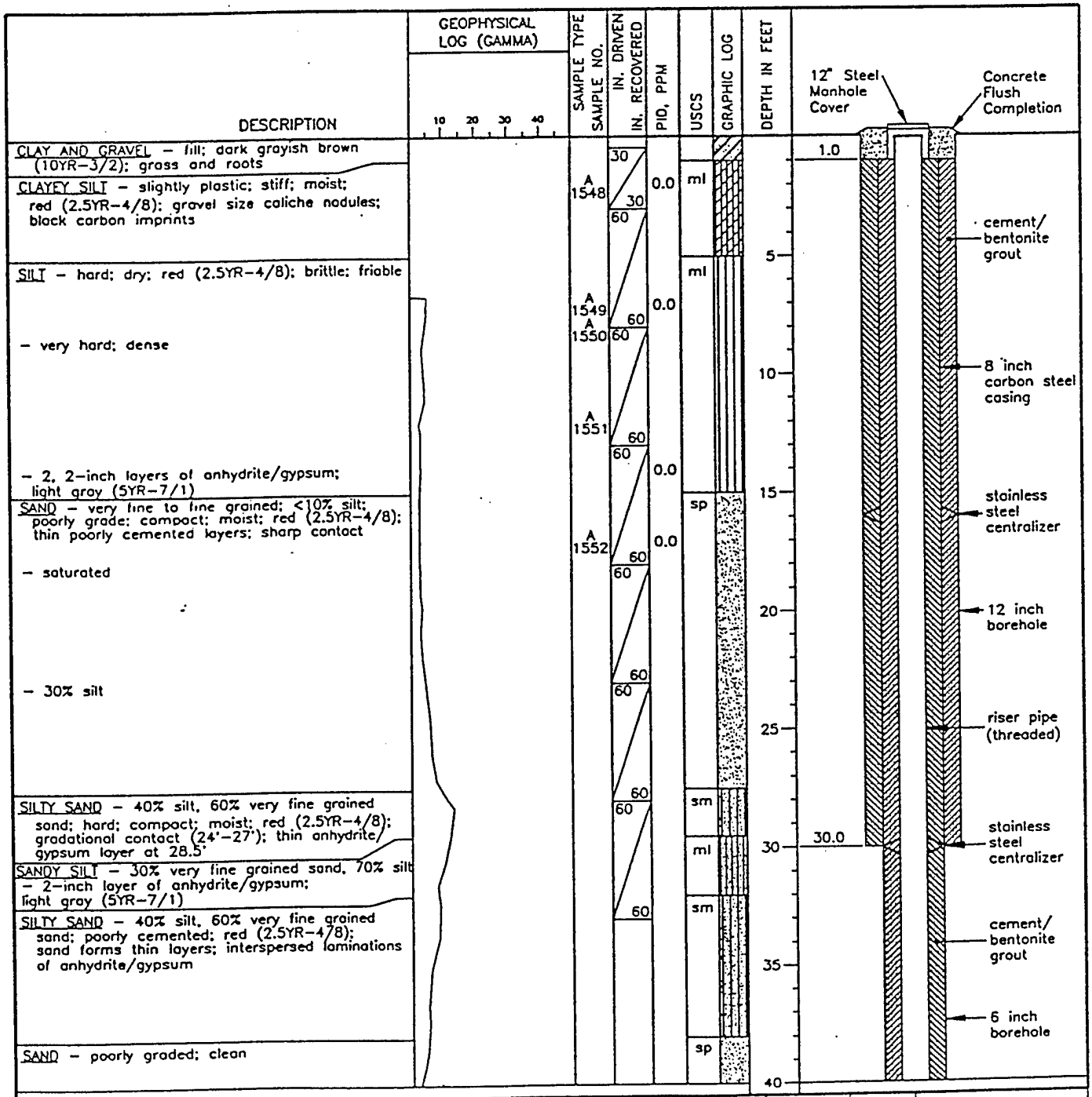
DRILLING AND SAMPLING INFORMATION

Boring Location: NORTH SIDE OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1246.052
TOTAL DEPTH(FT.): 75
Logged By: M. WILSON
Date Started: 11/18/93
Drilled By: D. MEYER
Date Completed: 11/22/93
GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER

Notes: N 150470.205, E 2181959.365

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL
1. Surf Casing-I.D.(in.): 8 — Depth(ft.): 30 — Type: Carbon Steel
   Centralizers-Type: S.Steel — Depths(ft.): 16
2. Riser Pipe-I.D.(in.): 2 — Depth(ft.): 56 — Type: S.Steel
   Centralizers-Type: S.Steel — Depths(ft.): 30, 54
3. Screen Dia.(in.): 2 — Type: S.Steel Wire Wound
   Depth Interval(ft.): 56-66 — Slot Size(in.): .010
   Centralizers-Type: — Depths(ft.):
4. Filter Pack Type: Silica Sand — Depth Interval(ft.): 54.5-67.0
   Conc. Pad Size: 4'x4'x6"



	DRAFT BY	RPS 1/15/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A59 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-64A

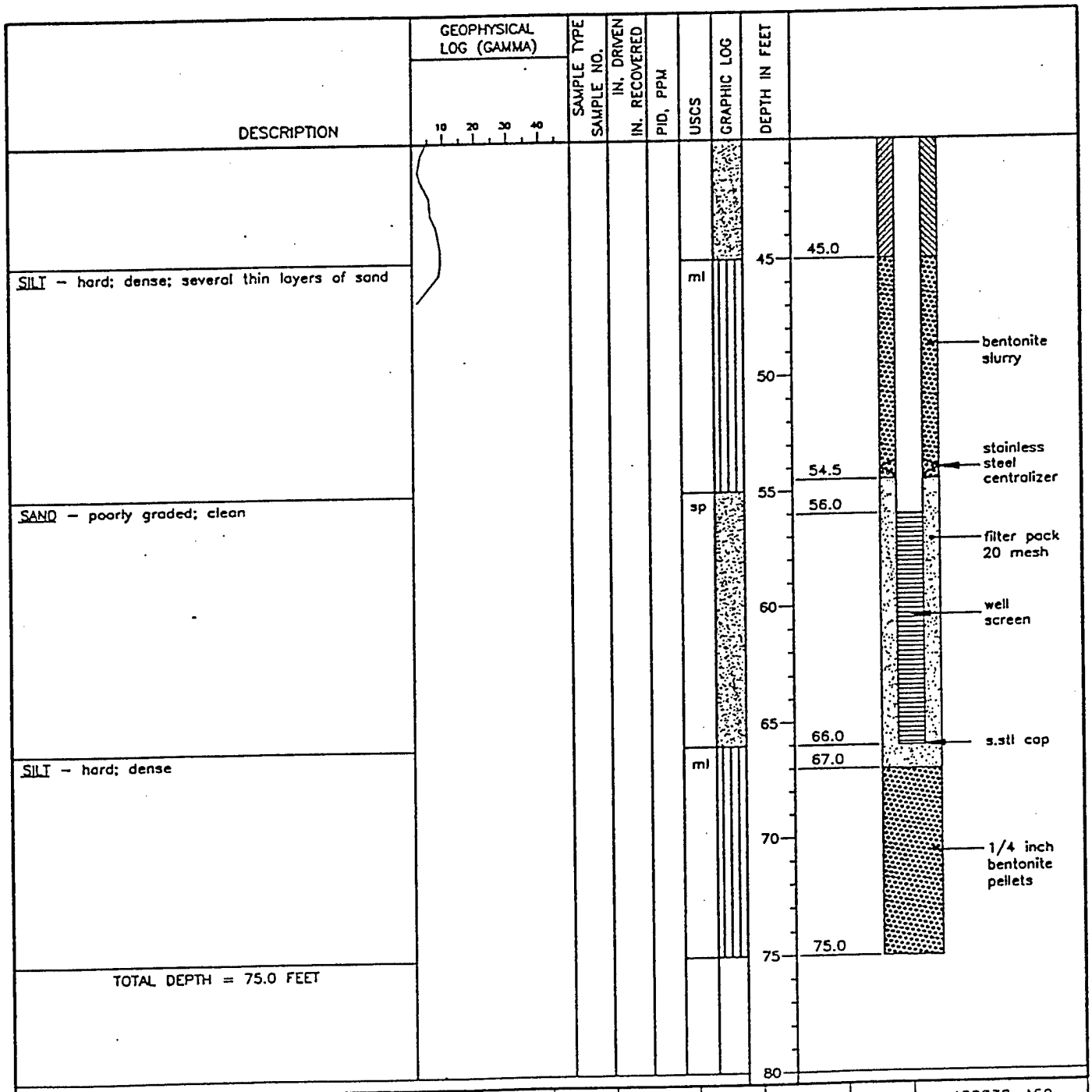
DRILLING AND SAMPLING INFORMATION

Boring Location: NORTH SIDE OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1246.052
TOTAL DEPTH(FT.): 75
Logged By: M. WILSON
Date Started: 11/18/93
Drilled By: D. MEYER
Date Completed: 11/22/93
GEOTECHNOLOGY. INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS AND MUD ROTORY WITH 5-5/8" TRICONE ROCK BIT
Sampling Method: 3"x5' CONTINUOUS SAMPLER

Notes: N 150470.205, E 2181959.365

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL
1. Surf Casing-I.D.(in.): 8
   Depth(ft.): 30 Type: Carbon Steel
   Centralizers-Type: S.Steel
   Depths(ft.): 16
2. Riser Pipe-I.D.(in.): 2
   Depth(ft.): 56 Type: S.Steel
   Centralizers-Type: S.Steel
   Depths(ft.): 30, 54
3. Screen Dia.(in.): 2
   Type: S.Steel Wire Wound
   Depth Interval(ft.): 56-66
   Slot Size(in.): .010
   Centralizers-Type:
   Depths(ft.):
4. Filter Pack Type: Silica Sand
   Depth Interval(ft.): 54.5-67.0
   Conc. Pad Size: 4'x4'x6"



	DRAFT BY	RPS 1/15/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A59 Sheet 2 of 2

Client: TINKER AFB
Project Name: TINKER 5001
Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65A

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1250.976
TOTAL DEPTH(FT.): 79
Logged By: M. WILSON
Date Started: 11/15/93
Drilled By: D. MEYER GEOTECHNOLOGY, INC.
Date Completed: 11/19/93
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS

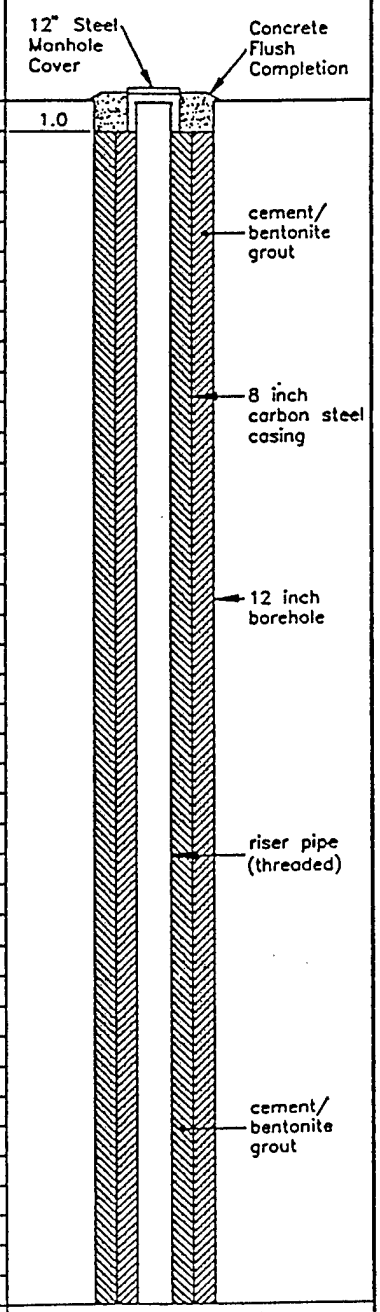
Sampling Method: 3"x5" CONTINUOUS SAMPLER AND 1-1/2"x2" SPLIT SPOON
Notes: N 150698.281, E 2182189.884

WELL COMPLETION DATA

Elev-Top of Casing(ft.):
Ref. Datum: MSL
1. Surf Casing-I.D.(in.): 8 Depth(ft.): 55 Type: Carbon Steel
   Centralizers-Type: Depths(ft.):
2. Riser Pipe-I.D.(in.): 2 Depth(ft.): 66 Type: S.Steel
   Centralizers-Type: S.Steel Depths(ft.): 61
3. Screen Dia.(in.): 2 Type: S.Steel Wire Wound
   Depth Interval(ft.): 66-76 Slot Size(in.): .010
   Centralizers-Type: Depths(ft.):
4. Filter Pack Type: Silica Sand Depth Interval(ft.): 64-77
   Conc. Pad Size: 4'x4'x6"

DESCRIPTION	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	FID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
CLAY - moderately plastic; stiff; moist; grayish brown (5YR-4/2); grass and roots		48		cl		
- gradational contact	A 1540	48	0.0	cl		
GRAVELLY CLAY - slightly plastic; 20% granule size gravel; firm; moist; red (2.5YR-4/8); rootlets; black carbon imprint		60				
- hard; dry; brittle	A 1541	60	0.0			5
- 50% light red caliche						
- 10% gravel						
- 30%-40% sand						
CLAYEY SILT - nonplastic; very hard; brittle; dry; red (2.5YR-4/8); sharp contact		60		ml		10
- dense; compact	A 1542	60	0.0			
SANDY SILT - 25% very fine grained sand; 75% silt; loose; dry; red (2.5YR-4/8); thin silt layers (0.1-0.5" thick)		60		ml		15
	A 1543	36	0.0			
- few thin seams of very fine grained sand; gray		30				20
- hard	A 1544	30				
SILTY SAND - 30% silt, 70% very fine grained sand; compact; stiff; dry; red (2.5YR-4/8); hard to drill		9 9		sm		25
- saturated	A 1545					
	A 1546					30
SAND - fine grained; <10% fines; poorly graded; compact; saturated; red (2.5YR-4/8)		24 24		sp		
SILTY SAND - 30% silt, 70% very fine grained sand; compact; saturated; red (2.5YR-4/8)		60		sm		35
CLAYEY GRAVELLY SAND - 30% clay, 40% gravel, 30% fine grained sand; loose; saturated; red (2.5YR-4/8)				sc-gc		
SAND - fine grained; poorly graded; compact; saturated; red (2.5YR-4/8)		60		sp		40

GEOPHYSICAL LOG (GAMMA) 10 20 30 40



	DRAFT BY	RPS 1/15/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A60 Sheet 1 of 2

Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

MONITORING WELL 2-65A

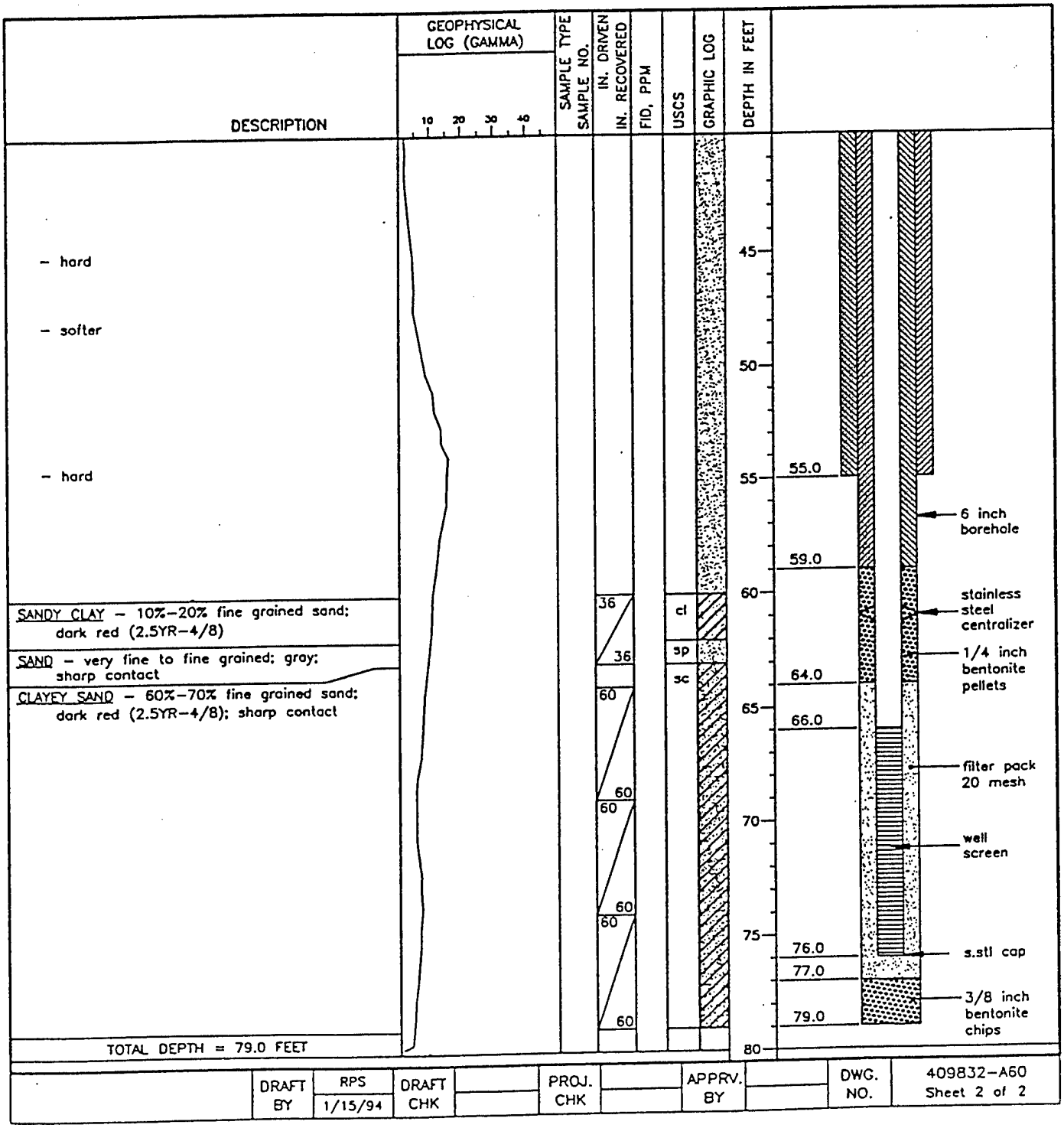
DRILLING AND SAMPLING INFORMATION

Boring Location: NORTHEAST OF FIRE TRAINING AREA 2
SURFACE ELEV.(FT): 1250.976
TOTAL DEPTH(FT.): 79
Logged By: M. WILSON
Date Started: 11/15/93
Drilled By: D. MEYER
Date Completed: 11/19/93
GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" AND 12" HOLLOW STEM AUGERS

Sampling Method: 3"x5' CONTINUOUS SAMPLER AND 1-1/2"x2' SPLIT SPOON
Notes: N 150698.281, E 2182189.884

WELL COMPLETION DATA

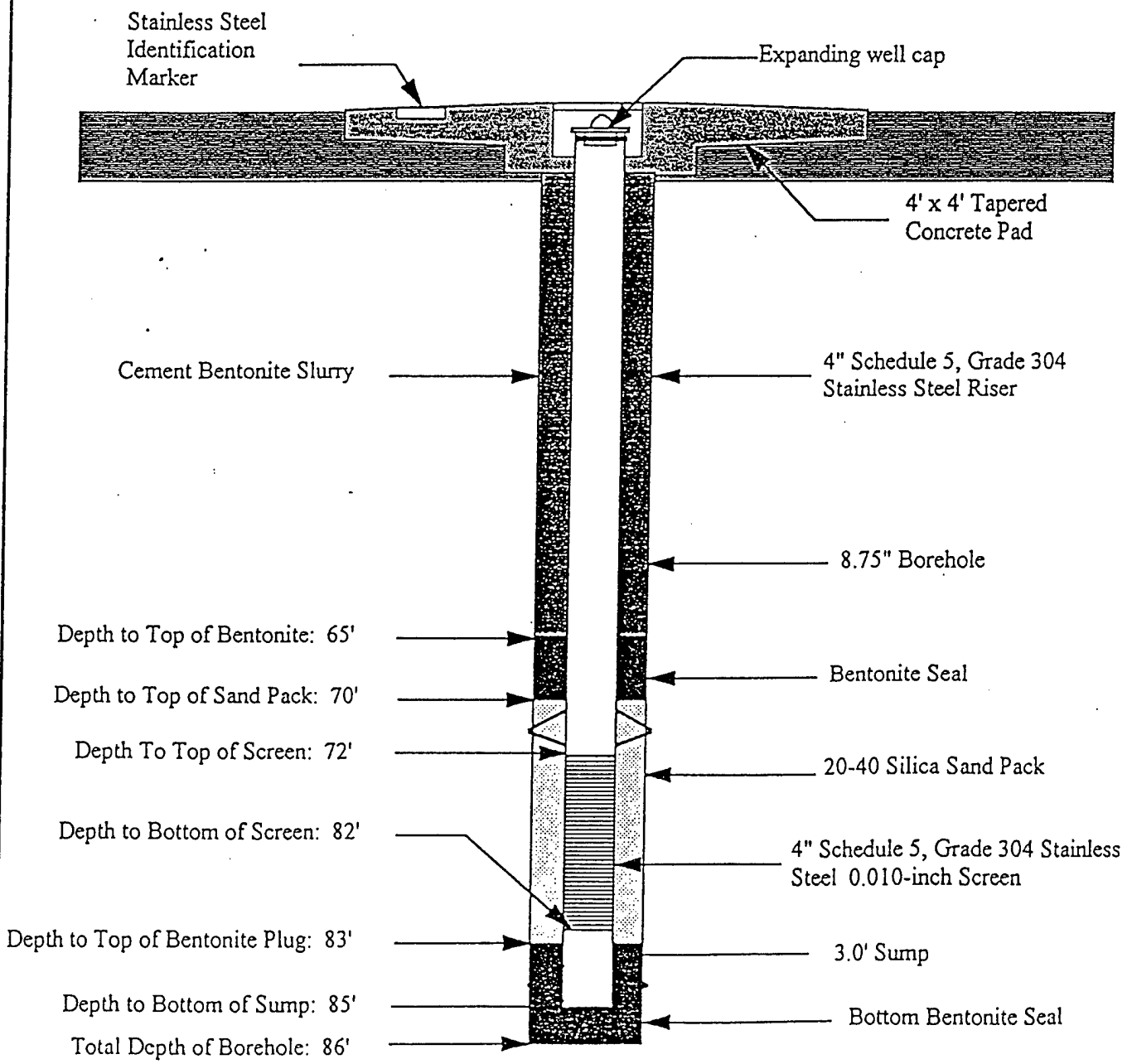
Elev-Top of Casing(ft.):
Ref. Datum: MSL
1. Surf Casing-I.D.(in.): 8
   Depth(ft.): 55 Type: Carbon Steel
   Centralizers-Type:
   Depths(ft.):
2. Riser Pipe-I.D.(in.): 2
   Depth(ft.): 66 Type: S.Steel
   Centralizers-Type: S.Steel
   Depths(ft.): 61
3. Screen Dia.(in.): 2
   Type: S.Steel Wire Wound
   Depth Interval(ft.): 66-76
   Slot Size(in.): .010
   Centralizers-Type:
   Depths(ft.):
4. Filter Pack Type: Silica Sand
   Depth Interval(ft.): 64-77
   Conc. Pad Size: 4'x4'x6"



	DRAFT BY	RPS 1/15/94	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A60 Sheet 2 of 2

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: **2-142A**
Location: TAFB, Oklahoma	Site: BW
Contract No: F34650-94-D-0082/5004 (P & A 3)	Date 4-Inch Riser Set: 05/19/95
Contractor: Brown & Root Environmental	Drilling Method: Mud Rotary
Project Manager: David Parker	Ground Level Elev. (AMSL): 1242.30'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1241.76'
Drlg Contractor: Associated Environmental, Inc.	Dedicated Pump: 2-inch Grundfos
Comments: Top Riser: 4" Schedule 40 PVC Casing.	



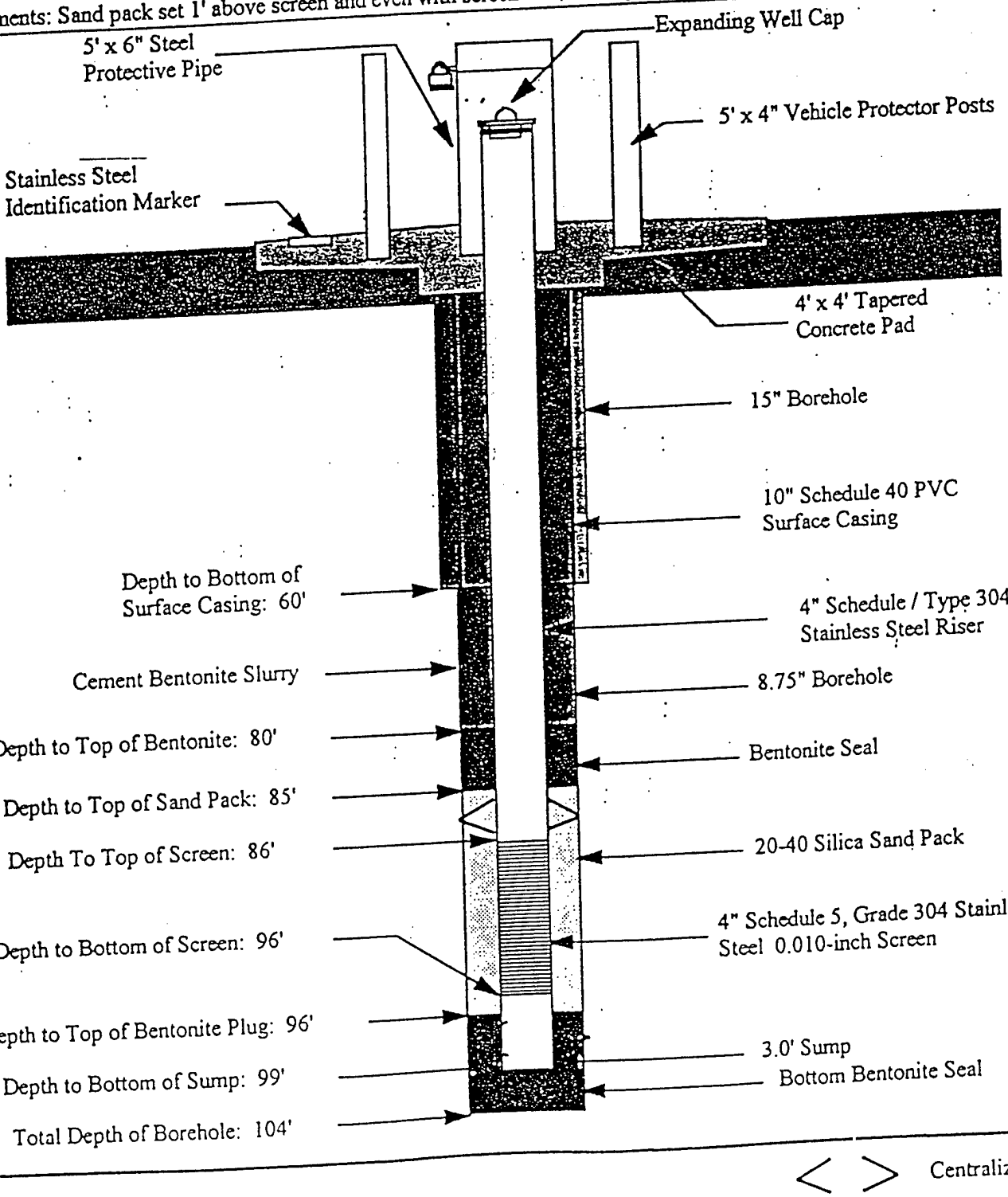
Drawing not to scale

< > Centralizers

WELL CONSTRUCTION SCHEMATIC

Client: Tinker Air Force Base	Well ID: 2-112A
Location: TAFB, Oklahoma	Site: LF15
Contract No: F34650-94-D-0082/5003 (P & A 2)	Date 4-Inch Riser Set: 1/23/95
Contractor: Brown & Root Environmental	Drilling Method: Auger
Project Manager: David Parker	Ground Level Elev. (AMSL): 1248.03'
Project Geologist: James W. Roberts	Top of Csg. Elev. (AMSL): 1251.41'
Drlg Contractor: Associated Environmental Inc.	Dedicated Pump: 2-inch Grundfos

Comments: Sand pack set 1' above screen and even with screen bottom. Top Riser: 4" Schedule 40 PVC Casing.



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Client: TINKER AFB
Project Name: TINKER 5001

Project Location: TINKER AFB, OKLAHOMA
Project Number: 409832

SOIL BORING 2-65P

DRILLING AND SAMPLING INFORMATION

Boring Location: NORTH OF FIRE TRAINING AREA
Logged By: K. KIRSCHENMANN
Drilled By: P. GUERREIN
GEOTECHNOLOGY, INC.
Drill Rig Type: CME-75
Drilling Method: 8" HOLLOW STEM AUGER AND MUD ROTARY WITH 3-7/8" BIT
Sampling Method:

SURFACE ELEV.(FT):
TOTAL DEPTH(FT.): 100.0
Date Started: 11/2/93
Date Completed: 11/3/93

Notes: STRATIGRAPHIC TEST USED FOR GEOPHYSICAL LOGGING

DESCRIPTION	GEOPHYSICAL LOG (GAMMA) 10 20 30 40	SAMPLE TYPE / SAMPLE NO.	IN. DRIVEN / IN. RECOVERED	PID, PPM	USCS	GRAPHIC LOG	DEPTH IN FEET
SILTY CLAY					cl		85
– very hard				0			90
							95
							100
TOTAL DEPTH = 100.0 FEET							105
							110
							115
							120

DRAFT BY	RPS	DRAFT CHK		PROJ. CHK		APPRV. BY		DWG. NO.	409832-A27 Sheet 3 of 3
	11/24/93								

Analytical Results for Fire Training Area 2
For USZ Groundwater
Tinker Air Force Base, Oklahoma
Table 5-3

	12/10/93		12/10/93			12/10/93	12/10/93		12/10/93	
Well/Boring:	2-62B		2-62B		2-62B	2-63B	2-64B		2-65B	
Sample ID:	A1601		A1602		A1665	A1600	A1603		A1604	
Depth in Feet:	0 - 0		0 - 0		0 - 0	0 - 0	0 - 0		0 - 0	
Parameters	Result	QFR	Result	QFR	Result QFR	Result QFR	Result	QFR	Result	QFR
Metals (mg/L)										
Aluminum	8.2		5.1			5.9	1.4		0.95	
Barium	0.21		0.19			0.35	0.23		0.24	
Calcium	48	N	58	N		61 N	59	N	80	N
Chromium	0.04	N	0.029	N		0.014 N				
Copper	0.043	N	0.049	N						
Iron	11		5.5			13	. 2		1.1	
Lead - Graphite Furnace	0.004		0.0031							
Magnesium	43		52			45	33		52	
Manganese	0.14	N	0.1	N		0.23 N	0.048	N	0.065	N
Potassium									1.7	
Selenium						0.1 N				
Sodium	110		130			59	46		43	
Zinc	0.024	N	0.021	N		0.022 N				
Semivolatile (ug/L)										
1,3-Dichlorobenzene	53		46							
Volatile (ug/L)										
1,1,2-Trichloroethane	9		7.3							
1,1-Dichloroethene	5.7		6							
1,2-Dichlorobenzene	1900	D	1700	D						
1,2-Dichloroethane	500		550		430	1.2 J	2	J		
1,2-Dichloropropane	7		7.3							
1,4-Dichlorobenzene	290	D	250	D						
Benzene	5.4		5.7							
Chlorobenzene	220		240		220		1.2	J		
Trichloroethene	8300	D	8900	D	7900 D	33	96		99	
cis-1,2-Dichloroethene	1600	D	1700	D	1300	45	39		24	
trans-1,2-Dichloroethene	130		140				3.5	J		

Analytical Results for Fire Training Area 2
For USZ Groundwater
Tinker Air Force Base, Oklahoma
Table 5-3

Well/Boring:	2-62B		2-62B		2-62B		2-63B		2-64B		2-65B	
Sample ID:	A1601		A1602		A1665		A1600		A1603		A1604	
Depth in Feet:	0 - 0		0 - 0		0 - 0		0 - 0		0 - 0		0 - 0	
Parameters	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR	Result	QFR
Miscellaneous (mg/L)												
Alkalinity, Titrimetric	520		330				470		380		500	
Chemical Oxygen Demand	35											
Chloride by Ion Chrom.	87		89				39		34		57	
Nitrate and Nitrite	2.9		2.7				3.8		3.8		2.6	
Silica	7.3		6.9				8.9		4.3		11	
Sulfate by Ion Chrom.	110		230				36		24		37	
Total Phosphorus	0.15											
Total Dissolved Solids	630		660				510		450		650	
Total Kjeldahl Nitrogen	0.38											
Total Organic Carbon	3		3				2.2		1.2		1.6	
Total Suspended Solids	190		250				750		160		42	

B = Analyte was also found in sample blank
D = Compound identified at a secondary dilution factor.
E = Concentration exceeds instrument calibration range for that specific analysis
J = Concentration is an estimated value
N = Sample is outside of Matrix Spike QC Limit
< = Not detected
QFR = Qualifier
Analytical data has not been validated

Analytical Results for Fire Training Area 2
For LSZ Groundwater
Tinker Air Force Base, Oklahoma
Table 5-4

	12/17/96	12/13	12/13	12/13
Well/Boring:	2-62A	2-63A	2-64A	2-65A
Sample ID:	A1648	A1607	A1608	A1609
Depth in Feet:	0 - 0	0 - 0	0 - 0	0 - 0
Parameters	Result QFR	Result QFR	Result QFR	Result QFR
Metals (mg/L)				
Aluminum	1.5	32 N	2.9 N	2.8 N
Arsenic - Graphite Furnace		0.018		
Barium	0.56	3.7	0.56	
Cadmium		0.0066		
Calcium	68	100	61	36
Chromium	0.021	0.12 N	0.075 N	0.053 N
Copper		0.1		
Iron	1.1	57	4.8	4.3
Lead - Graphite Furnace		0.025	0.0042	
Magnesium	42	57	35	19
Manganese	0.016	1.2 N	0.12 N	0.067 N
Nickel		0.079 N	0.067 N	
Potassium		7.3		
Sodium	45	25	23	22
Zinc		0.1 N	0.021 N	0.028 N
Miscellaneous (mg/L)				
Total Dissolved Solids	450	190	388	258
Total Kjeldahl Nitrogen				0.26 N
Total Suspended Solids	45	1900	200	
Alkalinity, Titrimetric	390	380	350	190
Chloride by Ion Chrom.	9.9	17	26	24
Nitrate and Nitrite	5.3	3.3	1.1	0.78
Silica	11	8.8	8.6	11
Sulfate by Ion Chrom.	17	17 N	14 N	24 N
Total Phosphorus		0.19 N		3.9 N

B = Analyte was also found in sample blank
E = Concentration exceeds instrument calibration range for that specific analysis
J = Concentration is an estimated value
N = Sample is outside of Matrix Spike QC Limit
< = Not detected
QFR = Qualifier
Analytical data has not been validated

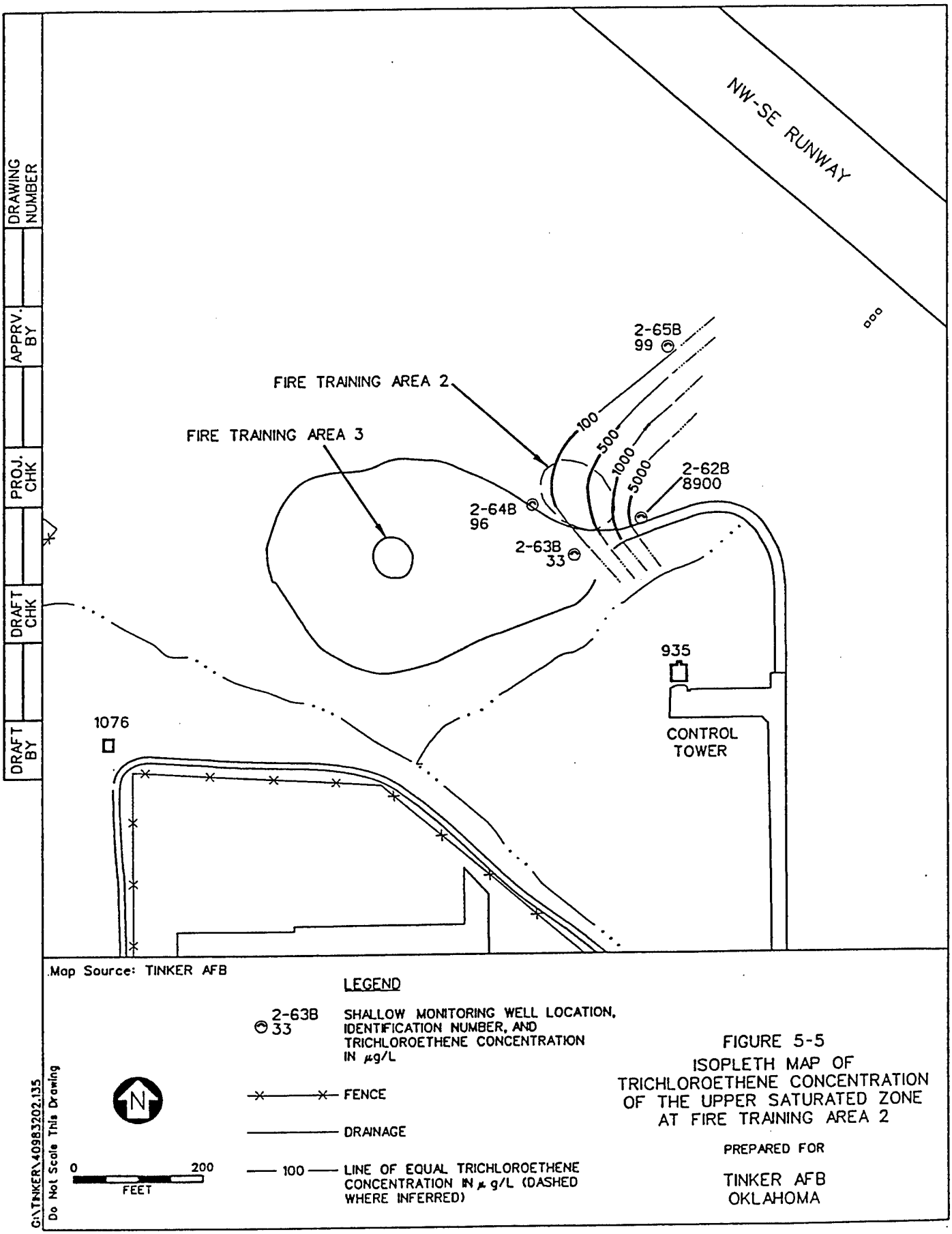
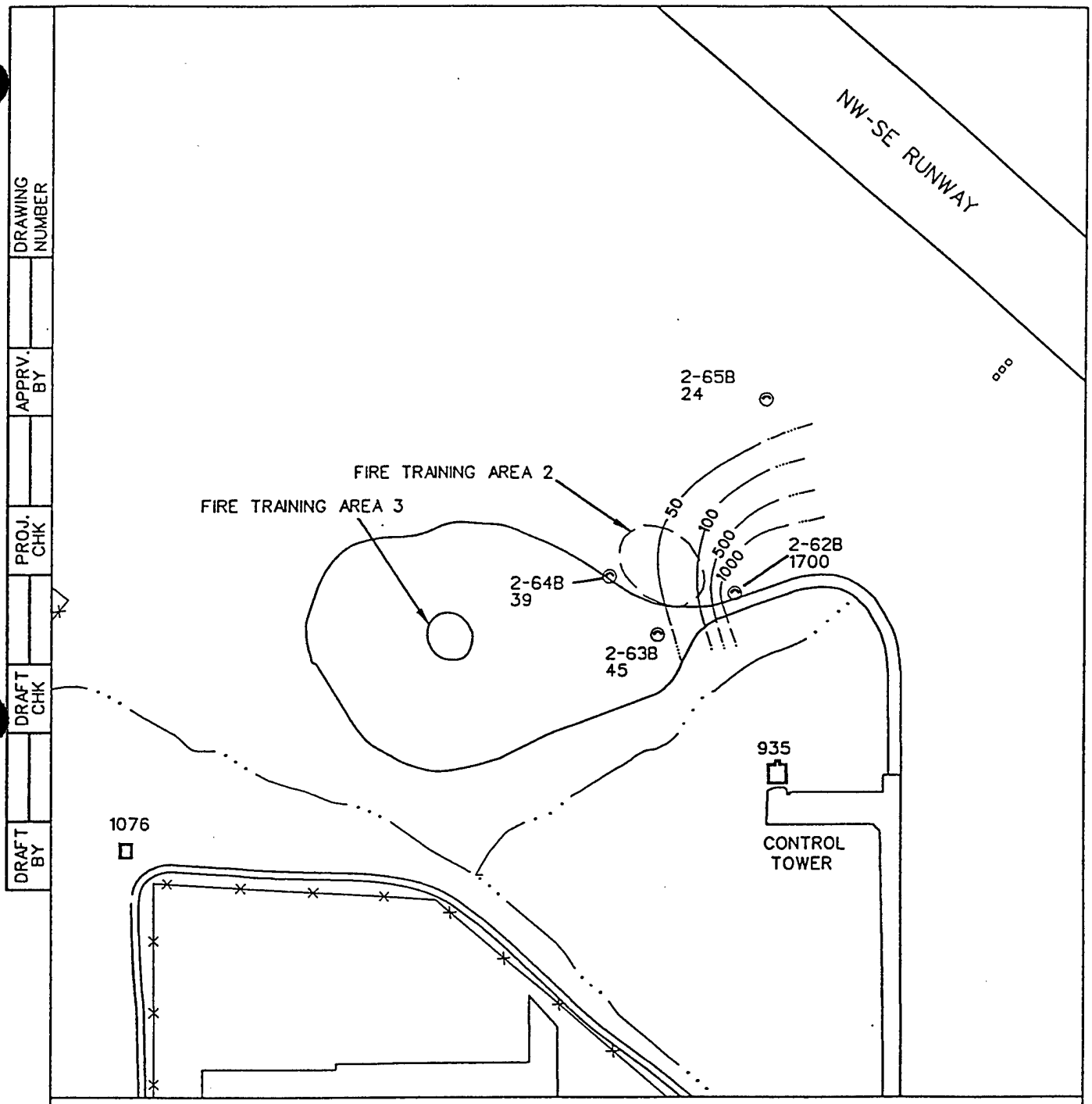


FIGURE 5-5
ISOPLETH MAP OF
TRICHLOROETHENE CONCENTRATION
OF THE UPPER SATURATED ZONE
AT FIRE TRAINING AREA 2

PREPARED FOR

TINKER AFB
OKLAHOMA



Map Source: TINKER AFB

LEGEND

2-63B / 45 — SHALLOW MONITORING WELL LOCATION, IDENTIFICATION NUMBER, AND 1,2 DICHLOROETHANE CONCENTRATION IN µg/L

FENCE

DRAINAGE

50 — LINE OF EQUAL 1,2 DICHLOROETHANE CONCENTRATION IN µg/L (DASHED WHERE INFERRED)

N

0 200 FEET

Do Not Scale This Drawing

G:\TINKER\40983202.136

DRAWING NUMBER | APPRV. BY | PROJ. CHK | DRAFT CHK | DRAFT BY

FIGURE 5-6
ISOPLETH MAP OF
CIS 1,2 DICHLOROETHENE CONCENTRATION
OF THE UPPER SATURATED ZONE
AT FIRE TRAINING AREA 2

PREPARED FOR

TINKER AFB
OKLAHOMA

APPENDIX B

GEOLOGIC BOREHOLE LOGS, GEOPHYSICAL BOREHOLE LOGS, WELL CONSTRUCTION DIAGRAMS, MONITORING WELL DEVELOPMENT AND SAMPLING RECORDS, SLUG TEST ANALYSES, AND SURVEY DATA

GEOLOGIC BORING LOG

JOB NUMBER:	729691	CLIENT:	AFCEE / TINKER AFB	DATE SPUD:	7/28/97
BORING NUMBER:	C039-897-41	BORING DIA.:	8 3/4" OD / 4 1/4" ID	DATE CMPL:	7/28/97
RIG TYPE:	FAILING FID	CONTRACTOR:	AEI Corp.	ELEVATION:	1245.6'
TEMPERATURE (°F):	90-95°F	WEATHER:	Sunny, Hot	DATUM:	Ground Surface
LOCATION:	FTAZ-MP1	DRLG MED:	Hollow Stem Auger	GEOLOGIST:	Bruce Henry
COMMENTS:					

Depth (ft.)	Pro-file	USCS	Geologic Description	Sample Interval	Laboratory Sample Identification	Sample Type	PID ppmv	Remarks
1		CL	SILT and CLAY - with trace gravel fill, brown, dry, loose	0-5'		CME	4-5' 0.1 / 0.0	3.5' Recovery
			1-5' CLAY - reddish brown, very firm, blocky, dry to slightly moist, with greenish calcareous nodules, NSO					
5		CL	5-10' SILTY CLAY - reddish brown, very firm to hard, dry to slightly moist, platy, with caliche nodules, NSO	5-10'		CME	9-10' 0.1 / 0.0	5.0' Recovery
10		CL	10-15' SILTY CLAY - reddish brown, occasionally mottled gray, with SILT stringers, moist SILT at Base, soft to firm, NSO	10-15'		CME	14-15' 1.0 / 0.0	4.5' Recovery
15		CL / ML	15-18' SILTY CLAY - As Above, moist, soft to firm, increasingly silty, w. thin SILT stringers, NSO	15-20'	C039-897-41-S18-19' 1130 (VOCs)	CME	18-19' 12.5 / 0.0	4.5' Recovery
		ML	18-20' SILT - reddish brown, soft, with thin streaks of moderately cemented sandy SILT, wet at Base					∇ WATER AT 19'
20		SM / ML	20-25' SILTY SAND - reddish brown, soft, with thin cemented layers, some clay matrix, very fine grained, NSO	20-25'		CME	24-25' 24 / 0.0	4.0' Recovery
25		SM / CL	25-30' SILTY CLAY AND SILTY SAND - light gray with thin streaks of reddish brown clay, silt - very fine grained, soft, with some firm and clayey, NSO	25-30'		CME	29-30' 11.5 / 0.0	1.5' Recovery
30		SM / ML	30-35' SILTY SAND - reddish brown w/ clay matrix, moist to wet, soft-firm, very fine grained, NSO, grading to CLAYEY SILT	30-35'		CME	34-35' 9.1 / 0.5	1.4' Recovery
35			35-40 SILTY SAND - gray with thin reddish brown layers, soft to firm, with a 2-3" very hard cemented layer, very moist to wet, NSO	35-40'		CME	39-40' 1.2 / 0.5	3.5' Recovery
40			TD = 40'					
			Logged for GR/SP/Resistivity and Caliper.					
45			Screened 34-39'					
50								

NOTES:

BGS - Below Ground Surface
NS - Not Sampled
TOC - Top of Casing
PID - Photoionization Detector
ppmv - Parts per Million, Volume per Volume

SS - Split Spoon Sample
G - Grab Sample
D - Drive Sample

NSO - no stain or odor

GEOLOGIC BORING LOG

JOB NUMBER:	728691	CLIENT:	AFCEE RNA/ TINKER AFB	DATE SPUD:	7/29/97
BORING NUMBER:	C39-897-43D/S	BORING DIA.:	8 3/4" OD / 4 1/4" ID	DATE CMPL:	7/29/97
RIG TYPE:	FAILING F10	CONTRACTOR:	AEI Corp.	ELEVATION:	1252.6'
TEMPERATURE (°F):	85°F	WEATHER:	Cloudy, Mild, Slight Breeze	DATUM:	Ground Surface
LOCATION:	FTA 2	DRLG MED:	Hollow Stem Auger	GEOLOGIST:	Bruce Henry
COMMENTS:					

Depth (ft.)	Pro-file	USCS	Geologic Description	Sample Interval	Laboratory Sample Identification	Sample Type	PID ppmv	Remarks
1			0-2' TOPSOIL - dark brown, soft, dry	0-5'		CME	4-5' 1.0/1.0	4.8' Recovery
		CL	2-5' CLAY - reddish brown with black streaks, firm to very stiff, silty in part, slightly moist, NSO					
5		CL	5-10' SILTY CLAY - reddish brown, firm - very firm, platty to blocky, slightly moist, with scattered calcareous nodules, NSO	5-10'		CME	9-10' 2.0/2.0	5.0' Recovery
10		CL	10-15' SILTY CLAY - reddish brown, firm to hard, blocky, slightly moist, NSO	10-15'		CME	14-15 3.2/3.2	4.8' Recovery
15		CL	15-20' SILTY CLAY - reddish brown, firm to hard, blocky, dry to slightly moist, trace black carbonaceous specs, NSO	15-20'		CME	19-20 3.0/5.0	5.0' Recovery
20		CL/ ML	20-25' SILT - reddish brown, firm, clayey, dry to slightly moist, with layers of CLAY SAA	20-25'		CME	24-25 2.2/ 2.2	3.0' Recovery
25		ML/ SM	25-30' SILT - reddish brown, soft to firm, slightly moist, increasingly sandy at base, grading to SILTY SAND - NSO	25-30'	C039-897-43 -S29 (UCC)	CME	29-30 3.4/3.4	2.8' Recovery SATURATED AT 30'
30		SM	30-35' SILTY SAND - orangish brown, loose, very fine grained, very silty, trace clay layers, wet, NSO	30-35'	C039-897-43-S34 (TOC) 0900	CME	34-35 8.1/3.7	5.2' Recovery
35		SM	35-40' SILTY SAND - reddish brown, loose, clayey - silty, very fine grained, poorly sorted, few 1-2" cemented layers, NSO	35-40'		CME	39-40 5.3/ 2.3	2.0' Recovery
40		SM	40-45' SILTY SAND - reddish brown, loose, very fine grained, silty to clayey, wet, NSO	40-45'		CME	44-45 4.7/ 2.2	3.2' Recovery
45		SM	45-50' SILTY SAND - reddish brown, soft to loose, clayey to silty, very fine grained, 3-4" clean sand at 49', 2-3" clay at base.	45-50'		CME	49-50 4.4/ 2.2	2.0' Recovery
50			TD at 50'					

NOTES:

BGS - Below Ground Surface
NS - Not Sampled
TOC - Top of Casing
PID - Photoionization Detector
ppmv - Parts per Million, Volume per Volume

SS - Split Spoon Sample
G - Grab Sample
D - Drive Sample
NSO - No Stain or Odor

GEOLOGIC BORING LOG

JOB NUMBER:	729691	CLIENT:	TINKER AFB	DATE SPUD:	7/31/97
BORING NUMBER:	C639-B97-45	BORING DIA.:	8 3/4" OD / 4 1/4" ID	DATE CMPL:	7/31/97
RIG TYPE:	FAILING F10	CONTRACTOR:	AEI Corp.	ELEVATION:	1242.2'
TEMPERATURE (°F):	75-85	WEATHER:	Clear, Sunny, Warm	DATUM:	GS
LOCATION:	ETA2	DRLG MED:	Hollow Stem Auger	GEOLOGIST:	BMH
COMMENTS:					

Depth (ft.)	Pro-file	USCS	Geologic Description	Sample Interval	Laboratory Sample Identification	Sample Type	PID ppmv	Remarks
1			0-2' TOPSOIL - dark brown, roots	0-5'		CME	4-5'	1.2' Recovery
		CL	2-5' SILTY CLAY - brown at top, becoming reddish brown, firm to hard, blocky, black organic inclusions, moist, NSO				0.8/0.8	
5								
		CL	5-10 SILTY CLAY - reddish brown, mottled grey in part, blocky, dry, hard to very hard, NSO	5-10'		CME	9-10'	5.0' Recovery
							0.9/0.7	
10								
		CL	10-15' SILTY CLAY - reddish brown, mottled light grey, hard, NSO	10-15'		CME	13-15	4.1' Recovery
							1.0/0.7	
15								
		CL	15-20' SILTY CLAY - reddish brown, blocky, hard with firm to friable SILT layers towards the base, dry to slightly moist, NSO	15-20		CME	18-20	4.0' Recovery
							5.5/4.5	
20								
		ML	20-22' SILT to SILTY CLAY - soft to firm, moist, grading	20-25	NOTE: WATER AT 20'	CME	22-25	3.5' Recovery
		SM	to SILTY SAND at 22' L reddish brown, loose, clayey, very fine grained, poorly cemented, wet				4.9/40	
25								
		SM	25-30' SILTY SAND - reddish brown to tan, loose to poorly cemented, very fine grained, clay matrix, wet, NSO	25-30		CME	25-30	2.5' Recovery
							3.1/3.1	
30								
		SM/CL	30-35' Interbedded SILTY SAND - reddish brown, soft, very clayey, and SANDY TO SILTY CLAY - reddish brown, soft to stiff, very moist, NSO	30-35'		CME	30-35	2.1' Recovery
							2.1/20	
35								
		SM	35-40' SILTY SAND - reddish brown, loose to soft, clay matrix, very fine to fine grained, wet, NSO	35-40		CME	35-40	1.5' Recovery
							3.9/27	
40				40-45'		CME		
		SM/SP	40-45' SAND - orangish brown, fine to medium grained, poorly to moderately sorted, loose, cemented at base, wet, NSO				40-45	1.0' Recovery HARD DRILLING AT 42-43'
							3.2/3.7	
45								
			TD at 45'					
50								

NOTES:

BGS - Below Ground Surface
NS - Not Sampled
TOC - Top of Casing
PID - Photoionization Detector
ppmv - Parts per Million, Volume per Volume

SS - Split Spoon Sample
G - Grab Sample
D - Drive Sample
NSO - No Stain or Odor

GEOLOGIC BORING LOG

JOB NUMBER:	73[illegible]7	CLIENT:	AFCEE RNA / TINKER AFB	DATE SPUD:	7/29/97
BORING NUMBER:	2-392B	BORING DIA.:	8 3/4" OD / 4 1/4" ID	DATE CMPL:	7/29/97
RIG TYPE:	Failing F10	CONTRACTOR:	AEI Corp.	ELEVATION:	1246.2'
TEMPERATURE (°F):	88°F	WEATHER:	Cloudy, Breezy, Warm	DATUM:	GS
LOCATION:	FTA2	DRLG MED:	Hollow Stem Auger	GEOLOGIST:	Bruce Henry
COMMENTS:					

Depth (ft.)	Profile	USCS	Geologic Description	Sample Interval	Laboratory Sample Identification	Sample Type	PID ppmv	Remarks
1			0-2' TOPSOIL - dark brown, dry, roots	0-5		CME	4-5	4.5' Recovery
		CL	2-5' SILTY CLAY - orangish brown to red, firm to very firm, slightly moist, with abundant organic material				0.1 / 0.1	
5		ML	5-7 SILT - orangish brown, soft to firm, sandy in part, dry, NSO	5-10		CME	9-10	4.2' Recovery
		CL	7-10 SILTY CLAY - reddish brown, mottled gray, firm - hard, dry				0.1 / 0.1	
10		CL	10-15' SILTY CLAY - reddish brown, firm to hard, platey to blocky, with mottled gray silty interbeds, dry, NSO	10-15		CME	14-15	1.9' Recovery
							1.0 / 1.0	
15		CL	15-20' SILTY CLAY - brick red, firm - hard, blocky, dry to slightly moist, mottled gray in part, NSO	15-20		CME	19-20	2.0' Recovery
							1.0 / 1.0	
20		CL / ML	20-25' SILTY CLAY - SAA becoming very silty at 22-23', grading to SILT - orangish brown, firm to soft, clayey, slightly moist, NSO	20-25		CME	24-25	4.1' Recovery
							3.4 / 1.7	
25		SM	25-30 SILTY SAND - orangish to reddish brown, loose, with 3-4" layers of poorly to moderately cemented, very fine grained, clay matrix, wet, NSO	25-30		CME	29-30	3.0' Recovery
							5.2 / 3.2	
30		CL / ML	30-33' SILT & SILTY CLAY - SAA	30-35		CME	33-35	4.5' Recovery
		SM	33-35' SILTY SAND - very silty to clayey - SAA				3.6 / 2.8	
35		SM / ML	35-40' SILTY SAND and SILT - reddish brown, soft to firm with layers of well cemented, clayey, very moist - NSO	35-40		CME	37-40	4.2' Recovery
							4.7 / 3.0	
40		SM	40-45' SILTY SAND - reddish brown, loose to soft, with 3-4" layers of hard and well cemented SAND, very fine grained, wet, NSO	40-45		CME	44-45	4.2' Recovery
							5.2 / 3.0	
45		SM / ML	45-50' SILTY SAND - reddish brown, loose to soft, clayey, grading to clayey silt, wet NSO	45-50		CME	49-50	0.8' Recovery
							4.7 / 2.3	
50								

TD = 50'

NOTES:

BGS - Below Ground Surface
NS - Not Sampled
TOC - Top of Casing
PID - Photoionization Detector
ppmv - Parts per Million, Volume per Volume

SS - Split Spoon Sample
G - Grab Sample
D - Drive Sample
NSO - no stain or odor

PARSONS ENGINEERING SCIENCE, INC.

GEOLOGIC BORING LOG

JOB NUMBER:	729691	CLIENT:	AFCEE BNA / TINKER AFB	DATE SPUD:	7/30/97
BORING NUMBER:	2-393B	BORING DIA.:	8 3/4" OD / 4 1/4" ID	DATE CMPL:	7/30/97
RIG TYPE:	FALCON F10	CONTRACTOR:	AEI Corp.	ELEVATION:	
TEMPERATURE (°F):	85-90°F	WEATHER:	Sunny, Hot	DATUM:	Ground Surface
LOCATION:	FTA 2	DRLG MED:	Hollow Stem Auger	GEOLOGIST:	Bruce Henry
COMMENTS:					

Depth (ft.)	Pro-file	USCS	Geologic Description	Sample Interval	Laboratory Sample Identification	Sample Type	PID ppmv	Remarks
1			0-1' TOPSOIL - dark brown, roots	0-5'		CME	4-5' 1.4/1.1	3.5' Recovery
		CL	1-5' SILTY CLAY - brown to reddish brown, firm to very firm, dry to slightly moist, some black organic material					
5								
		CL	5-10' SILTY CLAY - SAA with abundant black organic material, grading to SILT at base	5-10		CME	9-10 2.1/ 1.2	4.9' Recovery
		ML						
10								
		ML	10-15' SILT - orangish brown, mottled gray, dry, blocky, NSO	10-15		CME	14-15 2.5/ 1.3	4.4' Recovery
		CL	with SILTY CLAY - reddish brown, firm to hard, dry					
15								
		CL/ ML	15-20' SILTY CLAY - SAA, increasing silty with soft interbedded 3-4" SILT layers, dry to slightly moist, NSO	15-20		CME	19-20 3.0/ 1.1	2.1' Recovery
20								
		ML	20-25' SILT - reddish brown, soft to firm, clayey in part, sandy in part, moist to very moist, NSO	20-25		CME	24-25 3.3/ 1.7	0.5' Recovery WATER AT 23'
25								
		SM	25-30 SILTY SAND - reddish brown, loose to soft, with a few 1-2" layers of moderately cemented, fine grained, clay matrix, wet, NSO	25-30		CME	29-30 2.8/ 1.8	1.8' Recovery
30								
		SM	30-35 SILTY SAND - reddish brown, loose to soft, clay matrix, fine grained, NSO	30-35	2-393B/ S34 (TOC)	CME	34-35 4.1/ 1.2	2.0' Recovery
35								
		SM	35-40' SAND - reddish brown, very fine to medium grained, clay matrix, poorly sorted, wet, loose with 1-2" of poor to moderately cemented	35-40		CME	39-40 3.5/ 0.5	3.0' Recovery
40								
		SM	40-45' SAND - SAA - wet, with increasing thin layers of moderately cemented, fine to medium grained.	40-45	2-393B/ S44 (TOC)	CME	44-45 2.6/ 0.6	2.2' Recovery
45								
		SP CL	45-50 - 0.5' of hard SAND - fine to medium grained, well cemented, overlying SILTY CLAY - reddish brown, hard	45-50		CME	45-50 NR	1.8' Recovery
50								

TD at 50'

NOTES:

BGS - Below Ground Surface
NS - Not Sampled
TOC - Top of Casing
PID - Photoionization Detector
ppmv - Parts per Million, Volume per Volume
SS - Split Spoon Sample
G - Grab Sample
D - Drive Sample
NSO - no stain or

ASSOCIATED ENVIRONMENTAL IND.

HOLE NO: CG39B9741

LOGGED: 07/28/97 at

COMPANY TINKER AIR FORCE BASE
AREA SE/4 SEC 22 T11N R2W
PROSPECT N/A
OPERATOR MM

DRILLING DATA

PERM DAT GL
ELEV
AZIMUTH
INCLIN
HOLE POS
HOLE DIA 9"
DEPTH 40'

CASING DATA

CASE-TYP
CASE-DTH
CASE-DIA
CASE-THK

FLUID DATA

FLD TYPE AUGER
FLUIDLEV

LOGTYPE TD-3

TOOL: Tmrg--Merged Log
Serial Number: 886
Spacer (cm) : n/a

CHANNEL DATA

CHANNEL	AMPLITUDE	RANGE	CHART	AREA	SENSOR OFFSET	FILTER CNST	PLOT TYPE
1 - GAMMA	0.0 -	200.0	0.0 -	10.0	328	4.0	4
2 - PR	0 -	2000	12.0 -	32.0	453	0.0	2
2 - SP	-200 -	200	0.0 -	10.0	453	0.0	2
3 - CALIPER	4.00 -	24.00	12.0 -	32.0	318	0.0	2

Calibration Data

CHANNEL		slope	offset	C1	C2	C3	C4
1 - GAMMA	API	1.000000	0.000000	3568	0.000	0.000	0.000
2 - PR	ohm	0.326204	-569.169	0.000	1745	100.0	2051
2 - SP	mV	-0.89890	3428.191	0.000	3814	1500	2145
3 - CALIPER	IN	0.004103	-6.11253	3.100	2245	6.100	2977

Log No. FILENAME

1 - CG3941 2
2 - CG3941 4
3 - CG3941 5

REPLAY of C:\AUSLOG\TINKER6\Merge Log at 14:16 on 07/28/97

CG39397141

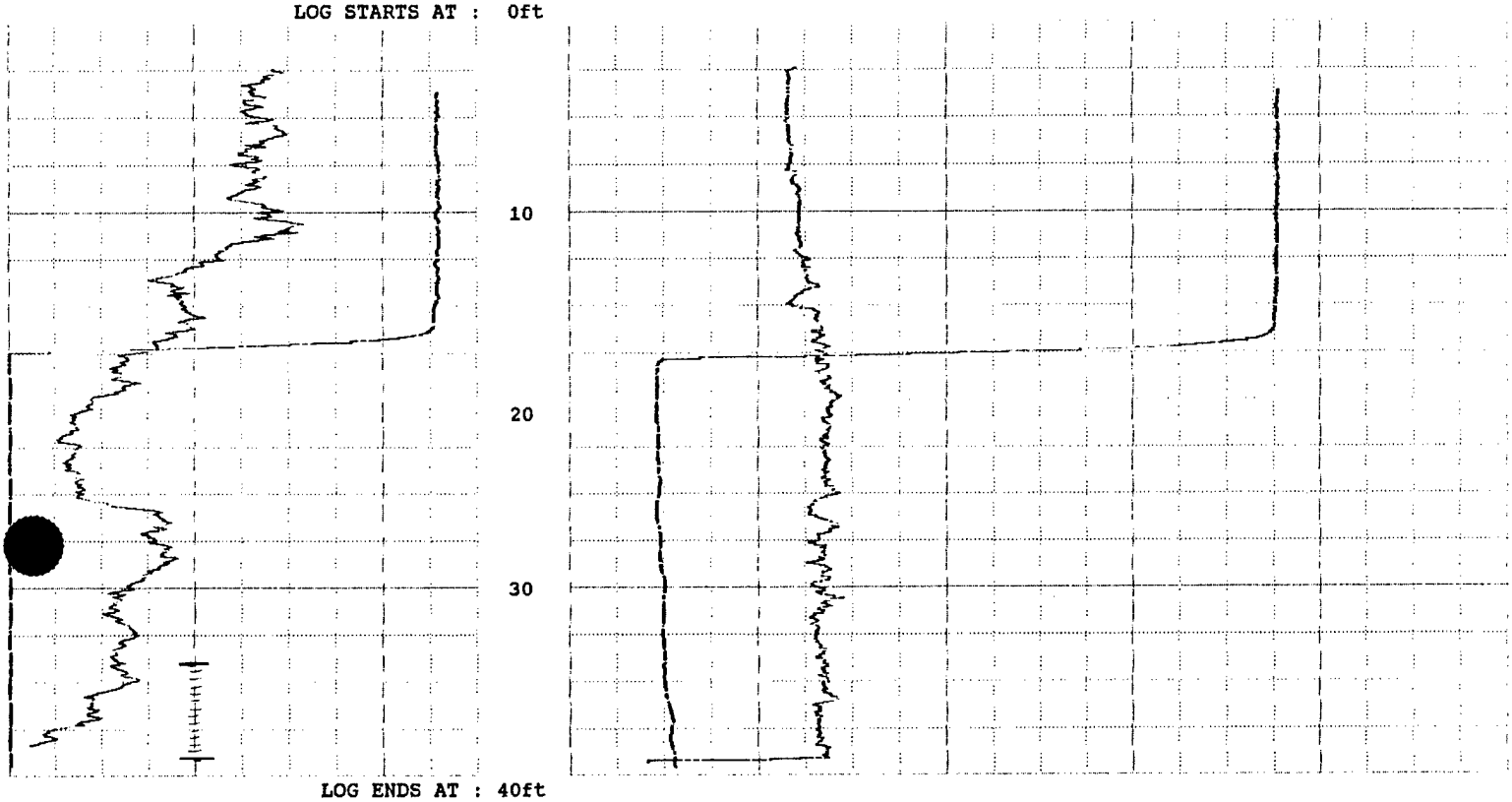
SCALE: 10 ft/in
using
DEPTH CORRECTION

1 - GAMMA
0 API 200

2 - PR
0 ohm 2000

2 - SP
-200 mV 200

3 - CALIPER
4 IN 24



ASSOCIATED ENVIRONMENTAL IND.

HOLE NO: CG39B9743

LOGGED: 07/29/97 at

COMPANY TINKER AIR FORCE BASE
AREA SE/4 SEC 22 T11N R2W
PROSPECT N/A
OPERATOR MM

DRILLING DATA

PERM DAT GL
ELEV
AZIMUTH
INCLIN
HOLE POS
HOLE DIA 9"
DEPTH 50'

CASING DATA

CASE-TYP
CASE-DTH
CASE-DIA
CASE-THK

FLUID DATA

FLD TYPE AUGER
FLUIDLEV

LOGTYPE TD-3

TOOL: Tmrg--Merged Log
Serial Number: 886
Spacer (cm) : n/a

CHANNEL DATA

CHANNEL	AMPLITUDE	RANGE	CHART	AREA	SENSOR OFFSET	FILTER CNST	PLOT TYPE
1 - GAMMA	0.0 -	200.0	0.0 -	10.0	328	4.0	4
2 - PR	0 -	2000	12.0 -	32.0	453	0.0	2
2 - SP	-200 -	200	0.0 -	10.0	453	0.0	2
3 - CALIPER	4.00 -	24.00	12.0 -	32.0	318	0.0	2

Calibration Data

CHANNEL		slope	offset	C1	C2	C3	C4
1 - GAMMA	API	1.000000	0.000000	3568	0.000	0.000	0.000
2 - PR	ohm	0.326204	-569.169	0.000	1745	100.0	2051
2 - SP	mV	-0.89890	3428.191	0.000	3814	1500	2145
3 - CALIPER	IN	0.004103	-6.11253	3.100	2245	6.100	2977

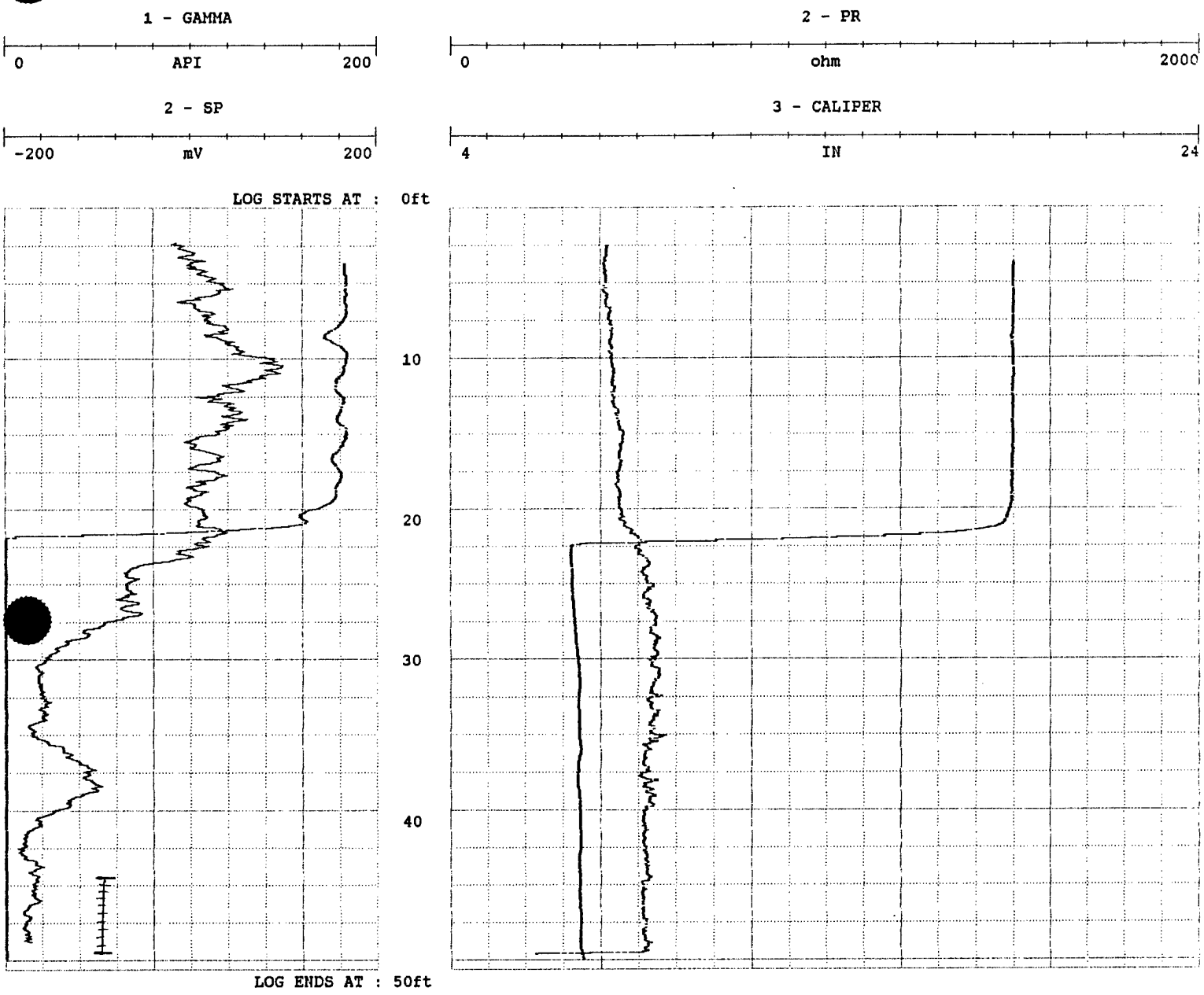
Log No. FILENAME

1 - CG3943 1
2 - CG3943 3
3 - CG3943 4

REPLAY of C:\AUSLOG\TINKER6\Merge Log at 10:33 on 07/29/97

CG39B9743

SCALE: 10 ft/in
using
DEPTH CORRECTION



ASSOCIATED ENVIRONMENTAL IND.

HOLE NO: CG39B9743S

LOGGED: 07/30/97 at

COMPANY TINKER AIR FORCE BASE
AREA SE/4 SEC 22 T11N R2W
PROSPECT N/A
OPERATOR MM

DRILLING DATA

PERM DAT GL
ELEV
AZIMUTH
INCLIN
HOLE POS
HOLE DIA 9"
DEPTH 37'

CASING DATA

CASE-TYP
CASE-DTH
CASE-DIA
CASE-THK

FLUID DATA

FLD TYPE AUGER
FLUIDLEV

LOGTYPE TD-3

TOOL: Tmrg--Merged Log
Serial Number: 886
Spacer (cm) : n/a

CHANNEL DATA

CHANNEL	AMPLITUDE	RANGE	CHART	AREA	SENSOR OFFSET	FILTER CNST	PLOT TYPE
1 - GAMMA	0.0 -	200.0	0.0 -	10.0	328	4.0	4
2 - PR	0 -	2000	12.0 -	32.0	453	0.0	2
2 - SP	-200 -	200	0.0 -	10.0	453	0.0	2
3 - CALIPER	4.00 -	24.00	12.0 -	32.0	318	0.0	2

Calibration Data

CHANNEL		slope	offset	C1	C2	C3	C4
1 - GAMMA	API	1.000000	0.000000	3568	0.000	0.000	0.000
2 - PR	ohm	0.326204	-569.169	0.000	1745	100.0	2051
2 - SP	mV	-0.89890	3428.191	0.000	3814	1500	2145
3 - CALIPER	IN	0.004103	-6.11253	3.100	2245	6.100	2977

Log No. FILENAME

1 - CG3943S 2
2 - CG3943S 4
3 - CG3943S 5

REPLAY of C:\AUSLOG\TINKER6\Merge Log at 15:33 on 07/30/97

CG39B97435

SCALE: 10 ft/in
using
DEPTH CORRECTION

1 - GAMMA

0 API 200

2 - PR

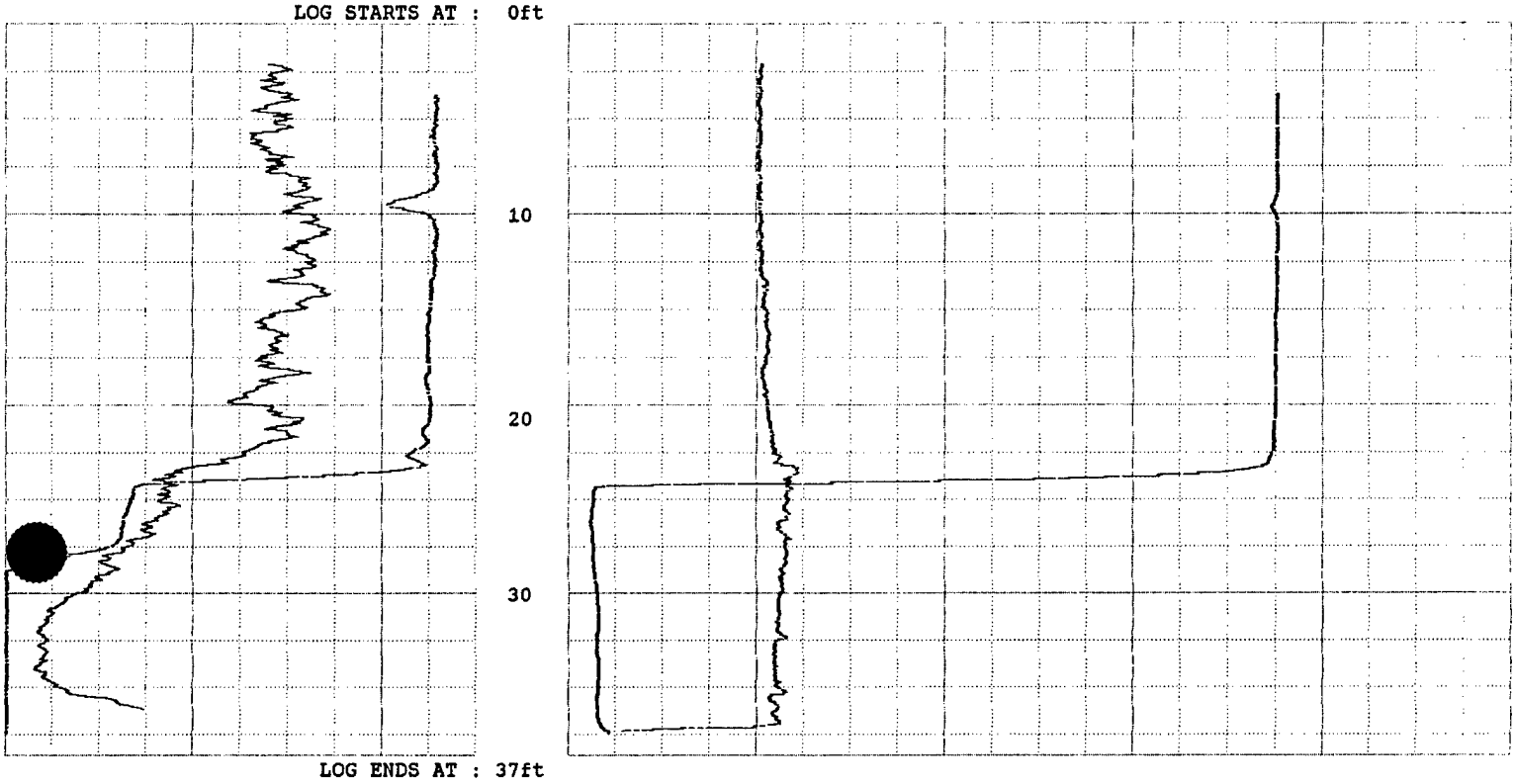
0 ohm 2000

2 - SP

-200 mV 200

3 - CALIPER

4 IN 24



ASSOCIATED ENVIRONMENTAL IND.

HOLE NO: CG39B9745

LOGGED: 07/31/97 at

COMPANY TINKER AIR FORCE BASE
AREA SE/4 SEC 22 T11N R2W
PROSPECT N/A
OPERATOR MM

DRILLING DATA

PERM DAT GL
ELEV
AZIMUTH
INCLIN
HOLE POS
HOLE DIA 9"
DEPTH 45'

CASING DATA

CASE-TYP
CASE-DTH
CASE-DIA
CASE-THK

FLUID DATA

FLD TYPE AUGER
FLUIDLEV

LOGTYPE TD-3

TOOL: Tmrg--Merged Log
Serial Number: 886
Spacer (cm) : n/a

CHANNEL DATA

CHANNEL	AMPLITUDE	RANGE	CHART	AREA	SENSOR OFFSET	FILTER CNST	PLOT TYPE
1 - GAMMA	0.0 -	200.0	0.0 -	10.0	328	4.0	4
2 - PR	0 -	2000	12.0 -	32.0	453	0.0	2
2 - SP	-200 -	200	0.0 -	10.0	453	0.0	2
3 - CALIPER	4.00 -	24.00	12.0 -	32.0	318	0.0	2

Calibration Data

CHANNEL		slope	offset	C1	C2	C3	C4
1 - GAMMA	API	1.000000	0.000000	3568	0.000	0.000	0.000
2 - PR	ohm	0.326204	-569.169	0.000	1745	100.0	2051
2 - SP	mV	-0.89890	3428.191	0.000	3814	1500	2145
3 - CALIPER	IN	0.004103	-6.11253	3.100	2245	6.100	2977

Log No. FILENAME

1 - CG3945 1
2 - CG3945 4
3 - CG3945 5

REPLAY of C:\AUSLOG\TINKER6\Merge Log at 10:34 on 07/31/97

CG39 B9745

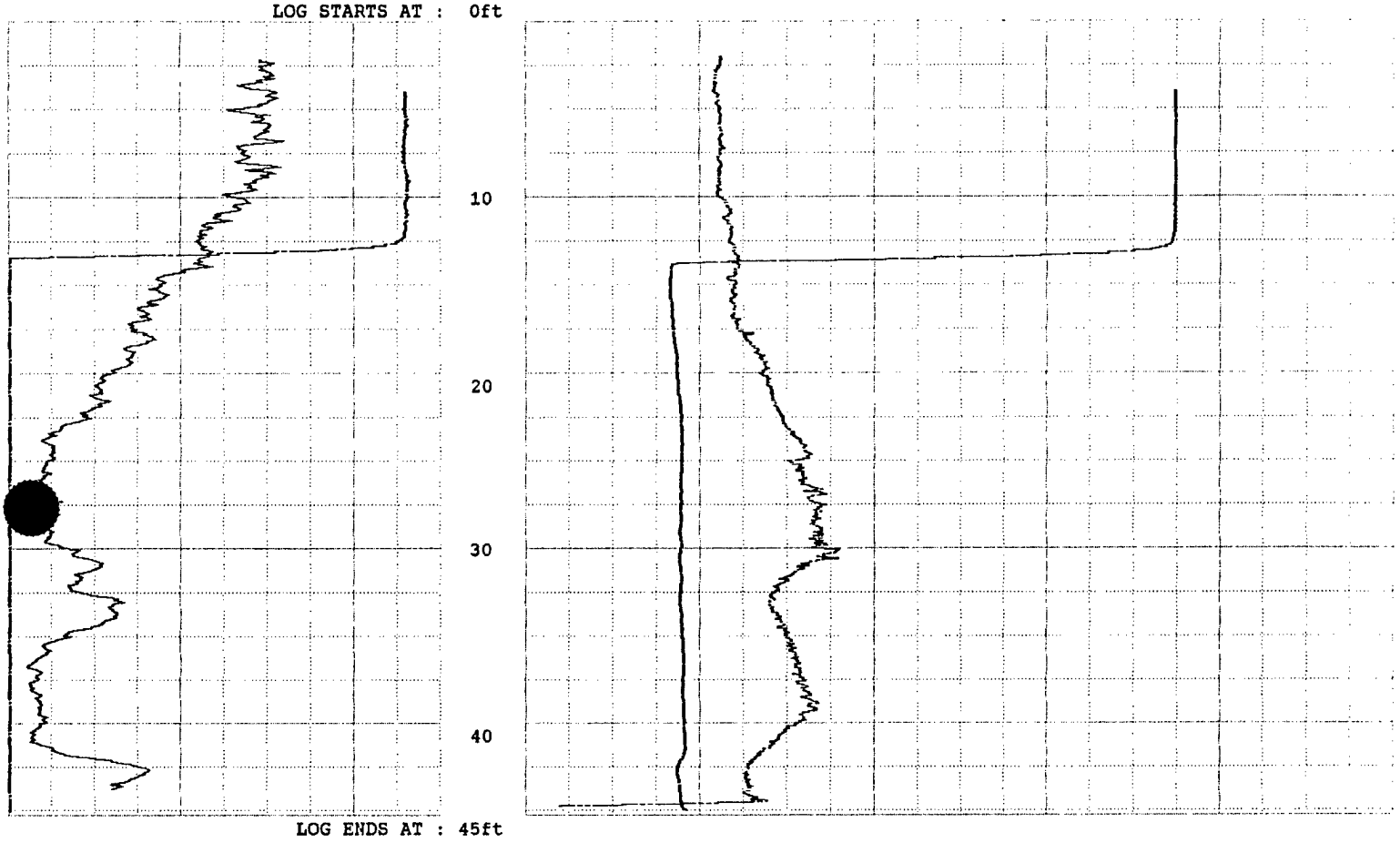
SCALE: 10 ft/in
using
DEPTH CORRECTION

1 - GAMMA
0 API 200

2 - PR
0 ohm 2000

2 - SP
-200 mV 200

3 - CALIPER
4 IN 24



ASSOCIATED ENVIRONMENTAL IND.

HOLE NO: 2-392B

LOGGED: 07/29/97 at

COMPANY TINKER AIR FORCE BASE
AREA SE/4 SEC 22 T11N R2W
PROSPECT N/A
OPERATOR MM

DRILLING DATA

PERM DAT GL
ELEV
AZIMUTH
INCLIN
HOLE POS
HOLE DIA 9"
DEPTH 50'

CASING DATA

CASE-TYP
CASE-DTH
CASE-DIA
CASE-THK

FLUID DATA

FLD TYPE AUGER
FLUIDLEV

LOGTYPE TD-3

TOOL: Tmrg--Merged Log
Serial Number: 886
Spacer (cm) : n/a

CHANNEL DATA

CHANNEL	AMPLITUDE	RANGE	CHART	AREA	SENSOR OFFSET	FILTER CNST	PLOT TYPE
1 - GAMMA	0.0 -	200.0	0.0 -	10.0	328	4.0	4
2 - PR	0 -	2000	12.0 -	32.0	453	0.0	2
2 - SP	-200 -	200	0.0 -	10.0	453	0.0	2
3 - CALIPER	4.00 -	24.00	12.0 -	32.0	318	0.0	2

Calibration Data

CHANNEL		slope	offset	C1	C2	C3	C4
1 - GAMMA	API	1.000000	0.000000	3568	0.000	0.000	0.000
2 - PR	ohm	0.326204	-569.169	0.000	1745	100.0	2051
2 - SP	mV	-0.89890	3428.191	0.000	3814	1500	2145
3 - CALIPER	IN	0.004103	-6.11253	3.100	2245	6.100	2977

Log No. FILENAME

1 - 2329B 1
2 - 2329B 3
3 - 2329B 4

REPLAY of C:\AUSLOG\TINKER6\Merge Log at 15:26 on 07/29/97

2-392B

SCALE: 10 ft/in
using
DEPTH CORRECTION

1 - GAMMA

0 API 200

2 - PR

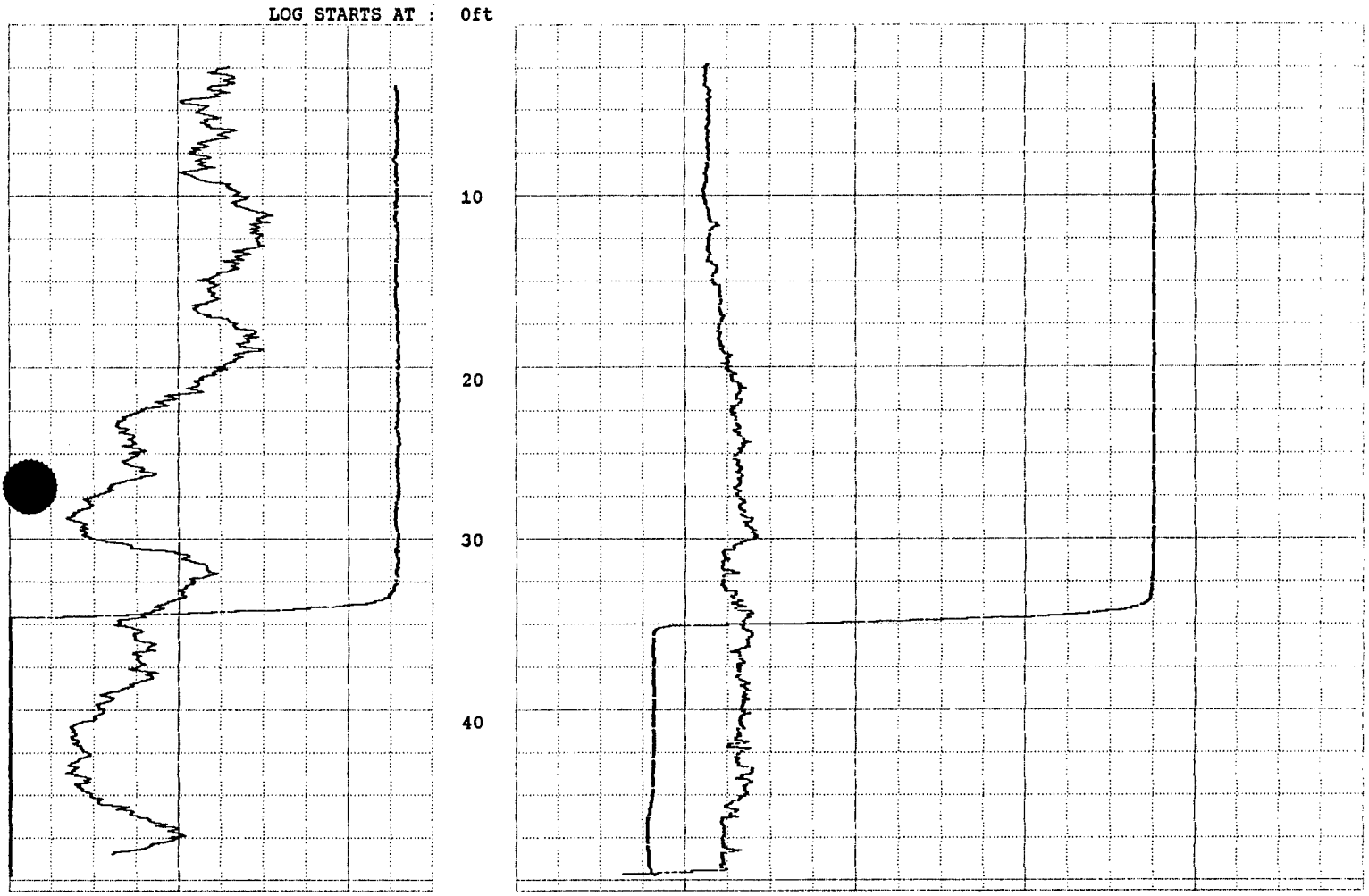
0 ohm 2000

2 - SP

-200 mV 200

3 - CALIPER

4 IN 24



ASSOCIATED ENVIRONMENTAL IND.

HOLE NO: 2-393B

LOGGED: 07/30/97 at

COMPANY TINKER AIR FORCE BASE
AREA SE/4 SEC 22 T11N R2W
PROSPECT N/A
OPERATOR MM

DRILLING DATA

PERM DAT GL
ELEV
AZIMUTH
INCLIN
HOLE POS
HOLE DIA 9"
DEPTH 50'

CASING DATA

CASE-TYP
CASE-DTH
CASE-DIA
CASE-THK

FLUID DATA

FLD TYPE AUGER
FLUIDLEV

LOGTYPE TD-3

TOOL: Tmrg--Merged Log
Serial Number: 886
Spacer (cm) : n/a

CHANNEL DATA

CHANNEL	AMPLITUDE	RANGE	CHART	AREA	SENSOR OFFSET	FILTER CNST	PLOT TYPE
1 - GAMMA	0.0 -	200.0	0.0 -	10.0	328	4.0	4
2 - PR	0 -	2000	12.0 -	32.0	453	0.0	2
2 - SP	-200 -	200	0.0 -	10.0	453	0.0	2
3 - CALIPER	4.00 -	24.00	12.0 -	32.0	318	0.0	2

Calibration Data

CHANNEL		slope	offset	C1	C2	C3	C4
1 - GAMMA	API	1.000000	0.000000	3568	0.000	0.000	0.000
2 - PR	ohm	0.326204	-569.169	0.000	1745	100.0	2051
2 - SP	mV	-0.89890	3428.191	0.000	3814	1500	2145
3 - CALIPER	IN	0.004103	-6.11253	3.100	2245	6.100	2977

Log No. FILENAME

1 - 2393B 1
2 - 2393B 3
3 - 2393B 4

REPLAY of C:\AUSLOG\TINKER6\Merge Log at 12:13 on 07/30/97

2-393B

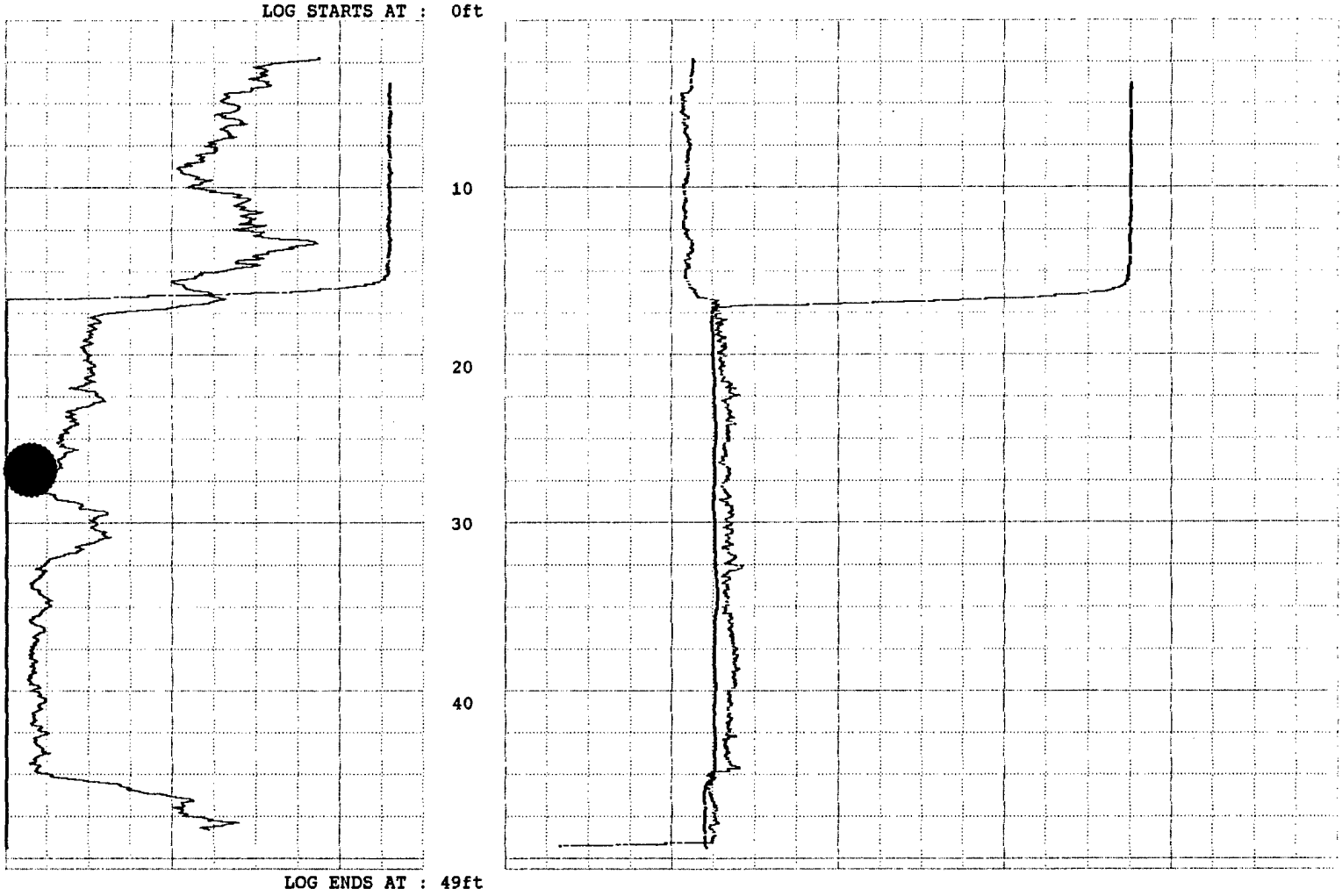
SCALE: 10 ft/in
using
DEPTH CORRECTION

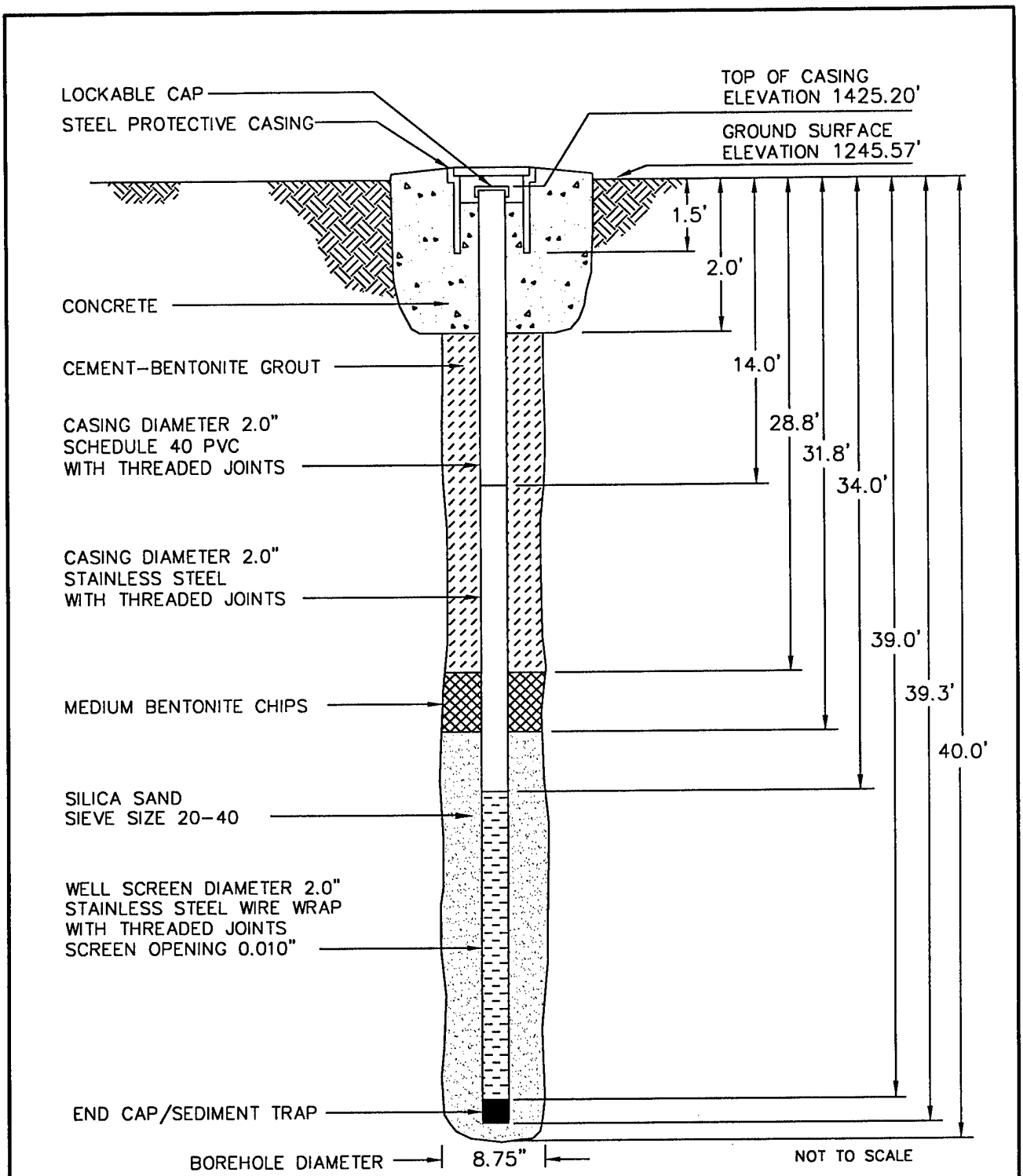
1 - GAMMA
0 API 200

2 - PR
0 ohm 2000

2 - SP
-200 mV 200

3 - CALIPER
4 IN 24





STATIC WATER LEVEL = 12.7' FEET BELOW GROUND SURFACE ON AUGUST 2, 1997

MONITORING WELL CONSTRUCTION-SINGLE CASED FLUSH MOUNT

WELL NUMBER: **CG39-B97-41**

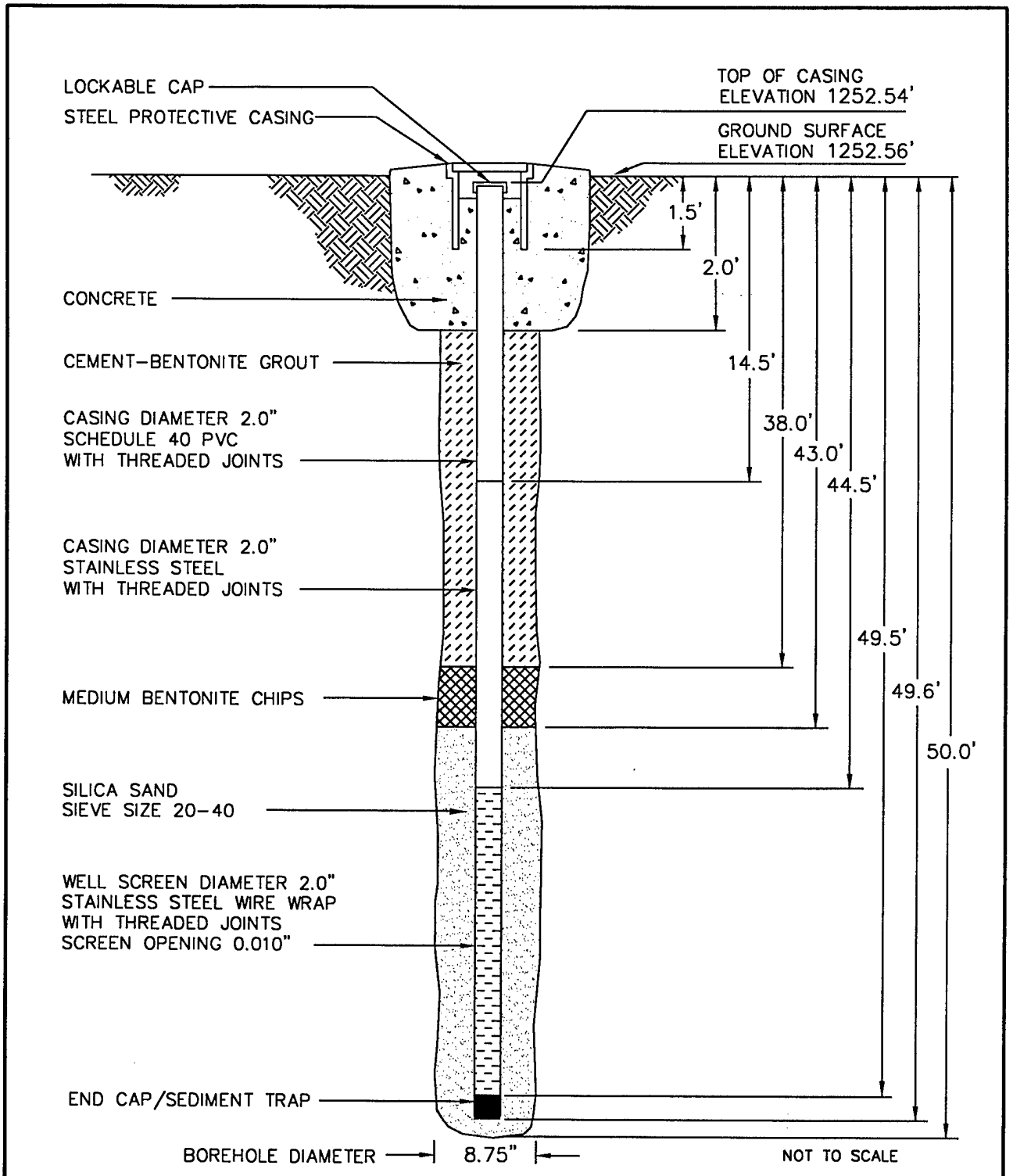
PROJECT NAME: **FTA2 RNA TS**

LOCATION: **TINKER AFB, OKLAHOMA**

COMPLETION DATE JULY 28, 1997

GEOLOGIST BMH

L:\TINKER\RPT-FTA2\MW-DIAG1.DWG



STATIC WATER LEVEL = 20.2' FEET BELOW GROUND SURFACE ON AUGUST 2, 1997

MONITORING WELL CONSTRUCTION-SINGLE CASED FLUSH MOUNT

WELL NUMBER: **CG39-B97-43D**

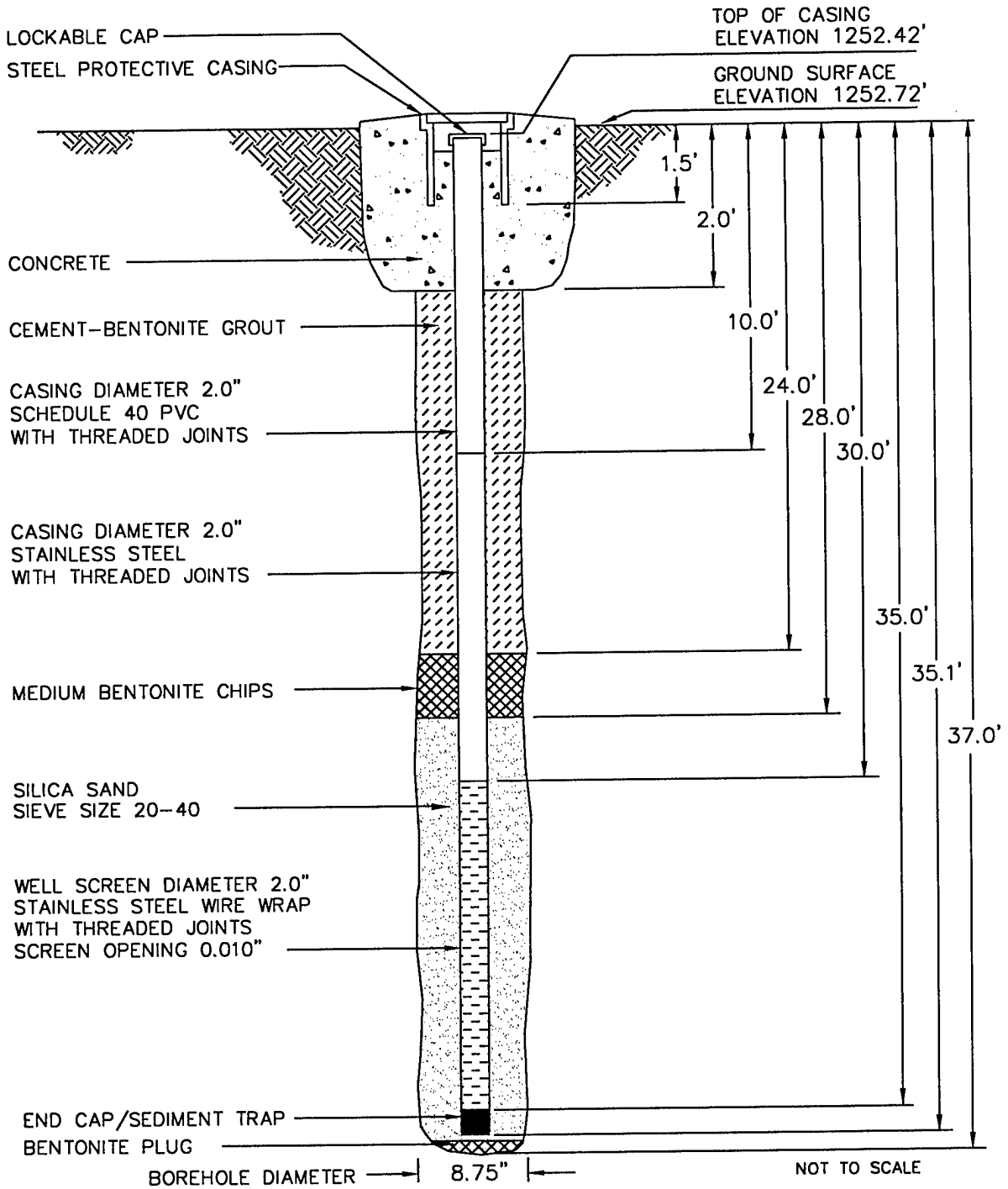
PROJECT NAME: **FTA2 RNA TS**

LOCATION: **TINKER AFB, OKLAHOMA**

COMPLETION DATE JULY 29, 1997

GEOLOGIST BMH

L:\TINKER\RPT-FTA2\MW-DIAG1.DWG



STATIC WATER LEVEL = 20.2' FEET BELOW GROUND SURFACE ON AUGUST 2, 1997

MONITORING WELL CONSTRUCTION-SINGLE CASED FLUSH MOUNT

WELL NUMBER: **CG39-B97-43S**

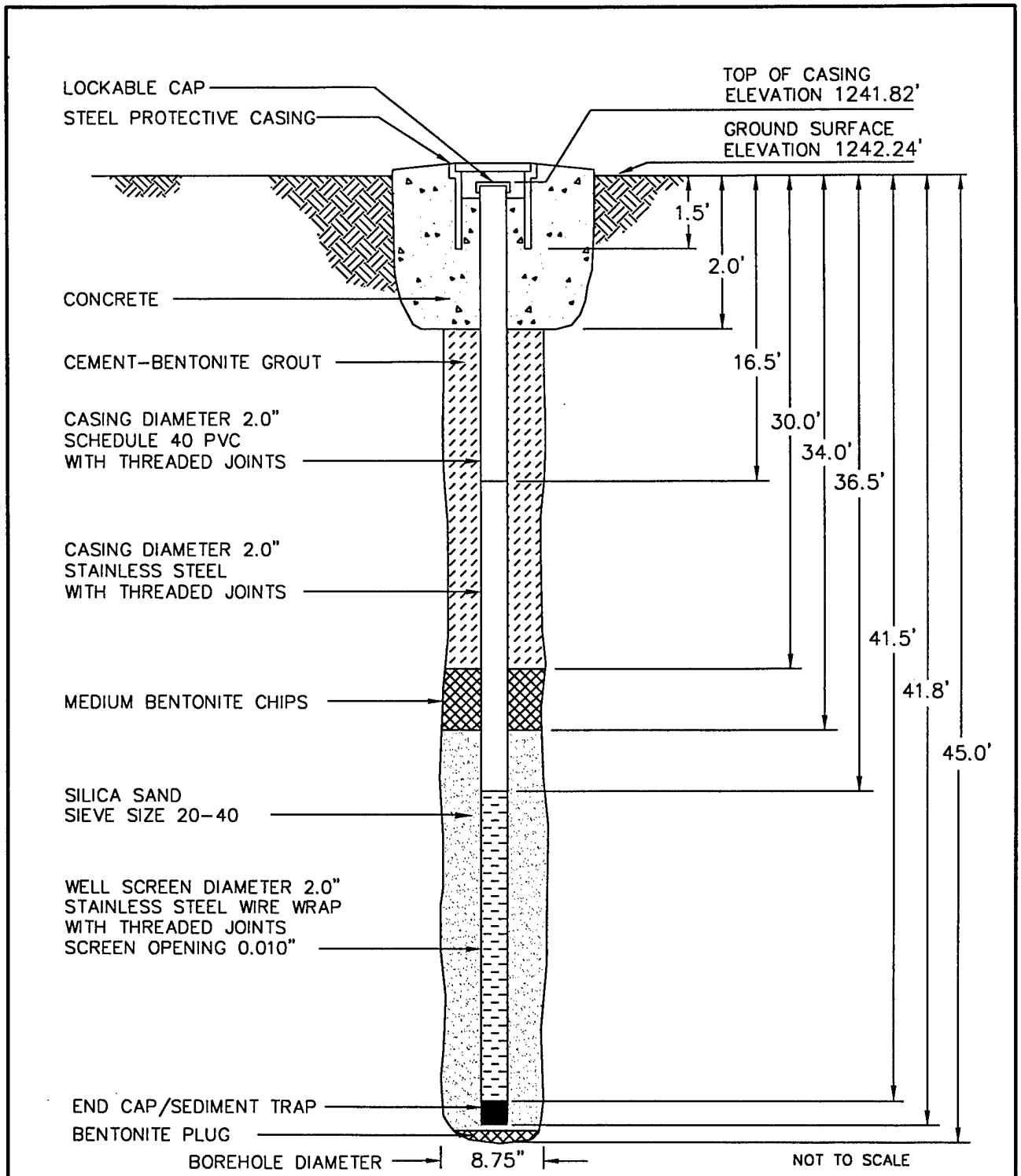
PROJECT NAME: **FTA2 RNA TS**

LOCATION: **TINKER AFB, OKLAHOMA**

COMPLETION DATE JULY 30, 1997

GEOLOGIST BMH

L:\TINKER\RPT-FTA2\MW-DIAG1.DWG



STATIC WATER LEVEL = 12.5' FEET BELOW GROUND SURFACE ON AUGUST 2, 1997

MONITORING WELL CONSTRUCTION-SINGLE CASED FLUSH MOUNT

WELL NUMBER: **CG39-B97-45**

PROJECT NAME: **FTA2 RNA TS**

LOCATION: **TINKER AFB, OKLAHOMA**

COMPLETION DATE JULY 31, 1997

GEOLOGIST BMH

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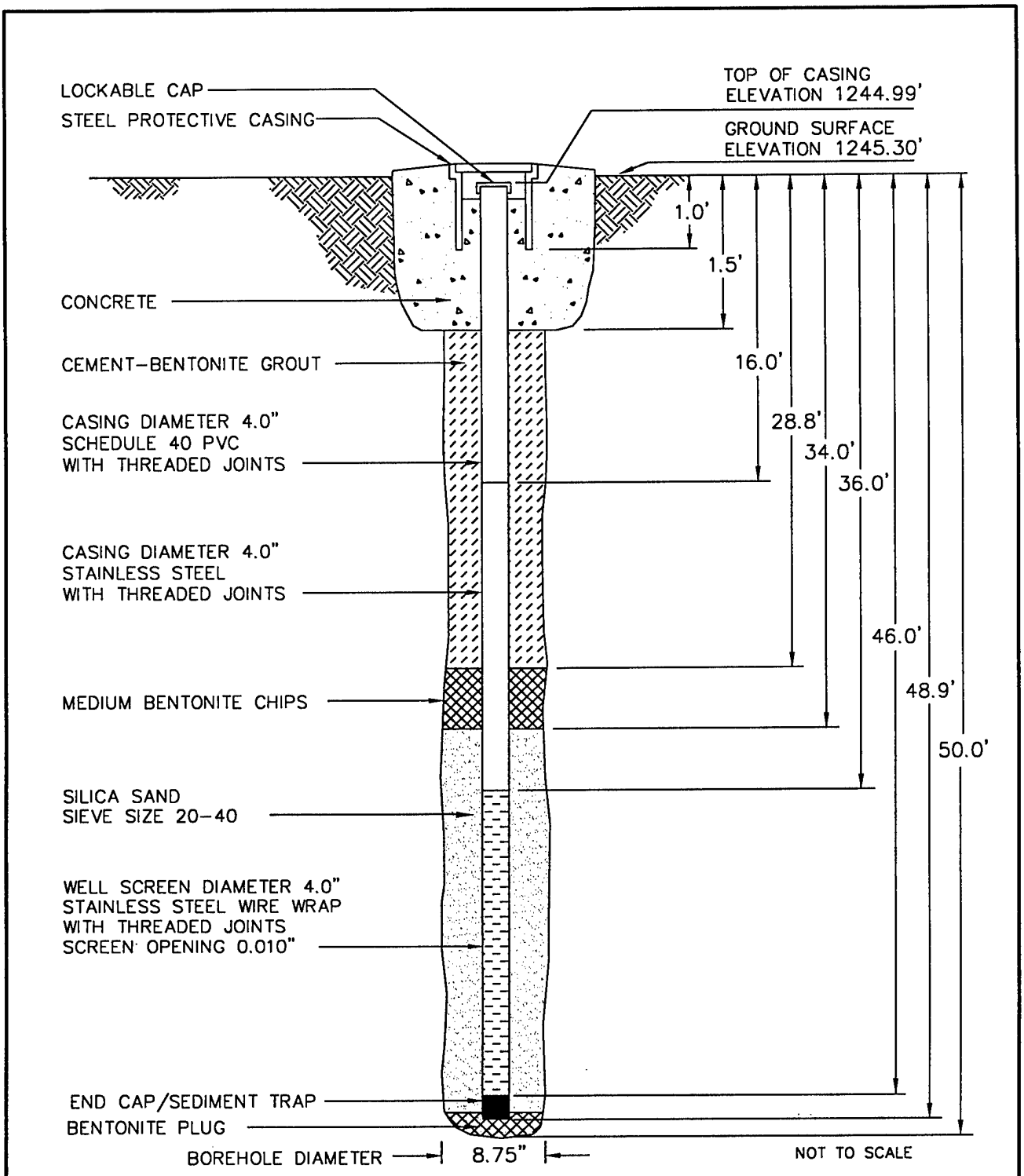


STATIC WATER LEVEL = 15.7' FEET BELOW GROUND SURFACE ON AUGUST 2, 1997

MONITORING WELL CONSTRUCTION-SINGLE CASED FLUSH MOUNT

WELL NUMBER: **2-392B**

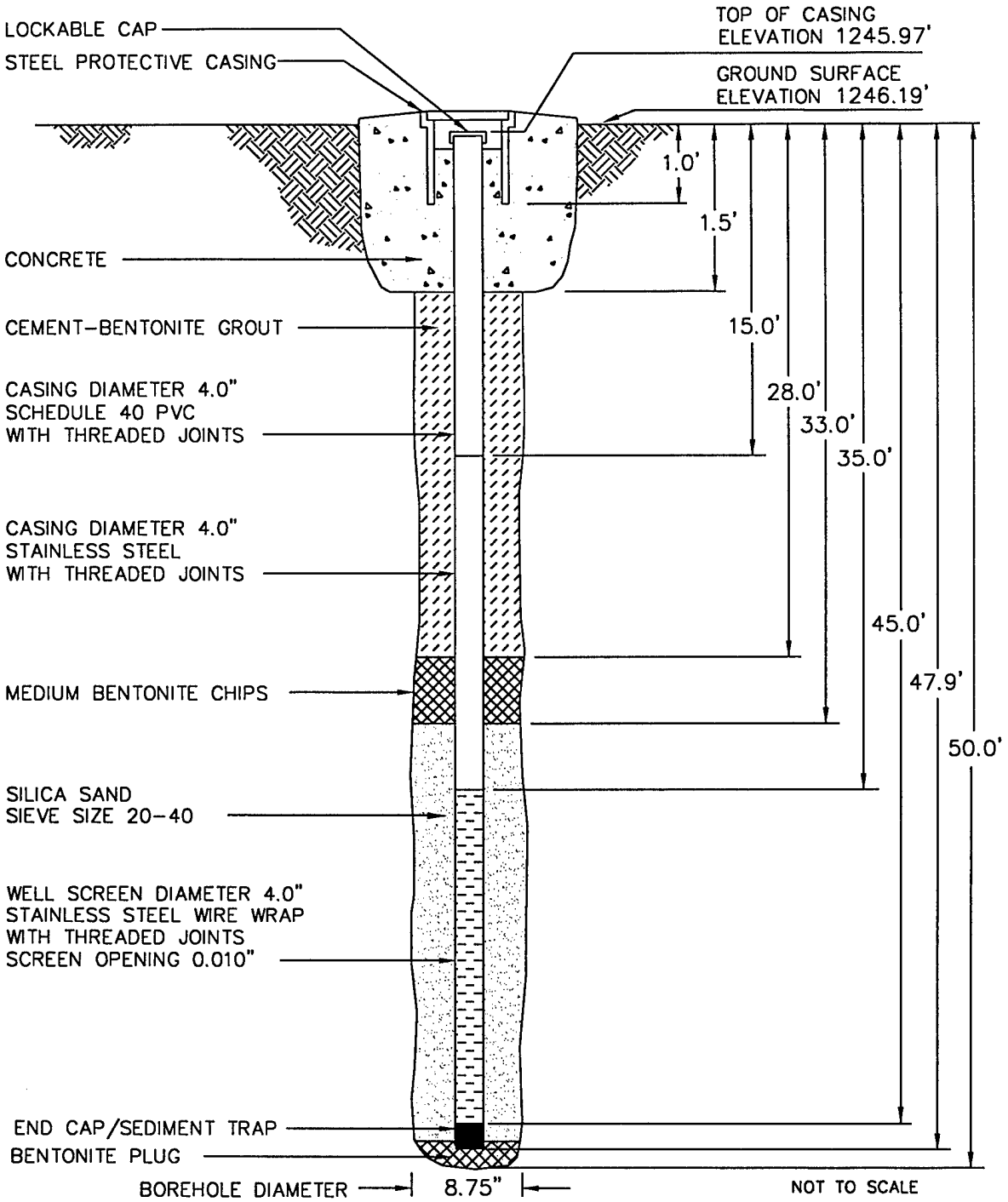
PROJECT NAME: **FTA2 RNA TS**

LOCATION: **TINKER AFB, OKLAHOMA**

COMPLETION DATE JULY 29, 1997

GEOLOGIST BMH

L:\TINKER\RPT-FTA2\MW-DIAG2.DWG



STATIC WATER LEVEL = 16.1' FEET BELOW GROUND SURFACE ON AUGUST 2, 1997

MONITORING WELL CONSTRUCTION-SINGLE CASED FLUSH MOUNT

WELL NUMBER: **2-393B**

PROJECT NAME: **FTA2 RNA TS**

LOCATION: **TINKER AFB, OKLAHOMA**

COMPLETION DATE JULY 30, 1997

GEOLOGIST BMH

L:\TINKER\RPT-FTA2\MW-DIAG2.DWG

WELL DEVELOPMENT RECORD

Project Name: Tinker AFB - FTA2
Project Number: 729691.34020
Well Designation: C639-B97-41d
Development Method: bail (pump) surge airlift other _____

Bailer Volume: NA — BV=(ID/24)^2(L)(PI)(7.48) gallons/bailer
Total Well Depth (TD): 39' — Water Column (TD-WL): 26.7'
Static Water Level (WL): 12.3' — Casing Diameter: 2.0"
Casing Volume: 4.35 gallons — CV =(CID/24)^2(TD-WL)(PI)(7.48) gallons/casing
Bails/Casing Volume: NA — CV/BV

Development Date: 8/1197

Time	Casing No./ Bailer No./ (Gallons)	Temp. °C	pH	Electrical Conductivity µs/cm	Dissolved Oxygen (mg/L)	Redox Potential (mv)	Turbidity (ntu)	Visual Appearance
1505	50	19.6	7.04	824	6.6	-	250	Cloudy
1538	100	19.5	7.18	822	-	-	6	Clear
1558	150	20.3	7.14	817	-	-	1.5	Clear

Total Volume Removed: ~34 (casing volumes) 150 (gallons)
Weather: Sunny and Hot, 90s°F
Notes: Sampled - Purged Later by EPA | Parsons ES

Developed By: Bmit | AEI Corp.

WELL DEVELOPMENT RECORD

Project Name: Tinker AFB - FTA 2
Project Number: 729691.34020
Well Designation: CG39-B97-43S
Development Method: bail (pump) surge airlift other _____

Bailer Volume: NA — BV=(ID/24)^2(L)(PI)(7.48) gallons/bailer
Total Well Depth (TD): 35' — Water Column (TD-WL): 15.1'
Static Water Level (WL): 19.9' — Casing Diameter: 2.0"
Casing Volume: 2.5 gallons — CV =(CID/24)^2(TD-WL)(PI)(7.48) gallons/casing
Bails/Casing Volume: NA — CV/BV

Development Date: 8/14/97

Time	Casing No./ Bailer No./ (Gallons)	Temp. °C	pH	Electrical Conductivity ms/cm	Dissolved Oxygen (mg/L)	Redox Potential (mv)	Turbidity (ntu)	Visual Appearance
0955	50	19.0	7.07	1325	—	—	—	Cloudy
1013	90	18.7	7.18	1265	—	—	—	Cloudy
1025	125	18.5	7.20	1273	—	—	82.7	Sl. cloudy
1035	150	18.2	7.26	1271	—	—	11.5	Clear
1045	175	18.2	7.27	1265	—	—	2.3	Clear

Total Volume Removed: ~70 (casing volumes) 175+ (gallons)
Weather: Sunny & Warm
Notes: Purge da Sampled by Parsons ES / EPA (See GW Sampling Forms)

Developed By: TSMH / AEI Corp.

WELL DEVELOPMENT RECORD

Project Name: Tinker AFB - FDA2
Project Number: 729691.34020
Well Designation: C639-B97-43d
Development Method: bail (pump) surge airlift other _____

Bailer Volume: NA — BV=(ID/24)^2(L)(PI)(7.48) gallons/bailer
Total Well Depth (TD): 49.5' — Water Column (TD-WL): 29.3
Static Water Level (WL): 20.2' — Casing Diameter: 2.0"
Casing Volume: 4.8 gallons. — CV =(CID/24)^2(TD-WL)(PI)(7.48) gallons/casing
Bails/Casing Volume: NA — CV/BV

Development Date: 8/1/97

Time	Casing No./ Bailer No./ (Gallons)	Temp. °C	pH	Electrical Conductivity ms/cm	Dissolved Oxygen (mg/L)	Redox Potential (mv)	Turbidity (ntu)	Visual Appearance
0940	25	19.5	7.62	1115	-	—	—	Cloudy
1005	75	18.8	7.58	1085	3.75	—	-	"
1020	125	18.5	7.49	1071	4.40	—	-	Slightly Cloudy
1030	175	18.4	7.41	1073	4.50	—	32.6	Very Sl. Cloudy
1045	200	18.4	7.40	1074	4.55	—	6.4	Clear

Total Volume Removed: ~42 (casing volumes) 200+ (gallons)
Weather: Clear, Sunny, Hot, 90°F's
Notes: Sampled after purging by EPA/Parsons ES

Developed By: BMH / AEI Corp.

WELL DEVELOPMENT RECORD

Project Name: Tinker AFB - FTAZ
Project Number: 729691.34020
Well Designation: CG39-897-45
Development Method: bail (pump) surge airlift other _____

Bailer Volume: NA — BV=(ID/24)^2(L)(PI)(7.48) gallons/bailer
Total Well Depth (TD): 42' — Water Column (TD-WL): 29.9'
Static Water Level (WL): 12.1' — Casing Diameter: 2.0"
Casing Volume: 4.9 gallons — CV =(CID/24)^2(TD-WL)(PI)(7.48) gallons/casing
Bails/Casing Volume: NA — CV/BV

Development Date: 8/4/97

Time	Casing No./ Bailer No./ (Gallons)	Temp. °C	pH	Electrical Conductivity ms/cm	Dissolved Oxygen (mg/L)	Redox Potential (mv)	Turbidity (ntu)	Visual Appearance
1115	30	18.8	7.27	902	—	—	—	Cloudy Brown
1140	100	17.6	7.31	844	—	—	85	Sl. Cloudy
1150	130	17.5	7.30	868	—	—	25.9	Sl. Cloudy
1200	175	17.5	7.32	854	—	—	5.4	Clear

Total Volume Removed: ~36 (casing volumes) 175 (gallons)
Weather: Sunny & Hot - 90's°F
Notes: Sampled & Purged by EPA/Parsons ES

Developed By: BMH / AEI Corp

WELL DEVELOPMENT RECORD

Project Name: Tinker AFB - FTA2
Project Number: 729691.34020
Well Designation: 2-392B
Development Method: bail (pump) surge airlift other _____

Bailer Volume: NA — BV=(ID/24)^2(L)(PI)(7.48) gallons/bailer
Total Well Depth (TD): 46' — Water Column (TD-WL): 30.6'
Static Water Level (WL): 15.4' — Casing Diameter: 4.0"
Casing Volume: 20 gal. — CV =(CID/24)^2(TD-WL)(PI)(7.48) gallons/casing
Bails/Casing Volume: NA — CV/BV

Development Date: 8/1 to 8/4/97

	Time	Casing No./ Bailer No./ (Gallons)	Temp. °C	pH	Electrical Conductivity uS/cm	Dissolved Oxygen (mg/L)	Redox Potential (mv)	Turbidity (ntu)	Visual Appearance
8/1	0912	80	22.1	7.82	739	5.63	NR	NR	Muddy Brown
8/4	1425	200	21.3	7.36	680	5.56	—	105	Sl. Cloudy
8/1	1435	210	—	—	—	—	—	40	Clear
8/4	1655	250	19.5	7.32	679	6.15	—	72	Sl. Cloudy
	1730	300	19.4	7.31	680	6.7	—	10.9	Clear

Total Volume Removed: 15 (casing volumes) 300 (gallons)
Weather: Clear - Partly Cloudy, Hot
Notes: Well Pumped dry ~ 20-40 gallons depending on how hard it was pumped. Well took 15-20 min. to recharge, ~30 min to within a couple feet of static. Developed several times on 8/1 up to ~ 150-160 gallons, then again on 8/4/97

Developed By: BMH | AEI Corp

WELL DEVELOPMENT RECORD

Project Name: Tinker AFB - FTA2
Project Number: 729691.34020

Well Designation: 2-393B

Development Method: bail (pump) surge airlift other _____

Bailer Volume: NA BV=(ID/24)^2(L)(PI)(7.48) gallons/bailer

Total Well Depth (TD): 41' Water Column (TD-WL): 25.1'

Static Water Level (WL): 15.91' Casing Diameter: 4.0"

Casing Volume: 16.3 gal. CV =(CID/24)^2(TD-WL)(PI)(7.48) gallons/casing

Bails/Casing Volume: NA CV/BV

Development Date: 8/4/97

Time	Casing No./ Bailer No./ Gallons	Temp. °C	pH	Electrical Conductivity us/cm	Dissolved Oxygen (mg/L)	Redox Potential (mv)	Turbidity (ntu)	Visual Appearance
1240	50	18.6	7.31	1202	—	—	—	Cloudy Brown
1400	200	18.2	7.60	1190	—	—	←	45.5
1415	250	17.8	7.49	1185	—	—	—	Sl. Cloudy
1430	300	17.5	7.39	1179	—	—	←	10.8 (BMH)
1445	350	17.5	7.38	1180	—	—	←	6.16

Total Volume Removed: 21 (casing volumes) 350+ (gallons)

Weather: Clear to Partly Cloudy, Hot

Notes: _____

Developed By: BMH / AEI Corp.

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - FTA2
Sampling Dates: 7/31/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-62B
(number)

REASON FOR SAMPLING: [✓] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 7/31/97 at 1625 a.m./p.m.
SAMPLE COLLECTED BY: CH/DK of Parsons/EPA.
WEATHER: sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): toc @ 2" bgs

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 DI water
Items Cleaned (List): probes

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 14.5' btc FT. BELOW DATUM
Measured with: water meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: clear
Turbidity:
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: dedicated grunfos
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. 2-52B (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:

Time	16:28	16:30	16:33	16:36			Measured with
Temp (°C)	18.8	18.9	18.8	18.8			
pH	7.26	7.33	7.35	7.34			
Cond (µS/cm)	1433	1437	1437	1441			
DO (mg/L)	0.2	0.2	0.3	0.2			
Redox (mV)	62.5	55.8	52.7	50.7			
Salinity							

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOA
2 Serum
2 250 mL

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method sulfuric acid Containers: 1 250 mL, 2 serum
Method sodium phosphate Containers: 4 VOA
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 - FTA2
Sampling Dates: 7/31/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-63 A
(number)

REASON FOR SAMPLING: [✓] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 7/31/97 at 14:05 a.m./p.m.
SAMPLE COLLECTED BY: Craig Harmon of Parsons ES / USEPA
Don Kemphill
WEATHER: sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top of 0.3 ft bgs

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 → used dedicated grunfos pump
Items Cleaned (List):

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:
WATER DEPTH ~~55.8 bgs~~ 54.8' btc FT. BELOW DATUM
Measured with: depth meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: ~~clear~~ orange
Turbidity: high
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: dedicated grunfos
Volume Removed: 7 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. 2-63A (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:

Time	14:05	14:09	14:14	14:20			Measured with
Temp (°C)	18.8	19.0	18.9	18.9			
pH 7.21	~~7.21~~	~~7.23~~	~~7.25~~ stat	7.31			
Cond (µS/cm)	661	660	655	654			
DO (mg/L)	7.0	7.2	7.2	7.2			
Redox (mV)	17.1	29.5	—	47.8			
Salinity							

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 - VOA
2 serum
2 250-mL

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method sulfuric acid Containers: 2 serum, 1 250-mL
Method sodium phosphate Containers: 4 - VOC
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 - FTA2
Sampling Dates: 7/31/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-63B
(number)

REASON FOR SAMPLING: [x] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 7/31/97 at 13:15 a.m./p.m.
SAMPLE COLLECTED BY: DK/CH of USEPA/Parsons ES
WEATHER: Sunny - hot
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC @ 0.3 ft bgs

MONITORING WELL CONDITION:
[x] LOCKED: [x] 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 [x] EQUIPMENT CLEANED BEFORE USE WITH → used dedicated grunfos pump
Items Cleaned (List):

2 [x] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH TOC - 12.1' (12.4' bgs) FT. BELOW DATUM
Measured with: Depth meter

3 [x] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: Clear
Turbidity:
Odor:
Other Comments:

4 [x] WELL EVACUATION:
Method: Grunfos
Volume Removed: 6 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. 2-63B (Cont'd)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of: stainless steel
[✓] Pump, type: Grundfos
[ ] Other, describe:

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

6 [ ] ON-SITE MEASUREMENTS:

Time	13:35	13:38	13:41	13:43			Measured with
Temp (°C)	19.4	19.9	19.9	19.9			Orion 840
pH	—	—	7.33	7.35			Orion 250A
Cond (µS/cm)	1513	1516	1517	1516			Orion 122
DO (mg/L)	0.5	0.4	0.4	0.6			Orion 540
Redox (mV)	129.2	100.2	84.6	79.4			Orion 250A
Salinity							

7 [ ] SAMPLE CONTAINERS (material, number, size): 4- VOA (2 dups) w/ preservative (w/ sodium phosph.
2- serum w/ sulfuric acid
2 250 mL Nalgene bottles (w/ sulfuric acid)

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method____ Containers:____
Method____ Containers:____
Method____ Containers:____

[ ] Preservatives added:

Method sulfuric acid Containers: 2 serum, 1 250-mL
Method sodium phosphate Containers: 4- VOA
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 - FTA2
Sampling Dates: _____

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-61A
(number)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/1 at 5:24 a.m./p.m. 0855 (BMH)
SAMPLE COLLECTED BY: BH/CH of Parsons.
WEATHER: sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
[ ] LOCKED: [X] 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 [X] EQUIPMENT CLEANED BEFORE USE WITH _____
Items Cleaned (List): _____

2 [X] PRODUCT DEPTH none FT. BELOW DATUM
Measured with: _____

WATER DEPTH 57.37' btc FT. BELOW DATUM
Measured with: water meter

3 [X] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: slight orange color
Turbidity: low - medium
Odor: none
Other Comments: _____

4 [X] WELL EVACUATION:
Method: dedicated bailers
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. 2-64A (Cont'd)

5 [H SAMPLE EXTRACTION METHOD:

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

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

6 [H ON-SITE MEASUREMENTS:

Volume (Eq.)	1.5	2.5	4.0	6.0			
Time	0826	0833	0842	0850			Measured with
Temp (°C)	19.7	20.9	20.9	20.2			YSI 55
pH	7.74	7.69	7.68	7.69			Orion 250A
Cond (µS/cm)	665	667	668	666			Orion 122
DO (mg/L)	6.41	6.09	6.02	6.05			YSI 55
Redox (mV)	~~225~~ 144	118.2	125.3	121.9			Orion 250A
Salinity	NR	NR	NR	NR			—

7 [H SAMPLE CONTAINERS (material, number, size): 2 VOAs
2 Symm Jars
2 250 ml. Plastic

8 [H ON-SITE SAMPLE TREATMENT:

[ ] Filtration; ~~Preservatives~~ Bomb

Method H Containers: Symm Jars
Method Sodium Phosphate Containers: VOAs
Method _____ Containers: Fixed Inorganics

[ ] Preservatives added:

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

9 [H CONTAINER HANDLING:

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

10 [H OTHER COMMENTS: Samples Handled by EPA

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - FTA2
Sampling Dates: 8/1

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-64B
(number)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/1/97 at 1120 a.m./p.m. (0810 PDT)
SAMPLE COLLECTED BY: BH/CH of Parsons ES.
WEATHER: clear & sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): no water depth measurement, used historical values (meter out)

MONITORING WELL CONDITION:
[ ] LOCKED: [Y] 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 DI water
Items Cleaned (List): probes

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH none (broken meter) FT. BELOW DATUM
Measured with:

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: clear
Turbidity: low
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: dedicated grundfos
Volume Removed: 7 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. 2-64B (Cont'd)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Volume (gal.) 2.0 4.0 6.0

Time	0743	0953	0806				Measured with
Temp (°C)	19.3	20.2	20.6				YSI 55
pH	NR	NR	NR				
Cond (µS/cm)	853	848	848				Orion 122
DO (mg/L)	2.33	2.10	1.84				YSI 54
Redox (mV)	123.4	111.3	123.5				Orion 250A
Salinity	NR	NR	NR				

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOA
2 125-mL
2 Serum

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method sulfuric acid Containers: 2 serum 1 125-mL
Method sodium bisulfate Containers: 4 VOA
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 - FTA2
Sampling Dates: 8/1/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-65A
(number)

REASON FOR SAMPLING: [✓] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/1/97 at 1352 a.m./p.m.
SAMPLE COLLECTED BY: CW/DK of Parsons/USEPA
WEATHER: Sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

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 probes
Items Cleaned (List): kim-wipe

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 61.5' btc FT. BELOW DATUM
Measured with: water meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: orange
Turbidity: high
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: dedicated grunfos
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. 2-65A (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:

volume(gal)	2.0	5.0	7.2				
Time	1352	1402	1407				Measured with
Temp (°C)	19.1	19.9	19.9				Orion 840
pH	7.69	7.46	7.67				Orion 250A
Cond (µS/cm)	535	577	576				Orion 122
DO (mg/L)	4.4	4.2	4.2				Orion 840
Redox (mV)	11.4	-45.0	-38.3				Orion 250A
Salinity	NR	NR	NR				

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 Serum
2 125-mL

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[√] Preservatives added:

Method sulfuric acid Containers: 1 125-mL, 2 serum
Method sodium phosphate Containers: 4 VOAs
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 - FTA2
Sampling Dates: 8/1/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-65 B
(number)

REASON FOR SAMPLING: [✓] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/1/97 at 1305 a.m./p.m.
SAMPLE COLLECTED BY: CH/DR of Parsons ES/USEPA
WEATHER: Sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

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 Kim-Wipe
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 17.2' btc FT. BELOW DATUM
Measured with: water meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: clear
Turbidity: low
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: dedicated grunfos
Volume Removed: ~15 gallons
Observations: Turbidity (clear slightly cloudy very cloudy)
Water level (rose fell no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. 2-65B (Cont'd)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

volume(gal)	4.0	12.0	15.0				
Time	1305	1325	1335				Measured with
Temp (°C)	19.8	18.7	18.8				
pH	6.62	7.21	7.13				
Cond (µS/cm)	877	966	1166				
DO (mg/L)	0.3	2.0	2.3				
Redox (mV)	100.4	93.0	91.2				
Salinity	NR	NR	NR				

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 Serum
1 125-mL

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method sodium phosphate Containers: 4 VOAs
Method sulfuric acid Containers: 1 125-mL, 2 Serum
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 - FTA2
Sampling Dates: 8/2/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-142A
(number)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/2/97 at 1325 a.m./(p.m.)
SAMPLE COLLECTED BY: Smith/Clt of Parsons.
WEATHER: Clear, Breezy, Hot 90°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top Dedicated Pump Access Port

MONITORING WELL CONDITION:
[ ] LOCKED: [X] 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 [Y] EQUIPMENT CLEANED BEFORE USE WITH DI Water
Items Cleaned (List): Probes

2 [Y] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH 53.08' TD=82' FT. BELOW DATUM
Measured with: Solinst level Indicator
Purge Vol. = 55 gal.

3 [Y] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: Reddish Brown
Turbidity: Slightly Cloudy
Odor: None
Other Comments:

4 [Y] WELL EVACUATION:
Method: Dedicated Grundfos Pump
Volume Removed: 50 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. 2-142A (Cont'd)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [✓] ON-SITE MEASUREMENTS:

Volume (gal.)	3.0	13.0	22	35	45	50	
Time	1200	1226	1240	1300	1313	1320	Measured with
Temp (°C)	18.9	18.2	17.9	17.5	19.1 *	18.9 *	YSI 55
pH	7.53	7.70	7.68	7.69	7.75		Orion 250A
Cond (µS/cm)	708	679	624	626	613	620	Orion 122
DO (mg/L)	0.62	0.90	0.59	1.26	1.34	1.20	YSI 55
Redox (mV)	37	NR	NR	NR	26.5	26.3	Orion 250A
Salinity	NR	NR	NR	NR	NR	NR	NR

* Stirred Pump Down.

7 [✓] SAMPLE CONTAINERS (material, number, size): 2 VOAs
2 Syrum Jars
2x 250 ml. Plastic

8 [✓] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method Sulfuric Acid Containers: Syrum Jars, Field Inorganics
Method Sodium Phosphate Containers: VOAs
Method_____ Containers:_____
Method_____ Containers:_____

9 [✓] CONTAINER HANDLING:

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

10 [✓] OTHER COMMENTS: EPA will handle samples Monday

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - FTA2
Sampling Dates: 8/2/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-142B
(number)

REASON FOR SAMPLING: [M] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/2/97 at 1445 a.m./p.m.
SAMPLE COLLECTED BY: BMH/CH of Parsons ES.
WEATHER: Clear, Sunny, Hot 90°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top well cap

MONITORING WELL CONDITION:
[ ] LOCKED: [M] 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 [M] EQUIPMENT CLEANED BEFORE USE WITH DI water
Items Cleaned (List): Probes

2 [M] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH 13.36' Top well cap TD = 42' FT. BELOW DATUM
Measured with: Solinst Purge Volume = 56 gal.

3 [M] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: yellowish brown
Turbidity: Slightly Cloudy
Odor: None
Other Comments:

4 [ ] WELL EVACUATION:
Method: Dedicated Grundfos 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. 2-142B (Cont'd)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [✓] ON-SITE MEASUREMENTS:

	10:10	25	35	45	50		
Time	1352	1408	1420	1430	1440		Measured with
Temp (°C)	16.8	16.9	16.9	17.1	16.9		YSI 55
pH	NR	7.90	7.41	7.35	7.36		Orion 250A
Cond (µS/cm)	1438	1460	1480	1481	1480		Orion 122
DO (mg/L)	2.40	3.25	3.18	3.35	3.06		YSI 55
Redox (mV)	NR	74.1	55.6	53.7	52.6		Orion 250A
Salinity	NR	NR	NR	NR	NR		NR

7 [✓] SAMPLE CONTAINERS (material, number, size): 2 VOAs
2 Symm Jars
2x 250ml Plastic

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 - FTA2
Sampling Dates: 7/31/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-62A
(number)

REASON FOR SAMPLING: [1] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 7/31/97 at 17:13 a.m./p.m.
SAMPLE COLLECTED BY: CH/DK of Parsons/ESE.
WEATHER: sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Toc @ 2" bgs

MONITORING WELL CONDITION:

[ ] LOCKED: [1] 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 DI water
Items Cleaned (List): pipes

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 57.36' toc FT. BELOW DATUM
Measured with: water meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: clear
Turbidity: low
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: grunfos (electric tape)
Volume Removed: 4 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. 2-62A (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:

Time	17:15	17:17	17:20	17:23			Measured with
Temp (°C)	22.3	21.7	21.5	21.5			
pH	7.35	7.42	7.42	7.42			
Cond (µS/cm)	989	986	984	982			
DO (mg/L)	5.2	5.3	5.5	5.6			
Redox (mV)	104.7	102.6	100.4	97.2			
Salinity							

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOA
2 125-mL
2 Serum

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method Sulfuric acid Containers: 2 serum, 1 125-mL
Method sodium phosphate Containers: 4 VOA
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 - FTA2
Sampling Dates: 8/1/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-167 B
(number)

REASON FOR SAMPLING: [✓] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/1/97 at 1150 a.m./p.m.
SAMPLE COLLECTED BY: CH/DK of Parsons/USEPA
WEATHER: sunny
DATUM FOR WATER/DEPTH MEASUREMENT (Describe): TOC

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 DI water
Items Cleaned (List): probes

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 13.08 FT. BELOW DATUM
Measured with: water meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: ~~clear~~ orangish
Turbidity: low
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: dedicated grunfos
Volume Removed: ~ 31 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. 2-16TB (Cont'd)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

volume (gal)	11.0	22.0	31.0				
Time	1150	1211	1227				Measured with
Temp (°C)	17.9	17.2	17.3				
pH	7.20	7.14	7.11				
Cond (µS/cm)	972	991	1008				
DO (mg/L)	3.1	2.8	2.3				
Redox (mV)	104.2	76.3	80.6				
Salinity	NR	NR	NR				

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOA
2 Serum
2 125-mL

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method Sodium phosphate Containers: 4 VOA
Method Sulfuric acid Containers: 1 125-mL 2 serum
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 - FTA2
Sampling Dates: 7/31/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-16B
(number)

REASON FOR SAMPLING: [✓] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 7/31/97 at 15:34 a.m./p.m.
SAMPLE COLLECTED BY: DK/CH of USEPA/Parsons ES
WEATHER: Sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC @ 3' ags

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 DI water
Items Cleaned (List): meters

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 12.56' ~~bgs~~ btc FT. BELOW DATUM
Measured with: water meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: ~~clear~~ orange
Turbidity: clear/~~light~~ in beginning, then ~~cloud~~ high
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: dedicated grunfos
Volume Removed: 50+ gallons
Observations: Turbidity (clear slightly cloudy very cloudy)
Water level (rose fell no change)
Water odors: none
Other comments:

Note: Had to purge 50+ gallons for turbidity to lower and water to clear

Groundwater Sampling Record

Monitoring Well No. 2-168B (Cont'd)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	15:34	15:37	15:42	15:48			Measured with
Temp (°C)	18.6	18.3	18.2	18.3			
pH	7.15	7.18	7.18	7.17			
Cond (µS/cm)	988	984	985	993			
DO (mg/L)	0.8	0.7	0.6	0.7			
Redox (mV)	43.1	21.3	-5.8	-24.7			
Salinity							

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOA
2 Serum
2 250-mL

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[ ] Preservatives added:

Method sulfuric acid Containers: 1 250-mL 2 Serum
Method sodium phosphate Containers: 4-VOC
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

8/1/97

Sampling Location: Tinker AFB - FTA2
Sampling Dates: 8/1/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-272B
(number)

REASON FOR SAMPLING: [✓] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/1/97 at 10:00 a.m./p.m.
SAMPLE COLLECTED BY: CH/DK of Parsons/USEPA
WEATHER: sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

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 DI water
Items Cleaned (List): probes

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 17.6' FT. BELOW DATUM
Measured with:

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: clear
Turbidity: low
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: dedicated grunfos
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. 2-272B (Cont'd)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

volume(gal)	6.5	18.0	30.0	35.0			
Time	1014	1032	1050	1056			Measured with
Temp (°C)	17.7	17.7	17.8	17.8			Orion 840
pH	7.31	7.25	7.34	7.24			Orion 250A
Cond (µS/cm)	1088	1083	1075	1075			Orion 122
DO (mg/L)	3.0	3.6	4.1	4.1			Orion 840
Redox (mV)	-32.1	-5.1	21.2	30.2			Orion 250A
Salinity							

7 [ ] SAMPLE CONTAINERS (material, number, size): 2 125-mL
2 Serum
4 VOA

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method sulfuric acid Containers: 1 125-mL, 2 Serum
Method sodium phosphate Containers: 4 VOA
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 - FTA2
Sampling Dates: 8/1/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-273 B
(number)

REASON FOR SAMPLING: [✓] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/1/97 at 0845 a.m./p.m.
SAMPLE COLLECTED BY: CH of Parsons.
WEATHER: sunny
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

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 DI
Items Cleaned (List): ~~pipes~~ probes

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 7.7' btc FT. BELOW DATUM
Measured with: water meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: clear
Turbidity: low
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: dedicated grunfos
Volume Removed: ~ 37 gallons
Observations: Turbidity (clear slightly cloudy very cloudy)
Water level (rose fell no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. 2-27B (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:

volume (gal) 5.0 17.0 34.0

Time	0845	0855	0907	0915			Measured with
Temp (°C)	18.3	18.3	18.3	18.3			Orion 540
pH	7.44	7.14	7.10	7.20			Orion 250A
Cond (µS/cm)	786	769	764	761			Orion 122
DO (mg/L)	0.1	0.2	0.2	0.2			Orion 840
Redox (mV)	-132.3	-141.2	-113.4	-105.1			Orion 250A
Salinity	NR	NR	NR	NR			

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOA

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method sulfuric acid Containers: 2 Serum 1 x 125 mL
Method sodium phosphate Containers: 4 VOA
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 - FTA2
Sampling Dates: 8/31/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-2713
(number)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/31/97 at 1315 a.m./p.m.
SAMPLE COLLECTED BY: BMH/CH of Parsons.
WEATHER: Partly Cloudy, Hot 85-95°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top Dedicated Pump Well cap

MONITORING WELL CONDITION:
[ ] LOCKED: [X] 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 DI water
Items Cleaned (List): Probes

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: Solinst

WATER DEPTH 18.4' Top Well Cap TD= 46' FT. BELOW DATUM
Measured with: Solinst Purge Vol. = 55 gal.

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: None
Turbidity: clear - very slightly cloudy
Odor: None
Other Comments:

4 [✓] WELL EVACUATION:
Method: Dedicated Grundfos Pump
Volume Removed: 50+ gallon
Observations: Turbidity (clear slightly cloudy very cloudy)
Water level (rose fell no change)
Water odors: None
Other comments:

Groundwater Sampling Record

Monitoring Well No. 2-271B (Cont'd)

5 [4] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Gallons	10	20	30	40	50		
Time	1217	1230	1242	1258	1310		Measured with
Temp (°C)	16.7	16.7	16.9	17.0	16.9		YSI 55
pH	7.15	7.14	7.13	7.19	7.19		Orion 250A
Cond (µS/cm)	948	1121	1195	1235	1238		Orion 122
DO (mg/L)	0.79	1.50	2.25	3.60	3.75		YSI 55
Redox (mV)	29.4	NR	60.7	63.8	67.8		Orion 250A
Salinity	NR	NR	NR	NR	NR		NR

7 [4] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 Syrum Jars
2 - 8 250 ml. Plastic

8 [4] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[4] Preservatives added:

Method H_2SO_4 Containers: Synmites / Fixed Inorganics
Method Sodium Phosphate Containers: VOAs
Method_____ Containers:_____
Method_____ Containers:_____

9 [4] CONTAINER HANDLING:

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

10 [4] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - FTA2
Sampling Dates: 8/3/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-27A (number)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/3/97 at 1005 a.m./p.m.
SAMPLE COLLECTED BY: TSMH / CH of Parsons.
WEATHER: Cloudy, Warm 85°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top PVC Riser

MONITORING WELL CONDITION:
[ ] LOCKED: [X] 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 DI water / Alconox
Items Cleaned (List): Grundfos Pump / Probes
→ Used Dedicated HDPE Tubing

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH 59.20' Top PVC (Solinst) FT. BELOW DATUM
Measured with: TD = 84' Top PVC Purge Vol. = 45 gal.

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: Slightly Reddish brown
Turbidity: Slightly Cloudy
Odor: None
Other Comments:

4 [✓] WELL EVACUATION:
Method: Grundfos 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. 2-27A (Cont'd)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [✓] ON-SITE MEASUREMENTS:

	10	20	30	45			
Time	0907	0925	0940	1000			Measured with
Temp (°C)	20.7	20.6	20.2	20.1			YSI 55
pH	7.78	7.79	7.61	7.60			Orion 250A
Cond (µS/cm)	527	533	516	516			Orion 122
DO (mg/L)	7.5	7.35	8.80*	8.1			YSI 55
Redox (mV)	62.8	60.7	62.5	63.1			Orion 250A
Salinity	NR	NR	NR	NR			NR

* Purge Water Bubbling

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 Syrum Jars
2 250 ml. Plastic

8 [✓] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method H_2SO_4 Containers: Fixed Inorganics / Syrum Jars
Method Sodium Phosphate Containers: VOAs
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 - FTA2
Sampling Dates: 8/31/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-27 B
(number)

REASON FOR SAMPLING: [V] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/31/97 at 0850 (AM)/p.m.
SAMPLE COLLECTED BY: Smith/CH of Parsons.
WEATHER: Partly cloudy, Warm, 80°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top Dedicated Pump Well Cap

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 DI Water
Items Cleaned (List): Probes

2 [+ PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH 16.72' TD = 42' FT. BELOW DATUM
Measured with: Solinst Purge Vol. = 50 gal.

3 [+ WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: Clear to Slightly Cloudy
Turbidity: "
Odor: None
Other Comments:

4 [+ WELL EVACUATION:
Method: Dedicated Grundfos Pump
Volume Removed: 50 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. 2-274B (Cont'd)

5 [X] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Gallons	10	20	30	40	50		
Time	0805	0815	0825	0835	0850		Measured with
Temp (°C)	17.5	17.5	17.5	17.6	17.7		YSI 55
pH	NR	6.82	7.09	7.17	17.20		Orion 250A
Cond (µS/cm)	906	915	918	920	919		Orion 122
DO (mg/L)	5.15	5.0	4.95	5.16	5.14		YSI 55
Redox (mV)	NR	106	79.8	49.0	50.0		Orion 250A
Salinity	NR	NR	NR	NR	NR		NR

7 [X] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 Synn Jars
2x 250 ml Plastic
500 ml. Plastic - Field Tests

8 [X] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[X] Preservatives added:

Method H_2SO_4 Containers: Synn Jars / Fixed Inorganics
Method Sodium Phosphate Containers: VOAs
Method_____ Containers:_____
Method_____ Containers:_____

9 [X] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS:_____

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - FTA2
Sampling Dates: 8/13/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-355B
(number)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/13/97 at 1600 a.m./p.m.
SAMPLE COLLECTED BY: SMH/CLH of Parsons.
WEATHER: Partly Cloudy, Hot 90-95°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top PVC - well head completion not completed

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED
WELL NUMBER (IS - ~~IS NOT~~) APPARENT
STEEL CASING CONDITION IS:
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 [X] EQUIPMENT CLEANED BEFORE USE WITH DI water / Alconox
Items Cleaned (List): Pump / Wiring
Probes

2 [X] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH 15.73' Top PVC Riser TD=39.24' TPVC FT. BELOW DATUM
Measured with: Solinst Purge Vol. = 46 gal.

3 [X] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: Brown
Turbidity: Cloudy
Odor: None
Other Comments:

4 [X] WELL EVACUATION:
Method: Grundfos Pump w/ dedicated HDPE Tubing
Volume Removed: 50 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. 2-355B (Cont'd)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

	10	20	30	40	50		
Time	1506	1525	1535	1545	1555		Measured with
Temp (°C)	17.9	17.8	17.7	17.8	17.8		YSI 55
pH	7.21	7.22	7.23	7.25	7.23		Orion 250A
Cond (µS/cm)	1450	1460	1480	1485	1490		Orion 122
DO (mg/L)	9.05	8.90	7.86	7.90	7.85		YSI 55
Redox (mV)	NR	122.8	124.9	NR	116.7		Orion 250A
Salinity	NR	NR	NR	NR	NR		NR

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 Syringe Jars
2 250 ml Plastic

8 [✓] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method H_2SO_4 Containers: Syringe Jars / Filtered Inorganics
Method Sodium Phosphate Containers: VOAs
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 - FTA2
Sampling Dates: 8/13/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-3723
(number)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/13/97 at 1915 a.m./p.m.
SAMPLE COLLECTED BY: Smith C.H. of Parsons.
WEATHER: Partly Cloudy, Hot, 90-95°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top PVC Casing - Notch North Side

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: New
INNER PVC CASING CONDITION IS: New
WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [X] EQUIPMENT CLEANED BEFORE USE WITH DI water / Alconox
Items Cleaned (List): Pump & Wiring / Probes
Dedicated HDPE Sample Tubing

2 [X] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH Water = 15.43' TD = 4600'-3' Sump FT. BELOW DATUM
Measured with: Solinst Purge Vol. = 60 gal.

3 [X] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: None
Turbidity: Slightly Cloudy
Odor: None
Other Comments:

4 [ ] WELL EVACUATION:
Method: Grundfos 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. 2-392B (Cont'd)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [✓] ON-SITE MEASUREMENTS:

	10	20	30	40	50		
Time	1710	1725	1750	1800	1810		Measured with
Temp (°C)	18.3	18.8	18.6	18.6	18.5		YSI 55
pH	7.13	7.17	7.15	7.17	7.18		Orion 250A
Cond (µS/cm)	693	698	696	695	697		Orion 122
DO (mg/L)	8.05	7.68	6.68	6.05	6.00		YSI 55
Redox (mV)	NR	NR	NR	135.2	138.7		Orion 250A
Salinity	NR	NR	NR	NR	NR		NR

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 Syrum Jars
2 250ml Plastic

8 [✓] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method H_2SO_4 Containers: Syrum Jars / Fixed Inorganics
Method Sodium Phosphate Containers: VOAs
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 - FTA2
Sampling Dates: 8/14/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL 2-393B
(number)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/14/97 at 1500 a.m./p.m.
SAMPLE COLLECTED BY: BMH/DK of Parsons/EPA.
WEATHER: Clear, Sunny, Hot
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top PVC casing - Notch North Side

MONITORING WELL CONDITION:
[ ] LOCKED: [X] 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 [X] EQUIPMENT CLEANED BEFORE USE WITH DI Water/Alconox
Items Cleaned (List): Probes/Pumps + Tubing

2 [X] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH 15.9' Top PVC FT. BELOW DATUM
Measured with: Solinst

3 [X] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: None
Turbidity: Clear
Odor: None
Other Comments:

4 [X] WELL EVACUATION:
Method: Grundfos Pump
Volume Removed: Developed 350 gallons + 15 gallons to monitor stability
Observations: Turbidity (clear) slightly cloudy very cloudy)
Water level (rose fell no change)
Water odors: None
Other comments:

Groundwater Sampling Record

Monitoring Well No. Z-393B (Cont'd)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [✓] ON-SITE MEASUREMENTS:

Developed 350 gals.

Time	1445	1450	1455				Measured with
Temp (°C)	18.3	18.4	18.2				YSI 55
pH	7.33	7.21	7.23				Orion 230A
Cond (µS/cm)	1195	1186	1184				Orion 122
DO (mg/L)	7.73	7.25	7.00				YSI 55
Redox (mV)	NR	105.3	110.9				Orion 230A
Salinity	NR	NR	NR				
	40 gal.	10 gal.	15 gal.				

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 Symm jars
2 250 ml. Plastic

8 [✓] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method H_2SO_4 Containers: Symm Jars / Final Inorganics
Method Sodium Phosphate Containers: VOAs
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 - FTA2
Sampling Dates: 8/4/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL CG39-B97-41
(number)

REASON FOR SAMPLING: [✓] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/4 at 9:50 a.m./p.m.
SAMPLE COLLECTED BY: CH/DK of Parsons/USEPA
WEATHER:
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

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 DI water
Items Cleaned (List): probes

2 [✓] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 12.33' FT. BELOW DATUM
Measured with: water meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: clear
Turbidity: low
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: grunfos
Volume Removed: 14 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. CG39-B97-41 (Cont'd)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS: calibrated pHa Redox

volume (gal) 4.0 8.0 & 12.0 14.0

Time	10:14	10:38	11:20	11:11			Measured with
Temp (°C)	21.1	21.7	22.0	22.1			
pH	7.11	6.92	6.99	6.88			
Cond (µS/cm)	862	863	861	861			
DO (mg/L)	3.7	3.6	3.9	3.9			
Redox (mV)	153.8	109.1	156.0	136.2			
Salinity	NR	NR	NR	NR			

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOA
2 125-mL
2 Serum

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method Sulfuric acid Containers: 2 Serum, 1 125-mL
Method sodium phosphate Containers: 4 VOAs
Method_____ Containers:_____
Method_____ Containers:_____

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: Conductivity standard checked out exactly
pH ~~with a 2 of standard~~ calibrated to within 0.02
Redox calibrated to within 10 mV

GROUNDWATER SAMPLING RECORD

Sampling Location: Tinker AFB - FTA2
Sampling Dates: CG39-B97-435 8/4/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL CG39-B97-435 (number)

REASON FOR SAMPLING: [✓] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/4 at 11:50 a.m./p.m.
SAMPLE COLLECTED BY: CH/DK of Parsons/USEPA
WEATHER: clear, hot (~95°F)
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

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 DI water
Items Cleaned (List): probes, pump

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 20.64' FT. BELOW DATUM
Measured with: water meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: clear
Turbidity: low
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: grunfos pump
Volume Removed: ~7 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. CG39-B97-435 (Cont'd)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Volume (gal)	1.5	3.0	5.0	7.0			
Time	11:47	11:55	12:07	12.21			Measured with
Temp (°C)	19.5	20.2	22.8	21.3			
pH	7.13	7.16	6.83	6.85			
Cond (µS/cm)	1265	1262	1269	1278			
DO (mg/L)	5.1	4.8	4.8	4.8			
Redox (mV)	122.7	117.3	109.1	116.7			
Salinity	NR	NR	NR				

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 125-mL
2 Serum

8 [ ] ON-SITE SAMPLE TREATMENT:

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

[X] Preservatives added:

Method sodium phosphate Containers: 4 VOAs
Method sulfuric acid Containers: 1 125-mL, 2 Serum
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 - FTA2
Sampling Dates: 8/4/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL CC39-B97-43d
(number)

REASON FOR SAMPLING: [x] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/4/97 at 0900 a.m./p.m.
SAMPLE COLLECTED BY: Smith (CH of Parsons.
WEATHER: Partly Cloudy, Hot, 85-90° F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): Top PVC Riser - Notch 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):

Check-off
1 [ ] EQUIPMENT CLEANED BEFORE USE WITH DI Water
Items Cleaned (List): Pump & Probes

2 [ ] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with:

WATER DEPTH Water = 20.19 TD = 49.93' (measured) FT. BELOW DATUM
Measured with: Solinst Purge Volume = 15gal.

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: slightly Reddish Brown
Turbidity: slightly Cloudy
Odor: None
Other Comments:

4 [ ] WELL EVACUATION:
Method: Centrifugal Pump
Volume Removed: 160+ 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. C659-897-43d (Cont'd)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of: (TEFLON)
[✓] Pump, type: ~~Dedicated~~ Grundfos Pump - Dedicated Tubing
[ ] Other, describe:

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

6 [✓] ON-SITE MEASUREMENTS:

	3.0	8.0	12.0	16.0	18.0		
Time	0810	0825	0835	0845	0850		Measured with
Temp (°C)	19.6	18.7	18.6	18.5°	18.4°		YSI 55
pH	7.25	7.14	7.09	7.08	7.07		Orion 250A
Cond (µS/cm)	1115	1110	1110	1105	1112		Orion 122
DO (mg/L)	3.29	3.33	3.36	3.35	3.34		YSI 55
Redox (mV)	NR	NR	136	134.6	129.8		Orion 250A
Salinity	NR	NR	NR	NR	NR		NR

7 [✓] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 Syrum Jars
2 250 ml. Plastic

8 [✓] ON-SITE SAMPLE TREATMENT:

[ ] Filtration: Method_____ Containers:_____
Method_____ Containers:_____
Method_____ Containers:_____

[✓] Preservatives added:

Method Sodium Phosphate Containers: VOAs
Method H_2SO_4 Containers: Syrum Jars / Fixed Inorganics
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 - FTA2
Sampling Dates: 8/4/97

GROUNDWATER SAMPLING RECORD - MONITORING WELL CG39-B97-45
(number)

REASON FOR SAMPLING: [✓ Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 8/4 at 1350 a.m./p.m.
SAMPLE COLLECTED BY: CH/DK of Parsons/USEPA
WEATHER: clear, hot (~95°F)
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

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 DI water
Items Cleaned (List): probes, grunfos pump

2 [ ] PRODUCT DEPTH none FT. BELOW DATUM
Measured with:

WATER DEPTH 12.14' FT. BELOW DATUM
Measured with: water meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Color: orange
Turbidity: moderate
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: grunfos pump
Volume Removed: 14 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. CG39-B97-45 (Cont'd)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

volume (gal) 5.0 8.0 11.0 14.0 20.0

Time	1410	1418	1430	1441	1458		Measured with
Temp (°C)	19.4	19.2	19.3	19.3	19.4		
pH	7.02	7.10	6.4 (6.3)	7.14	6.91		
Cond (µS/cm)	881	882	874	871	872		
DO (mg/L)	7.3	7.1	6.6	6.2	6.5		
Redox (mV)	114.6	105.1	102.8	104.0	103.2		
Salinity	NR	NR	NR	NR	NR		

7 [ ] SAMPLE CONTAINERS (material, number, size): 4 VOAs
2 Serum
2 125-mL

8 [ ] ON-SITE SAMPLE TREATMENT:

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

[X] Preservatives added:

Method sulfuric acid Containers: 2 Serum, 1 125-mL
Method sodium phosphate Containers: 4 VOAs
Method _____ Containers: _____
Method _____ Containers: _____

9 [ ] CONTAINER HANDLING:

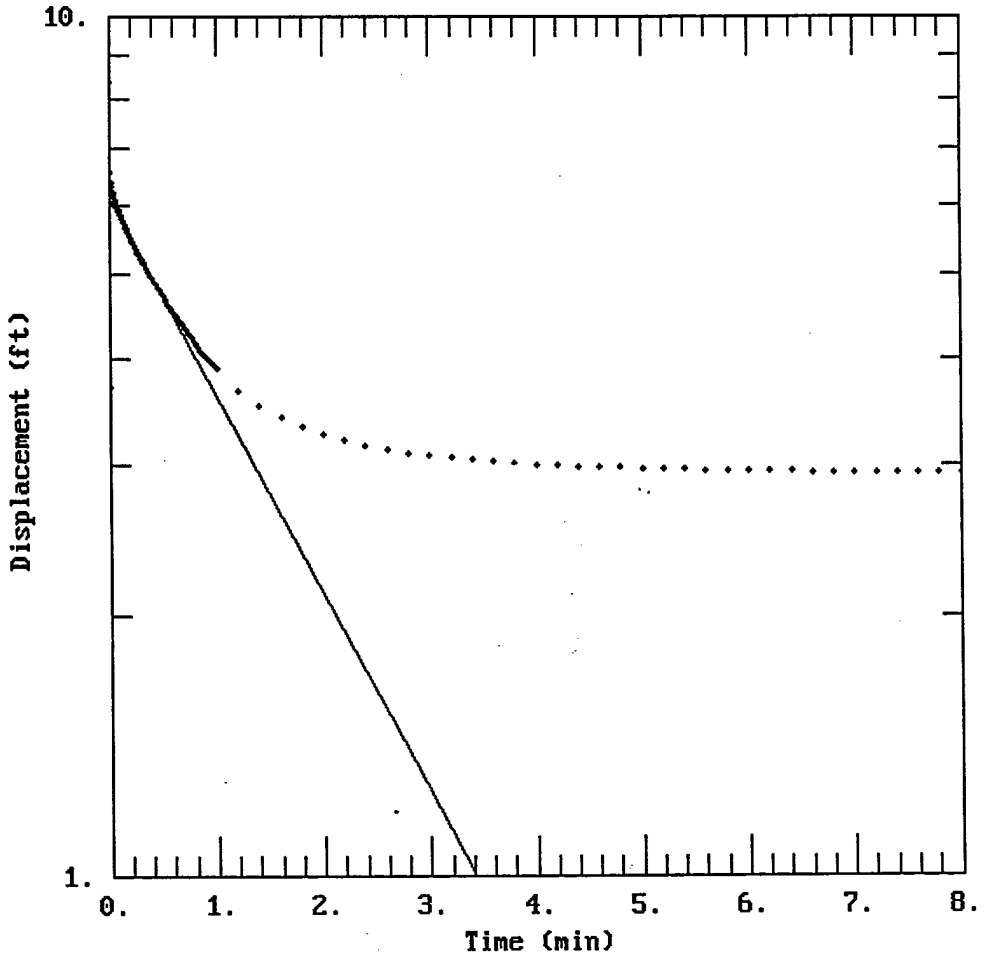
[ ] Container Sides Labeled
[ ] Container Lids Taped
[ ] Containers Placed in Ice Chest

10 [ ] OTHER COMMENTS: _____

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL CG39-B97-41: RUN 1



DATA SET:
CG-41-1.DAT
11/20/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

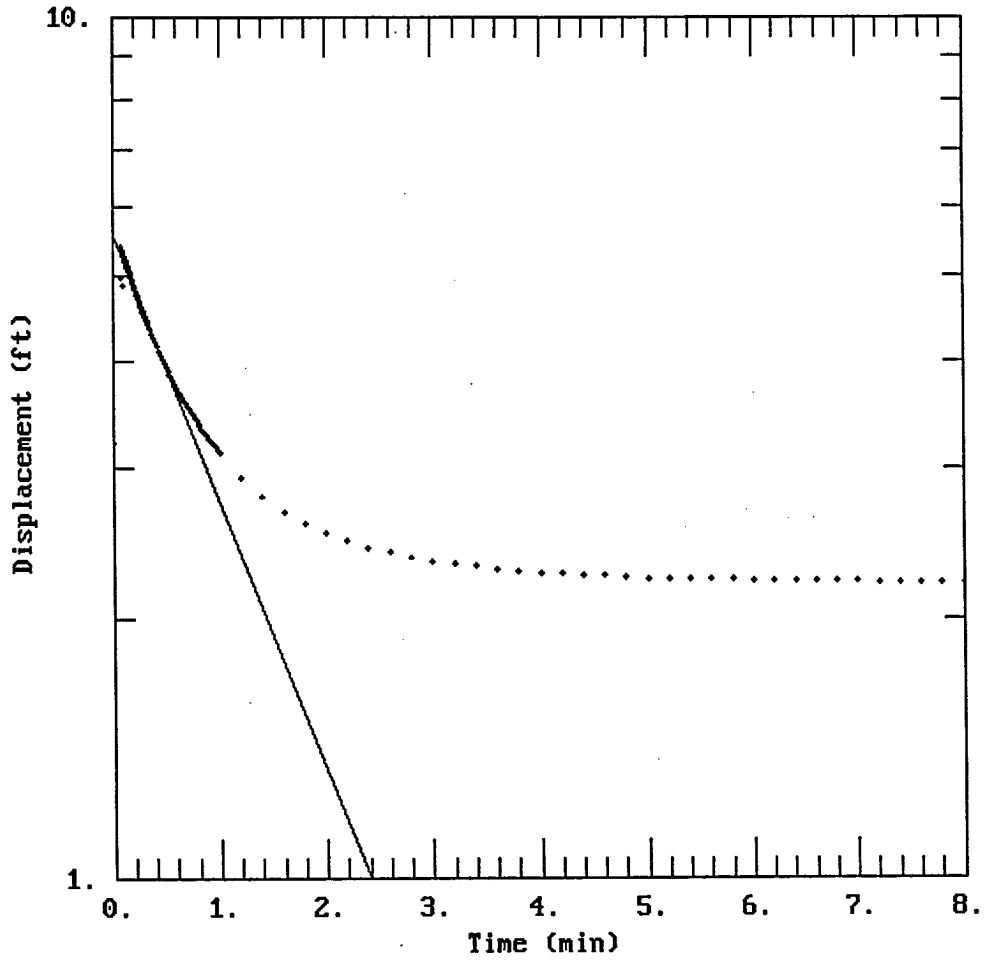
TEST DATA:
H0= 3.7 ft
r_c= 0.083 ft
r_w= 0.354 ft
L = 5. ft
b = 27.67 ft
H = 26.67 ft

PARAMETER ESTIMATES:
K = 0.006128 ft/min
y0 = 6.096 ft

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL CG39-B97-41: RUN 2



DATA SET:
CG-41-2.DAT
11/20/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

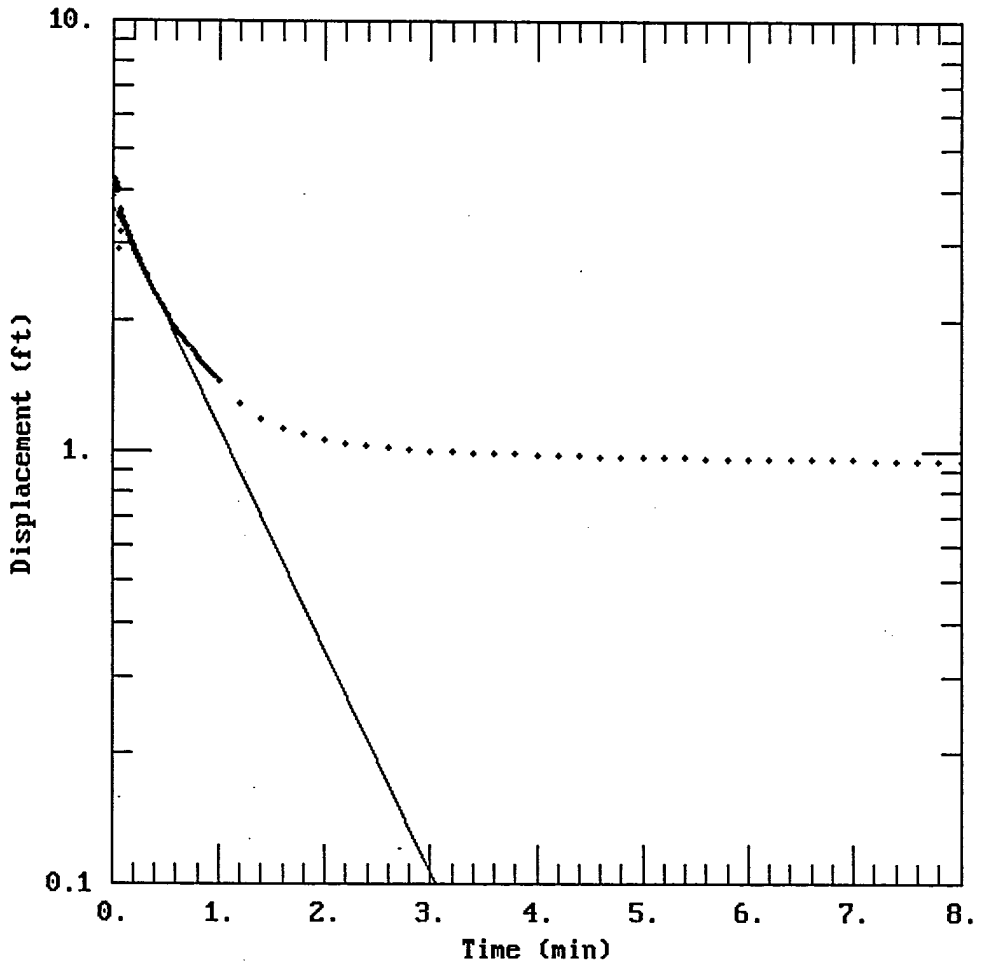
TEST DATA:
H0= 3.2 ft
r_c= 0.083 ft
r_w= 0.354 ft
L = 5. ft
b = 27.67 ft
H = 26.67 ft

PARAMETER ESTIMATES:
K = 0.008278 ft/min
y0 = 5.567 ft

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL CG39-B97-43S: RUN 1



DATA SET:
CG-43S-1.DAT
11/20/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATA:
H0= 3.3 ft
r_c= 0.083 ft
r_w= 0.354 ft
L = 5. ft
b = 16.1 ft
H = 15.1 ft

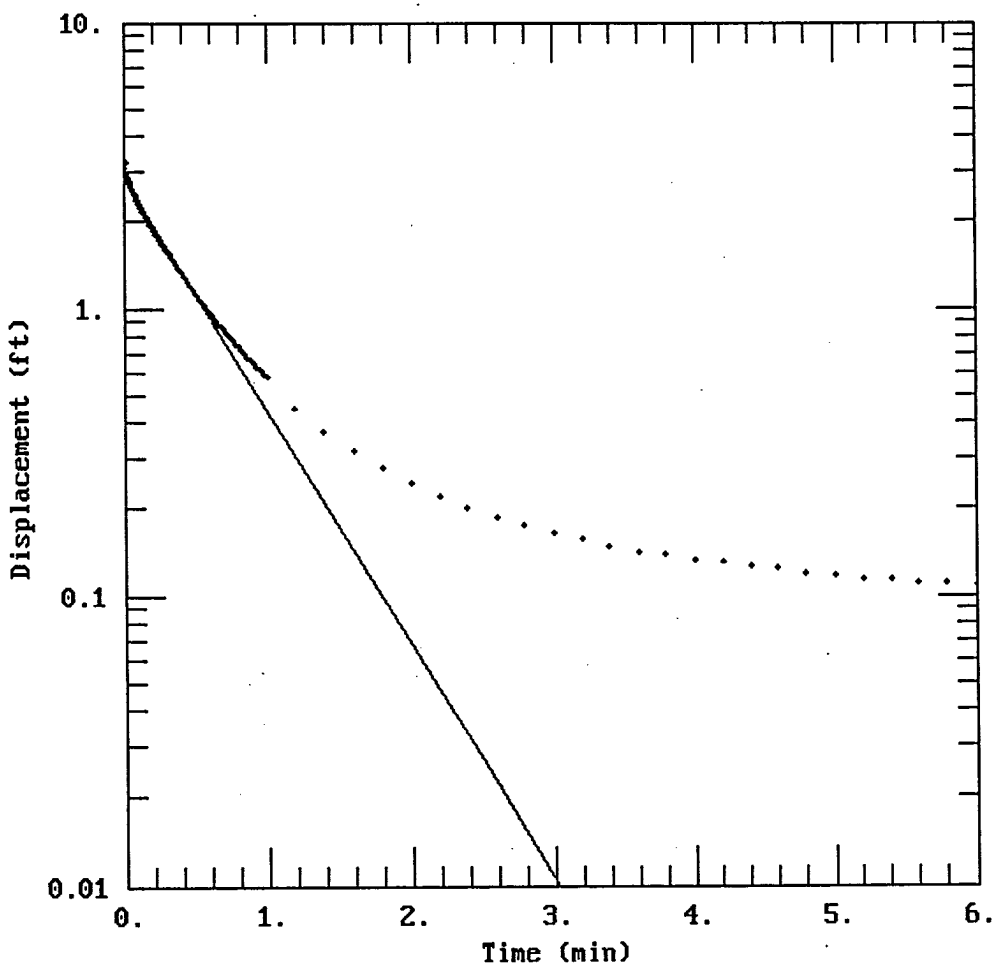
PARAMETER ESTIMATES:
K = 0.01256 ft/min
y0 = 3.681 ft

ESOLV

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL CG39-B97-43S: RUN 2



DATA SET:
CG-43S-2.DAT
11/20/97

AQUIFER MODEL:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

TEST DATA:
H0= 3.1 ft
r_c= 0.083 ft
r_w= 0.354 ft
L = 5. ft
b = 16.1 ft
H = 15.1 ft

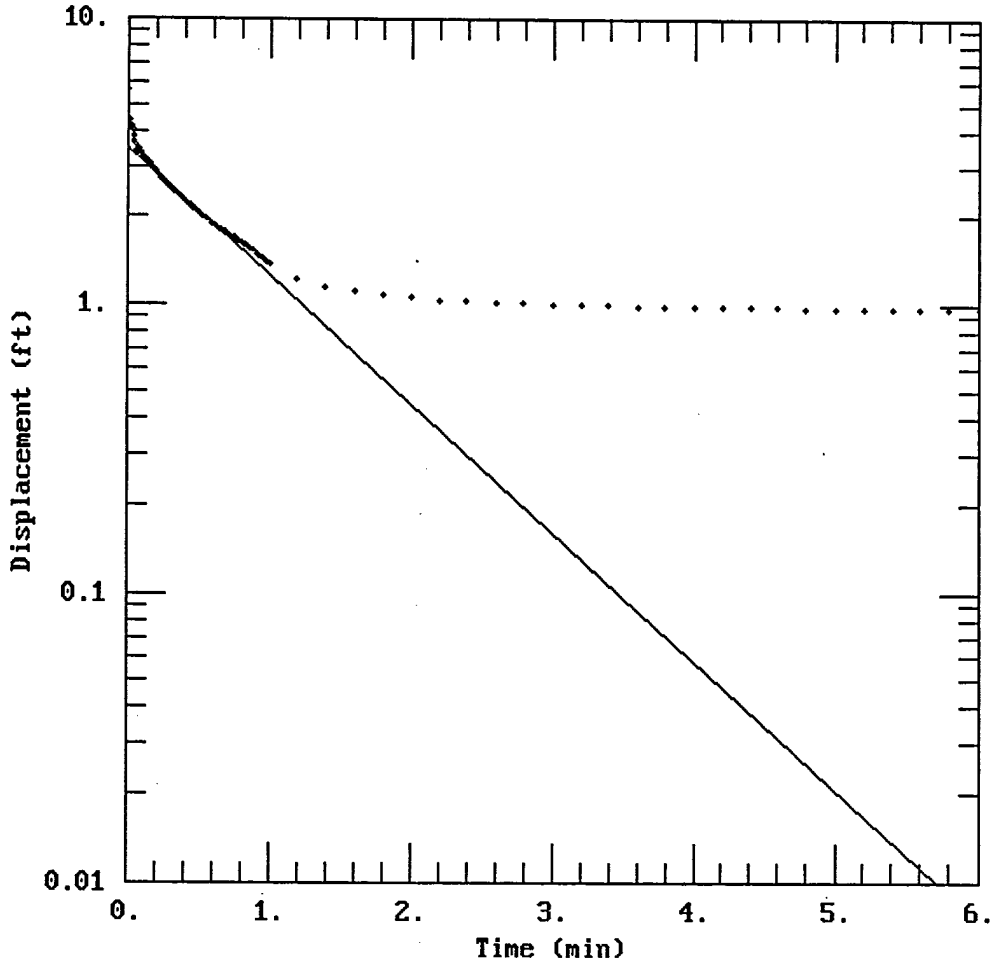
PARAMETER ESTIMATES:
K = 0.01971 ft/min
y0 = 2.82 ft

ESOLV

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL CG39-B97-43S: RUN 3



DATA SET:
CG-43S-3.DAT
11/17/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATA:
H0= 3.5 ft
r_c= 0.083 ft
r_w= 0.354 ft
L = 5. ft
b = 16.1 ft
H = 15.1 ft

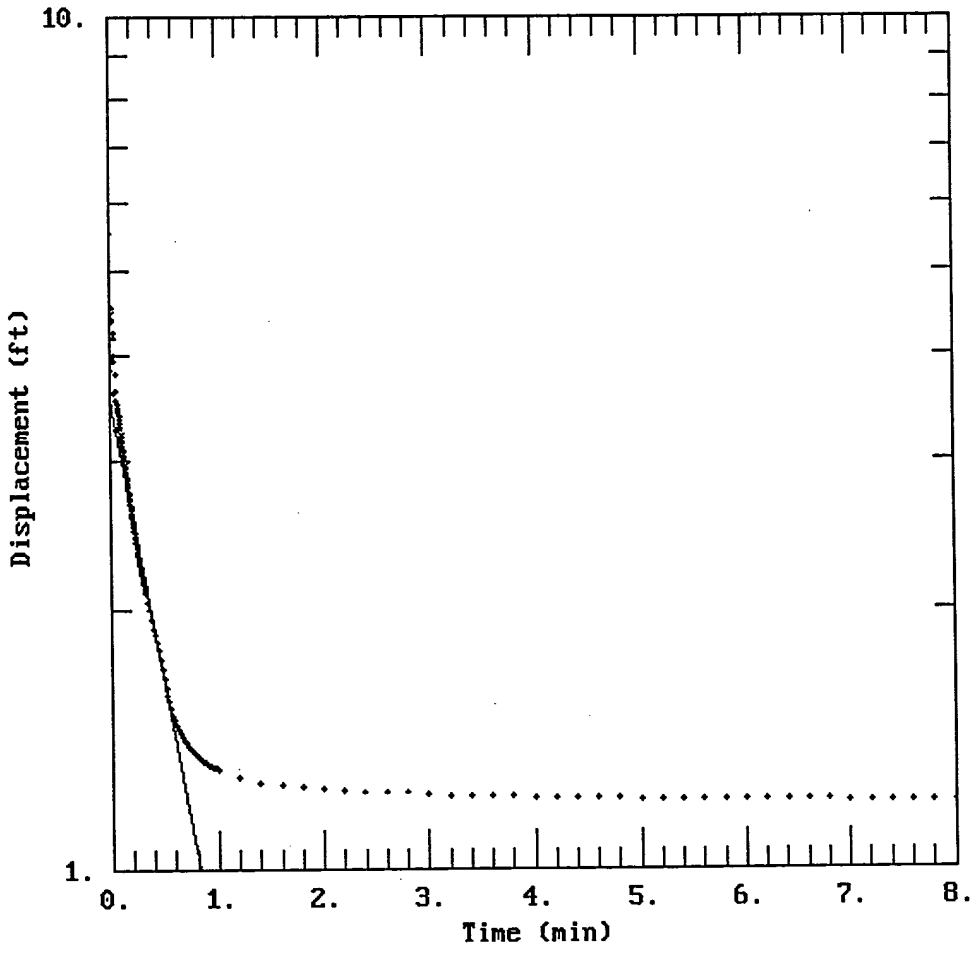
PARAMETER ESTIMATES:
K = 0.01086 ft/min
y0 = 3.496 ft

ESOLV

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL CG39-B97-43D: RUN 1



DATA SET:
CG-43D-1.DAT
11/17/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATA:
H0= 3.5 ft
r_c= 0.083 ft
r_w= 0.354 ft
L = 5. ft
b = 29.81 ft
H = 29.31 ft

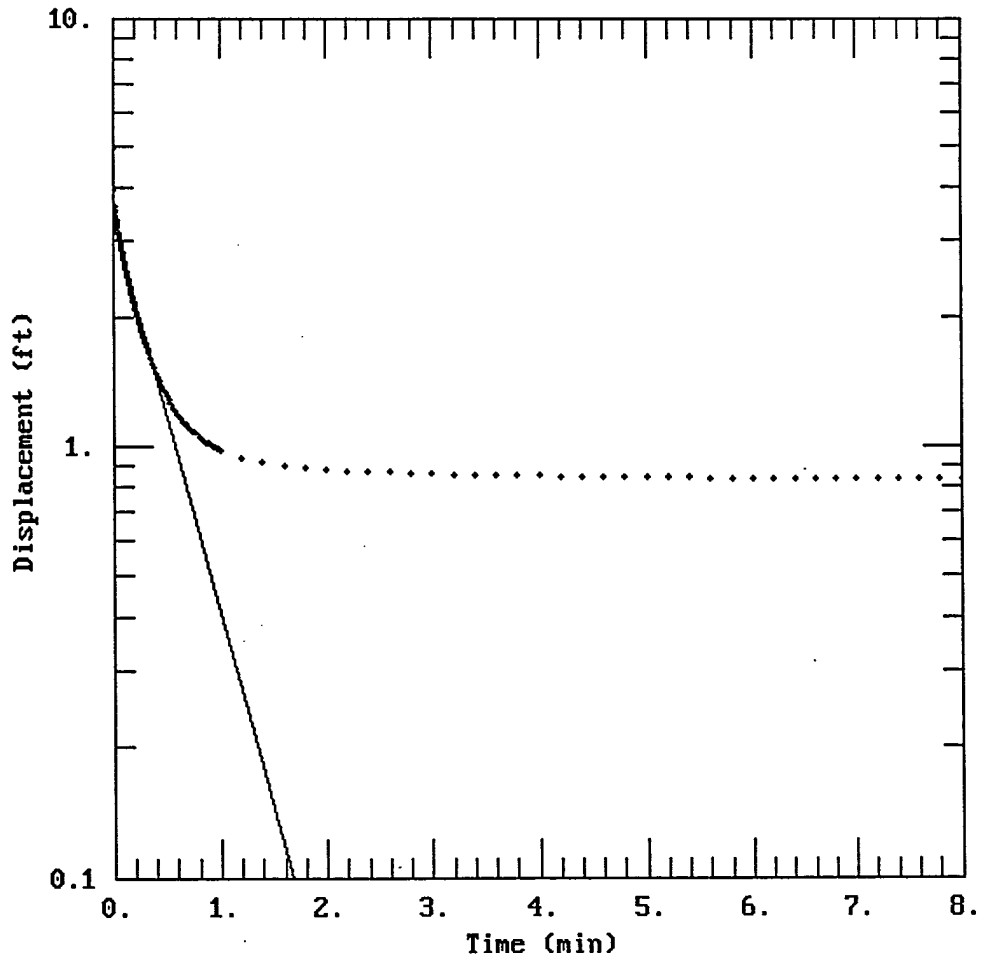
PARAMETER ESTIMATES:
K = 0.01873 ft/min
y0 = 3.528 ft

ESOLV

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL CG39-B97-43D: RUN 2



DATA SET:
CG-43D-2.DAT
11/21/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATA:
H0= 3.2 ft
r_c= 0.083 ft
r_w= 0.354 ft
L = 5. ft
b = 29.81 ft
H = 29.31 ft

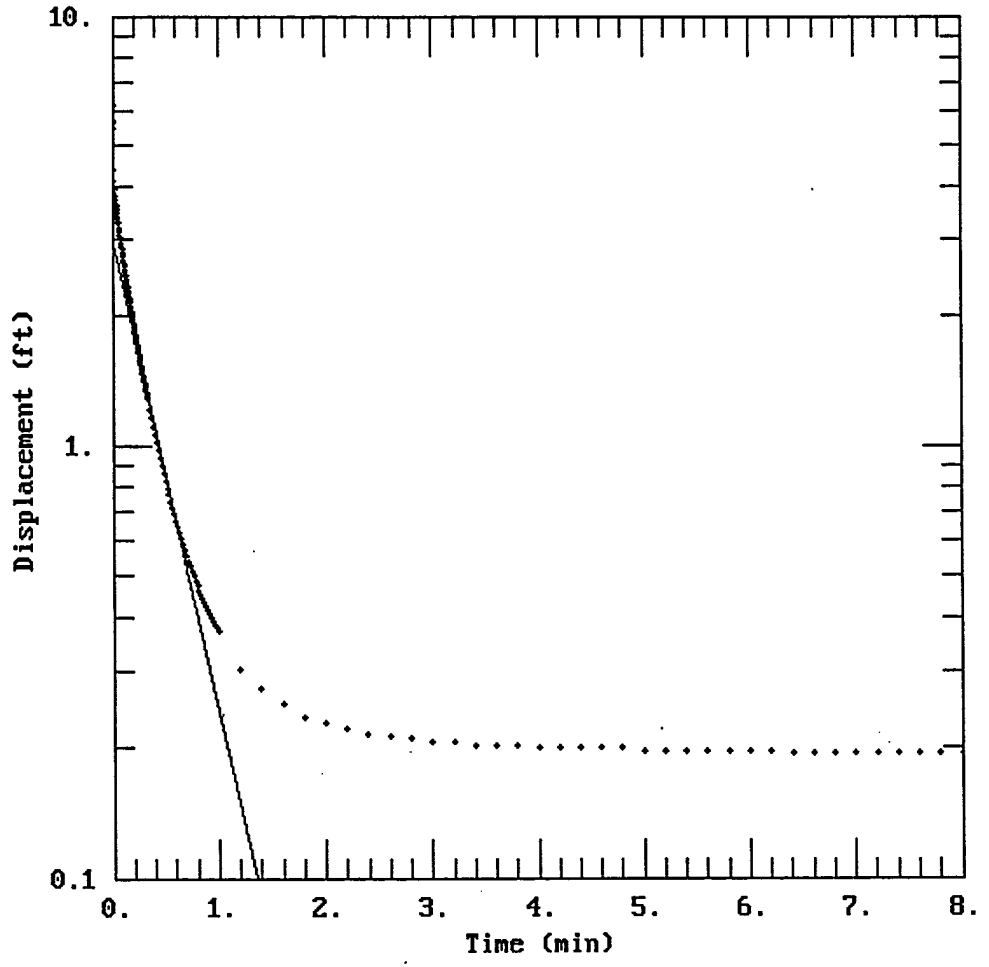
PARAMETER ESTIMATES:
K = 0.02524 ft/min
y0 = 3.282 ft

ESOLV

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL CG39-B97-45: RUN 1



DATA SET:
CG-45-1.DAT
11/21/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

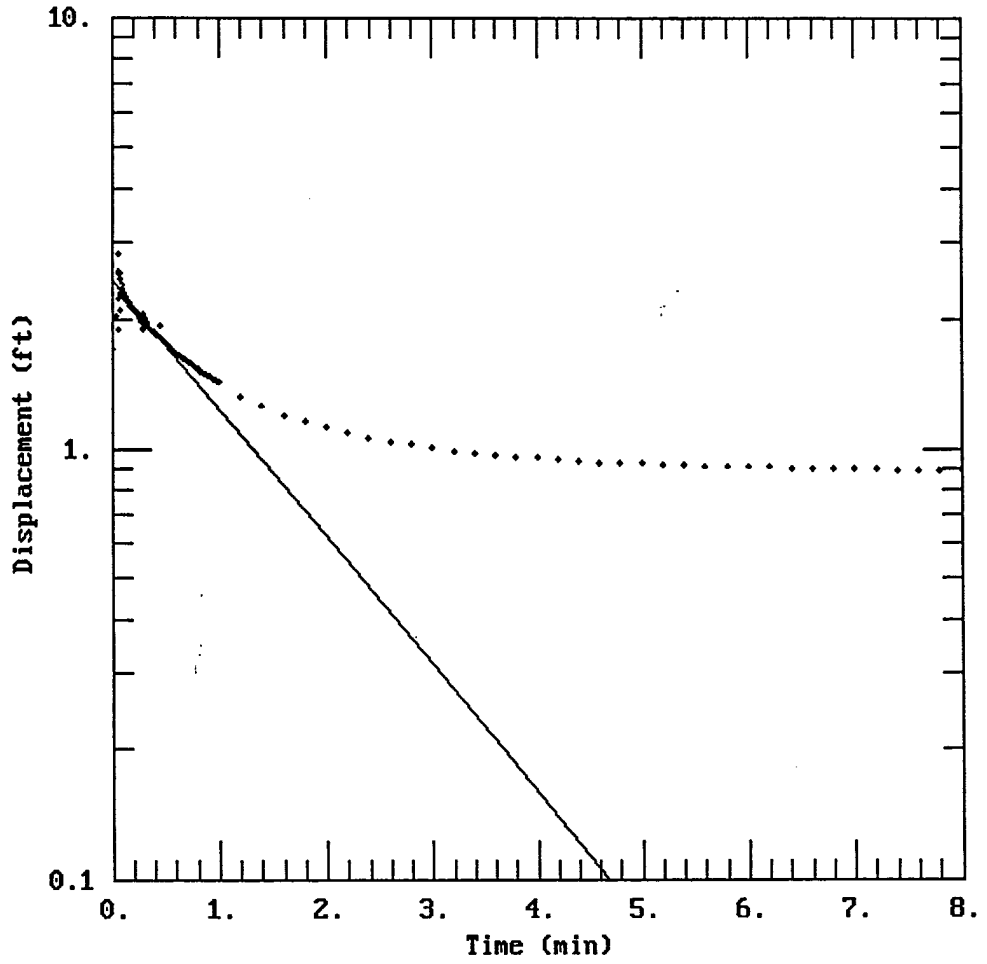
TEST DATA:
H0= 5.5 ft
r_c= 0.083 ft
r_w= 0.354 ft
L = 5. ft
b = 29.89 ft
H = 29.39 ft

PARAMETER ESTIMATES:
K = 0.03022 ft/min
y0 = 2.947 ft

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL 2-355B: RUN 1



DATA SET:
Z-355B-1.DAT
11/21/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

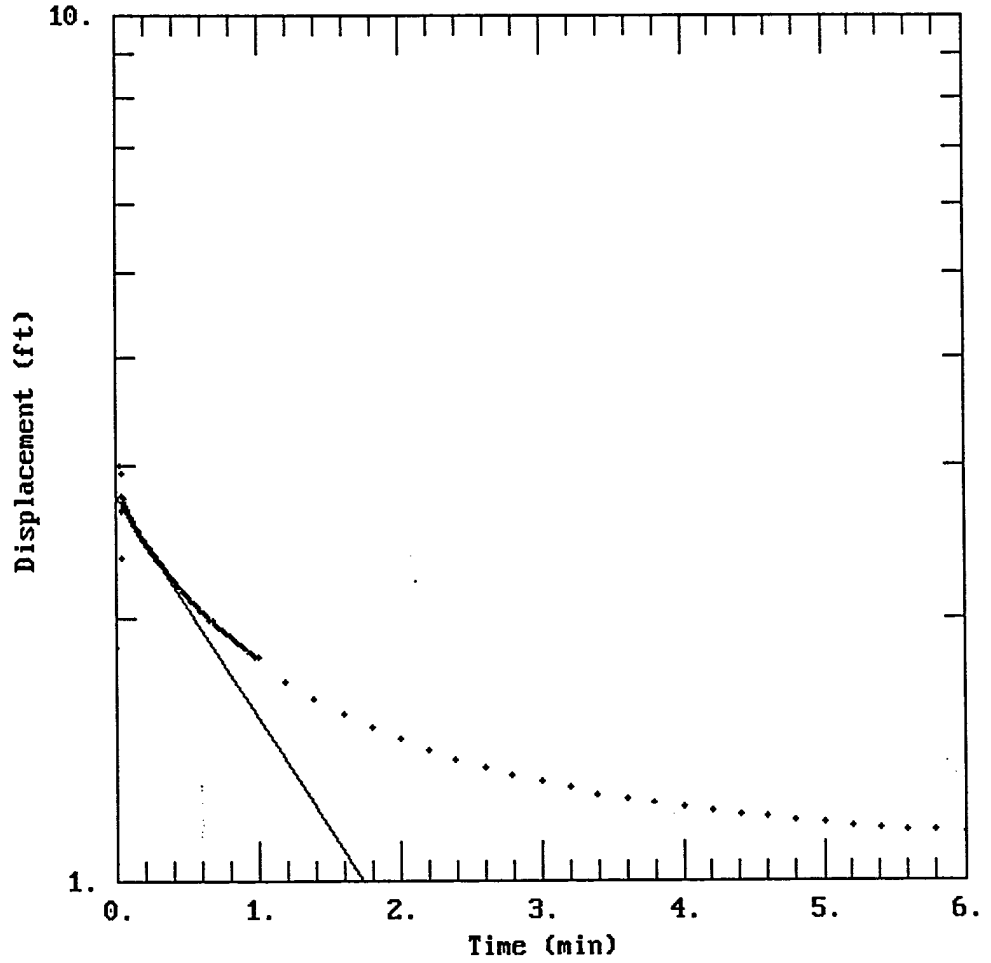
TEST DATA:
H0= 1.71 ft
r_c= 0.167 ft
r_w= 0.354 ft
L = 10. ft
b = 15.27 ft
H = 14.17 ft

PARAMETER ESTIMATES:
K = 0.005314 ft/min
y0 = 2.441 ft

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL 2-355B: RUN 2



DATA SET:
2-355B-2.DAT
11/17/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

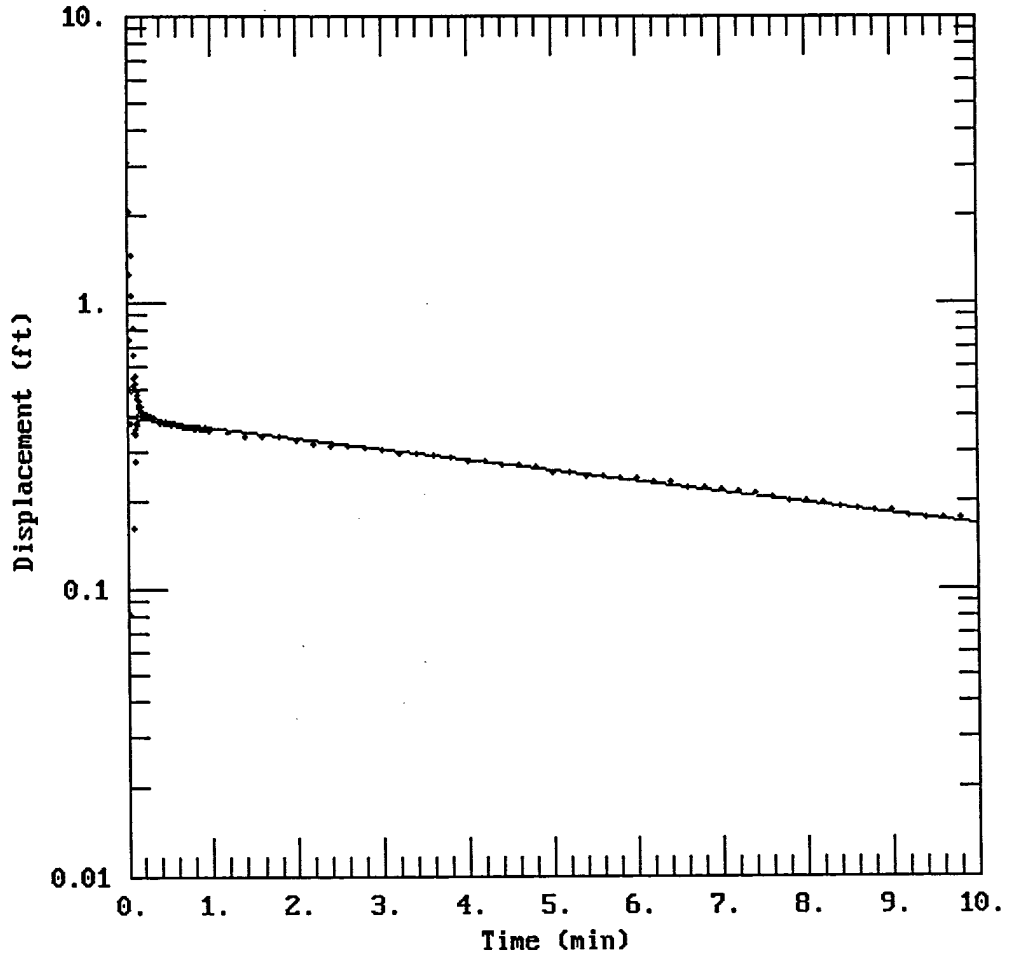
TEST DATA:
H0= 1.854 ft
r_c= 0.167 ft
r_w= 0.354 ft
L = 10. ft
b = 15.27 ft
H = 14.17 ft

PARAMETER ESTIMATES:
K = 0.004535 ft/min
y0 = 2.759 ft

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL 2-392B: RUN 1



DATA SET:
2-392B-1.DAT
11/21/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATA:
H0= 3.1 ft
r_c= 0.167 ft
r_w= 0.3554 ft
L = 10. ft
b = 30.57 ft
H = 30.57 ft

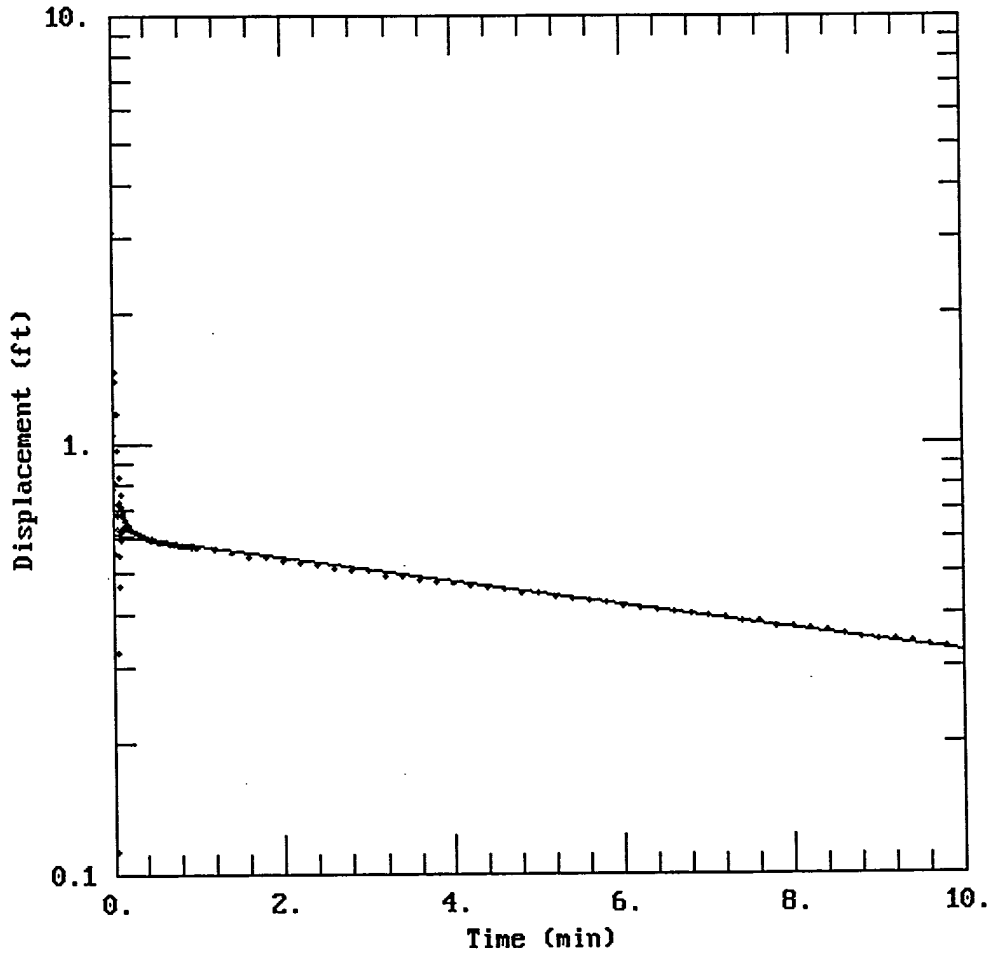
PARAMETER ESTIMATES:
K = 0.0008577 ft/min
y0 = 0.3967 ft

SOLV

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL 2-392B: RUN 2



DATA SET:
2-392B-2.DAT
11/17/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATA:
H0= 3.1 ft
r_c= 0.167 ft
r_w= 0.3554 ft
L = 10. ft
b = 30.57 ft
H = 30.57 ft

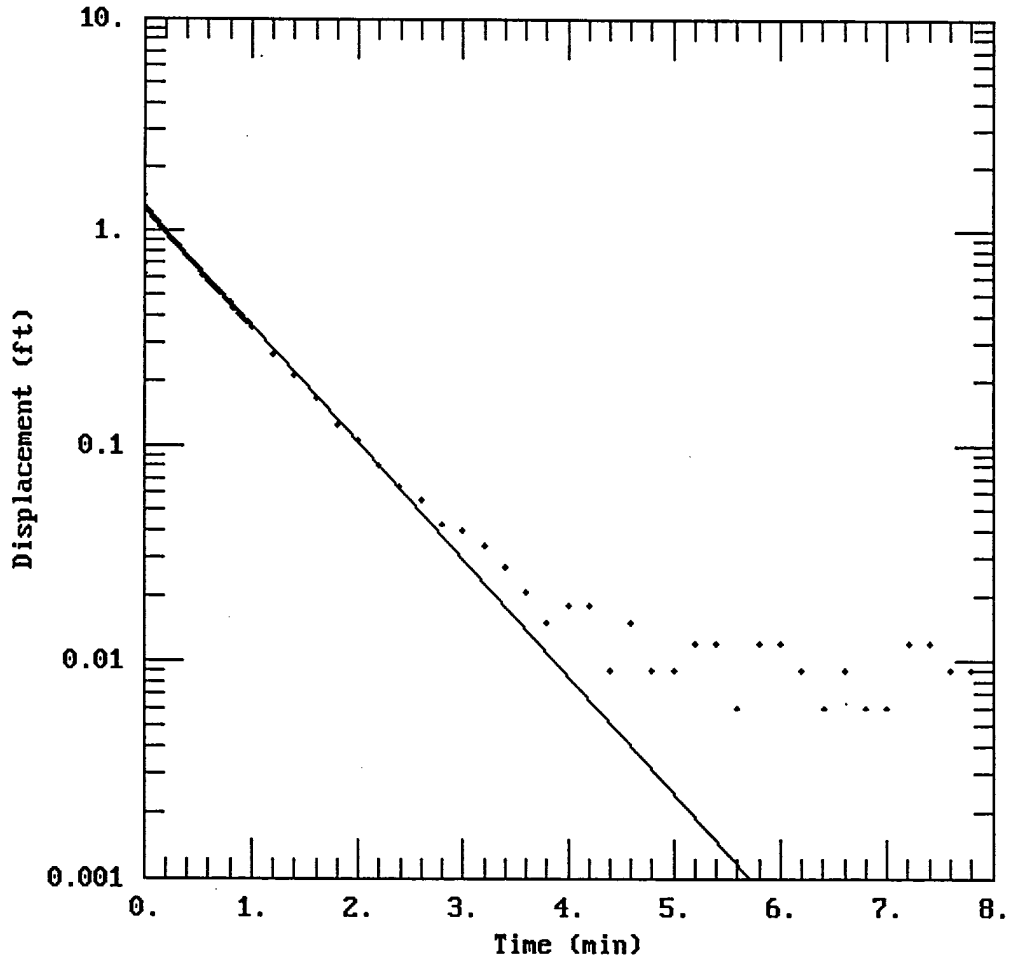
PARAMETER ESTIMATES:
K = 0.0006238 ft/min
y0 = 0.6133 ft

ESOLV

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL 2-393B: RUN 1



DATA SET:
2-393B-1.DAT
11/21/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATA:
H0= 1.475 ft
r_c= 0.167 ft
r_w= 0.354 ft
L = 10. ft
b = 29.14 ft
H = 29.14 ft

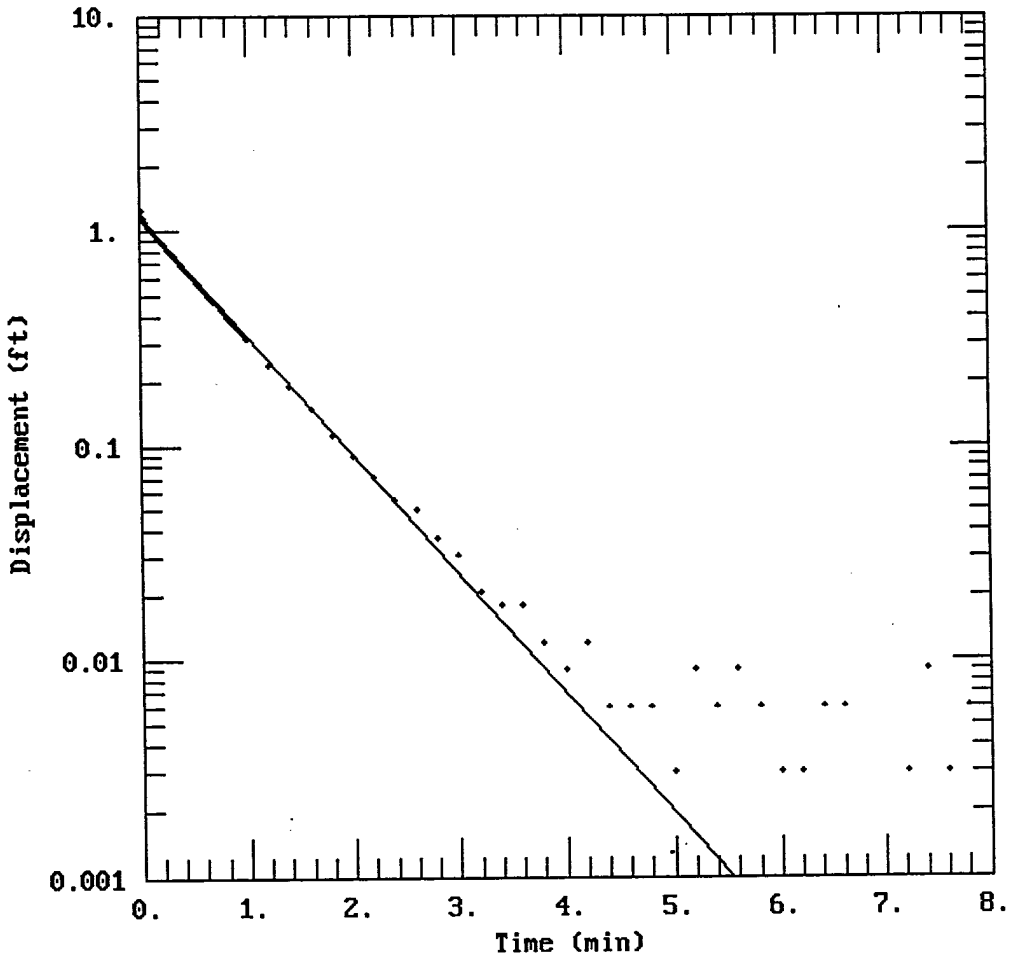
PARAMETER ESTIMATES:
K = 0.01222 ft/min
y0 = 1.261 ft

SOLV

<<

CLIENT: TINKER AFB	COMPANY: PARSONS ES
LOCATION: OKLAHOMA	PROJECT: 729691.34050

MONITORING WELL 2-393B: RUN 2



DATA SET:
2-393B-2.DAT
11/21/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

TEST DATA:
H0= 1.282 ft
r_c= 0.167 ft
r_w= 0.354 ft
L = 10. ft
b = 29.14 ft
H = 29.14 ft

PARAMETER ESTIMATES:
K = 0.01242 ft/min
y0 = 1.149 ft

ESOLV

LEMKE LAND SURVEYING, LLC

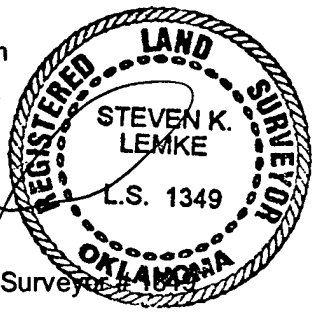
3625 W. Main, Suite 106 - Norman, OK 73072
Ph (405) 366-8541 FAX (405) 360-6670 E-mail LLSSKL@aol.com
C.A. No. 2471 (expires 6/30/99)

PARSONS ENGINEERING SCIENCE, INC
FORMER FIRE TRAINING PITS - 6 MONITOR WELLS
TINKER AIR FORCE BASE
BRUCE HENRY
HORIZONTAL - NAD27 (US SURVEY FEET)
VERTICAL - NGVD29 (US SURVEY FEET)

NORTHING (FT)	EASTING (FT)	ELEVATION (FT)	DESCRIPTION
151,085.60	2,181,167.63	1,241.82	CG39-B97-45 TOC
151,088.16	2,181,169.18	1,242.24	CG39-B97-45 GND
150,861.52	2,181,770.08	1,252.42	CG39-B97-43S TOC
150,863.36	2,181,772.35	1,252.72	CG39-B97-43S GND
150,866.94	2,181,777.04	1,252.54	CG39-B97-43B TOC
150,869.21	2,181,779.13	1,252.56	CG39-B97-43B GND
150,440.90	2,182,126.70	1,245.20	CG39-B97-41 TOC
150,443.53	2,182,126.53	1,245.57	CG39-B97-41 GND
151,434.08	2,181,280.87	1,245.97	2-393B TOC
151,436.52	2,181,282.08	1,246.19	2-393B GND
150,696.27	2,181,430.89	1,244.99	2-392B TOC
150,697.93	2,181,432.62	1,245.30	2-392B GND

HORIZONTAL DATUM: NAD 27 (US SURVEY FEET)
VERTICAL DATUM: NGVD 29 (US SURVEY FEET)
CONTROL MONUMENTS: SE30, SE32, SE28

Date of Survey: September 11, 1997
Crew: Arce / Young
Weather: Clear, calm, warm



Steven K. Lemke
Oklahoma Registered Land Surveyor #1349

APPENDIX C

LABORATORY ANALTYICAL DATA

MANTECH

Ref: 97-LB53
August 6, 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-3-276 requesting the analysis of ground water 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, most in duplicate, August 4, 1997 in capped, lead lined 40 mL VOA vials. The samples were analyzed on August 4-5, 1997. Samples were stored at 4°C until analyzed. All samples were acquired and processed using the Millennium data system. A 3 point (1-100 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

Lisa R. Black

xc: R.L. Cosby
G.B. Smith
J.L. Seeley SV fax

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

Printed 8/6/97 SF-3-276 Tinker AFB GW Sample Results Presented to Dr. Kampbell Units = ng/mL Analyst: L. Black

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
10 PPB	9.7	9.7	9.8	9.7	9.6	9.9	9.9	9.9	10.0	N/A
QC, OBSERVED, PPB	19.7	20.3	19.0	20.8	19.9	21.2	20.9	21.9	19.1	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
2-62A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-62B	6.0	1.2	ND	ND	ND	BLQ	BLQ	ND	ND	1140
2-63A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-63B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-64A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-64A Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-64B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-65A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-65B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-167B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-168B	2.5	ND	ND	ND	ND	ND	ND	ND	ND	5.8
1 PPB	1.0	0.9	1.0	1.0	1.0	0.9	0.9	1.0	1.1	N/A
2-272B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-273B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-273B Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-142A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-142B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-271B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-274A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-274A Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-274B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-392B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-393B	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	BLQ
50 PPB	50.4	50.7	50.5	50.9	50.4	51.2	51.1	51.9	51.9	N/A
2-355B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CG-39-B97-41	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CG-39-B97-43S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
* CG-39-B97-43D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CG-39-B97-45	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1 PPB	1.0	0.9	1.0	0.9	0.9	0.9	0.8	0.9	1.0	N/A

* Septa was inverted on the original sample and it's duplicate.

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb; N/A = Not Analyzed

MANTECH

Ref: 97-SH51

August 6, 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 25 liquids submitted August 6, 1997 under Service Request #SF-3-276. Sample analysis was begun August 6, 1997 and completed August 6, 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 SV fw

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-3-276

SAMPLE	MG/L TOC
2-62A	1.53
2-62B	3.30
2-63A	.745
2-63B	11.2
2-64A	.152
2-64B	.795
2-65A	<.4
2-65B	1.96
2-142A	2.14
2-142B	.929
2-167B	.488
2-168B	3.01
2-271B	.939
2-272B	.448
2-273B	.638
2-274A	<.4
2-274B	<.4
2-355B	.741
2-392B	<.4
2-393B	<.4
CG39-B97-41	<.4
DUP	<.4
CG39-B97-43D	.545
CG39-B97-45	<.4
CG39-B97-435	.539
WS37	58.7

WS37 std. t.v.=60.0

MANTECH

Ref: 97-MW50/vg
97-LP80/vg

August 6, 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 24 field samples from Tinker AFB, OK submitted to MERSC as part of Service Request #SF-3-276. The samples were received on August 4 and 5. 1997 and analyzed immediately. The methods used for analysis were EPA Methods 353.1 for NO_2 and NO_3, 350.1 for NH_3, and Waters capillary electrophoresis Method N-601 for Cl and SO_4. 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 us.

Sincerely,

Mark White

Lynda Pennington

Lynda Pennington

xc. R.L. Cosby
G.B. Smith
J.L. Seeley SV for

Sample	mg/l NO^-_2+NO^-_3(N)	mg/l NH_3(N)	mg/l Cl^-	mg/l SO_4^{-2}
2-62A	4.02	<.05	7.54	6.51
2-62B	3.92	<.05	173	127
2-63A	1.91	<.05	20.5	8.46
2-63B	2.39	<.05	94.4	65.7
2-64A	1.29	<.05	21.5	7.96
2-64A Dup	-----	-----	21.6	7.86
2-64B	3.42	<.05	49.3	27.0
2-65A	0.72	<.05	25.6	9.89
2-65B	3.18	<.05	78.5	44.4
2-65B Dup	3.19	<.05	-----	-----
2-167-B	0.27	<.05	4.49	18.1
2-168-B	0.58	<.05	14.4	42.4
2-272-B	1.95	<.05	130	37.6
2-273-B	0.35	<.05	16.5	12.1
2-273-B Dup	0.34	<.05	16.4	12.2
2-142-A	<.05	<.05	28.4	9.72
2-142-B	2.00	<.05	218	76.1
2-142-B Dup	2.03	<.05	-----	-----
2-271-B	1.11	.15	117	29.7
2-274-A	.62	<.05	18.0	10.4
2-274-B	3.08	<.05	74.6	24.0
2-392-B	2.57	<.05	10.6	5.91
2-392-B Dup	2.63	<.05	-----	-----
2-393-B	3.70	<.05	148	14.1
2-355-B	3.28	<.05	187	48.8
CG-39-B97-41	2.01	<.05	5.73	15.4
CG-39-B97-43S	4.22	<.05	159	49.0
CG-39-B97-43D	2.55	<.05	52.0	44.1
CG-39-B97-43D Dup	-----	-----	51.7	45.0
CG-39-B97-45	4.80	<.05	46.9	11.3
Blank	<.05	<.05	<.1	<.1
AQC	.58	.25	35.0	43.9
True Value	.62	.26	34.8	44.0
Spike Rec.	99%	99%	100%	99%

MANTECH

Ref: 97-LH40

August 8, 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-3-276, gas analysis was performed for methane, ethylene, and ethane on samples from Tinker AFB. The samples were received on August 4 and 5, 1997, and analyzed on August 5, 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,

Lisa Hopkins

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 CH4	100.8	**	**
100ppm C2H4	**	96.1	**
100ppm C2H6	**	**	102.5
HPHe	**	**	**
Lab Blank	**	**	**
2-62A	**	**	**
2-62B	1.05	**	**
2-63A	**	**	**
2-63B	0.002	**	**
2-64A	**	**	**
2-64A	**	**	**
Lab Dup			
2-65A	**	**	**
2-64B	**	**	**
2-65B	0.002	**	**
2-167B	0.022	**	**
2-168B	0.020	**	**
2-168B	0.020	**	**
Field Dup			
10ppm CH4	10.3	**	**
2-272B	**	**	**
2-273B	0.005	**	**
2-142A	**	**	**
2-142B	**	**	**
2-271B	**	**	**
2-271B	**	**	**
Lab Dup			
2-274A	**	**	**
2-274B	**	**	**
2-355B	**	**	**
2-392B	**	**	**
2-393B	**	**	**
2-393B	**	**	**
Field Dup			
10ppm C2H4	**	9.2	**
CG-39-B97-41	**	**	**
CG-39-B97-43S	**	**	**
CG-39-B97-43D	**	**	**
CG-39-B97-45	**	**	**
CG-39-B97-45	**	**	**
Lab Dup			
100ppm CH4	100.6	**	**
100ppm C2H4	**	99.3	**
100ppm C2H6	**	**	100.9
Lower Limit of Quantitation	0.001	0.003	0.002

Units for the samples are mg/L.
Units for the standards are parts per million.
** denotes None Detected.
* denotes Below Limit of Quantitation.

MANTECH

Ref: 97-BS4/vg
97-MAB9/vg
August 11, 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:

As per Service Request #SFTA-3-132, total alkalinity, hydrogen sulfide, ferrous iron, carbon dioxide, total phenols, and manganese were measured in 24 water samples from Tinker AFB, OK. The analysis began on July 31, 1997 and was completed on August 4, 1997.

WELL	CO_2	Fe^{+2}	Total Alk.	Phenols	Mn	H_2S
2-63B	75	<.01	460	<.01	<.01	<.01
2-63A	50	1.0	380	<.01	<.01	<.01
2-168B	65	<.01	380	<.01	<.01	<.01
2-62B	55	<.01	260	<.01	<.01	<.01
2-62A	45	0.10	310	<.01	<.01	<.01
2-64B	40	<.01	260	<.01	<.01	<.01
2-64A	45	0.10	270	<.01	<.01	<.01
2-73B	45	0.20	280	<.01	<.01	<.01
2-272B	45	<.01	280	<.01	<.01	<.01
2-167B	75	0.10	560	0.10	<.01	<.01
2-65B	75	<.01	350	<.01	<.01	<.01
2-65A	25	0.30	190	<.01	<.01	<.01
2-142A	45	<.01	270	0.20	<.01	<.01
2-142B	55	0.80	380	0.20	<.01	<.01
2-274B	45	0.20	310	0.20	<.01	<.01
2-274A	25	<.01	210	0.40	<.01	<.01
2-271B	65	0.60	420	0.30	<.01	<.01
2-355B	50	0.40	380	0.30	<.01	<.01
2-392B	60	<.01	350	0.20	<.01	<.01
39-B97-43D	75	<.01	450	0.20	<.01	<.01
39-B97-41	60	<.01	520	<.01	<.01	<.01
39-B97-43S	48	<.01	330	0.20	<.01	<.01
39-B97-45	75	<.01	380	<.01	<.01	<.01
2-393B	110	<.01	190	<.01	<.01	<.01

Note: All the data is in Mg\L.

If you have any questions, please see us at your convenience.

Sincerely,

Brad Scroggins

Mark Blankenship

xc: R.L. Cosby
G.B. Smith
J.L. Seeley

MANTECH ENVIRONMENTAL TECHNOLOGY

Ref: 97-DK22/vg
August 11, 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 Dr. Kampbell:

This report contains the results of my GC/MSD analysis of methylene chloride core sample extracts for Service Request #SF-3-276. The following target compound quantitations were requested: trichloroethene (TCE) and tetrachloroethene (PCE).

The analytical method was a modification of RSKSOP-124. Cool on-column injection (0.1 µl) was used with electronic pressure control set for a constant flow of 1.0 ml/min. The capillary GC column consisted of a 30m X 0.25mm Restek Stabilwax (Crossbonded Carbowax-PEG, 0.5µm film) plus an SGE 0.3m X 0.53 mm ID deactivated Carbowax deactivated capillary precolumn. SIM mode GC/MSD was used with the ions chosen from those listed in EPA method 524.2 Revision 3.0, where available. Multiple ions were acquired and ion ratios used to verify the accuracy of target compound identification. Standards calibration ranged from 0.025 to 250 µg/ml and was divided into a low level (0.025 to 2.5 ug/ml) and high level (2.5 to 250 ug/ml) curve for improved quantitative accuracy. Complete reports detailing the acquisition method and calibration curves have been recorded. The extracts were received on August 4, 1997 and SIM mode analyses for quantitation of target compounds performed August 5, 1997.

The quantitative results are as follows (mg/kg):

Sample	TCE	PCE
CG39-897-41 18-19' 1135 MPI 18-19' (Rep. 1)	0.019	ND
1135 MPI 18-19' (Rep. 2)	0.070	ND
CG39-897-43D 29-30' 0855 MPL 29-30' (Rep. 1)	ND	ND
0855 MPL 29-30' (Rep. 2)	ND	ND
Check Standards (ug/ml)		
0.25	0.24	0.24
25	26.1	26.2
QC (expected)	50	N/A
QC (observed)	47.7	N/A

If you require further information, please feel free to contact me.

Sincerely,

David A. Kovacs

xc: R.L. Cosby
J.L. Seeley JS
G.B. Smith GS

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

MANTECH

Ref: 97-DF38

Aug. 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: S.A. Vandegrift SV

Dear Don:

As requested in Service Request SF-3-276, GC/MS analysis for phenols and aliphatic/aromatic acids was done on one water sample from the Tinker AFB. This sample was labeled: CG-39-B97-43S. The sample was received on Aug. 6, 1997 and was extracted and derivatized by Amy Zhao on Aug. 8, 1997. The extracts were analyzed by GC/MS on Aug 8, 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 the Tinker AFB water sample. Derivative and extraction blanks, extraction recoveries 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
R. Cosby
D. Fine
J. 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 I. Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids in Water Samples from Tinker AFB, Service Request SF-3-276.

	Concentration ppb				% Recovery		
File Name:	106CG39B.TXT	88MTHBLK.TX	98EXTBLK.TXT	116EXTBL.TXT	97EXTREC.TX	115EXTRE.TXT	110100AA.TXT
Compound / Sample Name:	CG-39-B97-43S	Method Blank	Extraction Blank	Extraction Blank	50 ppb Extr. % Recovery	50 ppb Extr. % RecNvery	100 ppb Std. % Recovery
Propanoic Acid	***	***	23	***	52	11	97
2-Methylpropanoic Acid	***	***	***	***	33	28	93
Trimethylacetic Acid	14	***	15	12	110	107	96
Butyric Acid	***	***	5	***	37	28	97
2-Methylbutyric Acid	***	***	***	***	76	71	96
3-Methylbutryic Acid	***	***	***	***	72	67	98
3,3-Dimethylpropanoic Acid	***	*	***	***	103	90	96
Pentanoic Acid	***	***	4	***	82	74	90
2,3-Dimethybutyric Acid	***	***	***	***	99	92	91
2-Ethylbutyric Acid	***	***	***	***	104	89	91
2-Methylpentanoic Acid	***	***	***	***	107	92	96
3-Methylpentanoic Acid	*	***	***	***	102	93	92
4-Methylpentanoic Acid	***	*	***	***	105	94	93
Hexanoic Acid	5	***	14	5	128	101	91
2-Methylhexanoic Acid	*	*	***	***	115	89	82
Phenol	***	***	4	***	97	79	87
Cyclopentanecarboxylic Acid	*	*	***	***	86	79	94
5-Methylhexanoic Acid	*	*	***	***	114	95	93
o-Cresol	*	***	***	*	105	97	96
2-Ethylhexanoic Acid	21	***	***	***	122	103	94
Heptanoic Acid	***	***	6	***	123	98	92
m-Cresol	***	***	***	***	107	95	94
p-Cresol	***	***	***	***	102	93	91
1-Cyclopentene-1-carboxylic Acid	*	*	***	***	81	73	93
o-Ethylphenol	*	*	*	***	103	96	91
Cyclopentaneacetic Acid	*	*	***	***	107	94	92
2,6-Dimethyphenol	*	*	*	***	86	83	92
2,5-Dimethylphenol	*	*	*	***	96	88	90
Cyclohexanecarboxylic Acid	*	*	***	***	107	94	93
3-Cyclohexene-1-carboxylic Acid	*	*	***	***	89	85	91
2,4-Dimethylphenol	*	*	*	***	71	74	95
3,5-Dimethylphenol & m-Ethylphenol	*	*	***	***	107	92	93
Octanoic Acid	***	***	11	3	129	99	92
2,3-Dimetholphenol	*	*	*	*	95	85	93
p-Ethylphenol	*	*	*	*	105	98	93
Benzoic Acid	3	***	9	5	117	101	92
3,4-Dimethyphenol	*	*	***	*	95	89	92
m-Methylbenzoic Acid	*	*	*	*	89	82	89
1-Cyclohexene-1-carboxylic Acid	*	*	*	*	108	91	93
Cyclohexaneacetic Acid	*	*	***	***	110	93	91
2-Phenylpropanoic Acid	*	*	***	*	113	95	92
o-Methylbenzoic Acid	*	*	***	***	109	96	95
Phenylacetic Acid	*	***	***	*	109	94	90
m-Tolylacetic Acid	*	*	*	*	176	124	134
o-Tolylacetic Acid	*	*	*	*	102	99	108
2,6-Dimethylbenzoic Acid	*	*	***	***	114	99	89
p-Tolylacetic Acid	*	*	*	***	111	93	91
p-Methylbenzoic Acid	*	***	***	***	106	95	94
3-Phenylpropanoic Acid	*	*	***	*	102	87	96
2,5-Dimethylbenzoic Acid	*	*	*	*	109	91	94
Decanoic Acid	***	***	22	***	111	89	92
2,4-Dimethylbenzoic Acid	*	*	***	***	104	98	91
3,5-Dimethylbenzoic Acid	*	*	***	*	119	89	93
2,3-Dimethylbenzoic Acid	*	*	***	***	108	95	94
4-Ethylbenzoic Acid	*	*	***	*	107	93	94
2,4,6-Trimethylbenzoic Acid	*	***	***	***	110	95	93
3,4-Dimethylbenzoic Acid	*	*	***	*	108	87	93
2,4,5-Trimethylbenzoic Acid	*	*	*	***	113	89	93

*** indicates concentration of extract was below lowest calibration standard (3 ppb)

* indicates not found.

Printer: 12:45 PM 8/13/97

MANTECH

Ref: 97JAD51

August 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-3-276, headspace GC/MS analysis of 24 Tinker AFB water samples for chlorinated volatile oraganics was completed. The samples were received on August 4 and 5, 1997 and analyzed on August 8-9, 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 2000 ppb. The lower calibration limits were 1.0 ppb.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel

xc: R.L. Cosby
G.B. Smith
D.D. Fine
J.L. Seeley SV FW
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-3-276 from Tinker AFB.

Concentration = ppb

Compound	2-392B	2-393B	2-393B Field Dup	2-355B	CG39-B97 -41	CG39-B97 -435	2-142A	2-142B	2-271B	2-274A
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	---	---	ND	ND	1.1	ND	ND	ND	ND
T-1,2-DICHLOROETHENE	ND	---	---	---	ND	6.1	ND	ND	ND	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	54.3	54.5	50.0	---	183	ND	ND	ND	ND
CHLOROFORM	ND	---	---	---	ND	1.0	ND	ND	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	ND
1,2-DICHLOROETHANE	ND	45.4	49.2	1.8	---	2.4	ND	ND	ND	ND
TRICHLOROETHENE	---	406	425	344	3.6	1490	ND	---	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	---	ND	ND	ND	ND
CHLOROBENZENE	ND	---	---	---	ND	1.0	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	---	---	---	ND	1.6	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

	2-274B	2-274B Lab Dup	2-274B Field Dup	CG39-B97 -43D	CG39-B97 -45	2-62A	2-62B	2-62B Field Dup 1/10 Dil	2-63A	2-63B
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	1.7	ND	ND	6.6
1,1-DICHLOROETHENE	---	ND	---	ND	ND	ND	9.5	---	ND	1.0
T-1,2-DICHLOROETHENE	2.2	2.2	2.1	2.4	---	ND	76.2	77.0	ND	3.6
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.6
C-1,2-DICHLOROETHENE	51.7	51.4	53.4	31.8	22.6	---	1200	1110	ND	161
CHLOROFORM	---	---	---	ND	ND	ND	5.3	---	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	ND
1,2-DICHLOROETHANE	1.1	1.2	1.4	---	1.4	ND	260	239	ND	---
TRICHLOROETHENE	518	529	506	169	153	10.9	*****	9440	---	75.4
TETRACHLOROETHENE	---	---	---	ND	ND	ND	6.1	---	ND	1.9
CHLOROBENZENE	---	---	---	ND	ND	ND	117	104	ND	ND
1,3-DICHLOROBENZENE	---	---	---	---	---	ND	34.8	25.0	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	168	123	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	---	950	969	---	---

ND = None Detected --- = Below Calibration Limit(1.0 ppb) ***** = Above Calibration Limit(2000 ppb) Dup = Duplicate Dil = Dilution

Table 2. Quantitation Report for S.R. # SF-3-276 from Tinker AFB.

Concentration = ppb

Compound	2-64A	2-64B	2-65A	2-65B	2-65B Lab Dup	2-167B	2-168B	2-272B	2-273B	QC0808B 200 ppb
VINYL CHLORIDE	ND	---	ND	1.3	1.5	ND	ND	ND	ND	189
1,1-DICHLOROETHENE	ND	---	ND	---	---	ND	---	ND	ND	195
T-1,2-DICHLOROETHENE	ND	17.6	ND	2.5	2.5	ND	ND	ND	ND	188
1,1-DICHLOROETHANE	ND	ND	ND	---	---	ND	1.2	ND	ND	204
C-1,2-DICHLOROETHENE	ND	154	ND	37.0	36.9	ND	27.6	2.1	ND	200
CHLOROFORM	ND	---	ND	ND	ND	ND	ND	ND	ND	204
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	204
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	195
1,2-DICHLOROETHANE	ND	1.3	ND	3.2	3.3	ND	ND	---	ND	207
TRICHLOROETHENE	ND	914	ND	90.0	87.7	ND	1.4	28.1	ND	189
TETRACHLOROETHENE	ND	---	ND	52.0	50.7	ND	---	ND	ND	192
CHLOROBENZENE	ND	---	ND	9.5	9.6	ND	ND	ND	ND	205
1,3-DICHLOROBENZENE	ND	1.2	ND	---	---	ND	ND	ND	ND	232
1,4-DICHLOROBENZENE	ND	---	ND	1.8	1.8	ND	ND	ND	ND	239
1,2-DICHLOROBENZENE	ND	---	ND	3.6	3.7	ND	ND	ND	ND	238

	QC0808C 20 ppb	QC0808D 200 ppb	QC0808E 20 ppb	QC0813A 20 ppb	BL0808A BLANK
VINYL CHLORIDE	16.6	218	18.1	17.0	ND
1,1-DICHLOROETHENE	24.3	194	25.3	24.5	ND
T-1,2-DICHLOROETHENE	20.8	186	20.6	21.0	ND
1,1-DICHLOROETHANE	19.9	206	20.2	21.6	ND
C-1,2-DICHLOROETHENE	19.6	203	19.4	21.6	ND
CHLOROFORM	18.7	202	19.3	20.0	ND
1,1,1-TRICHLOROETHANE	21.2	204	22.1	21.6	ND
CARBON TETRACHLORIDE	22.2	194	22.7	22.1	ND
1,2-DICHLOROETHANE	18.5	206	16.8	20.7	ND
TRICHLOROETHENE	18.0	185	19.0	18.3	ND
TETRACHLOROETHENE	21.3	191	20.4	20.2	ND
CHLOROBENZENE	20.6	200	19.9	21.2	ND
1,3-DICHLOROBENZENE	21.0	231	20.2	20.3	ND
1,4-DICHLOROBENZENE	20.3	234	20.6	21.4	ND
1,2-DICHLOROBENZENE	20.0	234	20.3	20.7	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) QC = Quality Control Std. BL = Blank Dup = Duplicate

MANTECH

Ref: 97-SH53

August 18, 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 six Tinker soils submitted August 9, 1997 under Service Request #SF-3-276. Sample analysis was begun August 11, 1997 and completed August 18, 1997 using RSKSOP-102 and RSKSOP-120.

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

KAMPBELL TINKER SOIL SF-3-276

SAMPLE	SOIL FILTRATE % O.C.	SOLIDS %TOC	TOTAL SOIL % TOC	MEAN %TOC	STD DEV
MP2 0855,1-1	.894	<.001	.894	.865	.031
1-2	.832	<.001	.832		
1-3	.869	<.001	.869		
MW1 1335,1-1	.969	<.001	.969	.830	.176
1-2	.632	<.001	.632		
1-3	.888	<.001	.888		
MW1 1410,1-1	.806	<.001	.806	.819	.037
1-2	.860	<.001	.860		
1-3	.790	<.001	.790		
Z-395B,1-1	.857	<.001	.857	.731	.113
1-2	.638	<.001	.638		
1-3	.697	<.001	.697		
Z-593B,1-1	.681	.003	.684	.771	.095
1-2	.747	.008	.755		
1-3	.869	.004	.873		
MP1 1135,1-1	.939	.013	.952	.862	.078
1-2	.803	.013	.816		
1-3	.805	.014	.819		
WS37	55.3				
LECO STD		.921			

WS37 std t.v.=60.0
Leco soil std t.v.=.90+/-.04

COMPUCHEM ENVIRONMENTAL CORPORATION

Attention: Scott Boling
Brown & Root Environmental
5500 South Douglas Blvd.
Oklahoma City, OK 73150

Date of Report: 10/21/97
Date Collected: 09/04/97
Date Received: 09/05/97
Collected By: AJS

Cust. Proj: Tinker AFB IRW&B#1

Sample Desc: CG39 2-356B

Lab ID: 867403

	Result	Unit	Det. Limit	Dilutn Factor	Procedure	Test Data
ORGANIC						
SEMI-VOLATILES - GC/MS						
Benzyl Chloride	BDL	UG/L	10	1	8270	09/27/97
Ethyl Methacrylate	BDL	UG/L	10	1	8270	09/27/97
Acenaphthene	BDL	UG/L	10	1	8270	09/27/97
Acenaphthylene	BDL	UG/L	10	1	8270	09/27/97
Anthracene	BDL	UG/L	10	1	8270	09/27/97
Benzidine	BDL	UG/L	15	1	8270	09/27/97
Benzo(a)anthracene	BDL	UG/L	15	1	8270	09/27/97
Benzo(a)pyrene	BDL	UG/L	15	1	8270	09/27/97
Benzo(b)fluoranthene	BDL	UG/L	15	1	8270	09/27/97
Benzo(g,h,i)perylene	BDL	UG/L	20	1	8270	09/27/97
Benzo(k)fluoranthene	BDL	UG/L	30	1	8270	09/27/97
bis(2-Chloroethoxy)methane	BDL	UG/L	10	1	8270	09/27/97
bis(2-Chloroethyl)ether	BDL	UG/L	10	1	8270	09/27/97
bis(2-Chloroisopropyl)ether	BDL	UG/L	15	1	8270	09/27/97
bis(2-Ethylhexyl)phthalate	BDL	UG/L	15	1	8270	09/27/97
4-Bromophenyl phenyl ether	BDL	UG/L	10	1	8270	09/27/97
Butyl benzyl phthalate	BDL	UG/L	15	1	8270	09/27/97
2-Chloronaphthalene	BDL	UG/L	10	1	8270	09/27/97
4-Chlorophenyl phenyl ether	BDL	UG/L	15	1	8270	09/27/97
Chrysene	BDL	UG/L	15	1	8270	09/27/97
Dibenzo(a,h)anthracene	BDL	UG/L	20	1	8270	09/27/97
1,2-Dichlorobenzene	BDL	UG/L	15	1	8270	09/27/97
1,3-Dichlorobenzene	BDL	UG/L	15	1	8270	09/27/97
1,4-Dichlorobenzene	BDL	UG/L	10	1	8270	09/27/97
3,3'-Dichlorobenzidine	BDL	UG/L	15	1	8270	09/27/97
Diethyl phthalate	BDL	UG/L	10	1	8270	09/27/97
Dimethyl phthalate	BDL	UG/L	15	1	8270	09/27/97
Di-n-butyl phthalate	BDL	UG/L	40	1	8270	09/27/97
2,4-Dinitrotoluene	BDL	UG/L	10	1	8270	09/27/97
2,6-Dinitrotoluene	BDL	UG/L	10	1	8270	09/27/97
Di-n-octyl phthalate	BDL	UG/L	20	1	8270	09/27/97
1,2-Diphenylhydrazine	BDL	UG/L	10	1	8270	09/27/97
Fluoranthene	BDL	UG/L	15	1	8270	09/27/97
Fluorene	BDL	UG/L	10	1	8270	09/27/97
Hexachlorobenzene	BDL	UG/L	10	1	8270	09/27/97

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Date Collected: 09/04/97
Date Received: 09/05/97
Collected By: AJS

Cust. Proj: Tinker AFB IRW&B#1

Sample Desc: CG39 2-356B

Lab ID: 867403

	Result	Unit	Det. Limit	Dilutn Factor	Procedure	Test Date
ORGANIC						
VOLATILES - GC/MS						
1,1,1,2-Tetrachloroethane	BDL	UG/L	.8	1	8260	09/12/97
1,2,3-Trichloropropane	BDL	UG/L	1	1	8260	09/12/97
Bromobenzene	BDL	UG/L	.5	1	8260	09/12/97
Dibromomethane	BDL	UG/L	.8	1	8260	09/12/97
Xylenes (Total)	BDL	UG/L	.5	1	8260	09/12/97
2,2-Dichloropropane	BDL	UG/L	.5	1	8260	09/12/97
1,1-Dichloropropene	BDL	UG/L	1	1	8260	09/12/97
1,3-Dichloropropane	BDL	UG/L	.8	1	8260	09/12/97
Isopropylbenzene	BDL	UG/L	.8	1	8260	09/12/97
t-Butylbenzene	BDL	UG/L	.8	1	8260	09/12/97
n-Propylbenzene	BDL	UG/L	.8	1	8260	09/12/97
sec-Butylbenzene	BDL	UG/L	.8	1	8260	09/12/97
1,3,5-Trimethylbenzene	BDL	UG/L	.5	1	8260	09/12/97
1,2,4-Trimethylbenzene	BDL	UG/L	.5	1	8260	09/12/97
p-Isopropyltoluene	BDL	UG/L	.8	1	8260	09/12/97
n-Butylbenzene	BDL	UG/L	.8	1	8260	09/12/97
1,2-Dichlorobenzene	BDL	UG/L	.5	1	8260	09/12/97
1,3-Dichlorobenzene	BDL	UG/L	.5	1	8260	09/12/97
1,4-Dichlorobenzene	BDL	UG/L	.5	1	8260	09/12/97
Hexachlorobutadiene	BDL	UG/L	.8	1	8260	09/12/97
Naphthalene	BDL	UG/L	.8	1	8260	09/12/97
1,2,4-Trichlorobenzene	BDL	UG/L	.5	1	8260	09/12/97
1,2,3-Trichlorobenzene	BDL	UG/L	.8	1	8260	09/12/97

Note 'BDL' = Below Detection Limit

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Date Received: 09/05/97
Collected By: AJS

Cust. Proj: Tinker AFB IRW4B#1

Sample Desc: CG39 2-356B

Lab ID: 867403

	Result	Unit	Det. Limit	Dilutn Factor	Procedure	Test Date
ORGANIC						
VOLATILES - GC/MS						
Benzene	BDL	UG/L	.8	1	8260	09/12/97
Bromoform	BDL	UG/L	.5	1	8260	09/12/97
Carbon tetrachloride	BDL	UG/L	1	1	8260	09/12/97
Chlorobenzene	BDL	UG/L	.5	1	8260	09/12/97
Dibromochloromethane	BDL	UG/L	.5	1	8260	09/12/97
Chloroethane	BDL	UG/L	.5	1	8260	09/12/97
Chloroform	BDL	UG/L	.8	1	8260	09/12/97
Bromodichloromethane	BDL	UG/L	.5	1	8260	09/12/97
Dichlorodifluoromethane	BDL	UG/L	1	1	8260	09/12/97
1,1-Dichloroethane	BDL	UG/L	.5	1	8260	09/12/97
1,2-Dichloroethane	BDL	UG/L	.8	1	8260	09/12/97
1,1-Dichloroethene	BDL	UG/L	.8	1	8260	09/12/97
1,2-Dichloropropane	BDL	UG/L	.8	1	8260	09/12/97
Cis-1,3-Dichloropropene	BDL	UG/L	.5	1	8260	09/12/97
Ethylbenzene	BDL	UG/L	.5	1	8260	09/12/97
Bromomethane	BDL	UG/L	.5	1	8260	09/12/97
Chloromethane	BDL	UG/L	1	1	8260	09/12/97
Methylene chloride	.9JB	UG/L	2	1	8260	09/12/97
1,1,2,2-Tetrachloroethane	BDL	UG/L	.5	1	8260	09/12/97
Tetrachloroethene	BDL	UG/L	.8	1	8260	09/12/97
Toluene	BDL	UG/L	.8	1	8260	09/12/97
Trans-1,2-Dichloroethene	BDL	UG/L	.8	1	8260	09/12/97
1,1,1-Trichloroethane	BDL	UG/L	.8	1	8260	09/12/97
1,1,2-Trichloroethane	BDL	UG/L	.8	1	8260	09/12/97
Trichloroethene	BDL	UG/L	.8	1	8260	09/12/97
Trichlorofluoromethane	BDL	UG/L	1	1	8260	09/12/97
Vinyl chloride	BDL	UG/L	1	1	8260	09/12/97
Bromochloromethane	BDL	UG/L	1	1	8260	09/12/97
Cis-1,2-Dichloroethene	BDL	UG/L	.5	1	8260	09/12/97
2-Chlorotoluene	BDL	UG/L	.5	1	8260	09/12/97
4-Chlorotoluene	BDL	UG/L	.5	1	8260	09/12/97
1,2-Dibromoethane (Ethylene dibromide)	BDL	UG/L	.8	1	8260	09/12/97
Trans-1,3-Dichloropropane	BDL	UG/L	.8	1	8260	09/12/97
Styrene	BDL	UG/L	.5	1	8260	09/12/97
1,2-Dibromo-3-chloropropane (DBCP)	BDL	UG/L	2	1	8260	09/12/97

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Date Received: 09/05/97
Collected By: AJS

Cust. Proj: Tinker AFB IM#&B#1

Sample Desc: CG39 2-356B

Lab ID: 867403

	Result	Unit	Det. Limit	Dilutn Factor	Procedure	Test Date
ORGANIC						
SEMI-VOLATILES - GC/MS						
Hexachlorocyclopentadiene	BDL	UG/L	10	1	8270	09/27/97
Hexachloroethane	BDL	UG/L	15	1	8270	09/27/97
Indeno(1,2,3-cd)pyrene	BDL	UG/L	25	1	8270	09/27/97
Isophorone	BDL	UG/L	10	1	8270	09/27/97
Nitrobenzene	BDL	UG/L	10	1	8270	09/27/97
N-Nitrosodimethylamine	BDL	UG/L	20	1	8270	09/27/97
N-Nitroso-di-n-propylamine	BDL	UG/L	10	1	8270	09/27/97
N-Nitrosodiphenylamine(1)	BDL	UG/L	15	1	8270	09/27/97
Phenanthrene	BDL	UG/L	10	1	8270	09/27/97
Pyrene	BDL	UG/L	15	1	8270	09/27/97
1,3,5-Trichlorobenzene	BDL	UG/L	10	1	8270	09/27/97
Pentachloronitrobenzene	BDL	UG/L	15	1	8270	09/27/97
1,2,3,4-Tetrachlorobenzene	BDL	UG/L	10	1	8270	09/27/97
1,2,4,5-Tetrachlorobenzene	BDL	UG/L	35	1	8270	09/27/97
Aniline	BDL	UG/L	15	1	8270	09/27/97
Benzyl alcohol	BDL	UG/L	15	1	8270	09/27/97
4-Chloroaniline	BDL	UG/L	10	1	8270	09/27/97
Dibenzofuran	BDL	UG/L	10	1	8270	09/27/97
2-Methylnaphthalene	BDL	UG/L	10	1	8270	09/27/97
2-Nitroaniline	BDL	UG/L	15	1	8270	09/27/97
3-Nitroaniline	BDL	UG/L	15	1	8270	09/27/97
4-Nitroaniline	BDL	UG/L	20	1	8270	09/27/97
Pyridine	BDL	UG/L	15	1	8270	09/27/97
1-Naphthylamine	BDL	UG/L	20	1	8270	09/27/97
2-Naphthylamine	BDL	UG/L	20	1	8270	09/27/97
4-Aminobiphenyl	BDL	UG/L	10	1	8270	09/27/97
p-Dimethylaminoazobenzene	BDL	UG/L	10	1	8270	09/27/97
2-Acetylaminofluorene	BDL	UG/L	15	1	8270	09/27/97
4,4'-Methylene-bis(2-chloroaniline)	BDL	UG/L	15	1	8270	09/27/97
5-Nitro-O-toluidine	BDL	UG/L	10	1	8270	09/27/97
N-Nitrosodiethylamine	BDL	UG/L	15	1	8270	09/27/97
Acetophenone	BDL	UG/L	15	1	8270	09/27/97
N-Nitrosopiperidine	BDL	UG/L	10	1	8270	09/27/97
Safrole	BDL	UG/L	10	1	8270	09/27/97
1,4-Naphthoquinone	BDL	UG/L	25	1	8270	09/27/97

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Cust. Proj: Tinker AFB IRW&B#1

Sample Desc: CG39 2-356B

Lab ID: 867403

	Result	Unit	Det. Limit	Dilutn Factor	Procedure	Test Date
ORGANIC						
SEMI-VOLATILES - GC/MS						
Pentachloroethane	BDL	UG/L	15	1	8270	09/27/97
Pentachlorobenzene	BDL	UG/L	10	1	8270	09/27/97
1,3,5-Trinitrobenzene	BDL	UG/L	20	1	8270	09/27/97
2-Picoline	BDL	UG/L	25	1	8270	09/27/97
o-Toluidine hydrochloride	BDL	UG/L	25	1	8270	09/27/97
1,2,3,5-Tetrachlorobenzene	BDL	UG/L	35	1	8270	09/27/97
Ethyl methanesulfonate	BDL	UG/L	10	1	8270	09/27/97
Methapyrilene	BDL	UG/L	45	1	8270	09/27/97
7,12-Dimethylbenzanthracene	BDL	UG/L	15	1	8270	09/27/97
Benzal chloride	BDL	UG/L	10	1	8270	09/27/97
Sinophoo	BDL	UG/L	10	1	8270	09/27/97
Pronamide	BDL	UG/L	10	1	8270	09/27/97
Chlorobenzilate	BDL	UG/L	15	1	8270	09/27/97
Isosafrole	BDL	UG/L	15	1	8270	09/27/97
N-Nitrosopyrrolidine	BDL	UG/L	15	1	8270	09/27/97
Aramite	BDL	UG/L	10	1	8270	09/27/97
Trans-Diallate	BDL	UG/L	10	1	8270	09/27/97
Cis-Diallate	BDL	UG/L	10	1	8270	09/27/97
3,3'-Dimethoxybenzidine	BDL	UG/L	20	1	8270	09/27/97
Benzotrichloride	BDL	UG/L	10	1	8270	09/27/97
Nitrosomethylethylamine	BDL	UG/L	45	1	8270	09/27/97
N-Nitroso-di-n-butylamine	BDL	UG/L	15	1	8270	09/27/97
Hexachloropropene	BDL	UG/L	10	1	8270	09/27/97
Phenacetin	BDL	UG/L	15	1	8270	09/27/97
Dimethoate	BDL	UG/L	10	1	8270	09/27/97
Paraldehyde	BDL	UG/L	15	1	8270	09/27/97
Methyl methanesulfonate	BDL	UG/L	10	1	8270	09/27/97
N-Nitrosomorpholine	BDL	UG/L	15	1	8270	09/27/97
3,3'-Dimethylbenzidine	BDL	UG/L	20	1	8270	09/27/97
Cyclophosphamide	BDL	UG/L	10	1	8270	09/27/97
1-Chloronaphthalene	BDL	UG/L	15	1	8270	09/27/97
3-Methylcholanthrene	BDL	UG/L	10	1	8270	09/27/97
Dibenz(a,j)acridine	BDL	UG/L	20	1	8270	09/27/97
Diphenylamine	BDL	UG/L	15	1	8270	09/27/97
1-Methylnaphthalene	BDL	UG/L	10	1	8270	09/27/97

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Cust. Proj: Tinker AFB IMW&B#1

Sample Desc: CG39 2-356B

Lab ID: 867403

	Result	Unit	Det. Limit	Dilutn Factor	Procedure	Test Date
ORGANIC						
SEMI-VOLATILES - GC/MS						
1,3-Dinitrobenzene	BDL	UG/L	10	1	8270	09/27/97
Famphur	BDL	UG/L	20	1	8270	09/27/97
Isodrin	BDL	UG/L	10	1	8270	09/27/97
4-Nitroquinoline 1-oxide	BDL	UG/L	100	1	8270	09/27/97
O,O,O-Triethyl phosphorothioate	BDL	UG/L	90	1	8270	09/27/97
2-Chlorophenol	BDL	UG/L	25	1	8270	09/27/97
2,4-Dichlorophenol	BDL	UG/L	30	1	8270	09/27/97
2,4-Dimethylphenol	BDL	UG/L	20	1	8270	09/27/97
4,6-Dinitro-2-methylphenol	BDL	UG/L	80	1	8270	09/27/97
2,4-Dinitrophenol	BDL	UG/L	90	1	8270	09/27/97
2-Nitrophenol	BDL	UG/L	30	1	8270	09/27/97
4-Nitrophenol	BDL	UG/L	35	1	8270	09/27/97
4-Chloro-3-methylphenol	BDL	UG/L	20	1	8270	09/27/97
Pentachlorophenol	BDL	UG/L	85	1	8270	09/27/97
Phenol	BDL	UG/L	10	1	8270	09/27/97
2,4,6-Trichlorophenol	BDL	UG/L	55	1	8270	09/27/97
2-Methylphenol	BDL	UG/L	20	1	8270	09/27/97
3-Methylphenol	BDL	UG/L	120	1	8270	09/27/97
4-Methylphenol	BDL	UG/L	120	1	8270	09/27/97
Benzoic acid	BDL	UG/L	45	1	8270	09/27/97
2,4,5-Trichlorophenol	BDL	UG/L	65	1	8270	09/27/97
2,3,4,6-Tetrachlorophenol	BDL	UG/L	70	1	8270	09/27/97
2,6-Dichlorophenol	BDL	UG/L	65	1	8270	09/27/97

Note 'BDL' = Below Detection Limit

APPENDIX D

COST CALCULATIONS

LTM Well Installation Cost Estimate
Site FTA-2
RNA TS
Tinker AFB, Oklahoma
729691.3405

Design/Construction of 8 LTM/POC Wells		Description	Unit	Qty.	Unit Price	Subtotal	Total
Cost Calculations		Mobilization	lump sum	1	$500	$500	
Number of wells:	8	Well Installation	feet	480	$40	$19,200	
Depth (ft) each:	60	Soil Disposal	drum	20	$45	$900	
		Decontamination	lump sum	1	$700	$700	
							$20,600

Billing Category Cost Code/(Billing Category)	Billing Rate	Task 1 (hrs)	Install New LTM Wells ($)	Task 2 (hrs)	Procurement ($)	Task 3 (hrs)	Reporting & PM ($)
Word Processor 88/(15)	$30	0	$0	6	$180	8	$240
CADD Operator 58/(25)	$47	0	$0	2	$94	10	$470
Technician 42/(50)	$40	70	$2,800	0	$0	18	$720
Staff Level 16/(65)	$57	70	$3,990	10	$570	30	$1,710
Project Level 12/(70)	$65	8	$520	6	$390	8	$520
Senior Level 10/(80)	$85	2	$170	2	$170	4	$340
Principal 02/(85)	$97	0	$0	0	$0	0	$0
Total Labor (hrs/$)		150	$7,480	26	$1,404	78	$4,000

ODCs	Task 1	Task 2	Task 3
Phone	$50	$20	$10
Photocopy	$10	$0	$20
Mail	$0	$10	$20
Computer	$0	$50	$100
CAD	$0	$0	$100
WP	$0	$20	$100
Travel	$1,600	$0	$0
Per Diem	$1,050	$0	$0
Eqpt. & Supplies	$200	$0	$0
Total ODCs	$2,910	$100	$350

Outside Services	Task 1	Task 2	Task 3
LTM Well Installation Costs	$20,600	$0	$0
Surveying	$2,000	$0	$0
Other: Maintain Institutional Controls	$0	$0	$0
Total Outside Services	$22,600	$0	$0

Proposal Estimate	Task 1	Task 2	Task 3
Labor	$7,480	$1,404	$4,000
ODC's	$2,910	$100	$350
Outside Services	$22,600	$0	$0
Total by Task	$32,990	$1,504	$4,350

Total Labor	$12,884
Total ODCs	$3,360
Total Outside Services	$22,600
Total Project	$38,844

Task 1: Field Work (Installation of LTM Wells)
Task 2: Subcontracting/Permitting
Task 3: Reporting/PM per Event.

PARSONS Calculation Page				Job Number 729691.34050	Page 1 of 2
Rev	Date 3/24/99	By MLP	Ck	Subject: Cost Calculations for Alternative 1 RNA + LTM FTA-2, Tinker AFB	

Capital Costs

Design/Construct 8 LTM/POC Wells in 1999					Present Worth Cost	$38,844
Groundwater Sampling - Years 1999 - 2033						
30 Long-Term Monitoring Wells						
2 Surface-Water Stations						
10 QA/QC (3 dupl, 1 field blank, 2 trip blank, 2 MS, 2 MSD)						
42 Total Samples						
Sampling Labor		180	hours x	$60	/hour	$10,800
Analytical Subcontractor						
	42 VOCs[a/]			$160	/each	$6,720
	42 Methane/Ethane/Ethene			$101	/each	$4,242
	42 Nitrate/Nitrite			$20	/each	$840
	32 Field Parameters			$20	/each	$640
Supplies				$700	lump sum	$700
Travel				$800	lump sum	$800
Per Diem		24	days x	$88	/day	$2,112
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		$36,914

[a/] VOC analysis includes BTEX, CAHs, napgthalene, and MTBE.

Rev	Date	By	Ck	Subject:	Cost Calculations for Alternative 1 RNA + LTM FTA-2, Tinker AFB
	3/3/99	MLP			

Summary of Capital and Present Worth Costs

Capital Costs

Design/Construct 8 LTM/POC Wells in 1999	P/F i=7% n=1	Present Worth Cost	$38,844

Monitoring Costs

Annual Monitoring of 30 wells and 2 surface water stations, 1999-2013 (15 events)

Cost per Event		$36,914	
P/A i=7%, n=1.0	1999	$34,499.07	
P/A i=7%, n=2.0	2000	$32,242.12	
P/A i=7%, n=3.0	2001	$30,132.82	
P/A i=7%, n=4.0	2002	$28,161.51	
P/A i=7%, n=5.0	2003	$26,319.17	
P/A i=7%, n=6	2004	$24,597.36	
P/A i=7%, n=7	2005	$22,988.18	
P/A i=7%, n=8	2006	$21,484.28	
P/A i=7%, n=9	2007	$20,078.77	
P/A i=7%, n=10	2008	$18,765.21	
P/A i=7%, n=11	2009	$17,537.58	
P/A i=7%, n=12	2010	$16,390.26	
P/A i=7%, n=13	2011	$15,318.00	
P/A i=7%, n=14	2012	$14,315.89	
P/A i=7%, n=15	2013	$13,379.33	
	Total Present Worth Cost		$336,210

Biennial Monitoring of 30 wells and 2 surface water stations, 2013-2033 (10 events)

P/A i=7%, n=17	2015	$11,686.03	
P/A i=7%, n=19	2017	$10,207.03	
P/A i=7%, n=21	2019	$8,915.21	
P/A i=7%, n=23	2021	$7,786.89	
P/A i=7%, n=25	2023	$6,801.37	
P/A i=7%, n=27	2025	$5,940.58	
P/A i=7%, n=29	2027	$5,188.74	
P/A i=7%, n=31	2029	$4,532.04	
P/A i=7%, n=33	2031	$3,958.46	
P/A i=7%, n=35	2033	$3,457.47	
	Total Present Worth Cost		$68,474

Site Management every year (35 years)

Annual Cost	$6,000	
P/A i=7% n=35	PWF = 12.9476723	
	Present Worth Cost	$77,686

Total Capital and Present Worth Costs of LTM Program	$521,213

PARSONS *Calculation Page*				Job Number 729691.34050	Page 1 of 2
Rev	Date 3/3/99	By MLP	Ck	Subject:	Cost Calculations for Alternative 2 RNA, LTM, Soil Gas Source Identification/ Characterization, and Source Removal FTA-2, Tinker AFB

Capital Costs

Source Area Identification/ Characterization

Soil Gas Survey - Initial Investigation

- 50 ft node centered grid for an area of 920,000ft^2 = 412 sampling points.

Geoprobe Rental (8 pts. Per day)	52 days x	$1,000	/day	$52,000
Soil Gas Analysis (EPA TO-3)	412 samples x	$130	/sample	$53,560
Sampling Labor	832 hours x	$60	/hour	$49,920
Sample Shipping		$500	lump sum	$500
Per Diem	104 days x	$88	/day	$9,152
Travel		$200	lump sum	$200
Equipment Rental (Meters)		$2,000	lump sum	$2,000
Progress Report	40 hours x	$70	/hour	$2,800
Contingency (10%)				$11,813
	Subtotal for Initial Soil Gas Investigation:			$129,945

Soil Gas Survey - Hot Spot Investigation Investigation

- 20 ft node centered grid for 3 areas of 25,600ft^2 = 243 sampling points.

Geoprobe Rental (8 pts. Per day)	31 days x	$1,000	/day	$31,000
Soil Gas Analysis (EPA TO-3)	243 samples x	$130	/sample	$31,590
Sampling Labor	496 hours x	$60	/hour	$29,760
Sample Shipping		$500	lump sum	$500
Per Diem	62 days x	$88	/day	$5,456
Travel		$200	lump sum	$200
Equipment Rental (Meters)		$2,000	lump sum	$2,000
Progress Report	20 hours x	$70	/hour	$1,400
Contingency (10%)				$7,091
	Subtotal for Hot Spot Soil Gas Investigation:			$77,997

Geophysical Survey

Time and Materials	5 days x	$1,600	/day	$8,000
Mod/Demob		$3,500	lump sum	$3,500
Data Analysis/Reporting		$2,500	lump sum	$2,500
Contingency (10%)				$1,400
	Subtotal for Geophysical Survey:			$15,400

Slug Tests

Time, Materials, Labor, Data Analysis, Reporting	6 wells x	$300	/well	$1,800
Contingency (10%)				$180
		Subtotal for Slug Tests:		$1,980

Tracer Test

Install 3 Monitoring Well	3 well x	$3,000	/well	$9,000
Tracer (3 kg reagent grade Lithium bromide)		$200	lump sum	$200
Job Supplies		$2,000	lump sum	$2,000
Data Collection (Total present worth cost of data collection for life of test)		$36,741	lump sum*	$36,741
Mod/Demob/Data Analysis		$5,000	lump sum	$5,000
Contingency (10%)				$5,294
		Subtotal for Tracer Test:		$58,235

PARSONS	*Calculation Page*	Job Number 729691.34050	Page 2 of 2

Rev	Date	By	Ck	Subject:
	3/3/99	MLP		Cost Calculations for Alternative 2 RNA, LTM, Soil Gas Source Identification/ Characterization, and Source Removal FTA-2, Tinker AFB

Source Area Removal

Excavation

Total Area of Site:	15,000 ft^2
	1,666.7 yd^2
Total Volume of Soil to be Excavated (to an assumed 15 ft bgs):	225,000 ft^3
	8,325 yd^3
Total Weight of Soil to be Excavated (Weight of soil = 1.25 tons/yd^3):	10,406.3 tons
Total Volume of Soil to be Disposed of (Assume Contaminant thickness of 15 ft):	8,325 yd^3
Total Weight of Soil to be Disposed of:	10,406.3 tons

ITEM (With Costing Reference)	# Units	Unit	Unit Cost[a/]	Total
Soil Excavation (RSMeans 17 03 0278)	8,325.0	yd^3	$1.45 /$yd^3$	$12,071.25
Waste Soil Transport (RSMeans 33 19 0205)	8,325.0	20 yd^3/mile[a/]	$3.44 /20 yd^3/mile	$28,638.00
Waste Disposal at Landfill (Denver Arapahoe Disposal)	8,325.0	yd^3	$15.00 /$yd^3$	$124,875.00
Delivered and Dumped Backfill with Sand (RSMeans 17 03 040	8,325.0	yd^3	$8.45 /$yd^3$	$70,346.25
Pave Surface (RSMeans 18 02 0301[b/])	1667	yd^2	$6.69 /$yd^2$	$11,150.00
Engineering Oversight	120	HR	$50.00 /Hour	$6,000.00
			Subtotal for Soil Excavation:	$253,080.50

Summary of Capital Costs

Initial Soil Gas Investigation:	$129,945
Hot Spot Soil Gas Investigation:	$77,997
Geophysical Survey:	$15,400
Slug Tests	$1,980
Tracer Test:	$58,235
Soil Excavation:	$253,081
Total Capital Costs =	$536,637
LTM Plan (from Alternative 1) **Total Present Worth of LTM Program =**	$521,213
Total Cost Estimate of Alternative 2 =	$1,057,850

* The lump sum amount presented here is the total present worth cost for tracer sampling, as presented on the cost table 2-1 (Tracer Sampling).

Remedial Alternative 3 Cost Estimate
Site FTA-2
RNA TS
Tinker AFB, Oklahoma
729691.3405

Author: MLP
Date: 3/24/99
Checked by:
Date:

Capital Costs

Installation of the Groundwater Extraction System				
Design/perform/analyze 24-hour pumping test (lump sum)		$10,000	lump sum	$10,000
Well Installation (7 4-inch wells)	7 wells x	$4,000	/well	$28,000
Building/Controls/Piping/Accessories		$20,000	lump sum	$20,000
Equipment Costs 7 submersible pumps, air stripper, electronics, PLC valves, and guages		$600,000	lump sum	$600,000
System Installation		$50,000	lump sum	$50,000
			subtotal	$708,000

Annual Operating Costs--Pump and Treat System (10 years)

Labor	
Weekly System Checks (2 hr x 52 wk/yr x $60/hr)	$6,240
Monthly Sampling (12 hr x 12 mo x $60/hr)	$8,640
Monthly Reporting (8 hr x 12 mo x $60/hr)	$5,760
Maintenance (8 hr x 12 mo x $60/hr)	$5,760
Analytical	
VOCs (air) (2/mo x 12 mo x $250/ea)	$6,000
Sample ship. (2/mo x 12 mo x $30/ea)	$720
Supplies	
Install and Dispose of GAC (assume 2 replacements of 2,000 lb. of GAC/year)	$9,400
misc. (lump sum)	$1,000
Travel (52 trips from Midwest City OK per year @ $100/ea)	$5,200
Electricity	$5,000
Site Management (Included in LTM portion of Alternative 1)	$0
Recovered Solvent Disposal from Knock Out Tanks ($150/mo x 12 mo)	$1,800
subtotal	$55,520

Remedial Alternative 3 Cost Estimate
Site FTA-2
RNA TS
Tinker AFB, Oklahoma
729691.3405

Author: MLP
Date: 3/24/99
Checked by:
Date:

Summary of Present Worth Capital Costs (assuming system installation in 1999)

Installation of Groundwater Extraction System	$708,000	P/A i=7%, n=0	$708,000
		Total	$708,000

Summary of Present Worth Annual + Future Costs (assuming 10-yr operating period 1999-2008)

O&M for Pump and Treat System (10 years)

Annual Cost	$55,520
1999 n=1	$51,887.85
2000 n=2	$48,493.32
2001 n=3	$45,320.86
2002 n=4	$42,355.94
2003 n=5	$39,584.99
2004 n=6	$36,995.32
2005 n=7	$34,575.07
2006 n=8	$32,313.15
2007 n=9	$30,199.20
2008 n=10	$28,223.55

Total Present Worth Cost (O&M)	$389,949
Total Present Worth Cost of LTM Program/ Site Characterization/ Source Removal - Alternative 1 and 2 (includes site management)	$1,057,850
Total Capital + Annual + Future Costs for Alternative 3	$2,155,800

APPENDIX E

SUPPORTING MODEL INPUT AND CALCULATIONS FOR GROUNDWATER/FATE AND TRANSPORT MODELING

TABLE E.1
SUMMARY OF CHLORINATED SOLVENT DECAY RATES
AUGUST 1997
FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Contaminant	Sample Date	Flow Path	Analysis Method	Decay Rate (day^{-1})	Half Life (years)
TCE	August-97	2-62B > CG39B97-43S > 2-355B	Buscheck and Alcantar[a/]	3.06E-04	6.21
cis-1,2-DCE	August-97	2-62B > CG39B97-43S > 2-355B	Buscheck and Alcantar	4.08E-04	4.65
trans-1,2-DCE	August-97	2-62B > CG39B97-43S	Buscheck and Alcantar	7.58E-04	2.51
Total Chlorinated Ethenes	August-97	2-62B > CG39B97-43S > 2-355B	Buscheck and Alcantar	2.96E-04	6.42
Total Chlorinated Ethenes	August-97	2-62B > CG39B97-43S > 2-355B	Reductive Dechlorination	1.88E-07	10,091
1,2-DCA	August-97	2-62B > CG39B97-43S > 2-355B	Buscheck and Alcantar	1.53E-03	1.24
Total Chlorinated Ethanes	August-97	2-62B > CG39B97-43S > 2-355B	Buscheck and Alcantar	1.28E-03	1.49
Total Chlorinated Ethanes	August-97	2-62B > CG39B97-43S > 2-355B	Reductive Dechlorination	5.23E-07	3,630
Chlorobenzene	August-97	2-62B > 2-65B > CG39B97-43S	Buscheck and Alcantar	9.28E-04	2.05
1,2-Dichlorobenzene	August-97	2-62B > 2-65B	Buscheck and Alcantar	3.36E-03	0.57
1,3-Dichlorobenzene	August-97	2-62B > CG39B97-43S	Buscheck and Alcantar	2.97E-04	6.39
1,4-Dichlorobenzene	August-97	2-62B > 2-65B	Buscheck and Alcantar	2.33E-03	0.82
Total Chlorinated Benzenes	August-97	2-62B > 2-65B > CG39B97-43S	Buscheck and Alcantar	1.05E-03	1.81
Total Chlorinated Benzenes	August-97	2-62B > 2-65B	Reductive Dechlorination	3.41E-04	5.56

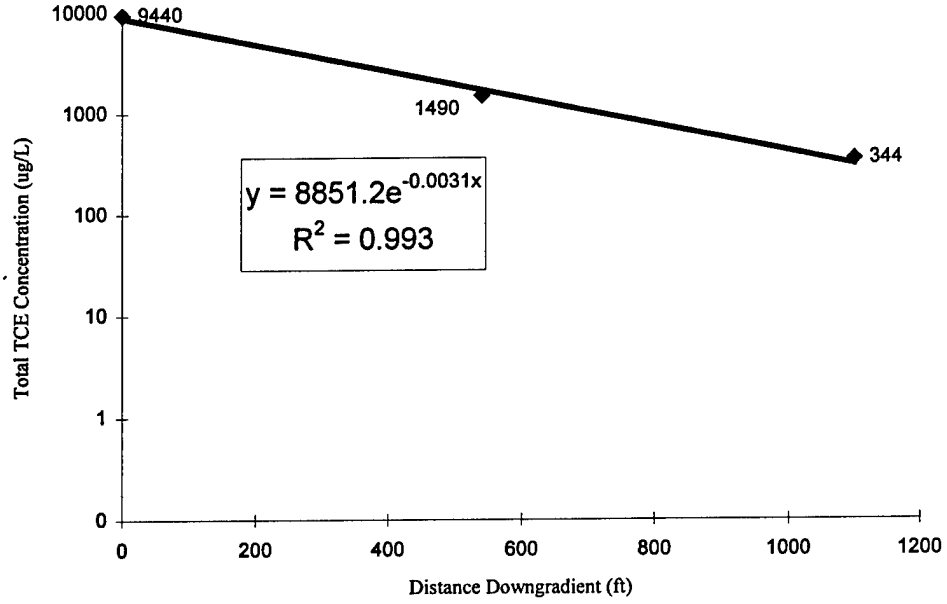
[a/] Method of Buscheck and Alcantar (1995) for steady-state plumes.

[b/] Reductive Dechlorination by method of Moutoux, et al., (1996), which gives decay rate attributable to reductive dechlorination.

FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Point	Distance (ft) Downgradient	TCE (µg/L) Aug-97
2-62B	0	9440
CG39B9743s	540	1490
2-355B	1100	344

PLOT OF TCE CONCENTRATION VERSUS DISTANCE



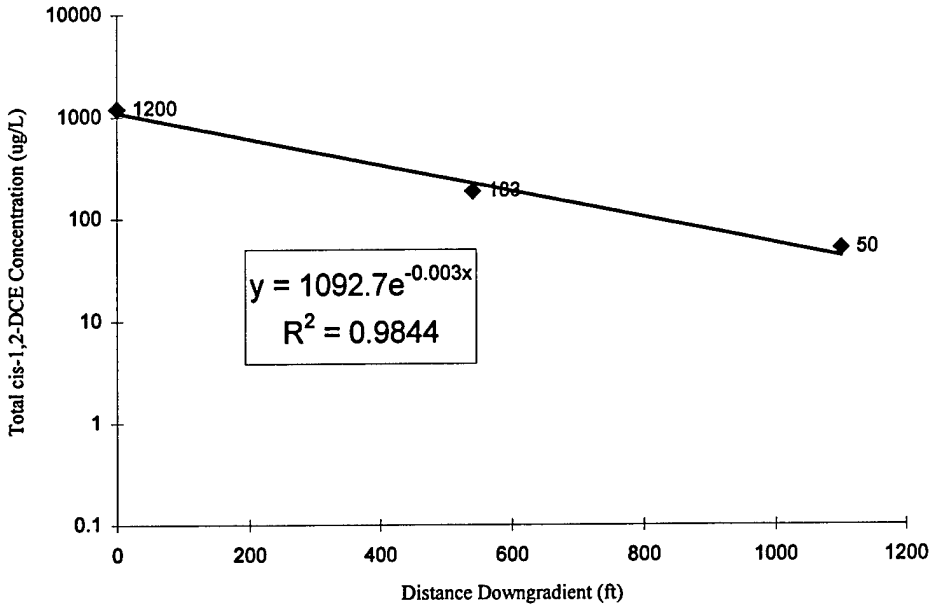
$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.066	ft/day
	α_x =	160	feet
	k/v =	0.0031	
therefore	λ =	3.06E-04	$days^{-1}$
	half life =	6.20	years

FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Point	Distance (ft) Downgradient	cis-1,2-DCE (µg/L) Aug-97
2-62B	0	1200
CG39B9743s	540	183
2-355B	1100	50

PLOT OF cis-1,2-DCE CONCENTRATION VERSUS DISTANCE



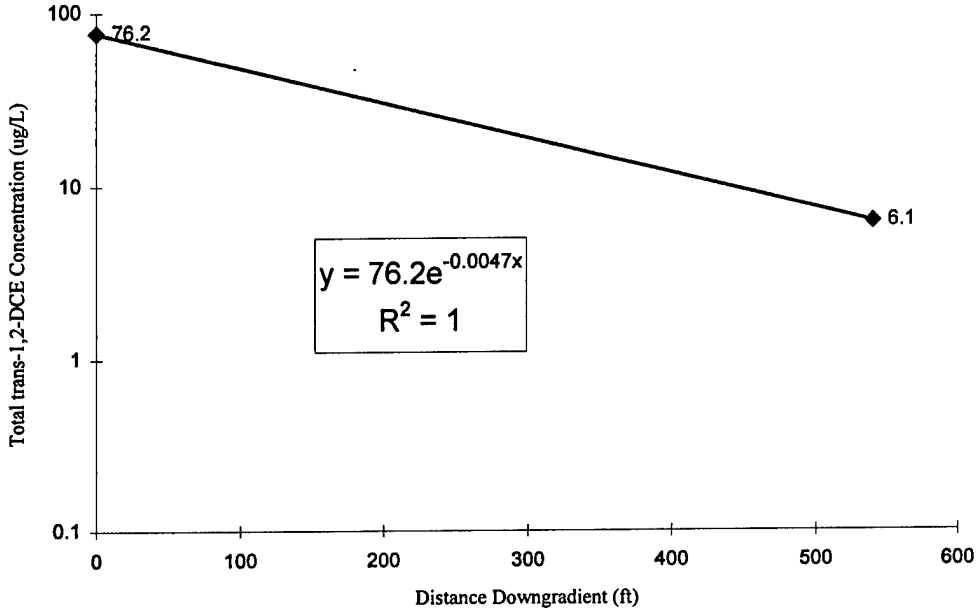
$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.092	ft/day
	α_x =	160	feet
	k/v =	0.003	
therefore	λ =	4.08E-04	$days^{-1}$
	half life =	4.65	years

FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Point	Distance (ft) Downgradient	trans-1,2-DCE (µg/L) Aug-97
2-62B	0	76.2
CG39B9743s	540	6.1

PLOT OF trans-1,2-DCE CONCENTRATION VERSUS DISTANCE

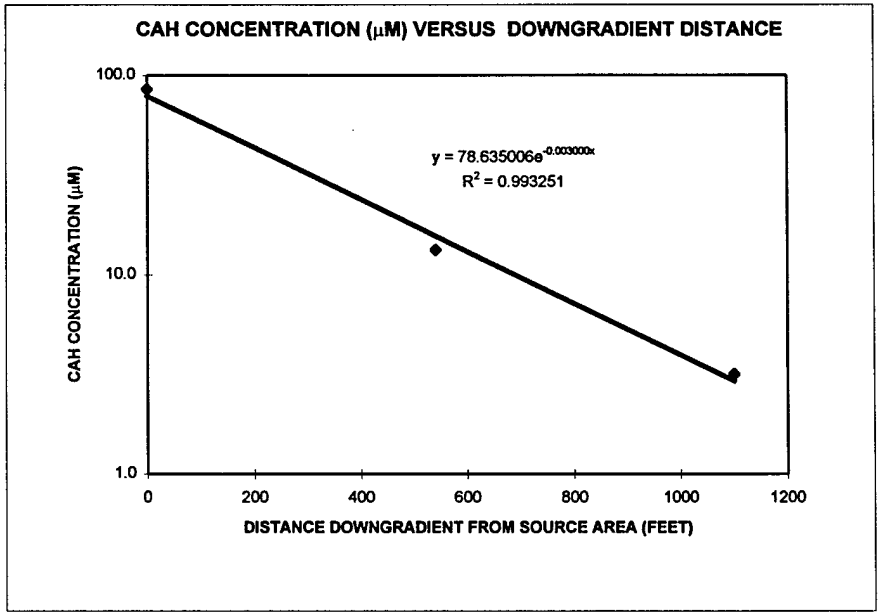


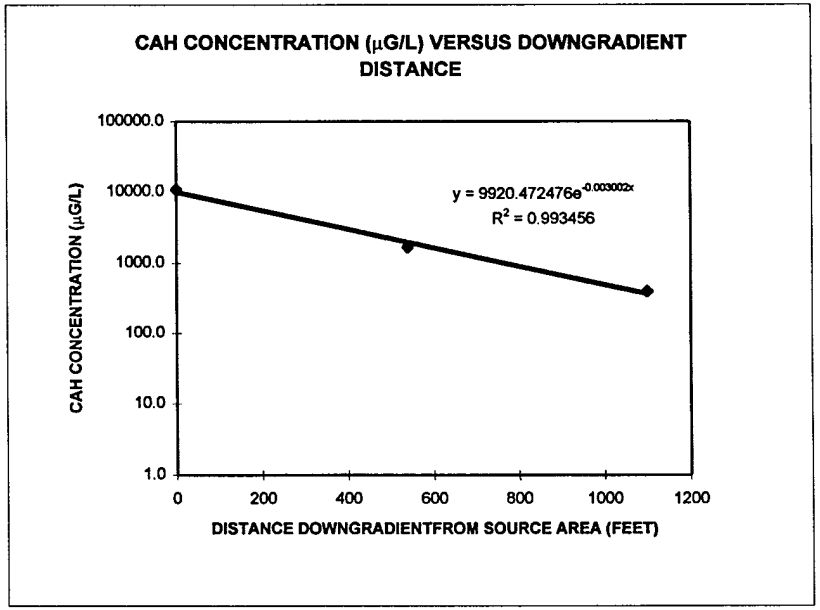
$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.092	ft/day
	α_x =	160	feet
	k/v =	0.0047	
therefore	λ =	7.58E-04	$days^{-1}$
	half life =	2.51	years

ESTIMATED FIRST-ORDER RATE CONSTANT CALCULATION FOR TOTAL CHLORINATED ETHENES
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
AUGUST, 1997
SITE FTA 2 RNA TS
TINKER AFB, OKLAHOMA

Well	Distance Downgradient	PCE (µg/L) Aug-97	PCE (µM) Aug-97	TCE (µg/L) Aug-97	TCE (µM) Aug-97	Total DCE (µg/L Aug-97	Total DCE (µM) Aug-97	VC (µg/L) Aug-97	VC (µM) Aug-97	Total CAH (µg/L) Aug-97	Total CAH (µM) Aug-97
2-62B	0	6.1	0.04	9440	71.9	1285.7	13.3	1.7	0.0	10733.5	85.2
CG39B9743s	540	0.0	0.00	1490	11.3	190.2	2.0	0.0	0.0	1680.2	13.3
2-355B	1100	0.0	0.00	344	2.6	50.0	0.5	0.0	0.0	394.0	3.1





Method of Buscheck & Alcantar (1995)

$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$

where	v_c =	0.066	ft/day
	α_x =	160	ft
	k/v =	0.003	
therefore	λ =	2.9304E-04	1/day
	λ =	2.9304E-02	%/day
	half life =	6.48	years

Method of Buscheck & Alcantar (1995)

$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$

where	v_c =	0.066	ft/day
	α_x =	160	ft
	k/v =	0.00302	
therefore	λ =	2.9563E-04	1/day
	λ =	2.9563E-02	%/day
	half life =	6.42	years

REDUCTIVE DECHLORINATION RATE FOR CHLORINATED ETHENES
2-62B > CG39B97-43S > 2-355B
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

The following procedures outlined by Moutoux et al. (1996)

Step 1: Enter Observed Contaminant Concentration (mg/L)

Well	PCE	TCE	DCE	VC	Ethene	Total CAHs
2-62B	6.1	9440.0	1285.7	1.7	0	10733.5
CG39B97-43S	0.0	1490.0	190.2	0.0	0	1680.2
2-355B	0.0	344.0	50.0	0.0	0	394.0

Step 2: Compute Molar Concentrations (micromoles/Liter)

Well	M_{PCE}	M_{TCE}	M_{DCE}	M_{VC}	M_{Ethene}	Total M_{CAHs}
2-62B	0.04	71.85	13.26	0.03	0.00	85.18
CG39B97-43S	0.00	11.34	1.96	0.00	0.00	13.30
2-355B	0.00	2.62	0.52	0.00	0.00	3.13

Step 3: Compute Carbon Equivalents

Well	Total M_{CAHs}	x 2	= Ceqi
2-62B	85.18		170.36
CG39B97-43S	13.30		26.61
2-355B	3.13		6.27

Step 4: Compute Chlorine Equivalents

Well	M_{PCE} x 4	M_{TCE} x 3	M_{DCE} x 2	M_{VC}	S = $Cleq_i$
2-62B	0.15	215.56	26.53	0.03	242.26
CG39B97-43S	0.00	34.02	3.92	0.00	37.95
2-355B	0.00	7.86	1.03	0.00	8.89

Step 5: Compute Corrected CAH Concentrations

$$C_{i,corr} = C_{i-1,corr} \times (Cleq_i / Cleq_{i-1}) \times (Ceq_{i-1} / Ceq_i)$$

Well	$C_{i-1,corr}$	$Cleq_i / Cleq_{i-1}$	Ceq_{i-1} / Ceq_i	$C_{i,corr}$
2-62B	10733.500300			10733.500300
CG39B97-43S	10733.500300	0.156641	6.402853	10765.153575
2-355B	10765.153575	0.234182	4.244514	10700.462928

Step 6: Plot Exponential Trendline of Contaminant Concentration vs. Time

Well	Distance From Source (ft)	CAH avg. velocity (ft/day)*	CAH Travel Time (day)	$C_{i,corr}$
2-62B	0	0.066	0	10733.500300
CG39B97-43S	540	0.066	8182	10765.153575
2-355B	1100	0.066	16667	10700.462928

*Assumes an unretarded velocity of 0.33 feet/day and a retardation coefficient of 5.0.

Reductive Dechlorination Rate

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

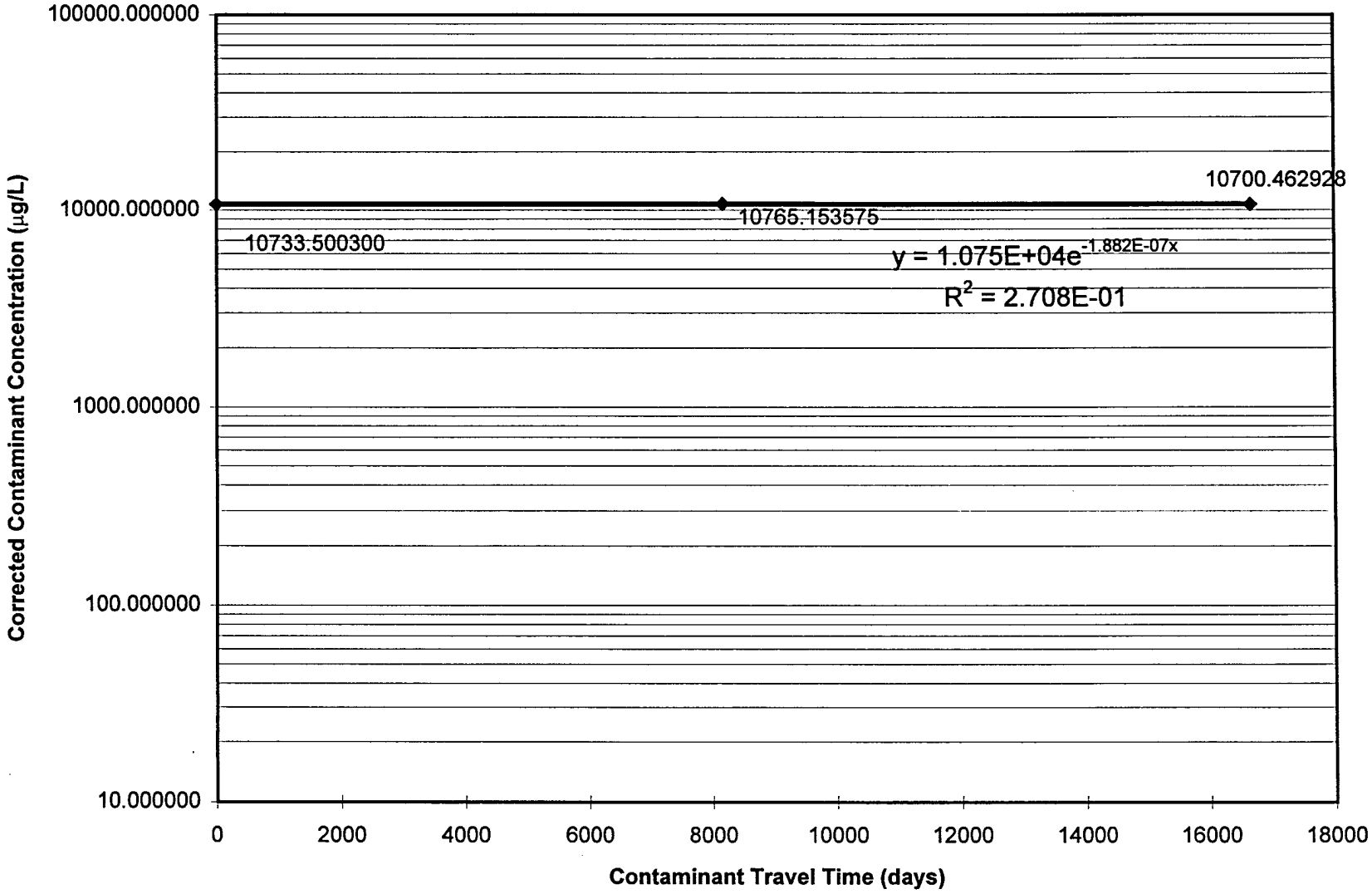
C = Corrected Contaminant Concentration (mg/L) at time t (days)

C_0 = Initial Contaminant Concentration (mg/L)

k = Reductive Dechlorination Rate ($days^{-1}$)

from plot: $y = 10{,}750e^{-1.882E-07x}$ $k = 1.882$ E-07 $days^{-1}$

REDUCTIVE DECHLORINATION RATE FOR CHLORINATED ETHENES
2-62B > CG39B97-43S > 2-355B
AUGUST, 1997
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

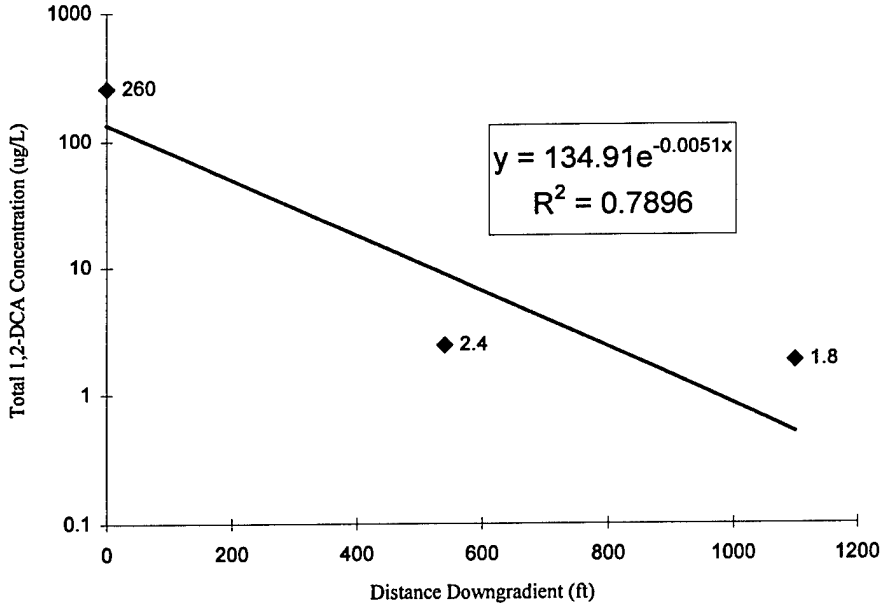


S:\ES\REMED\BIOPLUME\TINKER\RPT-FTA2\COREFTA2.XLS CHART-CHLORINATED ETHENES

FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Point	Distance (ft) Downgradient	1,2-DCA (µg/L) Aug-97
2-62B	0	260
CG39B9743s	540	2.4
2-355B	1100	1.8

PLOT OF 1,2-DCA CONCENTRATION VERSUS DISTANCE

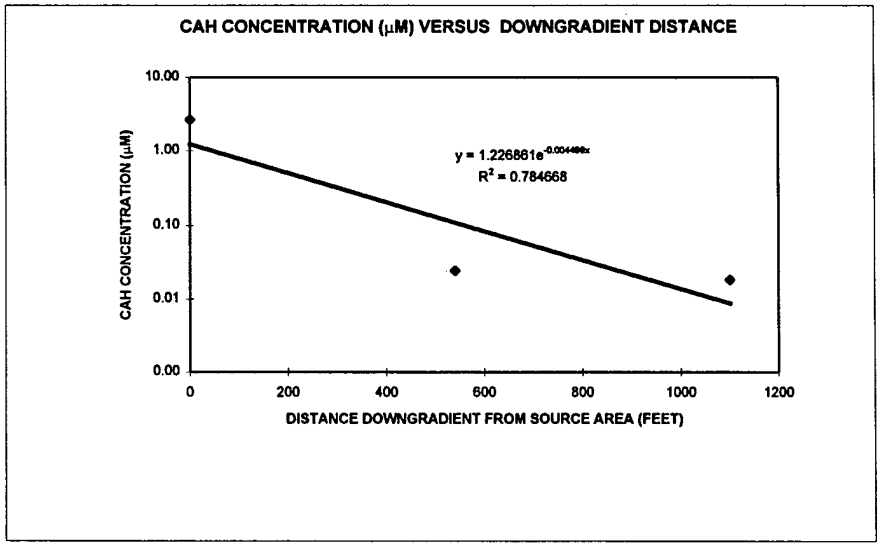


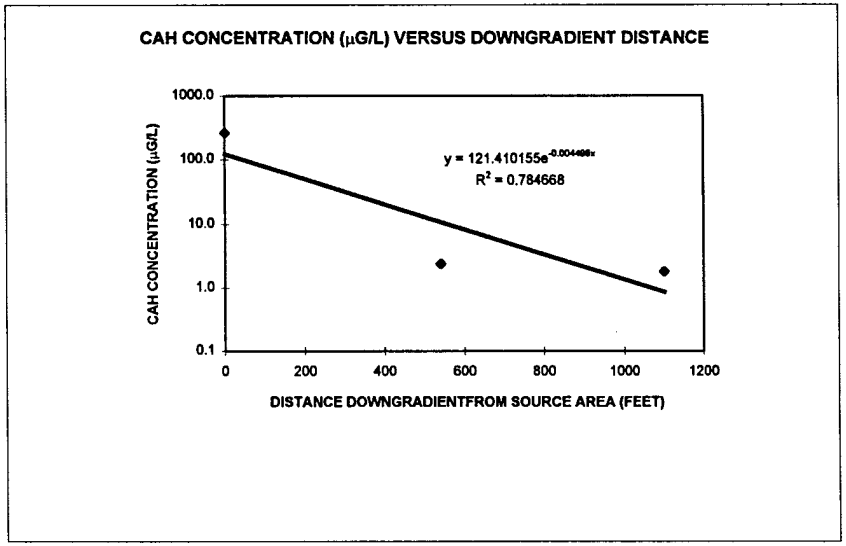
$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.165	ft/day
	α_x =	160	feet
	k/v =	0.0051	
therefore	λ =	1.53E-03	$days^{-1}$
	half life =	1.24	years

ESTIMATED FIRST-ORDER RATE CONSTANT CALCULATION FOR TOTAL CHLORINATED ETHANES
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
Aug-97
SITE FTA2 RNA TS
TINKER AFB, OKLAHOMA

Well	Distance Downgradient	1,1,1-TCA (µg/L) Aug-97	1,1,1-TCA (µM) Aug-97	1,2-DCA (µg/L) Aug-97	1,2-DCA (µM) Aug-97	1,2-DCA (µg/L) Aug-97	1,2-DCA (µM) Aug-97	Total CAH (µg/L) Aug-97	Total CAH (µM) Aug-97
2-62B	0	0.00	0.00	0.00	0.00	260.0	2.6	260.0	2.6
CG39B9743S	540	0.00	0.00	0.00	0.00	2.4	0.02	2.4	0.02
TMP-3	1100	0.00	0.00	0.00	0.00	1.8	0.02	1.8	0.02





Method of Buscheck & Alcantar (1995)

$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$

where v_c = 0.165 ft/day
α_x = 160 ft
k/v = 0.004496

therefore λ = 1.2755E-03 1/day
λ = 1.2755E-01 %/day

half life = 1.49 years

Method of Buscheck & Alcantar (1995)

$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$

where v_c = 0.165 ft/day
α_x = 160 ft
k/v = 0.004496

therefore λ = 1.2755E-03 1/day
λ = 1.2755E-01 %/day

half life = 1.49 years

REDUCTIVE DECHLORINATION RATE FOR CHLORINATED ETHANES
2-62B > CG39B97-43S > 2-355B
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

The following procedures outlined by Moutoux et al. (1996)

Step 1: Enter Observed Contaminant Concentration (µg/L)

Well	1,1,1-TCA	1,1-DCA	1,2-DCA	CA	Total CAHs
2-62B	0.0	0.0	260.0	0.0	260.0
CG39B97-43S	0.0	0.0	2.4	0.0	2.4
2-355B	0.0	0.0	1.8	0.0	1.8

Step 2: Compute Molar Concentrations (micromoles/Liter)

Well	$M_{1,1,1\text{-TCA}}$	$M_{1,1\text{-DCA}}$	$M_{1,2\text{-DCA}}$	M_{CA}	Total M_{CAHs}
2-62B	0.0000	0.0000	2.6273	0.0000	2.6273
CG39B97-43S	0.0000	0.0000	0.0243	0.0000	0.0243
2-355B	0.0000	0.0000	0.0182	0.0000	0.0182

Step 3: Compute Carbon Equivalents

Well	Total M_{CAHs}	x 2	= Ceqi
2-62B	2.6273241714		5.2546483428
CG39B97-43S	0.0242522231		0.0485044462
2-355B	0.0181891673		0.0363783347

Step 4: Compute Chlorine Equivalents

Well	$M_{1,1,1\text{-TCA}} \times 3$	$M_{1,1\text{-DCA}} \times 2$	$M_{1,2\text{-DCA}} \times 2$	M_{CA}	$\Sigma = Cleq_i$
2-62B	0.0000000000	0.0000000000	5.2546483428	0.0000000000	5.2546483428
CG39B97-43S	0.0000000000	0.0000000000	0.0485044462	0.0000000000	0.0485044462
2-355B	0.0000000000	0.0000000000	0.0363783347	0.0000000000	0.0363783347

Step 5: Compute Corrected CAH Concentrations

$$C_{i,corr} = C_{i-1,corr} \times (Cleq_i / Cleq_{i-1}) \times (Ceq_{i-1} / Ceq_i)$$

Well	$C_{i-1,corr}$	$Cleq_i / Cleq_{i-1}$	Ceq_{i-1} / Ceq_i	$C_{i,corr}$
2-62B	260.0000000000			260.0000000000
CG39B97-43S	260.0000000000	0.0092307692	108.3333333333	260.0000000000
2-355B	260.0000000000	0.7500000000	1.3333333333	260.0000000000

Step 6: Plot Exponential Trendline of Contaminant Concentration vs. Time

Well	Distance From Source (ft)	CAH avg. velocity (ft/day)*	CAH Travel Time (day)	$C_{i,corr}$
2-62B	0.0000000000	0.1650000000	0.0000000000	260.0000000000
CG39B97-43S	540.0000000000	0.1650000000	3272.7272727273	260.0000000000
2-355B	1100.0000000000	0.1650000000	6666.6666666667	260.0000000000

*Assumes an unretarded velocity of 0.33 feet/day and an average retardation coefficient of 2.0.

Reductive Dechlorination Rate

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

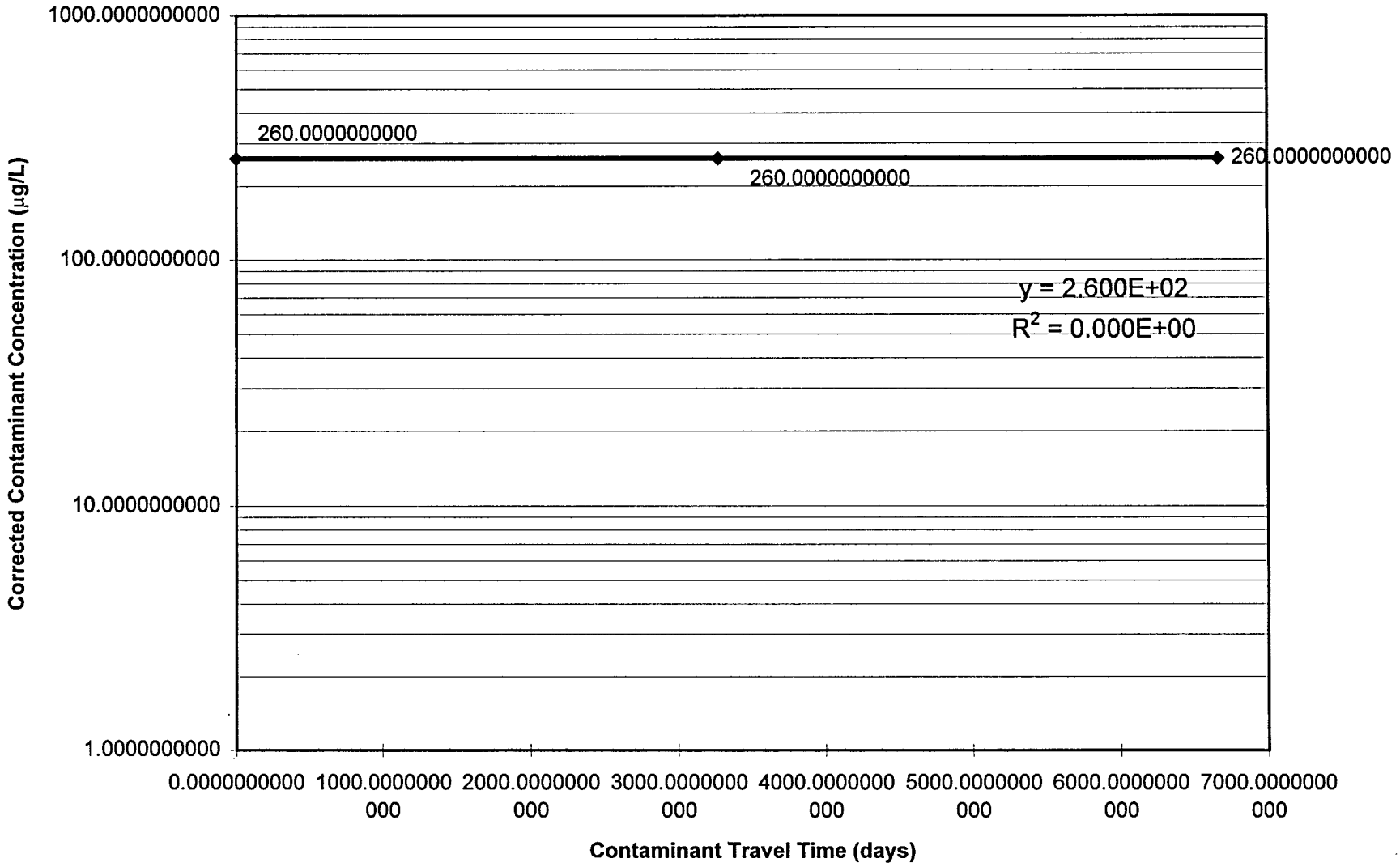
C = Corrected Contaminant Concentration (µg/L) at time t (days)
C_0 = Initial Contaminant Concentration (µg/L)
k = Reductive Dechlorination Rate ($days^{-1}$)

from plot: $y = 2673e^{-5.2324E-07x}$ $k = 5.232E\text{-}07\ days^{-1}$

REDUCTIVE DECHLORINATION RATE FOR CHLORINATED ETHANES

2-62B > 2-65B

SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

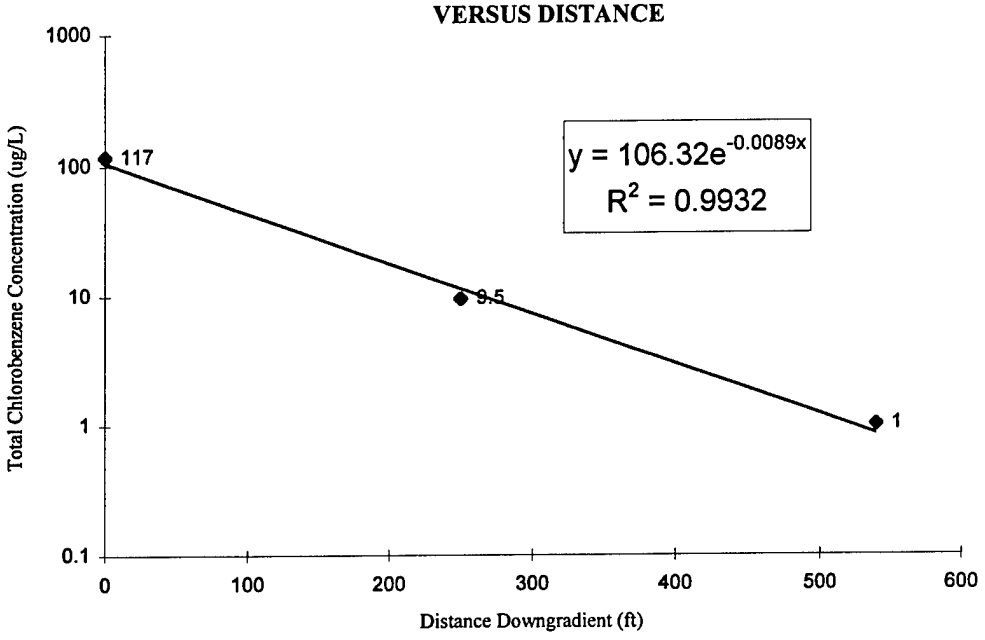


S:\ES\REMED\BIOPLUME\TINKER\RPT-FTA2\COREFTA2.XLS Chart - CHLOROETHANES

FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Point	Distance (ft) Downgradient	Chlorobenzene (µg/L) Aug-97
2-62B	0	117
2-65B	250	9.5
CG39B9743s	540	1

PLOT OF CHLOROBENZENE CONCENTRATION VERSUS DISTANCE



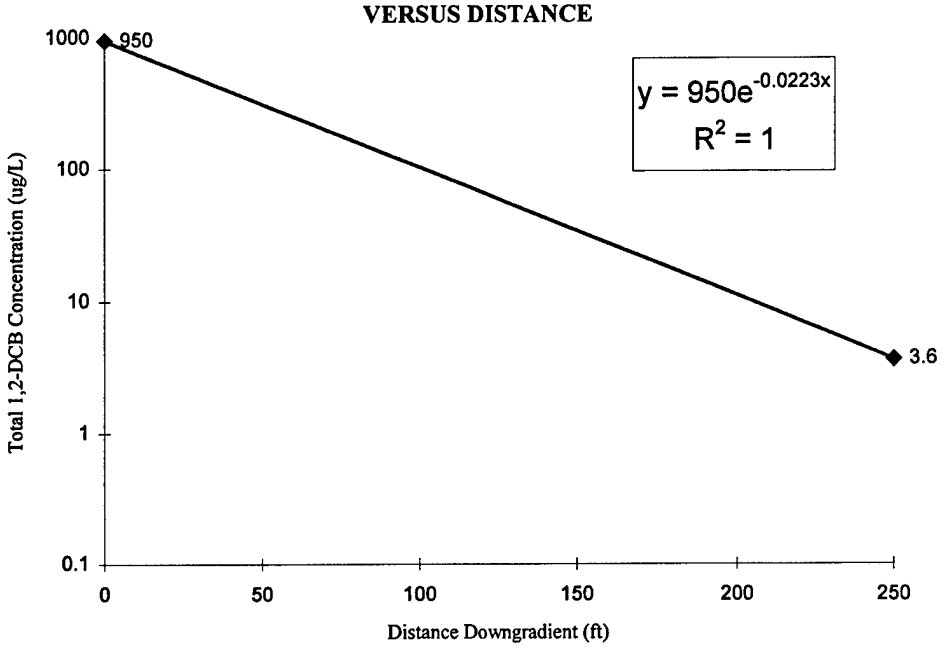
$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.043	ft/day
	α_x =	160	feet
	k/v =	0.0089	
therefore	λ =	9.28E-04	$days^{-1}$
	half life =	2.05	years

FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Point	Distance (ft) Downgradient	1,2-DCB (µg/L) Aug-97
2-62B	0	950
2-65B	250	3.6

PLOT OF 1,2-DCB CONCENTRATION VERSUS DISTANCE



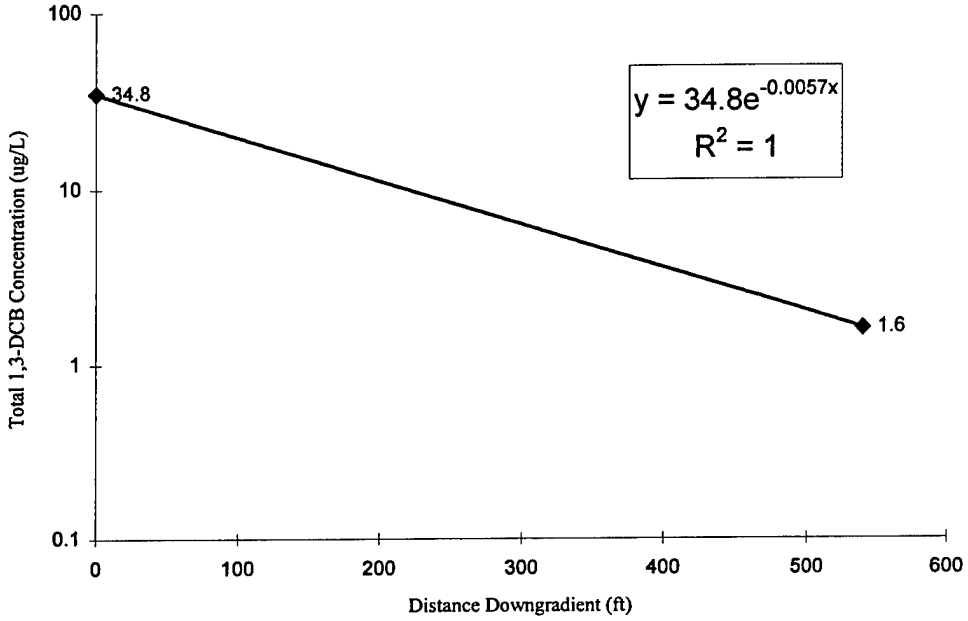
$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.033	ft/day
	α_x =	160	feet
	k/v =	0.0223	
therefore	λ =	3.36E-03	$days^{-1}$
	half life =	0.56	years

FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Point	Distance (ft) Downgradient	1,3-DCB (µg/L) Aug-97
2-62B	0	34.8
CG39B9743s	540	1.6

PLOT OF 1,3-DCB CONCENTRATION VERSUS DISTANCE



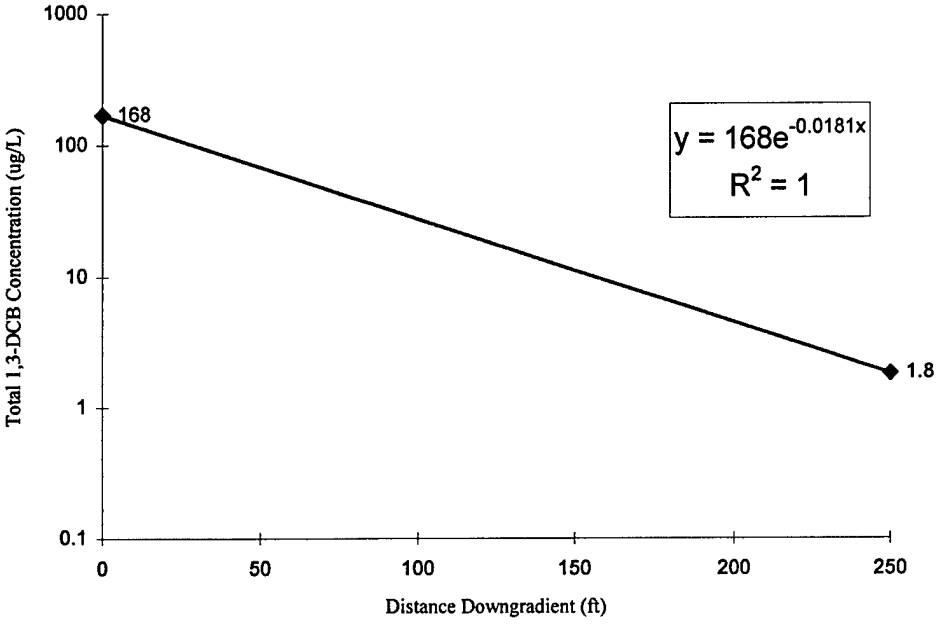
$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.033	ft/day
	α_x =	160	feet
	k/v =	0.005	
therefore	λ =	2.97E-04	$days^{-1}$
	half life =	6.39	years

FIRST-ORDER DECAY RATE CALCULATION
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

Point	Distance (ft) Downgradient	1,4-DCB (µg/L) Aug-97
2-62B	0	168
2-65B	250	1.8

PLOT OF 1,3-DCB CONCENTRATION VERSUS DISTANCE

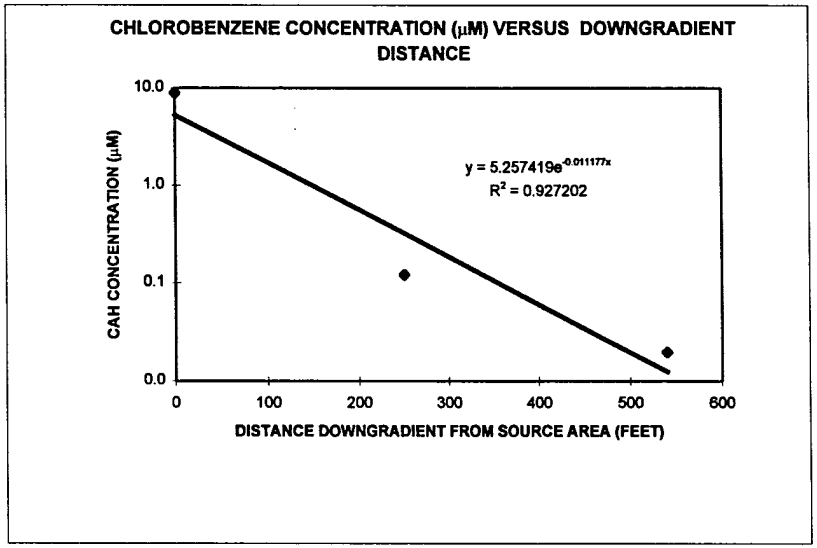


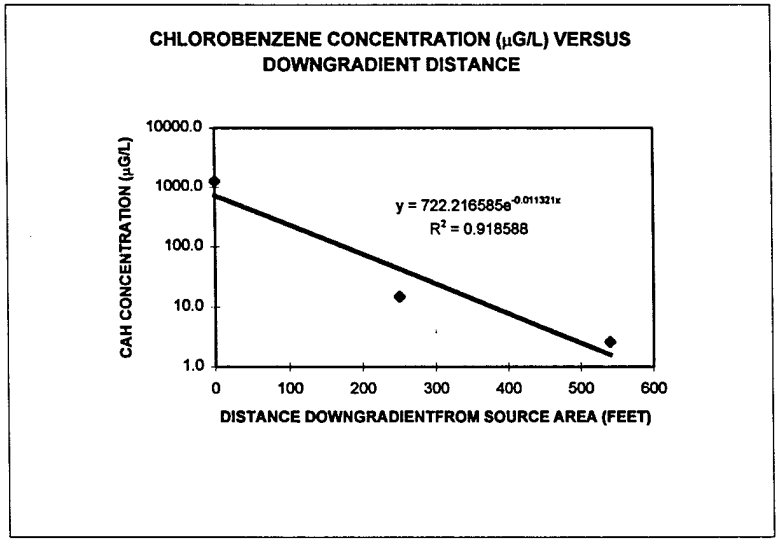
$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.033	ft/day
	α_x =	160	feet
	k/v =	0.0181	
therefore	λ =	2.33E-03	$days^{-1}$
	half life =	0.82	years

ESTIMATED FIRST-ORDER RATE CONSTANT CALCULATION FOR TOTAL CHLORINATED BENZENES
USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)
AUGUST 1997
SITE FTA- 2 RNA TS
TINKER AFB, OKLAHOMA

Well	Distance Downgradient	1,2-DCB (µg/L) Aug-97	1,2-DCB (µM) Aug-97	1,3-DCB (µg/L) Aug-97	1,3-DCB (µM) Aug-97	1,4-DCB (µg/L) Aug-97	1,4-DCB(µM) Aug-97	CB (µg/L) Aug-97	CB (µM) Aug-97	Total C-Benz. (µg/L) Aug-97	Total C-Benz. (µM) Aug-97
2-62B	0	950	6.5	34.8	0.2	168	1.1	117	1.0	1269.8	8.9
2-65B	250	3.6	0.0	0.0	0.0	1.8	0.0	9.5	0.1	14.9	0.1
CG39B97-43S	540	0.0	0.0	1.6	0.0	0.0	0.0	1.0	0.0	2.6	0.0





Method of Buscheck & Alcantar (1995)

$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.033	ft/day
	α_x =	160	ft
	k/v =	0.011177	
therefore	λ =	1.0284E-03	1/day
	λ =	1.0284E-01	%/day
	half life =	1.85	years

Method of Buscheck & Alcantar (1995)

$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	v_c =	0.033	ft/day
	α_x =	160	ft
	k/v =	0.011321	
therefore	λ =	1.0503E-03	1/day
	λ =	1.0503E-01	%/day
	half life =	1.81	years

REDUCTIVE DECHLORINATION RATE FOR CHLORINATED BENZENES
2-62B > 2-65B
SITE FTA-2 RNA TS
TINKER AFB, OKLAHOMA

The following procedures outlined by Moutoux et al. (1996)

Step 1: Enter Observed Contaminant Concentration (µg/L)

Well	1,2-DCB	1,3-DCB	1,4-DCB	CB	Total CB's
2-62B	950.0	34.8	168.0	117.0	1269.8
2-65B	3.6	0.0	1.8	9.5	14.9

Step 2: Compute Molar Concentrations (micromoles/Liter)

Well	$M_{1,2\text{-DCB}}$	$M_{1,3\text{-DCB}}$	$M_{1,4\text{-DCB}}$	M_{CB}	Total M_{CBs}
2-62B	6.46	0.24	1.14	1.04	8.88
2-65B	0.02	0.00	0.01	0.08	0.12

Step 3: Compute Carbon Equivalents

Well	Total M_{CBs}	x 6	= Ceqi
2-62B	8.88		53.29
2-65B	0.12		0.73

Step 4: Compute Chlorine Equivalents

Well	$M_{1,2\text{-DCB}}$ x 2	$M_{1,3\text{-DCB}}$ x 2	$M_{1,3\text{-DCB}}$ x 2	M_{CB}	$\Sigma = Cleq_i$
2-62B	12.93	0.47	2.29	1.04	16.72
2-65B	0.05	0.00	0.02	0.08	0.16

Step 5: Compute Corrected CAH Concentrations

$$C_{i,corr} = C_{i-1,corr} \times (Cleq_i / Cleq_{i-1}) \times (Ceq_{i-1} / Ceq_i)$$

Well	$C_{i-1,corr}$	$Cleq_i / Cleq_{i-1}$	Ceq_{i-1} / Ceq_i	$C_{i,corr}$	
2-62B	1269.80			1269.80	
2-65B	1269.80	0.01	73.32	931.02	878.87

Step 6: Plot Exponential Trendline of Contaminant Concentration vs. Time

Well	Distance From Source (ft)	CB avg. velocity (ft/day)*	CB Travel Time (day)	$C_{i,corr}$
2-62B	0	0.033	0	1269.80
2-65B	30	0.033	909	931.02

*Assumes an unretarded velocity of 0.33 feet/day and an average retardation coefficient of 10.

Reductive Dechlorination Rate

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

C = Corrected Contaminant Concentration (µg/L) at time t (days)

C_0 = Initial Contaminant Concentration (µg/L)

k = Reductive Dechlorination Rate ($days^{-1}$)

from plot: $y = 1270e^{-3.414E-04x}$ $k = 3.414E\text{-}04\ days^{-1}$

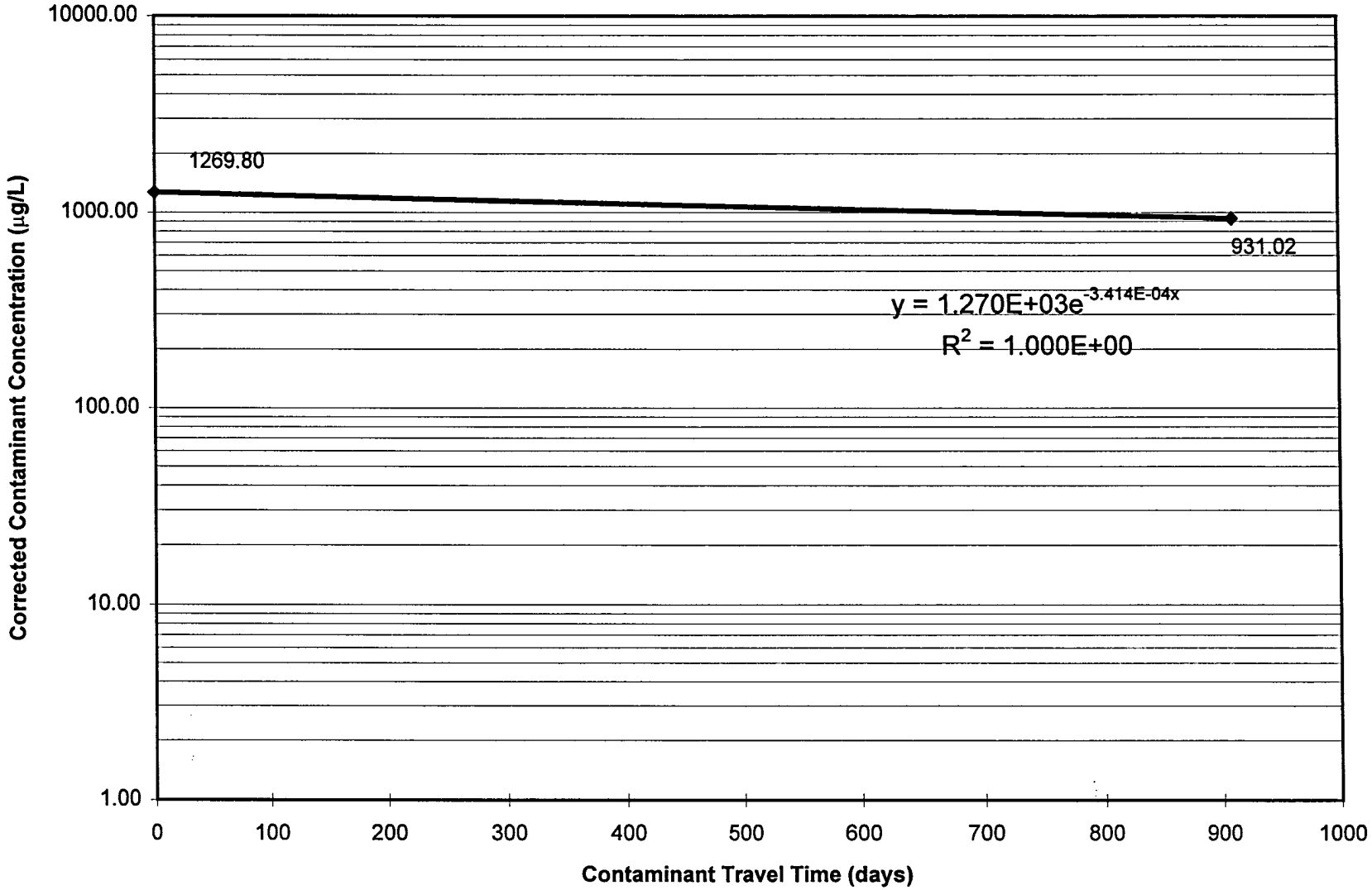
REDUCTIVE DECHLORINATION RATE FOR DICHLOROBENZENES TO MONOCHLOROBENZENE

2-62B > 2-65B

AUGUST, 1997

SITE FTA-2 RNA TS

TINKER AFB, OKLAHOMA



S:\ES\REMED\BIOPLUME\TINKER\RPT-FTA2\COREFTA2.XLS Chart - CHLOROBENZENES

MODFLOW Input Form: FTA-2

MODEL RUN :	**FTA2-17**			
FLOW RMS:	**0.657717**	**SOLVER:**	**WHS**	
TCE RMS:	**314.83**	**ADVECTION:**	**UPSTREAM FD**	
Head Calib Input File:			**Initial Head File:**	FTA-SS4.HDS
TCE Calib Input File:				@ 12775

GRID (see map)

# rows	63	# layers	3
# columns	69	top of layer elev.	1253 ft. msl
source area cell size	50 ft X 50 ft	bottom of layer elev.	1161 ft. msl
total area of model	30,000,000 sq ft		
# cells	4347		

CONDUCTIVITY (see map)

Zone #	K_x	K_y	K_z	Color
1	1.5	2.25	0.015	White
2	1.00E-02	1.00E-02	1.00E-20	Blue
3	1.5	2.25	0.15	Green
4	10	15	0.1	Teal
5	24	36	0.24	Red
6	24	36	36	Purple
7	24	36	36	Olive
8	18	27	27	Grey

STORAGE

S_s	S_y	n_e	n_{total}
.00001 ft-1	0.2	0.2	0.3

BOUNDARY CONDITIONS (see map)

-- constant head boundaries up- and down-gradient

East: 1243' to 1234'

West: Layer 1 1214 to 1213
Layer 2 1212 to 1211
Layer 3 1210 to 1209

MT3D Input Form: FTA-2

SOURCE CONCENTRATION CELL (see map)

	ROW	COLUMN
Cell A	43	52
Cells B	44	51
	45	50
Cell C	42	52

CONCENTRATION SCHEDULE (ug/l):		Cell A	Cells B	Cell C
0 to	1825	75,000	0	9500
1825	3650	65,000	5000	9500
3650	5475	55,000	7500	9500
5475	7300	50,000	9500	9500
7300	9125	40,000	9500	9500
9125	10950	30,000	9500	9500
10950	12775	20,000	9500	9500

ANIOSOTROPY RATIO

Tx/Ty 6-6-3

DISPERSION COEFFICIENTS

Longitudinal Dispersion (D_L) - all layers

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
	20	20	20	2	5

Transverse Horizontal Dispersion (D_{TH})

Ratio D_L/D_{TH}		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Layer 1	0.1	2	2	2	0.2	0.5
Layer 2	0.2	4	4	4	0.4	1
Layer 3	0.22	4.4	4.4	4.4	0.44	1.1

Transverse Vertical Dispersion (D_{TV})

Ratio D_L/D_{TV}		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Layer 1	0.01	0.2	0.2	0.2	0.02	0.05
Layer 2	0.02	0.4	0.4	0.4	0.04	0.1
Layer 3	0.05	1	1	1	0.1	0.25

CHEMICAL REACTION PACKAGE (see map)

Zone #	Kd (ft3/kg)	Bulk Density	Decay Rate (1/yr)	Sorbed (1/yr)
1 - white	0.004	46.73	0.0001	0.0005
2 - blue	0.004	46.73	0.00003	0.000015
3 - green	0.003	46.73	0.00003	0.000015
4 - teal	0.004	46.73	0.00034	0.00017
5 - red	0.004	46.73	0.0002	0.0001

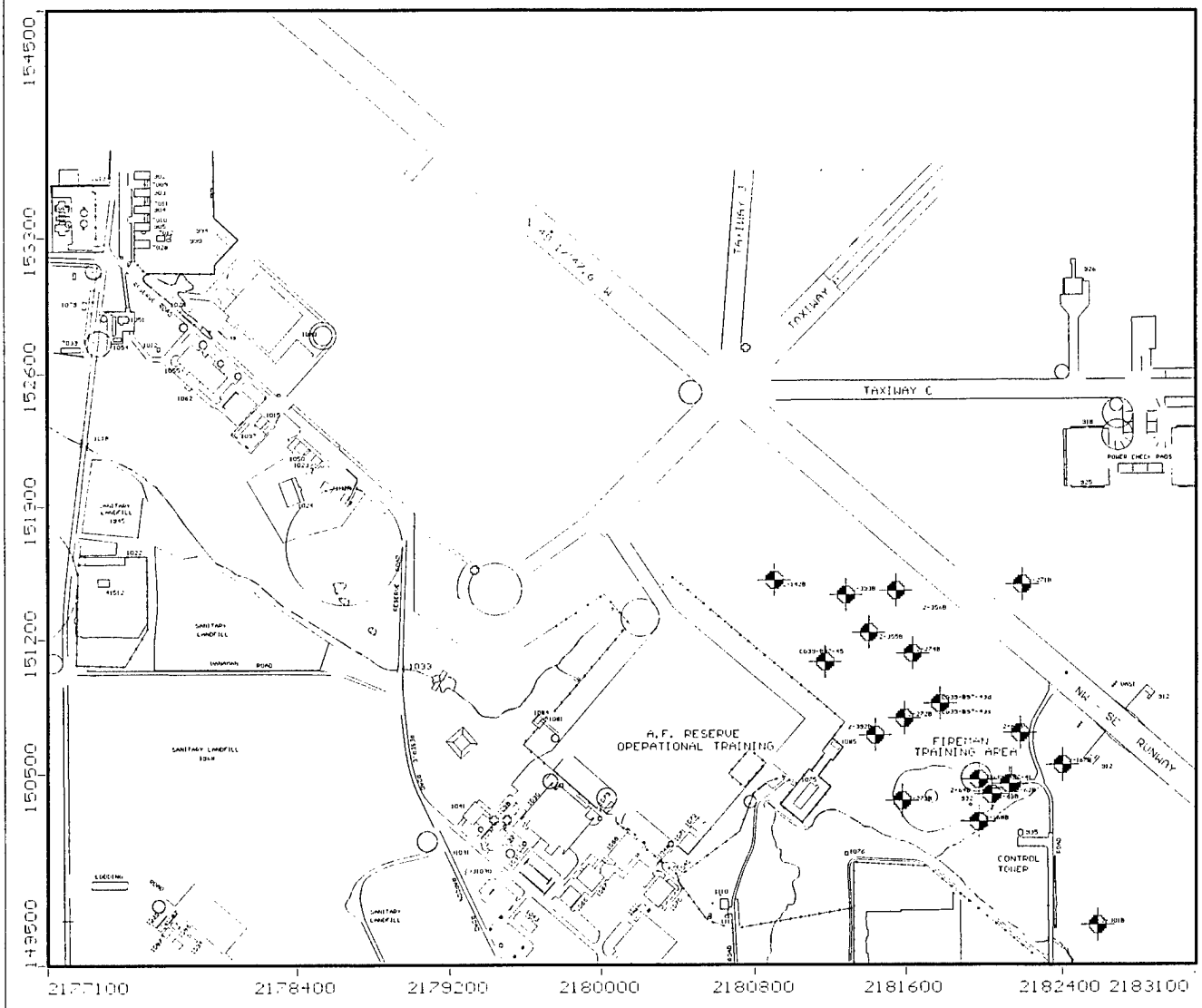
HEAD CALIBRATION

SHALLOW		DEEP	
2-62B	1231.43	41	1232.87
43S	1232.52	43D	1232.35
2-64B	1231.48	2-274B	1231.65
2-355B	1230.19	2-393B	1230.11
2-63B	1231.22	45	1229.71
2-272B	1231.12	2-65B	1233.71
2-168B	1230.45	2-271B	1233.78
2-167B	1234.67	2-142B	1228.78
2-273B	1230.16	2-392B	1229.56
2-356B	1231.06		
2-301B	1233.86		

TCE CALIBRATION

SHALLOW		DEEP	
2-62B	9440	2-274B	518
43S	1490	2-393B	406
2-64B	914	43D	169
2-355B	344	45	153
2-63B	75	2-65B	90
2-272B	28	41	4
2-168B	1	2-271B	0
2-167B	0	2-142B	0
2-273B	0	2-392B	0
2-356B	0		
2-301B	0		

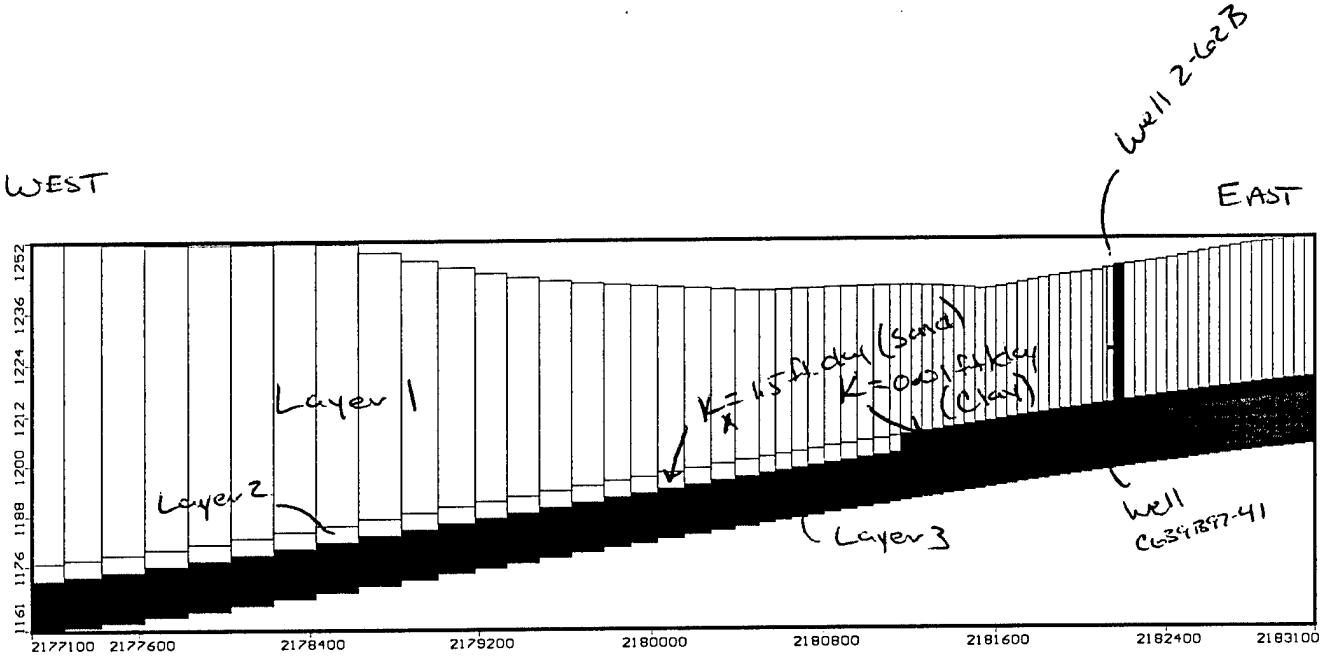
Well Locations



Parsons Eng Science, Inc – Denver, CO
Project: Tinker AFB FTA–2
Description: FTA2–17.VMF
Modeller: Well IDs
23 Mar 99

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 69 NR: 63 NL: 3
Current Layer: 1

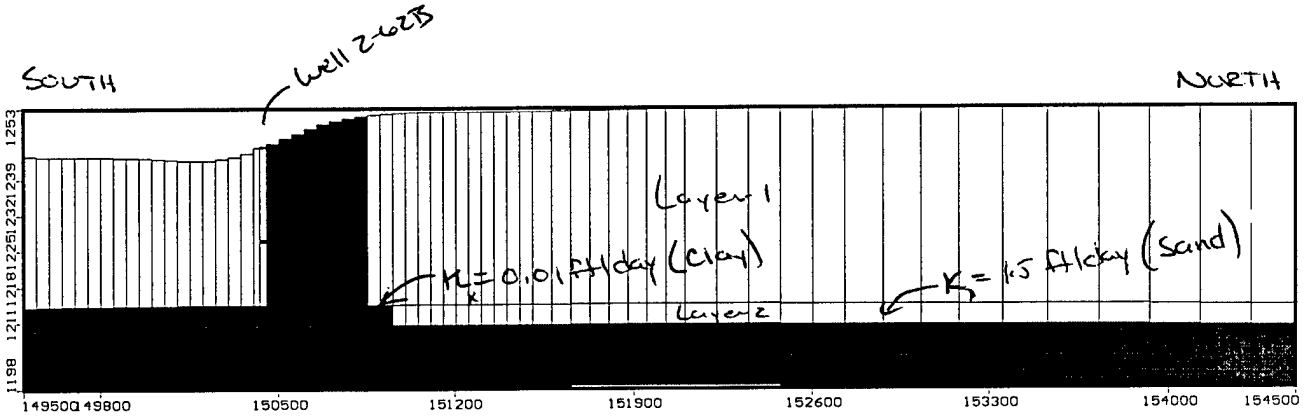
MODFL CROSS-SECTION



Vertical Exaggeration = 20x

Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA-2 Description: FTA2-17.VMF Modeller: East to West Cross-Sect 20 Dec 99	Visual MODFLOW v.2.50, (C) 1995-1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Row: 45

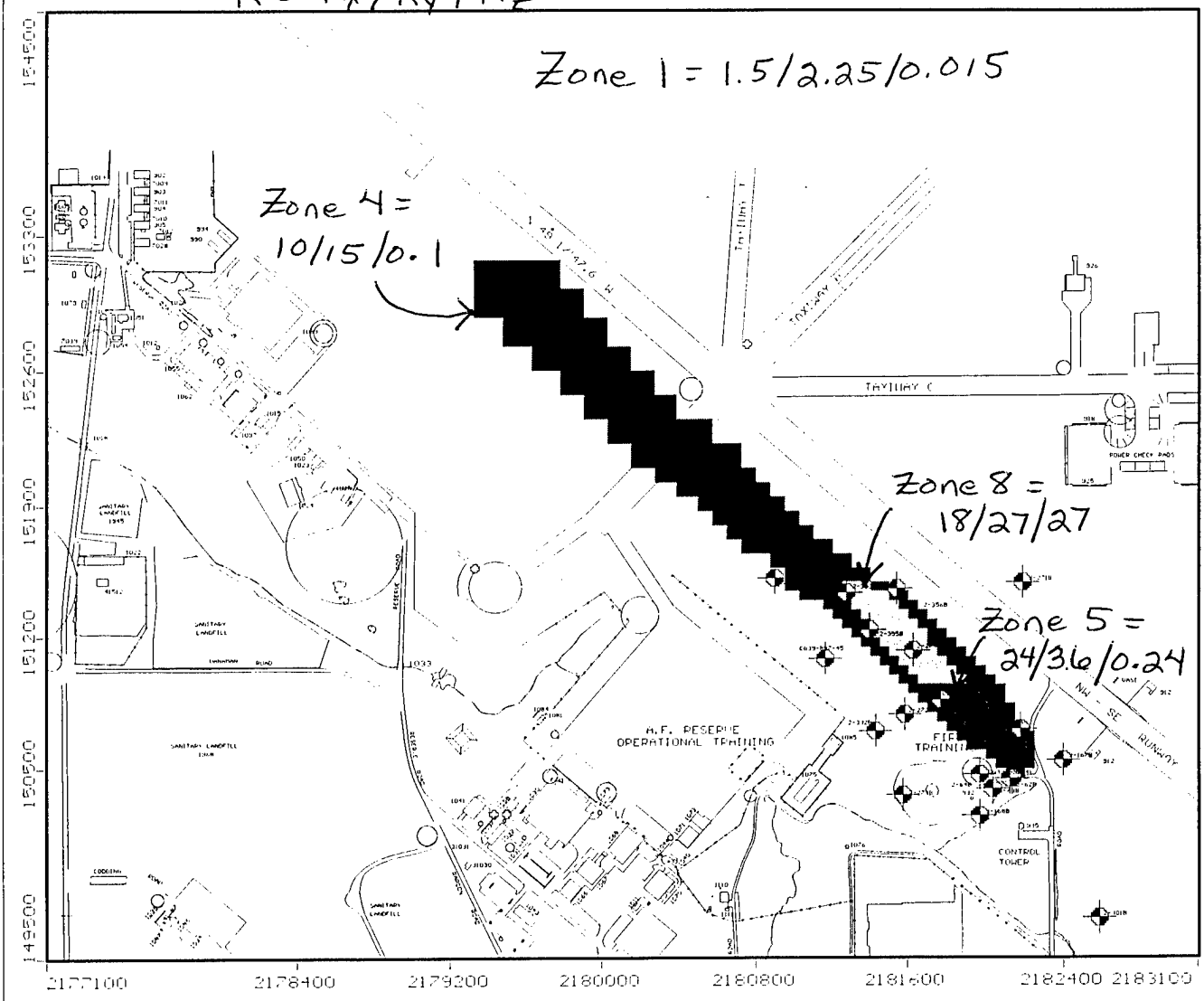
MODEL CROSS-SECTION



Vertical Exaggeration = 20X

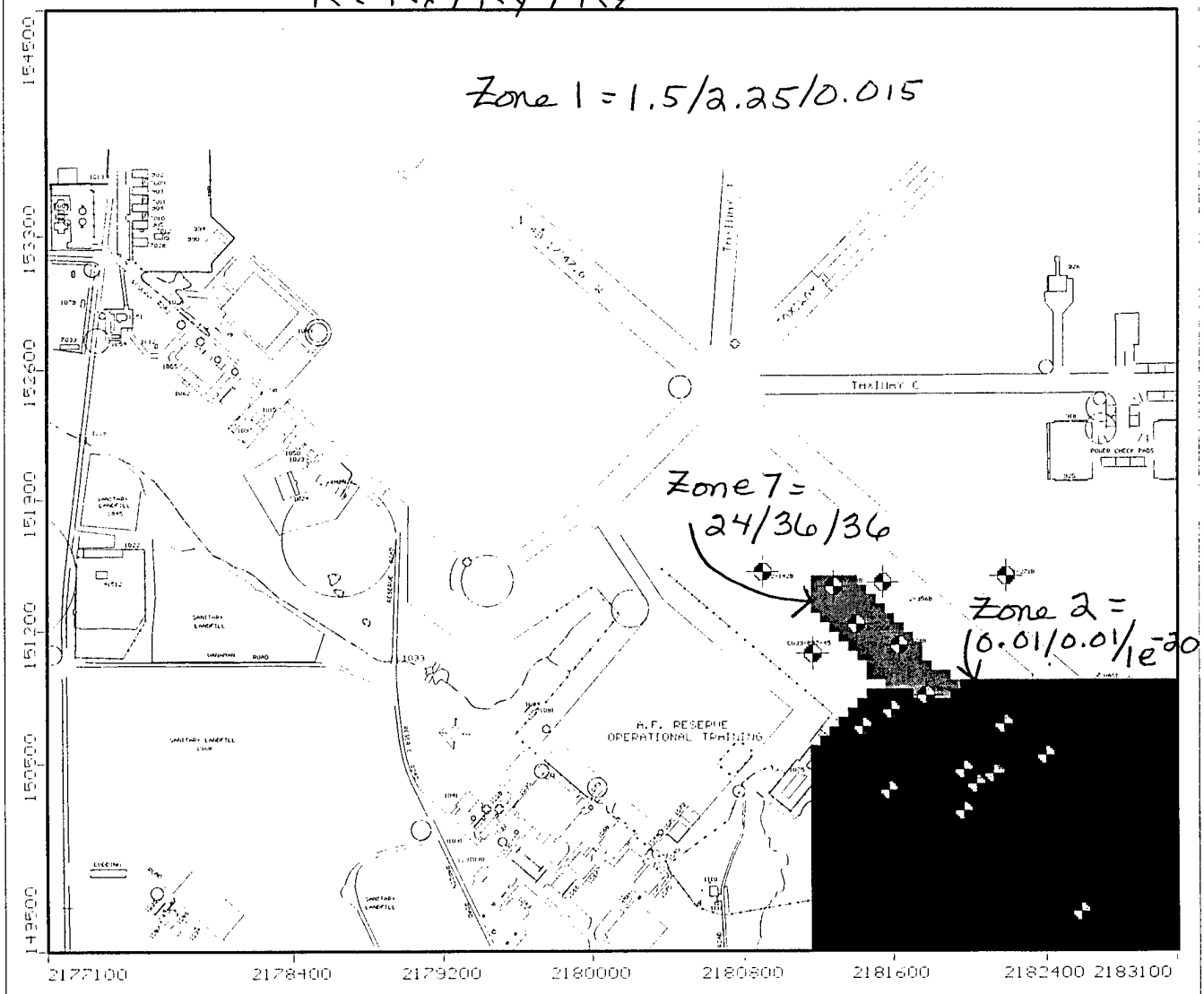
Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA–2 Description: FTA2–17.VMF Modeller: South to North Cross–Sect 20 Dec 99	Visual MODFLOW v.2.50, (C) 1995–1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Column: 50

Hydraulic Conductivity (ft/day)
Layer 1
K = $K_x / K_y / K_z$



Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA–2 Description: FTA2–17.VMF Modeller: Hyd. Cond. Layer 1 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995–1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 1

Hydraulic Conductivity (ft/day)
Layer 2
K = Kx / Ky / Kz

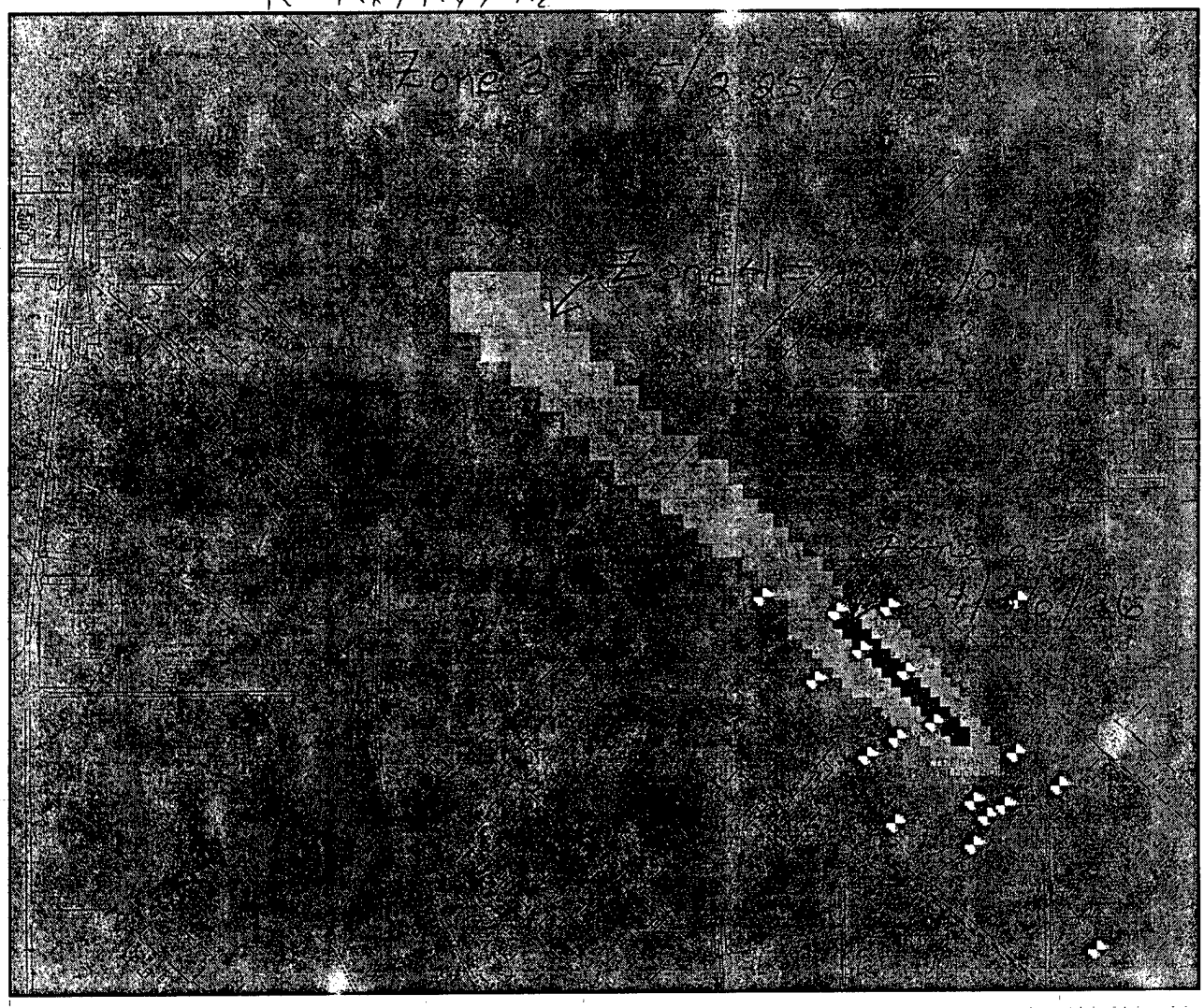


Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA–2 Description: FTA2–17.VMF Modeller: Hyd. Cond. Layer 2 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995–1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 2

Hydraulic Conductivity (ft/day)

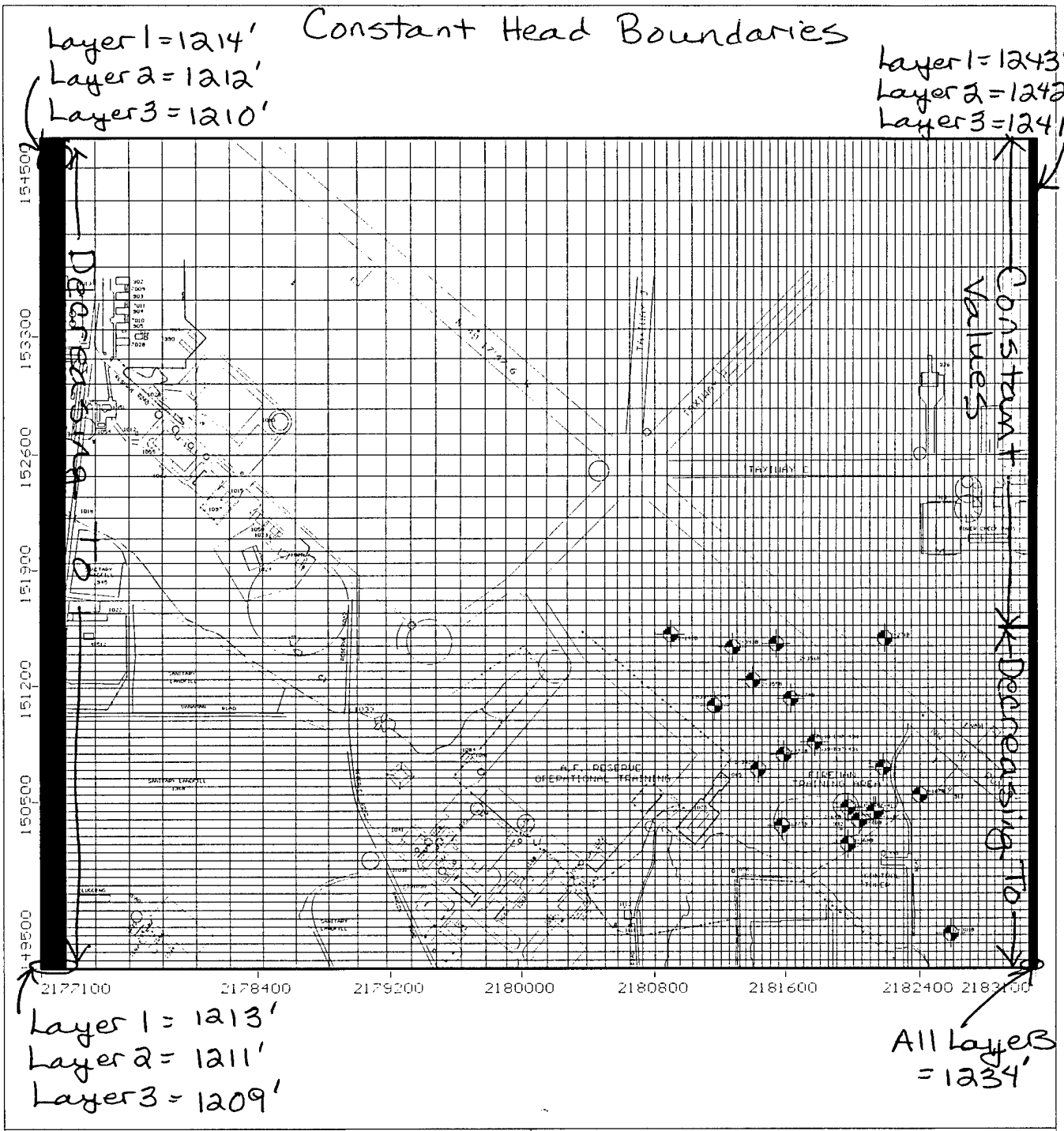
Layer 3

K = Kx / Ky / Kz



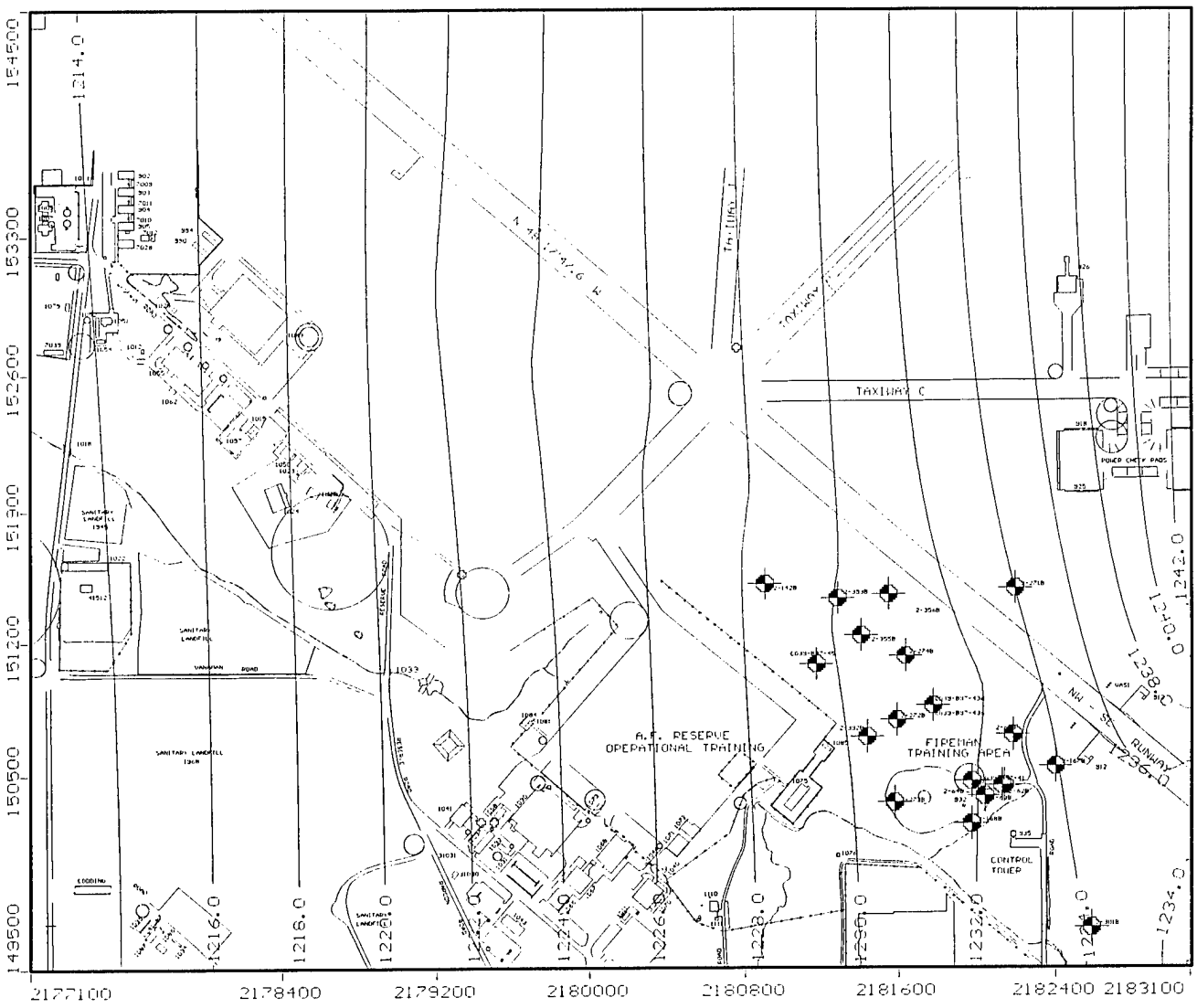
Parsons Eng Science, Inc — Denver, CO
Project: Tinker AFB FTA-2
Description: FTA2-17.VMF
Modeller: Hyd. Cond. Layer 3
23 Mar 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 69 NR: 63 NL: 3
Current Layer: 3



Parsons Eng Science, Inc — Denver, CO Project: Tinker AFB FTA-2 Description: FTA2-17.VMF Modeller: Constant Head Boundaries 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995-1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 1

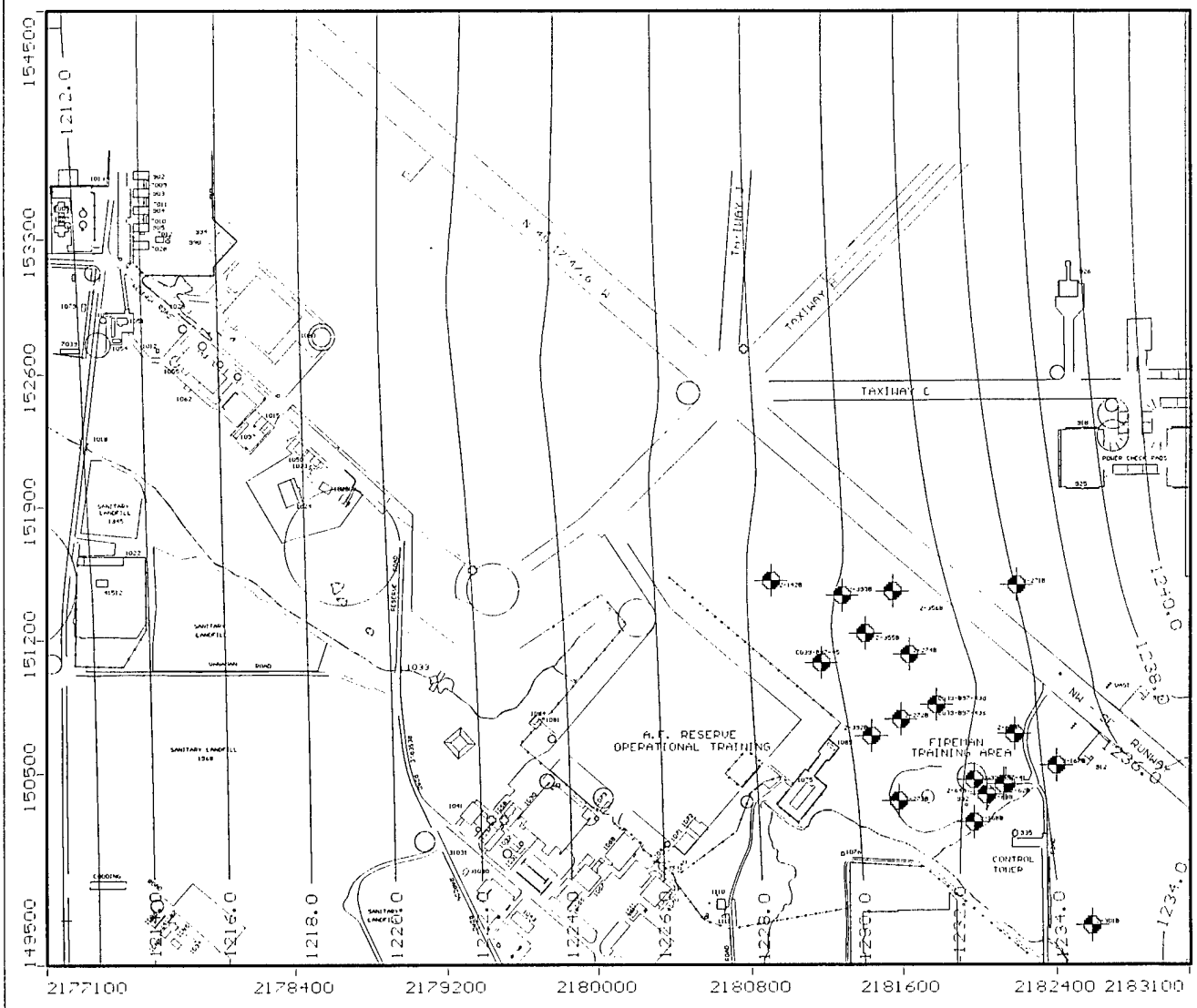
Flow Calibration Layer 1 35 years



Parsons Eng Science, Inc – Denver, CO
Project: Tinker AFB FTA–2
Description: FTA2–17.VMF
Modeller: Calibrated Heads Lay 1
23 Mar 99

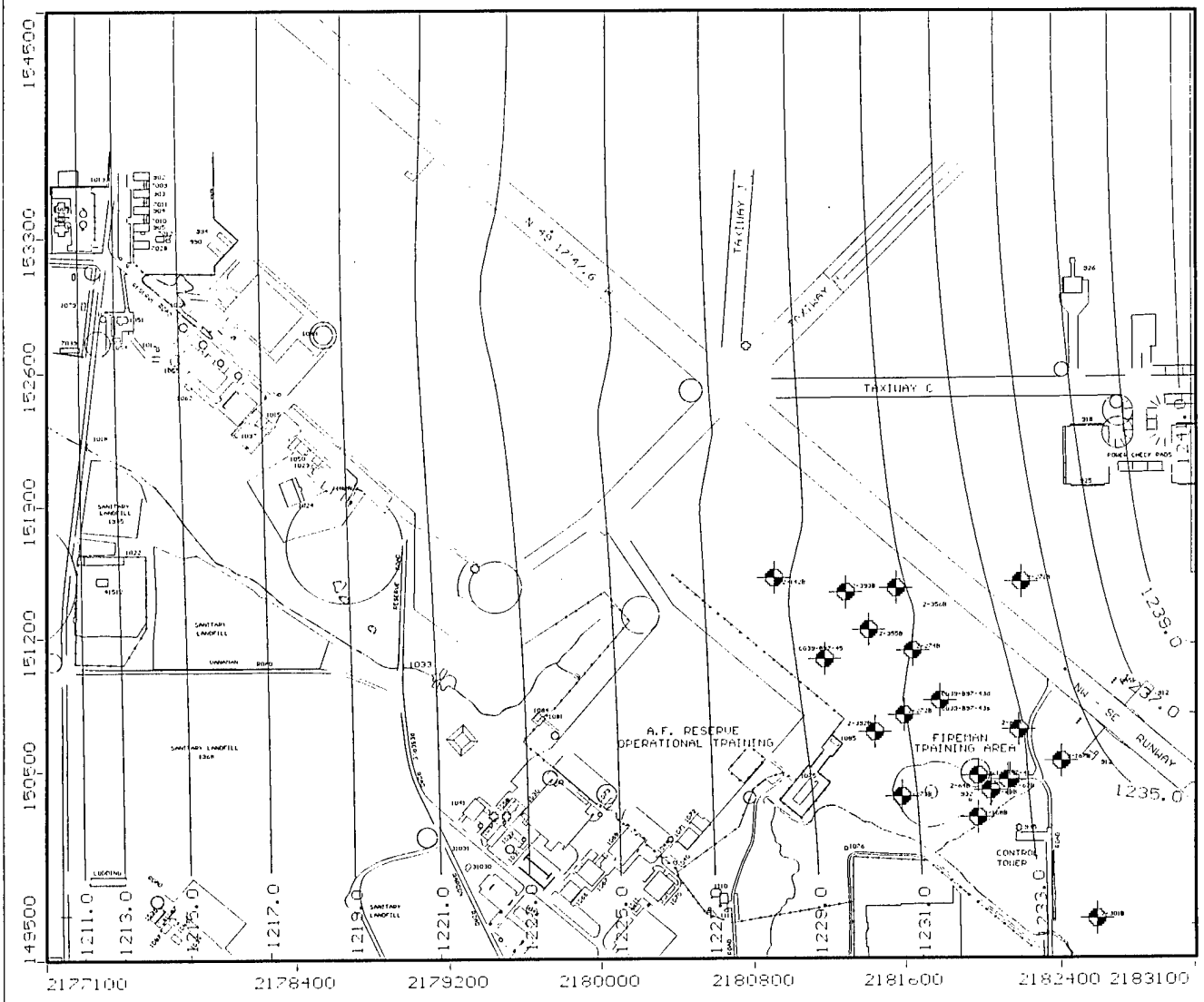
Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 69 NR: 63 NL: 3
Current Layer: 1

Flow Calibration Layer 2 35 years



Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA-2 Description: FTA2-17.VMF Modeller: Calibrated Heads Lay 2 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995-1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 2

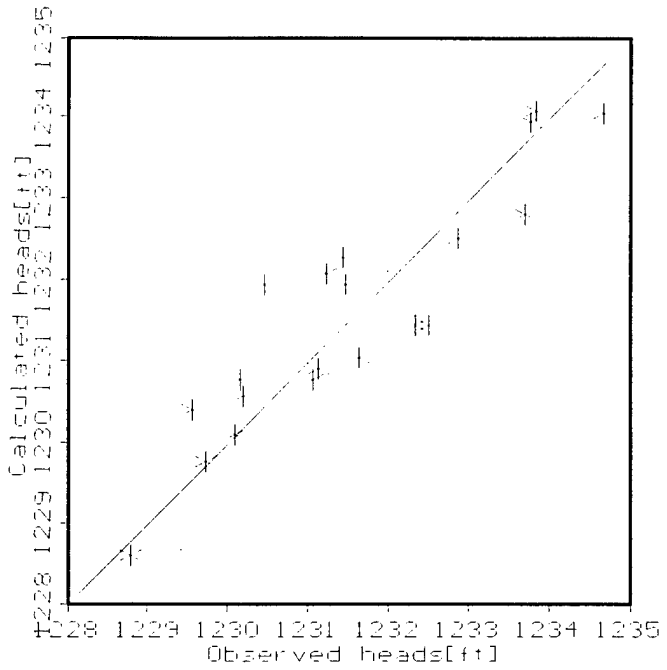
Flow Calibration Layer 3 35 years



Parsons Eng Science, Inc – Denver, CO
Project: Tinker AFB FTA–2
Description: FTA2–17.VMF
Modeller: Calibrated Heads Lay 3
23 Mar 99

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 69 NR: 63 NL: 3
Current Layer: 3

Flow Calibration 35 years

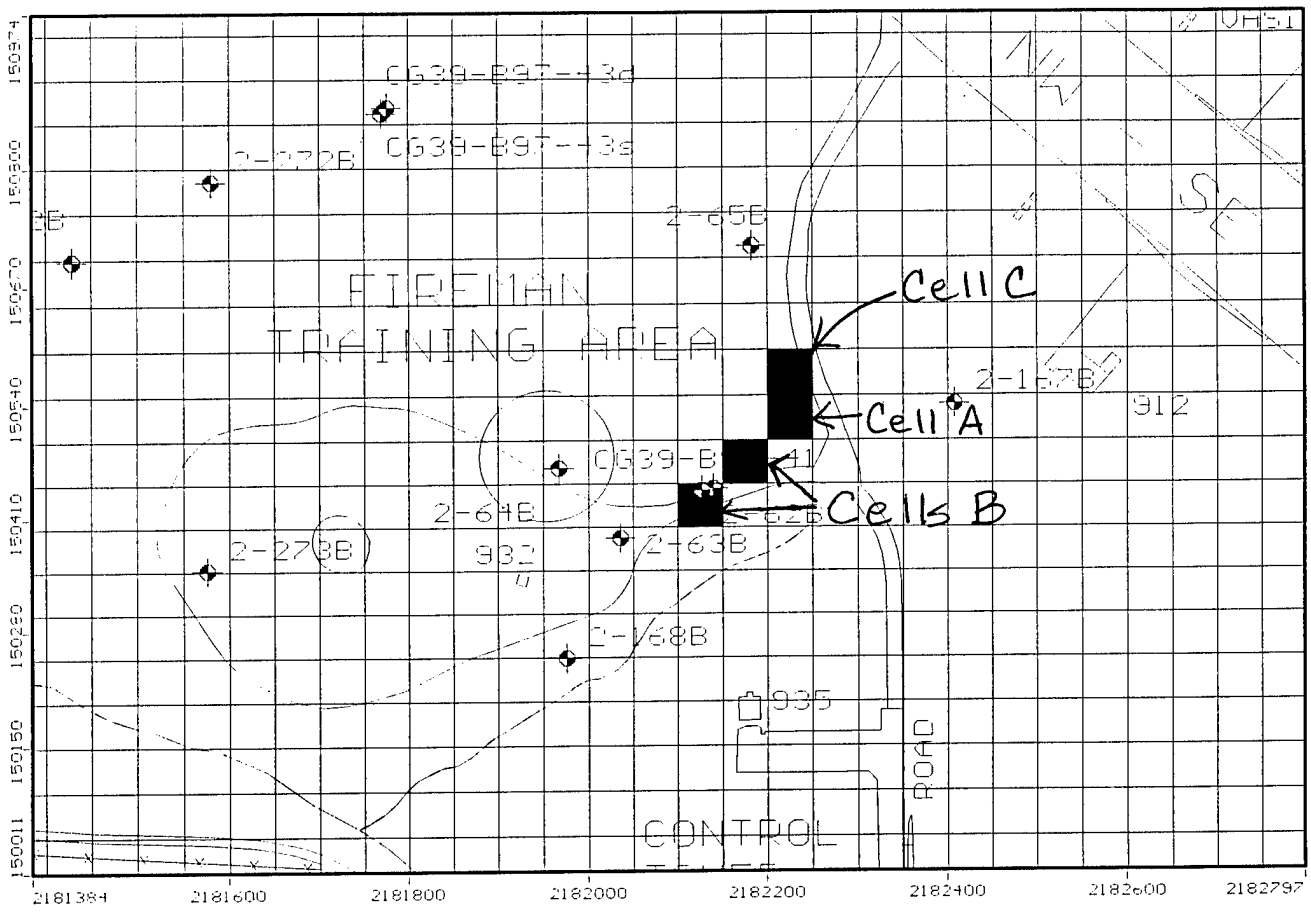


Period: 7
Step: 10

Mean error: 0.00233468 Mean abs. err: 0.558848 RMS error: 0.670091

Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA–2 Description: FTA2–17.VMF Modeller: Obs. vs. Calc. Heads 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995–1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 1

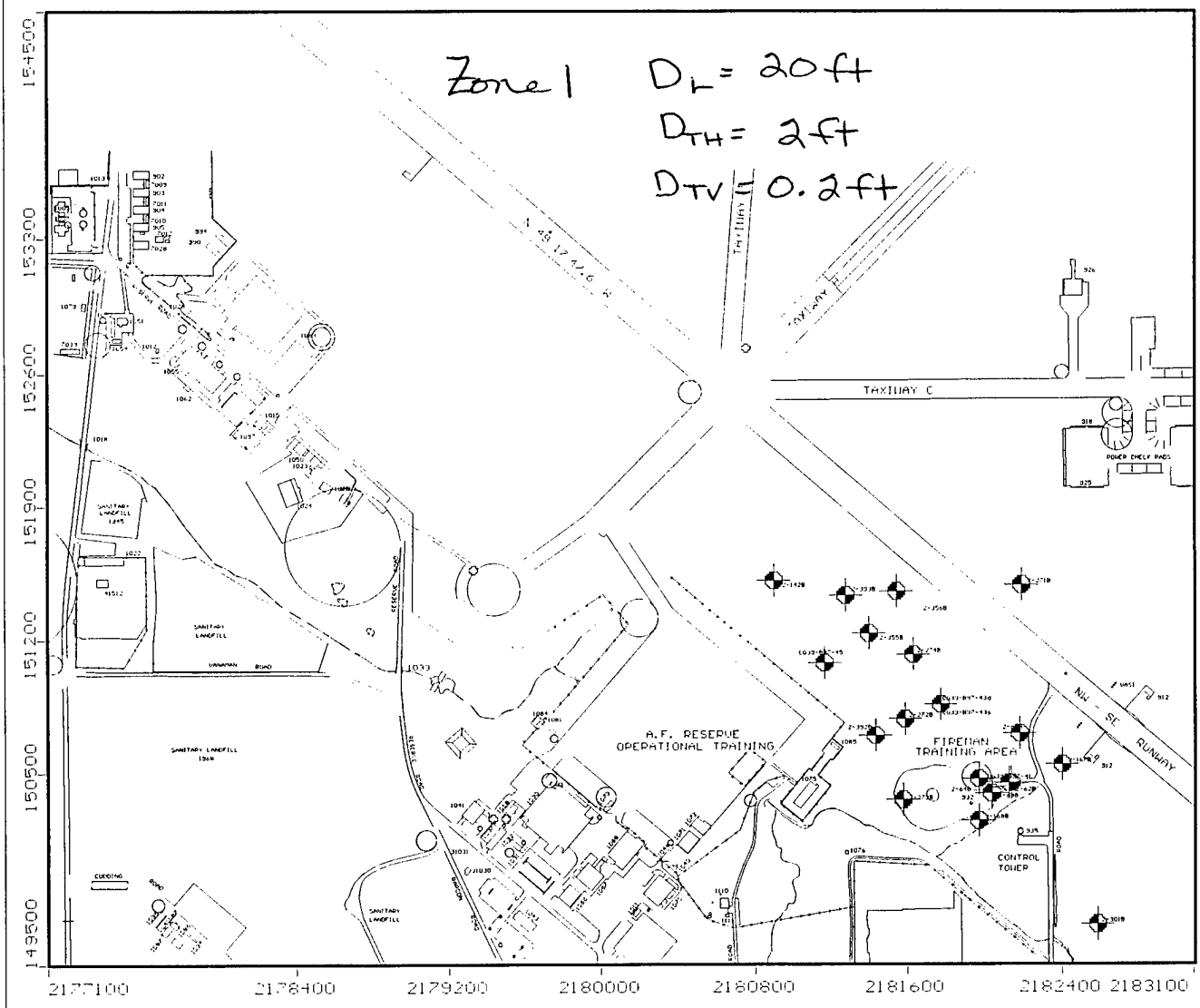
Constant Concentration Cells



Parsons Eng Science, Inc – Denver, CO
Project: Tinker AFB FTA-2
Description: FTA2-17.VMF
Modeller: Constant Concentration
23 Mar 99

Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 69 NR: 63 NL: 3
Current Layer: 1

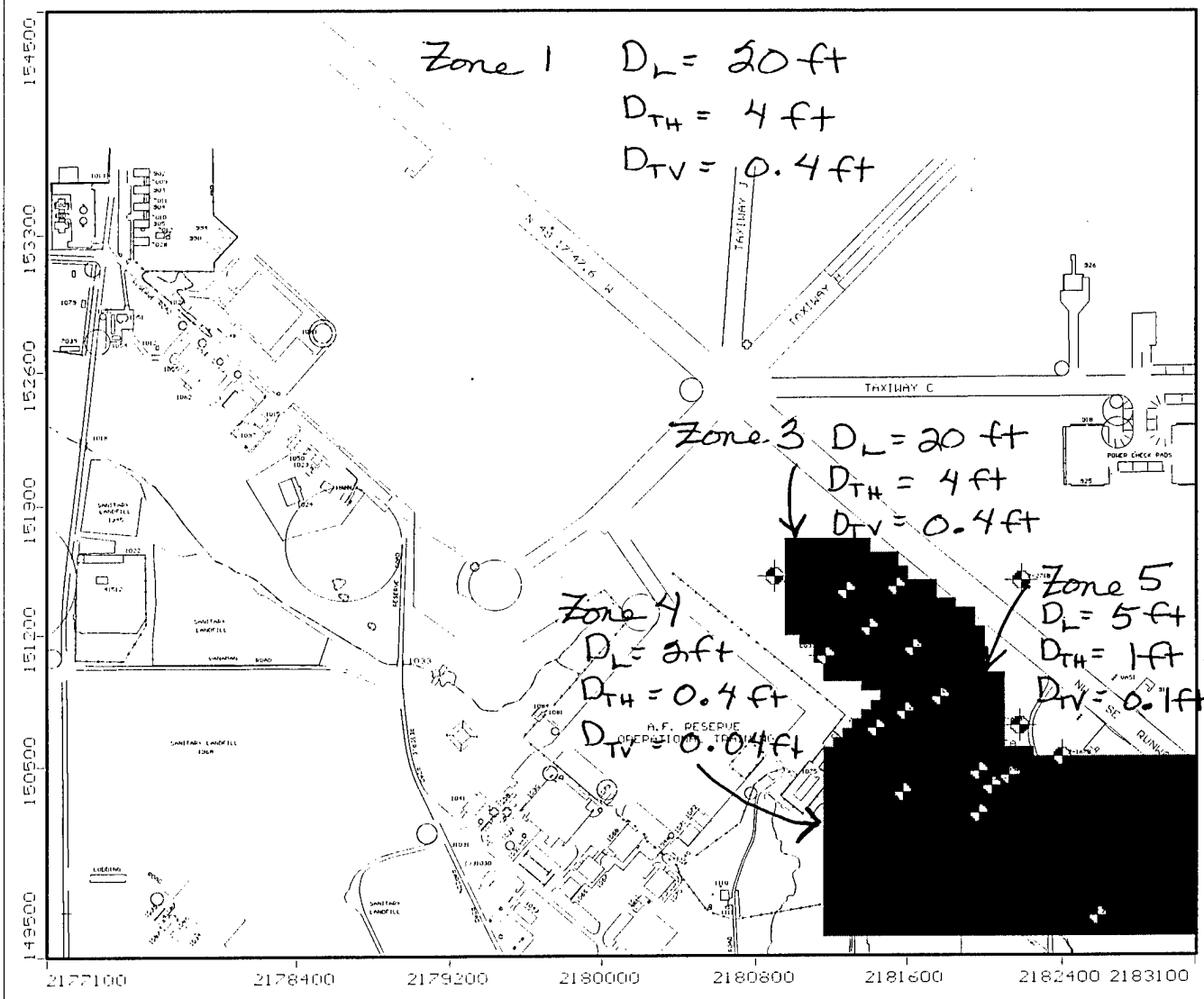
Dispersion Layer 1



Parsons Eng Science, Inc – Denver, CO
Project: Tinker AFB FTA–2
Description: FTA2–17.VMF
Modeller: Dispersion Layer 1
23 Mar 99

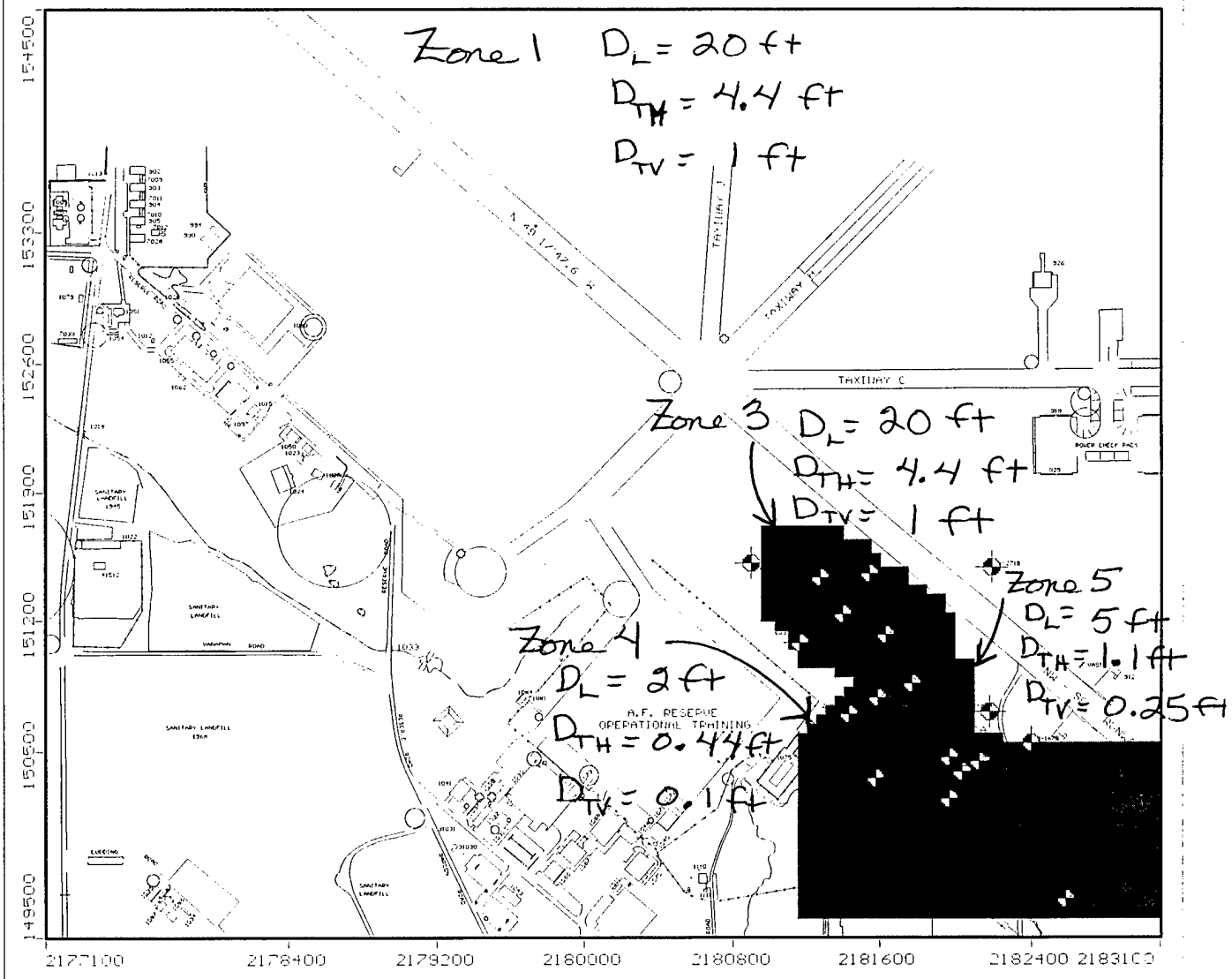
Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 69 NR: 63 NL: 3
Current Layer: 1

Dispersion Layer 2



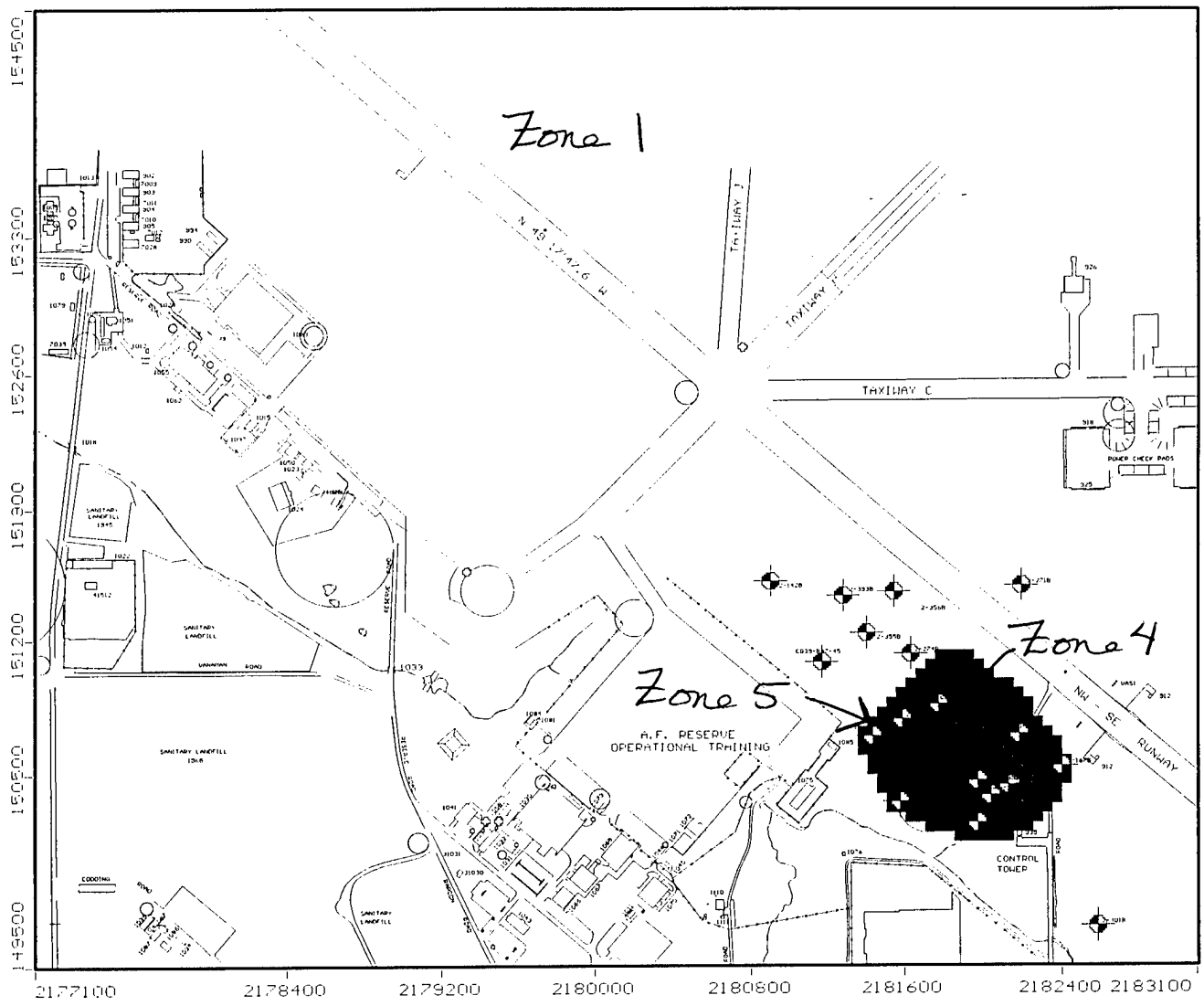
Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA–2 Description: FTA2–17.VMF Modeller: Dispersion Layer 2 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995–1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 2

Dispersion Layer 3



Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA–2 Description: FTA2–17.VMF Modeller: Dispersion Layer 3 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995–1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 3

Chemical Reactions Layer 1



Parsons Eng Science, Inc – Denver, CO
Project: Tinker AFB FTA–2
Description: FTA2–17.VMF
Modeller: Chem. Reaction Layer 1
23 Mar 99

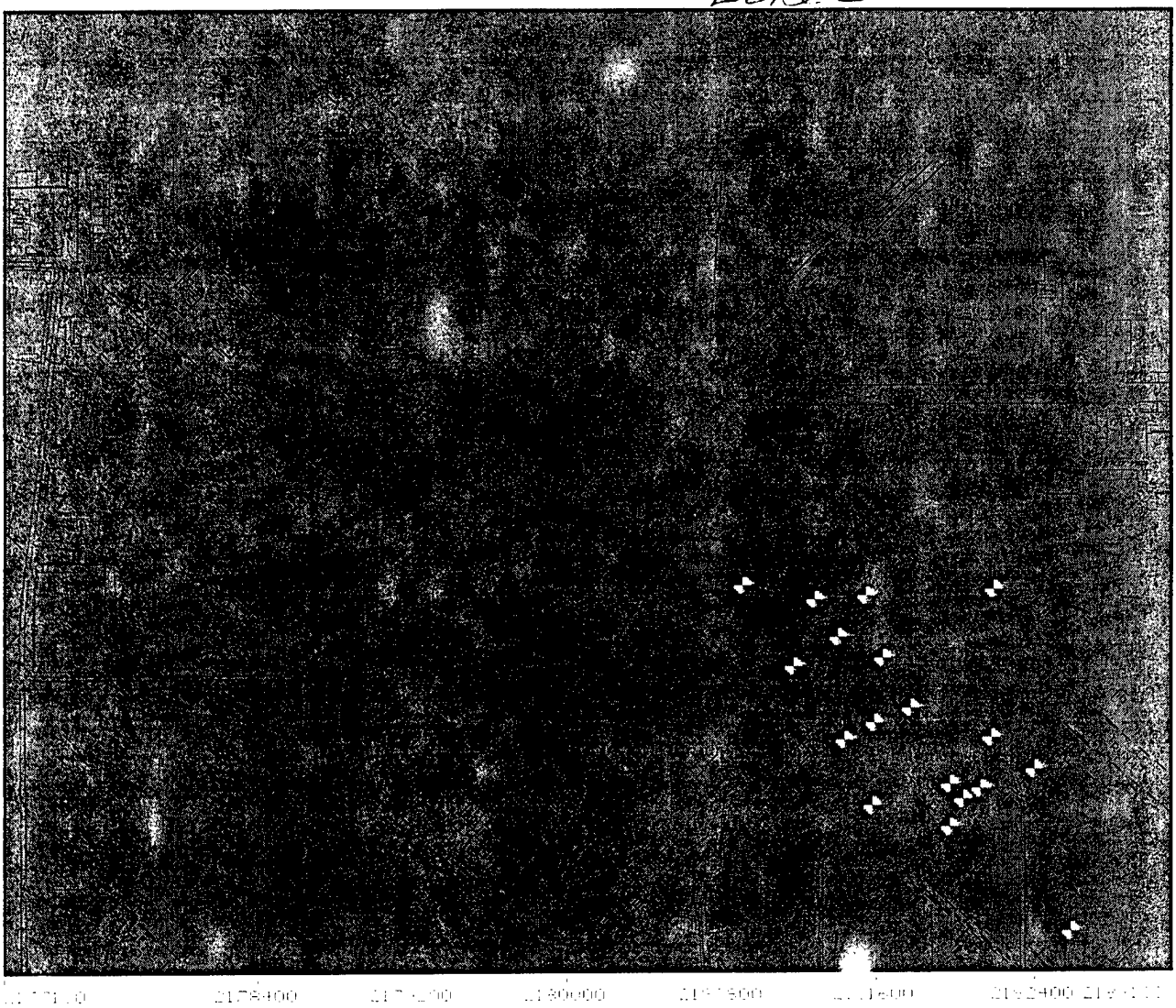
Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 69 NR: 63 NL: 3
Current Layer: 1

Chemical Reactions
Layer 2
Zone 2

Parsons Eng Science, Inc – Denver, CO
Project: Tinker AFB FTA–2
Description: FTA2–17.VMF
Modeller: Chem. Reaction Layer 2
23 Mar 99

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 69 NR: 63 NL: 3
Current Layer: 2

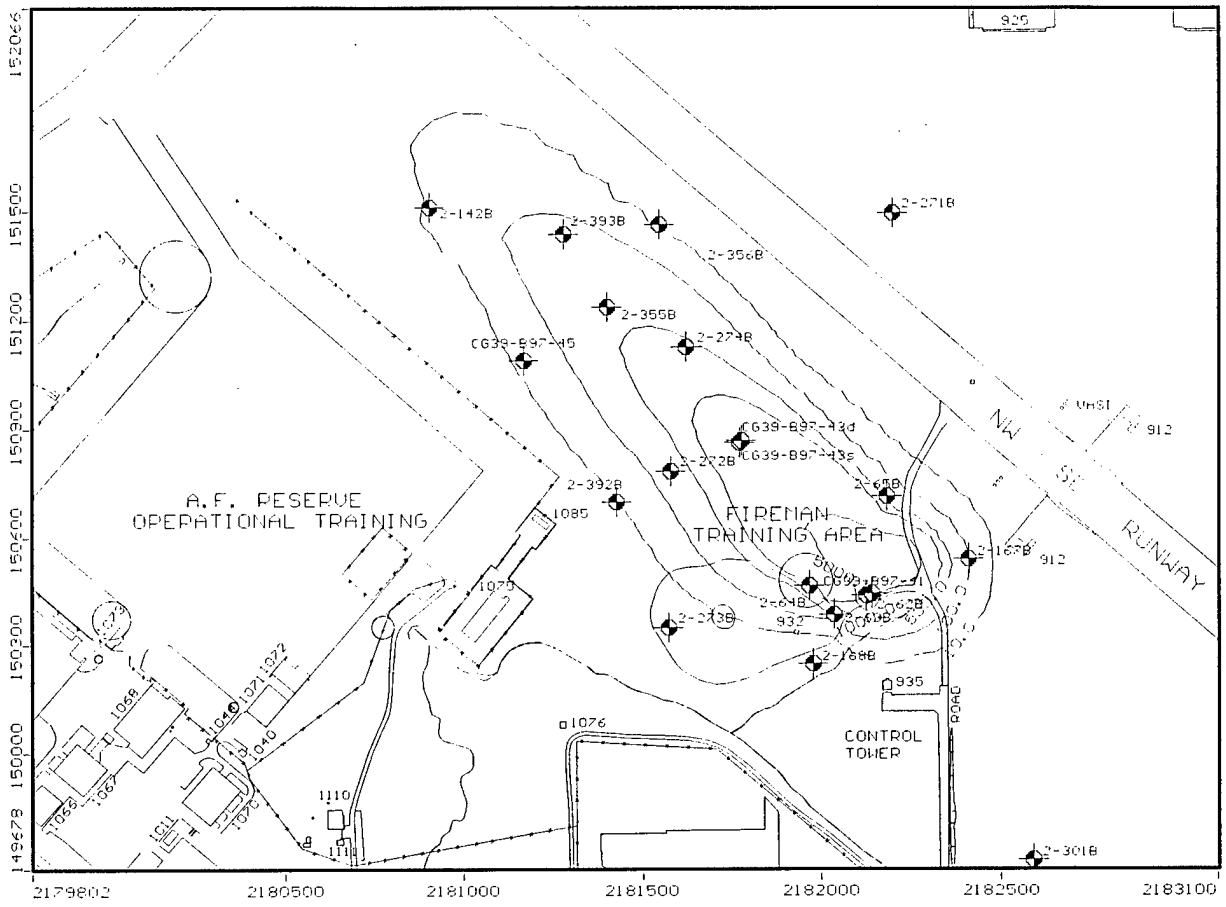
Chemical Reactions
Layer 3 Zone 3



Parsons Eng Science, Inc – Denver, CO
Project: Tinker AFB FTA-2
Description: FTA2-17.VMF
Modeller: Chem. Reaction Layer 3
23 Mar 99

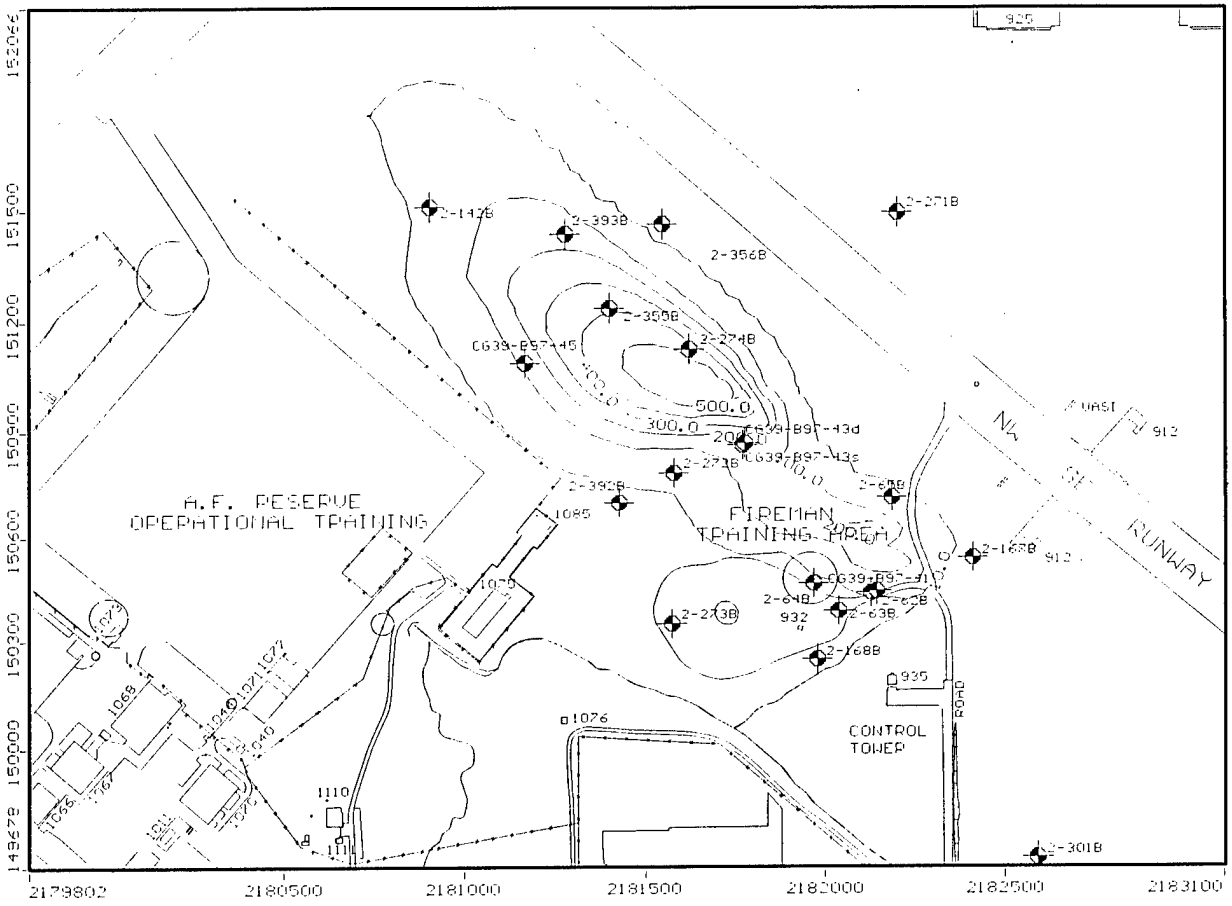
Visual MODFLOW v.2.50, (C) 1995-1997
Waterloo Hydrogeologic Software
NC: 69 NR: 63 NL: 3
Current Layer: 3

TCE Calibration
Layer 1 35 years



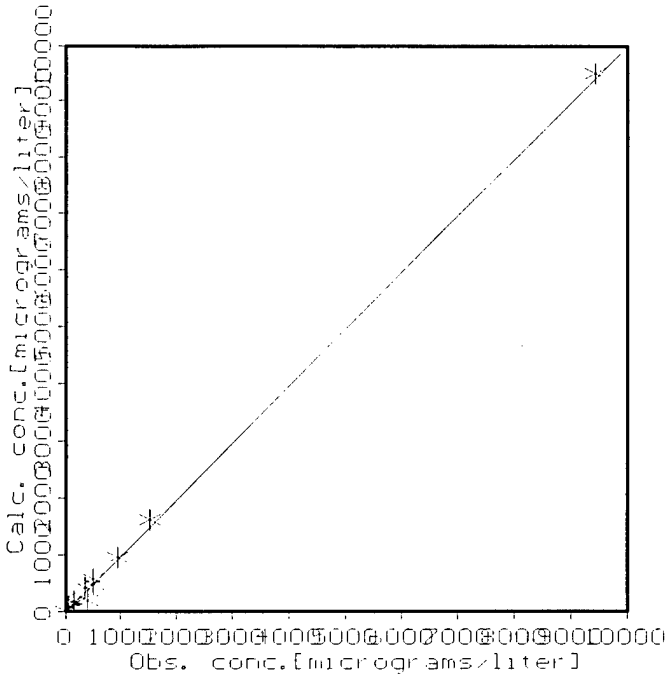
Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA–2 Description: FTA2–17.VMF Modeller: Calibrated TCE Lay 1 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995–1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 1

TCE Calibration
Layer 3 35 years



Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA–2 Description: FTA2–17.VMF Modeller: Calibrated TCE Lay 3 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995–1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 3

TCE Calibration 35 years

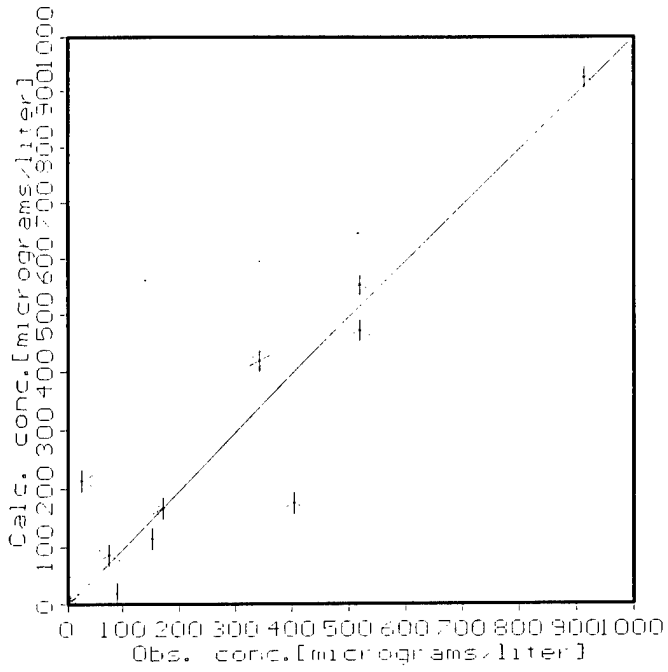


Period: 7
Step: 10

Mean error: 6.84024 Mean abs. err: 44.2538 RMS error: 74.4457

Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA-2 Description: FTA2-17.VMF Modeller: Obs. vs. Calc. TCE 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995-1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 1

TCE Calibration 35 years



Period: 7
Step: 10

Mean error: 6.84024 Mean abs. err: 44.2538 RMS error: 74.4457

Parsons Eng Science, Inc – Denver, CO Project: Tinker AFB FTA-2 Description: FTA2-17.VMF Modeller: Obs. vs. Calc. TCE 23 Mar 99	Visual MODFLOW v.2.50, (C) 1995-1997 Waterloo Hydrogeologic Software NC: 69 NR: 63 NL: 3 Current Layer: 1

APPENDIX F

MODEL INPUT AND OUTPUT FILES

APPENDIX F
MODFLOW/MT3D MODEL
INPUT AND OUTPUT FILES

Filename	Description
FTA217IN.ZIP	FTA2 Model Calibration Input Files
FTA217OU.ZIP	FTA2 Model Calibration Output Files
FTA2A1IN.ZIP	FTA2 Remedial Alternative One Input Files
FTA2A1OU.ZIP	FTA2 Remedial Alternative One Output Files
FTA2A2IN.ZIP	FTA2 Remedial Alternative Two Input Files
FTA2A2OU.ZIP	FTA2 Remedial Alternative Two Output Files
FTA2A3IN.ZIP	FTA2 Remedial Alternative Three Input Files
FTA2A3OU.ZIP	FTA2 Remedial Alternative Three 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. On the general 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.
filename.BAS	Translated MODFLOW file containing data for the BASIC Package.
filename.BCF	Translated MODFLOW file containing data for the Block-Centred Flow Package.
filename.CH	Translated MODFLOW file containing data for the transient constant head package.
filename.DRN	Translated MODFLOW file containing data for the Drain Package.
filename.EVP	Translated MODFLOW file containing data for the Evapotranspiration Package.
filename.GHB	Translated MODFLOW file containing data for the General Head Boundary Package.
filename.OC	Translated MODFLOW file containing data for the output control options.
filename.PCG	Translated MODFLOW file containing data for the PCG2 solver.
filename.RCH	Translated MODFLOW file containing data for the Recharge Package.
filename.RIV	Translated MODFLOW file containing data for the River Package.
filename.SIP	Translated MODFLOW file containing data for the SIP solver.
filename.SOR	Translated MODFLOW file containing data for the SOR solver.
filename.WAL	Translated MODFLOW file containing data for the Horizontal Flow Boundary Package.
filename.WEL	Translated MODFLOW file containing data for the Well Package.
filename.WHS	Translated MODFLOW file containing data for the WHS Solver.

Translated MT3D Files

filename.AD3	Translated MT3D file containing Advection data
filename.BT3	Translated MT3D file containing Basic Transport data
filename.DP3	Translated MT3D file containing Dispersion data
filename.RC3	Translated MT3D file containing Chemical Reaction data
filename.SS3	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

filename.ASC	Visual MODFLOW output file containing data to be used by plotting programs, such as Surfer (Golden Software) - ASCII format
* *filename*.LST	Visual MODFLOW output file containing the listing information and messages from MODFLOW - ASCII format
filename.PS	Visual MODFLOW output file containing the POSTSCRIPT graphics file - ASCII format
filename.DXF	Visual MODFLOW output file containing the DXF graphic file - ASCII format

MODFLOW

filename.DDN	MODFLOW output file containing drawdown X, Y, Z heads for each node - Binary format
filename.DVT	MODFLOW output file containing drawdown versus time results- Binary format
* *filename*.FLO	MODFLOW output file containing output for input to MT3D cell-by-cell flow terms (See MT3D manual for format) - Binary format
* *filename*.HDS	MODFLOW output file containing equipotential results - Binary format;
filename.HVT	Contains MODFLOW head versus time results - Binary format;

MT3D

* *filename*.OT	MT3D output file containing listing information and messages from MT3D - ASCII format;
* *filename*.UCN	MT3D output file containing unformatted concentration information - Binary format;
* *filename*.MAS	MT3D output file containing mass balance file - ASCII format
* *filename*.CNF	MT3D output file containing model grid configuration file - ASCII format

APPENDIX G

RESPONSES TO COMMENTS

PARSONS

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1700 Broadway, Suite 900 • Denver, Colorado 80290 • (303) 831-8100 • Fax: (303) 831-8208 • www.parsons.com

07 December 1999

Mr. Jerry Hansen
AFCEE/ERT
Brooks AFB, TX

Subject: Responses to Comments on the Draft Treatability Study in Support of Remediation by Natural Attenuation for Groundwater at Site FTA-2, Tinker Air Force Base, Oklahoma (Contract F4164-92-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 Site FTA-2, 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 TS was to determine the role of natural attenuation in remediating chlorinated solvent and hydrocarbon fuel contamination in groundwater at Fire Training Area No. 2 (FTA-2). The draft TS was submitted to AFCEE and Tinker AFB in April 1999. Comments on the draft TS were received from Sara Sayler of Tinker AFB on 17 May 1999; and from AFCEE as reviewed by Jon Atkinson, dated 08 June 1999. Responses to these comments were prepared by Parsons ES and are presented herein.

Responses to Tinker AFB Comments: 17 May 1999

Comment 1) Page 3-13, Figure 3.7, There is a well labeled 2-G2B/, I think you mean 2-62B.

Parsons ES Response: *The well label will be corrected to 2-62B.*

Comment 2) Page 4-12/4-13, since you are including the soil as possible source, it would be good to also include soil contaminant maps also.

Parsons ES Response: *A description of historical and TS soil analytical results is provided in Section 4.2.1. For all previous site investigations, the only chlorinated aliphatic hydrocarbon (CAH) detected in soil was 1,1,1-trichloroethane (1,1,1-TCA) at concentrations less than 10 micrograms per kilogram (ug/kg). For this TS report, only TCE was detected, at a concentration of 19 ug/kg at well location CG39-B97-41. Therefore, the nature and extent of soil*

contamination has not been determined at FTA-2, and a soil contaminant map would not provide any further insight. Further site characterization to address this data deficiency is recommended in this TS.

Comment 3) Page 4-15, fourth paragraph mentions TCE contamination in the Lower Sat. Zone. This is the first evidence of contamination in the LSZ, no samples have showed this previously, any clues as to how the contamination got down there? Is there a 'hole' in the confining layer, if so, where do you think it is? Maybe 2-62 or a well upgradient, created the pathway down to the LSZ?

Parsons ES Response: *TCE was detected at monitoring well 2-62A for the first time at concentration of 10.9 µg/L. Parsons ES interprets this to be a result of contaminant migration across the USZ/LSZ aquitard. While the permeability (hydraulic conductivity) of the USZ/LSZ aquitard is low relative to sediments of the USZ, it is not absolutely impermeable. Contaminant migration may occur across the USZ/LSZ aquitard given sufficient time (i.e., the approximate 30 year age of the contaminant source).*

Comment 4) Page 4-47, under the Temperature heading, the second sentence reads "Temperature can affects the types and growth....". Need to change "affects" to 'affect'.

Parsons ES Response: *The text will be changed as indicated.*

Comment 5) Page 4-52, fifth paragraph, last sentence, need to add a comma after the word "site".

Parsons ES Response: *The text will be changed as indicated.*

Comment 6) Page 5-1, just curious if you had considered using a modeling algorithm that accounts for viscosity and density differences of the contamination (such as SWANFLOW). When modeling contaminant transport over a large chunk of time, such as 35 years, the densities and viscosities can have a large effect (depending on the contaminant being considered) on contaminant migration.

Parsons ES Response: *Modeling algorithms were not considered to account for viscosity and density differences of TCE relative to groundwater. Density and viscosity differences were not considered to be significant due to the dilute concentrations of TCE in groundwater (relative to the solubility limit of TCE).*

Comment 7) Page 5-3, under the Grid Design heading, first sentence, "The model area for FTA-2 includes the FTA-1 source area...", I think you mean FTA-3, not FTA-1.

Parsons ES Response: *The text will be changed to indicate the model area includes the FTA-3 fire training area.*

Comment 8) Page 5-5, second paragraph, fourth sentence states "Layer 2 was defined using borehole data, and was specified as sand with a .....", according to the model description in the previous paragraph, "The upper layer....., a middle layer represents the intra-USZ clay horizon,....". Shouldn't Layer 2 be specified as a clay?

It would also be helpful to include a simplified cross-section of the 3 Layers used for the model. The model layers could have pertinent model information relating to that layer printed directly on the model cross-section.

Near the end of the second paragraph in the sentence "All three layers were assumed to be hydraulically connected, with the presence of vertical hydraulic gradients largely ignored". The wording on this statement confused me a little. Does is mean to say that the vertical hydraulic gradients were ignored because this was accounted for by hydraulically connected the layers. Would it be correct (and maybe more clear) to say 'All three layers were assumed to be hydraulically connected, therefore, including vertical hydraulic gradients in the model was not necessary'.

Parsons ES Response: *Layer 2 will be specified as intra-USZ clay where present (based on borehole logs), and as sand elsewhere. A simplified cross-section figure of the model to illustrate this will be added to Appendix E.*

Assuming all three layers to be hydraulically connected indicates that groundwater flow and contaminant transport across layer boundaries is allowed in the model. While vertical gradients have been observed at the site, the model does not attempt to duplicate those gradients. Note that this does not necessarily

preclude simulation of vertical gradients in the model, only that this was not a criteria for model calibration. Vertical contaminant transport is accomplished by simulated vertical flow and/or dispersion.

Comment 9) Page 5-7, second paragraph under the heading Aquifer Properties, last sentence, "The flow model developed for this exercise contains both a preferred pathway (a channel of sand more permeable than surrounding materials) and horizontal hydraulic conductivity anisotropy". How was the location of this channel inferred and what hydraulic conductivity was used for this channel versus non-channel in the model?

Parsons ES Response: *The location of the sand channel was inferred from hydraulic conductivity measurements (Table 3.2) and the contaminant plume configuration. It should be noted this reflects the conceptual model of a single source area with a preferential flowpath oblique to the direction of maximum hydraulic gradient. This represents only one possible interpretation for the observed plume configuration. Additional data is necessary to determine if this is a correct conceptual model. Ranges of hydraulic conductivity were initially selected from Table 3.2, and the values used in the calibrated model are described in Section 5.5.1.*

Comment 10) Page 4-29. Table 4.10 shows some erratic behavior for the Trans DCE and the VC plots but there is no discussion about this in the text. Can you discuss why these plots appear this way?

Parsons ES Response: *VC has only been detected at well 2-62B in 1997 at a concentration of 1.7 ug/L, only slightly higher that the detection limit (1 ug/L). This is not sufficient to determine trends in VC behavior.*

Non-detects for trans-1,2-DCE are incorrectly plotted at 1 ug/L for 1995 and 1996 . The detection limit for trans-1,2-DCE in 1995 was not provided with the historical data table, and the detection limit in 1996 was 250 ug/L. Therefore, the figure will be corrected delete the non-detection for 1995, and to plot the non-detection for 1996 as one-half the detection limit (125 ug/L). This does not preclude erratic behavior in trans-1,2-DCE concentration, but will aid the reader in interpreting the limited data.

Comment 11) Page 5-15, under section 5.5.2.3, middle of paragraph. Mention is made of a "Section 4.6". There is no section 4.6. My copy only goes to section 4.5.

Parsons ES Response: *The reference to "Section 4.6" will be corrected to "Section 4.5."*

Responses to AFCEE Comments: 08 June 1999

General

Comment 1) The computer model grid design is flawed as described in comment eight below. Consequently, consideration should be given to reorienting the MODFLOW and MT3D grids and re-executing the modeling portion of this study.

Parsons ES Response: *The MODFLOW and MT3D grid will not be re-oriented as indicated in the response to Specific Comment 8.*

Specific

Comment 2) Page ES-2, Para 1, Line 8: To correct verb-subject agreement, recommend changing "has" to "have."

Parsons ES Response: *The sentence will be changed as recommended.*

Comment 3) Page 1-4, Sec 1.2, Para 3, Line 8: Suggest changing "air" to "aerial."

Parsons ES Response: *The sentence will be changed as suggested.*

Comment 4) Page 2-4, Sec 2.1.2, Sent 3: Suggest expanding by adding SP (Spontaneous Potential) to the list geophysical logging methods used. Additionally, recommend adding the rationale for running these down-hole tests.

Parsons ES Response: *The text will be expanded to include the SP logging method and the rationale for running downhole logs (i.e., required Base protocol and enhanced resolution of lithologic contacts).*

Comment 5) Pages 3-9 and 3-10, Figs 3.4 and 3.5: Suggest adding a bar scale for horizontal distance.

Parsons ES Response: *Bar scales for horizontal distance will be added to Figures 3.4 and 3.5 as suggested.*

Comment 6) Page 3-16, Sec 3.3.2.1, Para 3 and Page 3-19, Para 3: To better reflect the problematic accuracy/certainty of hydraulic conductivity (K) values calculated from slug tests, recommend reporting K values to two significant figures.

Parsons ES Response: *Values for hydraulic conductivity (K) will be reported to two significant figures throughout the final TS.*

Comment 7) Page 4-28, Sec 4.3.2, Para 2, Sent 1: Recommend changing "would expected" to "would be expected."

Parsons ES Response: *The text will be changed as recommended.*

Comment 8) Page 5-3, Sec 5.4.1, Sent 3: Although the direction of maximum hydraulic gradient is the rationale given for orienting the model grid, the long axis of the grid should be parallel to features or conditions (e.g., faults, sand channels) controlling predominant flow direction. Anderson and Woessner (*Applied Groundwater Modeling*, 1992) note (p. 5-1) that: "The horizontal plane of the grid should be aligned so that the x and y coordinate axes are colinear with K_x and K_y." Because the longitudinal axis of the TCE plume and the sand channel unit have an approximate bearing of N 45 W, the long axis of the grid should also have this approximate compass direction.

Parsons ES Response: *A preferential flowpath has not been delineated, but was inferred based on relative changes in hydraulic conductivity and a conceptual model that included a singular source area. As recommended in the draft TS, additional source and site characterization should be performed to verify the conceptual model for the site. Parsons ES suspects multiple sources may be present at FTA-2. Parsons ES requests that the model not be re-oriented, as the work required to modify the model is not warranted until the conceptual model can be validated.*

Comment 9) Page 5-5, Sec 5.4.2, Para 1, Line 12: Recommend deleting "and."

Parsons ES Response: *The text will be changed as recommended.*

Comment 10) Page 5-11, Sec 5.5.1, Para 3, Sent 4: The stated K_y to K_x ratio is 2:1; however, a work sheet containing MODFLOW input in Appendix E annotates a K_y to K_x ratio of 1.5. Based on the MODFLOW BCF file for Alternative 3 provided in Appendix F, horizontal anisotropy ratios were 6.0 and 3.0 for layer 1 (Upper USZ) and layer 3 (Lower USZ), respectively. These apparent discrepancies should be addressed in the text and resolved appropriately.

Parsons ES Response: *The stated Ky to Kx ratio will be corrected to 1.5:1, and the text will be modified to indicate anisotropy under the Block-Centered-Flow option in MODFLOW was set to 6.0 for layer 1 and 3.0 for layer 3.*

Comment 11) Page 5-13, Sec 5.5.1, Para 1, Sent 1: A RMS error of 0.67 feet and the total relief of the water table over the modeled area of 20 feet (based on Fig 5.2) results in a calibration error of 3.4 percent, not 11.1 percent. Recommend the text state the relief of the water table used to calculate calibrated hydraulic head errors.

Parsons ES Response: *The RMS error of 0.67 feet is calculated over the relief of the monitoring wells used for calibration, not over the entire model domain. The relief in observed elevations for the area of the available calibration data is approximately 7 feet, as shown on Figure 5.3. Therefore the calculated calibration error is 11.1 percent. The text will be changed to indicate that the calibration error is calculated using the change in relief in the water table for the calibration wells only.*

Comment 12) Page 5-15, Sec 5.5.2.4, Sent 1: Suggest reporting porosity to two significant figures because it reflects better the accuracy/certainty of site-specific values.

Parsons ES Response: *Page 5-15, Section 5.5.2.4, Sentence 1 refers to retardation coefficients. Retardation values will be reported to two significant figures throughout the text to better reflect the accuracy/certainty of site-specific values (i.e., organic carbon).*

Comment 13) Page 5-16, Sec 5.5.2.6: Recommend stating here, or in Section 5.7, whether the modeling results and other data document a steady-state or nonsteady-state plume.

Parsons ES Response: *The text will be changed in Sections 5.5.2.6 and 5.7 to indicate that the modeling results represent a nonsteady-state contaminant plume.*

Comment 14) Page 5-20, Sec 5.6.3, Para 2, Last Sent: To better reflect accuracy/certainty of simulated values, recommend rounding concentrations to no more than four significant figures.

Parsons ES Response: *Simulated concentrations will be rounded to four figures on Table 5.3 and in Section 5.6.3 as suggested.*

Comment 15) Page 6-4, Sec 6.2.3.1, Para 1, Last Sent: To better reflect accuracy/certainty of the groundwater velocities, recommend rounding these values to no more than three significant figures.

Parsons ES Response: *Values for groundwater velocity will be rounded to no more than three significant figures as suggested.*

Comment 16) Page 6-13, Sec 6.3.3: Suggest adding to the heading "Source Characterization and Removal" to better reflect content of sentence one.

Parsons ES Response: *The heading will be changed as suggested.*

Comment 17) Page 6-17, Sec 6.4.1.3 and Table 6.3: Here and throughout the remainder of Section 6.4, recommend rounding total cost estimates to no more than four significant figures to better reflect accuracy/certainty of these estimates.

Parsons ES Response: *Total costs will be rounded to no more than four significant figures throughout Section 6.4 as suggested.*

Comment 18) Page 6-21, Sec 6.4.3.1, Para 2, Sent 1:

a. The stated pumping rate for the seven extraction wells is given as 5 gpm. The MODFLOW well package file for Alternative 3 contains two wells with a pumping rate of 3.1 gpm and five wells with a 1.8-gpm pumping rate. These discrepancies should be discussed in the text and resolved.

b. Two of the proposed extraction wells for the upper USZ sand layer are located outside of the relatively high-K channel where K is assigned a low 1.5 ft/day value. Because of this low K, these two wells cannot pump at a very high rate, cannot develop large capture zones, and cannot extract significant TCE mass. Consequently, recommend that these wells be deleted from Alternative 3 or that they be repositioned in the buried sand-filled channel. Additionally, suggest that an optimization computer code (e.g., MODMAN, REMAX) be used to help identify optimal well number, locations and pumping rates.

Parsons ES Response:

a. *Parsons ES verified the pumping rates for the seven extraction wells specified in Alternative 3 is 5.0 gallons per minute. New MODFLOW input files will be generated for the Final TS to ensure they are correct.*

b. Parsons ES concurs. The two proposed extraction wells should be moved to the model area with higher K-values. However, it should be noted that the assignment of hydraulic conductivity in the model is limited by the available K data (Table 3.2), and that the exact location of high hydraulic conductivity sand channels is not known with certainty. Therefore, further site characterization is recommended before exact locations are selected for extraction wells and before trying to optimize the collection system.

Comment 19) Page 6-22, Fig 6.3: Suggest depicting and labeling the proposed extraction wells as described on page 6-21, paragraph two.

Parsons ES Response: *The proposed extraction wells for Alternative 3 will be added to Figure 6.3 as suggested.*

Comment 20) Page 6-24, Sec 6.5, Para 2, Sent 1: Recommend stating whether Figures 5.4 and 6.1 substantiate the assertion of an expanding plume.

Parsons ES Response: *The following sentence will be added after Page 6-24, Section 6.5, Paragraph 2, Sentence 1: "Under all three remedial alternatives the TCE plume is predicted to expand, but without impact to potential receptors (Figures 6.1, 6.2, and 6.3)."*

Comment 21) Pages 7-2 and 7-3, Sec 7.2, Line 10: Suggest changing "will be sampled" to "would be sampled" because the LTM is a proposed plan, not an approved, funded or implemented plan.

Parsons ES Response: *The text will be changed as suggested.*

Comment 22) Page 7-4, Sec 7.6 and Page 7-7, Table 7.2: Recommend rounding total cost estimates to no more than four significant figures to better reflect accuracy/certainty of these estimates.

Parsons ES Response: *The cost estimates in Section 7 will be rounded to no more than four significant figures as suggested.*

Comment 23) Page 8-2, Sec 8, Para 4, Line 3: Recommend correcting the typo "wit."

Parsons ES Response: *The text will be corrected as recommended.*

If you have any questions, have additional comments, or require additional information, please call me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Bruce M Henry

Bruce M. Henry, P.G.
Project Manager

cc: File 729691.34000

APPENDIX H

FINAL ADDENDUM TO THE TREATABILITY STUDY IN SUPPORT OF REMEDIATION BY NATURAL ATTENUATION FOR GROUNDWATER AT SITE FTA-2, TINKER AIR FORCE BASE, OKLAHOMA

FINAL
ADDENDUM TO THE TREATABILITY STUDY IN SUPPORT OF REMEDIATION BY NATURAL ATTENUATION FOR GROUNDWATER AT SITE FTA-2

at

TINKER AIR FORCE BASE
OKLAHOMA

December 1999

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

and

TINKER AIR FORCE BASE
OKLAHOMA

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LIST OF ACRONYMS AND ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
1,1-DCA	1,1-dichloroethane
1,2-DCA	1,2-dichloroethane
1,2-DCB	1,2-dichlorobenzene
1,3-DCB	1,3-dichlorobenzene
1,4-DCB	1,4-dichlorobenzene
1,1-DCE	1,1-dichloroethene
µg/L	micrograms per liter
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AOC	Area of Concern
BTEX	benzene, toluene, ethylbenzene, and xylenes
CAHs	chlorinated aliphatic hydrocarbons
CBs	chlorobenzenes
cis-1,2-DCE	*cis*-1,2-dichloroethene
DO	dissolved oxygen
FTA-2	Fire Training Area 2
ft/day	feet per day
ft/ft	foot per foot
LSZ	lower saturated zone
LTM	long-term monitoring
MCL	maximum contaminant level
mg/L	milligrams per liter
MTBE	methyl tertiary-butyl ether
mV	millivolts
N	nitrogen
NAPL	non-aqueous phase liquid
NRMRL	National Risk Management Research Laboratory
ORP	oxidation-reduction potential
Parsons ES	Parsons Engineering Science, Inc.
PCE	tetrachloroethene
RCRA	Resource Conservation and Recovery Act
RNA	Remediation by Natural Attenuation
SWMU	solid waste management unit
TCE	trichloroethene
TMBs	trimethylbenzenes
trans-1,2-DCE	*trans*-1,2-dichloroethene
TS	Treatability Study
USEPA	United States Environmental Protection Agency
USZ	upper saturated zone
VC	vinyl chloride

1.0 INTRODUCTION

This document was prepared for the Air Force Center for Environmental Excellence (AFCEE) by Parsons Engineering Science, Inc. (Parsons ES) as an addendum to the Draft Treatability Study (TS) in Support of Remediation by Natural Attenuation (RNA) for Fire Training Area No. 2 (FTA-2), Tinker Air Force Base (AFB), Oklahoma (Parsons ES, 1999), under Air Force contract number F41624-92-D-8036. The TS was completed to evaluate the use of intrinsic remediation (natural attenuation) with long-term monitoring (LTM) for remediation of groundwater contaminated with chlorinated solvents and fuel hydrocarbons at FTA-2.

1.1 Scope and Objectives

This addendum documents the effectiveness of natural attenuation at Site FTA-2 by summarizing results of a groundwater sampling event conducted by researchers from the United States Environmental Protection Agency (USEPA) National Risk Management Research Laboratory (NRMRL) Subsurface Protection and Remediation Division in April 1999. Groundwater was initially sampled in July and August 1997 for the TS. The focus of this addendum is to evaluate changes in concentrations of dissolved chlorinated aliphatic hydrocarbons (CAHs), or chlorinated solvents; CAH plume extent; and natural attenuation mechanisms through time. Concentrations of dissolved benzene, toluene, ethylbenzene, and xylenes (BTEX) also are evaluated. Results, calculations, and predictions presented in the TS are used as the basis for comparison. Analytical data for the April 1999 sampling event is presented in Attachment A.

1.2 Site Background

Tinker AFB covers approximately 5,000 acres in the southeastern Oklahoma City metropolitan area. The Base has supported air operations since its founding as the Midwest Air Depot in July 1941. The Base was formally activated by the Air Force in March 1942 and serves as an international repair depot for a variety of aircraft, weapons, and engines.

Site FTA-2 is located in the south-central portion of the Base, and was established as a temporary, unlined pit used infrequently for fire training exercises between 1962 and 1966. Standard operating procedures reportedly included adding water to the pit to saturate the soil and reduce fuel infiltration. Fuel was then brought in by tank truck, placed on top of the water, ignited, and extinguished using water and foam. Any residues were left in the pit to evaporate and infiltrate until the next fire training exercise. Available aerial photographs indicate that the site is currently a gently sloping, open grassy area with no visible evidence of former training practices. Records for facility operation do not exist. Therefore, data on composition, frequency, and quantity of fuel or extinguishing agents are not available.

Tinker AFB currently operates under a Resource Conservation 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 FTA-2, and to perform corrective action at those sites identified as posing a threat to human health or the environment.

Sources of dissolved groundwater contamination at FTA-2 are not clearly defined. It is likely that residues from fuel or extinguishing agents have leached into soil and groundwater at the fire training pit and are a primary source of groundwater contamination. However, the exact locations and nature of the releases is not clear from the available data. Secondary sources also may be present that are not associated with the fire training pit. Residual non-aqueous phase liquid (NAPL) has not been identified during either previous or current subsurface investigations.

Engineered remediation has not been implemented at the site. Natural attenuation is the only process acting to reduce dissolved CAH concentrations and mass at the site. Additional site information, including site background, geology, and hydrogeology, is available in the TS (Parsons ES, 1999).

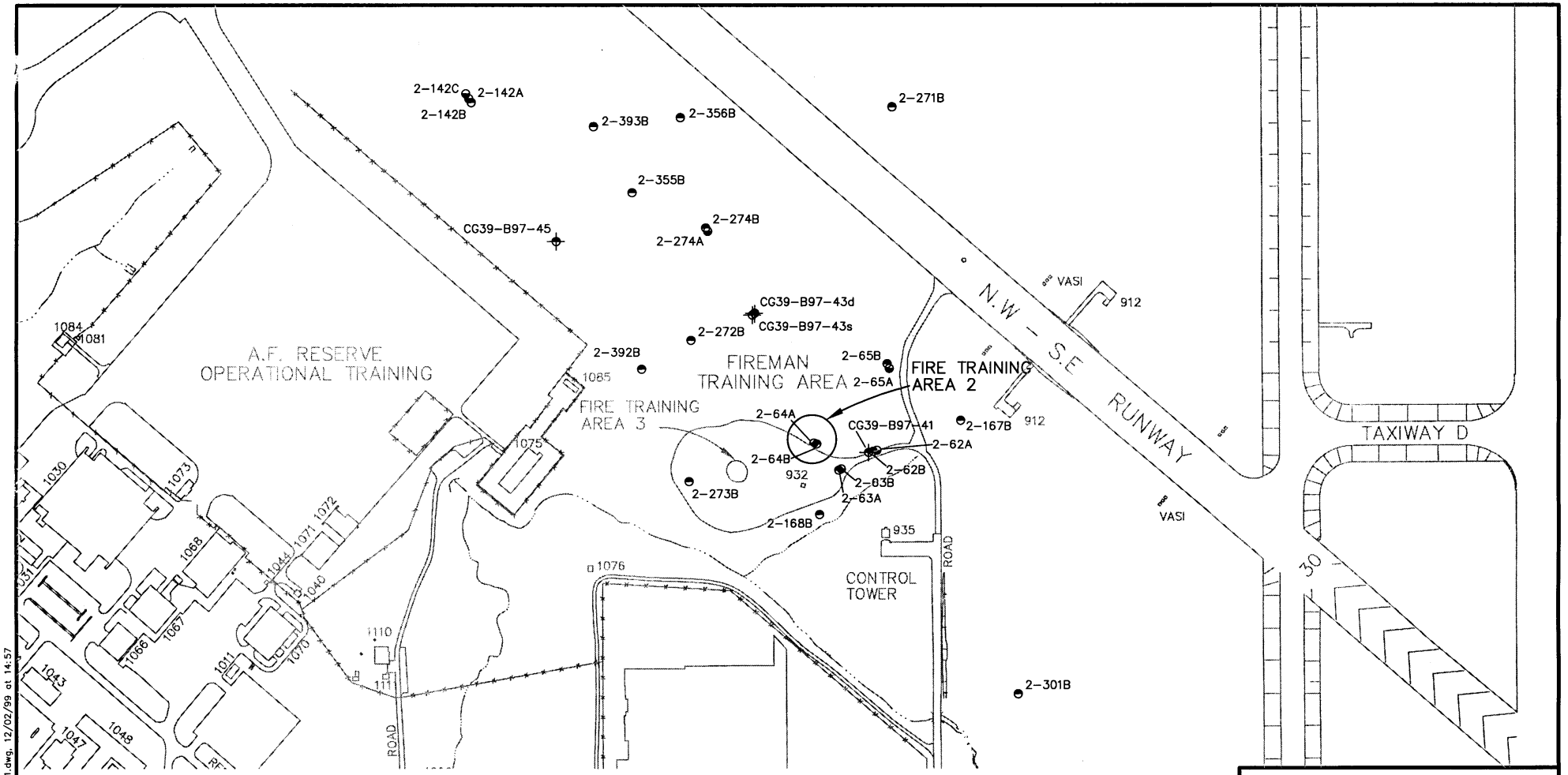
1.3 Groundwater Monitoring

Since the July/August 1997 groundwater sampling event performed for the TS (Parsons ES, 1999), researchers from the USEPA NRMRL collected an additional round of groundwater samples in April 1999. Sampling locations for the site are shown on Figure 1. Nineteen monitoring wells/points were evaluated at FTA-2 in April 1999. Monitoring wells/points sampled in 1997 but not in 1999 include CG39-B97-45, 2-142B, 2-167B, 2-271B, 2-356B, and 2-142A. Monitoring wells 2-271B and 2-142A were not recommended for LTM in the TS. The USEPA NRMRL elected not to sample the other four locations.

Samples collected in April 1999 were analyzed in the field for temperature, pH, conductivity, dissolved oxygen (DO), oxidation reduction potential (ORP), alkalinity, sulfide, and ferrous iron. Additionally, samples were analyzed at the USEPA NRMRL in Ada, Oklahoma for BTEX, trimethylbenzenes (TMBs), methyl tertiary-butyl ether (MTBE), CAHs, chlorobenzenes (CBs), chloroform, sulfate, chloride, nitrate + nitrite as nitrogen (N), ammonia, methane, ethene, and ethane. Analytical methods for April 1999 are summarized in Table 1.

2.0 HYDROGEOLOGY

Prior to purging and collecting samples from each monitoring location, depth to groundwater was measured to the nearest 0.1 foot in April 1999. Groundwater elevation data and monitoring well/point completion information are summarized in Table 2. The hydrogeology at FTA-2 is characterized by groundwater flow within an upper saturated zone (USZ) and a lower saturated zone (LSZ) as described in the TS (Parsons ES, 1999). The low permeability USZ/LSZ aquitard separates the two zones, and extends across the site. The USZ is generally considered an unconfined aquifer. However, because the underlying LSZ may exist as an unconfined aquifer in the area, the USZ may exhibit characteristics of a perched aquifer in the vicinity of FTA-2.



LEGEND

2-142B ●	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-142A ●	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
CG39-B97-41 ⊕	MONITORING POINT LOCATION/ UPPER SATURATED ZONE
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR

0 150 300 600
FEET

FIGURE 1

SAMPLING LOCATIONS
FIRE TRAINING AREA 2

Site FTA-2 RNA TS Addendum
Tinker AFB, Oklahoma

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TABLE 1
GROUNDWATER ANALYTICAL PROTOCOLS
APRIL 1999
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

MATRIX Analyte	METHOD	FIELD (F) OR ANALYTICAL LABORATORY (L)
WATER		
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
Ferrous Iron (Fe^{+2})	Titrimetric, Chemetrics Method or equivalent	F
Alkalinity (Carbonate [CO_3^{-2}] and Bicarbonate [HCO_3^{-1}])	Titrimetric, Hach Method 8221 or equivalent	F
Sulfide	Chemetrics Method or equivalent	F
Ammonia (NH_3)	Lachat FIA Method 10-107-06-1	L
Nitrate + Nitrite	Lachat FIA Method 10-107-04-2-A	L
Chloride	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane, Ethane, Ethene	RSKSOP-194[a/] /RSKSOP-175	L
VOCs (BTEX, TMBs, and MTBE)[b/]	RSKSOP-122	L
VOCs (CAHs, CBs, and chloroform)[c/]	RSKSOP-148	L

[a/]RSKSOP = Robert S. Kerr Laboratory standard operating procedure.

[b/]VOCs = volatile organic compounds; BTEX = benzene, toluene, ethylbenzene, and xylenes; TMBs = trimethylbenzenes; MTBE = methyl tertiary-butyl ether.

[c/]CAHs = chlorinated aliphatic hydrocarbons; CBs = chlorobenzenes.

TABLE 2
MONITORING WELL SUMMARY AND GROUNDWATER ELEVATIONS
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

Well/Borehole Identification	Screened Interval (Feet bgs)[a/]	Elevation Datum (Feet msl)[b/]	Ground Surface Elevation	Survey Northing (State Plane)	Survey Easting (State Plane)	Depth to Water August-1997 (Feet btoc)[c/]	Elevation of Water Table - August 1997 (Feet msl)	Depth to Water April-1999 (Feet btoc)	Elevation of Water Table - April 1999 (Feet msl)
Monitoring Points and Monitoring Wells - Upper Saturated Zone									
CG39-B97-41	34 - 39	1245.20	1245.57	150440.90	2182126.70	12.33	1232.87	11.2	1234.0
CG39-B97-43s	30 - 35	1252.42	1252.72	150861.52	2181770.08	19.90	1232.52	19.4	1233.0
CG39-B97-43d	44.5 - 49.5	1252.54	1252.56	150866.94	2181777.04	20.19	1232.35	19.4	1233.1
CG39-B97-45	36.5 - 41.5	1241.82	1242.24	151085.60	2181167.63	12.11	1229.71	NM[d/]	NM
2-62B	14-24	1245.94	1245.94	150444.52	2182140.56	14.51	1231.43	13.9	1232.0
2-63B	18-23	1243.28	1243.28	150386.11	2182035.36	12.06	1231.22	10.9	1232.4
2-64B	16-26	1245.59	1245.59	150467.40	2181967.76	14.11	1231.48	13.0	1232.6
2-65B	37-47	1250.81	1250.81	150712.88	2182183.20	17.10	1233.71	17.0	1233.8
2-142B	32-42	1242.09	1242.45	NA[e/]	NA	13.31	1228.78	NM	NM
2-167B	19-29	1250.70	1247.70	150539.81	2182408.35	16.03	1234.67	NM	NM
2-168B	10-20	1243.00	1240.10	150249.00	2181976.69	12.55	1230.45	11.2	1231.8
2-271B	36-46	1252.13	1252.41	151494.42	2182196.43	18.35	1233.78	NM	NM
2-272B	25-35	1248.91	1249.38	150784.70	2181581.74	17.79	1231.12	17.2	1231.7
2-273B	17-27	1238.42	1238.92	150351.11	2181576.36	8.26	1230.16	7.2	1231.2
2-274B	37-42	1248.32	1248.77	151126.23	2181625.92	16.67	1231.65	16.9	1231.4
2-301B	16-26	1244.00	1244.00	149701.00	2182586.00	10.14	1233.86	NM	NM
2-355B	19.9-29.9	1245.92	1246.61	151233.46	2181400.66	15.73	1230.19	15.9	1230.0
2-356B	27.8-37.8	1249.30	1249.75	151462.29	2181548.00	18.24	1231.06	NM	NM
2-392B	36 - 46	1244.99	1245.30	150696.27	2181430.89	15.43	1229.56	15.1	1229.9
2-393B	35 - 45	1245.97	1246.19	151434.08	2181280.87	15.86	1230.11	16.2	1229.8
Monitoring Wells - Lower Saturated Zone									
2-62A	54-64	1246.21	1246.21	150447.89	2182152.17	57.32	1188.89	57.0	1189.2
2-63A	53-63	1243.39	1243.39	150389.96	2182043.02	54.70	1188.69	54.0	1189.4
2-64A	56-66	1246.05	1246.05	150470.21	2181959.37	57.34	1188.71	56.6	1189.5
2-65A	66-76	1250.98	1250.98	150698.28	2182189.88	61.48	1189.50	61.2	1189.8
2-274A	76-81	1248.75	1249.10	151115.88	2181631.94	59.20	1189.55	58.9	1189.9
2-142A	72-82	1241.76	1242.30	NA	NA	53.03	1188.73	NM	NM

[a/] Feet bgs indicates elevation in feet below ground surface.

[b/] Feet msl indicates elevation in feet above mean sea level.

[c/] Feet btoc indicates feet below top of casing.

[d/] NM = Not measured.

[e/] NA = Not available.

2.1 Upper Saturated Zone

Figure 2 is a groundwater potentiometric surface map for the USZ based on data from August 1997 and April 1999. The horizontal hydraulic gradient in the USZ in August 1997 was approximately 0.003 to 0.01 foot per foot (ft/ft), while in April 1999 the hydraulic gradient was similar at 0.004 to 0.008 ft/ft. The direction of maximum horizontal hydraulic gradient in the USZ for 1999 is consistent with gradient data observed in 1997 (Parsons ES, 1999). Assuming isotropic horizontal hydraulic conductivity, horizontal flow direction in the vicinity of FTA-2 was generally towards the west-southwest in both 1997 and 1999.

The USZ can be further divided into the upper USZ sand and the lower USZ sand based on a persistent clay layer that separates the two sands in the southern portion of the site. Vertical hydraulic gradients between the upper and lower USZ sand intervals were calculated for monitoring well pair CG39-B97-43s and CG39-B97-43d, and well pair 2-62B and CG39-B97-41. The vertical gradients were calculated by dividing the water level elevation difference between two clustered wells by the distance between the midpoints of the saturated portions of the well screens. The vertical groundwater gradient at well pair CG39-B97-43s and CG39-B97-43d was 0.012 ft/ft in a downward direction in 1997 and 0.007 ft/ft in an upward direction in 1999. The vertical groundwater gradient at well pair 2-62B and CG39-B97-41 was 0.081 ft/ft in an upward direction in 1997, and 0.11 ft/ft in a likewise upward direction in 1999.

The upward vertical gradients observed in 1999 are typical to aquifers that are semi-confined or confined. While the USZ is regionally considered an unconfined aquifer, semi-confined to confined conditions may exist locally within the lower USZ sand interval. At FTA-2, an upward USZ groundwater gradient within the source area at well pair 2-62B and CG39-B97-41, and along the contaminant plume axis at well pair 2-62B and CG39-B97-41, may impact contaminant transport at the site.

While the upper and lower USZ sand intervals are hydraulically connected, where it is developed, the intermediate clay and silt interval may act as a significant vertical permeability barrier to local groundwater flow and contaminant transport.

Hydraulic conductivity in the USZ was estimated by performing slug tests in seven monitoring wells (CG39-B97-41, CG39-B97-43s, CG39-B97-43d, CG39-B97-45, 2-392B, 2-393B, and 3-335B) in August 1997. Well 2-392B, located on the western edge of the site, had the lowest hydraulic conductivity of 1.1 feet/day (ft/day). The remainder of the wells, located to the east of 2-392B, had hydraulic conductivities that averaged 15 ft/day. The difference in hydraulic conductivities from east to the west suggest the presence of low permeability conditions to the west (downgradient) of the site, which may impact contaminant transport.

Using an estimated effective porosity of 0.20, an average hydraulic conductivity of 14 ft/day, and an average hydraulic gradient of 0.006 ft/ft, the average advective groundwater flow velocity in the upper USZ sand interval in 1997 was calculated to be 0.42 ft/day (152 ft/yr) (Parsons ES, 1999). Similarly, using an average hydraulic gradient of 15 ft/day, the average advective groundwater flow velocity in the lower USZ sand

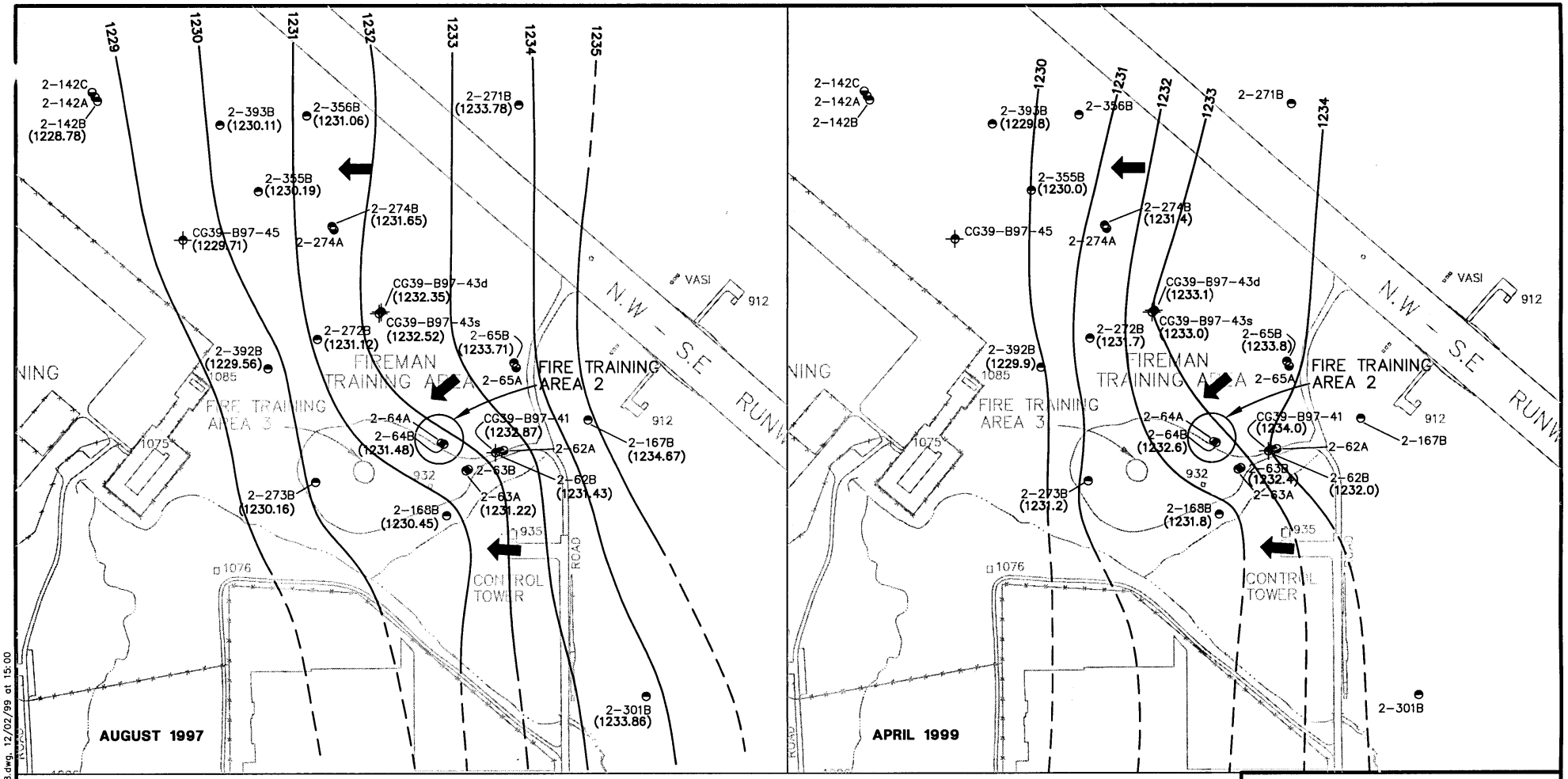

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FIGURE 2

UPPER SATURATED ZONE POTENTIOMETRIC SURFACE AUGUST 1997 AND APRIL 1999

Site FTA-2 RNA TS Addendum
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

interval in 1997 was calculated to be 0.46 ft/day (167 ft/yr). Advective groundwater velocities in preferential or anisotropic flow directions other than the direction of maximum hydraulic gradient would be less than these computed values.

2.2 Lower Saturated Zone

The top of the LSZ coincides with the base of the USZ/LSZ aquitard. The LSZ potentiometric surface locally lies beneath the base of the USZ/LSZ aquitard under unconfined conditions. Locally the LSZ may be confined where the LSZ potentiometric surface rises above the USZ/LSZ aquitard. Figure 3 is a groundwater potentiometric surface map for the LSZ based on data from August 1997 and April 1999. The direction of maximum hydraulic gradient and groundwater flow in the LSZ is towards the southwest. The horizontal hydraulic gradient in April 1999 was approximately 0.002 ft/ft. The flow direction and gradient in the LSZ for 1999 are consistent with the southwesterly groundwater flow direction and a hydraulic gradient of 0.003 ft/ft observed in August 1997 (Parsons ES, 1999).

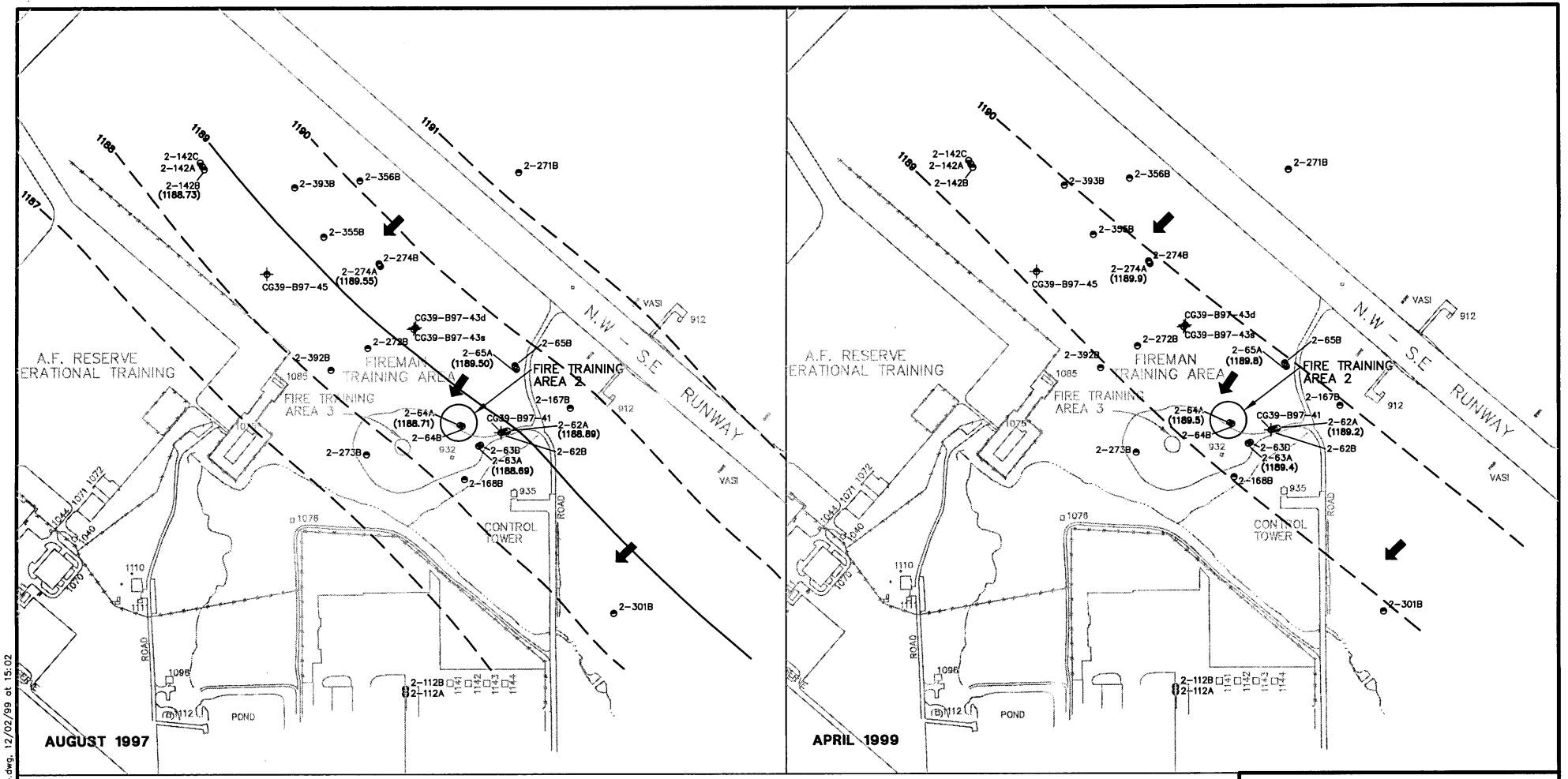
3.0 NATURE AND EXTENT OF CONTAMINATION

Both fuel hydrocarbons and CAHs have been detected in groundwater at FTA-2. Because CAHs have been detected at significantly higher concentrations than the BTEX compounds, the TS and this addendum focus on the natural attenuation potential for CAHs at the site.

3.1 Fuel Hydrocarbons In Groundwater

Results of analysis for dissolved fuel hydrocarbon compounds in groundwater at FTA-2 are presented in Table 3. Compound specific fuel hydrocarbons detected in groundwater at FTA-2 are BTEX; 1,2,3-TMB; and 1,2,5-TMB. In 1997, benzene was detected at two locations, 2-62B and 2-168B, at concentrations of 6.0 and 2.5 micrograms per liter (µg/L), respectively. In 1999, benzene was detected only at location 2-62B at a concentration of 3.9 µg/L, a decrease from the 1997 concentration at this location. Toluene was only detected at location 2-62B in 1997 at a concentration of 1.2 µg/L. In 1999, toluene was detected at concentrations of 13.6 µg/L and 7.5 µg/L at locations 2-64A and 2-392B, respectively. Ethylbenzene and xylenes were detected for the first time in 1999 at location 2-274A at concentrations of 1.6 µg/L and 1.0 µg/L, respectively. 1,2,3-TMB was detected in 1999 at a low concentration of 2.7 µg/L at well location 2-168B; and 1,3,5-TMB was detected at a low concentration of 3.7 µg/L at well location 2-392B.

Only benzene exceeded its respective USEPA maximum contaminant level (MCL) for drinking water (USEPA, 1996). Benzene exceeded the MCL of 5 µg/L at a concentration of 6.0 µg/L at well location 2-62B in 1997. However, no fuel hydrocarbons exceeded respective MCLs in 1999. Because of the limited occurrence and low concentrations of fuel hydrocarbons detected at the site, natural attenuation of BTEX is not further analyzed. However, the presence of low levels of anthropogenic carbon (fuel hydrocarbons) may be beneficial to biodegradation of CAHs as discussed in Section 3.2



LEGEND

2-142B	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-142A (1188.73)	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER / GROUNDWATER ELEVATION IN FEET ABOVE MEAN SEA LEVEL
CG39-B97-41	MONITORING POINT LOCATION/ UPPER SATURATED ZONE
	DIRECTION OF GROUNDWATER FLOW
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
1190	LINE OF EQUAL GROUNDWATER ELEVATION (FEET MSL), DASHED WHERE INFERRED

0 200 400 800
FEET

FIGURE 3

LOWER SATURATED ZONE POTENTIOMETRIC SURFACE AUGUST 1997 AND APRIL 1999

Site FTA-2 RNA TS Addendum
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 3
SUMMARY OF FUEL HYDROCARBONS IN GROUNDWATER
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

Sample Location	Sample Date	Total Fuel Carbon (µg/L)[c]	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total BTEX[a] (µg/L)	1,3,5-TMB[b] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
	MCL[d]	--[e]	5	1000	700	10,000[f]	10,000[f]	10,000[f]	--	--	--	--
Upper Saturated Zone												
CG39-B97-41	Aug-97	ND[g]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA[h]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CG39-B97-43s	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CG39-B97-43d	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CG39-B97-45	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-62B	Jul-97	1,140	6.0	1.2	ND	ND	ND	BLQ[i]	7.2	BLQ	ND	ND
	Apr-99	NA	3.9	ND	ND	ND	ND	ND	3.9	ND	ND	ND
2-63B	Jul-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-64B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-65B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	BLQ	BLQ	ND	ND	BLQ	ND	ND	ND	ND	ND
2-142B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-167B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-168B	Jul-97	5.8	2.5	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	BLQ	ND	ND	ND	1.3	ND	1.3	ND	BLQ	2.7
2-271B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-272B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	ND	ND	BLQ	BLQ	ND	ND	ND	ND	ND
2-273B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-274B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	ND

TABLE 3 (Continued)
SUMMARY OF FUEL HYDROCARBONS IN GROUNDWATER
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

Sample Location	Sample Date	Total Fuel Carbon (µg/L)[c]	Benzene (µg/L)	Toluene (µg/L)	Ethyl-benzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total BTEX[a] (µg/L)	1,3,5-TMB[b] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
	MCL[d]	--[e]	5	1000	700	10,000[f]	10,000[f]	10,000[f]	--	--	--	--
Upper Saturated Zone												
2-355B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3-356B	Sep-97	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA
2-392B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	7.5	ND	ND	ND	ND	7.5	3.7	ND	ND
2-393B	Aug-97	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	ND
Lower Saturated Zone												
2-62A	Jul-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-63A	Jul-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-64A	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	13.6	ND	ND	ND	ND	13.6	ND	ND	ND
2-65A	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	ND	ND	ND	BLQ	ND	ND	ND	ND	ND
2-274A	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	NA	ND	ND	1.6	ND	1.0	ND	2.6	ND	ND	ND
2-142A	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a] BTEX = benzene, toluene, ethylbenzene, and xylenes.

[b] TMB = trimethlbenzene.

[c] µg/L = micrograms per liter.

[d] MCL = Maximum Contaminant Level, State of Oklahoma OAC 165:25-3-65+A21, or U.S. EPA Primary Drinking Water Regulations, May 14, 1996.

[e] -- = no standard listed.

[f] Standard listed is for total xylenes.

[g] ND = Not Detected.

[h] NA = not analyzed.

[i] BLQ = below limit of quantitation (1 microgram per liter).

3.2 Chlorinated Aliphatic Hydrocarbons

As discussed in the TS, chlorinated solvents can be transformed, directly or indirectly, by biological processes. Biodegradation of CAHs and CBs results from the same general processes that bring about biodegradation of fuel hydrocarbons. However, a more complex series of processes often is involved, and CAHs and CBs may act as either substrates (electron donors) or electron acceptors depending upon prevailing geochemical conditions.

Whereas fuel hydrocarbons are biodegraded in essentially one step by acting as an electron donor/carbon source, CAHs and CBs may undergo several types of biodegradation involving multiple steps. CAHs may undergo biodegradation through four different pathways: use as an electron acceptor, use as an electron donor, abiotic transformation, 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 likely.

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, less-chlorinated CAHs, or CBs with four or fewer chlorines) is present, it may also be utilized as an electron donor. Most chlorinated solvents that can act as electron donors have thus far only been demonstrated to do so under aerobic conditions, with the notable exception of vinyl chloride (VC) (Bradley and Chapelle, 1996). After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, manganese, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. Evaluation of the distribution of these electron acceptors can provide evidence of where and how fuel hydrocarbon or CAH biodegradation is occurring. 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 also will provide evidence of the types of biodegradation processes acting at a site.

3.2.1 Chlorinated Ethenes

Chlorinated ethenes detected in groundwater at FTA-2 include tetrachloroethene (PCE), trichloroethene (TCE), 1,1-dichloroethene (1,1-DCE), *cis*-1,2-dichloroethene (*cis*-1,2-DCE), *trans*-1,2-dichloroethene (*trans*-1,2-DCE), and VC. Data for chlorinated ethenes and other chlorinated compounds are presented in Table 4.

PCE

PCE was detected in 4 of the 14 groundwater samples collected from the USZ at Site FTA-2 in April 1999 (Figure 4). Concentrations of PCE in groundwater ranged from less than the limit of quantitation (<1.0 µg/L) up to 154 µg/L at monitoring location 2-65B. Compared to August 1997 sampling results, PCE concentrations decreased at locations 2-62B (from 6.1 to 3.7 µg/L) and 2-63B (from 1.9 to 1.0 µg/L). PCE concentrations increased at locations 2-64B (from <1.0 µg/L to 1.3 µg/L) and 2-65B (from 52 µg/L to

TABLE 4
CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER
SITE FTA-2 RNA TS ADDENDUM
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)	1,1,1-TCA[a] (µg/L)	1,1-DCA[a] (µg/L)	1,2-DCA (µg/L)	Chlorobenzene (µg/L)	1,2-DCB[a] (µg/L)	1,3-DCB (µg/L)	1,4-DCB (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)
	MCL[c]	5	5	7	70	100	2	200	--[d]	5	100	600	600	75	5	--
Surface Water																
Creek Grab	Apr-99	ND[e]	1.7	ND	1.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Upper Saturated Zone																
CG39-B97-41	Aug-97	ND	3.6	ND	---[f]	ND	ND	ND	ND	---	ND	---	ND	ND	ND	ND
	Apr-99	ND	6.4	ND	---	ND	ND	ND	ND	ND	ND	---	ND	ND	ND	ND
CG39-B97-43s	Aug-97	---	1,490	1.1	183	6.1	ND	ND	ND	2.4	1	ND	1.6	ND	ND	1
	Apr-99	---	751	---	98.6	3.3	ND	ND	ND	1.5	---	ND	1.1	ND	ND	---
CG39-B97-43d	Aug-97	ND	169	ND	31.8	2.4	ND	ND	ND	---	ND	ND	---	ND	ND	ND
	Apr-99	ND	92.6	ND	19.1	1.2	ND	ND	ND	---	ND	ND	ND	ND	ND	ND
CG39-B97-45	Aug-97	ND	153	ND	22.6	---	ND	ND	ND	1.4	ND	ND	---	ND	ND	ND
2-62B	Jul-97	6.1	>2000	9.5	1,200	76.2	1.7	ND	ND	260	117	950	34.8	168	ND	5.3
	Jul-97 (dup)[g]	---	9,440	---	1,110	77	ND	ND	ND	239	104	969	25	123	ND	---
	Apr-99	3.7	6,200	5.1	650	47.5	ND	ND	ND	37.2	19.5	101	8.0	15.5	ND	5.0
2-63B	Jul-97	1.9	75.4	1	161	3.6	6.6	ND	4.6	---	ND	---	ND	ND	ND	ND
	Apr-99	1.0	53.7	---	126	3.2	3.6	ND	3.4	---	ND	ND	---	ND	ND	ND
2-64B	Aug-97	---	914	---	154	17.6	---	ND	ND	1.3	---	---	1.2	---	ND	---
	Apr-99	1.3	2,130	1.2	328	31.1	ND	ND	ND	2.0	1.5	ND	2.8	ND	ND	1.5
	Apr-99(dup)	1.1	1,870	1.1	302	26.7	ND	ND	ND	2.0	1.3	ND	2.2	ND	ND	1.1
2-65B	Aug-97	52	90	---	37	2.5	1.3	ND	---	3.2	9.5	3.6	---	1.8	ND	ND
	Apr-99	154	250	1.4	147	8.9	5.1	ND	1.7	18.3	51.6	23.8	1.4	9.6	ND	---
2-167B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-168B	Jul-97	---	1.4	---	27.6	ND	ND	ND	1.2	ND	ND	ND	ND	ND	ND	ND
	Apr-99	ND	1.0	ND	6.3	ND	ND	ND	---	ND	ND	ND	ND	ND	ND	ND
2-271B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-272B	Aug-97	ND	28.1	ND	2.1	ND	ND	ND	ND	---	ND	ND	ND	ND	ND	ND
	Apr-99	---	455	---	34.9	1.9	ND	ND	ND	---	---	ND	---	ND	ND	---
2-273B	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-274B	Aug-97	---	518	---	51.7	2.2	ND	ND	ND	1.1	---	ND	---	ND	ND	---
	Aug-97(dup)	---	506	---	53.4	2.1	ND	ND	ND	1.4	---	ND	---	ND	ND	---
	Apr-99	---	942	---	99.2	4.0	ND	ND	ND	2.1	---	ND	1.6	ND	ND	---
	Apr-99(dup)	---	1,060	ND	90.6	4.0	ND	ND	ND	2.0	---	ND	1.6	ND	ND	---
2-355B	Aug-97	ND	344	ND	50	---	ND	ND	ND	1.8	---	ND	---	ND	ND	---
	Apr-99	ND	186	ND	28.5	---	ND	ND	ND	---	ND	ND	---	ND	ND	ND
2-356B[h]	Sep-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

TABLE 4
CHLORINATED ALIPHATIC HYDROCARBONS IN GROUNDWATER
SITE FTA-2 RNA TS ADDENDUM
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)	1,1,1-TCA[a] (µg/L)	1,1-DCA[a] (µg/L)	1,2-DCA (µg/L)	Chlorobenzene (µg/L)	1,2-DCB[a] (µg/L)	1,3-DCB (µg/L)	1,4-DCB (µg/L)	Carbon Tetrachloride (µg/L)	Chloroform (µg/L)
	MCL[c]	5	5	7	70	100	2	200	--[d]	5	100	600	600	75	5	--
Upper Saturated Zone (Continued)																
2-392B	Aug-97	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-393B	Aug-97	ND	406	---	54.3	---	ND	ND	ND	45.4	---	ND	---	ND	ND	---
	Aug-97(dup)	ND	425	---	54.5	---	ND	ND	ND	49.2	---	ND	---	ND	ND	---
	Apr-99	ND	114	ND	13.3	ND	ND	ND	ND	---	ND	---	---	ND	ND	ND
2-142B	Aug-97	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lower Saturated Zone																
2-62A	Jul-97	ND	10.9	ND	---	ND	ND	ND	ND	ND	ND	---	ND	ND	ND	ND
	Apr-99	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-63A	Jul-97	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	---	ND	ND	ND	ND
	Apr-99	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-64A	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-65A	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-274A	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-99	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-142A	Aug-97	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a] PCE = tetrachloroethene, TCE = trichloroethene, DCE = dichloroethene, VC = vinyl chloride, TCA = trichloroethane, DCA = dichloroethane, and DCB=dichlorobenzene.

[b] µg/L = micrograms per liter.

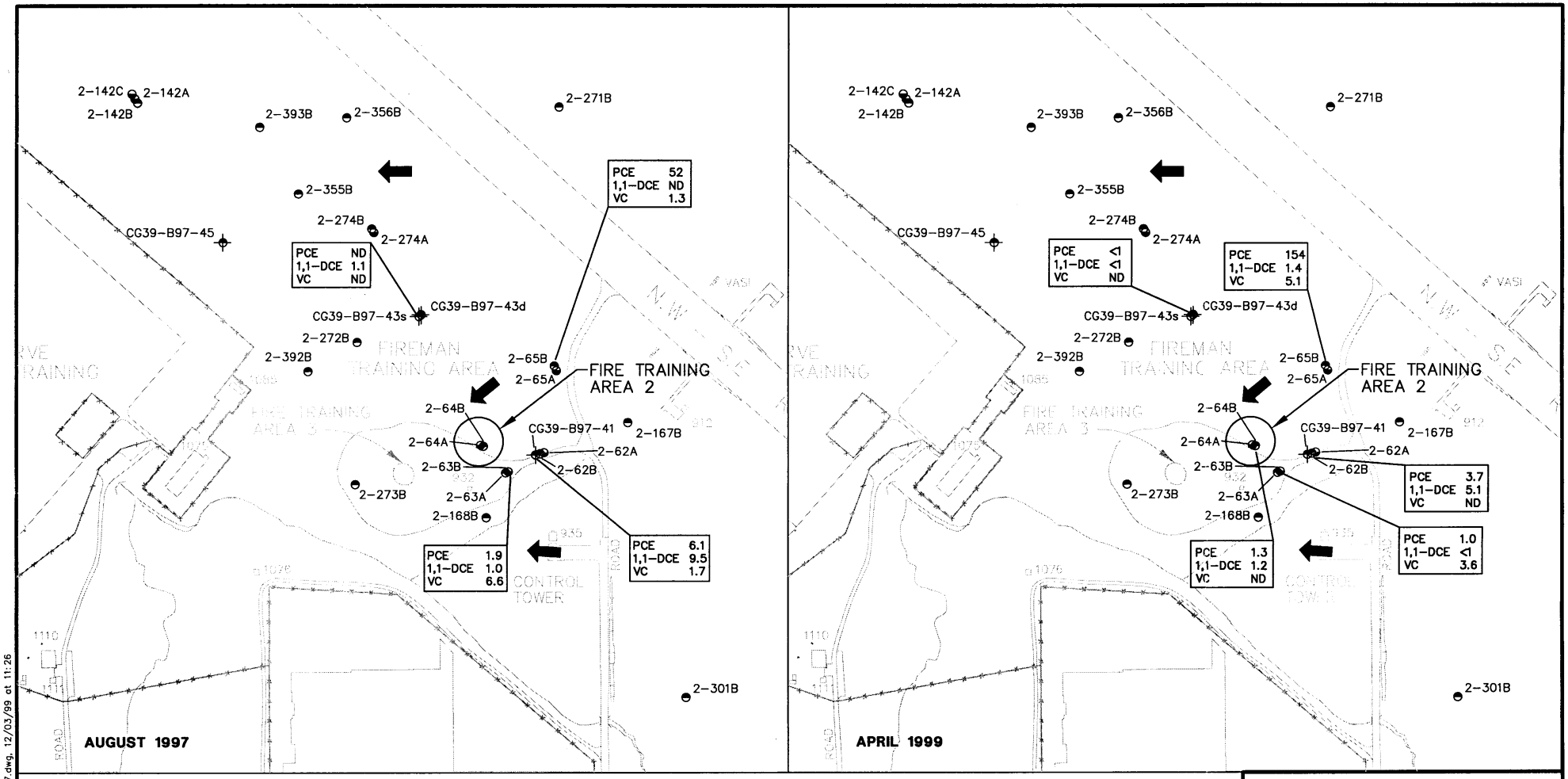
[c] MCL = Maximum Contaminant Level, U.S. EPA Primary Drinking Water Regulations, May 14, 1996.

[d] -- = no standard listed.

[e] ND = not detected.

[f] --- = below calibration limit (1 microgram per liter).

[g] Dup = field duplicate of preceding sample.



LEGEND

- 2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- CG39-B97-41 — TEMPORARY MONITORING POINT LOCATION/ UPPER SATURATED ZONE
- s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
- ND — NOT DETECTED
- PCE — TETRACHLOROETHENE
- 1,1-DCE — 1,1-DICHLOROETHENE
- VC — VINYL CHLORIDE
- 1.1 — ALL CONCENTRATIONS IN MICROGRAMS PER LITER (μg/L)
- DIRECTION OF GROUNDWATER FLOW

0 150 300 600
FEET

FIGURE 4

CONCENTRATIONS OF PCE, 1,1-DCE, AND VC IN USZ GROUNDWATER AUGUST 1997 AND APRIL 1999

Site FTA-2 RNA TS Addendum
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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154 µg/L), respectively. The concentration of 154 µg/L at monitoring well 2-65B is above the USEPA MCL for PCE of 5 µg/L.

Monitoring well 2-64B is located in the former FTA-2 fire pit area. The other six locations correspond to an area upgradient (east) and crossgradient of the FTA-2 fire pit area. It is unclear to what extent the presence of PCE is associated with the former FTA-2 fire pit or other unknown sources at the site. The elevated concentration of PCE at well location 2-65 does suggest a source other than the FTA-2 fire pit.

TCE

As measured in April 1999, TCE was detected in 12 of the 14 groundwater samples collected from the USZ aquifer at FTA-2 (Table 4). TCE concentrations detected in USZ groundwater in 1999 ranged from <1.0 µg/L to 6,200 µg/L at 2-62B, with concentrations at 11 locations exceeding the USEPA MCL of 5 µg/L. Figures 5 and 6 show the distribution of TCE in the upper USZ sand and the lower USZ sand, respectively. Comparison of Figures 5 and 6 indicates that the areal distribution and concentration of TCE in groundwater differs between the upper and lower USZ sands.

Concentrations of TCE in the upper USZ sand increased at two locations (2-64B and 2-272B) and decreased at five locations (CG39-B97-43s, 2-62B, 2-63B, 2-168B, and 2-355B). Figure 5 suggests that the contaminant plume is migrating toward the west in the direction of maximum hydraulic gradient, based on an increase in concentration of TCE at well locations 2-64B and 2-272B. TCE concentration versus time is plotted for select monitoring wells in Figure 7. The concentration of TCE in 1999 at 2-62B (6,200 µg/L) remained within the range of historical values for this location (4,300 µg/L in 1996 to 9,440 µg/L in 1997). Based on the elevated TCE concentrations at well 2-62B, this location is suspected to be located near the primary contaminant source for the site. Downgradient from 2-62B, well 2-64B has experienced a historical increase in TCE concentration from 96 µg/L in 1993 to a maximum of 2,130 µg/L in 1999. This is likely a result of downgradient transport of TCE from a source near the 2-62B well location.

The concentration of TCE also has increased over time at well 2-272B, located downgradient from well CG39-B97-43s (Figure 5). This may be a result of downgradient migration of contamination from an area near well CG39-B97-43s. While there are limited historical data for wells CG39-B97-43s and 2-355B, concentrations of TCE decreased from August 1997 to April 1999 at both these locations.

In the lower USZ sand, concentrations of TCE increased at three wells (CG39-B97-41, 2-65B, and 2-274B) and decreased at two wells (CG39-B97-43d and 2-393B). Figure 6 shows the TCE plumes for August 1997 and April 1999, and suggests that the extent of the contaminant plume in the lower USZ sand has not increased significantly. TCE concentration versus time is plotted for four of these wells on Figure 8. Concentrations of TCE did increase significantly from 1997 to 1999 for well 2-274B (from 518 µg/L to 942 µg/L) and for well 2-65B (from 90 µg/L to 250 µg/L).

The increase in the concentration of TCE at well 2-274B suggests vertical migration of contaminants from the upper USZ sand to the lower USZ sand. Alternately, elevated

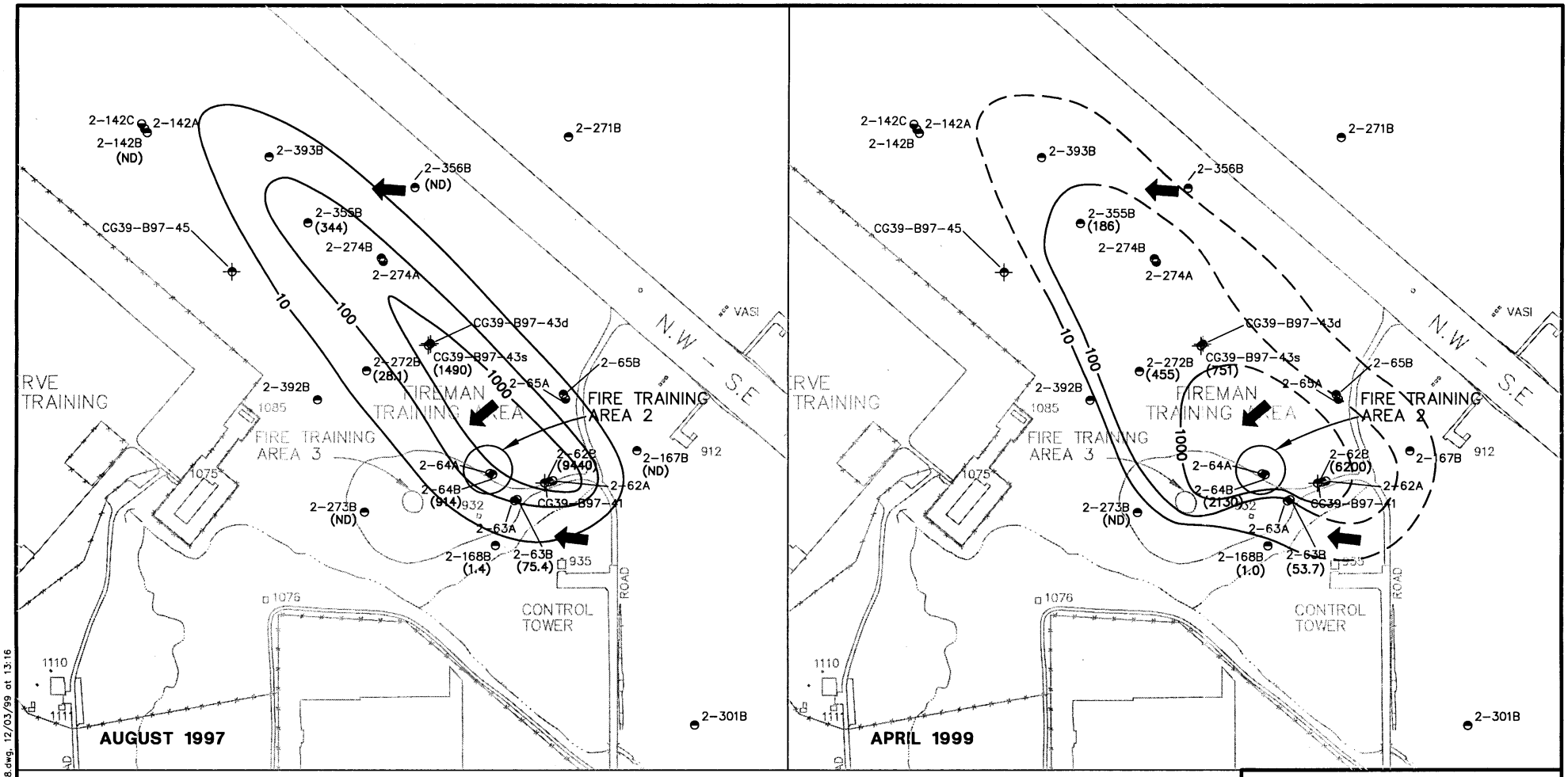

FIGURE 5

CONCENTRATION OF TCE IN UPPER USZ GROUNDWATER AUGUST 1997 AND APRIL 1999

Site FTA-2 RNA TS Adendum
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

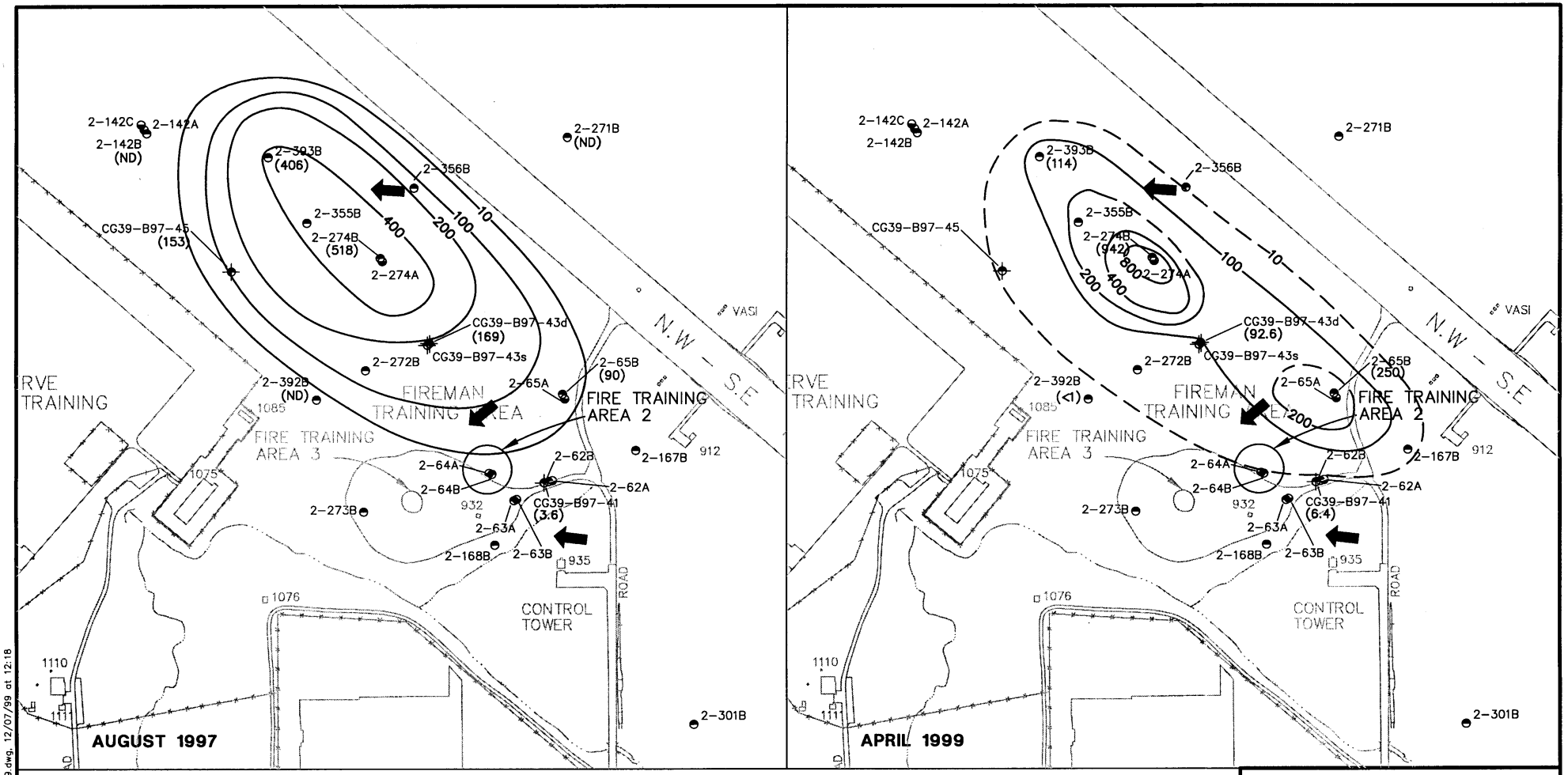

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FIGURE 6

CONCENTRATION OF TCE IN LOWER USZ GROUNDWATER AUGUST 1997 AND APRIL 1999

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FIGURE 7
TCE CONCENTRATION VERSUS TIME FOR SELECTED WELLS
UPPER USZ SAND
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

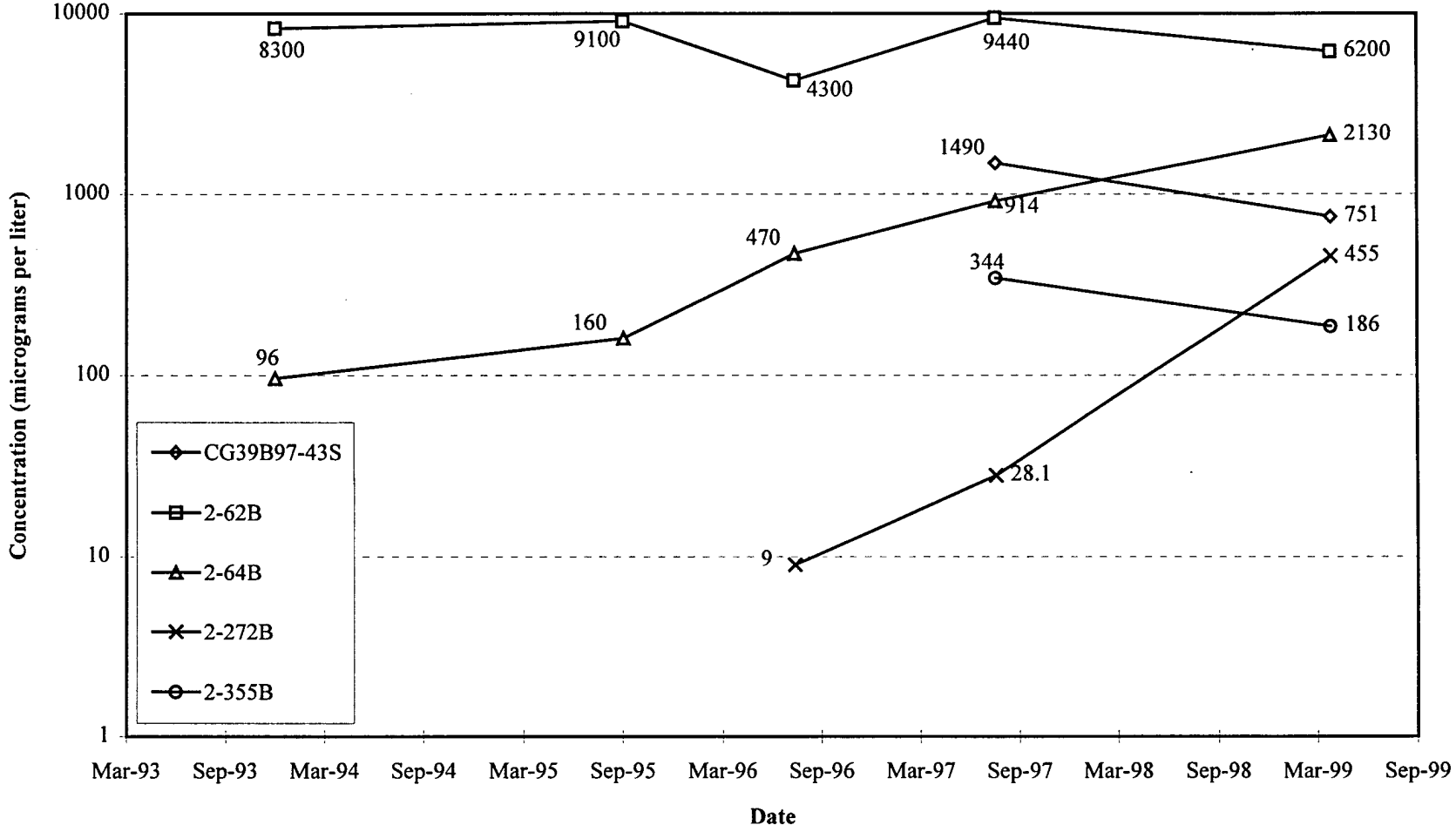
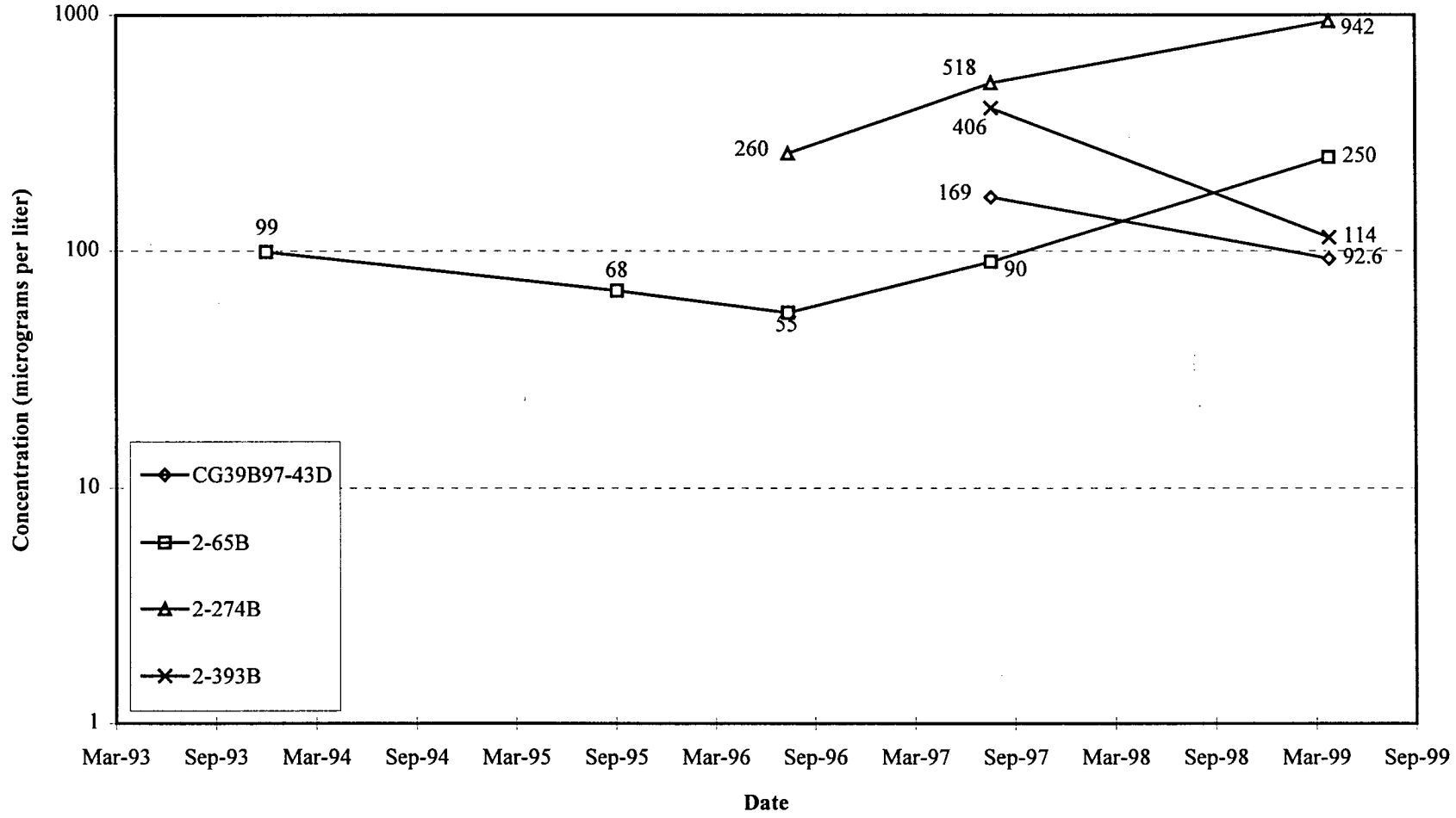


FIGURE 8
TCE CONCENTRATION VERSUS TIME FOR SELECTED WELLS
LOWER USZ SAND
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA



TCE concentrations at well 2-274B suggest a secondary source near or upgradient of this location. Well 2-65B is located hydraulically up- and crossgradient from the FTA-2 fire pit location, along a former access road to the FTA-2 fire pit. Conversely, a significant decrease in TCE concentration occurred at well 2-393B (406 µg/L to 114 µg/L). The cause of the decrease in TCE concentration at this location is not readily apparent.

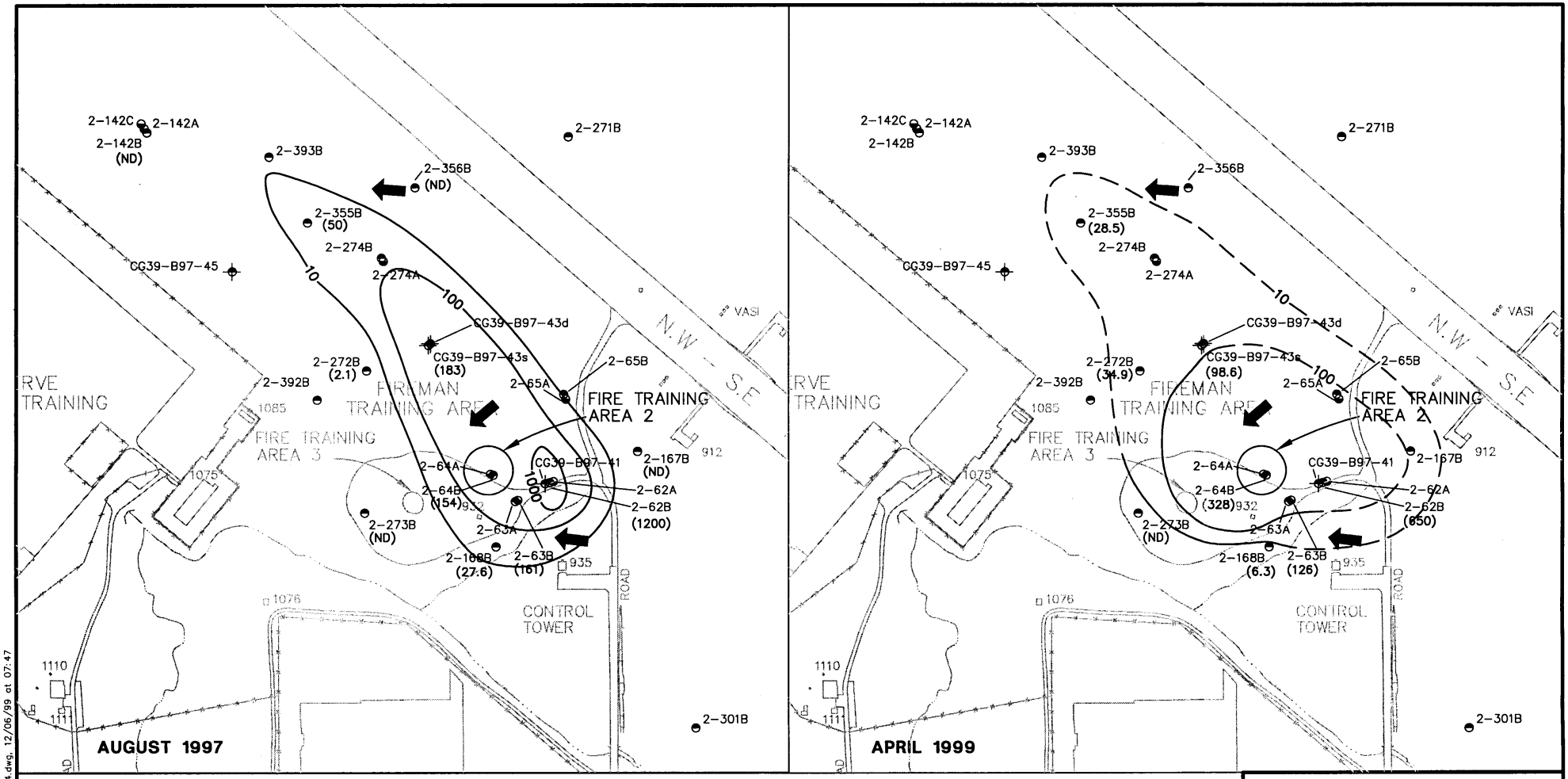
The TS presented a conceptual model where the primary source of TCE was near the FTA-2 fire pit and well 2-62B, where the TCE plume migrated toward the northwest due to a preferential flow path and anisotropy of the aquifer matrix. Alternately, Figures 5 and 6 suggest that the TCE plume may be migrating in the direction of maximum hydraulic gradient (west-southwest) from multiple sources. The presence of TCE "hotspots" at wells 2-62B, 2-65B, and 2-274B does not support a conceptual model of a single source and linear contaminant transport.

In any case, as contamination migrates downgradient it appears to be slowed by the presence of an area of low permeability near well 2-392B, which appears to trend northwest to southeast based upon the shape and location of the TCE plumes in the upper and lower USZ sands. The hydraulic conductivity measured at well 2-392B (Parsons ES, 1999) in 1997 was 1.1 ft/day, compared to an average hydraulic conductivity of 15 ft/day for wells measured to the east of well 2-392B (Section 2.1). Further discussion of this low permeability zone can be found in the TS (Parsons ES, 1998), Section 3.3 and cross-sections C-C', D-D', and E-E'.

cis-1,2-DCE

cis-1,2-DCE was detected in 11 of 14 wells sampled in the USZ during the April 1999 sampling event (Table 4). Concentrations of *cis*-1,2-DCE ranged up to 650 µg/L at well 2-62B. Concentrations of *cis*-1,2-DCE exceeded the USEPA MCL of 70 µg/L at six locations (CG39-B97-43s, 2-62B, 2-63B, 2-64B, 2-65B, and 2-274B). The two locations with the highest concentration of *cis*-1,2-DCE (2-62B and 2-64B) coincide with the highest TCE concentrations in the USZ. Figures 9 and 10 show the extent of *cis*-1,2-DCE in the upper and lower USZ sands, respectively.

cis-1,2-DCE concentrations in the upper USZ sand interval increased at two locations (2-64B and 2-272B), and decreased at five locations (CG39-B97-43s, 2-62B, 2-63B, 2-168B, and 2-355B). The contaminant plumes depicted in Figure 9 suggest that *cis*-1,2-DCE is migrating to the west-southwest in the direction of maximum hydraulic gradient, based on an increase in concentration of *cis*-1,2-DCE at well locations 2-64B and 2-272B. Concentrations of *cis*-1,2-DCE for the upper USZ sand over time are plotted for select monitoring wells in Figure 11. *cis*-1,2-DCE concentrations at 2-62B decreased from 1,200 µg/L to 650 µg/L from 1997 to 1999. Downgradient from 2-62B, well 2-64B shows an increase in *cis*-1,2-DCE concentration from 154 µg/L in 1997 to 328 µg/L in 1999, likely due to the downgradient transport of *cis*-1,2-DCE from a source area near 2-62B. The concentration of *cis*-1,2-DCE also increased at well 2-272B, from 2.1 µg/L in 1997 to 34.9 µg/L in 1999. Conversely, concentrations of *cis*-1,2-DCE decreased from August 1997 to April 1999 for wells CG39-B97-43s and 2-355B.



LEGEND

2-142B ●	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-142A ●	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
CG39-B97-41 ⌖	MONITORING POINT LOCATION/ UPPER SATURATED ZONE
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
—10—	LINE OF EQUAL cis-1,2-DCE CONCENTRATION (μg/L)
(2.1)	ALL CONCENTRATIONS IN MICROGRAMS PER LITER (μg/L)
(ND)	NOT DETECTED
◀	DIRECTION OF USZ GROUNDWATER FLOW

0 150 300 600
FEET

FIGURE 9

CONCENTRATION OF cis-1,2-DCE IN UPPER USZ GROUNDWATER AUGUST 1997 AND APRIL 1999

Site FTA-2 RNA TS Addendum
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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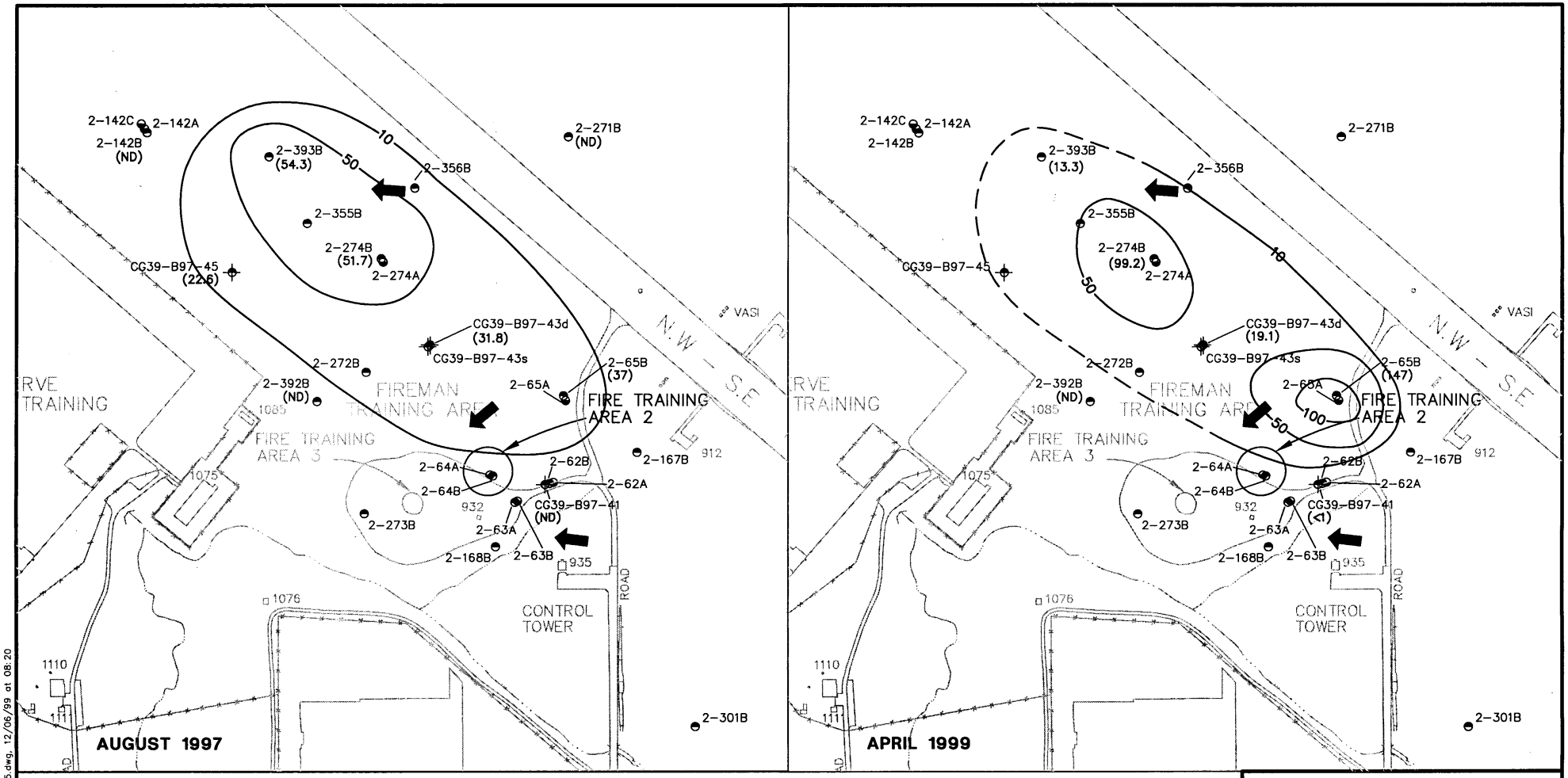

LEGEND

2-142B ●	UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
2-142A ●	LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
CG39-B97-41 ⊕	MONITORING POINT LOCATION/ UPPER SATURATED ZONE
s,d	SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
—10—	LINE OF EQUAL cis-1,2-DCE CONCENTRATION (µg/L)
(31.8)	ALL CONCENTRATIONS IN MICROGRAMS PER LITER (µg/L)
(ND)	NOT DETECTED
◀	DIRECTION OF USZ GROUNDWATER FLOW

0 150 300 600
FEET

FIGURE 10

CONCENTRATION OF cis-1,2-DCE IN LOWER USZ GROUNDWATER AUGUST 1997 AND APRIL 1999

Site FTA-2 RNA TS Addendum
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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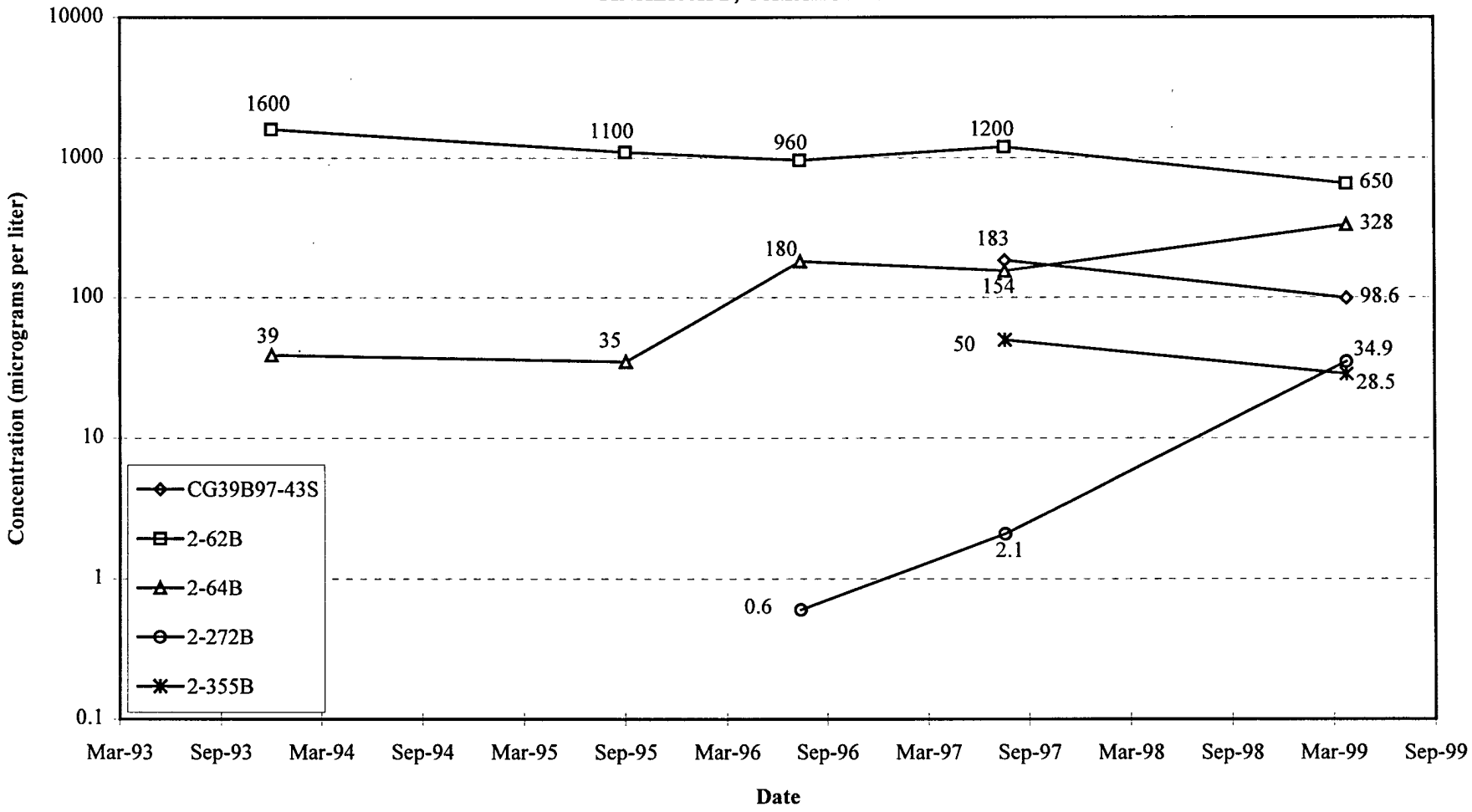
FIGURE 11
***cis*-1,2-DCE VERSUS TIME FOR SELECTED WELLS**
UPPER USZ SAND
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA



Concentrations of *cis*-1,2-DCE in the lower USZ sand interval (Figure 10) increased at two locations (2-65B and 2-274B) and decreased at two locations (CG39-B97-43d and 2-393B). Concentrations of *cis*-1,2-DCE versus time for these four wells are plotted on Figure 12. While the areal extent of cis-1,2-DCE plume from August 1997 to April 1999 is relatively stable, concentrations of *cis*-1,2-DCE increased significantly at well 2-65B (37 to 147 µg/L) and at well 2-274B (51.7 to 99.2 µg/L). The increase in concentration of *cis*-1,2-DCE at these two locations is similar to the increase in concentration of TCE in the lower USZ sand.

trans-1,2-DCE

Measurable concentrations of *trans*-1,2-DCE were detected at eight locations in 1999 at concentrations ranging up to 47.5 µg/L at well 2-62B. Concentrations of *trans*-1,2-DCE did not exceed the USEPA MCL of 100 µg/L. Locations with increases and decreases in concentrations of *trans*-1,2-DCE were similar to those for TCE and *cis*-1,2-DCE. Elevated concentrations of *trans*-1,2-DCE were encountered for wells 2-274B and 2-65B, screened in the lower USZ sand interval. This suggests downward vertical migration from the upper to lower USZ sand. Concentrations of *trans*-1,2-DCE were significantly lower than *cis*-1,2-DCE. This would be expected if TCE is being degraded to DCE via reductive dehalogenation, where under the influence of biodegradation *cis*-1,2-DCE is a more common daughter product than the other DCE isomers (USEPA, 1998). Furthermore, the *trans* isomer is more common when DCE is used for commercial applications.

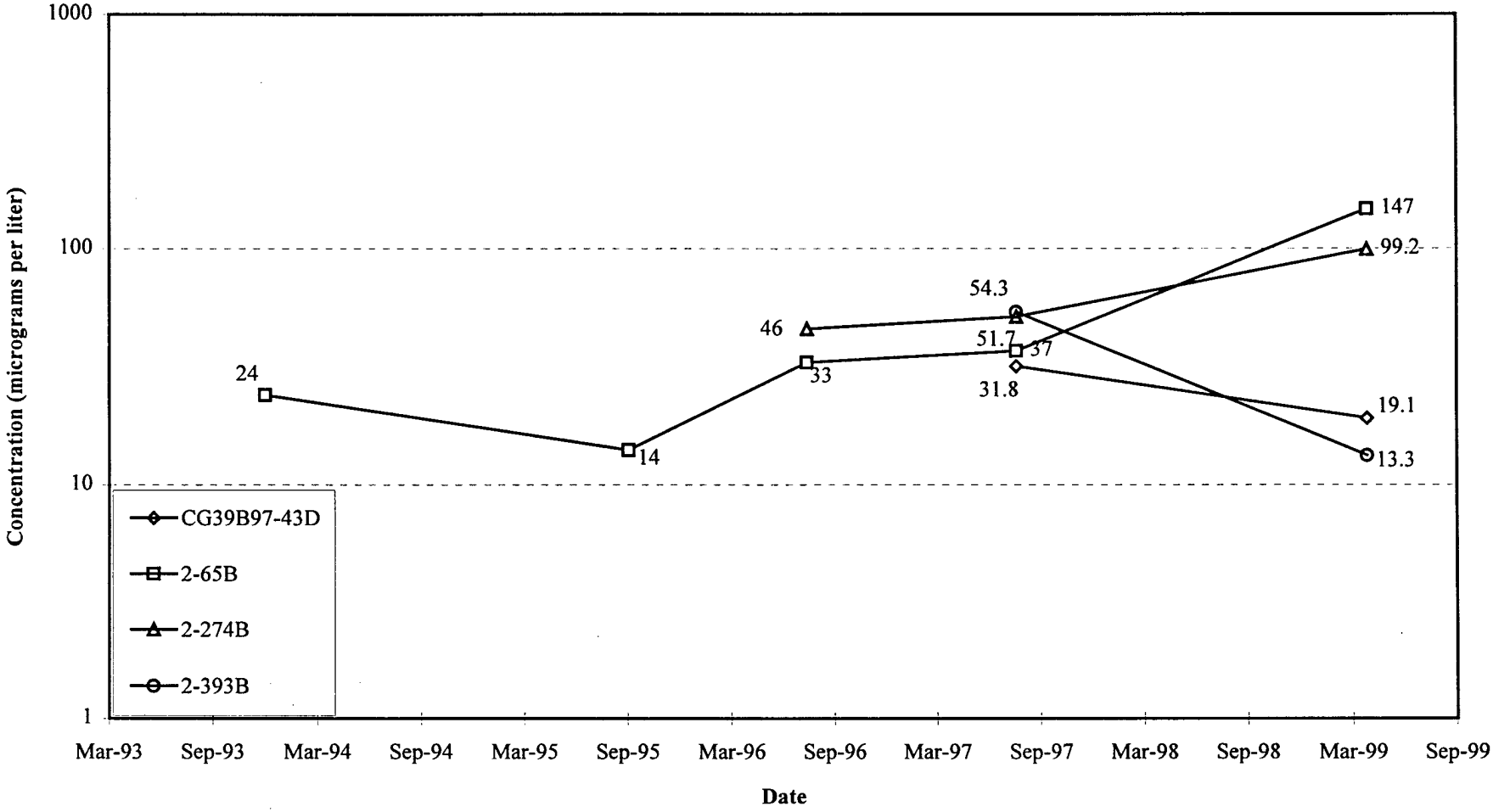
1,1-DCE

Measurable concentrations of 1,1-DCE were detected in samples from 3 of the 14 USZ monitoring wells sampled at FTA-2 in April 1999 (Table 4, Figure 4). Concentrations of 5.1 µg/L, 1.2 µg/L and 1.4 µg/L were detected in samples from wells 2-62B, 2-64B, and 2-65B, respectively. Concentrations of 1,1-DCE did not exceed the USEPA MCL of 7 µg/L. TCE and the other isomers of DCE also were detected in these wells suggesting that 1,1-DCE may have been produced by reductive dehalogenation of TCE.

Vinyl Chloride

VC was detected in samples from 2 of the 14 USZ groundwater monitoring wells sampled at FTA-2 in April 1999 (Table 4, Figure 4). Concentrations of 3.6 µg/L and 5.1 µg/L were detected in samples from wells 2-63B and 2-65B, respectively. Both concentrations exceed the USEPA MCL of 2 µg/L for VC. The distribution of VC is similar to that for PCE, with VC detected at two of the four locations where PCE was detected. The presence of VC in groundwater is an indicator of reductive dehalogenation of DCE if VC was not released as a contaminant compound. Because VC is typically a gas at most working temperatures [the boiling point of VC is about -13.5 degrees Celsius (°C) or 7 degrees Fahrenheit (°F) (Montgomery, 1990)], VC is not typically found in chemical spills. VC is generally used for plastic manufacturing instead of being used as a solvent. In addition, when liquid VC is spilled, most of the mass is likely to volatilize before reaching groundwater unless there is a large-volume release.

FIGURE 12
***cis*-1,2-DCE VERSUS TIME FOR SELECTED WELLS**
LOWER USZ SAND
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA



3.2.2 Chlorinated Ethanes

Chlorinated ethanes detected in groundwater at FTA-2 include 1,1-dichloroethane (1,1-DCA) and 1,2-dichloroethane (1,2-DCA) (Table 4). 1,1-DCA was detected in 2 of the 14 USZ wells sampled in 1999. Relatively low concentrations of 1,1-DCA were detected, with the maximum 1,1-DCA concentration of 3.4 µg/L occurring at well 2-63B, a decrease from 4.6 µg/L in 1997. There is no USEPA MCL listed for 1,1-DCA.

The distribution of 1,2-DCA in USZ groundwater is shown on Figure 13, with measurable concentrations of 1,2-DCA detected in 5 of the 14 USZ groundwater samples analyzed in 1999. The maximum concentrations of 1,2-DCA in 1999 were 37.2 µg/L at 2-62B and 18.3 µg/L at 2-65B, both exceeding the USEPA MCL of 5 µg/L. These two locations are both in the same general locations as suspected sources of the CAH contaminant plume. 1,1-DCA is not commonly used as a solvent, whereas 1,2-DCA is used as a solvent. Therefore, the presence of 1,2-DCA rather than 1,1-DCA suggests that 1,2-DCA is a result of source release, rather than a biodegradation byproduct. Furthermore, 1997 data indicate the possibility of a secondary 1,2-DCA source located northwest of the FTA-2 fire pit in the vicinity of 2-393B (Figure 13).

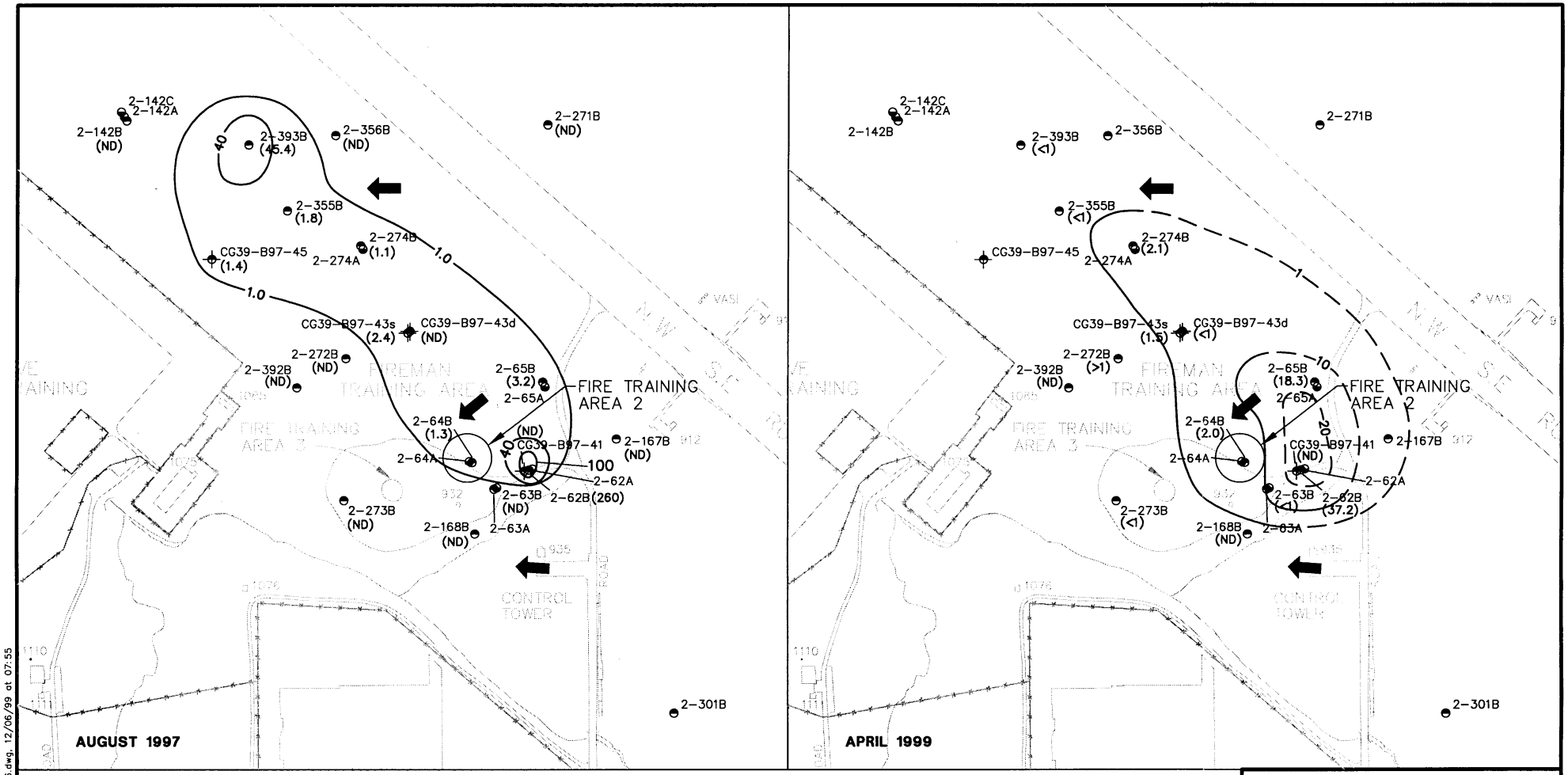
3.2.3 Chlorobenzenes

CBs detected in groundwater at FTA-2 include chlorobenzene (CB), 1,2-dichlorobenzene (1,2-DCB), 1,3-dichlorobenzene (1,3-DCB), and 1,4-dichlorobenzene (1,4-DCB) (Table 4). These compounds were detected in three wells associated within the general CAH source area(s) (2-62B, 2-64B, and 2-65B), and two wells along the apparent CAH plume axis (CG39-B9743s and 2-274B). In 1997, the CB and 1,2-DCB plume appeared to be originating from the vicinity of 2-62B, with migration toward the northwest. April 1999 data indicates that the plume has become less concentrated and reduced in size.

The concentration of CB at well 2-65B increased from 9.5 to 51.6 µg/L. CB was detected at a concentration of 19.5 µg/L for well 2-62B, a decrease from the August 1997 concentration of 117 µg/L. Concentrations of CB did not exceed the USEPA MCL for CB of 100 µg/L. 1,2-DCB was detected in two wells. Well 2-62B exhibited a decrease in 1,2-DCB concentration from 969 µg/L in August 1997 to 101 µg/L in 1999. Well 2-65B had an increase in 1,2-DCB concentration from 3.6 µg/L in 1997 to 23.8 µg/L in 1999. Neither of these concentrations is above the USEPA MCL of 600 µg/L for 1,2-DCB. Similarly, neither 1,3-DCB or 1,4-DCB were detected above their respective MCLs of 600 µg/L and 75 µg/L.

3.2.4 Surface Water Quality

A single surface water sample was collected and analyzed for CAHs in 1999 from the tributary that flows northeast to southwest along the southern perimeter of the FTA-2 site (Figure 1). TCE was detected in the surface water sample at a concentration of 1.7 µg/L, and *cis*-1,2-DCE at a concentration of 1.0 µg/L. There are no background data for surface water flowing through the site along this tributary. However, due to the upward vertical gradient observed for well pair 2-62B and CG39-B97-41 in the source area near



LEGEND

- 2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- CG39-B97-41 — TEMPORARY MONITORING POINT LOCATION/ UPPER SATURATED ZONE
- s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
- 40 — LINE OF EQUAL 1,2-DCA CONCENTRATION (μg/L)
- (1.3) — ALL CONCENTRATIONS IN MICROGRAMS PER LITER (μg/L)
- (ND) — NOT DETECTED
- DIRECTION OF GROUNDWATER FLOW

FIGURE 13

CONCENTRATION OF 1,2-DCA IN USZ GROUNDWATER AUGUST 1997 AND APRIL 1999

Site FTA-1 RNA TS Addendum
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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the tributary, the detection of CAHs in surface water suggests discharge of contaminated groundwater to the tributary.

3.2.5 LSZ Groundwater Quality

Low concentrations of toluene, ethylbenzene, and m-xylene were detected in LSZ groundwater samples in April 1999. Toluene was detected at a concentration of 13.6 µg/L at well location 2-64A, ethylbenzene at a concentration of 1.6 µg/L at well 2-274A, and m-xylene at a concentration of 1.0 µg/L at well 2-274A. These fuel hydrocarbons were not previously detected in LSZ groundwater in 1997, but the concentrations are below respective USEPA MCLs.

CAHs were not detected at measurable concentrations for any of the five wells sampled in the LSZ for the April 1999 sampling event (Table 4). In the August 1997 sampling event, TCE was detected at a concentration of 10.9 µg/L at well 2-62A. The 1997 sampling event was the first time that CAHs were detected in LSZ groundwater at the site. In April 1999, TCE was not detected in well 2-62A above the reporting limit of 1.0 µg/L.

Monitoring well 2-62A is located beneath the primary source area, immediately adjacent to well 2-62B, the USZ well with the highest detected concentration of TCE in USZ groundwater at FTA-2. TCE is the most mobile (lowest retardation) of the CAHs detected at FTA-2, and its detection in LSZ groundwater indicated that CAH contamination was starting to migrate vertically through the USZ/LSZ aquitard to the LSZ. However, the presence of an upward vertical hydraulic gradient within the USZ in this area may counteract the downward migration of TCE to the LSZ.

4.0 NATURAL ATTENUATION ANALYSIS

As discussed in the TS, available information indicates that the CAH plume primarily exhibits Type 1 behavior within a source area delimited by monitoring wells 2-63B, 2-168B, 2-62B, and 2-64B. Fuel hydrocarbons, while greatly decreased, and CBs remain in this area, and the electron donor supply may be adequate to allow continued microbial reduction of CAHs. The role of competing alternate electron acceptors (e.g., DO, nitrate, nitrate, ferric iron, and sulfate) is described later in this section. The Type 1 conditions result in significant degradation of the highly chlorinated solvents PCE and TCE in the source area. Degradation of DCE also may be occurring, as evidenced by the presence of low levels of VC dissolved in groundwater.

The downgradient (northern) portion of the CAH plume appears to primarily exhibit Type 3 behavior. There is little or no anaerobic reductive dehalogenation of TCE and DCE occurring; however, DCE may be aerobically degraded (oxidized). VC may be rapidly oxidized as it migrates into a more aerobic environment. The rapid decrease, or lack of, chlorobenzenes in the downgradient portions of the plume may indicate that CB and DCB are being utilized as electron donors in the source area of the CAH plume.

In addition to the distribution of contaminants and daughter products, other evidence can be used to support the interpretation that biodegradation of fuel hydrocarbons and chlorinated solvents is ongoing at FTA-2. Analysis of temporal changes in contaminant

concentrations over time may indicate field-scale contaminant mass loss as a result of biodegradation processes. Changes in molar fractions of contaminants and daughter products also may indicate biodegradation is occurring. By comparing concentrations and distributions of electron donors, electron acceptors, and byproducts of microbially mediated reactions, types of biodegradation processes operating at a site can be identified. Geochemical parameters, including chloride, ORP, DO, and other changes in groundwater chemistry also can provide supporting evidence.

4.1 Field-Scale Contaminant Mass Loss

Groundwater quality data collected for five sampling events between December 1993 and April 1999 from monitoring wells 2-62B, 2-63B, 2-64B, and 2-65B were reviewed to assess temporal changes in contaminant concentrations over time (Parsons ES, 1999 and 1997). In the absence of source remediation, decreasing contaminant concentrations reflect natural attenuation trends. In a stable or attenuating contaminant plume, decreasing concentration trends may be used to support loss of contaminant mass through destructive processes such as biodegradation.

4.1.1 Chlorinated Ethenes Over Time

Available concentration-versus-time data for chlorinated ethenes in samples from source area wells 2-62B, 2-63B, 2-64B, and 2-65B were examined to assess trends in chlorinated ethene concentrations. Concentrations of TCE and *cis*-1,2-DCE versus time for wells 2-62B, 2-64B, and 2-65B are shown on Figures 7, 8, 11, and 12. Total chlorinated ethene concentrations for wells 2-62B, 2-63B, 2-64B, and 2-65B are shown on Figure 14.

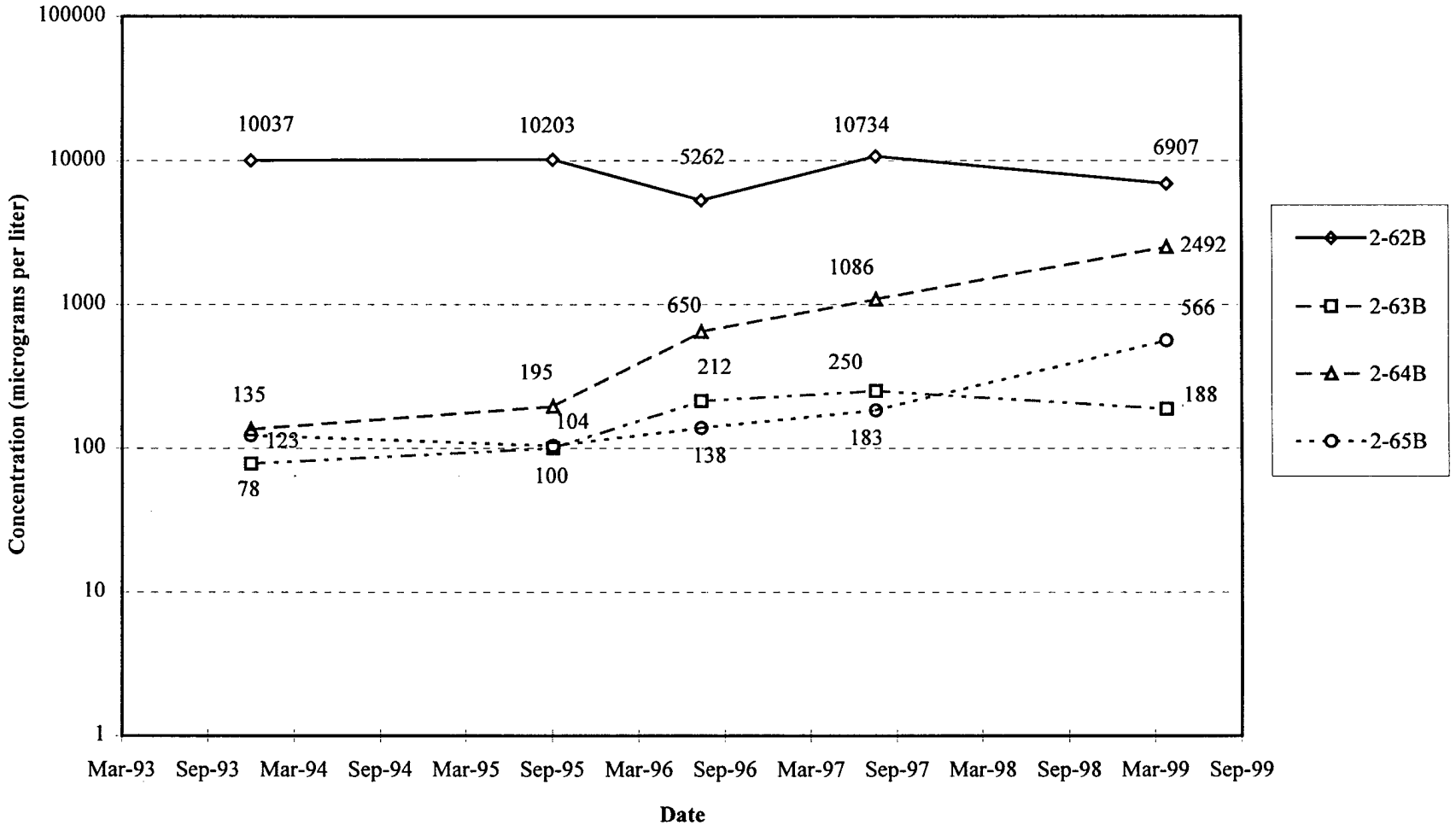
Total chlorinated ethene concentrations at these wells are relatively stable (wells 2-62B and 2-63B), or are gradually increasing over time (wells 2-64B and 2-65B). Well 2-62B has consistently exhibited the highest concentrations of CAHs at the site, and is assumed to represent dissolved contaminant concentrations in the primary source area. Concentrations at well 2-62B do not show a discernible trend indicating that the primary source of chlorinated ethenes at FTA-2 has not attenuated significantly. Well 2-64B is located in the former FTA-2 pit and concentrations at this well have shown a steady increase. This well is located along the migration pathway from the suspected source area, and increasing concentration levels could result from migration from the primary CAH source.

Well 2-65B is located upgradient from the suspected FTA-2 source area along the eastern edge of the contaminant plume. Total chlorinated ethene concentrations at this well have steadily increased with time, suggesting a secondary source of CAHs. Given the available data, it appears that the plume is expanding both upgradient and downgradient from the suspected primary FTA-2 source, based on increased concentration data for wells 2-63B, 2-64B, and 2-65B.

4.1.2 Chlorinated Ethanes Over Time

Concentration-versus-time data for total chlorinated ethanes detected in samples from wells 2-62B, 2-63B, 2-64B, and 2-65B were examined to assess trends in chlorinated

FIGURE 14
TOTAL CHLORINATED ETHENES VERSUS TIME
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA



ethanes (Figure 15). Concentrations of total chlorinated ethanes decrease through time at well 2-62B, while total chlorinated ethane concentrations increase through time at wells 2-63B, 2-64B, and 2-65B. A significant decrease in total chlorinated ethanes occurred at well 2-62B, from 509 µg/L in 1993 to 37 µg/L in 1999. Concentrations of total chlorinated ethanes increased over time for wells 2-63B and 2-64B, but only at low concentrations (less than 5 µg/L). Results of this analysis indicate an attenuation of total chlorinated ethanes at well 2-62B, with some migration or dispersion of chlorinated ethanes near the primary source in the vicinity of wells 2-63B and 2-64B.

Concentrations of total chlorinated ethanes increased from non-detect to 20 µg/L at upgradient well 2-65B, similar to increases in chlorinated ethenes and chlorobenzenes at this location. These data support the presence of a secondary source near well 2-65B.

4.1.3 Chlorobenzenes Over Time

Available concentration-versus-time data for CBs in samples from source area wells 2-62B, 2-64B, and 2-65B are shown on Figure 16. Total CB concentrations gradually increased over time for wells 2-64B and 2-65B, and decreased through time at well 2-62B. Similar to total chlorinated ethanes, an overall decrease in CBs occurs for well 2-62B, with low level migration or dispersion of CBs downgradient of the primary source area (well 2-64B). There also is an increase in total chlorobenzenes at well 2-65B, from non-detect in 1993 to 86.4 µg/L in 1999.

4.2 Presence of Daughter Products and CAH Molar Fractions

Results of the TS indicated that the presence of daughter products *cis*-1,2-DCE and VC provides strong evidence that parent solvents (TCE and/or PCE) are being reductively dehalogenated. Anaerobic condition conducive to reductive dehalogenation are limited to the primary source area. Concentrations of VC present at the site are low and suggest that if VC is produced by reductive dehalogenation, it is quickly degraded as it is transported downgradient into an aerobic environment. The geochemical conditions conducive to the aerobic degradation of VC do not at the same time support anaerobic reductive dechlorination of TCE or DCE. However, DCE may also be aerobically degraded, but at a rate much slower than for VC.

Changes in the molar fraction of the chlorinated ethenes can provide an indication that higher chlorinated ethenes are being degraded to lesser chlorinate ethenes (i.e., PCE to TCE to DCE to VC to ethene). Figure 17 shows molar fractions of chlorinated ethenes at well 2-62B over time. Only low levels of PCE or VC were detected at this location (Table 4), while ethene has not been detected at the site. The ratio of TCE to DCE at well 2-62B has remained relatively constant over time. While the data suggest that some TCE has degraded by reductive dehalogenation to DCE, the lack of VC indicates that the process does not occur past the initial step of TCE to DCE. Furthermore, the persistence of TCE indicates that either TCE has not continued to degrade to DCE, or that the rate of degradation of TCE to DCE is offset by the rate of mass loading to groundwater from a continuing TCE source. Figure 18 shows the molar fractions of chlorinated ethenes along the apparent CAH plume axis for August 1997. The relatively constant ratio of TCE to DCE indicates little, if any, degradation of TCE to DCE along the plume axis. Therefore,

FIGURE 15
TOTAL CHLORINATED ETHANES VERSUS TIME
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

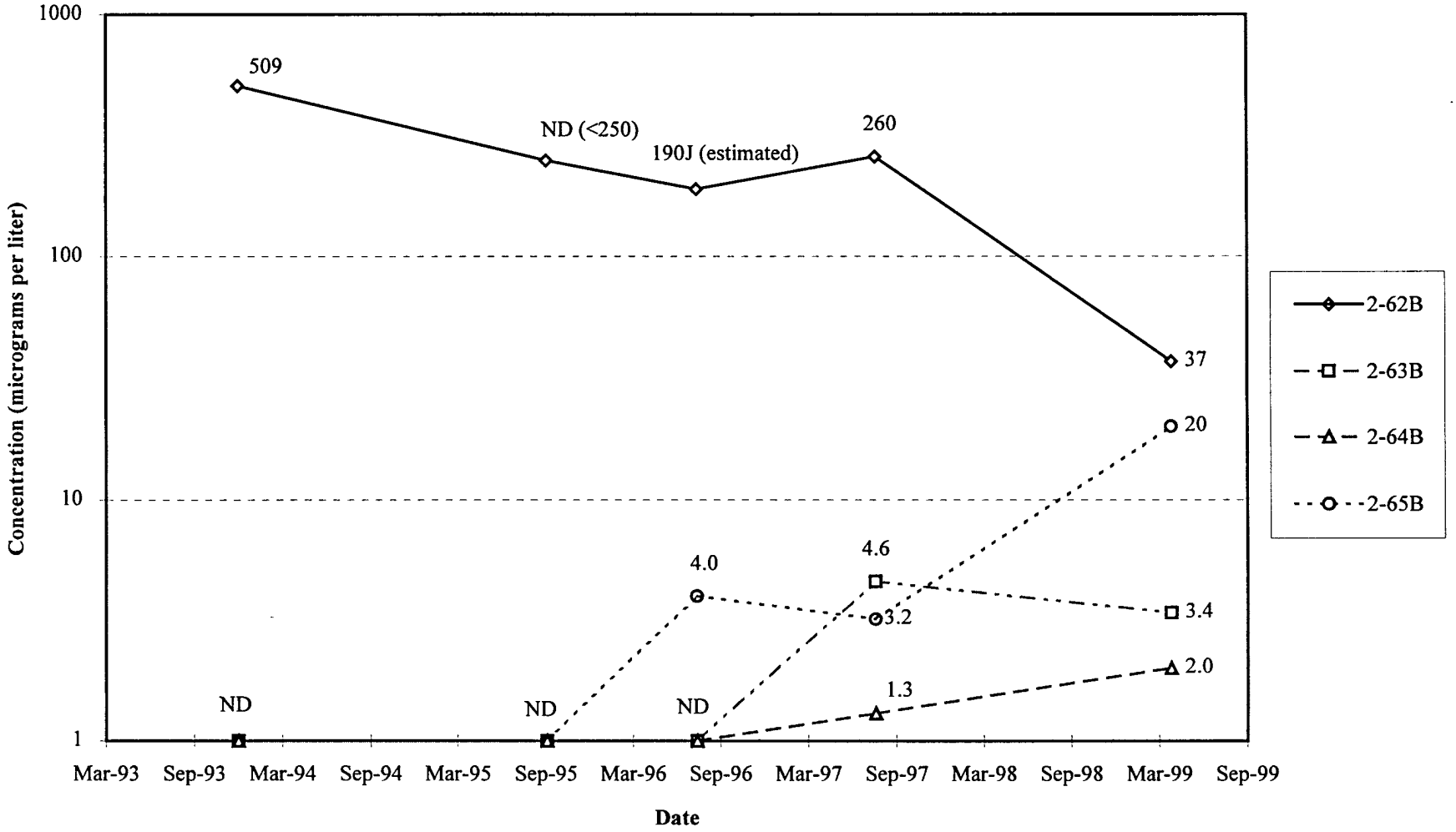


FIGURE 16
TOTAL CHLOROBENZENES VERSUS TIME
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

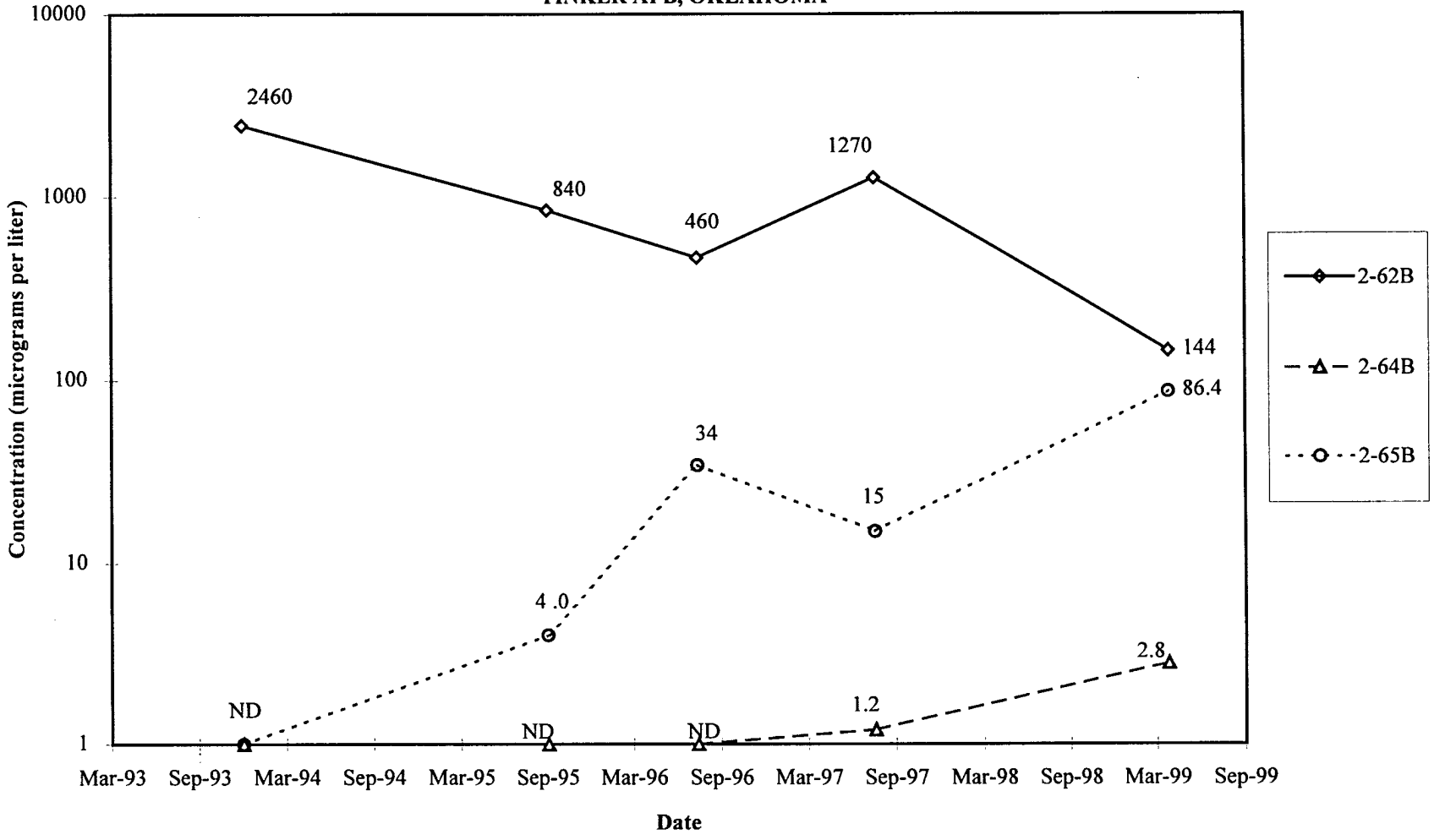


FIGURE 17
MOLAR FRACTION OF CHLORINATED ETHENES OVER TIME
WELL 2-62B
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

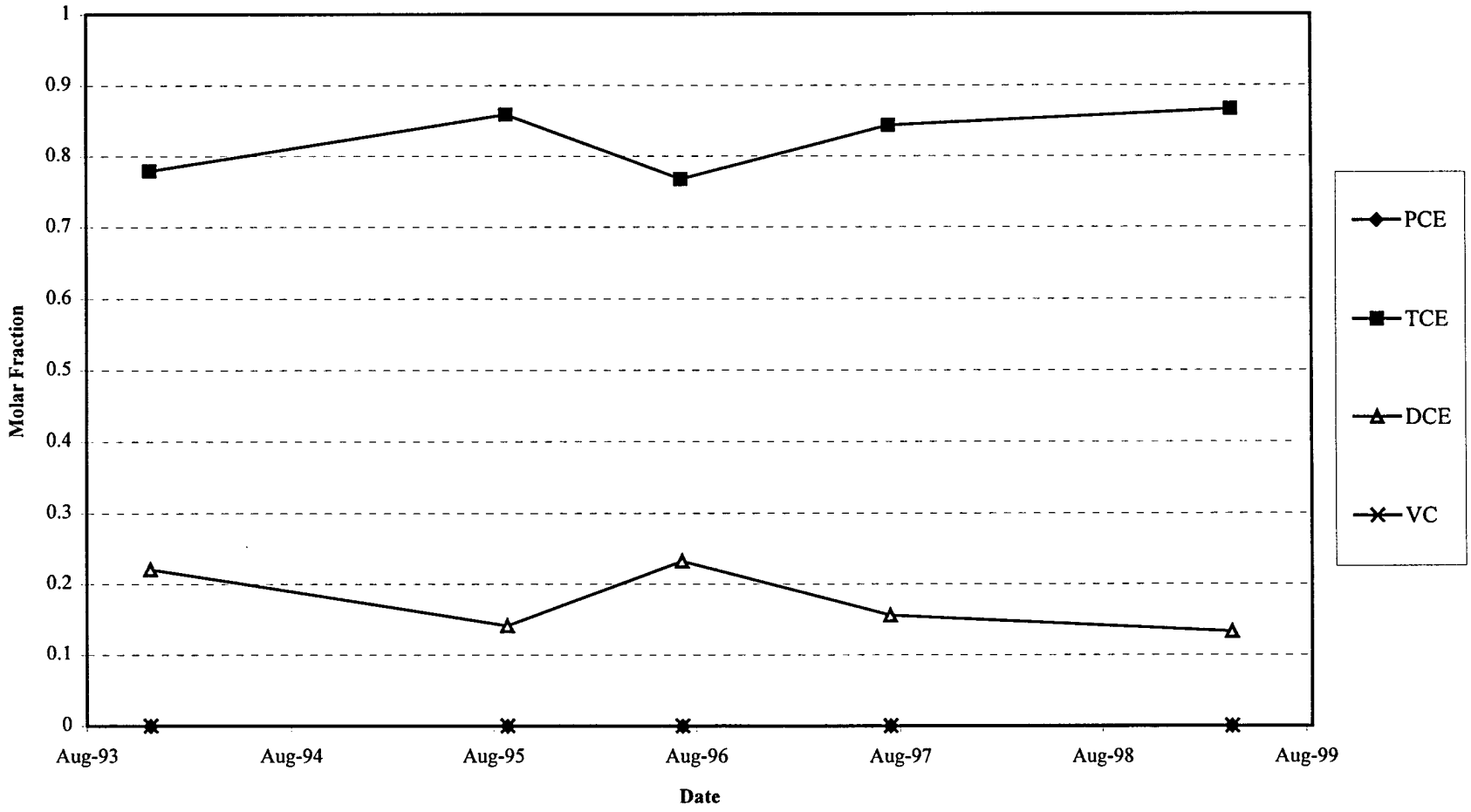
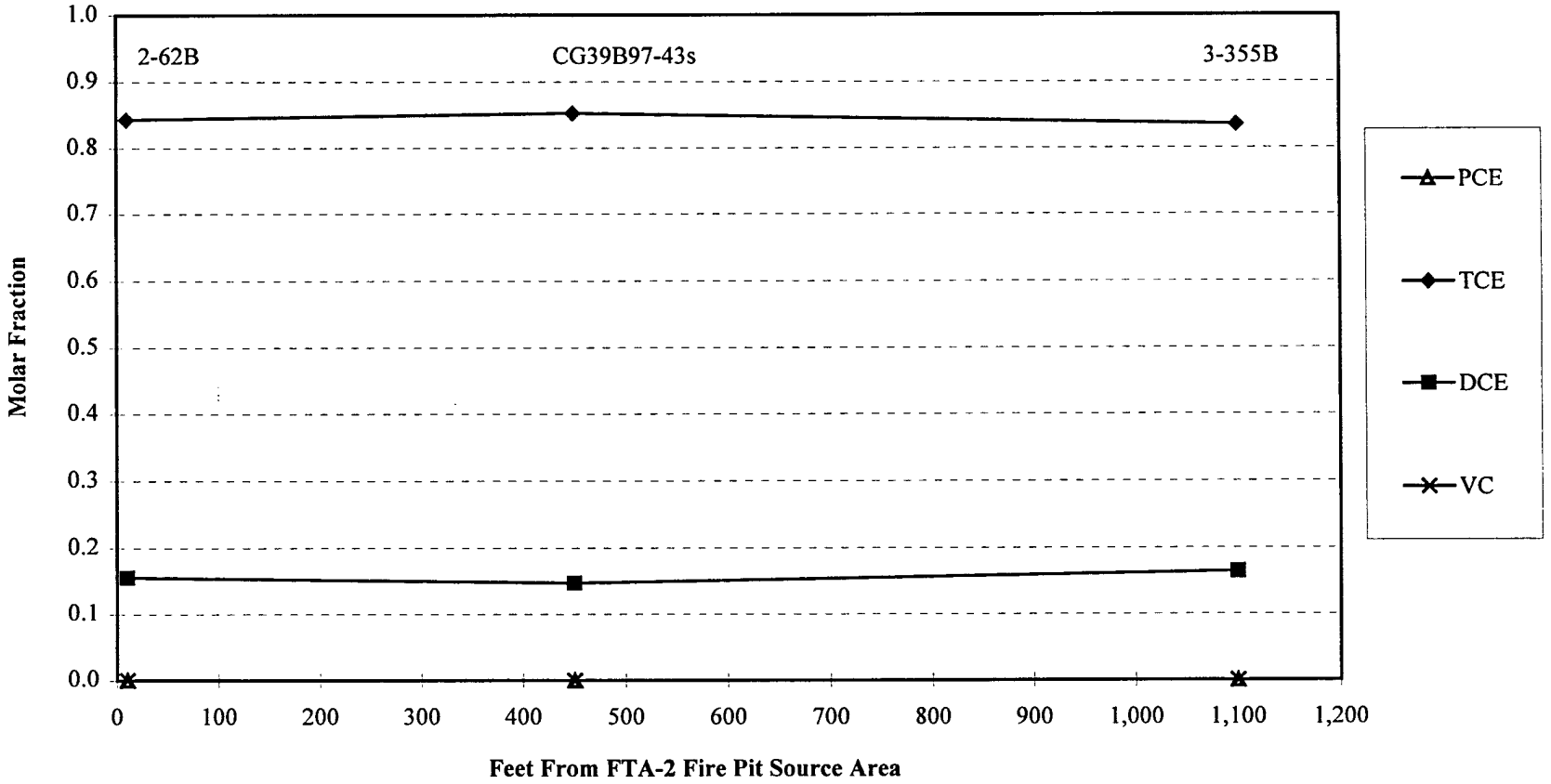


FIGURE 18
MOLAR FRACTION OF CHLORINATED ETHENES VERSUS DISTANCE
AUGUST 1997
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA



while elevated concentrations of DCE indicate some degradation of TCE to DCE has occurred, there is insufficient data to indicate this process continues or occurs outside of the primary source area.

Increasing concentrations of CAHs at upgradient well 2-65B indicate the presence of a secondary source. Molar fractions of chlorinated ethenes over time at well 2-65B are shown on Figure 19. An overall decrease in the fraction of TCE, with an increase in fraction of DCE and the presence of VC indicates that TCE is degrading to DCE, and DCE to VC. DO concentrations measured at this location in 1999 support the presence of sufficiently reducing conditions for reductive dehalogenation (Section 4.6.1). Conversely, the ORP measured at well 2-65B in 1999 does not support sufficiently reducing conditions (Section 4.5). Increasing concentrations of PCE and TCE at this location indicate a continuing source of chlorinated solvents. Because well 2-65B is screened in the lower USZ sand interval, it is possible that concentrations at this location may reflect degradation at an upgradient or more shallow (upper) USZ sand interval.

4.3 Electron Donors

The distribution of potential electron donors (carbon sources) such as BTEX or native organic carbon are useful for evaluating the feasibility of reductive dehalogenation of CAHs. The coincidence of dissolved BTEX with the highest concentrations of the reductive dehalogenation daughter products *cis*-1,2-DCE and VC is considered a favorable factor in the potential biodegradation of CAHs by reductive dehalogenation in the general source area. However, BTEX and fuel carbon concentrations are much lower than CAH concentrations (Tables 3 and 4), and the extent and concentrations of the BTEX/fuel carbon plumes are such that these compounds have not significantly migrated beyond the general source area of the contaminant plumes.

Dissolved organic carbon can also act as a source of electron donors during the reductive dehalogenation of CAHs. TOC concentrations in excess of 20 milligrams per liter (mg/L) are desirable to drive dehalogenation reactions (USEPA, 1998). However, TOC concentrations detected in shallow groundwater at FTA-2 in August 1997 were less than 12 mg/L. Native organic carbon concentrations of this magnitude are insufficient to drive reductive dehalogenation of CAHs.

4.4 Chloride as an Indicator of Dehalogenation

Chloride ions are removed from chlorinated solvents and enter solution during biodegradation, whether via reductive dehalogenation or aerobic oxidation. Therefore, chloride concentrations in groundwater may increase above background levels in areas where reductive dehalogenation or aerobic biodegradation are taking place. Chloride concentrations measured in August 1997 and April 1999 are presented in Table 5.

Chloride concentrations within the boundaries of the chlorinated solvent plume were slightly elevated above background in August 1997, with a maximum concentration of 187 mg/L at 2-355B (Parsons ES , 1999). When 1999 chloride concentrations are compared with 1997 concentrations, all locations sampled within the boundaries of the CAH plume have increased concentrations with the exception of locations 2-65B and

FIGURE 19
MOLAR FRACTION OF CHLORINATED ETHENES OVER TIME
WELL 2-65B
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

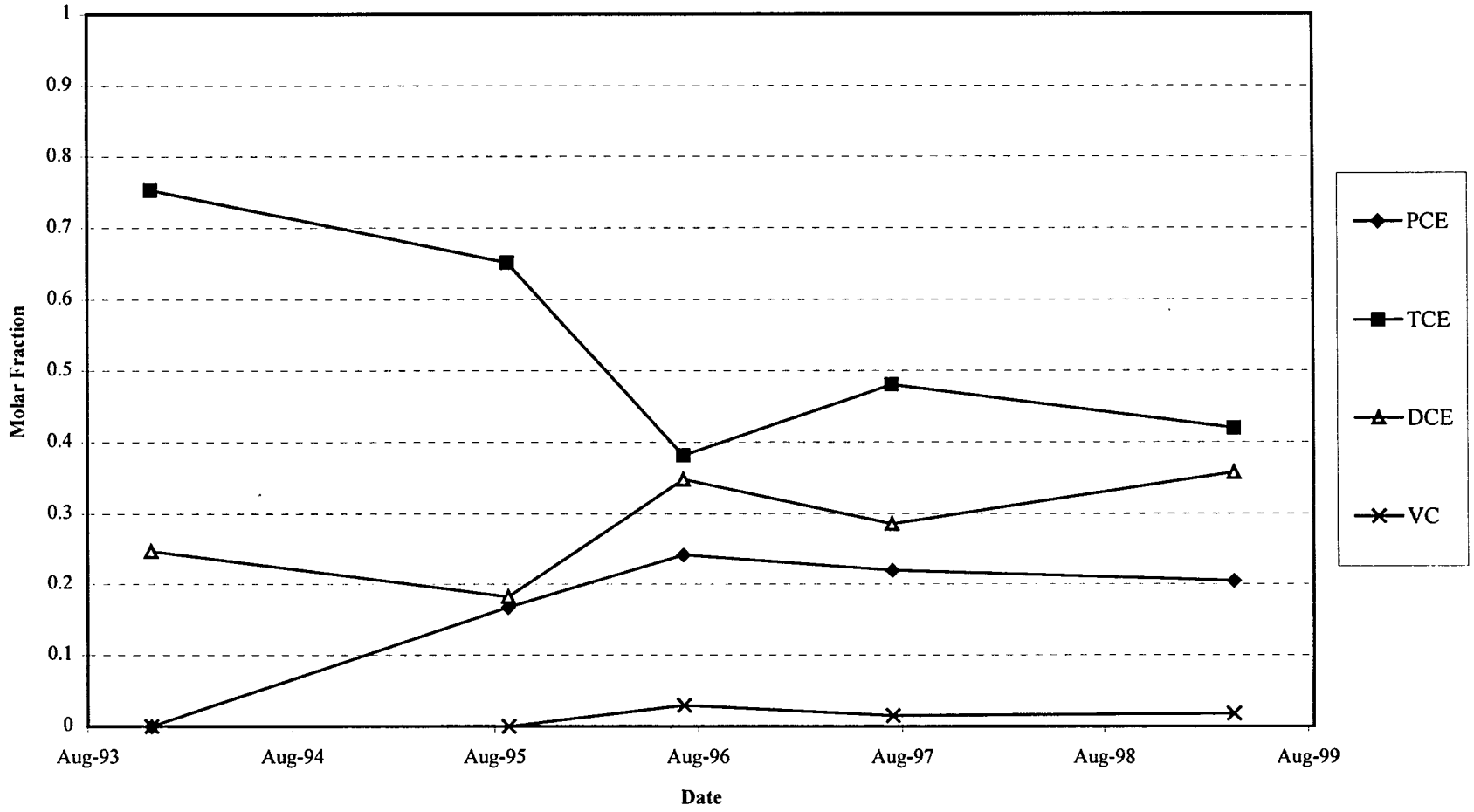


TABLE 5
GROUNDWATER GEOCHEMICAL DATA
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

Sample Location	Sample Date	Temp (°C)[a/]	pH (su)[b/]	Conductivity (µs/cm)[c/]	Dissolved Oxygen (mg/L)[d/]	Redox Potential (mV)[e/]	Total Alkalinity (mg/L)	Chloride (mg/L)	Ammonia (mg/L)	Ferrous Iron (mg/L)	Nitrite+ Nitrate (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Manganese (mg/L)	Total Phenols (mg/L)	Carbon Dioxide (mg/L)	TOC (mg/L)	Methane (mg/L)	Ethane (mg/L)	Ethene (mg/L)
Upper Saturated Zone																				
CG39-B97-41	Aug-97	22.0	6.88	861	3.9	136	520	5.73	<0.05	<0.01	2.01	15.4	<0.01	<0.01	<0.01	60	<0.4	<0.001	<0.003	<0.002
	Apr-99	17.9	7.12	848	5.4	315	380	7.17	<0.10	<0.1	3.00	16.5	<0.1	NA[f/]	NA	NA	NA	<0.001	<0.003	<0.002
CG39-B97-43s	Aug-97	21.5	6.80	1,280	4.8	117	330	159	<0.05	<0.01	4.22	49.0	<0.01	<0.01	0.2	48	0.539	<0.001	<0.003	<0.002
	Apr-99	17.7	7.00	1,290	3.5	24	280	160	<0.10	<0.1	4.31	46.0	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
CG39-B97-43d	Aug-97	18.4	7.07	1,110	3.3	130	450	52.0	<0.05	<0.01	2.55	44.1	<0.01	<0.01	0.2	75	0.545	<0.001	<0.003	<0.002
	Apr-99	17.7	7.10	1,090	3.1	313	400	55.7	<0.10	<0.1	3.60	38.3	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
CG39-B97-45	Aug-97	19.4	6.91	872	6.5	103	380	46.9	<0.05	<0.01	4.80	11.3	<0.01	<0.01	<0.01	75	<0.4	<0.001	<0.003	<0.002
2-62B	Aug-97	18.8	7.34	1,440	0.2	51	260	173	<0.05	<0.01	3.92	127	<0.01	<0.01	<0.01	55	3.30	1.05	<0.003	<0.002
	Apr-99	18.2	7.20	1,440	1.2	70	360	176	<0.10	0.1	5.52	111	<0.1	NA	NA	NA	NA	0.122	<0.003	<0.002
2-63B	Aug-97	19.9	7.35	1,520	0.6	79	460	94.4	<0.05	<0.01	2.39	65.7	<0.01	<0.01	<0.01	75	11.2	0.002	<0.003	<0.002
	Apr-99	19.4	7.10	1,690	0.2	244	600	112	<0.10	<0.1	3.09	84.2	<0.1	NA	NA	NA	NA	0.001	<0.003	<0.002
2-64B	Aug-97	20.6	NA	848	1.8	124	260	49.3	<0.05	<0.01	3.42	27.0	<0.01	<0.01	<0.01	40	0.795	<0.001	<0.003	<0.002
	Apr-99	19.8	7.30	921	1.0	177	360	53.3	<0.10	<0.1	4.27	26.3	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
2-65B	Aug-97	18.8	7.13	1,670	2.3	91	350	78.5	<0.05	<0.01	3.18	44.4	<0.01	<0.01	<0.01	75	1.96	0.002	<0.003	<0.002
	Apr-99	17.5	7.10	749	0.2	347	400	56.4	<0.10	<0.1	0.52	23.8	<0.1	NA	NA	NA	NA	0.010	<0.003	<0.002
2-167B	Aug-97	17.3	7.11	1,010	2.3	81	560	4.49	<0.05	0.1	0.27	18.1	<0.01	<0.01	0.1	75	0.488	0.022	<0.003	<0.002
2-168B	Aug-97	18.3	7.17	993	0.7	-22	380	14.4	<0.05	<0.01	0.58	42.4	<0.01	<0.01	<0.01	65	3.01	0.02	<0.003	<0.002
	Apr-99	17.2	6.90	1,170	0.9	283	520	3.24	<0.10	<0.1	0.41	36.1	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
2-271B	Aug-97	16.9	7.19	1,240	3.8	68	420	117	0.15	0.6	1.11	29.7	<0.01	<0.01	0.3	65	0.939	<0.001	<0.003	<0.002
2-272B	Aug-97	17.8	7.24	1,080	4.1	30	280	130	<0.05	<0.01	1.95	37.6	<0.01	<0.01	<0.01	45	0.448	<0.001	<0.003	<0.002
	Apr-99	18.9	7.20	942	4.7	185	300	106	<0.10	<0.1	2.83	28.9	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
2-273B	Aug-97	18.3	7.20	761	0.2	-105	280	16.5	<0.05	0.2	0.35	12.1	<0.01	<0.01	<0.01	45	0.638	0.005	<0.003	<0.002
	Apr-99	19.3	7.20	779	2.0	277	320	18.6	<0.10	<0.1	0.60	9.75	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
2-274B	Aug-97	17.7	7.20	919	5.1	50	310	74.6	<0.05	0.2	3.08	24	<0.01	<0.01	0.2	45	<0.4	<0.001	<0.003	<0.002
	Apr-99	18.6	7.40	970	4.4	247	380	82.6	<0.10	<0.1	4.32	27.2	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
2-355B	Aug-97	17.8	7.23	1,490	7.9	117	380	187	<0.05	0.4	3.28	48.8	<0.01	<0.01	0.3	50	0.741	<0.001	<0.003	<0.002
	Apr-99	19.0	7.00	1,320	6.1	353	340	202	<0.10	0.1	3.32	15.5	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
2-392B	Aug-97	18.5	7.18	697	6.0	139	350	10.6	<0.05	<0.01	2.57	5.91	<0.01	<0.01	0.2	60	<0.4	<0.001	<0.003	<0.002
	Apr-99	17.4	9.90	236	5.5	151	100	0.64	<0.10	<0.1	0.43	6.39	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
2-393B	Aug-97	18.2	7.23	1,180	7.0	111	190	148	<0.05	<0.01	3.70	14.1	<0.01	<0.01	<0.01	110	<0.4	<0.001	<0.003	<0.002
	Apr-99	17.5	7.20	620	4.7	270	320	187	<0.10	<0.1	0.43	13.9	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
2-142B	Aug-97	16.9	7.36	1,480	3.1	53	380	218	<0.05	0.8	2.00	76.1	<0.01	<0.01	0.2	55	0.929	<0.001	<0.003	<0.002

TABLE 5
GROUNDWATER GEOCHEMICAL DATA
SITE FTA-2 RNA TS ADDENDUM
TINKER AFB, OKLAHOMA

Sample Location	Sample Date	Temp (°C)[a/]	pH (su)[b/]	Conductivity (µs/cm)[c/]	Dissolved Oxygen (mg/L)[d/]	Redox Potential (mV)[e/]	Total Alkalinity (mg/L)	Chloride (mg/L)	Ammonia (mg/L)	Ferrous Iron (mg/L)	Nitrite+ Nitrate (mg/L)	Sulfate (mg/L)	Sulfide (mg/L)	Manganese (mg/L)	Total Phenols (mg/L)	Carbon Dioxide (mg/L)	TOC (mg/L)	Methane (mg/L)	Ethane (mg/L)	Ethene (mg/L)
Lower Saturated Zone																				
2-62A	Aug-97	21.5	7.42	782	5.6	97	310	7.54	<0.05	0.1	4.02	6.51	<0.01	<0.01	<0.01	45	1.53	<0.001	<0.003	<0.002
	Apr-99	NA	NA	NA	NA	NA	360	5.55	<0.10	0.1	4.8	3.43	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
2-63A	Aug-97	18.9	7.31	654	7.2	48	380	20.5	<0.05	1.0	1.91	8.46	<0.01	<0.01	<0.01	50	0.745	<0.001	<0.003	<0.002
	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2-64A	Aug-97	20.2	7.69	666	6.1	122	270	21.5	<0.05	0.1	1.29	7.96	<0.01	<0.01	<0.01	45	0.152	<0.001	<0.003	<0.002
	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2-65A	Aug-97	19.9	7.67	576	4.2	-38	190	25.6	<0.05	0.3	0.72	9.89	<0.01	<0.01	<0.01	25	<0.4	<0.001	<0.003	<0.002
	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2-274A	Aug-97	20.1	7.60	516	7.4	63	210	18.0	<0.05	<0.01	0.62	10.4	<0.01	<0.01	0.4	25	<0.4	<0.001	<0.003	<0.002
	Apr-99	19.4	8.00	382	3.4	264	200	10.7	<0.10	<0.1	0.80	10.1	<0.1	NA	NA	NA	NA	<0.001	<0.003	<0.002
2-142A	Aug-97	17.5	7.75	620	1.2	26	270	28.4	<0.05	<0.01	<0.05	9.72	<0.01	<0.01	0.2	45	2.14	<0.001	<0.003	<0.002

[a/] °C = degrees Centigrade.

[b/] su = standard pH units.

[c/] µs/cm = microsiemens per centimeter.

[d/] mg/L = milligrams per liter.

[e/] mV = millivolts.

[f/] NA = not analyzed.

2-272B. Wells 2-271B and 2-148B had anomalous elevated concentrations of chloride in 1997, but were not sampled in 1999. The elevated chloride concentrations observed at FTA-2 are a moderate indication that CAHs are undergoing microbially mediated degradation when reviewed in conjunction with the distributions of CAHs.

4.5 ORP as an Indicator of Redox Processes

As discussed in the TS, redox potential is a measure of the relative tendency of a solution to accept or transfer electrons. The redox potential of a groundwater system depends on which electron acceptors are being reduced by microbes during oxidation of organic compounds. Redox potentials were measured at 15 groundwater monitoring wells in April 1999 (Table 5 and Figure 20). Redox potentials for USZ groundwater at the site ranged from –105 millivolts (mV) to 139 mV in 1997, and from 24 mV to 353 mV in April 1999. The 1999 results indicate a significant increase in ORP at the site. However, ORP is very sensitive to methods of field measurement and sampling technique. Therefore, additional ORP data are required to assess whether this is an actual trend, or a result of sampling error.

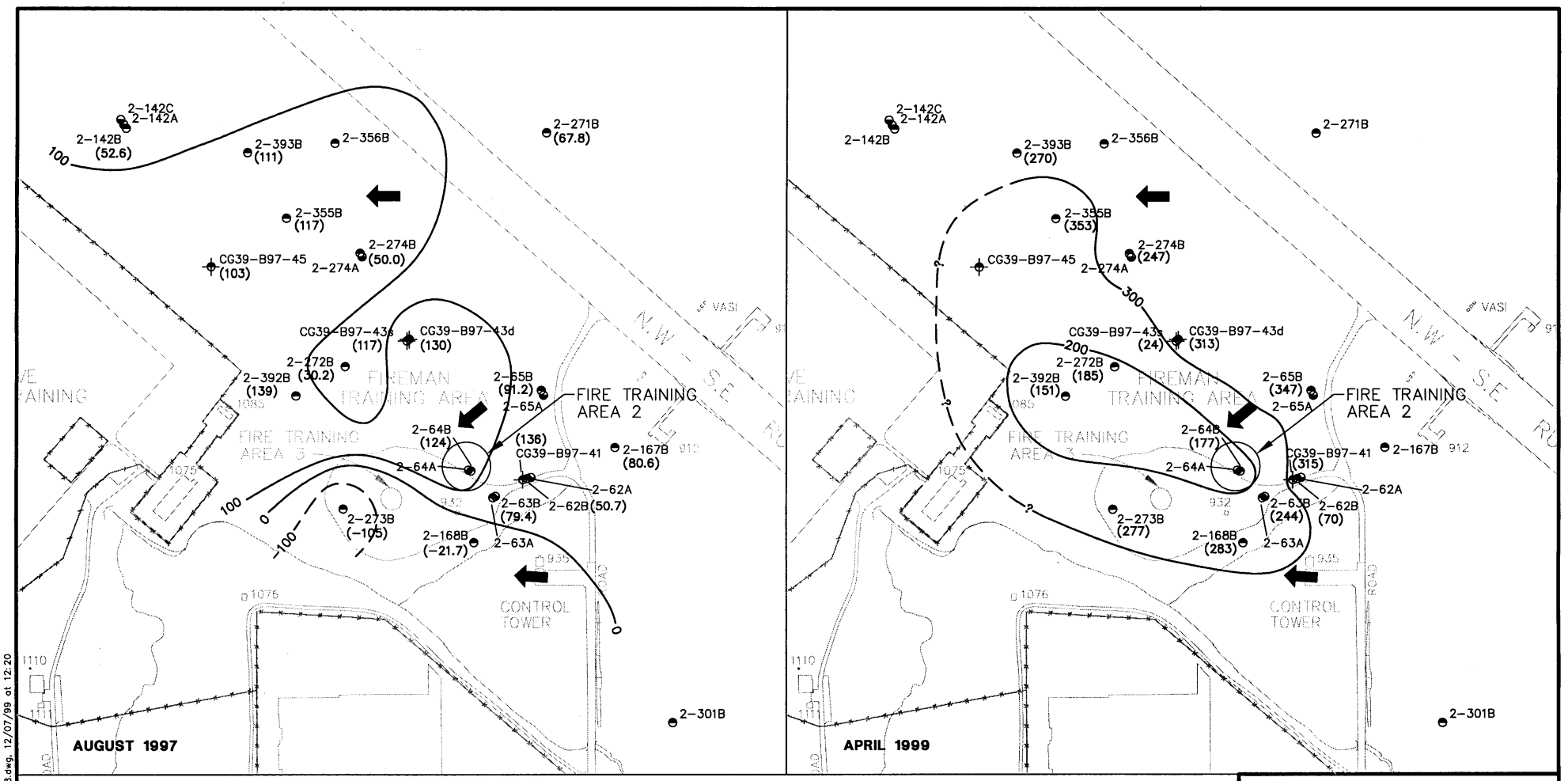
In many locations, relatively lower redox potentials continue to coincide with areas of elevated solvent concentrations; decreased DO, nitrate, and sulfate concentrations; and elevated ferrous iron and methane concentrations. As noted in the TS, this is not always the case and the correlation between redox potential and geochemical indicators is not strong.

4.6 Alternate Electron Acceptors and Metabolic Byproducts

As discussed in the TS, microorganisms obtain energy for cell production and maintenance by facilitating thermodynamically advantageous oxidation/reduction 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 acceptors are elements or compounds that occur in relatively oxidized stated and include DO, nitrate, manganese, ferric iron, sulfate, and carbon dioxide. DO is used first as the prime electron acceptor, after which anaerobic microorganisms use electron acceptors in the following order of preference: nitrate, manganese, ferric iron, sulfate, and finally carbon dioxide. Concentrations of compounds used as electron acceptors are depleted, and byproducts of electron acceptor reduction (e.g., ferrous iron, methane, and sulfide) are enhanced. By measuring these changes, it is possible to evaluate the importance of natural attenuation at a site. The following paragraphs discuss those parameters most useful in evaluating site biodegradation processes.

4.6.1 Dissolved Oxygen

DO concentrations were measured during the August 1997 and April 1999 sampling events (Table 5). Concentrations ranged from 0.2 mg/L to 7.9 mg/L in 1997, and from 0.2 to 6.1 mg/L in 1999. Within and immediately downgradient of the suspected FTA-2 source area (well location 2-62B) concentrations were below 2.0 mg/L in both 1997 and



LEGEND

- 2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- CG39-B97-41 — TEMPORARY MONITORING POINT LOCATION/ UPPER SATURATED ZONE
- s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
- -100- LINE OF EQUAL REDOX POTENTIAL (mv)
- (30.2) ALL POTENTIALS IN MILLIVOLTS (mv)
- DIRECTION OF GROUNDWATER FLOW

0 150 300 600
FEET

FIGURE 20

REDOX POTENTIAL OF USZ GROUNDWATER AUGUST 1997 AND APRIL 1999

Site FTA-2 RNA TS Addendum
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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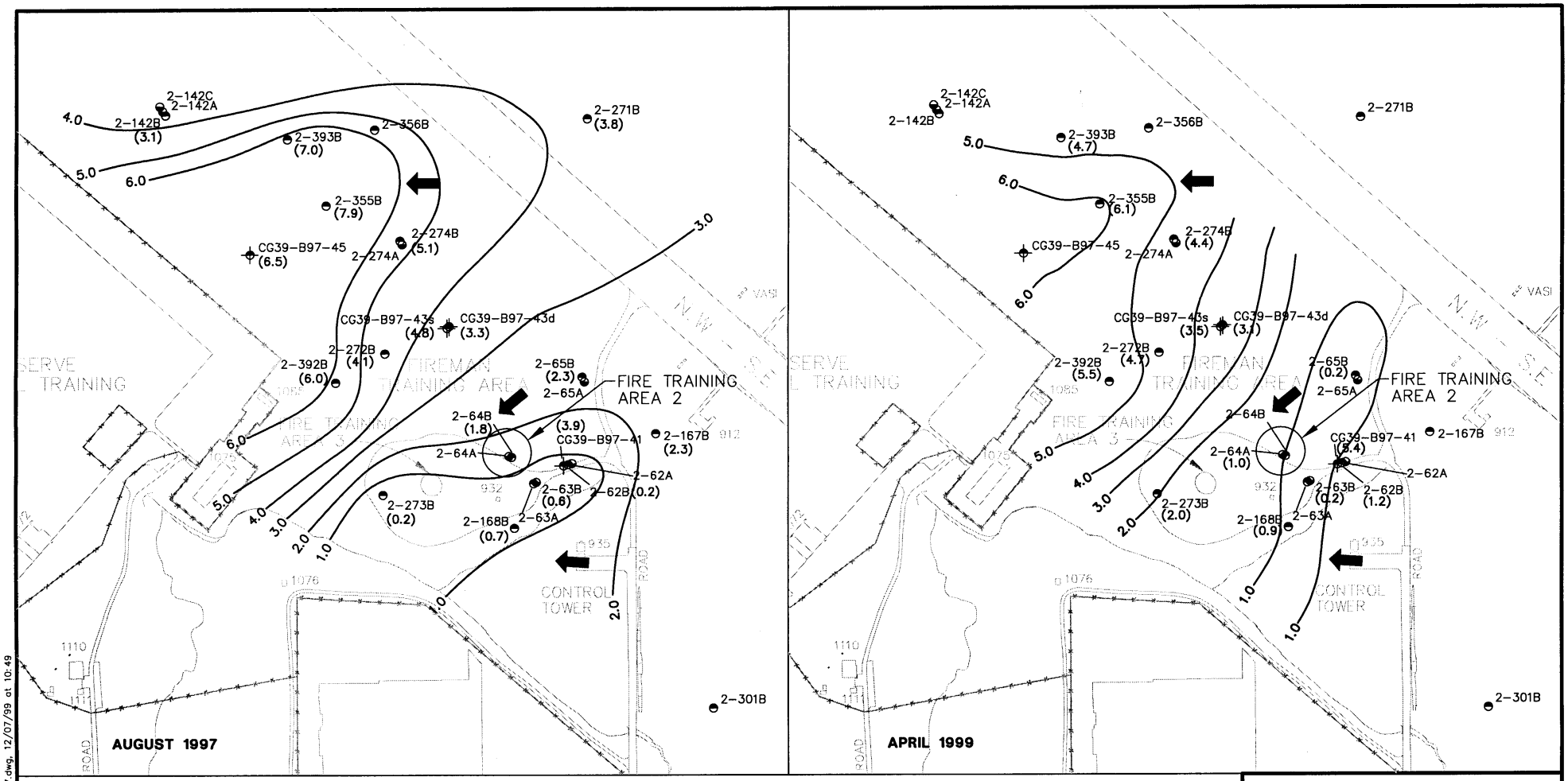

LEGEND

- 2-142B — UPPER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- 2-142A — LOWER SATURATED ZONE MONITORING WELL LOCATION AND ID NUMBER
- CG39-B97-41 — TEMPORARY MONITORING POINT LOCATION/ UPPER SATURATED ZONE
- s,d — SHALLOW AND DEEP USZ MONITORING POINT/WELL PAIR
- -1.0- — LINE OF EQUAL DISSOLVED OXYGEN CONCENTRATION (mg/L)
- (0.7) — ALL CONCENTRATIONS IN MILLIGRAMS PER LITER (mg/L)
- DIRECTION OF GROUNDWATER FLOW

0 150 300 600
FEET

FIGURE 21

CONCENTRATION OF DISSOLVED OXYGEN IN USZ GROUNDWATER AUGUST 1997 AND APRIL 1999

Site FTA-2 RNA TS Addendum
Tinker AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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1999 (Figure 21). Concentrations of DO at well location 2-65B also are depleted, decreasing from 2.3 mg/L in 1997 to 0.2 mg/L in 1999.

Depletion of DO within the CAH source area relative to upgradient and crossgradient concentrations at FTA-2 indicates that microbial activity stimulated by the presence of anthropogenic hydrocarbons (e.g., fuel hydrocarbons) is consuming DO and creating anaerobic conditions. However, outside of the suspected source areas, DO concentrations gradually increase from less than 1.0 mg/L to more than 6.0 mg/L in a north-westerly direction. Therefore, aerobic conditions exist for the majority of the CAH plume.

4.6.2 Nitrate + Nitrite

Concentrations of nitrate + nitrite (as N) were measured for groundwater samples collected in August 1997 and April 1999 (Table 5). Nitrate + nitrite concentrations generally range from less than 1 to as high as 5.52 mg/L (well 2-62B in 1999). There is no apparent correlation between depleted nitrate + nitrite and elevated CAH concentrations. However, concentrations of nitrate + nitrite did decrease at well 2-65B from 3.18 mg/L in 1997 to 0.52 mg/L in 1999, corresponding to an increase in CAHs at that location.

4.6.3 Ferrous Iron

Ferrous iron concentrations measured in groundwater samples collected in August 1997 and April 1999 are summarized in Table 5. Concentrations of ferrous iron in the USZ ranged from less than 0.1 mg/L to a maximum of 0.8 mg/L (well 2-142B in 1997). Elevated concentrations of ferrous iron were not detected at the site in the area of the contaminant plume. This suggests that ferric iron hydroxide is not being reduced to soluble ferrous iron during biodegradation of native organic carbon, fuel hydrocarbons, or less-chlorinated solvents. It is therefore unlikely that ferric iron reduction is an ongoing anaerobic biodegradation process at FTA-2.

4.6.4 Sulfate

Sulfate concentrations in USZ groundwater at the site ranged from 5.91 mg/L to 127 mg/L in 1997, and from 6.39 mg/L to 111 mg/L in 1999 (Table 5). The highest concentration of sulfate was detected in well 2-62B in both 1997 and 1999. Areas of lower sulfate concentrations do not correlate with elevated CAHs. It is therefore unlikely that sulfate reduction is an ongoing anaerobic biodegradation process at FTA-2.

4.6.5 Methane, Ethane and Ethene

Methane, ethane, and ethene concentrations measured in groundwater samples collected in August 1997 and April 1999 are listed on Table 5. Methane was detected at six locations in 1997 (2-62B, 2-63B, 2-65B, 2-167B, 2-168B, and 2-73B), and at three locations in 1999 (2-62B, 2-63B, and 2-65B). Location 2-167B was not sampled in 1999. Methane concentrations ranged up to 1.05 mg/L at well 2-62B in 1997, and up to 0.122 mg/L at well 2-62B in 1999. Ethane and ethene were not detected in either 1997 or 1999. The area of elevated methane concentrations coincides with suspected fuel hydrocarbon and chlorinated solvent source areas near wells 2-62B and 2-65B. The

presence of methane within these suspected source areas indicates highly reducing conditions favorable for oxidation of fuel hydrocarbons and native organic matter, as well as reductive dehalogenation of chlorinated solvents.

4.7 Other Geochemical Parameters

4.7.1 Ammonia

The presence of ammonia in groundwater can result from either nitrate reduction or fixing of atmospheric nitrogen. Because fixation of atmospheric nitrogen only occurs under reducing conditions [ORP less than -500 mV (Stumm and Morgan, 1981)], ammonia production via nitrate reduction is probably more common than by fixation of atmospheric nitrogen. In either case, the presence of ammonia in groundwater is a strong indication of microbial activity. Ammonia was not detected at any locations in the USZ groundwater at a concentration greater than the detection limit of 0.10 mg/L for samples collected in April 1999 (Table 5). Because nitrate is not widespread in USZ groundwater or present at any significant concentrations, it is unlikely that biodegradation by nitrate reduction is occurring at the site. Therefore, ammonia concentrations are not likely to be elevated at FTA-2.

4.7.2 Alkalinity

Total alkalinity (as calcium carbonate) was measured in groundwater samples collected in August 1997 and April 1999 (Table 5). Alkalinity is a measure of the ability of groundwater to buffer changes in pH. Total alkalinity in USZ groundwater at the site varied from 190 mg/L to 560 mg/L in 1997, and from 100 mg/L to 600 mg/L in 1999. Alkalinity within the plume area remains highly variable, but appears to be sufficient to buffer potential changes in pH caused by biologically mediated reactions.

4.8 Summary of Biodegradation of Chlorinated Solvents

Concentration versus time data indicate that the source(s) of CAHs at FTA-2 have not significantly attenuated. Concentrations of chlorinated ethenes are stable at well 2-62B, but increasing at wells 2-64B and 2-65B. This suggests downgradient migration of contaminants from the primary source area near well 2-62B to well 2-64B, and the presence of a secondary source near well 2-65B (located upgradient from well 2-62B). Concentrations of chlorinated ethanes and chlorobenzenes are likewise increasing at well locations 2-64B and 2-65B, but do appear to be gradually decreasing at well 2-62B.

The presence of daughter products *cis*-1,2-DCE and VC provides strong evidence that parent solvents (TCE and/or PCE) are being reductively dehalogenated. While the data suggest that TCE has been degraded by reductive dehalogenation to DCE, a relative lack of VC and ethene indicates that the process does not significantly proceed past the initial step of TCE to DCE. The persistence and strength of TCE in groundwater indicates that either TCE has not continued to degrade to DCE, or that the rate of degradation of TCE to DCE is offset by the rate of mass loading to groundwater from a continuing TCE source. Molar fractions of chlorinated ethenes along the apparent CAH plume axis indicates little, if any, degradation of TCE to DCE outside the immediate source area(s). While elevated concentrations of DCE indicate some degradation of TCE to DCE has occurred, there is

insufficient data to indicate this process continues or occurs outside of the primary source area. At well 2-65B, an overall decrease in the molar fraction of TCE, with an increase in fraction of DCE and the presence of VC indicates that TCE is degrading to DCE, and DCE to VC.

Geochemical data indicate that DO is being consumed and methane is being produced in the primary and secondary source areas near wells 2-62B and 2-65B. Nitrate reduction, ferric iron reduction, and sulfate reduction do not appear to be significant anaerobic degradation processes at the site. Away from the source areas, DO concentrations are aerobic (>1.0 mg/L) and measured redox potentials do not indicate that conditions are in the ranges that produce a sufficient environment for the reduction of CAH compounds.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The FTA-2 fire pit location was identified as a potential source of fuel hydrocarbons and CAHs in the TS. Analytical data indicate that the highest concentrations of CAHs occur in the vicinity of well 2-62B, located approximately 100 to 120 feet upgradient from the former fire pit along an access road (Figure 5). The presence of a secondary source near well 2-65B (located further upgradient from well 2-62B and the former fire pit along another access road) is suggested by increasing concentrations of CAHs at that location.

Temporal data for concentrations of TCE and *cis*-1,2-DCE from monitoring wells/points at FTA-2 indicates that concentrations in the potential source areas are stable or gradually increasing. Given the available data, it appears that the plume is expanding downgradient from the suspected primary FTA-2 source and also at an upgradient location, based on increased concentration data for wells 2-63B, 2-64B, and 2-65B. An increase in concentrations within the center of the CAH plume at wells 2-72B and 2-274B further indicate the presence of secondary source(s) and/or expansion of the CAH plume in that area. Conversely, decreasing CAH concentration data for wells 2-355B and 2-393B along the plume axis at the most northern portion of the plume indicate the plume may be either decreasing or approaching equilibrium in this area.

The TS presented a conceptual model where the primary source of TCE was near the FTA-2 fire pit and well 2-62B, and the TCE plume migrated toward the northwest due to a preferential flow path and anisotropy of the aquifer matrix. This conceptual model was primarily based on the plume configuration. Linear transport in a northwest direction is suggested by the geometry of the CAH plume. Alternately, the TCE plume may be migrating in the direction of maximum hydraulic gradient (west-southwest) from multiple sources. The presence of TCE "hotspots" at wells 2-62B, 2-65B, and 2-274B does not support a conceptual model of a single source; rather, the "hotspots" support a conceptual model at multiple sources.

The presence of daughter products *cis*-1,2-DCE and VC provides strong evidence that parent solvents (TCE and/or PCE) are being reductively dehalogenated. However, a relative lack of VC and ethene indicates that the process does not significantly proceed past the initial step of TCE to DCE. Molar fractions of chlorinated ethenes along the apparent CAH plume axis indicates little, if any, degradation of TCE to DCE outside the

immediate source area(s). At well 2-65B, an overall decrease in the molar fraction of TCE, with an increase in molar fraction of DCE and the presence of VC indicates that TCE is degrading to DCE, and DCE to VC at that location. Geochemical data indicate that biodegradation of native or anthropogenic carbon is occurring via aerobic respiration and methanogenesis in suspected source areas, but that nitrate, ferric iron, and sulfate reduction are not significant anaerobic degradation processes at the site. Away from the suspected source areas, DO concentrations and ORPs indicate that environmental conditions are not sufficiently reducing for dehalogenation of CAH compounds.

Fate and transport modeling results presented in the TS indicated that dissolved TCE contamination present in groundwater north and west of the FTA-2 fire pit has the potential to migrate at least 1,000 feet beyond the August 1997 plume toe within 35 years. In addition, the model suggests that dissolved TCE concentrations in excess of the USEPA MCL groundwater quality standard of 5 µg/L for TCE will persist for more than 100 years. However, concentrations for wells located at the northern toe of the TCE plume (2-355B in the upper USZ sand interval and 2-393B in the lower USZ sand interval) decreased substantially from 1997 to 1999. Increases in the concentration of TCE at wells 2-64B and 2-272B in the upper USZ sand interval suggest a more westerly migration in the direction of maximum hydraulic conductivity. Increases in concentrations at wells 2-65B and 2-274B further suggest the presence of multiple CAH sources or "hotspots". Therefore, the numerical model presented in the TS should be considered as only one of multiple possible interpretations.

Continued long-term monitoring is recommended to evaluate the evolution of the CAH plume and the ability of microbially mediated biodegradation to limit and stabilize plume migration and expansion. To better evaluate the potential expansion of the plume, monitoring wells CG39-B97-45, 2-142B, 2-167B, and 2-356B are recommended to be included in future sampling events. Due to the uncertainty associated with the source(s) of CAHs, further source and site characterization is necessary to validate a conceptual fate and transport model for the FTA-2 site. Source characterization activities could include a soil gas survey, a geophysical survey, additional aquifer tests, and tracer tests as described in Section 6.4.2 of the TS (Parsons ES, 1999).

6.0 REFERENCES

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Montgomery, J.H. and L.M. Welkom. 1990. Groundwater Chemicals Desk Reference. Lewis Publishers, Inc. Chelsea, Michigan. 640 pp.

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Parsons ES, 1999. Final Demonstration of Remediation by Natural Attenuation for Groundwater at Sites FTA 2 and Area A. Tinker Air Force Base, Oklahoma City, Oklahoma. December.

Stumm, W. and Morgan, J.J. 1981. Aquatic Chemistry. John Wiley & Sons, New York, NY.

USEPA. 1998. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water.* EPA/600/R-98/128. September.

USEPA. 1996. *National Primary Drinking Water Regulations.*

Attachment A
Analytical Data

MANTECH

MEMORANDUM

MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP.
Environmental Science

In reply refer to: 99/JAD26
Contract # 68-c-98-138

To: Dr. Don Kampbell

Thru: Dr. Dennis Fine DF

From: John Daniel JAD

Subject: SF-0-68

Date: May 10, 1999

Copies: R.L Cosby
G.B. Smith
J. L. Seeley JLS

As requested in Service Request # SF-0-68, headspace GC/MS analysis of 20 water samples from Tinker AFB for volatile organic compounds was completed. The samples were received April 11, 1999 and analyzed on May 4-5, 1999. 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 15 compounds. The standard curves were prepared from 1.0 to 10000 ppb. The lower calibration limits were 1.0 ppb.

A quantitation report for the samples, lab duplicates, field duplicates, QCs, standards and lab blank is presented in table 1.

If you should have any questions, please feel free to contact me.

Table I. Quantitative Report for S.R. # SF-0-68 from Tinker AFB.

Date received = 4/11/99

Originator = G. Sewell
Concentration ppb

Date analyzed = 5/4-5/99

Compound Sample Name:	43D	43S	2-62A	2-62B	2-62C	2-63A	2-63B	2-64A	2-64B	2-64B Field Dup
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	3.6	ND	ND	ND
1,1-DICHLOROETHENE	ND	---	ND	5.1	ND	ND	---	ND	1.2	1.1
T-1,2-DICHLOROETHENE	1.2	3.3	ND	47.5	ND	ND	3.2	ND	31.1	26.7
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	3.4	ND	ND	ND
C-1,2-DICHLOROETHENE	19.1	98.6	ND	650	---	ND	126	ND	328	302
CHLOROFORM	ND	---	ND	5.0	ND	ND	ND	ND	1.5	1.1
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	ND
1,2-DICHLOROETHANE	---	1.5	ND	37.2	ND	ND	---	ND	2.0	2.0
TRICHLOROETHENE	92.6	751	---	6200	6.4	ND	53.7	ND	2130	1870
TETRACHLOROETHENE	ND	---	ND	3.7	ND	ND	1.0	ND	1.3	1.1
CHLOROBENZENE	ND	---	ND	19.5	ND	ND	ND	ND	1.5	1.3
1,3-DICHLOROBENZENE	ND	1.1	ND	8.0	ND	ND	---	ND	2.8	2.2
1,4-DICHLOROBENZENE	ND	ND	ND	15.5	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	101	---	ND	ND	ND	ND	ND

	2-65A	2-65A Lab Dup	2-65B	2-168B	2-272B	2-273B	2-274A	2-274B	2-274B Field Dup	2-392B
VINYL CHLORIDE	ND	ND	5.1	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	1.4	ND	---	ND	ND	---	---	ND
T-1,2-DICHLOROETHENE	ND	ND	8.9	ND	1.9	ND	ND	4.0	4.0	ND
1,1-DICHLOROETHANE	ND	ND	1.7	---	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	ND	147	6.3	34.9	ND	ND	99.2	90.6	ND
CHLOROFORM	ND	ND	---	ND	---	ND	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	ND
1,2-DICHLOROETHANE	ND	ND	18.3	ND	---	ND	ND	2.1	2.0	ND
TRICHLOROETHENE	---	---	250	1.0	455	ND	ND	942	1060	---
TETRACHLOROETHENE	ND	ND	154	ND	---	ND	ND	---	---	ND
CHLOROBENZENE	ND	ND	51.6	ND	---	ND	ND	---	---	ND
1,3-DICHLOROBENZENE	ND	ND	1.4	ND	---	ND	ND	1.6	1.6	ND
1,4-DICHLOROBENZENE	ND	ND	9.6	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	23.8	ND	ND	ND	ND	ND	ND	ND

	2-393B	2-355B	2-355B Lab Dup	Creek Grab	QC0504C 20 ppb	QC0504D 200 ppb	QC0504E 20 ppb	QC0504F 200 ppb	BL0504A
VINYL CHLORIDE	ND	ND	ND	ND	16.9	156	16.0	155	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	21.7	197	20.2	219	ND
T-1,2-DICHLOROETHENE	ND	---	---	ND	21.9	223	23.8	202	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	21.5	204	22.0	205	ND
C-1,2-DICHLOROETHENE	13.3	28.5	28.7	1.0	23.0	237	22.0	224	ND
CHLOROFORM	ND	ND	ND	ND	22.8	213	22.4	193	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	20.1	209	20.5	196	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	19.7	212	20.4	201	ND
1,2-DICHLOROETHANE	---	---	---	ND	22.4	216	21.5	185	ND
TRICHLOROETHENE	114	186	162	1.7	19.4	213	18.9	180	ND
TETRACHLOROETHENE	ND	ND	ND	ND	19.4	200	19.7	189	ND
CHLOROBENZENE	ND	ND	ND	ND	22.7	228	23.4	208	ND
1,3-DICHLOROBENZENE	---	---	---	ND	21.3	212	21.4	206	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	22.2	197	20.3	205	ND
1,2-DICHLOROBENZENE	---	ND	ND	ND	23.1	204	21.8	205	ND

Printer: 3:37 PM 5/10/1999

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate QC = Quality Control Std

MANTECH

MEMORANDUM
MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP.
Environmental Sciences

In reply refer to: 99-MB14

To: Dr. Don Kampbell

From: Mark Blankenship

THRU: Dr. Dennis Fine

Date: April 13, 1999

Copies: R.L. Cosby
G.B. Smith
J.L. Seeley

Please find attached the analytical results for Service Request SF-0-68 requesting the analysis of Tinker AFB, OK ground water samples to be analyzed for BTEXXX, TMB's and MTBE. The samples were collected April 7, 1999 and April 8, 1999. I received a total of 19 samples, in duplicate, in capped, 40 mL VOA vials on April 12, 1999. Samples were analyzed April 12,1999. The samples were acquired and processed using the Millennium data system. A 5 point (1-1000 ppb) external calibration curve was used to determine the concentration for for all compounds.

RSKSOP-122 " Analysis of Volatile Aromatic Hydrocarbons with Separation of Xylene Isomers by Purge and Trap Gas Chromatography" was used for these analyses. Autosampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Printed [redacted]/3/99 SF-0-68 Tinker AFB

Analyses for Dr. Kampbell

Units = ng/ml Analyst M. Blankenship

SAMPLE NAME	MTBE	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
10 PPB STD	8.3	9.5	9.5	10.3	9.8	9.8	9.4	10.3	9.8	9.4
20 PPB QA\QC	18.1	21.4	21.7	22.2	22.4	22.3	21.8	21.2	23.2	20.1
GC LAB BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
43-D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
43-S	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-62A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-62B	ND	3.9	ND	ND	ND	ND	ND	ND	ND	ND
2-62C	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-63A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-63B	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	ND
2-64A	ND	ND	13.6	ND	ND	ND	ND	ND	ND	ND
2-64B	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	ND
2-64B LAB DUPLICATE	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	ND
10 PPB STD	10.1	9.8	9.9	10.6	10.2	10.2	10.2	10.7	10.6	10.5
2-65A	ND	ND	ND	ND	ND	BLQ	ND	ND	ND	ND
2-65B	BLQ	BLQ	BLQ	ND	ND	BLQ	ND	ND	ND	ND
2-168B	ND	BLQ	ND	ND	ND	1.3	ND	ND	BLQ	2.7
2-272B	ND	ND	ND	ND	BLQ	BLQ	ND	ND	ND	ND
2-273B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-274A	ND	ND	ND	1.6	ND	1.0	ND	ND	ND	ND
2-274B	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	ND
2-355B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
2-392B	ND	ND	7.5	ND	ND	ND	ND	3.7	ND	ND
2-393B	ND	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
20 PPB QA\QC	18.6	18.0	18.8	18.1	18.2	18.2	18.5	18.9	18.1	17.9

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb

Samples Collected 4/7/99 and 4/8/99; Analyzed 4/12/99

Printed 04/15/99 SF-0-68 Originator: D. Kampbell Site: Tinker AFB Analyst: A. Zhao

Sample Received 04/11/99 Sample Analyzed 04/13/99

	ppm (Gas)	ppm mg/L(Water)	ppm (Gas)	ppm mg/L(Water)	ppm (Gas)	ppm (Water)
100 ppm CH4	9.35E+01	~	**	~	**	~
100 ppm C2H4	**	~	9.20E+01	~	**	~
100 ppm C2H6	**	~	**	~	9.60E+01	~
HP. Helium Blank	~	**	~	**	~	**
Lab Blank	~	**	~	**	~	**
43-D(4/8)	~	**	~	**	~	**
43-S(4/8)	~	**	~	**	~	**
2-62A(4/8)	~	**	~	**	~	**
2-62B(4/7)	~	0.122	~	**	~	**
2-62C(4/7)	~	**	~	**	~	**
2-62C(4/7)	~	**	~	**	~	**
2-63B(4/8)	~	0.001	~	**	~	**
2-64B(4/8)	~	**	~	**	~	**
2-65B(4/8)	~	0.010	~	**	~	**
2-168B(4/8)	~	**	~	**	~	**
2-272B(4/8)	~	**	~	**	~	**
2-272B Field Dup(4/8)	~	**	~	**	~	**
1000 PPM CH4	9.63E+02	~	**	~	**	~
2-273B((4/8)	~	**	~	**	~	**
2-274A(4/8)	~	**	~	**	~	**
2-274B(4/8)	~	**	~	**	~	**
2-392B(4/8)	~	**	~	**	~	**
2-393B(4/8)	~	**	~	**	~	**
2-393B Lab Dup(4/8)	~	**	~	**	~	**
2-355B(4/8)	~	**	~	**	~	**
10 PPM CH4	9.10E+00	~	**	~	**	~
10PPM C2H4	**	~	1.06E+01	~	**	~
10PPM C2H6	**	~	**	~	9.80E+00	~
Lower Limit of Quantitatio	10.0	0.001	10.0	0.003	10.0	0.002

Units for the samples are mg/L dissolved in water.
Units for the standards are parts per million.

sample date is represented in( ) 1999
** denotes None Detected.
* denotes Below Limit of Quantitation.
~ denotes Not Applicable.

MANTECH

MEMORANDUM

MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP.
Environmental Science

In reply refer to: 99-28LP/lp
Contract # 68-C-98-138

To: Dr. Don Kampbell

Thru: D.D. Fine

From: Lynda Pennington LKP

Subject: SR # SF-0-68

Ref:

Copies: R.L. Cosby
G.B. Smith
J.L. Seeley

Date: April 19, 1999

Attached are inorganic results for 16 Tinker AFB samples submitted to MERSC under Service Request # SF-0-68. The samples were received April 12, and were analyzed April 13, 1999. The methods used for analysis were Waters capillary electrophoresis method N-601 for chloride and sulfate and Lachat FIA methods 10-107-04-2-A for nitrate+ nitrite and 10-107-06-1 for ammonia.

Quality control measures performed along with your samples included analysis of blanks, duplicates, spikes, known WPO samples and check standards.

If you have any questions concerning this data, please feel free to contact me.

SAMPLE	NH_3 (N)	$NO_2^-+NO_3^-$ (N)	Cl^-	SO_4^{-2}
	mg/L	mg/L	mg/L	mg/L
4/8 43-D	<0.10	3.60	55.7	38.3
4/8 43-S	<0.10	4.31	160	46.0
4/7 2-62A	<0.10	4.80	5.55	3.43
4/7 2-62B	<0.10	5.52	176	111
4/7 2-62C	<0.10	3.00	7.17	16.5
4/8 2-63B	<0.10	3.09	(112) (112)	(84.2) (84.3)
4/8 2-64B	<0.10	4.27	53.3	26.3
4/7 2-65B	<0.10	0.52	56.4	23.8
4/8 2-168B	(<0.10) (<0.10)	(0.41) (0.41)	3.24	36.1
4/8 2-272B	<0.10	2.83	106	28.9
4/8 2-273B	<0.10	0.60	18.6	9.75
4/7 2-274A	<0.10	0.8	10.7	10.1
4/7 2-274B	<0.10	4.32	82.6	27.2
4/7 2-355B	<0.10	3.32	202	15.5
4/8 2-392B	(<0.10) (<0.10)	0.43	(0.64) (0.69)	(6.39) (6.49)
4/7 2-393B	<0.10	(0.43) (0.41)	187	13.9
Blank	<0.10	<0.10	<.50	<.50
AQC	4.92	12.5	10.4	58.3
AQC T.V.	4.80	12.0	10.8	58.0
Check Std.	2.49	2.46	4.74	4.76
Check Std. T.V.	2.50	2.50	5.00	5.00
Spike Recovery	100%	102%	101%	101%

MANTECH

MEMORANDUM
MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP
Environmental Science

In reply refer to : 99-SH38
Contract #68-C-99-138

To: Dr. Don Kampbell From: Sharon Hightower

Thru: Dennis Fine DF fine

Subject: SF-0-68 Date: April 15, 1999 SH

Copies: R.L. Cosby
G.B. Smith
J.L. Seeley JS
L.K. Pennington LKP

Attached are TOC results for 16 Tinker samples submitted April 11, 1999 under Service Request #SF-0-68. Sample analysis was begun April 14, 1999 and completed April 14, 1999 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.

KAMPBELL TINKER LIQUIDS SF-0-68
SAMPLES RECEIVED 4/11/99
SAMPLES ANALYZED 4/14/99 BY SHARON HIGHTOWER

SAMPLE	MG/L TOC
43D, 4/8/99	3.33
43S, 4/8/99	3.71
2-62A, 4/7/99	1.36
2-62B, 4/7/99	2.84
2-62C, 4/7/99	4.38
2-63B, 4/8/99	8.40
2-64B, 4/7/99	2.72
2-65B, 4/7/99	2.58
2-168B, 4/8/99	4.42
2-272B, 4/8/99	3.66
DUP	3.69
WP40	22.3
5 MG/L	5.13
2-273B, 4/8/99	3.99
2-274A, 4/7/99	2.85
2-274B, 4/7/99	3.49
2-355B, 4/7/99	2.65
2-392B, 4/8/99	8.30
2-393B, 4/7/99	2.34
5 MG/L	5.21
WP40	22.7
BLANK	<.4

WP40 std. t.v.=24.0 +/- 2.40

Tinker AFB - March 1999 - FTA-2 site

Sample	TOC ▽feet	Temp. °C	D.O. mg/L	Redox mV	Cond. µS/cm	pH SU	Fe++ mg/L	sulfide mg/L	Alk. mg/L
2-64B	13.0'	19.8	1.0	+177	921	7.3	<.1	<.1	360
2-62B	13.9'	18.2	1.2	+70	1435	7.2	0.1	<.1	360
2-62A	57.0	well pumped dry - did not recharge					0.1	<.1	360
2-62C	11.2	17.9	5.4	+315	848	7.12	<.1	<.1	380
2-274A	58.9	19.4	3.4	+264	382	8.0	<.1	<.1	200
2-274B	16.9	18.6	4.4	+247	970	7.4	<.1	<.1	380
2-355B	15.9	19.0	6.1	+353	1323	7.0	0.1	<.1	340
2-65B	17.0	17.5	0.2	+347	749	7.1	<.1	<.1	400
2-65A	61.2	Low yield - VOA samples only							
2-393B	16.2	17.5	4.7	+270	620	7.2	<.1	<.1	320
2-272B	17.2	18.9	4.7	+195	942	7.2	<.1	<.1	300
43-D	19.4	17.7	3.1	+313	1089	7.1	<.1	<.1	40[redacted]
43-S	19.4	17.7	3.5	+24	1293	7.0	<.1	<.1	280
2-392B	15.1	17.4	5.5	+151	236	9.9	<.1	<.1	100
2-273B	7.2	19.3	2.0	+277	779	7.2	<.1	<.1	320
2-63B	10.9	19.4	0.2	+244	1693	7.1	<.1	<.1	600
2-63A	54.0	Low water yield - Took VOA's only.							
2-168B	11.2	17.2	0.9	+283	1170	6.9	<.1	<.1	520
2-64A	56.6	Low water yield - Took VOA's only							

Attachment B

Responses to Comments

PARSONS

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27 December, 1999

Mr. Jerry Hansen
AFCEE/ERT
3207 North Road, Bldg. 532
Brooks AFB, TX 78235-5363

Subject: Responses to AFCEE Comments on the Draft Addendum to the Remediation by Natural Attenuation Treatability Study for Groundwater at Site FTA-2, Tinker AFB, Oklahoma

Dear Mr. Hansen:

This letter provides responses to comments received on the Draft Addendum to the Remediation by Natural Attenuation (RNA) Treatability Study (TS) for Groundwater at Site FTA-2, Tinker Air Force Base (AFB), Oklahoma. The draft Addendum to the 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 draft Addendum to the TS was to determine the role of natural attenuation in remediating chlorinated solvent and fuel contamination in groundwater at FTA-2 over time. The draft Addendum was submitted to AFCEE in December 1999. Comments on the draft Addendum were received from AFCEE as reviewed by Jon Atkinson dated 22 December 1999. Responses to these comments were prepared by Parsons ES and are presented herein.

Responses to AFCEE Comments: 22 December 1999

Comment 1) Page 6, Table 2: Suggest rounding northing and easting values to one decimal place because most surveyed horizontal locations are accurate only to 0.1 foot.

Parsons ES Response: *Northings and eastings were surveyed to two decimal places. Therefore, the reported surveying accuracy on page 6, Table 2 is correct, and no change is required.*

Comment 2) Page 24, Sec 3.2.1, Para 2, Last Sent:

a. Suggest stating whether a slug test or other aquifer test has been conducted at well 2-392B, and if so, what was the measured hydraulic conductivity value.

b. Recommend depicting the areal extent of the stated low-permeability zone on Figure 5 or another appropriate figure and adding a representative east-west hydrogeologic cross section through well 2-392B.

Parsons ES Response:

a. The text will be changed to indicate a slug test was conducted at well 2-393B, and that the measured hydraulic conductivity was 1.1 feet per day (ft/day). This information is also provided in Section 2.1, Upper Saturated Zone.

b. A discussion of the low permeability zone is included in the TS (Section 3-3), along with an east-west cross-section (Cross-Section E-E'). References to these items will be added to the Addendum.

Comment 3) Page 27, Sec 3.2.1, Para 1, Line 3: Recommend correcting the typo "re.".

Parsons ES Response: The text will be corrected as recommended.

Comment 4) Page 30, Sec 3.2.1, Para 2, Sent 6: A Celsius temperature of 13.5 degrees corresponds to a Fahrenheit temperature of 56 degrees, not seven degrees.

Parsons ES Response: The text will be corrected to indicate that the boiling point of vinyl chloride (VC) is ***–13.5 degrees Celsius****, which corresponds to a Fahrenheit temperature of 7 degrees.*

Comment 5) Page 30 Sec 3.2.2, Line 2: Suggest writing out the "2" in "2 of the 14 wells" and other numbers less than 10 that occur throughout the report unless they describe units of analytical measurement (e.g., mg/L) or are components of dates. This practice of writing numbers less than 10 as words is consistent with the Air Force *The Tongue and Quill.*

Parsons ES Response: Parsons ES concurs with the practice of writing out numbers less than 10 for quantities that do not specify time, money, or measure. However, a noted exception to this practice is the use of numerals for numbers less than 10 when numbers greater than 10 describing the same item are used in the same sentence. Therefore, the sentence is correct as written, and no change is required.

Comment 6) Page 55, Sec 5.0, Para 1: Recommend briefly discussing if the noted hotspots support a conceptual site model of multiple sources with linear contaminant transport in a northwest direction..

Parsons ES Response: *The noted hotspots do support a conceptual model of multiple sources, and this will be noted in the text. However, they do not necessarily support linear contaminant transport in a northwest direction. Linear transport in a northwest direction is suggested by the geometry of the CAH plume at the site.*

Comment 7) Page 56, Para 1, Last Sent: Suggest that more details be provided regarding further source and site characterization. Specifically, recommend proposing number and location for additional soil borings and for temporary and/or permanent monitoring wells and media-specific analytes.

Parsons ES Response: *The details of recommended source and site characterization are included the TS. A sentence will be added to the text referencing the recommended characterization described in the TS.*

If you have any questions, have additional comments, or require additional information, please call me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Bruce M. Henry

Bruce M. Henry, P.G.
Project Manager

cc: File 733939.20010