FINAL

Remediation by Natural Attenuation Treatability Study for Operable Unit 1

Altus Air Force Base
Altus, Oklahoma

Prepared For

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

and

97 CES/CEVR
Altus Air Force Base
Altus, Oklahoma

December 1999

Walton, Norman

From: Hansen, Jerry E, Mr, HQAFCEE [Jerry.Hansen@HQAFCEE.brooks.af.mil]
Sent: Tuesday, August 08, 2000 10:16 AM
To: 'nwalton@dtic.mil'
Subject: Distribution statement for AFCEE/ERT reports

Norman, This is a followup to our phone call. The eight boxes of reports you received from us are all for unlimited distribution. If you have any questions, you can contact me at DSN 240-4353.

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20 December 1999

Mr. Jerry Hansen
Technical Program Manager
AFCEE/ERT
3207 North Road, Bldg. 532
Brooks AFB, TX 78235-5363

Subject: Submittal of the Final Remediation by Natural Attenuation Treatability Study for Operable Unit 1, Altus Air Force Base, Oklahoma (Contract F41624-92-D-8036-0006)

Dear Mr. Hansen:

Enclosed please find two copies of the December 1999 Final Remediation by Natural Attenuation (RNA) Treatability Study (TS) for Operable Unit 1 (OU1), Altus Air Force Base (AFB), Oklahoma. This report was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) and Altus AFB.

The intent of the RNA TS was to determine the role of natural attenuation in remediating fuel hydrocarbon and chlorinated solvent contamination in groundwater at OU1. The draft RNA TS was submitted to AFCEE in November 1997. Comments on the draft TS were received from AFCEE as reviewed by John Atkinson dated 09 February 1998. Responses to these comments were prepared by Parsons ES and are contained in Appendix G.

In addition, sample data collected by the US Environmental Protection Agency (USEPA) National Risk Management Research laboratory (NRMRL) in April 1999 have been incorporated into this report as an addendum (Appendix H). Conclusions and recommendations from the addendum have been added to the Final TS Executive Summary and Section 8, Conclusions and Recommendations.

If you have any questions or comments regarding this package please do not hesitate to contact me at (303) 831-8100.

Sincerely,

PARSONS ENGINEERING SCIENCE, INC.

Bruce M. Henry

Bruce M. Henry, P.G.
Project Manager

Enclosures
c.c. Mr. Dan Stanton – Altus AFB (two copies)
Mr. Don Kampbell – USEPA NRMRL

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FINAL

REMEDIATION BY NATURAL ATTENUATION TREATABILITY STUDY FOR OU-1

ALTUS AIR FORCE BASE, OKLAHOMA

December 1999

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS
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97 CES/CEVR
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Prepared by:

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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 Operable Unit 1 (OU-1), Landfill 4 (LF-04), Altus Air Force Base, Oklahoma 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 surficial water-bearing zone. The presence of groundwater contamination at the site was documented during the remedial investigation performed by the United States Geological Survey (USGS, 1996). This TS focused on the impact of dissolved CAHs on groundwater and surface water at and downgradient from the site. Site history and the results of soil, groundwater, and surface water investigations conducted previously also are summarized in this report.

The chlorinated solvent plume at OU-1 exhibits conditions of anaerobic reductive dechlorination, where the primary source of biologically available organic carbon is anthropogenic fuel hydrocarbons (BTEX). Typical of these conditions is a decrease in concentrations of TCE, an increase in cis-1,2-DCE, and eventually the accumulation of VC. Some of these characteristics are observed at the OU-1 site. Much of the TCE has been effectively degraded to cis-1,2-DCE by reductive dechlorination. However, the occurrence of this process is limited to the general source area and core of the TCE plume. As a result, the parent CAH (TCE) still comprises the majority of the contamination present throughout most of the plume. The lack of VC in groundwater at OU-1 indicates that reductive dechlorination is not proceeding past the initial step that involves the transformation of TCE to DCE.

The evidence supporting the localized occurrence of TCE biodegradation is summarized below:

- The presence of TCE biodegradation metabolites (e.g., *cis*-1,2-dichloroethene [DCE]), which were not used in Base operations, in groundwater in the source area and central portion of the TCE plume is a direct indication that TCE is being reductively dechlorinated in these areas;

- The presence of elevated chloride concentrations in the southeastern (downgradient) portion of the TCE plume suggests that reductive dechlorination reactions have occurred in the source area and central portions of the TCE plume, and that resultant chloride has migrated in the direction of groundwater flow;

- Dissolved oxygen, oxidation/reduction potential, nitrate/nitrite concentrations, and dissolved hydrogen data indicate that the groundwater environment is anaerobic, but not optimally reducing, in the source area and central portion of the TCE plume, and therefore is more conducive to the occurrence of moderate rates of reductive dechlorination;

- Volatile fatty acid detection near the source area suggest moderate recent microbial activity in this area.

Additional data collected in April 1999 indicate the TCE and cis-1,2-DCE plumes are stable with little change in the extent of TCE and cis-1,2-DCE, although some vertical expansion was observed. The contaminant plume also shows indications of less reducing conditions in 1999 with an increase in nitrate concentrations, an increase in redox potential, and a decrease in methane concentrations. The stability of the cis-1,2-DCE plume observed in April 1999 suggests that cis-1,2-DCE may degrade by aerobic oxidation or cometabolism (which do not produce VC) further downgradient under more aerobic conditions.

An important component of this study was an assessment of the potential for contamination in groundwater to migrate from the source area to potential receptor exposure points at concentrations above regulatory levels intended to be protective of human health and the environment. To accomplish this study objective, the numerical model codes MODFLOW and MT3D$^{\underline{96}}$® were used to estimate the impacts of planned and probable engineered remedial actions on the future migration and persistence of dissolved CAHs within the surficial water-bearing zone 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.

Two remedial alternatives were simulated using the calibrated numerical model. Alternative 1 simulated the effects of RNA with no engineered remediation. Alternative 2 simulated the combined effects of RNA with dual-phase extraction (DPE) (source reduction through groundwater and soil vapor extraction) near the source area.

Model simulations indicate that substantial plume migration could occur, and that the plume could potentially migrate to the Base boundary and Stinking Creek without source reduction activities (Alternative 1). In addition, the plume could persist for all intents and purposes indefinitely. However, model results suggest that drinking water standards and aquatic life criteria would not be exceeded in the creek at any time during the Alternative 1 simulation. Model simulations performed using a rate of source decay that could be expected for DPE (Alternative 2) indicates that the plume may, nevertheless, migrate downgradient to the Base boundary. However, under Alternative 2, central plume concentrations will be considerably decreased within 3 years of system operation, thereby decreasing the life expectancy of the plume.

Observed BTEX and CAH plume behavior in April 1999 have not exceeded the conservative predictions made using the numerical models developed in this TS report. However, because of the predicted longevity of the dissolved contaminant plume under Alternative 1, implementation of Alternative 2 (RNA, DPE, institutional controls, and LTM) should be considered. Performance of LTM would be used to confirm the success of the DPE system in reducing source area contamination as well as to monitor the downgradient migration of the plume.

To assess the effectiveness of natural processes at reducing contaminant mass and minimizing contaminant migration, groundwater and surface water sampling should continue on an annual basis for approximately 5 years, followed by less frequent sampling (e.g., every other year). The LTM plan should be periodically reevaluated and modified as necessary on the basis of newly obtained data. 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., plume containment at the Base boundary) should be implemented.

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ACRONYMS AND ABBREVIATIONS

AETC	Air Education Training Command
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AMC	Air Mobility Command
ASCII	American Standard Code for Information Interchange
bls	below land surface
BTEX	benzene, toluene, ethylbenzene, xylenes
°C	degrées Celcius
$CaCO_3$	calcium carbonate
CAH	chlorinated aliphatic hydrocarbon
97 CES/CEVR	97th Civil Engineering Squadron-Environmental Restoration Branch
2-D	two-dimensional
3-D	three-dimensional
DCA	dichloroethane
DCE	dichloroethene
DNAPL	dense, nonaqueous-phase liquid
DO	dissolved oxygen
DPE	dual-phase extraction
ES	Engineering-Science, Inc.
°F	degrees Fahrenheit
Fe^{2+}	ferrous iron
Fe^{3+}	ferric iron
FID	flame ionization detector
ft/day	feet per day
ft^2/day	square feet per day
ft/ft	feet per foot
ft amsl	feet above mean sea level
ft/yr	feet per year
ft^3/sec	cubic feet per second
GC	gas chromatography
gpm	gallons per minute
H_2	hydrogen
H_2S	hydrogen sulfide
HDPE	high density polyethylene
ID	inside diameter
IDW	investigation-derived waste
IRP	Installation Restoration Program
kg/L	kilograms per liter
kg/yr	kilograms per year
K_{oc}	soil sorption coefficient
K_{ow}	octanol-water partitioning coefficient
lb/yr	pounds per year
LCS	laboratory control sample

LMB	laboratory method blank
LF 3	Landfill Number 3
LF-04	Landfill Number 4
LTM	long-term monitoring
MAC	Military Airlift Command
MOC	Method of Characteristics
MSDS	material safety data sheets
µg/L	microgram(s) per liter
µmol/L	micromoles per liter
µS/cm^2	microsiemen(s) per square centimeter
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
mV	millivolts
NAPL	nonaqueous-phase liquid
NRMRL	National Risk Management Research Laboratory
nM/L	nanomoles per liter
OD	outside diameter
OHM	OHM Remediation Services Corp.
ORD	Office of Research and Development
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
OU-1	Operable Unit 1
OVA	Organic Vapor Analyzer
Parsons ES	Parsons Engineering Science, Inc.
PCE	tetrachloroethene
PID	photoionization detector
POC	point of compliance
POL	petroleum, oils, and lubricants
ppb	parts per billion
ppmv	parts per million, volume per volume
PRC	PRC Environmental Management, Inc.
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
Radian	Radian International, LCC
RAO	remedial action objective
RAP	remedial action plan
redox	reduction/oxidation
RI	Remedial Investigation
RMS	root mean squared
RNA	remediation by natural attenuation
SAC	Strategic Air Command
SCAPS	Site Characterization and Analysis Penetrometer System
SI	Site Investigation
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TAC	Tactical Air Command

TARGET	TARGET Environmental Services, Inc.
TCA	trichloroethane
TCE	trichloroethene
TCLP	toxicity characteristic leaching procedure
TDS	total dissolved solids
TMB	trimethylbenzene
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TRPH	total recoverable petroleum hydrocarbons
TS	Treatability Study
US	United States
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VC	vinyl chloride
VFA	volatile fatty acids
VOC	volatile organic compound
WCC	Woodward-Clyde Consultants

SECTION 1

INTRODUCTION

This report, prepared by Parsons Engineering Science, Inc. (Parsons ES), 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 a portion of Operable Unit 1 (OU-1), including Landfill 3 (LF 3) and the petroleum, oils, and lubricants (POL) Tank Sludge Burial area, collectively known as Landfill 04 (LF-04), located at Altus Air Force Base (AFB), Oklahoma. 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 include both destructive and non-destructive processes. Non-destructive processes may reduce contaminant toxicity, mobility, volume, or concentration; however, mass is unaffected. Of these processes, biodegradation is the most common mechanism working to transform fuel hydrocarbons and chlorinated solvents into innocuous byproducts. Contaminant destruction occurs through biodegradation when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without engineered intervention (e.g., the 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 as 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 can be 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 relatively more toxic intermediates, such as vinyl chloride. Under certain geochemical conditions, vinyl chloride may accumulate in the subsurface rather than be transformed to innocuous byproducts.

The main emphasis of the work described herein was to evaluate the potential for naturally occurring degradation mechanisms to reduce dissolved CAH concentrations in groundwater to levels that are protective of human health and the environment. This TS report 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 at the USEPA National Risk Management Research Laboratory (NRMRL), was retained by the United States (US) 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 LF-04.

Performance of the following tasks was required in order to fulfill the project objectives:

- Reviewing existing hydrogeologic and soil and groundwater quality data for the site;

- Conducting supplemental site characterization activities to more thoroughly characterize the nature and extent of soil, surface water, and groundwater contamination;

- Collecting geochemical data in support of natural attenuation;

- Developing a conceptual hydrogeologic model of the shallow saturated zone, including the current distribution of contaminants;

- Evaluating site-specific data to determine whether naturally occurring processes of contaminant attenuation and destruction are occurring in groundwater at the site;

- Designing and calibrating a groundwater flow and contaminant fate and transport model for the site;
- Simulating the fate and transport of CAHs in groundwater under the influence of advection, dispersion, adsorption, and biodegradation using the calibrated model;
- Evaluating 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;
- Determining if natural processes are minimizing dissolved CAH plume expansion so that groundwater and surface water quality standards can be met at downgradient points of compliance (POCs);
- Conducting an exposure pathways analysis for potential current and future receptors;
- Developing remedial action objectives and reviewing available remedial technologies for treating groundwater containing dissolved CAHs;
- Using the results of modeling to recommend the most appropriate remedial option based on specific effectiveness, implementability, and cost criteria; and
- Developing a LTM plan that includes LTM and POC wells and a sampling and analysis plan.

Site characterization activities conducted for this TS in support of RNA were performed in accordance with the project work plan (Parsons ES, 1997). These activities included the collection of soil samples and installation of groundwater monitoring points using a Geoprobe®; collection of soil samples and installation of groundwater monitoring wells using a hollow-stem auger drill rig; measurement of static groundwater levels; collection and analysis of surface water samples; aquifer testing; and collection and analysis of groundwater samples from pre-existing monitoring wells, newly installed monitoring wells, and newly installed monitoring points.

Additional groundwater sampling was performed by the USEPA NRMRL in April 1999. Data for this event were not availbalb efor 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 groundwater flow/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 concentrations of the dissolved CAH plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation. Results of the model were used to predict future discharge to surface water, to assess the potential for completion of other exposure pathways involving groundwater, and to identify whether RNA with LTM is an appropriate and defensible remedial option for contaminated groundwater, possibly in conjunction with engineered remedial actions. The results will be used to provide technical support for the RNA with LTM remedial option during regulatory negotiations, as appropriate.

Alternate remedial options were considered to identify the major advantages and disadvantages associated with different groundwater remedial strategies. Hydrogeologic and groundwater chemical data necessary to evaluate these remedial options were either collected under this program, or were available from previous site investigations or technical literature. Field work conducted under this program, however, 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.

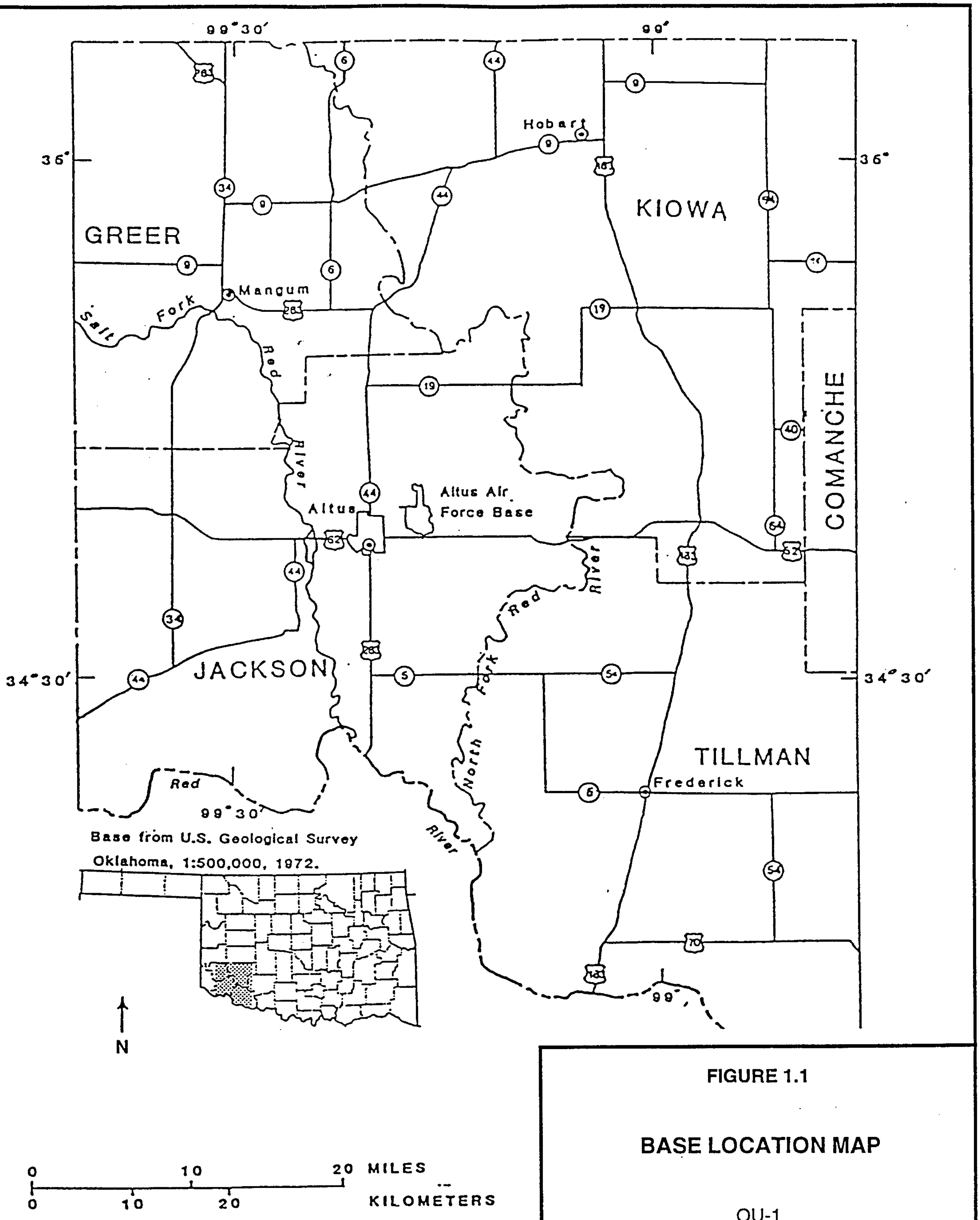
This TS contains nine sections, including this introduction, and six appendices. Section 2 summarizes site characterization activities. Section 3 summarizes the physical characteristics of the study area. Section 4 describes the nature and extent of soil, groundwater, and surface water contamination, and the geochemical 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 analyses, model output, and the modeling results. Section 6 presents a comparative analysis of remedial alternatives. Section 7 presents the LTM plan for the site. Section 8 presents the conclusions of this work and provides recommendations for further work at the site. Section 9 lists the references used to develop this document.

Appendix A contains pertinent tables and figures from previous reports and unpublished data. Appendix B contains Geoprobe® borehole logs, hollow-stem auger drill rig borehole logs, monitoring well/point construction diagrams, well development and sampling forms, aquifer test results, and survey data. Appendix C presents soil, surface water, and groundwater analytical results that were used in the preparation of this report and collected as a part of this TS. Appendix D contains model input parameters, calculations related to model calibration, and model sensitivity analysis results. Appendix E contains model input and output in American Standard Code for Information Interchange (ASCII) format on a diskette. Appendix F contains calculations for remedial option design and costing. Appendix G contains responses to comments on the Draft TS, and Appendix H contains the Final Addendum to this Treatability Study.

1.2 FACILITY BACKGROUND

Altus AFB occupies an area of over 2,500 acres in eastern Jackson County, Oklahoma. It is bordered by the city of Altus on the west, Highway 62 on the south, and agricultural land on the north and east (Figure 1.1).

Altus AFB began operating as a flight-training Base in 1942. The Base was deactivated 5 days after the completion of the European phase of World War II, and was given to the city of Altus for use as a municipal airport (US Geological Survey [USGS], 1996). At the beginning of the Korean conflict, Altus AFB was reactivated under the Tactical Air Command (TAC) in January 1953. In late 1953, the Strategic Air Command



Source: USGS, 1996.

FIGURE 1.1

BASE LOCATION MAP

OU-1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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(SAC) was given control of the Base. The 577th Strategic Missile Squadron was assigned to the Base between 1961 and 1965.

In 1968, control of Altus AFB was transferred to the Military Airlift Command (MAC), and the Base became the training center for the C-5A transport aircraft. Since 1968, the primary mission of Altus AFB has been training aircraft crews for SAC and MAC operations. On July 1, 1992, MAC became the Air Mobility Command (AMC). In late 1992, land northeast of Altus AFB was acquired by the Base to allow for the construction of new runways and taxiways to be used for the training of crews for C-17 aircraft. On July 1, 1993, Altus AFB was transferred from AMC to the Air Education Training Command (AETC). Aircraft currently assigned to the Base include C-5, C-17, and C-141 transport, KC-135 tanker, and T-37 training aircraft.

LF-04, located on approximately 15 acres in the northeastern portion of Altus AFB (Figure 1.2), operated from 1956 through 1983. LF-04 includes LF 3 and the POL Tank Sludge Burial area. LF 3 is located at the eastern end of Taxiway 3, and the POL Tank Sludge Burial area is located north of LF 3 (Figure 1.3). LF-04 is bordered by the Ozark 4.6 lateral irrigation canal on the west and south, Stinking Creek on the northeast, an unnamed drainage canal on the north, and the old Base boundary and Taxiway "M" on the east. In March 1993, Stinking Creek was temporarily rechanneled to flow east from LF-04 during the construction of new runways and taxiways (USGS, 1996). The construction was completed in August 1994, and Stinking Creek has been returned to its original channel.

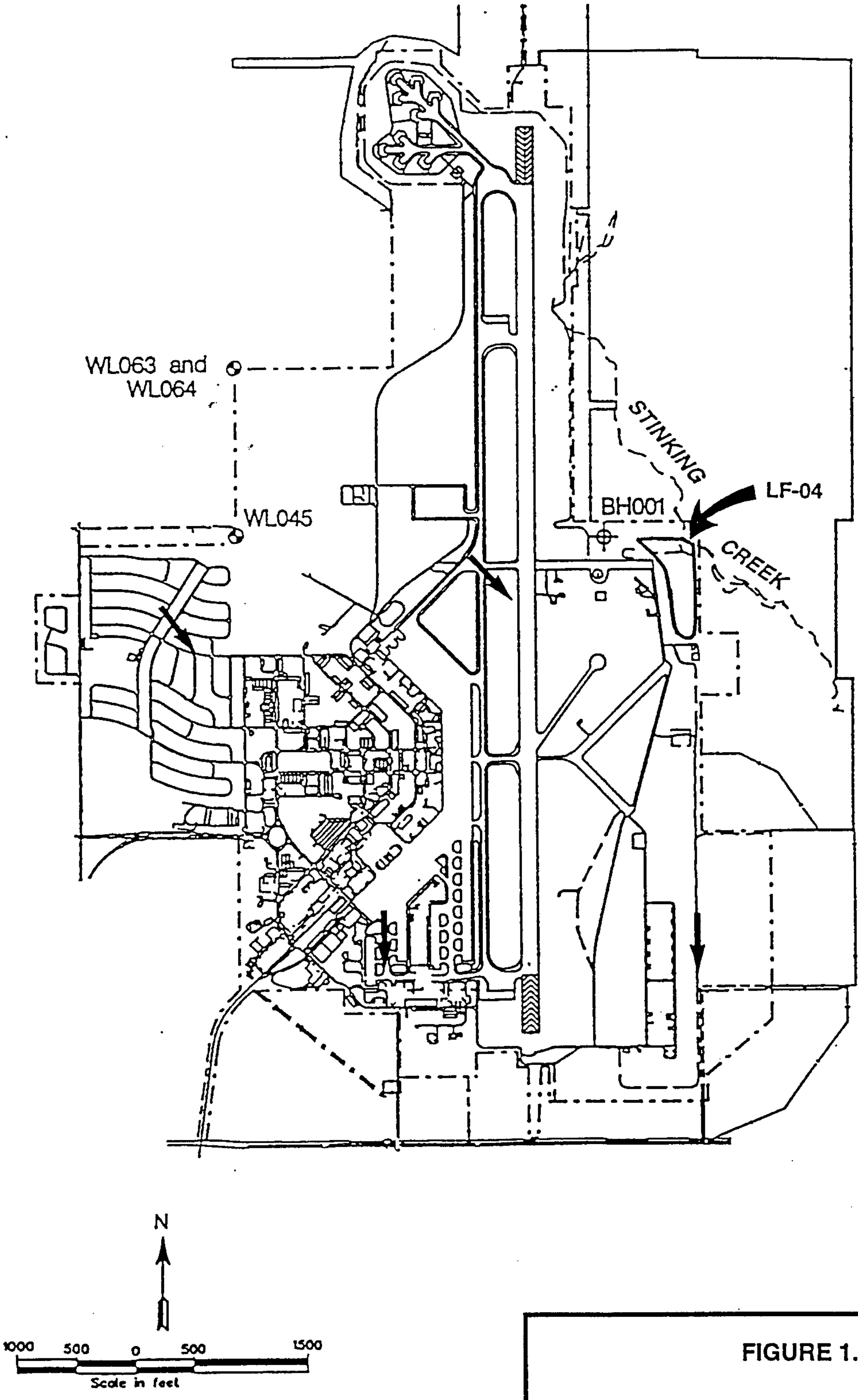
From 1956 to 1965, the LF 3 portion of LF-04 received waste materials including garbage, wood, metal, paper, and shop wastes. After 1965, LF 3 (also known as Solid Waste Management Unit [SWMU] 7), received construction debris, concrete, brush, and several drums of paint waste (PRC Environmental Management, Inc. [PRC], 1990). The sludge burial area located in the northern portion of LF-04 received POL tank sludge from the 1950s through the 1970s. Through the early 1960s, it was common practice to burn waste materials prior to disposal.

From 1956 to 1965, waste at LF 3 was buried in trenches with an east-west orientation and depths ranging from 6 to 8 feet below land surface (bls). After 1965, waste was buried 6 feet bls in trenches with a north-south orientation. POL tank sludge waste was buried 3 feet bls at the northern and northwestern edges of LF-04 (PRC, 1990).

LF-04 is one portion of OU-1. Other sites within OU-1 that have been investigated include Fire Training Area 3 (FT-03), Fire Training Area 4 (FT-07), and the Skeet and Trap Range (Figure 1.3). Because these sites are upgradient from LF-04, groundwater contamination potentially migrating as far as LF-04 was evaluated as part of this LF-04 investigation. Interactions between contaminant plumes were examined, and the leading edge of contamination for the entire OU was investigated.

1.3 PREVIOUS INVESTIGATIONS

From 1989 through 1991, an Installation Restoration Program (IRP) Phase I Remedial Investigation (RI) was conducted for IRP Sites 01 through 10 (USGS, 1992). LF-04 was included in the Phase I RI as IRP Site 04. Electromagnetic conductivity and



LEGEND

- ⊕ BACKGROUND WELL
- -⊕- BOREHOLE
- → GROUNDWATER FLOW DIRECTION

Source: USGS, 1996.

FIGURE 1.2

SITE LOCATION MAP

OU-1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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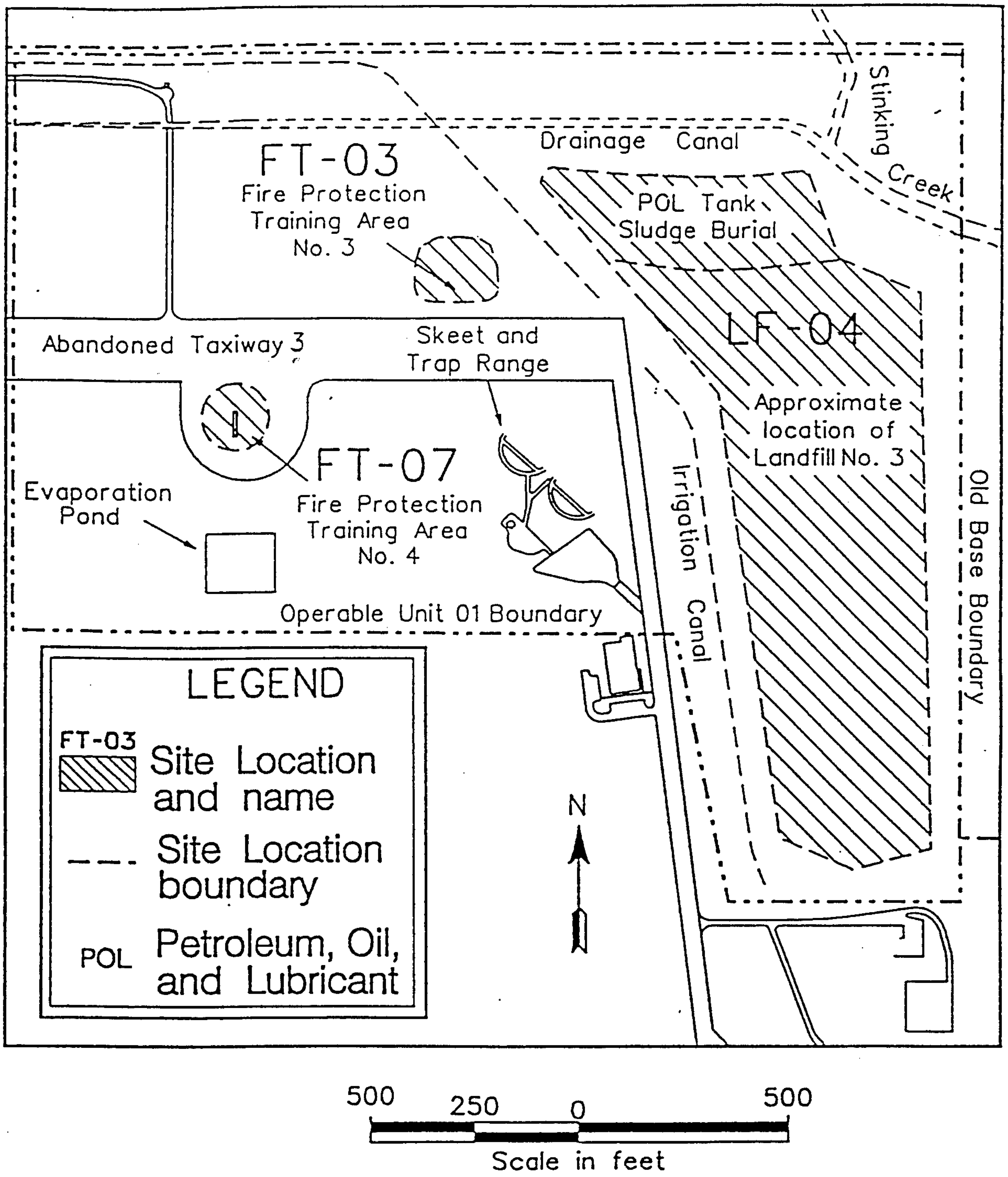

Source: USGS, 1996.

FIGURE 1.3

OU-1 SITE LOCATIONS

OU-1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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Denver, Colorado

magnetometer surveys were conducted. Six boreholes were augered at LF-04, five of which were completed as wells WL018 through WL022. Soil samples were obtained from the drill cuttings and analyzed for metals. Sediment and surface water samples were obtained from four locations adjacent to LF-04, in an irrigation canal, a drainage ditch, and Stinking Creek (CH001, CH002, RV001, and RV002). Sediment samples were screened for total petroleum hydrocarbons (TPH) and analyzed for volatile organic compounds (VOCs) by USEPA Method SW8240. TPH at one location was the only detected analyte. Surface water samples were analyzed for VOCs using Method SW8240. 1,1,1-Trichloroethane (TCA) and 1,2-dichloroethane (DCA) were detected in samples at concentrations less than 2 µg/L. Groundwater samples were collected from the five wells (WL018 through WL022) in July 1989 and February 1991, and were analyzed by Method 418.1 for TPH, by USEPA Method 601 for CAHs, and for general water quality parameters. Concentrations of TCE, *trans*-1,2-DCE, and TPH were detected. TCE concentrations detected in groundwater samples obtained during the 1991 sampling event decreased or remained constant in relation to 1989 results. A summary of the analytical data is provided in Appendix A. During Phase I RI groundwater sampling activities, groundwater and surface water samples also were screened for water temperature, pH, specific conductance, chloride, sulfate, nitrate nitrogen, fluoride, carbonate and bicarbonate alkalinity, total dissolved solids (TDS), and cations (USGS, 1992).

In 1992, an Initial Landfill Investigation was conducted as a part of the C-17 Shortfield Assault Strip/Parallel Runway Project (US Army Corps of Engineers [USACE], 1992). This preliminary site investigation (SI) was conducted at five landfills, including LF-04. The purpose of the SI was to determine the boundaries and contents of the landfills and to determine the potential impact of the landfills to the proposed C-17 project. A series of trenches was dug along the eastern boundary of LF-04. Soil samples from the trenches were analyzed for VOCs, semivolatile organic compounds (SVOCs), total recoverable petroleum hydrocarbons (TRPH), and metals. One soil sample from the POL Tank Sludge Burial area was analyzed for all toxicity characteristic leaching procedure (TCLP) parameters. Four monitoring wells (WL-049 through WL-052) were installed south of LF-04. Groundwater samples from these wells were analyzed for VOCs, SVOCs, metals, total anions, and total cations. TCE was the only VOC detected above laboratory detection limits (111 µg/L at WL049) (USACE, 1992).

In 1993, TARGET Environmental Services, Inc. (TARGET, 1993) conducted soil gas and groundwater sampling surveys at Altus AFB, including LF-04. Fifty-four groundwater samples were collected from temporary points in the area of LF-04 in June 1993 (TARGET, 1993). The locations are prefixed "4" or "DC" denoting IRP Site 4 (LF-04) or the drainage canal which runs through the area (Figure 1.4). The groundwater and soil gas samples were analyzed for benzene, toluene, ethylbenzene and xylenes (BTEX) and CAHs. Groundwater samples were analyzed on site in TARGET's mobile laboratory by USEPA Methods SW8010 (VOCs) and SW8020 (BTEX). Vinyl chloride (VC) was not analyzed for during the SW8010 analysis. TCE was the most frequently detected analyte, found in 33 of the 54 groundwater samples obtained in June 1993 from locations in the LF-04 area. *cis*-1,2-DCE was detected in 25, and *trans*-1,2-DCE was detected in 12 of the groundwater samples (Appendix A). The highest concentrations of TCE, *cis*-1,2-DCE, and *trans-1,2*-DCE were observed in groundwater samples collected from locations near sampling location 4-5-W. TCE concentrations ranged up to 1,090 micrograms per liter (μg/L) in the sample from this point. *cis*-1,2-DCE concentrations were generally significantly higher the *trans*-1,2-DCE concentrations. No other chlorinated solvent analytes were detected in the groundwater samples. BTEX was not detected in any of the 54 groundwater samples from the LF-04 area. Summarized laboratory analytical results are presented in Appendix A.

Phase II of the RI was conducted for OU-1 from September 1992 to September 1993 (USGS, 1996). During the Phase II RI (USGS, 1996), 16 boreholes were drilled along a north-south axis near the eastern boundary of LF-04 at 100-foot intervals (Figure 1.4). The boreholes were designated S4H1 through S4H16. The total depths of the boreholes ranged from 15 to 24 feet bls. Groundwater samples were obtained from the boreholes in November 1992 and analyzed on site for BTEX and CAHs, including tetrachloroethene (PCE), TCE, *cis*- and *trans*-1,2-DCE, and VC. TCE was detected in 15 of the 16 groundwater samples at concentrations ranging up to 5,800 μg/L. *cis*-1,2-DCE was detected in 12 of the groundwater samples, with a maximum concentration of 1,700 μg/L. Detected less frequently and at lower concentrations was *trans*-1,2-DCE, at concentrations ranging to 250 μg/L. PCE was detected in three of the groundwater samples. Benzene and toluene were the only fuel hydrocarbon compounds detected. Both were detected at concentrations near method detection limits and well below regulatory levels. The groundwater samples from the boreholes also were sent to a laboratory for similar analyses. Results were comparable to those of the onsite analyses, although CAHs were generally detected at higher concentrations in the laboratory samples, and were more frequently detected during onsite analyses. Laboratory results indicated that TCE was detected in 14 groundwater samples, with a maximum concentration of 15,000 μg/L (S4H5). Isomers of DCE were not individually analyzed, but total DCE was found to be present in nine of the groundwater samples, with a maximum concentration of 2,800 μg/L (S4H5). No other analytes were detected.

In September 1993, five monitoring wells, WL018 through WL022, were sampled. The groundwater samples were analyzed for VOCs, including CAHs and BTEX. TCE and total DCE were detected in all of the groundwater samples. TCE and total DCE concentrations ranged up to 930 μg/L (WL019) and 100 μg/L (WL022), respectively. One sediment sample (RV003) was collected from a location south of (downstream from) RV002 on Stinking Creek. The sediment sample was analyzed for VOCs, SVOCs, major elements, and trace elements. No VOCs or SVOCs were detected. A surface water sample was collected from location RV003 and analyzed for VOCs using Method SW8240. No analytes were detected in the surface water sample from RV003. Analytical results can be found in Appendix A.

An environmental investigation was performed by USACE (1996) using the Site Characterization and Analysis Penetrometer System (SCAPS). Sixty-eight sampling points were installed in the LF-04 area. Fifty-eight sampling points were sampled, and the groundwater samples were analyzed for VOCs with an onsite gas chromatograph (GC). Three groundwater samples were also analyzed for nitrate and sulfate. The most recent groundwater investigation to be completed was accomplished during the SCAPS investigation of March and April 1996 (USACE, 1996). Sixty-eight temporary wells, designated SB01 through SB68 on Figure 1.4, were installed in the LF-04 area.

Groundwater samples were collected from 58 locations (10 locations were dry) and analyzed using an on site GC. TCE again was the most commonly detected analyte, present in 30 of the 58 groundwater samples. The highest concentration of TCE was greater than 5,000 µg/L (SB15). *cis*-1,2-DCE was detected in six groundwater samples, with concentrations ranging up to 800 µg/L (SB15). *trans*-1,2-DCE was detected in 4 groundwater samples. The groundwater sample from SB15 contained the highest *trans*-1,2-DCE concentration at 34 µg/L. No other VOCs were detected

A technology evaluation was conducted [Radian International, LCC (Radian), 1996] in September 1996. One extraction well (OU-1-01), three piezometers (OU-1-02 through OU-1-04), and three vapor points (OU-1-VP1 through OU-1-VP3) were installed. A vacuum-enhanced groundwater recovery test was conducted, including measuring drawdown and obtaining and analyzing soil vapor and groundwater samples.

In October 1996, eight monitoring points (four clustered pairs) were installed by USACE (SB10WS, SB10WD, SB11WS, SB11WD, SB15WS, SB15WD, SB16WS, and SB16WD). These monitoring points were sampled for the first time during the RNA TS in April 1997. Analytical results for these samples are discussed in Section 4.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

This section presents the methods used by Parsons ES personnel to collect site-specific data at OU-1, Altus 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 the Geoprobe® direct-push system for soil sample collection and temporary groundwater monitoring point installation, and using a hollow-stem auger drill rig for soil sample collection and groundwater monitoring well installation. Groundwater samples were collected during this investigation from both newly installed and previously installed monitoring points and wells. Hydraulic conductivity (slug) tests were conducted at selected site monitoring wells. 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 indicated on Figure 2.1, and a summary of activities conducted during the RNA TS at each location is provided in Table 2.1. The following sections describe the procedures that were followed when collecting site-specific data for this TS. Additional details regarding investigative activities are presented in the work plan (Parsons ES, 1997).

Following the RNA TS, a deep monitoring well (000IU1-MW1) was installed by Woodward-Clyde Consultants (WCC) at OU-1. Construction details for 000IU1-MW1 are provided in Table 2.2, and boring logs and analytical data are presented in Appendix B.

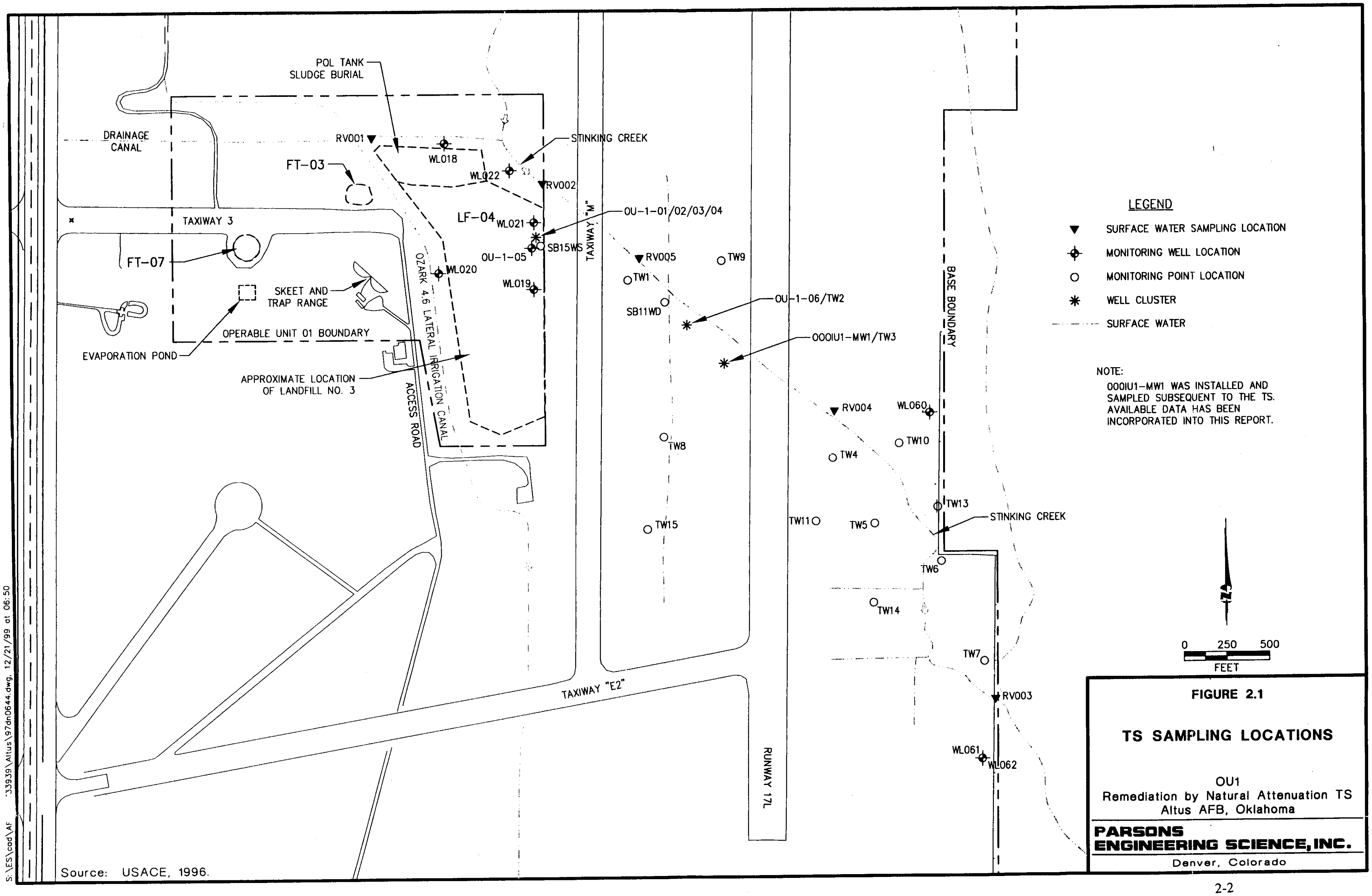
2.1 SOIL SAMPLE COLLECTION AND GROUNDWATER MONITORING WELL/POINT INSTALLATION

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 any drilling activities.

2.1.2 GEOPROBE® FIELD ACTIVITIES

The Geoprobe® system is a hydraulically powered, percussion probing machine used to advance sampling tools through unconsolidated soils. This system provides for the



LEGEND

▼ SURFACE WATER SAMPLING LOCATION
⊕ MONITORING WELL LOCATION
○ MONITORING POINT LOCATION
✳ WELL CLUSTER
— · — SURFACE WATER

NOTE:
000IU1-MW1 WAS INSTALLED AND SAMPLED SUBSEQUENT TO THE TS. AVAILABLE DATA HAS BEEN INCORPORATED INTO THIS REPORT.

Source: USACE, 1996.

FIGURE 2.1

TS SAMPLING LOCATIONS

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

TABLE 2.1
SUMMARY OF TREATABILITY STUDY ACTIVITIES
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Location	Monitoring Well/Point Installation	Slug Test Analysis	Soil TOC[a] Analysis	Groundwater and Surface Water Analyses														
				CAHs[b]	Aromatic VOCs[c] 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_2[j]	CO_2[k]	Phenols	Fatty Acids	Metals
OU-1-01		X[l]		X	X	X	X	X	X	X	X	X	X	X	X	X	X	
OU-1-02				X	X	X	X	X	X	X	X	X	X	X	X	X	X	
OU-1-03				X	X	X	X	X	X	X	X	X	X	X	X			
OU-1-04				X	X	X	X	X	X	X	X	X	X	X	X			
OU-1-05	X			X	X	X	X	X	X	X	X	X	X		X			
OU-1-06	X		X	X	X	X	X	X	X	X	X	X	X					
OU-1-TW1	X		X	X	X		X	X	X	X	X	X	X		X			
OU-1-TW2	X		X	X	X		X	X	X	X	X	X	X					
OU-1-TW3	X		X	X	X	X	X	X	X	X	X	X	X		X			
OU-1-TW4	X			X		X	X	X	X	X	X	X	X					
OU-1-TW5	X			X	X	X	X	X	X	X	X	X	X		X			
OU-1-TW6	X			X	X	X	X	X	X	X	X	X	X		X			
OU-1-TW7	X		X															
OU-1-TW8	X			X	X		X	X	X	X	X	X	X					
OU-1-TW9	X			X	X	X	X	X	X	X	X	X	X		X			
OU-1-TW10	X			X	X	X	X	X	X	X	X	X	X					
OU-1-TW11	X																	
OU-1-TW13	X			X	X	X	X	X	X	X	X	X	X		X			
OU-1-TW14	X			X														
OU-1-TW15	X			X	X	X	X	X	X	X	X	X	X		X			
WL018				X	X	X	X	X	X	X	X	X	X	X	X			
WL019				X	X	X	X	X	X	X	X	X	X	X	X			
WL020				X	X	X	X	X	X	X	X	X	X	X	X			
WL021				X	X	X	X	X	X	X	X	X	X	X	X			
WL022				X	X	X	X	X	X	X	X	X	X	X	X			
WL060		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	
WL061		X		X	X	X	X	X	X	X	X	X	X	X	X			
WL062		X		X	X	X	X	X	X	X	X	X	X	X	X			

TABLE 2.1 (concluded)
SUMMARY OF TREATABILITY STUDY ACTIVITIES
OU1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Location	Monitoring Well/Point Installation	Slug Test Analysis	Soil TOC[a/] Analysis	Groundwater and Surface Water Analyses														
				CAHs[b/]	Aromatic VOCs[c/] 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/]	Phenols	Fatty Acids	Metals
SB10WS																		
SB10WD																		
SB11WS																		
SB11WD				X		X	X	X	X	X	X	X	X		X			
SB15WS				X		X	X	X	X	X	X	X	X	X	X			
SB15WD																		
SB16WS																		
SB16WD																		
RV001				X	X													
RV002				X	X													
RV003				X	X													
RV004				X	X													
RV005				X	X													

[a/] TOC = Total organic carbon.

[b/] CAHs = Chlorinated volatile organics.

[c/] VOCs = Volatile organic compounds.

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

[e/] Mobile lab analyses include reduction-oxidation potential, pH, total alkalinity, ferrous iron, pH, 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.

TABLE 2.2
MONITORING WELL AND POINT COMPLETION SUMMARY
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Location	Well Installation Date	Ground Elevation (ft amsl)[a/]	Top of Casing Elevation (ft amsl)	Total Depth (ft btoc)[b/]	Total Depth (ft bls)[c/]	Depth to Screen		Top of Screen Elevation (ft amsl)	Screen Length (ft)	Well Diameter (inches)
						Top (ft bls)	Bottom (ft bls)			
OU-1-01	Sep-96	1351.96	1354.50	24.5	22.0	6.0	21.0	1346.0	15.0	4.0
OU-1-02	Sep-96	1352.10	1354.61	27.5	25.0	6.0	23.5	1346.1	17.5	2.0
OU-1-03	Sep-96	1352.72	1355.04	27.8	25.5	6.1	23.6	1346.6	17.5	2.0
OU-1-04	Sep-96	1352.22	1354.51	27.3	25.0	6.1	23.6	1346.1	17.5	2.0
OU-1-05	Apr-97	1352.21	1354.43	30.7	28.5	22.9	27.9	1329.3	5.0	2.0
OU-1-06	Apr-97	1348.00	1350.43	25.8	23.4	18.1	23.1	1329.9	5.0	2.0
OU-1-TW1	Apr-97	1356.00	1355.81	15.9	16.1	12.9	16.1	1343.2	3.2	0.5
OU-1-TW2	Apr-97	1348.00	1347.76	14.0	14.2	11.0	14.2	1337.1	3.2	0.5
OU-1-TW3	Apr-97	1353.09	1352.80	12.7	13.0	9.8	13.0	1343.3	3.2	0.5
OU-1-TW4	Apr-97	1346.62	1346.54	8.1	8.2	5.0	8.2	1341.7	3.2	0.5
OU1-TW5	Apr-97	1343.23	1342.89	11.8	12.1	8.9	12.1	1334.4	3.2	0.5
OU-1-TW6	Apr-97	1341.74	1341.33	12.8	13.2	10.0	13.2	1331.8	3.2	0.5
OU-1-TW7	Apr-97	1340.07	1339.53	12.3	12.8	9.6	12.8	1330.5	3.2	0.5
OU-1-TW8	Apr-97	1350.04	1349.78	14.9	15.2	12.0	15.3	1338.1	3.2	0.5
OU-1-TW9	Apr-97	1352.97	1352.55	13.4	13.8	10.6	13.8	1342.4	3.2	0.5
OU-1-TW10	Apr-97	1342.80	1342.42	8.0	8.4	5.2	8.4	1337.7	3.2	0.5
OU-1-TW11	Apr-97	1348.52	1348.18	11.1	11.4	8.2	11.4	1340.4	3.2	0.5
OU-1-TW13	Apr-97	1342.37	1342.33	13.1	13.1	9.9	13.1	1332.5	3.2	0.5
OU-1-TW14	Apr-97	1342.52	1342.22	11.6	11.9	8.7	11.9	1333.9	3.2	0.5
OU-1-TW15	Apr-97	1349.72	1349.51	17.1	17.3	14.1	17.3	1335.7	3.2	0.5
000IU1-MW1	May-97	1352.6	1355.8	45.2	42.0	37.0	42.0	1315.6	5.0	2.0
WL018	Apr-89	1353.14	1356.39	27.7	24.4	7.3	21.3	1345.8	14.0	2.0
WL019	Apr-89	1354.12	1356.62	25.5	23.0	6.1	20.1	1348.0	14.0	2.0
WL020	Apr-89	1359.08	1362.37	29.4	26.1	9.0	23.0	1350.1	14.0	2.0
WL021	Apr-89	1351.94	1354.36	26.0	23.6	6.7	20.7	1345.2	14.0	2.0
WL022	Apr-89	NA[d/]	1354.53	NA	23.5	6.8	20.8	NA	14.0	2.0
WL060	Aug-93	1344.67	1346.81	15.6	13.5	8.0	13.0	1336.7	5.0	2.0
WL061	Aug-93	1337.07	1340.92	37.9	34.0	28.5	33.5	1308.6	5.0	2.0
WL062	Aug-93	1338.21	1340.80	21.6	19.0	8.5	18.5	1329.7	10.0	2.0
SB10WS	Oct-96	1355.64	1355.32	12.0	12.3	9.0	12.0	1346.6	3.0	0.5
SB10WD	Oct-96	1355.64	1355.27	21.3	21.7	18.0	21.0	1337.6	3.0	0.5
SB11WS	Oct-96	1351.88	1351.66	11.8	12.0	8.8	11.8	1343.1	3.0	0.5
SB11WD	Oct-96	1351.88	1351.58	20.0	20.3	17.0	20.0	1334.9	3.0	0.5
SB15WS	Oct-96	1355.11	1355.01	7.0	7.1	4.0	7.0	1351.1	3.0	0.5
SB15WD	Oct-96	1355.11	1355.01	18.2	18.3	15.3	18.3	1339.8	3.0	0.5
SB16WS	Oct-96	1357.71	1357.52	12.3	12.4	9.3	12.3	1348.4	3.0	0.5
SB16WD	Oct-96	1357.71	1357.42	24.1	24.4	21.1	24.1	1336.6	3.0	0.5

[a] ft amsl = Feet above mean sea level.

[b/] ft btoc = Feet below top of casing.

[c/] ft bls = Feet below land surface.

[d/] NA = Not available.

rapid collection of soil, soil gas, and groundwater samples at shallow depths while minimizing the generation of investigation-derived waste (IDW) materials. Figure 2.2 is a diagram of the Geoprobe® system.

Geoprobe®-related field work occurred from April 7 through 15, 1997, and consisted of soil characterization, soil sample collection, and groundwater monitoring point installation at monitoring points OU-1-TW1 through OU-1-TW3, OU-1-TW6 through OU-1-TW9, OU-1-TW13, and OU-1-TW15. These activities were performed according to the procedures described in the work plan (Parsons ES, 1997) and in the following sections. The term "monitoring point" is used in this report to distinguish these groundwater monitoring stations from conventionally constructed monitoring wells.

Six locations proposed for monitoring points were inaccessible to the Geoprobe® system due to heavy rain. Monitoring points OU-1-TW4, TW5, TW10, TW11, and TW14 were installed by hand-driving the boreholes at the proposed locations. Attempts were made to install OU-1-TW12 in a hand-driven borehole, but the PVC well could not be installed because of borehole collapse.

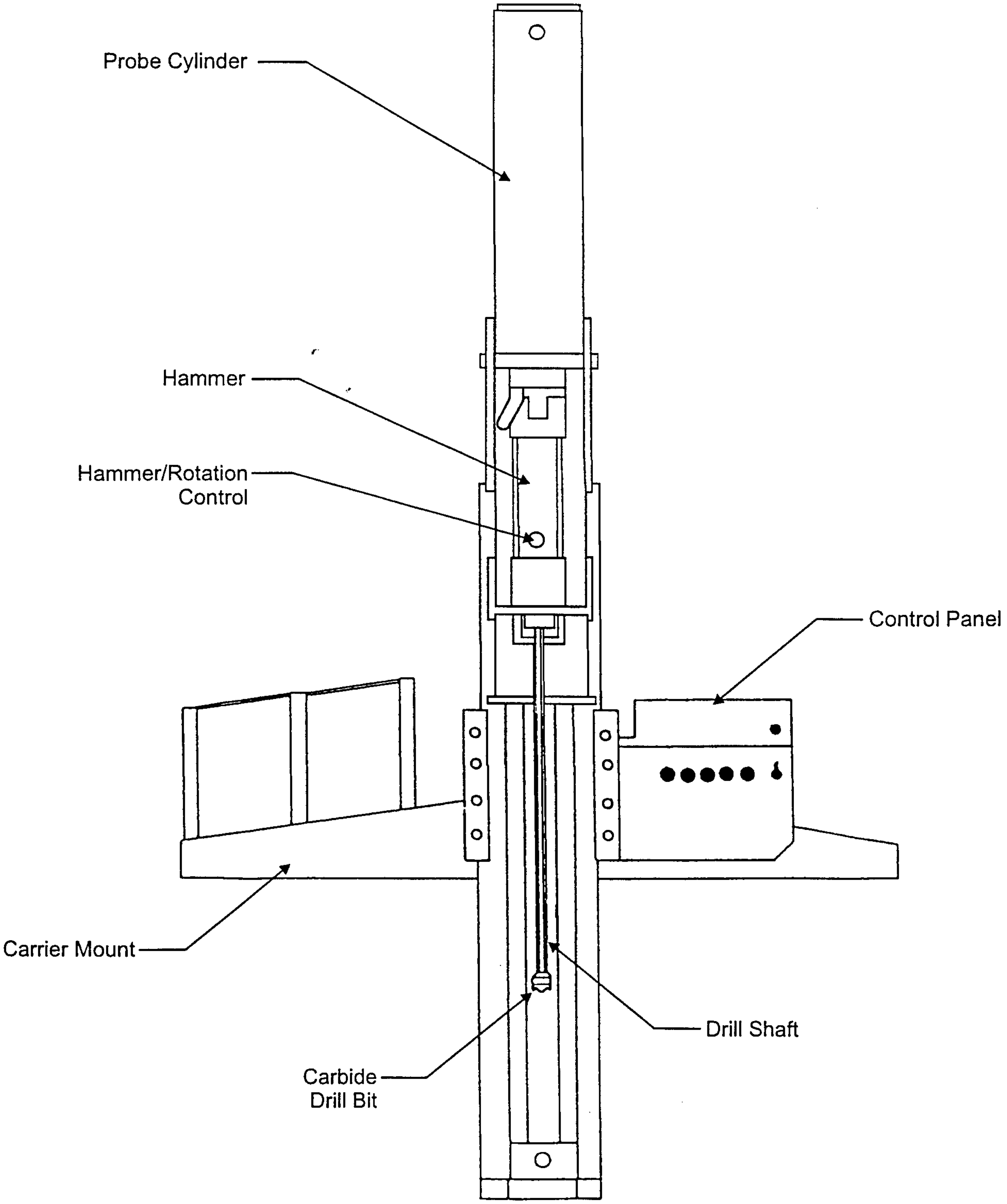
2.1.2.1 Equipment Decontamination

Prior to arriving at the site and between each monitoring point location, all probe rods, tips, sleeves, pushrods, samplers, tools, and other downhole equipment were decontaminated using an Alconox® detergent and potable water solution followed by a potable water rinse. Water used in equipment cleaning was obtained from an on-Base potable water supply.

2.1.2.2 Soil Sample Collection and Analysis

Soil samples were collected using a Geoprobe® drive sampler as boreholes were advanced at each monitoring point location. The probe-driven sampler serves as both the driving point and the sample collection device and is attached to the leading end of the probe rods. To collect a soil sample, the sampler was pushed or driven to the desired sampling depth, and the stop pin was removed, allowing the piston and drive point to retract as the sample barrel was pushed into undisturbed soil. The soil cores were retained within a clear, acetate liner inside the sampling barrel. The probe rods were then retracted, bringing the sampling device to the surface.

At each soil borehole location, soil samples were collected and logged at a frequency of at least every 5 feet. After visual examination, the soil sample was extruded from the liner, transferred to analyte-appropriate jars, and submitted to NRMRL for total organic carbon (TOC) analysis using methods RSKSOP-102 and RSKSOP-120. In addition, a portion of the soil sample 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



NOT TO SCALE

FIGURE 2.2

CROSS-SECTION OF GEOPROBE®

OU-1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

isobutylene calibration standard. The PID also was used to monitor for VOCs in the worker breathing zone.

Screening results indicate that none of the soil samples had headspace with VOC concentrations above 15 parts per million by volume (ppmv); therefore, soil samples were sent to the NRMRL for TOC analysis only. Soil samples could not be obtained from the hand-driven boreholes.

The Parsons ES field scientist observed Geoprobe® sampling and monitoring point installation activities and maintained a descriptive log of subsurface materials recovered. Final geologic borehole logs are presented in Appendix B. The excess soils generated during monitoring point installation and sampling were drummed along with the soils generated during monitoring well installation to await transport, sampling, analysis, and disposal by the Base.

2.1.2.3 Monitoring Point Installation

Groundwater monitoring points were installed in 14 boreholes under this program. Detailed monitoring point installation procedures are described in the following paragraphs.

2.1.2.3.1 Materials

Monitoring point completion materials were inspected by a Parsons ES field scientist and determined to be clean and acceptable prior to use. All monitoring point completion materials were factory-sealed in plastic wrap. Pre-packaged casing, sand, bentonite, and concrete mix were used in point construction, and the bags were inspected for possible external contamination before use. Materials that could not be cleaned to the satisfaction of the field scientist were not used.

2.1.2.3.2 Installation

Boreholes were advanced using a 2.5-inch outside-diameter (OD) Geoprobe® pre-probe, a 1-inch-OD Geoprobe® soil sampler, or 1-inch-OD rods used for hand-driving boreholes. The monitoring points were constructed of Schedule 40 polyvinyl chloride (PVC) riser pipe connected to factory-slotted PVC screens having an inside diameter (ID) of 0.5 inch. The PVC points were placed into the boreholes after the pre-probe, soil sampler, or rod was extracted. All PVC casing and screen sections on the monitoring points were flush-threaded; glued joints were not used. The riser pipe at each monitoring point was fitted with a PVC slip cap. The bottom of the screen was fitted with a metal tip and a seal was created with a rubber o-ring. Monitoring point screens constructed of PVC were 3.2 feet long, and factory-slotted with 0.010-inch openings. Collapsing soils prevented the placement of the PVC screen and riser after extraction of the 1-inch-OD rods during the attempted installation of OU-1-TW12.

The field scientist verified and recorded the borehole depth and the lengths of all casing and screen sections. All lengths and depths were measured to the nearest 0.1 foot. Monitoring point construction records are included in Appendix B. Monitoring point construction details are summarized in Table 2.2.

2.1.2.3.3 Development

Before being sampled, newly installed monitoring points were developed. Typically, 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. Use of the Geoprobe® system to place monitoring points eliminates cuttings and drilling fluids. Therefore, development of monitoring points was primarily intended to minimize the amount of fine sediment that might accumulate in the casing.

Development was accomplished using a peristaltic pump with dedicated silicon and high-density polyethylene (HDPE) tubing. The pump tubing was regularly lowered to the bottom of the monitoring points so that fines were agitated and removed from the point in the development water. Development was continued until at least 10 casing volumes of water were removed, and the pH, temperature, dissolved oxygen (DO), oxidation/reduction potential (ORP), and conductivity of the groundwater had stabilized or until the monitoring point had been purged dry. Monitoring point development records are included in Appendix B.

2.1.3 Hollow-Stem Auger Drill Rig Field Activities

Subsurface conditions at the site were characterized and two new monitoring wells were installed in boreholes advanced by USEPA personnel using a hollow-stem auger rig from April 7 through April 16, 1997. Boring logs and monitoring well installation records for the two newly installed monitoring wells (OU-1-05 and OU-1-06) are included in Appendix B.

2.1.3.1 Equipment Decontamination

Prior to arriving at the site and after drilling each soil boring, augers and push rods were cleaned with the hollow-stem auger rig's steam-cleaning system. Water used in equipment cleaning was obtained from an on-Base potable water supply. Equipment cleaning was performed at a bermed decontamination pad constructed of concrete. Rinseate drained from the pad and flowed onto an adjacent field.

2.1.3.2 Soil Sample Collection and Analysis

The hollow-stem auger rig was used to collect soil samples for visual description, VOC screening, and TOC analysis during the installation of monitoring wells OU-1-05 and OU-1-06 in April 1997 (Figure 2.1). The samples were collected from multiple depths. Discrete soil samples were collected using a drive barrel fitted with an acetate liner.

Soils generated while using the hollow-stem auger rig were drummed to await transportation to a central staging area, chemical analysis, and proper disposal by Altus AFB, in accordance with the Base's IDW management plan.

2.1.3.3 Monitoring Well Installation

Using the hollow-stem auger drill rig, Parsons ES and USEPA staff installed two 2-inch-ID monitoring wells in hollow-stem auger boreholes in the vicinity of OU-1. These wells are designated OU-1-05 and OU-1-06.

2.1.3.3.1 Materials

Monitoring wells were constructed of flush-threaded 2-inch-ID, 2.25-inch-OD, PVC casing and screen. Installed screens were 4.5 feet in length and factory-slotted with 0.010-inch openings. Each monitoring well 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 materials.

2.1.3.3.2 Installation

Monitoring wells were installed through the inside of the 4.25-inch-ID, 8.25-inch-OD, steel casing. This method allowed the monitoring well screen and casing to be placed in the borehole at the desired depth without experiencing difficulties related to borehole collapse. After the monitoring well screen and riser pipe were in place, the annular backfill materials were added through the casing as it was gradually removed from the borehole. Monitoring wells were completed by filling the borehole around the well with 10/20-grade sand, bentonite chips, and cement grout. The tops of the wells were fitted with expandable, locking well caps. Monitoring well completion logs are included in Appendix B.

2.1.3.3.3 Development

Prior to sampling, newly installed monitoring wells 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 development was accomplished using a peristaltic pump with new dedicated or decontaminated (Section 2.1.4) HDPE tubing or a two-stage downhole pump with dedicated PVC tubing. The pump tubing (or pump) was lowered to the bottom of the well so that fines were agitated and removed from the well in the development water. Development was continued until the well purged dry at least three times or 10 casing volumes were removed from the monitoring well and the temperature, pH, ORP, conductivity, and DO concentrations of the extracted groundwater had stabilized. Monitoring well development records are included in Appendix B.

All development water was contained in 55-gallon drums and screened with a PID. All development water had headspace PID screening results of less than 5 ppmv and was, therefore, stored in a centralized location to await disposal in the sanitary sewer by Base personnel.

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 during April 1997, and consisted of collecting groundwater samples from 12 previously installed wells, 2 previously installed monitoring points, 13 newly installed monitoring points, and 2 newly installed monitoring wells. Due to difficulties with groundwater yield, samples from several monitoring points were not analyzed for all parameters. Refer to Table 2.1 for analyses conducted for each monitoring well and point.

2.2.1 Preparation and Equipment Cleaning

All equipment used for sampling was assembled and 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 well or shallow monitoring points, 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). Based on these measurements and previously-recorded well depths, the volume of water to be purged from the wells and points was estimated.

2.2.3 Monitoring Well/Point Purging

Where possible, three times the calculated casing volume was removed from each monitoring well and point prior to sampling. 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. A peristaltic pump with dedicated silicone and HDPE tubing was used for well and point evacuation. All purge water from monitoring points and wells was collected in 55-gallon drums. All purge water had a PID headspace screening result of 5 ppmv or less and, therefore, was released to the Base for disposal into the sanitary sewer.

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 an Orion® Model 840 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, dissolved hydrogen, ferrous iron, alkalinity, and hydrogen sulfide, were analyzed at the USEPA mobile laboratory immediately after sample collection.

2.2.5 Sample Collection

A peristaltic pump with dedicated silicone and HDPE tubing was used to extract groundwater samples from monitoring points and wells. The dedicated HDPE tubing was lowered down the casing to approximately the middle of the screened interval. 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 (VFAs) 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 SURFACE WATER SAMPLING

In addition to soil and groundwater sampling, five surface water samples (RV-001 through RV-005) were collected from the drainage canal north of LF-04 and from

TABLE 2.3
ANALYTICAL METHODS FOR GROUNDWATER, SURFACE WATER, SOIL, AND SEDIMENT SAMPLES
OU5 RNA TS
OFFUTT AFB, NEBRASKA

MATRIX/PARAMETER	METHOD	ANALYTICAL LABORATORY
GROUNDWATER		
Phenols, Aliphatic/Aromatic Acids	RSKSOP-177	NRMRL[a/]
Phenol	CHEMetrics Method 4AAP	Field
Dissolved Hydrogen	Reduction Gas Analyzer	Field
Ferrous Iron (Fe+2)	Colorimetric, Hach Method 8146	Field
Manganese	Colorimetric, Hach Method 8034	Field
Sulfate	N-601 [b/]	NRMRL
Nitrate + Nitrite (as Nitrogen)	E353.1	NRMRL
Oxidation-Reduction Potential	Direct-reading meter	Field
Dissolved Oxygen	Direct-reading meter	Field
pH	Direct-reading meter	Field
Conductivity	Direct-reading meter	Field
Temperature	Direct-reading meter	Field
Alkalinity (Carbonate [CO3-2] and Bicarbonate [HCO3-1])	Titrimetric, Hach Method 8221	Field
Hydrogen Sulfide	Colorimetric, Hach Method 8131	Field
Carbon Dioxide	CHEMetrics Method 4500	Field
Chloride	N-601 [b/]	NRMRL
Ammonia--Diss. Gas in Water	E350.1	NRMRL
Methane	RSKSOP-175/RSKSOP-147	NRMRL
Ethene	RSKSOP-175/RSKSOP-147	NRMRL
Total Organic Carbon	RSKSOP-102	NRMRL
Aromatic Hydrocarbons (Including Trimethylbenzenes and Tetramethylbenzene) + Fuel Carbon	RSKSOP-133	NRMRL
Metals	ICP, GFAA (lead only) [c/]	NRMRL
Chlorinated Volatile Organics	RSKSOP-146	NRMRL
SURFACE WATER		
Volatile Organics	RSKSOP-146	NRMRL
SOIL		
Total Organic Carbon	RSKSOP-102/RSKSOP-120	NRMRL
SEDIMENT		
Total Organic Carbon	RSKSOP-102/RSKSOP-120	NRMRL
Aromatic Hydrocarbons	RSKSOP-124	NRMRL

a/ USEPA National Risk Management Research Laboratory in Ada, Oklahoma.

b/ Waters capillary electrophoresis Method N-601.

c/ ICP = Inductively Coupled Plasma Spectrometry; GFAA = Graphite Furnace Atomic Absorption.

Stinking Creek west and southwest of LF-04 (Figure 2.1) in April 1997. These samples were collected in order to assess the impact of groundwater discharge on surface water quality. The surface water samples were analyzed for CAHs, BTEX, TMBs, and fuel carbon (Table 2.1).

Surface water samples were collected directly into the sample bottle by placing the sample bottle in the creek with the opening facing up and allowing the water to slowly fill the bottle. Sample handling proceeded as described for groundwater samples in Section 2.4.

2.4 SAMPLE HANDLING

The fixed-base analytical laboratory, NRMRL, provided pre-preserved sample containers where appropriate. The sample containers were filled as described in Sections 2.1.2.1, 2.1.3.1, 2.2.2.4, and 2.3. 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.

2.5 AQUIFER TESTING

Slug tests were performed at LF-04 by Parsons ES in April 1997. Falling and rising head slug tests were performed at monitoring wells OU-1-01 and WL-060 through WL-062. 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 & Miller, Inc., 1994) and the methods of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. These slug test results are presented in Section 3.4 and Appendix B of this document.

2.6 SURVEYING

After completion of field work, the locations and elevations of all new monitoring points and wells were surveyed by North Fork Surveying and Drafting, an Oklahoma-licensed land surveyor from Snyder, 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 Oklahoma State plane coordinate system. Horizontal locations were surveyed to the nearest 0.01 foot. Measurement datum and ground surface elevations were surveyed to the nearest 0.01 foot. Survey data are presented in Appendix B.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section incorporates data presented by USGS (1992 and 1996), USACE (1992 and 1996), OHM Remediation Services Corp. (OHM, 1996), and TARGET (1993) with data collected by Parsons ES in collaboration with researchers from the USEPA NRMRL in April 1997. Investigative procedures used to determine the physical characteristics of the LF-04 area of Altus AFB during this RNA TS are discussed in Section 2.

3.1 SURFACE FEATURES

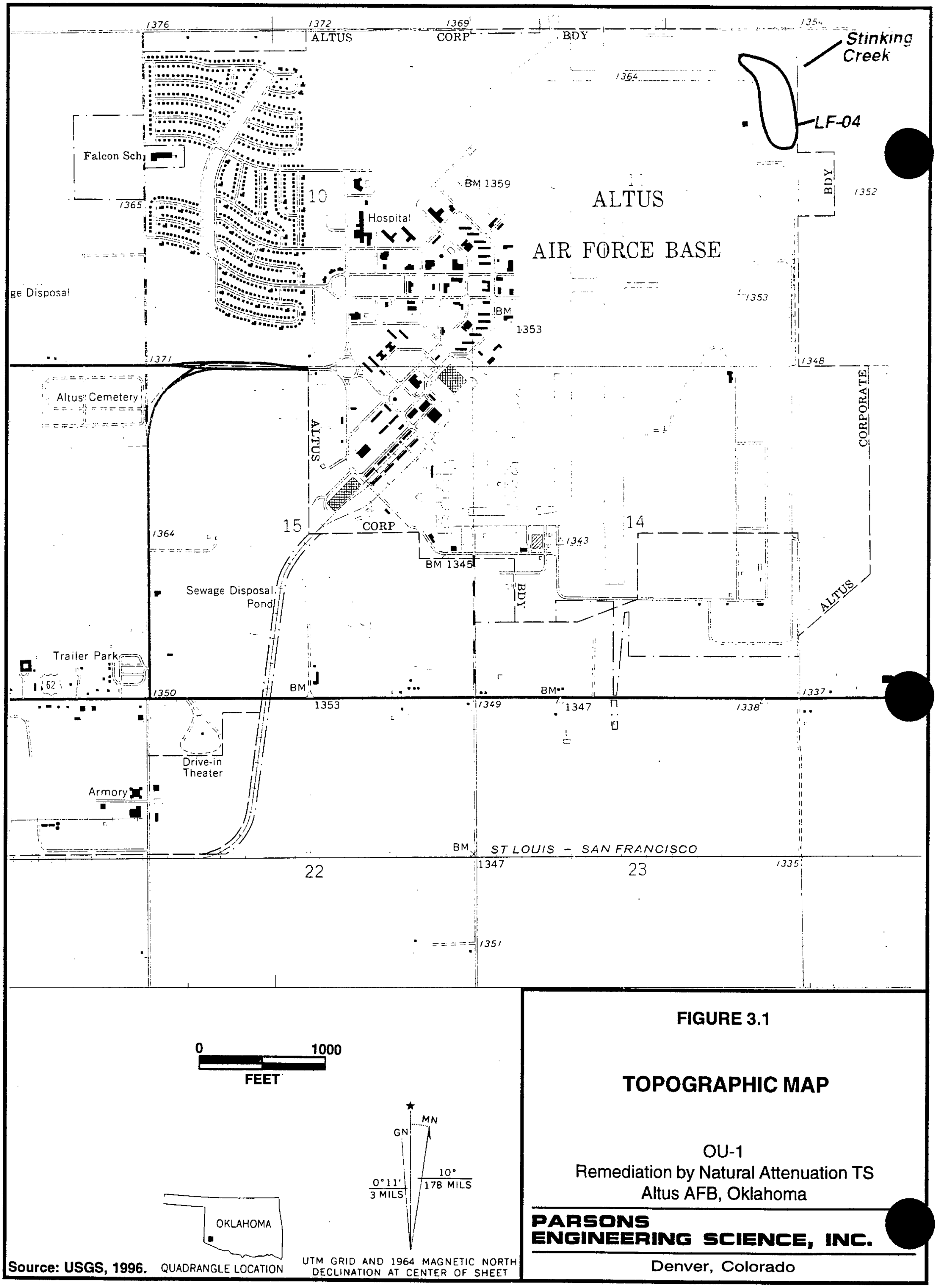
3.1.1 Topography

Information pertaining to topography and surface hydrology is based on a review of the Phase II RI (USGS, 1996). Altus AFB is located in the Central Redbed Plains (Curtis and Ham, 1972). The plains are characterized by a gently sloping land surface. Base surface elevations range from 1,330 to 1,390 feet above mean sea level (ft amsl) (USGS, 1996). Relief in the area of LF-04 has resulted from stream erosion and landfill and runway construction. The local topography slopes to the east-southeast with approximately 10 feet of relief across the LF-04 site (Figure 3.1).

3.1.2 Surface Water Hydrology

Runoff from LF-04 is drained by Stinking Creek (Figure 3.1). Stinking Creek, temporarily diverted during construction of the C-17 runway, has been returned to its original channel, except that the creek now flows beneath Taxiway "M" and Runway 17L via a concrete culvert. Other ditches have been dug to collect surface water drainage from the area and channel the flow into Stinking Creek (Figure 1.4). Flow velocity was measured by placing a floating object in the middle of the stream and recording the time it took to travel a premeasured distance. Flow velocity data was collected at five locations (RV001 through RV005) in Stinking Creek in the LF-04 area (Figure 2.1). Surface flow velocity ranged from no flow at location RV001 to 1 foot per second at RV003. The average flow velocity of Stinking Creek, estimated as 85 percent of the surface flow velocity (Daugherty and Franzini, 1977), ranged from 0.0 to 0.85 feet per second.

The Ozark 4.6 Lateral irrigation canal flows southeastward between LF-04 and FT-03 (Figure 1.4), forming the western boundary of LF-04. The irrigation canal receives no drainage from Altus AFB, and flow in the canal occurs only during the irrigation season, from June to August; at other times the canal is dry or ponded.



Source: USGS, 1996.

FIGURE 3.1

TOPOGRAPHIC MAP

OU-1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

3.1.3 Manmade Features

Manmade features in the area of study include an access road, Perimeter Road, Taxiways E2 and M, Runway 17L, and parking lots (Figure 2.1). No buildings are located within LF-04 or immediately downgradient (southeast). Various buildings are located west and south of (up- and crossgradient from) the LF-04 area.

3.1.4 Vegetation

Vegetation on the site consists largely of grasses in the area of LF-04. A plowed field lies to the east of Runway 17L. Areas of pavement and vegetation were taken into account during conceptual model development.

3.2 CLIMATE

The climate at Altus AFB is continental, characterized by cold winters, hot summers, and moderate rainfall. Average daily temperatures range from 39 degrees Fahrenheit (°F) in January to greater than 80°F in July and August. It is common for high temperatures in June, July, August, and September to exceed 100°F.

Precipitation occurs primarily as thunderstorms during spring. May is generally the wettest month of the year, with an average rainfall of about 5 inches. The mean annual Base precipitation is approximately 25 inches. Annually, potential evaporation usually exceeds precipitation. Maximum evaporation occurs during June, July, and August (ES, 1985).

3.3 REGIONAL GEOLOGY AND HYDROGEOLOGY

Regional sediments are of Mississippian, Pennsylvanian, and Permian ages, consisting mostly of sandstones and shales surrounding the nearby Wichita Mountain granite (Denison *et al.*, 1964). These sediments are up to 7,000 feet thick. The Base is underlain almost entirely by the Hennessey Group of Permian age, except in the northern portion of the Base where unconsolidated terrace deposits are present. The estimated regional dip of the Hennessey Group is to the west at less than 1 degree (Sears, 1951). The Hennessey Group in southwestern Oklahoma ranges in thickness from 200 to 1,000 feet, and consists of reddish-brown shale with thin interbeds of siltstone and sandstone (Johnson, 1967; Havens, 1977). The uppermost 5 to 40 feet of the formation is predominantly yellowish-gray, buff, tan, orange, yellow, or greenish gray shale. Locally, the Hennessey Group contains gypsum veins composed of satin spar and selenite crystals.

Surface soils overlying the Hennessey Group at Altus AFB consist of three major types: Tillman/Hollister, Miles, and Altus. Tillman/Hollister soil consists of clay loams with 0 to 1 percent slopes and is the most extensive unit in Jackson County (Bailey and Graft, 1961). The Tillman/Hollister soil type has a reddish-brown, granular, clay loam surface layer, underlain by a more clayey and block-structured subsoil, with respective thicknesses of approximately 10 and 18 inches. The Miles soil type is characterized by a fine, sandy loam surface soil and a reddish-brown, sandy clay loam subsoil, with thicknesses of approximately 10 and 44 inches, respectively. Both layers are friable, noncalcareous, and neutral to mildly alkaline. The Altus soil type consists of dark grayish-brown, friable, fine sandy loam at the surface. The subsoil, approximately 2 feet thick, is a moderately tight, brown sandy clay. Material beneath the subsoil is generally a stiff calcareous clay containing many soft carbonate concretions. The thickness of the surface soils generally ranges from 10 to 25 feet. Observations made while drilling boreholes during the Phase II RI described the surficial 20 feet as clay or silty clay, and deeper than 20 feet bls as shale or silty shale (USGS, 1996).

The primary hydrogeologic unit on and near Altus AFB is the Hennessey Group. On the Base, two water-bearing zones have been encountered in the upper 42 feet. The depths of the two water-bearing zones coincide with the two distinct lithologic layers, the less-consolidated clay material extending to a depth of 20 to 30 feet bls, and the underlying layer of well-cemented, better-lithified shale of the Hennessey Group.

Shallow groundwater generally flows to the southeast at the Base. Depth to water on the Base ranges from less than 1 foot to 13 feet bls. The groundwater surface generally reflects surface topography. Groundwater flow is generally toward drainage canals and Stinking Creek. The hydraulic gradient from the northwestern corner of the Base to the southeastern corner was 0.0033 foot per foot (ft/ft) in January 1993 (USGS, 1996).

3.4 LF-04 GEOLOGY AND HYDROGEOLOGY

Site-specific geologic and hydrogeologic information was obtained primarily from the Phase I RI (USGS, 1992), the SCAPS report (USACE, 1996), and the Current Conditions Report (OHM, 1996). New information gathered during TS site activities in April 1997 was used to confirm and augment the results of the previous investigations. Construction details for monitoring wells and points installed during the Phase I RI and the TS are summarized in Table 2.2. Geologic boring logs and monitoring point and well construction diagrams for activities conducted during the TS in April 1997 are included in Appendix B.

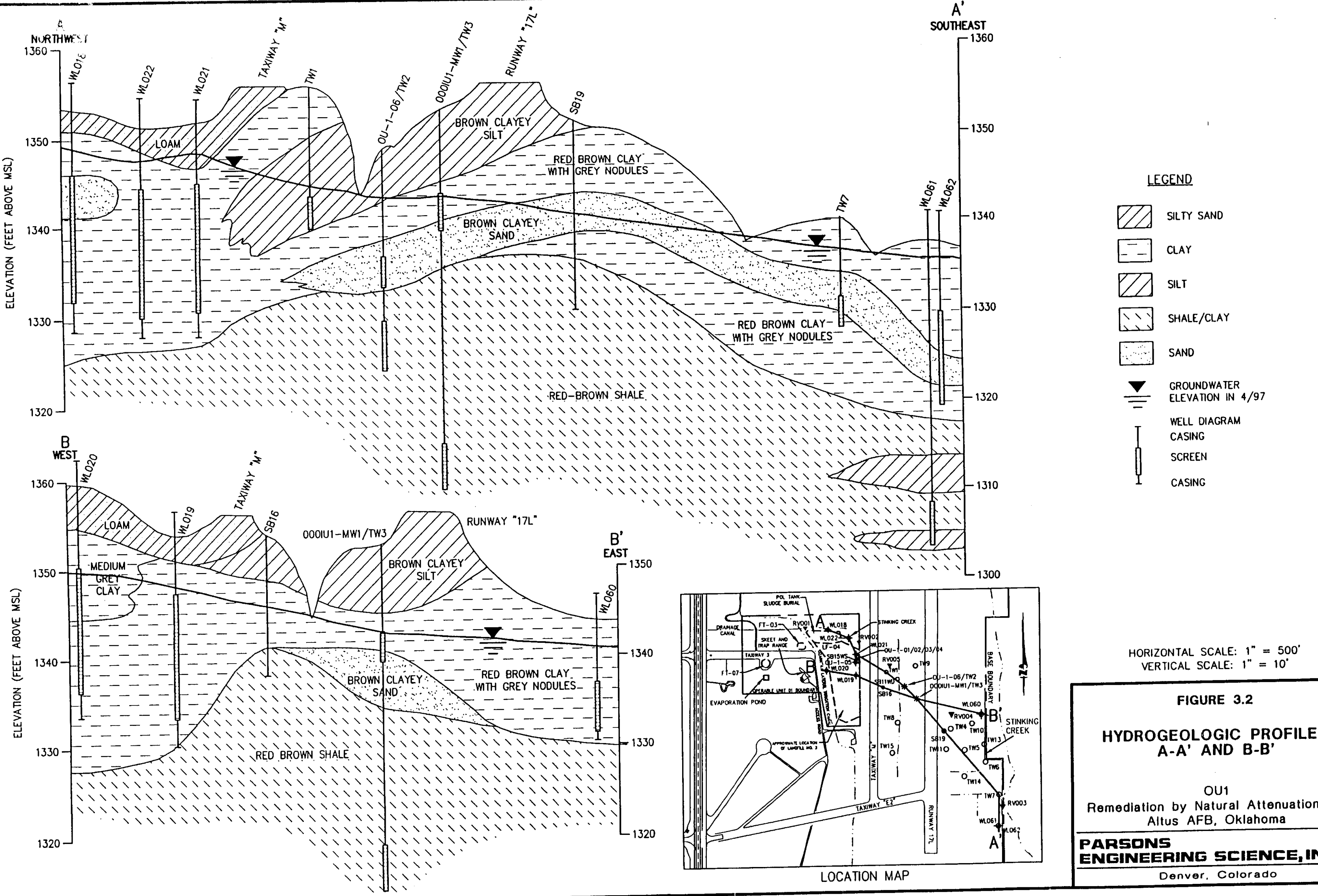
3.4.1 Lithology and Stratigraphic Relationships

Two hydrogeologic profiles were constructed using data collected during the Phase I RI (USGS, 1992) in conjunction with data from the SCAPS investigation (USACE, 1996) and the TS. The profile locations and profiles are shown on Figure 3.2. A red-brown shale is encountered at approximately 10 to 20 feet bls in the area of LF-04. Overlying the shale is a layer of saprolitic, red-brown clay with gray nodules and green-gray lenses. Where the clay does not extend to the land surface, it is overlain with a loam or brown silty sand. A discontinuous 3- to 5-foot clayey sand layer was detected between 7 and 20 feet bls east of taxiway "M".

The boundaries of LF-04 were investigated during the Initial Landfill Investigation (USACE, 1992). The approximate boundaries of LF-04 are shown on Figure 1.4. The depth of the landfill deposits was estimated to be 7 feet.

3.4.2 Groundwater Hydraulics

The unconfined surficial aquifer at LF-04 is encountered within the two main lithologic units discussed above: the unconsolidated clay and the deeper, more competent shale. The following is a discussion of the hydraulic parameters of the surficial aquifer specific to the LF-04 site. As shown on Figure 3.2, the depth to groundwater in the



HORIZONTAL SCALE: 1" = 500'
VERTICAL SCALE: 1" = 10'

FIGURE 3.2

HYDROGEOLOGIC PROFILES A-A' AND B-B'

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

immediate vicinity of LF-04 ranged from 6 to 10 feet bgs in April 1997. The depth to groundwater decreases as ground surface elevation decreases toward the east.

3.4.2.1 Flow Direction and Gradient

Table 3.1 presents groundwater elevation data collected in 1992 and 1993, and data collected by Parsons ES in April 1997. A water table map (Figure 3.3) of the LF-04 area was constructed using the April 1997 data. The map indicates that the groundwater flow direction is toward the east and southeast, with a possible convergent divide along Stinking Creek. A convergent divide would suggest either discharge to the creek or a preferential groundwater flow pathway along the creek channel. The lateral hydraulic gradient was approximately 0.003 ft/ft along the primary plume axis in April 1997. The flow of groundwater toward Stinking Creek may be attributed to the large amount of recharge from precipitation in the weeks preceding the investigation. It is possible that through most of the year, groundwater flows parallel to the creek, with the creek acting as a divergent divide during more arid seasons.

Vertical hydraulic gradients were calculated using April 1997 groundwater elevation data for well clusters; these data are summarized in Table 3.2. The well clusters include OU-1-06/TW2, WL061/WL062, SB10WS/D, SB11WS/D, SB15WS/D, and SB16WS/D. 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. A slight upward gradient (0.008 ft/ft) was measured between wells WL061 and WL062. At all other well clusters, downward gradients from 0.017 to 0.703 ft/ft in magnitude were measured.

3.4.2.2 Hydraulic Conductivity

During TS field activities, slug tests were performed in four monitoring wells to provide estimates for the hydraulic conductivity of the two water-bearing zones. The hydraulic conductivity values obtained during the TS ranged from 8.4 feet per day (ft/day) in the overburden clay to 43 ft/day in the shale bedrock (Table 3.3).

3.4.2.3 Effective Porosity

The effective porosity of a given lithology is a measure of the amount of void space available for fluid flow through the lithologic unit. Within the overburden clay, the effective porosity is estimated to be approximately 5 percent, based on accepted literature values (Spitz and Moreno, 1996). The primary porosity of the shale bedrock would be less than that of the overburden; however, secondary porosity (fractures) within the bedrock may increase the effective porosity of the shale to as high as 3 percent (Spitz and Moreno, 1996).

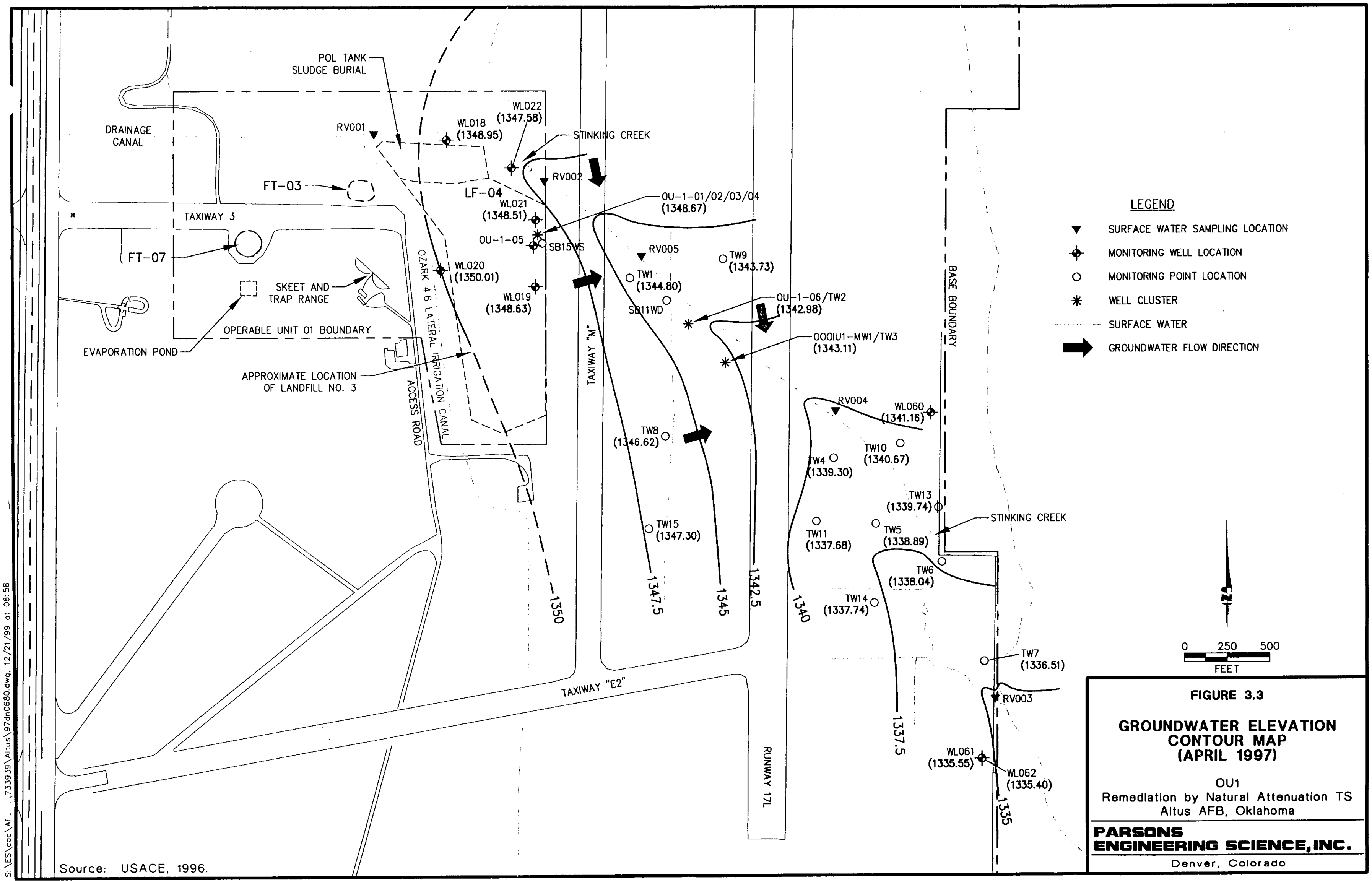
3.4.2.4 Advective Groundwater Velocity

The advective velocity of groundwater in the direction parallel to groundwater flow is given by:

TABLE 3.1
SUMMARY OF GROUNDWATER ELEVATIONS
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Location	Top of Casing Elevation (ft asml)[a/]	September 1992		October 1992		December 1992		January 1993		February 1993		March 1993		September 1993		April 1997	
		Depth to Water (ft bls)[b/]	Water Elevation (ft amsl)	Depth to Water (ft bls)	Water Elevation (ft amsl)	Depth to Water (ft bls)	Water Elevation (ft amsl)	Depth to Water (ft bls)	Water Elevation (ft amsl)	Depth to Water (ft bls)	Water Elevation (ft amsl)	Depth to Water (ft bls)	Water Elevation (ft amsl)	Depth to Water (ft bls)	Water Elevation (ft amsl)	Depth to Water (ft btoc)[c/]	Water Elevation (ft amsl)
OU-1-01	1354.50	NM[d/]	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	5.29	1349.21
OU-1-02	1354.10	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	5.43	1348.67
OU-1-03	1355.04	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	5.84	1349.20
OU-1-04	1354.51	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	5.35	1349.16
OU-1-05	1354.43	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	7.95	1346.48
OU-1-06	1350.43	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	13.07	1337.36
OU-1-TW1	1355.81	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	11.01	1344.80
OU-1-TW2	1347.76	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	4.78	1342.98
OU-1-TW3	1352.80	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	9.69	1343.11
OU-1-TW4	1346.54	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	7.24	1339.30
OU1-TW5	1342.89	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	4.00	1338.89
OU-1-TW6	1341.33	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	3.29	1338.04
OU-1-TW7	1339.53	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	3.02	1336.51
OU-1-TW8	1349.78	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	3.16	1346.62
OU-1-TW9	1352.55	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	8.82	1343.73
OU-1-TW10	1342.42	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	1.75	1340.67
OU-1-TW11	1348.18	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	10.50	1337.68
OU-1-TW13	1342.33	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	2.59	1339.74
OU-1-TW14	1342.22	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	4.48	1337.74
OU-1-TW15	1349.51	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	2.21	1347.30
WL018	1356.39	4.23	1349.29	5.03	1348.49	2.08	1351.44	2.73	1350.79	2.74	1350.78	2.31	1351.21	6.62	1346.90	7.44	1348.95
WL019	1356.62	4.97	1348.51	5.66	1347.82	2.02	1351.46	2.92	1350.56	2.95	1350.53	2.11	1351.37	9.60	1343.88	7.99	1348.63
WL020	1362.37	9.81	1349.67	11.09	1348.39	6.87	1352.61	7.57	1351.91	7.56	1351.92	7.18	1352.30	12.57	1346.91	12.36	1350.01
WL021	1354.36	2.72	1348.63	3.30	1348.05	0.69	1350.66	1.24	1350.11	1.23	1350.12	0.64	1350.71	7.56	1343.79	5.85	1348.51
WL022	1354.53	2.42	1348.81	2.98	1348.25	0.20	1351.03	0.61	1350.62	0.58	1350.65	0.22	1351.01	5.51	1345.72	6.95	1347.58
WL060	1346.81	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	6.78	1337.43	5.65	1341.16
WL061	1340.92	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	4.20	1334.03	5.37	1335.55
WL062	1340.80	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	5.07	1333.19	5.40	1335.40
SB10WS	1355.32	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	8.51	1346.81
SB10WD	1355.27	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	9.16	1346.11
SB11WS	1351.66	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	5.45	1346.21
SB11WD	1351.58	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	5.84	1345.74
SB15WS	1355.01	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	3.37	1351.64
SB15WD	1355.01	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	4.14	1350.87
SB16WS	1357.52	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	8.85	1348.67
SB16WD	1357.42	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	NM	--	8.95	1348.47

a/ ft amsl = Feet above mean sea level. b/ ft bls = Feet below land surface. c/ ft btoc = Feet below top of casing. d/ NM = Not measured



Source: USACE, 1996.

FIGURE 3.3

GROUNDWATER ELEVATION CONTOUR MAP (APRIL 1997)

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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Denver, Colorado

TABLE 3.2
VERTICAL GRADIENT CALCULATIONS
OU-1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Well	Groundwater Elevation (ft amsl[a/]) Apr-97	Bottom of Screen Elevation (ft amsl)	Top of Screen Elevation (ft amsl)	Saturated Screen Midpoint Elevation (ft amsl)	Vertical Gradient [b/] (ft/ft)
WL061	1335.55	1303.6	1308.6	1306.1	
WL062	1335.40	1319.7	1329.7	1324.7	-0.008 [c/]
SB10WS	1346.81	1343.6	1346.6	1345.1	
SB10WD	1346.11	1334.6	1337.6	1336.1	0.078
SB11WS	1346.21	1340.1	1343.1	1341.6	
SB11WD	1345.74	1331.9	1334.9	1333.4	0.057
SB15WS	1351.64	1348.1	1351.1	1349.6	
SB15WD	1350.87	1336.8	1339.8	1338.3	0.068
SB16WS	1348.67	1345.4	1348.4	1346.9	
SB16WD	1348.47	1333.6	1336.6	1335.1	0.017
OU-1-06	1337.36	1324.9	1329.9	1327.4	
OU-1-TW2	1342.98	1333.8	1337.0	1335.4	0.703

a/ ft amsl = Feet above mean sea level.

b/ $$\text{Vertical gradient} = \frac{\text{Difference in groundwater elevations of clustered wells}}{\text{Difference in elevations of saturated portions of well screens}}$$

Calculations were completed using April 1997 data.

c/ A negative value indicates upward gradient, and a positive value indicates downward gradient.

TABLE 3.3
HYDRAULIC CONDUCTIVITIES AND AVERAGE GROUNDWATER VELOCITIES
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Monitoring Well	Test Date	Soil Type[a] (USCS)	Screened Interval Elevation (ft msl)[b]	Hydraulic Conductivity (K)			Estimated Effective Porosity	Hydraulic Gradient (ft/ft)[f]	Average Groundwater Velocity (ft/day)
				(ft/day)[c]	(cm/sec)[d]	(gpd/ft^2)[e]			
OU-1-01	Apr-97	SH	1346-1331	20	7.1E-03	151	0.03	0.003	2.0
WL060	Apr-97	CL	1336.7--1331.7	8.4	3.0E-03	63	0.05	0.003	0.50
WL061	Apr-97	SH	1308.6--1303.6	43	1.5E-02	322	0.03	0.003	4.3
WL062	Apr-97	CL/SP	1329.7--1319.7	14	4.9E-03	105	0.05	0.003	0.84

[a] Dominant lithology of the screened interval [Unified Soil Classification System (USCS)].

[b] ft msl = Feet above mean sea level.

[c] ft/day = Feet per day.

[d] cm/sec = Centimeters per second.

[e] gpd/ft^2 = Gallons per day per square foot.

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

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 hydraulic conductivity (8.4 to 43 ft/day), lateral hydraulic gradient (0.003 ft/ft), and an estimated effective porosity (0.05 for clay and 0.03 for shale), the advective groundwater flow velocity in the overburden clay is calculated to be 0.50 to 0.84 ft/day [183 to 307 feet per year (ft/yr)]. The advective groundwater flow velocity in the weathered shale is calculated to be 2.0 to 4.3 ft/day (730 to 15,700 ft/yr).

3.4.3 Groundwater Use

Except for a few wells used for domestic and livestock purposes, the Hennessey Group is not a primary water source in the Altus AFB area. The Base obtains its water from the city of Altus, which obtains water from wells located 16 miles south of the Base and from Lake Altus located 15 miles north of the Base. Well yields in the area of Altus AFB vary. Monitoring wells at Altus AFB, probably screened in soils overlying the Hennessey Group, yield from less than 1 gallon per minute (gpm) to 10 gpm (USGS, 1996). There are two private wells screened in the lithified Hennessey Group near the Base (Engineering-Science, Inc. [ES], 1985). One well, located approximately 8,000 feet west of (upgradient from) LF-04, has a total depth of 60 feet, a depth to water of 19 feet, and a yield of 150 gpm. The other well, located approximately 4,000 feet north of (crossgradient from) LF-04, has a total depth of 122 feet, a depth to water of 60 feet, and a yield of 100 gpm.

SECTION 4

CONTAMINANT DISTRIBUTION AND EVIDENCE OF BIODEGRADATION

As discussed in Section 1, CAH contamination in the study area was introduced as a result of activities conducted at LF-04. The Phase I and Phase II RIs performed by USGS (1992 and 1996) and investigations by TARGET (1993) and USACE (1996) focused on defining the nature and extent of contamination at the site. Results of the investigations are useful for the objectives of this TS and are summarized in the following subsections, along with data collected during the field phase of this investigation. In particular, this section focuses on data useful for evaluating and modeling natural attenuation of CAHs.

4.1 RESULTS OF SOIL ANALYSES

4.1.1 Soil and Soil Gas Contamination

Summary soil and soil gas data from previous investigations at LF-04 are presented in Appendix A. During Phase I RI borehole drilling activities, four soil core samples were collected from each of six boreholes, screened for TPH, and analyzed for metals. Significant concentrations of TPH were detected in soils from WL022, located in the POL tank waste sludge disposal area (Figure 2.2). The TPH concentrations ranged from 530 milligrams per kilogram (mg/kg) at 5 feet bls to 2,200 mg/kg at 8 feet bls. During drilling of WL022 a black, sludge-like material was found in the 5- to 10-foot depth interval.

During the soil gas and groundwater survey (TARGET, 1993), soil gas samples were collected at four locations near LF-04 at a depth of 6 feet bls. Three locations (DC-9, DC-27, and DC-28) are north of and upgradient from LF-04, while one location (4-6) is east of and downgradient from LF-04 (Figure 2.1). The soil gas was analyzed for total volatile compounds with a flame ionization detector (FID), fuel hydrocarbons by USEPA Method SW8020, and chlorinated hydrocarbons by USEPA Methods SW8010. None of the soil gas samples contained detectable levels of total volatile compounds (by FID) or fuel hydrocarbons (by laboratory analysis). Only one soil gas sample, at downgradient location 4-6, contained a chlorinated hydrocarbon. This sample contained 2.3 μg/L of *cis*-1,2-DCE. Analytical results are included in Appendix A.

4.1.2 TS Headspace Screening Results

During the installation of monitoring wells and monitoring points as part of this TS, soil samples were screened for VOCs with a PID. The only soil samples that exhibited PID headspace readings above 10.0 ppmv were from boreholes for OU-1-05 (21.5 ppmv at 7.5 feet bls), OU-1-TW1 (13.0 ppmv at 3.5 feet bls and 15.6 ppmv at 7 feet bls), and

OU-1-TW7 (10.1 ppmv at 6.5 feet bls and 10.5 ppmv at 11.5 feet bls). Borehole OU-1-05 is located in the source area. The other two boreholes are located along the downgradient flow path in close proximity to Stinking Creek. Most PID readings above 10.0 ppmv were recorded for soil samples from below the water table, indicating that some of the elevated headspace readings may be due to dissolved contamination in the groundwater.

4.1.3 Soil Total Organic Carbon Content

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 soil is an important parameter used to estimate the amount of contaminant that could potentially be sorbed to the aquifer matrix. Sorption results in retardation of the contaminant plume relative to the average 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 electrons (i.e., substrate) for microbial activity.

Two soil samples were analyzed for TOC during the SCAPS investigation (USACE, 1996). The soil sample collected from SB15 at a depth of 13.5 to 14.0 feet bls contained a TOC concentration of 247 mg/kg (0.0247 percent), and the soil sample collected from SB19 at a depth of 11.0 to 11.5 feet bls contained a TOC concentration of 814 mg/kg (0.0814 percent).

As part of the RNA TS, 11 soil samples obtained during the installation of monitoring wells and points were analyzed for TOC. Analytical results are presented in Table 4.1. Mean TOC concentrations of soils obtained ranged from 0.022 percent to 0.749 percent. The TOC of site soils is likely too low to provide sufficient organic carbon to supply electron donors for reductive dechlorination of CAHs (see Section 4.2.4), but may increase solute sorption.

4.2 OVERVIEW OF CAH BIODEGRADATION IN GROUNDWATER

Groundwater quality data obtained during the previous investigations and this TS indicate that CAH compounds are the primary contaminants of concern in groundwater; dissolved petroleum hydrocarbons are not present at sufficient concentrations in groundwater to be considered contaminants of concern. Therefore, this section focuses on natural attenuation (specifically biodegradation) of CAHs. Mechanisms for natural attenuation of CAHs include biodegradation, dispersion, dilution from recharge and upgradient flow, sorption, and volatilization. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. When indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients, these biodegradation processes are considered intrinsic.

In the past several years, numerous studies have demonstrated that indigenous microorganisms can degrade a variety of hydrocarbons, including components of kerosene, gasoline (BTEX), diesel, and jet fuel (Jamison *et al.*, 1975; Barker *et al.*, 1987; Grbic-Galic and Vogel, 1987; Altas, 1988; Lee, 1988; Chiang *et al.*, 1989; Cozzarelli *et al.*, 1990; Alvarez and Vogel, 1991; Edwards *et al.*, 1992; Edwards and Grbic-Galic, 1992; Lovley *et al.*, 1994; and Wilson *et al.*, 1994). Chlorinated solvents also can be

TABLE 4.1
SOIL TOC RESULTS
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Sample Location	Sample Depth (feet bls)[a]	Mean Soil %TOC
OU-1-TW-1	3.5	0.085
	7.0	0.097
	10.0	0.100
OU-1-TW-2	3.0	0.062
	7.0	0.099
	13.5	0.022
OU-1-TW3	6.0	0.749
	12.0	0.056
OU-1-TW7	6.5	0.059
	11.5	0.256
OU-1-06	23.0	0.064

[a] feet bls = feet below land surface.

transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Miller and Guengerich, 1982; Wilson and Wilson, 1985; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994). Biodegradation of CAHs, while similar in principle to biodegradation of BTEX, typically results from a more complex series of processes.

Microorganisms produce energy for life processes (i.e., cell production and maintenance) by oxidizing organic matter. Microorganisms facilitate the degradation of these organic compounds by transferring electrons from the electron donor to available electron acceptors. The amount of energy that can be released when a reaction occurs or that is required to drive the reaction to completion is quantified by the free energy of the reaction (Stumm and Morgan, 1981; Chappelle, 1993; Bouwer, 1994; Godsey, 1994). Microorganisms will facilitate only those reduction/oxidation (redox) reactions that will yield energy. By coupling the oxidation of the electron donor (e.g., fuel hydrocarbons, native organic carbon, low-molecular weight CAHs) which requires energy, to the reduction of the electron acceptor (e.g., oxygen, nitrate, manganese, ferric iron, sulfate, carbon dioxide, and possibly chlorinated solvents), which yields energy, the overall reaction will yield energy.

In a pristine aquifer, native organic carbon is utilized as an electron donor and DO is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or low-molecular-weight CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide.

Whereas BTEX is biodegraded in essentially one step by acting as an electron donor/carbon source, CAHs may undergo several types of biodegradation involving several 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. Because CAHs may be used as electron acceptors or electron donors (in competition with other acceptors or donors), isopleth maps showing the distribution of these compounds can provide evidence on the types and locations of biodegradation processes acting at a site. In order to provide a foundation for interpreting site data, the following sections present the major biodegradation processes that act upon CAHs.

4.2.1 Electron Acceptor Reactions (Reductive Dechlorination)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dechlorination. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. Figure 4.1 illustrates the transformation of chlorinated ethenes via reductive dechlorination. In general, reductive dechlorination occurs by sequential dechlorination from PCE to TCE to DCE to VC to

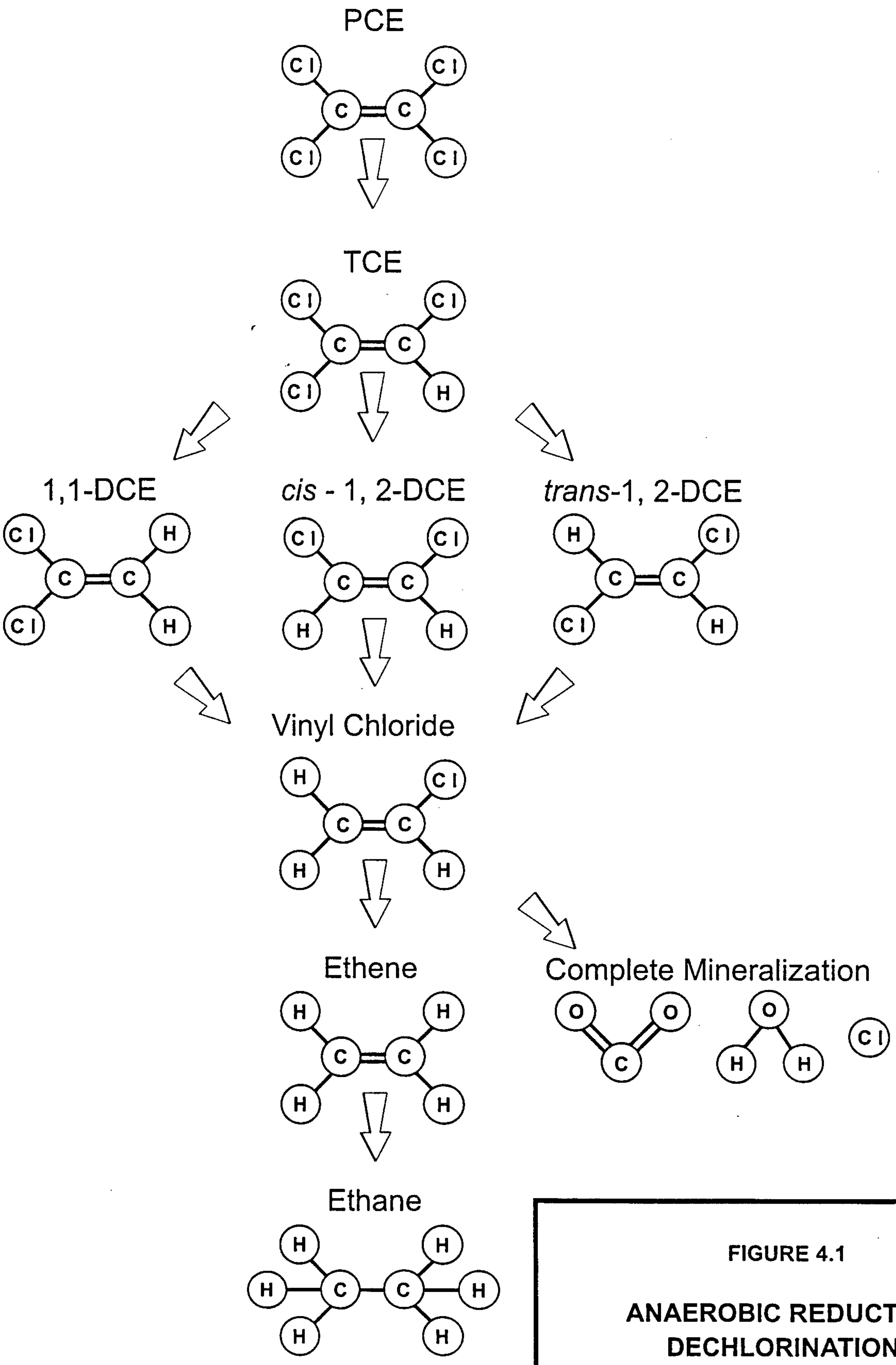


FIGURE 4.1

ANAEROBIC REDUCTIVE DECHLORINATION

OU-1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

G:\COREL\DRAW\AEROBIC1.CDR 2 nap 10/13/98 ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dechlorination, 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. Reductive dechlorination of chlorinated solvent compounds is associated with the accumulation of daughter products, an elevated ratio of the *cis*- to *trans*- isomer of 1,2-DCE, and an increase in chloride.

Reductive dechlorination affects each of the chlorinated ethenes differently. Of these compounds, PCE is the most susceptible to reductive dechlorination because it is the most oxidized. Conversely, VC is the least susceptible to reductive dechlorination because it is the least oxidized of these compounds. The rate of reductive dechlorination also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dechlorination.

In addition to being affected by the degree of chlorination of the CAH, reductive dechlorination can also be controlled by the redox conditions of the site groundwater system. In general, reductive dechlorination has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid biodegradation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994). Dechlorination of PCE and TCE to DCE can proceed under mildly reducing conditions such as nitrate reduction or iron (III) reduction (Vogel *et al.*, 1987), while 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).

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

4.2.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAHs (e.g., VC, DCE, or chlorobenzene) may be utilized as electron donors in biologically mediated redox reactions.

For example, while Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE, other less chlorinated CAHs have been shown to be used as substrates. Davis and Carpenter (1990) describe the aerobic oxidation of VC in groundwater. McCarty and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates.

These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. Klier *et al.* (1996) describe aerobic mineralization of all three isomers of DCE. In addition, Bradley and Chapelle (1996) show evidence of oxidation of VC under iron-reducing conditions so long as there is sufficient bioavailable iron (III).

4.2.3 Cometabolism

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

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

In the cometabolic process, TCE is indirectly transformed by bacteria as they use BTEX or another substrate to meet their energy requirements. Therefore, TCE does not enhance the degradation of BTEX or other carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. It is likely that depletion of suitable substrates (BTEX or other organic carbon sources) limits cometabolism of CAHs.

4.2.4 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. The different types of plume behavior are summarized below.

4.2.4.1 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:

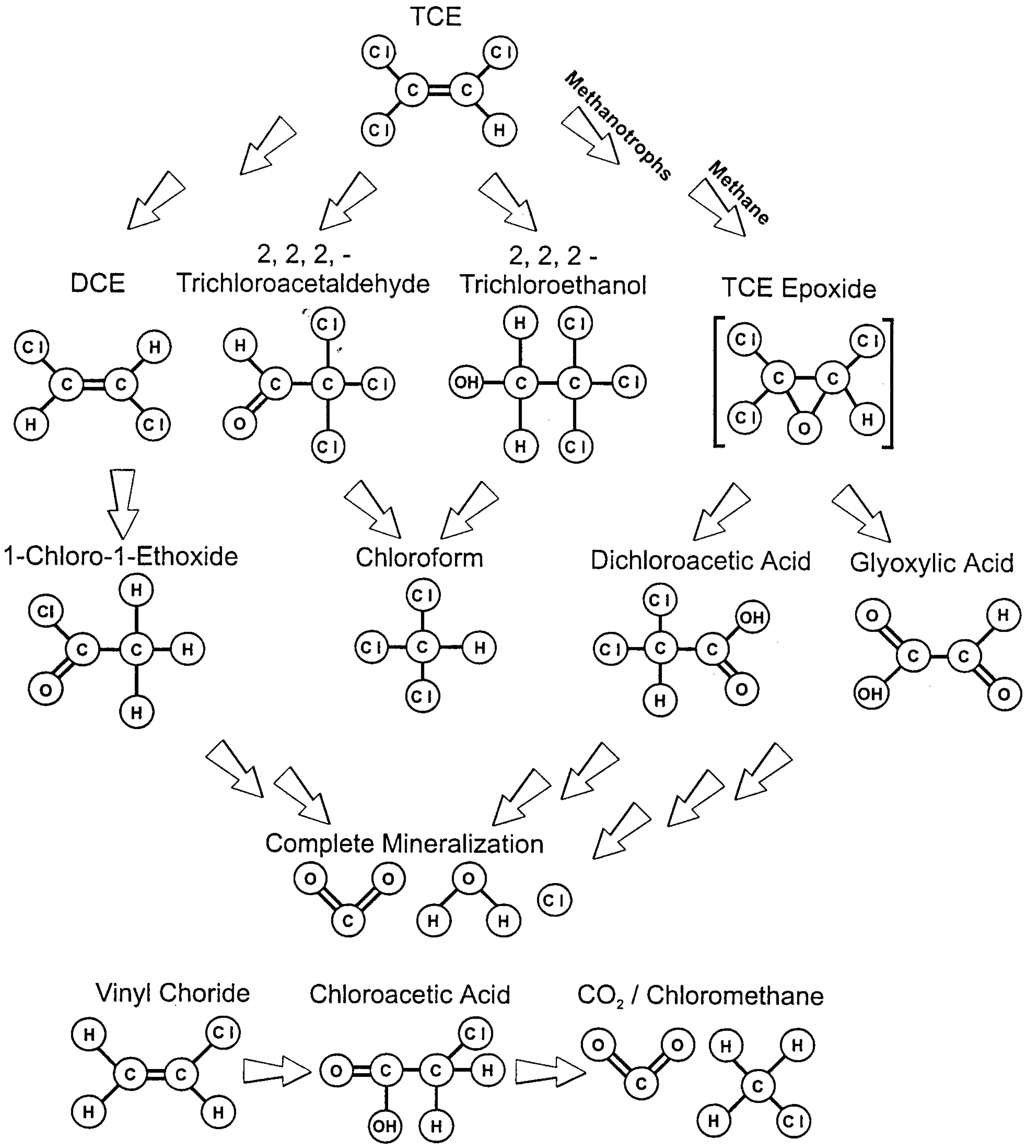


FIGURE 4.2

AEROBIC DEGRADATION

OU-1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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 chlorinated aliphatic hydrocarbons (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) Is VC being oxidized, or is it being reduced?

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

4.2.4.2 Type 2 Behavior

Type 2 behavior dominates in areas that are characterized by relatively high concentrations of biologically available native organic carbon. This natural carbon source drives reductive dechlorination (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 these compounds.

4.2.4.3 Type 3 Behavior

Type 3 behavior dominates in areas that are 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 dechlorination 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, and cometabolism also may occur.

4.2.4.4 Mixed Behavior

As mentioned above, a single chlorinated solvent plume can exhibit all three types of behavior in different portions of the plume. This can be beneficial for natural biodegradation of CAH plumes. For example, Wiedemeier *et al.* (1997) describe a plume at Plattsburgh AFB, New York that exhibits Type 1 behavior in the source area and Type 3 behavior downgradient from the source. The best scenario involves a plume in which PCE, TCE, and DCE are reductively dehalogenated (Type 1 or Type 2 behavior), then VC is oxidized (Type 3 behavior), either aerobically or 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 this type of mixed behavior.

PCE → TCE → DCE → VC →Carbon Dioxide

Note that no ethene is produced during this reaction. VC is removed from the system much faster under these oxidizing conditions than it is 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 → TCE → DCE → VC → Ethene or Ethane

This sequence has been investigated by Freedman and Gossett (1989). In this type of plume, VC degrades more slowly than TCE, and thus tends to accumulate.

4.3 DISTRIBUTION OF CAHS AND METABOLITES

One of the most straightforward methods for evaluating the site-specific occurrence and method(s) of biodegradation of CAHs is to measure the distribution of target CAHs and the metabolites or biodegradation byproducts. At the same time, it is also useful to measure the distribution of other contaminants that may be acting as sources of electron donors (e.g., BTEX).

Because reductive dechlorination is the most common biodegradation reaction, a typical pattern would have TCE concentrations being highest in the source area, with elevated DCE concentrations (consisting mostly of *cis*-1,2-DCE) in and just downgradient from the source area (Vogel, 1994). VC concentrations could be present along the entire plume length, with the highest VC concentrations likely to be found near the downgradient end of the CAH plume. If VC is being reductively dehalogenated, dissolved ethene will also be present downgradient of the source area, in the vicinity of the highest concentrations of VC. Data collected at OU-1 are discussed in the following subsections.

4.3.1 Distribution of TCE

As described in Section 1.2, TCE was introduced into the groundwater as a result of activities at OU-1. Similar to previous investigations, the April 1997 groundwater quality data indicate that TCE is the most prevalent CAH in both extent and concentration in groundwater at OU-1. Analytical results for TCE and other CAHs dissolved in groundwater samples are summarized in Table 4.2 and included in Appendix C. The areal distribution of TCE measured in April 1997 is presented on Figure 4.3. The 1997 TCE distribution is similar to that measured during previous sampling events performed by USGS (1992 and 1996) and USACE (1996) (Appendix A).

The source of TCE contamination appears to be located at the western portion of LF-04, evidenced by the TCE concentrations in groundwater obtained from clustered monitoring wells OU-1-01, OU-1-02, and OU-1-03 ranging up to 12,700 μg/L (Figure 4.3). TCE concentrations in the suspected source area are consistent with results from previous investigations (Parsons ES, 1997). The TCE plume extends southeastward approximately 4,000 feet to WL062 (3.2 μg/L). TCE concentrations from the 2,000 feet of plume between OU-1-TW4 and WL-062 are diffuse and detected intermittently. For

TABLE 4.2
CHLORINATED ORGANIC COMPOUNDS DETECTED IN GROUNDWATER AND SURFACE WATER (APRIL 1997)
OU1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Sample Location	TCE (µg/L)[a]	*cis-1,2*-DCE (µg/L)	*trans-1,2*-DCE (µg/L)	1,1-DCE (µg/L)	1,2-DCB (µg/L)	Chloroform (µg/L)
OU-1-01	8,910	1,340	33.3	4.3	ND[b]	<1[c]
OU-1-02	11,400	1,130	19.2	3.8	ND	1.1
OU-1-03	12,700	1,080	16.3	3.5	ND	1.9
OU-1-04	1,670	756	148	1.9	ND	ND
OU-1-05	ND	63.2	1.1	<1	ND	ND
OU-1-06	360	37.9	8.1	<1	ND	<1
OU-1-TW1	690	118	22.9	1.8	ND	ND
OU-1-TW2	736	54.1	16.4	1.1	ND	ND
OU-1-TW3	347	28.7	20	2.1	ND	ND
OU-1-TW4	51.1	2.0	1.4	ND	ND	ND
OU1-TW5	<1	<1	ND	ND	ND	ND
OU-1-TW6	ND	ND	ND	ND	<1	ND
OU-1-TW7	ND	ND	ND	ND	ND	<1
OU-1-TW8	483	2.1	<1	<1	ND	<1
OU-1-TW9	<1	ND	ND	ND	ND	ND
OU-1-TW10	ND	ND	ND	ND	ND	ND
OU-1-TW11	NS[d]	NS	NS	NS	NS	NS
OU-1-TW13	ND	ND	ND	ND	<1	ND
OU-1-TW14	<1	ND	ND	ND	ND	ND
OU-1-TW15	13.6	<1	ND	ND	ND	ND
000IU-MW1*	ND	ND	ND	ND	ND	ND
WL018	1.3	<1	ND	ND	<1	ND
WL019	224	207	27.4	1.0	<1	ND
WL020	<1	ND	ND	ND	ND	ND
WL021	41.8	15.7	3.4	<1	ND	ND
WL022	36.2	31.7	4.3	<1	ND	ND
WL060	ND	ND	ND	ND	ND	ND
WL061	ND	ND	ND	ND	ND	ND
WL062	3.2	ND	ND	ND	ND	ND
SB10WS	NS	NS	NS	NS	NS	NS
SB10WD	NS	NS	NS	NS	NS	NS
SB11WS	NS	NS	NS	NS	NS	NS
SB11WD	457	31.8	6.8	<1	1.1	<1
SB15WS	3,520	444	23.7	1.9	ND	<1
SB15WD	NS	NS	NS	NS	NS	NS
SB16WS	NS	NS	NS	NS	NS	NS
SB16WD	NS	NS	NS	NS	NS	NS
RV001	ND	<1	ND	ND	ND	ND
RV002	<1	<1	ND	ND	ND	ND
RV003	1.4	<1	ND	ND	ND	ND
RV004	2.8	<1	ND	ND	ND	ND
RV005	1.6	<1	ND	ND	ND	ND

a/ µg/L = micrograms per liter.

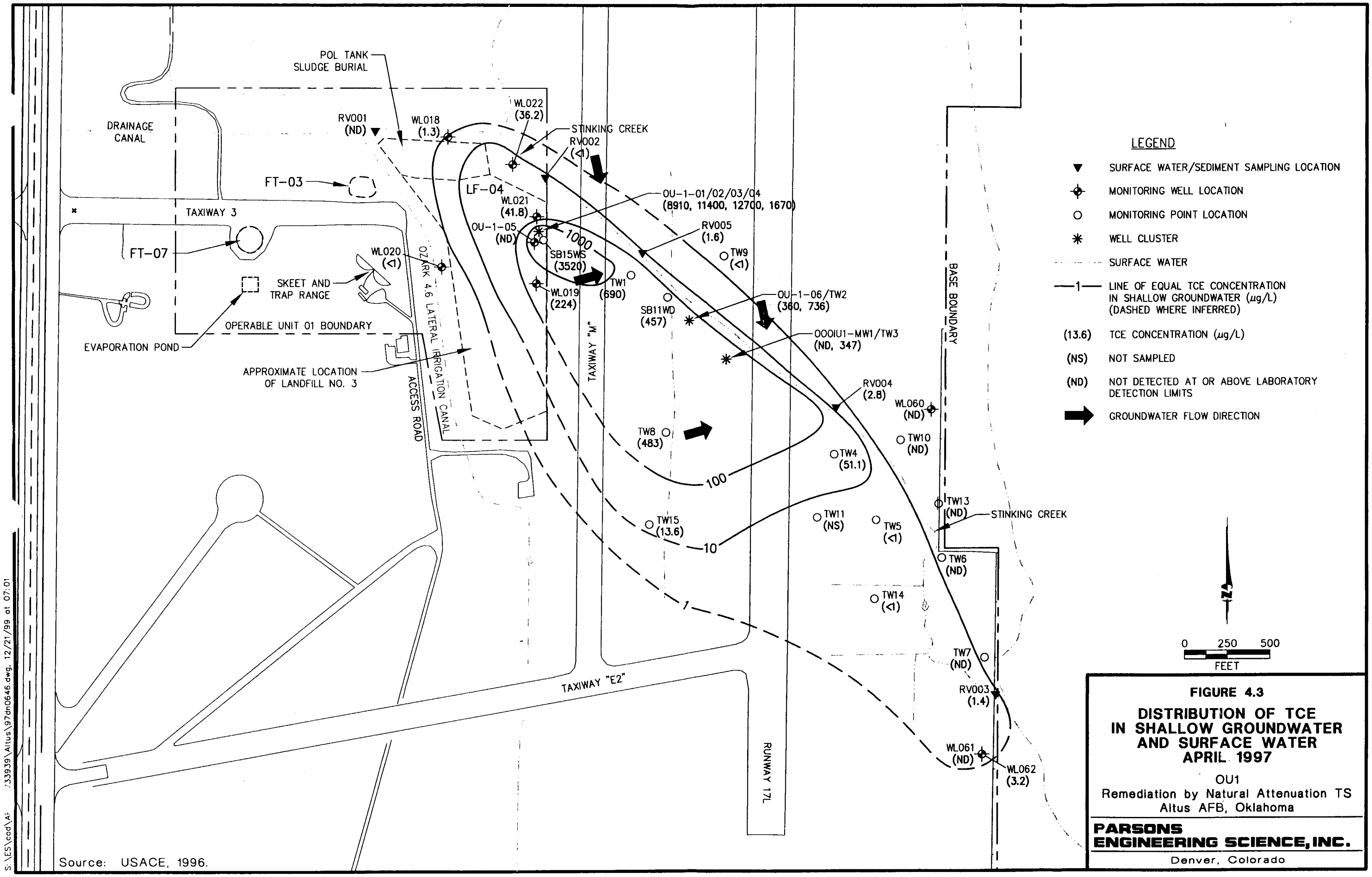
b/ ND = Compound not detected.

c/ < 1 = Compound detected below limit of quantitation.

d/ Monitoring well/point not sampled.

Note: TCE = trichloroethene; DCE = dichloroethene; DCB = dichlorobenzene.

* 000IU1-MW1 was installed and sampled subsequent to the April 1997 RNA TS, and available data has been incorporated into this report.



Source: USACE, 1996.

FIGURE 4.3

DISTRIBUTION OF TCE IN SHALLOW GROUNDWATER AND SURFACE WATER APRIL 1997

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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instance, groundwater samples from OU-1-TW5 and OU-1-TW14 are suspected to contain TCE, but the amount detected was below the analytical reporting limit.

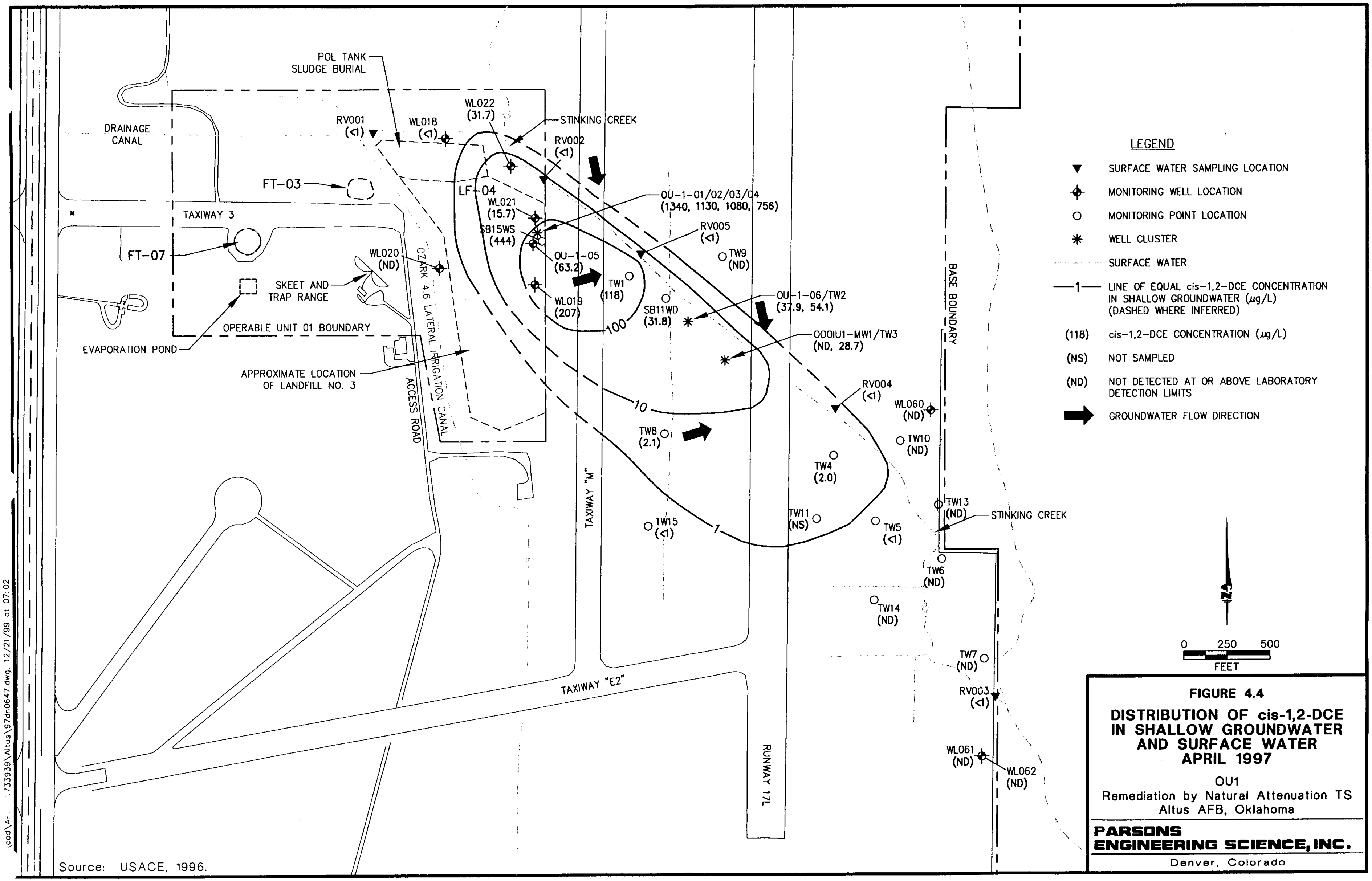
Expansion of the TCE plume to the northeast appears to be limited by Stinking Creek. None of the groundwater samples collected from monitoring wells or points northeast of Stinking Creek contained detectable levels of TCE or other CAHs. Stinking Creek may be exerting hydraulic control, resulting in no further TCE plume migration northeast of Stinking Creek. Hydraulic control could occur under both gaining- and losing-stream scenarios and could vary seasonally. Under a losing-stream scenario, the groundwater influx could create a barrier to flow in the form of a subtle mound. Under a gaining-stream scenario, a significant percentage of under-flow could be captured by the creek. Strack (1989) provides an example in which a gaining stream penetrated one-tenth of the aquifer thickness and captured 94 percent of the groundwater flow from its upgradient side.

The vertical extent of the TCE plume is defined near the source area and near the center of the downgradient extent. TCE was not detected in the groundwater sample from deep monitoring well OU-1-05; however, TCE was detected in the groundwater sample from OU-1-06 (360 µg/L). TCE was not detected in the groundwater sample collected from deep well 000IU1-MW1, which was installed and sampled subsequent to the RNA TS by WCC. The three monitoring wells screened within the shale (OU-1-05, OU-1-06, and 000IU1-MW1) were installed during and following the RNA TS; therefore, historical data are not available for comparison.

4.3.2 Distribution of DCE

Isomers of DCE detected in April 1997 groundwater samples include *cis*-1,2-DCE, *trans*-1,2-DCE, and 1,1-DCE (Table 4.2). The DCE isomer detected most frequently and at the highest concentrations (ranging up to 1,340 µg/L) was *cis*-1,2-DCE. *cis*-1,2-DCE is the DCE isomer preferentially produced during reductive dechlorination of TCE (Section 4.2.1). Lower concentrations of *trans*-1,2-DCE and 1,1-DCE (ranging up to 33.3 and 4.3 µg/L, respectively) also were detected during the April 1997 sampling event. The low magnitudes of detected *trans*-1,2-DCE and 1,1-DCE concentrations relative to that of *cis*-1,2-DCE are common in environments where reductive dechlorination of TCE is occurring. In contrast, a greater prevalence of the *trans*-1,2-DCE isomer would be expected where DCE was used as an industrial solvent (Arthur D. Little, 1985).

The areal extent of the *cis*-1,2-DCE plume in April 1997 (Figure 4.4) mimics the TCE plume. The highest concentrations of *cis*-1,2-DCE were detected in and just downgradient from the suspected source area (wells OU-1-01, OU-1-02, and OU-1-03). The downgradient extent of the *cis*-1,2-DCE plume is near OU-1-TW14. *cis*-1,2-DCE was detected in the groundwater samples from deep wells OU-1-05 (though TCE was not) and OU-1-06; it was not detected in the groundwater sample collected from 000IU1-MW1 by WCC after the RNA TS. The measured concentrations of *trans*-1,2-DCE and 1,1-DCE (Figures 4.5 and 4.6) also are significantly lower than those of the *cis*- isomer in groundwater samples from the vertical extent wells.



Source: USACE, 1996.

FIGURE 4.4

DISTRIBUTION OF cis-1,2-DCE IN SHALLOW GROUNDWATER AND SURFACE WATER APRIL 1997

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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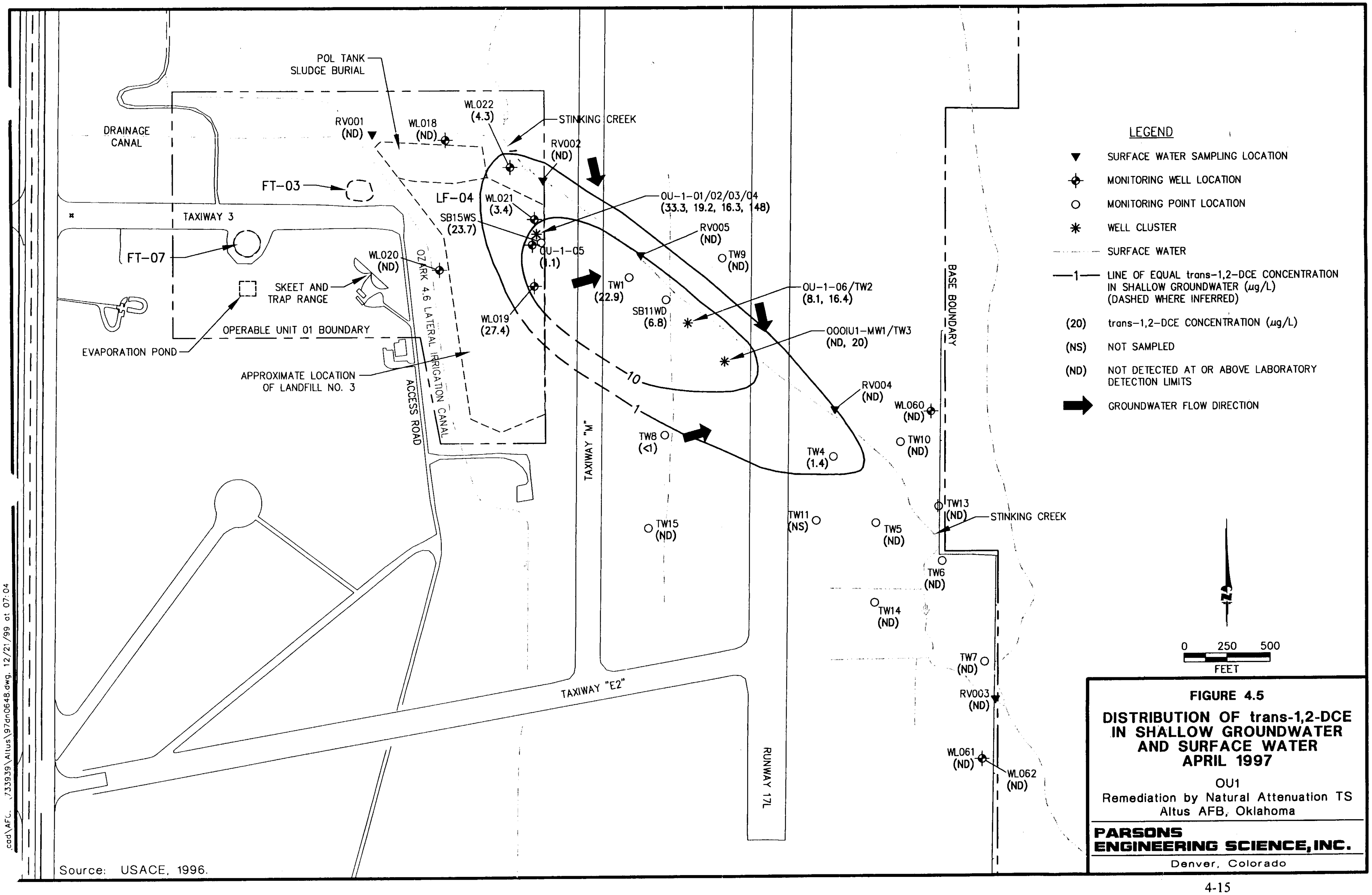

Source: USACE, 1996.

FIGURE 4.5

DISTRIBUTION OF trans-1,2-DCE IN SHALLOW GROUNDWATER AND SURFACE WATER APRIL 1997

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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Denver, Colorado

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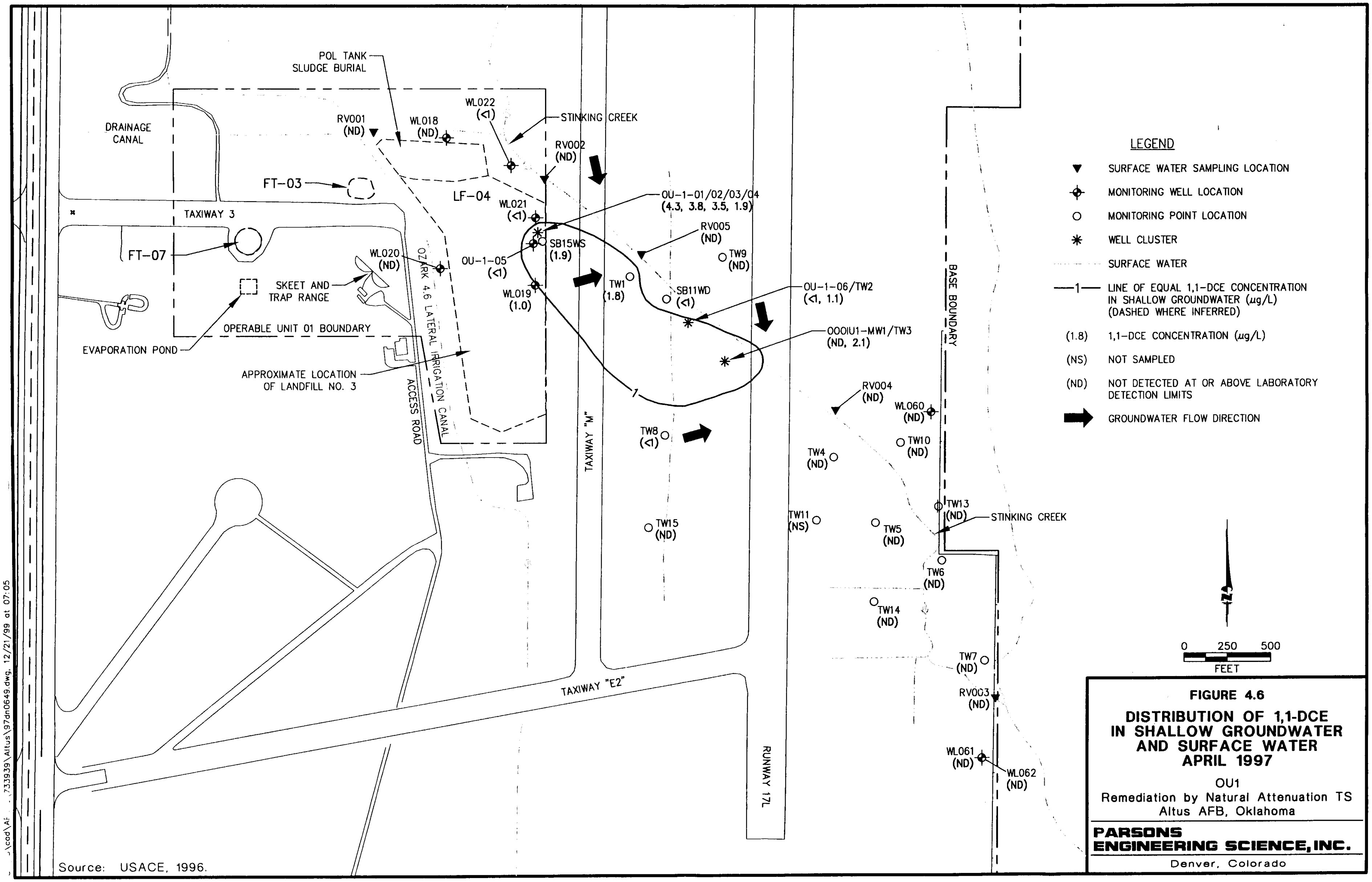

Source: USACE, 1996.

FIGURE 4.6

DISTRIBUTION OF 1,1-DCE IN SHALLOW GROUNDWATER AND SURFACE WATER APRIL 1997

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

4.3.4 Distribution of VC

None of the groundwater samples obtained in April 1997 contained detectable concentrations of VC, a biodegradation product of DCE. The lack of VC detections in groundwater at OU-1 indicates that reductive dechlorination is not proceeding past the initial step that involves the transformation of TCE to DCE (Figure 4.1).

4.3.5 Distribution of Ethene

Ethene is the end product in the series of reductive dechlorination reactions that begin with TCE. The lack of VC detections in groundwater indicates that ethene should also be scarce in groundwater at OU-1. Ethene was not detected at quantifiable concentrations in the groundwater samples collected for this TS in April 1997.

4.3.6 Distribution of Other Chlorinated Organic Compounds

The only other chlorinated organic compounds detected in the April 1997 groundwater samples were 1,2-dichlorobenzene (1,2-DCB) and chloroform (Table 4.2). 1,2-DCB was detected at 1.1 μg/L in the groundwater sample from monitoring point SB11WD. Chloroform was detected in groundwater samples from OU-1-02 (1.1 μg/L) and OU-1-03 (1.9 μg/L).

4.3.7 CAHs in Surface Water

In April 1997, surface water samples for VOC analysis were collected from one location in a drainage canal upgradient of LF-04 (RV-001) and four locations along Stinking Creek (RV-002 through RV-005) (Figure 2.2). TCE was detected at quantifiable concentrations in surface water samples from RV-003 (1.4 μg/L), RV-004 (2.8 μg/L), and RV-005 (1.6 μg/L). No other analytes (CAHs or fuel hydrocarbons) were detected in the surface water samples (Table 4.2). The detection of TCE in surface water samples suggests that groundwater containing CAHs is discharging to Stinking Creek east of Taxiway "M" during at least some portion of the year. The substantially lower TCE concentrations in the surface water samples indicates that TCE entering Stinking Creek is being attenuated via the processes of dilution and volatilization.

4.4 RNA ANALYSIS

Biodegradation of the TCE plume in OU-1 groundwater appears to be occurring, primarily by reductive dechlorination of TCE to *cis*-1,2-DCE. Available information indicates that the TCE plume originating at LF-04 exhibits Type 1 behavior, where anthropogenic carbon (i.e., landfill leachate) concentrations may drive reductive dechlorination. Various parameters are reviewed in the following subsections to further evaluate the occurrence of RNA.

4.4.1 Field-Scale Contaminant Mass Loss

One line of evidence that should be assessed to evaluate the occurrence of natural attenuation of CAHs at OU-1 is the change in dissolved contaminant concentrations over time. Historical data for OU-1 are limited, as only five monitoring wells (WL018, WL019, WL020, WL021, AND WL022) have been sampled periodically during the past several years. Most of the previous groundwater samples were obtained from temporary monitoring points that have since been abandoned. Groundwater quality data for samples collected from the five monitoring wells during previous investigations and during the RNA TS indicate that TCE concentrations in groundwater have fluctuated through time, but overall have remained relatively constant since 1989. In addition, DCE concentrations in the three wells along the western, downgradient edge of the landfill exhibit a slightly increasing trend. These trends support reductive dechlorination, but do not suggest significant contaminant mass loss.

4.4.2 Presence of Metabolites

The presence of TCE biodegradation metabolites that were not used in Base operations, particularly *cis*-1,2-DCE, is a direct indication of TCE reductive dechlorination and provides specific evidence supporting the attenuation of CAH compounds. Progressive transformation of TCE to *cis*-1,2-DCE as the contamination migrates away from the source area can be evaluated by computing the molar ratio of TCE to *cis*-1,2-DCE concentrations along the TCE plume axis. The molar ratios for one monitoring well (OU-1-03) and five monitoring points (SB11WD, OU-1-TW1, OU-1-TW2, OU-1-TW3, and OU-1-TW4) from the April 1997 sampling event are shown on Figure 4.7. Because reductive dechlorination proceeds in only one direction (i.e., TCE to DCE and not vice versa) and because TCE does not enter groundwater downgradient of the landfill, the TCE to DCE ratio would decrease along the flowpath where reductive dechlorination of TCE dominates the contaminant attenuation process. The lowest ratio is found at OU-1-TW1, indicating that TCE is being reductively dechlorinated most significantly in the suspected source area and immediately downgradient. However, downgradient from OU-1-TW1, the ratio begins to increase. This means that *cis*-1,2-DCE concentrations are decreasing more rapidly than TCE concentrations. Because VC (the DCE reductive dechlorination metabolite) is not observed, DCE oxidation is inferred. Because optimal conditions for DCE oxidation implies less-than-optimal conditions for TCE reductive dechlorination, TCE biodegradation is assumed to cease downgradient from OU-1-TW1.

4.4.3 Chloride as an Indicator of Dechlorination

Chloride is removed from CAHs during dechlorination degradation and enters solution. Therefore, chloride concentrations in groundwater should increase above background within the plume where degradation is occurring. Chloride concentrations are presented in Table 4.3, and Figure 4.8 shows the distribution of chloride in groundwater at the site. The highest chloride concentrations (>500 mg/L) were detected within the downgradient portion of the plume. Background chloride concentrations ranged from 321 mg/L (WL020) to 384 mg/L (WL018). Analytical data indicate that chloride, generated as a byproduct of reductive dechlorination occurring in the TCE plume and oxidation of the resulting DCE plume, is migrating in the direction of groundwater flow (southeast). Data also indicate that CAH degradation (and the generation of chloride) is occurring in the shale. Chloride concentrations were elevated in two deep monitoring wells within the TCE plume, containing 657 and 811 mg/L (OU-1-06 and WL061, respectively), whereas monitoring well OU-1-05, screened below TCE vertical extent, contained 390 mg/L of chloride.

FIGURE 4.7
RATIO OF TCE TO cis-1,2-DCE VS. DISTANCE FROM SOURCE AREA
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

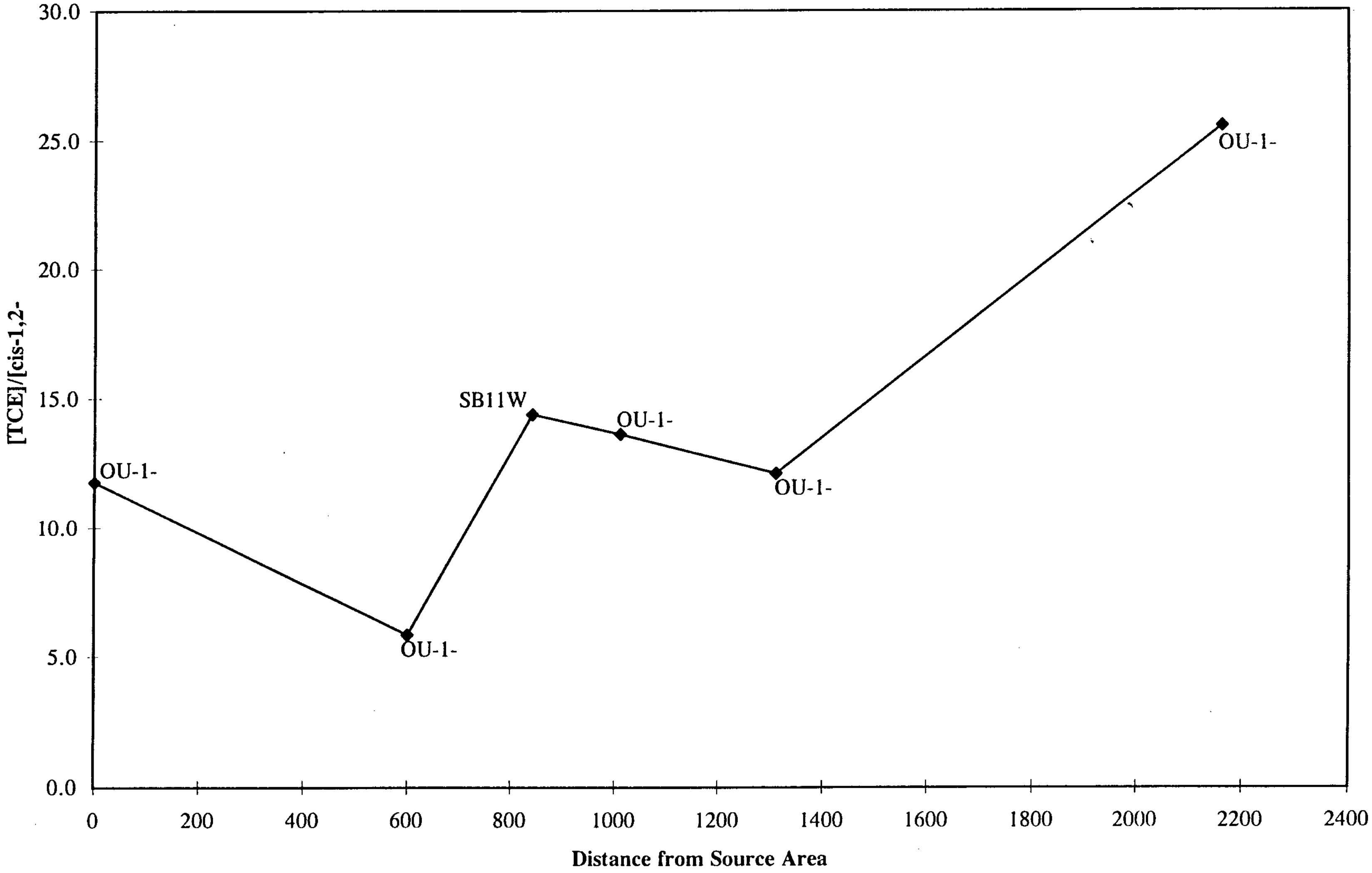

TABLE 4.3
GROUNDWATER GEOCHEMICAL DATA (APRIL 1997)
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Sample Location	Temperature[a/] (°C)[d/]	Dissolved Oxygen[a/] (mg/L)[e/]	pH[a/]	ORP[a/] (mV)[f/]	Conductivity[b/] (µs/cm)[g/]	Total Alkalinity[b/] (mg/L $CaCO_3$)[h/]	Ferrous Iron[b/] (mg/L)	Chloride[c/] (mg/L)	Sulfate[c/] (mg/L)	$NO_2^- + NO_3^-$ Nitrogen[c/] (mg/L)	Ammonia Nitrogen[c/] (mg/L)	Carbon Dioxide (mg/L)	Dissolved TOC[c/] (mg/L)	Hydrogen Sulfide[b/] (mg/L)	Dissolved Hydrogen[b/] (nM/L)[j/]	Ethene (mg/L)	Ethane (mg/L)	Methane[c/] (mg/L)
OU-1-01	13.6	< 0.1	6.8	140	3.880	379	<0.05	330	1780	<0.05	<0.05	210	4.19	NA[k/]	2.15	ND	ND	0.006
OU-1-02	14.0	< 0.1	6.8	197	4.050	386	<0.05	341	1690	<0.05	<0.05	420	3.10	NA	0.14	ND	ND	0.007
OU-1-03	14.1	0.1	6.8	151	4.090	383	<0.05	384	1780	<0.05	<0.05	262	45.8	NA	2.24	ND	ND	0.008
OU-1-04	13.6	0.2	6.8	188	3.380	446	<0.05	207	1440	0.17	<0.05	264	17.0	NA	1.12	ND	ND	0.002
OU-1-05	16.6	0.3	8.1	201	4,620	220	<0.05	390	2080	2.37	<0.05	100	1.44	NA	NA	ND	ND	0.001
OU-1-06	17.5	1.3	NA	-25	7,060	NA	NA	657	3050	1.00	<0.05	NA	2.53	NA	NA	ND	ND	0.005
OU-1-TW1	18.5	4.1	6.9	165	4.610	320	<0.05	378	2170	<0.05	<0.05	306	NA	NA	NA	ND	ND	0.058
OU-1-TW2	18.3	3.3	NA	108	8,640	NA	NA	952	3620	<0.05	<0.05	NA	NA	NA	NA	ND	ND	0.008
OU-1-TW3	18.3	0.1	6.9	103	6.820	417	<0.05	699	2880	<0.05	<0.05	320	2.48	NA	NA	ND	ND	0,021
OU-1-TW4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
OU1-TW5	16.3	0.2	6.9	180	4,180	405	<0.05	579	1460	0.37	<0.05	180	2.07	NA	NA	ND	ND	0.058
OU-1-TW6	15.3	0.9	7.2	131	3,400	325	<0.05	.260	1240	0.79	<0.05	264	29.8	NA	NA	ND	ND	<0.001
OU-1-TW7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
OU-1-TW8	16.9	< 0.1	6.9	150	5,550	319	<0.05	724	1920	0.99	<0.05	160	NA	NA	NA	ND	ND	0.011
OU-1-TW9	21.0	2.4	6.9	33	2,670	408	<0.05	230	680	7.80	<0.05	160	14.2	NA	NA	ND	ND	0.001
OU-1-TW10	18.2	4.3	6.9	140	3,720	504	<0.05	417	1150	2.29	<0.05	NA	1.06	NA	NA	ND	ND	ND
OU-1-TW11	NS[l/]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
OU-1-TW13	15.0	0.1	7.1	63	4.300	320	<0.05	400	1580	1.42	<0.05	128	1.55	NA	NA	ND	ND	ND
OU-1-TW14	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
OU-1-TW15	16.6	0.5	7.0	220	5.530	205	<0.05	687	2160	2.23	<0.05	80	0.290	NA	NA	ND	ND	ND
000IU-MW1	NA	NA	NA	NA	NA	210	NA	1500	5300	19	NA	NA	52	NA	NA	NA	NA	NA
WL018	14.6	0.4	7.0	165	3,800	283	<0.05	384	1500	0.72	<0.05	184	16.1	NA	0.16	ND	ND	<0.001
WL019	14.8	< 0.1	6.8	192	4.130	418	<0.05	320	1900	<0.05	<0.05	212	3.56	NA	0.38	ND	ND	0.037
WL020	16.3	3.6	7.0	158	3,000	250	<0.05	321	1070	0.45	<0.05	114	15.7	NA	0.35	ND	ND	ND
WL021	12.9	0.0	6.8	174	4.080	415	<0.05	341	2010	<0.05	<0.05	402	3.67	NA	0.42	ND	ND	0.001
WL022	13.3	< 0.1	7.0	-179	4.930	422	<0.05	398	2180	0.37	<0.05	344	8.35	<0.1	0.66	ND	ND	0.078
WL060	14.4	0.3	7.1	136	4.800	311	<0.05	537	2010	4.11	<0.05	120	1.18	NA	0.66	ND	ND	0.001
WL061	16.4	1.2	7.1	151	5.700	157	<0.05	811	2340	1.50	<0.05	82	0.330	NA	0.29	ND	ND	ND
WL062	13.7	< 0.1	7.0	140	6.100	272	<0.05	830	2480	1.41	<0.05	240	1.04	NA	0.19	ND	ND	ND
SB10WS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SB10WD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SB11WS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SB11WD	17.1	1.9	6.9	76	5.280	256	<0.05	517	2230	1.41	<0.05	204	6.30	NA	NS	ND	ND	ND
SB15WS	12.2	0.4	6.9	151	3,810	332	<0.05	406	1820	<0.05	<0.05	256	3.90	NA	0.27	ND	ND	0.001
SB15WD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SB16WS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SB16WD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[a/] Analysis performed at the well head by Parsons ES and USEPA personnel.

[b/] Analysis performed in field laboratory by USEPA.

[c/] Analysis performed at NRMRL.

[d/] °C = degrees celsius.

[e/] mg/L = milligrams per liter.

[f/] mV = millivolts.

[g/] µs/cm = microsiemens per centimeter.

[h/] mg/L CaCO^3 = milligrams per liter calcium carbonate.

[i/] ppm = parts per million.

[j/] nM/L = nanomoles per liter

[k/] NA = sample not analyzed for this parameter.

[l/] NS = well/point not sampled.

[m/] Nitrate only.

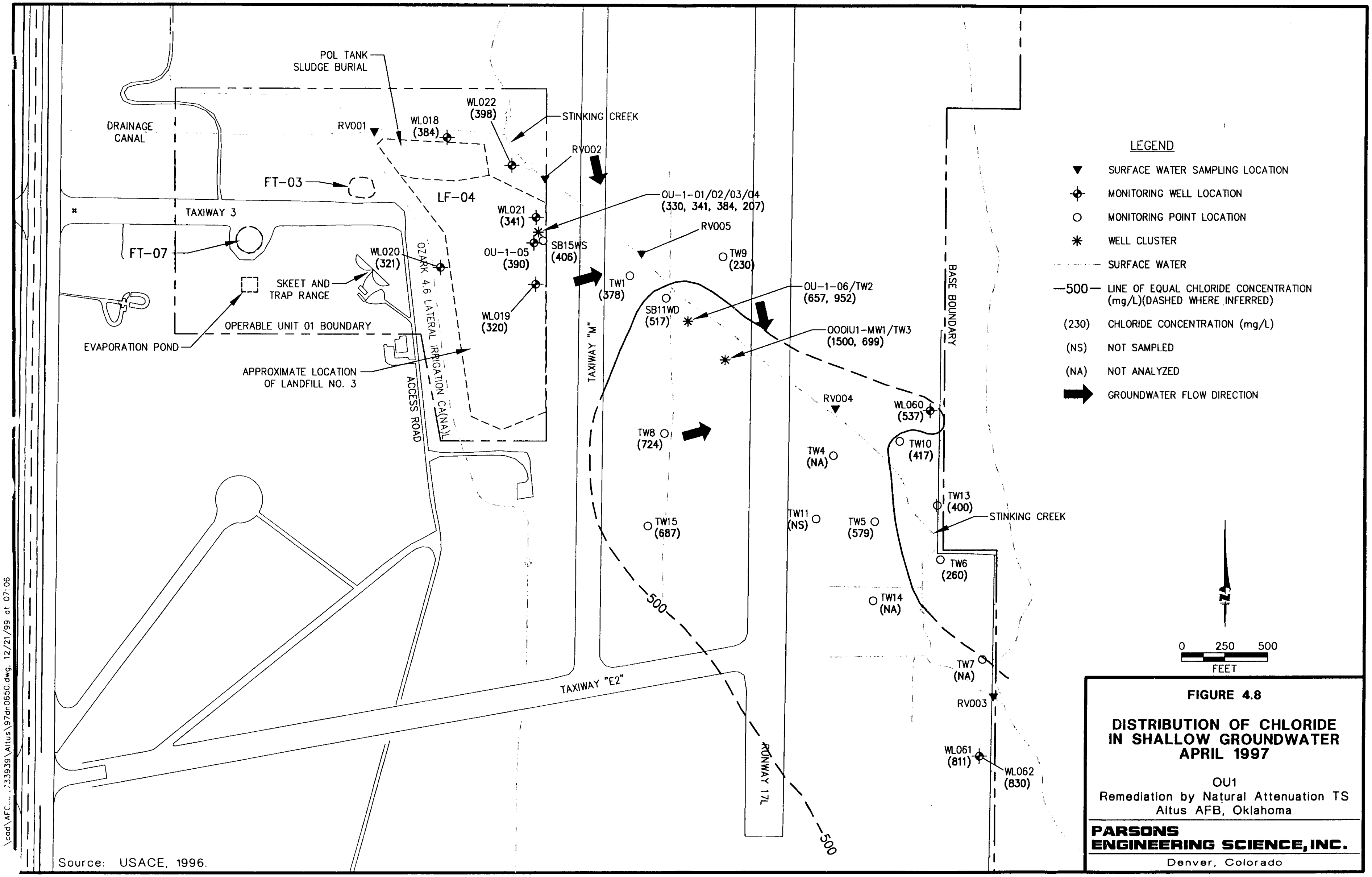

FIGURE 4.8

DISTRIBUTION OF CHLORIDE IN SHALLOW GROUNDWATER APRIL 1997

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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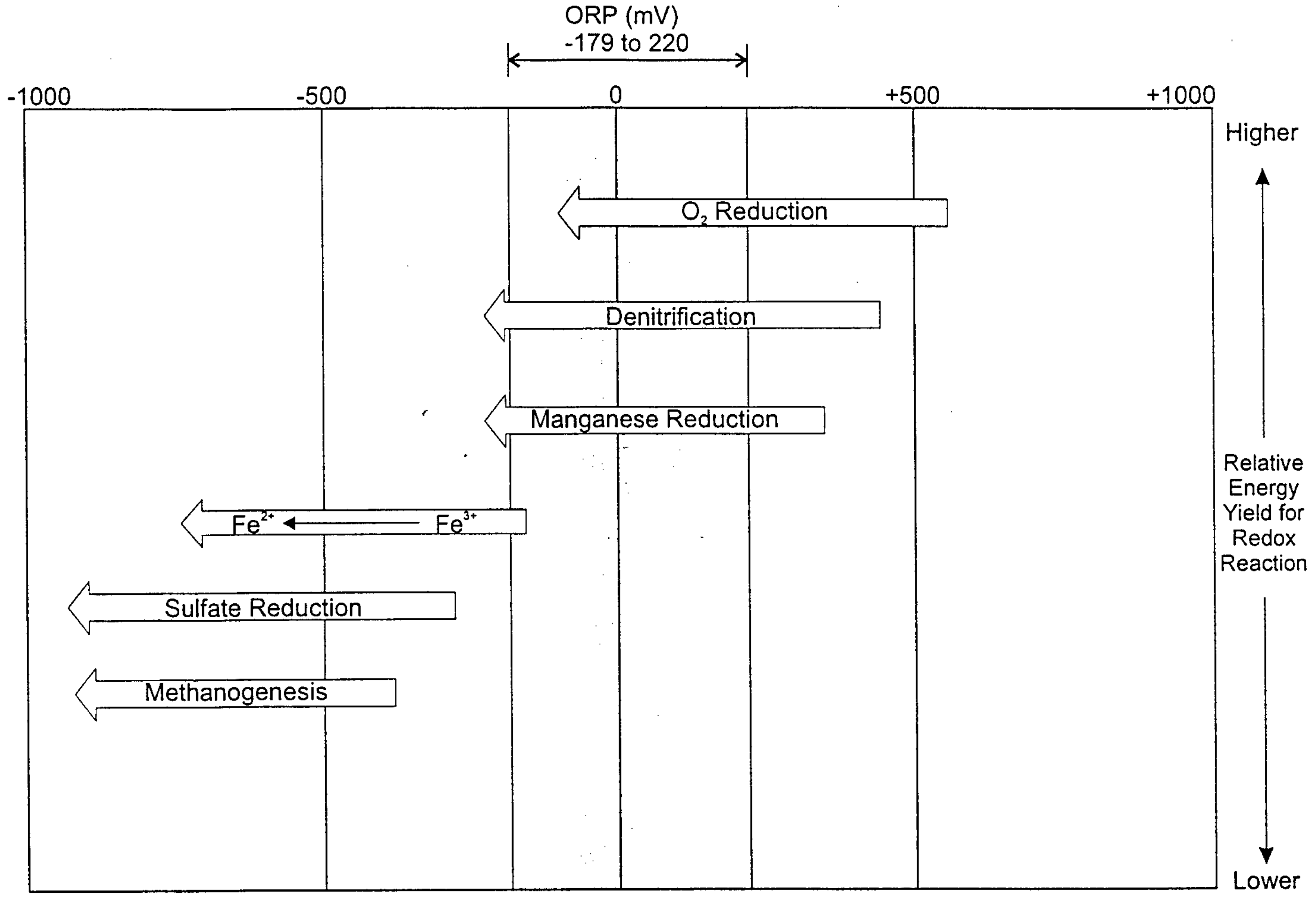
4.4.4 Redox Potential and Dissolved Hydrogen as Indicators of Redox Processes

As described in Section 4.2, microorganisms will facilitate those redox reactions that yield energy. For example, by coupling the oxidation of fuel hydrocarbon compounds or native organic carbon, which requires energy, to the reduction of other compounds, such as oxygen, nitrate, manganese, ferric iron, sulfate, carbon dioxide, or possibly *cis*-1,2-DCE, which yield energy, the overall reaction will yield energy. Figure 4.9 illustrates the sequence of microbially mediated redox processes and identifies the approximate ranges of ORPs that are favorable for each reaction. In general, reactions yielding more energy tend to occur more readily than processes that yield less energy (Stumm and Morgan. 1981; Godsey, 1994). As Figure 4.9 indicates, oxygen reduction would be expected to occur in an aerobic environment with microorganisms capable of aerobic respiration. because oxygen yields significant energy (Bouwer, 1992; Chapelle, 1993). However, once the available oxygen is depleted and anaerobic conditions prevail, anaerobic microorganisms can utilize alternate electron acceptors in the following order of preference: nitrate (denitrification), manganese (manganese reduction), ferric iron (iron reduction), sulfate (sulfate reduction), and carbon dioxide (methanogenesis). Each successive redox reaction provides less energy to the system, and each decrease in redox energy yield is paralleled by an ecological succession of microorganisms capable of facilitating the pertinent reactions.

ORPs measured in groundwater of the OU-1 area in April 1997 ranged from -179 to 220 millivolts (mV) (Table 4.3). Negative ORP values in groundwater were limited to wells WL022 and OU-1-05. The presence of relatively reducing conditions is an indication that conditions are favorable for reductive dechlorination to occur in these areas. The remainder of the values ranged from 33 to 220 mV, indicating a reducing environment that is favorable for denitrification and manganese reduction. This range, however, is outside the optimal range for reductive dechlorination, but within the possible range. Furthermore, it is important to note that field measurements for ORP may be biased high and in addition, that field ORP data alone cannot reliably predict the electron acceptors that are operating at the site, because the platinum electrode probes are not sensitive to some redox couples (e.g., sulfate/sulfide) (Stumm and Morgan, 1981; Godsey, 1994; Lovley *et al.*, 1994).

Concentrations of dissolved hydrogen (H_2) also can be used to evaluate redox processes in groundwater systems (Lovley and Goodwin, 1988; Lovley *et al.*, 1994; Chapelle *et al.*, 1995). H_2 is continuously produced in anaerobic groundwater systems by fermenting microorganisms that decompose natural and anthropogenic organic matter. H_2 is then consumed by respiratory microorganisms that use nitrate, ferric iron, sulfate or carbon dioxide as terminal electron acceptors. The microorganisms exhibit different efficiencies in utilizing the H_2 that is being continually produced. Nitrate reducers are highly efficient H_2 utilizers, maintaining very low H_2 concentrations. Ferric iron reducers are significantly less efficient and thus maintain higher H_2 concentrations, and sulfate reducers are even less efficient. Because each terminal electron accepting process is associated with a characteristic H_2 concentration, H_2 concentrations can be an indicator of predominant redox processes. These characteristic ranges are given in Table 4.4.



Notes

ORP = Oxidation Reduction Potential

☐ Range of ORP measured at OU-1 LF-04, Altus AFB

1. These reactions would be expected to occur in sequence if the system is moving toward equilibrium.

2. These redox processes occur in order of their energy-yielding potential (provided microorganisms are available to mediate a specific reaction). Reduction of a highly oxidized species decreases the ORP of the system.

3. The ORP of the system determines which electron acceptors are available for organic carbon oxidation.

4. Redox sequence is paralleled by an ecological succession of biological mediators.

Adapted from Stumm and Morgan, 1981.

FIGURE 4.9

SEQUENCE OF MICROBIALLY MEDIATED REDOX PROCESSES

OU-1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

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Denver, Colorado

TABLE 4.4
RANGE OF HYDROGEN CONCENTRATIONS OF VARIOUS TERMINAL ELECTRON ACCEPTOR PROCESSES
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Terminal Electron-Accepting Process	Hydrogen Concentration (nM/L)[a/]
Denitrification	<0.1
Ferric Iron Reduction	0.2 - 0.8
Sulfate Reduction	1 - 4
Methanogenesis (CO_2 Reduction)	5 - 20

[a/] nM/L = nanomoles per liter.

Dissolved H_2 concentrations measured in groundwater in the OU-1 area in April 1997 are summarized in Table 4.3. Detected concentrations ranged from 0.14 to 2.24 nanomoles per liter (nM/L). The highest H_2 concentrations were measured at the suspected source area in samples from OU-1-01 (2.15 nM/L), OU-1-03 (2.24 nM/L), and OU-1-04 (1.12 nM/L), suggesting that sulfate-reducing conditions conducive to the occurrence of TCE reductive dechlorination are present in this area. The remaining H_2 concentrations ranged from 0.14 to 0.66 nM/L, indicating ferric-iron-reducing conditions. The magnitudes of these values suggest that the dominant electron accepting process varies spatially within the study area. H_2 was measured in groundwater from one deep monitoring well, WL061, which had 0.29 nM/L H_2, indicating iron-reducing conditions.

4.4.5 Electron Donors

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

4.4.5.1 BTEX in Groundwater

The presence of fuel hydrocarbons, specifically BTEX, in the same area as the CAH plume creates favorable conditions for reductive dechlorination, because the BTEX can function as an electron donor and facilitate microbial reactions that drive down the local groundwater DO concentration. Fuel hydrocarbons, including BTEX, TMBs, and total fuel carbon, were detected in six groundwater samples in April 1997 (Table 4.5). TMBs are largely biologically recalcitrant (nonbiodegradable) under anaerobic conditions, and are therefore used as tracer compounds in groundwater. The areal extent of BTEX is shown on Figure 4.10. The source area for BTEX appears to be the same or near to the source area for TCE; however, the highest concentration of BTEX was detected in the groundwater sample from OU-1-TW2 (43.0 µg/L). BTEX were detected in only one deep monitoring well (OU-1-06 at 4.5 µg/L). The downgradient extent of BTEX lies between wells OU-1-TW5 and OU-1-TW6 (Figure 4.10), with the BTEX plume wholly encompassed by the TCE plume and coincident with the axis of the TCE plume. Unlike

TABLE 4.5

FUEL HYDROCARBONS DETECTED IN GROUNDWATER AND SURFACE WATER (APRIL 1997)

OU-1

REMEDIATION BY NATURAL ATTENUATION TS

ALTUS AFB, OKLAHOMA

Sample Location	Total Fuel Carbon (µg/L)[a]	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	Xylenes (µg/L)	BTEX[b] (µg/L)	1,3,5-TMB[c] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
OU-1-01	883	ND[d]	1.4	ND	ND	1.4	ND	ND	ND
OU-1-02	NA[e]	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-03	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-04	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-05	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-06	84.7	ND	1.8	<1[f]	2.7	4.5	ND	1.0	ND
OU-1-TW1	166	<1	7.8	2.6	14.0	24.4	1.1	4.5	<1
OU-1-TW2	239	1.1	16.9	4.1	20.9	43.0	1.1	4.3	1.0
OU-1-TW3	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-TW4	NS[g]	NS	NS	NS	NS	NS	NS	NS	NS
OU1-TW5	7.6	ND	2.1	<1	2.8	4.9	ND	1.1	ND
OU-1-TW6	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-TW7	NS	NS	NS	NS	NS	NS	NS	NS	NS
OU-1-TW8	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-TW9	NA	ND	<1	ND	ND	ND	ND	ND	ND
OU-1-TW10	2.2	ND	2.5	ND	ND	2.5	ND	ND	ND
OU-1-TW11	NS	NS	NS	NS	NS	NS	NS	NS	NS
OU-1-TW13	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-TW14	NS	NS	NS	NS	NS	NS	NS	NS	NS
OU-1-TW15	NA	ND	ND	ND	ND	ND	ND	ND	ND
000IU1-MW1	NA	ND	ND	ND	ND	ND	NA	NA	NA
WL018	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL019	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL020	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL021	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL022	NA	<1	ND	ND	ND	ND	ND	ND	ND
WL060	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL061	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL062	NA	ND	ND	ND	ND	ND	ND	ND	ND
SB10WS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SB10WD	NS	NS	NS	NS	NS	NS	NS	NS	NS
SB11WS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SB11WD	NA	ND	ND	ND	ND	ND	ND	ND	ND
SB15WS	NA	ND	ND	ND	ND	ND	ND	ND	ND
SB15WD	NS	NS	NS	NS	NS	NS	NS	NS	NS
SB16WS	NS	NS	NS	NS	NS	NS	NS	NS	NS
SB16WD	NS	NS	NS	NS	NS	NS	NS	NS	NS
RV001	NA	ND	ND	ND	ND	ND	ND	ND	ND
RV002	NA	ND	ND	ND	ND	ND	ND	ND	ND
RV003	NA	ND	ND	ND	ND	ND	ND	ND	ND
RV004	NA	ND	ND	ND	ND	ND	ND	ND	ND
RV005	NA	ND	ND	ND	ND	ND	ND	ND	ND

[a] µg/L = Micrograms per liter.

[b] BTEX = Benzene, toluene, ethylbenzene and xylenes.

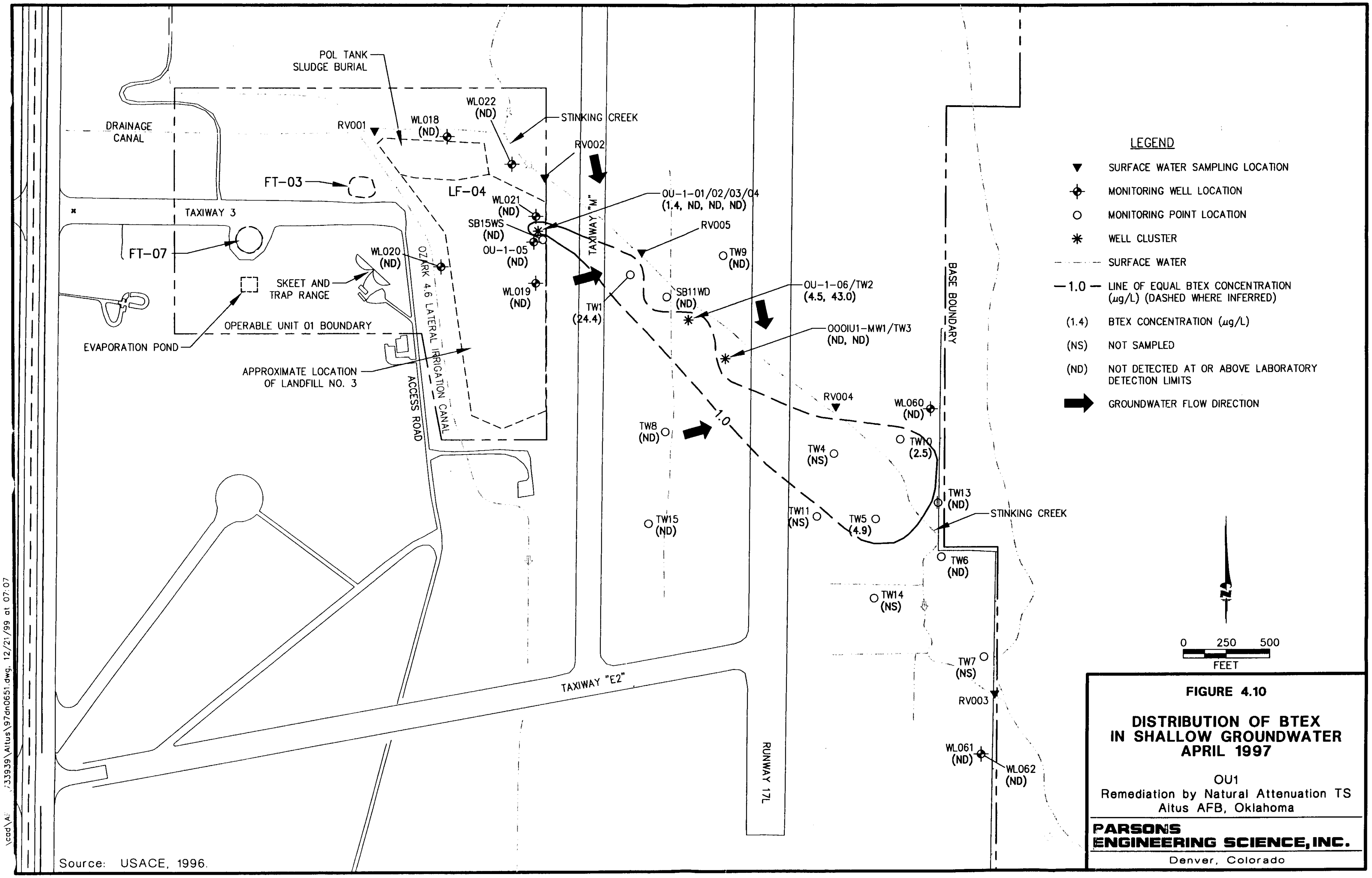
[c] TMB = Trimethylbenzene.

[d] ND = Compound not detected.

[e] NA = Not analyzed.

[f] < 1 = Compound detected below limit of quantitation.

[g] NS = Not sampled..



Source: USACE, 1996.

LEGEND

▼	SURFACE WATER SAMPLING LOCATION
⊕	MONITORING WELL LOCATION
○	MONITORING POINT LOCATION
✱	WELL CLUSTER
— · —	SURFACE WATER
—1.0—	LINE OF EQUAL BTEX CONCENTRATION (μg/L) (DASHED WHERE INFERRED)
(1.4)	BTEX CONCENTRATION (μg/L)
(NS)	NOT SAMPLED
(ND)	NOT DETECTED AT OR ABOVE LABORATORY DETECTION LIMITS
➡	GROUNDWATER FLOW DIRECTION

FIGURE 4.10

DISTRIBUTION OF BTEX IN SHALLOW GROUNDWATER APRIL 1997

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TCE, BTEX were detected in the groundwater sample from a monitoring point northeast of Stinking Creek (2.5 µg/L in OU-1-TW10). Where BTEX compounds are present and the ORP is sufficiently low, BTEX may be supplying organic carbon for the reductive dechlorination of TCE, indicating Type 1 plume behavior (Section 4.2.4).

4.4.5.2 Organic Carbon in Groundwater

Dissolved native organic carbon also can act as a source of electron donors to reduce the groundwater ORP and sustain the reductive dechlorination of CAHs. In wells outside of the area containing high concentrations of dissolved BTEX (anthropogenic organic carbon), dissolved TOC concentrations can be used as an indicator of the availability of native carbon compounds in site groundwater. Background concentrations of dissolved TOC in site groundwater range from 0.290 mg/L to 45.8 mg/L (Table 4.3). Wiedemeier *et al.* (1996) indicate that dissolved TOC concentrations less than 20 mg/L may not be sufficient to significantly and sustainably drive dechlorination reactions. Dissolved TOC was detected in only two wells (OU-1-03 and OU-1-TW6) at concentrations greater than 20 mg/L. All other detections from wells at the site were less than 20 mg/L. This native carbon source may be insufficient to provide a continuing source of electron donors to be used in microbial redox reactions (Type 2 plume behavior - Section 4.2.4); however, it may be instrumental in facilitating the geochemical conditions spawned by the anthropogenic carbon.

4.4.6 Alternate Electron Acceptors and Metabolic Byproducts

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

4.4.6.1 Dissolved Oxygen

Reductive dechlorination is an anaerobic process, therefore DO concentrations above approximately 1.0 mg/L may suppress the reductive dechlorination pathway. Highly chlorinated compounds, such as TCE, are biologically recalcitrant under aerobic conditions. DO concentrations were measured at monitoring wells and points during the April 1997 sampling event. These concentrations are summarized in Table 4.3 and displayed on Figure 4.11. DO concentrations ranged from less than 0.1 mg/L at WL019, WL021, WL022, WL062, OU-1-TW8, OU-1-01, and OU-1-02 to 4.3 mg/L in well OU-1-TW10. Background DO concentrations measured outside of the TCE plume also ranged from 0.1 to 4.3 mg/L and averaged 1.18 mg/L. DO concentrations within the 100-µg/L TCE isopleth (Figure 4.3) ranged from less than 0.1 to 4.1 mg/L and averaged 0.95 mg/L. DO concentrations below 1.0 mg/L through most of the TCE plume area as well as parts of the background indicate that anaerobic conditions exist throughout much of the area. Most DO concentrations in excess of 1.0 mg/L were measured in close proximity to either Stinking Creek or other waterways.

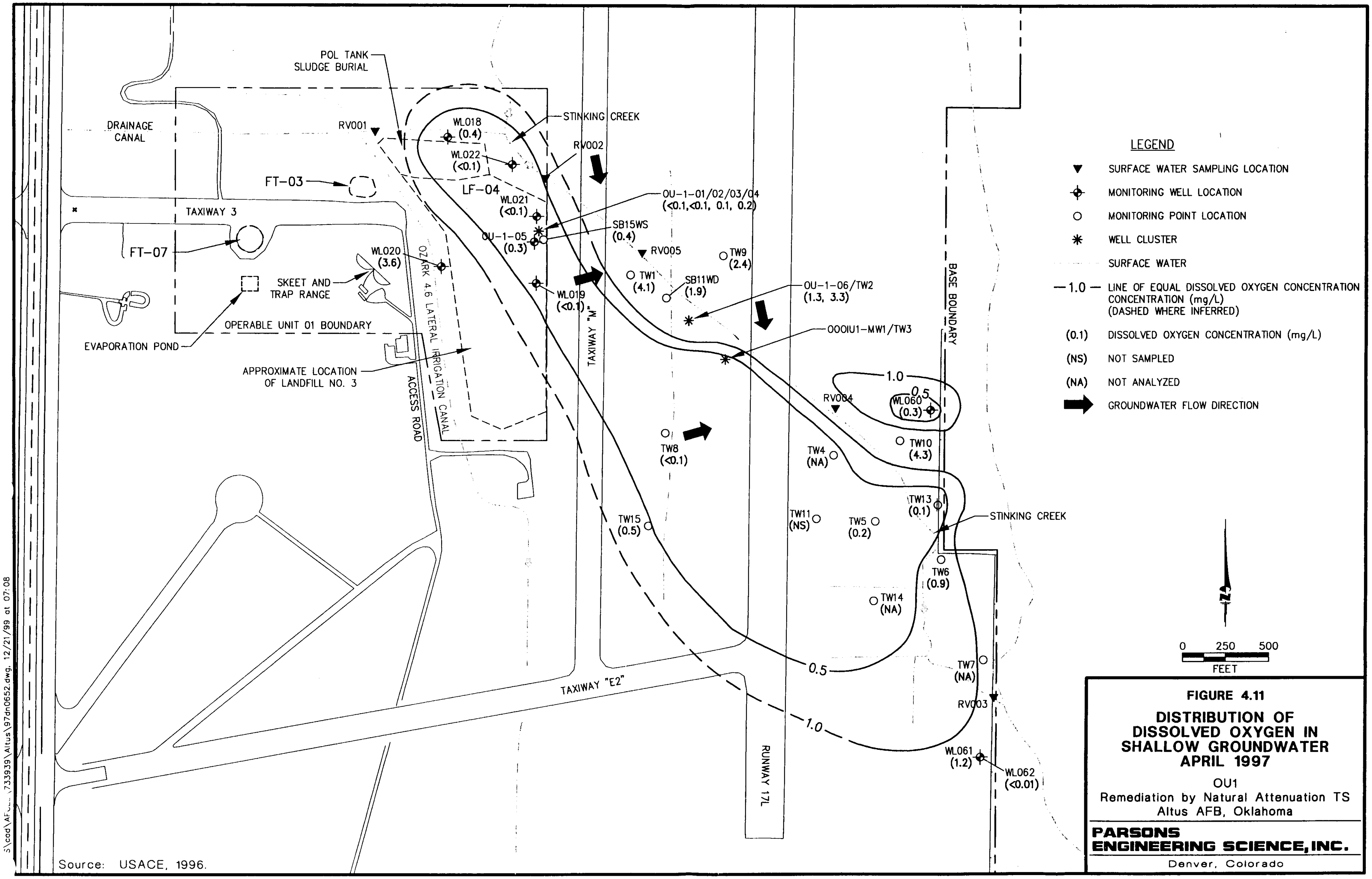

FIGURE 4.11

DISTRIBUTION OF DISSOLVED OXYGEN IN SHALLOW GROUNDWATER APRIL 1997

OU1
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Denver, Colorado

4.4.6.2 Nitrate/Nitrite

After DO has been depleted in the microbiologically active 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 concentrations are indicative of denitrification. The oxidation of organic carbon via the process of denitrification (using nitrate as an electron acceptor) yields a relatively large amount of free energy to microorganisms, and therefore is energetically preferable to the use of CAHs as electron acceptors. If nitrate concentrations exceed 1 mg/L, then microorganisms may use nitrate instead of CAHs to produce energy (Wiedemeier *et al.*, 1996).

Concentrations of nitrate + nitrite (as nitrogen) were measured at monitoring wells and points during the April 1997 sampling event. These concentrations are summarized in Table 4.3 and displayed on Figure 4.12. Nitrate + nitrite nitrogen within the TCE plume is depleted (< 1 mg/L), allowing TCE to be utilized as an electron acceptor. Concentrations of nitrate + nitrite nitrogen at background locations are significantly higher, ranging from 0.79 (OU-1-TW6) to 7.80 mg/L (OU-1-TW9). It appears that nitrite and nitrate are being utilized as electron acceptors during the metabolism of naturally-occurring organic carbon, and that naturally occurring (background) concentrations of nitrate + nitrite nitrogen are sufficient to be utilized by microorganisms to produce energy.

4.4.6.3 Ferrous Iron

Although relatively little is known about the anaerobic metabolic pathways involving the reduction of ferric iron (Fe^{3+}) to ferrous iron (Fe^{2+}), this process has been shown to be a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). The reduction of ferric iron results in the formation of ferrous iron. Elevated concentrations of ferrous iron often are found in anaerobic groundwater systems. These concentrations once were attributed to the spontaneous and reversible reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as BTEX, TMB, and naphthalene. However, laboratory 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 ferrous iron 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.

To determine if ferric iron is being used as an electron acceptor for CAH biodegradation at the OU-1 site, ferrous iron concentrations were measured at selected groundwater monitoring wells and monitoring points in April 1997. These concentrations are summarized in Table 4.3. Ferrous iron was not detected in any groundwater sample analyzed. This absence indicates that microbial biodegradation via iron reduction is not an important process in the contaminant plume at the site.

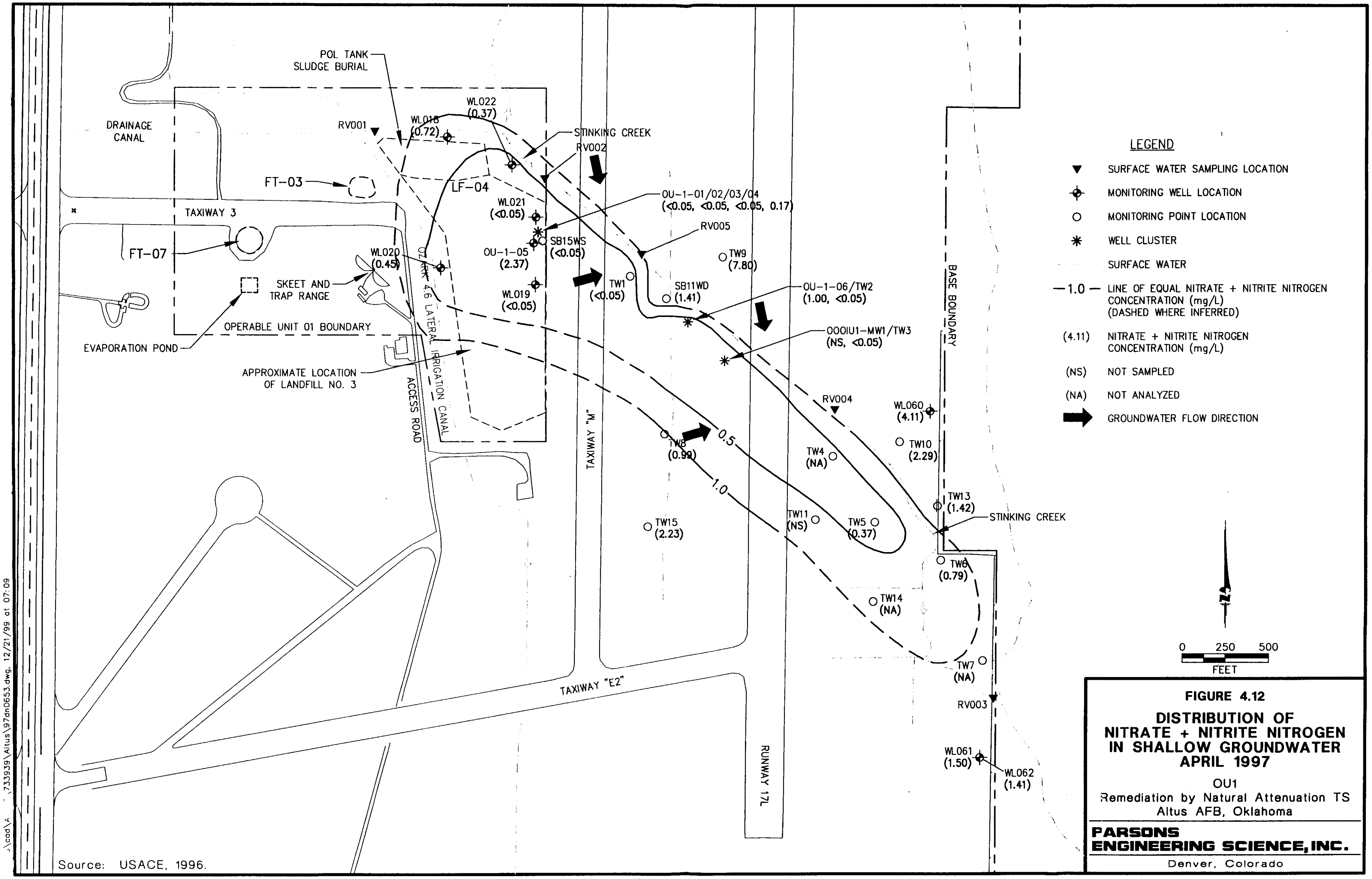

FIGURE 4.12

DISTRIBUTION OF NITRATE + NITRITE NITROGEN IN SHALLOW GROUNDWATER APRIL 1997

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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4.4.6.4 Sulfate

Sulfate also may be used as an electron acceptor during microbial degradation of organic carbon under anaerobic conditions (Grbic-Galic, 1990). This redox reaction is commonly called sulfate reduction. Sulfate is reduced to sulfide during the oxidation of organic carbon compounds. Wiedemeier *et al.*, (1996b) report that sulfate may compete with CAHs as an electron acceptor (sulfate may be preferentially used by microorganisms instead of CAHs) if sulfate concentrations exceed 20 mg/L. To investigate the potential for sulfate reduction at OU-1, sulfate and hydrogen sulfide (H_2S) concentrations were measured at groundwater monitoring wells and monitoring points during the April 1997 sampling event. Under pH conditions found throughout OU-1 (Section 4.4.7.2), sulfide will exist as H_2S (Snoeyink and Jenkins, 1980). Sampling results are summarized in Table 4.3.

Sulfate concentrations at OU-1 ranged from 680 mg/L to 3,620 mg/L and averaged 2,056 mg/L. The site-wide detection of sulfate concentrations greater than 20 mg/L indicates that use of CAHs as electron acceptors under sulfate-reducing conditions may be inhibited due to the preferential use of sulfate. Hydrogen sulfide was not detected in groundwater from the one monitoring well sampled for this parameter, providing no indication of the occurrence of sulfate reduction.

4.4.6.5 Methane

Under highly reducing conditions, carbon dioxide is utilized as an electron acceptor, producing methane (methanogenesis). Methane concentrations were measured in groundwater samples collected in April 1997 to determine if methanogenesis is occurring in site groundwater. Table 4.3 lists methane concentrations, which ranged from <0.001 to 0.078 mg/L at the site. Figure 4.13 shows the distribution of methane in site groundwater. The highest methane concentration was detected in monitoring well WL022, located upgradient from the suspected source area. Methane is commonly found in groundwater near landfill areas, such as LF-04.

4.4.6.6 Volatile Fatty Acids

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

Samples for VFA analysis were collected from three monitoring wells in or near the source area (WL022, OU-1-01, and OU-1-02) in April 1997. Results are presented in Table 4.6 and Appendix C. Nine of the 58 compounds analyzed were detected in various samples. 2-Ethylhexanoic acid was detected at the highest concentrations (ranging up to

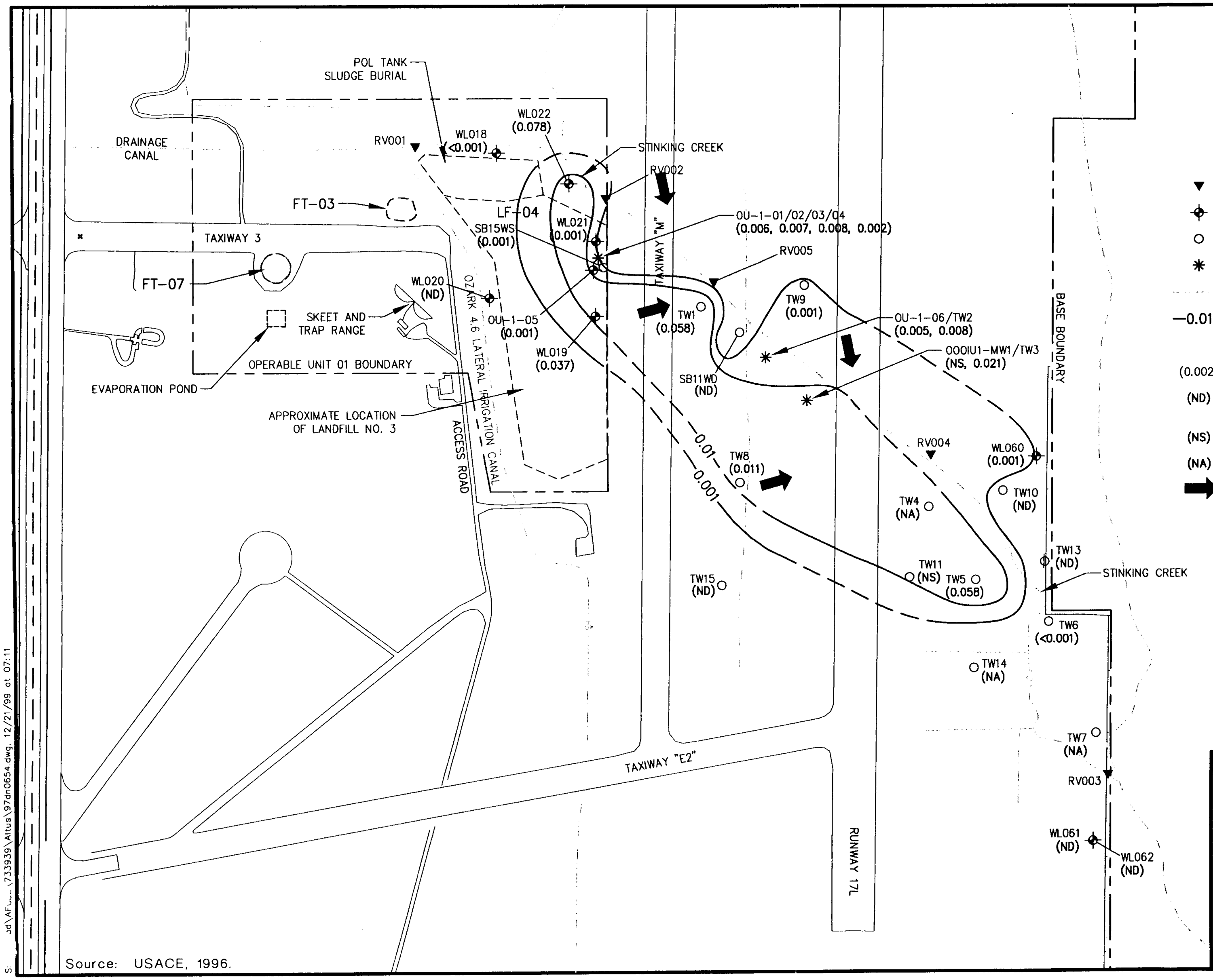

FIGURE 4.13

DISTRIBUTION OF METHANE
IN SHALLOW GROUNDWATER
APRIL 1997

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS
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Denver, Colorado

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TABLE 4.6
VOLATILE FATTY ACIDS DETECTED IN GROUNDWATER
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Volatile Fatty Acid (μg/L)[a]	WL022	OU-1-01	OU-1-02
Trimethylacetic Acid	10	9	10
Pentanoic Acid	<3[b]	<3	3
Hexanoic Acid	4	5	10
Phenol	4	4	<3
2-Ethylhexanoic Acid	35	33	35
Heptanoic Acid	<3	<3	4
Octanoic Acid	<3	<3	8
Benzoic Acid	4	5	4
Decanoic Acid	<3	ND[c]	4

[a] Units are micrograms per liter.

[b] Compound detected below lowest calibration standard (3 μg/L).

[c] Compound not detected.

35 parts per billion) in the three groundwater samples. Because nine VFAs were detected at various concentrations, results suggest recent microbial activity.

4.4.6.7 Ammonia

The presence of ammonia in groundwater can result from nitrate reduction (facilitated by microorganisms), fixing of atmospheric nitrogen (also a microbial process), or anthropogenic sources such as land application of fertilizer. Fixation of nitrogen normally occurs only under reducing conditions (ORP less than -500 mV [Stumm and Morgan, 1981]). Ammonia was not detected in any groundwater samples analyzed (Table 4.3).

4.4.7 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.

4.4.7.1 Alkalinity and Carbon Dioxide Evolution

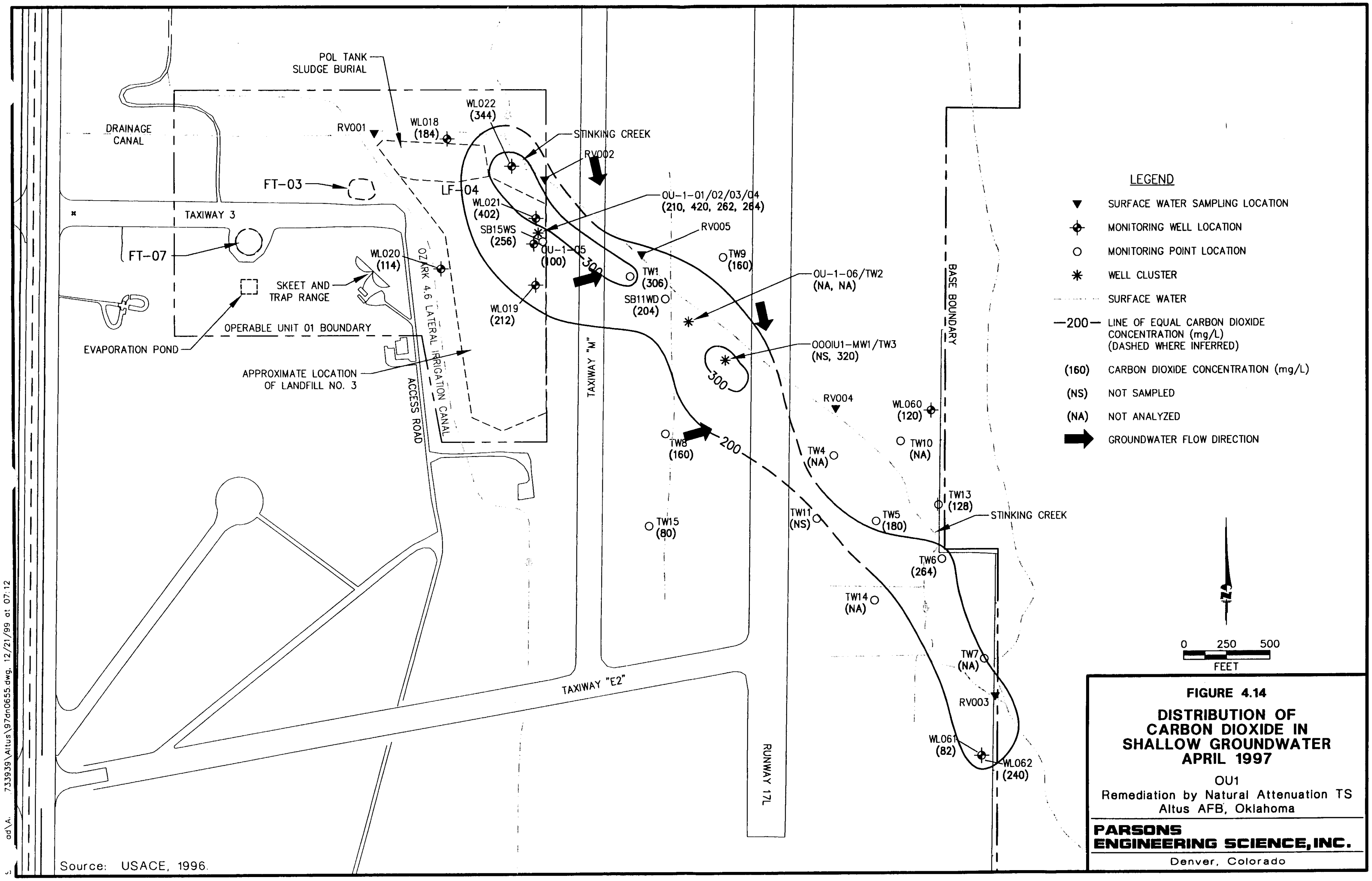
Carbon dioxide is produced during the biodegradation of native or anthropogenic organic carbon compounds. In aquifers that have carbonate minerals as part of the matrix, carbon dioxide forms carbonic acid, which dissolves these minerals, increasing the alkalinity of the groundwater. An increase in alkalinity (measured as calcium carbonate [$CaCO_3$]) in an area with BTEX or chlorinated solvent (particularly less-chlorinated solvents) concentrations elevated above background conditions can be used to infer that petroleum hydrocarbons, less-chlorinated solvents, or native organic carbon have been destroyed through aerobic and anaerobic microbial respiration.

Total alkalinity (as $CaCO_3$) was measured in groundwater samples collected in April 1997. These measurements are summarized in Table 4.3. Alkalinity is a measure of the ability of groundwater to buffer changes in pH caused by the addition of biologically generated acids. Total alkalinity at the site varied from 157 mg/L to 504 mg/L. This range of alkalinity is sufficient to buffer potential changes in pH caused by biologically mediated reactions and suggests that biodegradation processes should not cause detrimental shifts in pH.

Free carbon dioxide concentrations also were measured in groundwater samples collected in November 1996 (Table 4.3). As shown on Figure 4.14, carbon dioxide concentrations within the full extent of the chlorinated solvent plume are elevated above background concentrations. Background concentrations are about 80 to 160 mg/L, while within the plume area, concentrations are in the range of 80 to 400 mg/L. Carbon dioxide concentrations above background result from both aerobic and anaerobic biodegradation processes as contaminants are ultimately converted to carbon dioxide and water.

4.4.7.2 pH

The pH of groundwater samples collected from groundwater monitoring points and monitoring wells in April 1997 was measured. These measurements are summarized in



LEGEND

▼	SURFACE WATER SAMPLING LOCATION
⌖	MONITORING WELL LOCATION
○	MONITORING POINT LOCATION
✳	WELL CLUSTER
------	SURFACE WATER
—200—	LINE OF EQUAL CARBON DIOXIDE CONCENTRATION (mg/L) (DASHED WHERE INFERRED)
(160)	CARBON DIOXIDE CONCENTRATION (mg/L)
(NS)	NOT SAMPLED
(NA)	NOT ANALYZED
➡	GROUNDWATER FLOW DIRECTION

Source: USACE, 1996.

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FIGURE 4.14

DISTRIBUTION OF CARBON DIOXIDE IN SHALLOW GROUNDWATER APRIL 1997

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

Table 4.3. Groundwater pH measured at the site ranges from 6.8 to 8.1 standard units. This range of pH is within the optimal range for CAH-degrading microbes. The limited and relatively neutral range of pHs also indicates that microbial reactions have a minimal effect on groundwater pH, likely due to the moderately high alkalinity of site groundwater.

4.4.7.3 Temperature

Groundwater temperature was measured at groundwater monitoring points and monitoring wells in April 1997. Table 4.3 summarizes groundwater temperature readings. Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures generally resulting in higher growth rates. The temperature of groundwater samples ranged from 12.2 to 21.0 degrees Celsius (°C). These temperatures are within the optimal growth range for relatively rare psychrophilic microorganisms and below optimal for the more common mesophilic microorganisms (Atlas, 1988), suggesting that bacterial growth rates will be moderate.

4.5 APPROXIMATION OF BIODEGRADATION RATES

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

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

Another method for estimating dechlorination rates of CAHs is described by Moutoux *et al.* (1996). This method can be used to estimate the theoretical contaminant concentration resulting from reductive dechlorination alone for every point along a flow path on the basis of the measured contaminant concentration at the point of plume origin and the contaminant/tracer ratios between consecutive points along the flow path. This series of points can then be used to estimate a first-order rate of biodegradation. The carbon core of the CAH compounds, which is subject to the same non-destructive attenuation mechanisms that act on the larger chlorinated molecule, but is unaffected by biologically mediated reductive dechlorination, is used as the tracer. This method provides a total dechlorination rate for all dechlorination steps. All rates (including the rapid TCE to DCE rate and the slow VC to ethene) are averaged in using the Moutoux *et al.* (1996) method. Because abiotic reactions and reactions that involve CAH compounds in the role of an electron donor are not included in this rate, the rate should be considered a lower bound on the destructive attenuation rate

Although a first-order rate assumption may provide a reasonable approximation of how quickly CAH compounds are degrading in groundwater systems, this approach may not provide the best approximation of the dechlorination rate of CAH compounds in the presence of an electron donor such as BTEX. These reactions may be more appropriately approximated by a second-order rate expression.

The Buscheck and Alcantar (1995) and Moutoux (1996) methods were used to estimate first-order biodegradation rate constants for CAHs at OU-1. Because concentrations of the parent solvent (TCE) are dominant, the rates are substantially equivalent to TCE decay rates. The decay rate calculations are summarized in Appendix D.

Rates of CAH biodegradation estimated from data collected for this investigation range from 8×10^{-6} to 2×10^{-3} day^{-1}. The rates computed using the method of Buscheck and Alcantar (1995) are approximately 3 orders of magnitude higher than the rates derived for reductive dechlorination using the method of Moutoux (1996). As described above, the Buscheck and Alcantar method can be viewed as an upper bound on the biodegradation rate, and the Moutoux method can be viewed as a lower limit to the rate of reductive dechlorination. Given the evidence that limited reductive dechlorination is occurring and the possibility of a slowly expanding plume, the value derived using the method of Moutoux may be more representative of the rate of reductive dechlorination of TCE occurring at OU1 beyond the confines of the landfill. However, in the downgradient region of the plume, DCE may be degraded through oxidation reactions. If DCE mass is lost to processes that do not affect the TCE mass in a similar fashion, the Moutoux (1996) method is overly conservative.

4.6 SUMMARY

The dissolved CAH plume appears to have migrated 4,000 feet southeast of the source area at OU1. Several lines of chemical and geochemical evidence indicate that, although dissolved TCE at OU-1 is undergoing biologically facilitated reductive dechlorination, the occurrence of this process is limited. Near the source area, this is most clearly observed by a decreasing ratio of TCE to the primary metabolite *cis*-1,2-DCE. Downgradient from the source area, increasing TCE to DCE ratios suggest that DCE is degraded through oxidation reactions, while the TCE mass is relatively unaffected by destructive attenuation mechanisms. As a result, the parent CAH (TCE) still comprises the majority of the contamination present in groundwater throughout most of the plume.

The dissolved CAH plume at OU-1 exhibits characteristics of Type 1 behavior. The evidence supporting the reductive dechlorination of TCE is summarized below:

The presence of TCE biodegradation metabolites in groundwater in the source area and central portion of the TCE plume that were not used in Base operations, particularly *cis*-1,2-DCE, is a direct indication that TCE is being reductively dechlorinated in these areas;

The presence of elevated chloride concentrations in the southeastern (downgradient) portion of TCE plume indicates that biodegradation reactions are occurring in the source area and central portion of the TCE plume and that chloride is migrating in the direction of groundwater flow;

DO, ORP, and dissolved H_2 data indicate that the groundwater environment is anaerobic, but not optimally reducing, in the source area and central portion of the TCE plume and therefore more conducive to the occurrence of moderate rates of reductive dechlorination;

Nitrate + nitrite (as nitrogen) concentrations are less than 1 mg/L within the TCE plume, indicating that TCE may be utilized as an electron acceptor rather than nitrate in the process of reductive dechlorination; and

VFA detections near the source area suggests moderate recent microbial activity in this area.

Wiedemeier *et al.* (1996b) present a worksheet to allow an initial assessment of the prominence of natural attenuation at a site. The worksheet, including the point values determined for OU-1, is presented in Table 4.7.

The interpretation of points awarded during the screening process outlined in Table 4.7 is shown in Table 4.8. The score is 11, indicating that limited evidence for biodegradation of chlorinated organics is present.

TABLE 4.7
ANALYTICAL CAH DEGRADATION PARAMETERS AND WEIGHTING FOR PRELIMINARY SCREENING
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AIR FORCE BASE, OKLAHOMA

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value	Score for LF-4 Plume
Oxygen	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	3	3
Oxygen	>1 mg/L	VC may be oxidized aerobically	-3	0
Nitrate	<1 mg/L	At higher concentrations may compete with reductive pathway	2	2
Ferrous Iron	>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	--[a/]
Methane	>0.5 mg/L	Ultimate reductive daughter product, VC accumulates	3	0
ORP	<50 mV <-100mV	Reductive pathway possible Reductive pathway likely	1 2	0 0
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 processes are accelerated	1	0
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	1	1
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	1	0
Chloride	>2x background	Daughter product of organic chlorine	2	0
Hydrogen	>1 nM/L	Reductive pathway possible, VC may accumulate	3	3
Hydrogen	<1 nM/L	VC oxidized	0	0
Volatile Fatty Acids	> 0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	2	0
BTEX	>100 mg/L	Carbon and energy source; drives dechlorination	2	0
PCE		Material released	0	0
TCE		Material released Daughter product of PCE	0 2	0 0
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	0 2

TABLE 4.7 (Continued)
ANALYTICAL PARAMETERS AND WEIGHTING FOR PRELIMINARY SCREENING
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AIR FORCE BASE, OKLAHOMA

Analysis	Concentration in Most Contaminated Zone	Interpretation	Value	Score for LF-4 Plume
VC		Material released Daughter product of DCE	0 2	0 0
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	0
1,1,1-Trichloroethane		Material released	0	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[b/]	--
		TOTAL		11

a/ -- indicates that the analysis was not completed.

b/ 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 4.8
INTERPRETATION OF POINTS AWARDED DURING NATURAL ATTENUATION SCREENING
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AIR FORCE BASE, 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

SECTION 5

GROUNDWATER FLOW AND CONTAMINANT TRANSPORT MODEL

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

In order to help predict the future migration and fate of CAHs dissolved in groundwater at Altus AFB OU-1, Parsons ES modeled shallow groundwater flow and the fate and transport of the dissolved CAH plume. The modeling effort had three primary objectives: 1) predict the future extent and concentrations of the dissolved 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 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. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes. The model input data are believed to be reasonably conservative so that the actual reduction in contaminant mass caused by natural attenuation should meet or exceed model predictions.

The model codes MODFLOW (McDonald and Harbaugh, 1988) and MT3D$^{\underline{96}®}$ (S.S. Papadopulos & Associates, Inc., 1996) were used to estimate the potential for dissolved CAH migration and degradation by naturally occurring mechanisms operating at the site. MODFLOW was used to generate a steady-state groundwater flow model for the site. The MODFLOW flow field was incorporated into the transport solution computed by MT3D$^{\underline{96}®}$ (version 1.1). The pre- and post- processors contained in Visual MODFLOW, version 2.20 (Waterloo Hydrogeologic Software, 1996) were used to facilitate model development and analysis and presentation of the model results. The MT3D$^{\underline{96}®}$ code incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. MT3D$^{\underline{96}®}$ uses solution routines based on the Method of Characteristics (MOC) solute transport model [e.g., as developed by Konikow and Bredehoeft (1978) for the 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 was called MT3D. MT3D$^{\underline{96}®}$ is an improvement on MT3D that allows for spatial variation of solute transport parameters (e.g., retardation and first-order decay rate).

Ideally, a code for simulating degradation of CAHs would track daughter products as well as parent compounds and allow specification of varying decay rates for each compound. Although not yet available, Battelle National Laboratories is in the process of developing such a code by modifying MT3D.

5.2 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

On the basis of the data presented in Section 3, the shallow saturated zone was conceptualized and modeled as a heterogeneous, unconfined aquifer. Hydrogeologic profiles of the site (Figure 3.2) show that the major subsurface units of the aquifer are a saprolitic clay layer and the underlying shale bedrock. The CAH plume is migrating primarily through the overburden clay, though the contaminant has been detected in groundwater from wells screened within the top 10 feet of the more competent shale (OU-1-06). Depth to groundwater across the site ranges from 6 to 10 feet bls, though the depth increases beneath the built-up taxiway and runway. The configuration of groundwater elevation isopleths on Figure 3.3 indicates that groundwater in the LF-04 area primarily flows southeast, parallel to Stinking Creek, with discharge to or recharge from the creek preventing significant contaminant migration north of the creek. The horizontal hydraulic gradient across the study area is approximately 0.003 ft/ft. Vertical flow profiles indicate downward flow (0.017 to 0.703 ft/ft) at well clusters across the site except at well cluster WL061/WL062, where there is an upward gradient (0.008 ft/ft). These April 1997 data are generally consistent with the data collected during previous investigations, though water levels were higher in Spring 1997 due to recent rainfall. Therefore, it was assumed that the groundwater flow patterns interpreted from April 1997 water levels were reasonably representative of steady-state conditions. The water table across the study area is assumed to be influenced by continuous recharge from north and west of the site, recharge or discharge at Stinking Creek, and discharge to the southeast of the site. It is assumed that recharge from precipitation is negligible because annual precipitation at the Base is approximately 25 inches, annual evaporation usually exceeds precipitation, and clayey soils prevent rapid infiltration (Section 3.2).

For the purposes of the model, it is assumed that contaminants were first introduced to the groundwater at this site when LF-04 was used for solid waste disposal and POL sludge disposal from 1956 through the 1970s. Therefore, for the model it was assumed that a large slug of contamination entered the groundwater upon waste deposition, and that residual contamination associated with the buried waste acts as a continuous source. It is likely that the source will weather over time, and the mass of contaminants entering groundwater will decline.

The most important assumption made when using the MT3D$^{96®}$ code is that dispersion, sorption and biodegradation are major factors controlling contaminant fate and transport at the site. According to data presented in Sections 3 and 4, concentrations of organic carbon within the site soil may support significant sorption. Data also suggest that limited biodegradation of CAHs is occurring within the plume. 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 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 (4,000 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. 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 5.3.3.

5.3 INITIAL MODEL SETUP

Where possible, the initial setup for this model was based on site-specific data. Where site-specific data were not available (e.g., effective porosity), reasonable assumptions were made on the basis of widely-accepted literature values for materials similar to those found in the shallow aquifer at OU-1. The following sections describe the basic model setup. Those model parameters that were varied during model calibration are discussed in Section 5.4.

5.3.1 Grid Design

The model domain for Altus AFB OU-1 is represented using one layer, with a 52- by 74-cell horizontal grid. Relatively small grid cells (50 feet by 50 feet) were used within the central portion of the contaminant plume to allow more accurate simulation of transport; the cell size was gradually increased with distance from the source area, with the largest cell measuring 150 feet wide by 100 feet long. A SURFER™ topographic file of the ground surface was created using lithologic logs and imported into Visual Modflow. The grid thickness varies from 35 feet in the east to 55 feet in the west. The grid was oriented with the longest dimension parallel to the main direction of dissolved contaminant migration. The model grid covers an area of approximately 436 acres. The full extent of the model grid is indicated on Figure 5.1.

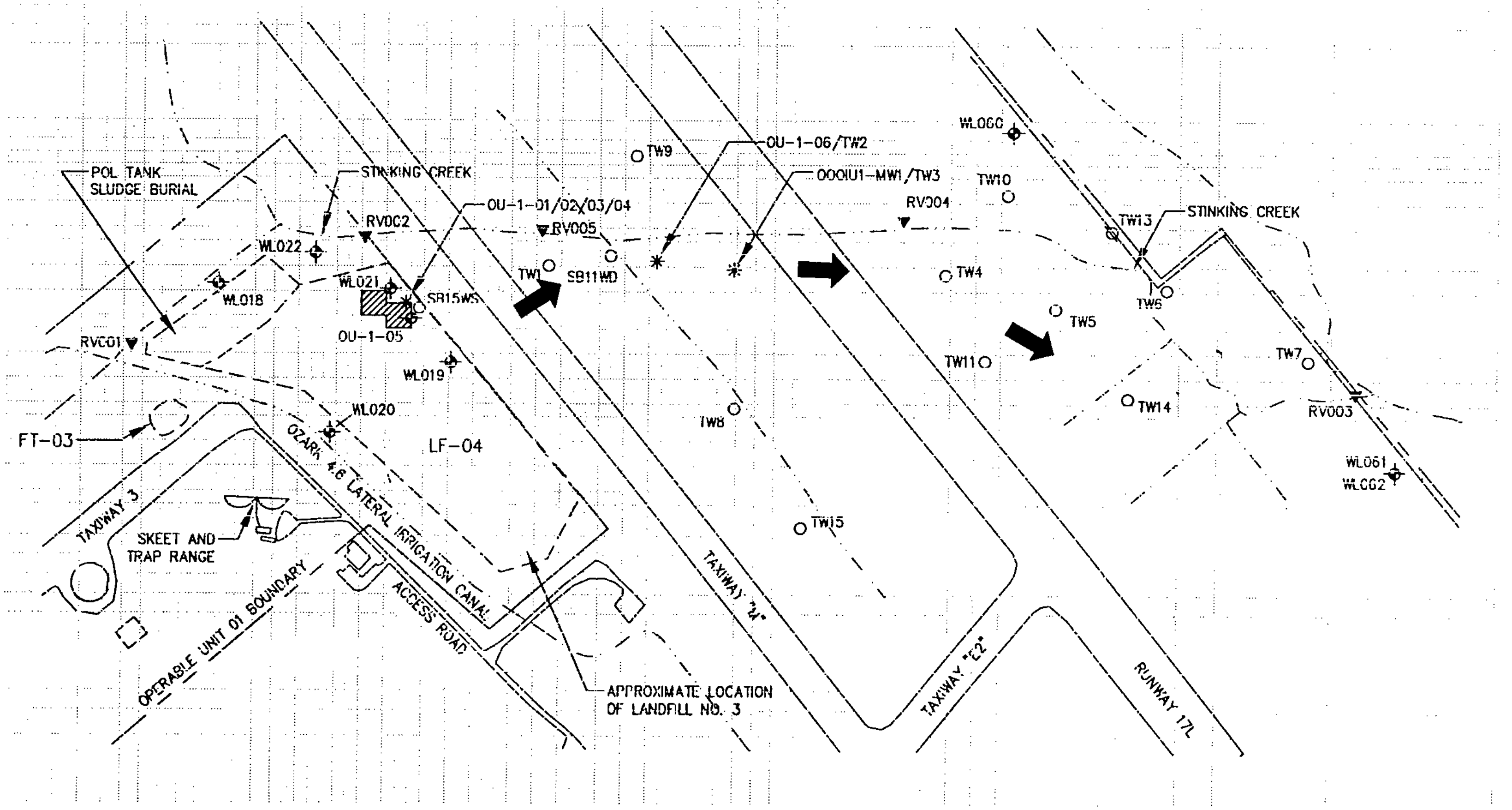
5.3.2 Groundwater Flow Model

5.3.2.1 Boundary Conditions

In defining the model domain, the area of interest must be separated from the surrounding system. 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 (derivative of the head or contaminant concentration with respect to time) at the model grid boundaries.

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

In flow models, boundary conditions are ideally used to specify actual hydrogeologic boundaries to the system, such as a geologic feature that may bound a system or areas where properties (e.g., flux) are known and can be defined. When using a numerical flow model, hydrologic boundaries such as constant-head features (e.g., lakes, streams, etc.) or constant-flux features (e.g., groundwater divides, confining units, etc.,) should, when possible, coincide with the perimeter of the model. In areas that lack obvious hydrologic



LEGEND

▼ SURFACE WATER SAMPLING LOCATION

⌖ MONITORING WELL LOCATION

○ MONITORING POINT LOCATION

✳ WELL CLUSTER

—·—·— SURFACE WATER

▨ RECHARGE CONCENTRATION SOURCE CELLS

⬅ GROUNDWATER FLOW DIRECTION

0 225 450
FEET

FIGURE 5.1

MODEL GRID

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 5.1
COMMON DESIGNATIONS FOR SEVERAL IMPORTANT BOUNDARY CONDITIONS
(Modified from Franke *et al.*, 1987)
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB. OKLAHOMA

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

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 will not be affected by inaccuracies in the boundary conditions.

Specified-head cells were defined at the model boundaries. The specified heads were estimated by projecting heads from the groundwater flow maps. These constant-head cells were placed far enough from the simulated CAH plume to avoid potential boundary interferences. The MODFLOW river package was used to simulate Stinking Creek. Heads at Stinking Creek were estimated to range from 1350 ft amsl at the northwestern boundary of the model domain to 1335 ft amsl at the eastern boundary of the model domain. The base or lower boundary of the model is assumed to be no-flow and is set at 1300 ft amsl within the shale bedrock. The upper model boundary is defined by the simulated water table surface.

5.3.2.2 Recharge and Evapotranspiration

Because evapotranspiration is expected to exceed precipitation, recharge from precipitation is assumed to be negligible at the site (Section 3.2). Therefore, no recharge or evapotranspiration was defined for the site, except for low rates of recharge at four cells located near the western boundary of LF-04 to help simulate partitioning of CAHs to groundwater (Section 5.3.3.1).

5.3.2.3 Aquifer Properties

As discussed in Section 3.3.2.3, the effective porosity is the percentage of a rock or sediment through which fluids can travel. A general value of 5 percent for effective porosity was defined for the model domain on the basis of the grain-size distribution observed in the shallow surficial aquifer (Spitz and Moreno, 1996).

Hydraulic conductivity values were calculated from field data obtained from 12 slug tests performed at four site wells. The calculated values are summarized in Table 3.3 and discussed in Section 3.3. It was assumed that the majority of the contaminant plume is migrating through the silty and sandy clay overlying the shale bedrock. An average hydraulic conductivity of 15 ft/day was initially defined for the model domain.

5.3.3 Contaminant Transport Model

The total dissolved chlorinated ethene concentrations obtained from April 1997 laboratory analytical results for each monitoring well/point location were used as targets for model calibration. Table 4.2 presents dissolved CAH concentration data for April 1997, and Figures 4.3 through 4.6 show the spatial distribution of dissolved CAHs in September 1996. For the purposes of this model, the concentrations of the individual compounds were converted from micrograms per liter (μg/L) to micromoles per liter (μmol/L) before being summed. This was done because the primary biodegradation reaction operating at the site is reductive dechlorination. As discussed in Section 4.2, reductive dechlorination is a mole-to-mole transformation from parent to daughter product involving replacement of one chlorine atom with a hydrogen atom. The process results in decreased contaminant mass because the mass of the daughter compound is significantly lower; however, the molar concentration is unchanged. Because the biodegradation rates calculated from site data and used in the model represent rates of dechlorination only, and not rates of mass loss due to dechlorination, simulation of changes in molar concentrations is a more appropriate manner in which to simulate progressive dechlorination of CAHs.

5.3.3.1 Source

Transport models use boundary conditions to express the influence of contaminant sources such as nonaqueous-phase liquid (NAPL) bodies and dissolved mass entering through recharge, injection wells, surface water bodies, and 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, not the source characteristics (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 (Feenstra and Guiguer, 1996; Abriola, 1996).

Rather than using various calculations to attempt to estimate CAH partitioning from NAPL into groundwater, the "black box" source approach was used. Experience modeling contaminated sites as part of the AFCEE Natural Attenuation Initiative has suggested that this is the best method for reproducing observed plumes. At the LF-04 site, the contaminant is assumed to enter groundwater in the study area through contact between groundwater and residual NAPL at or below the water table. Partitioning of

CAHs from this source into groundwater was simulated by defining source area recharge concentrations in four model cells near the western boundary of LF-04 (Figure 5.1). The concentrations were initially spiked to simulate the dissolution of pure product into the groundwater at the time of the initial contaminant introduction, and then the recharge source concentration was decreased geometrically to reach its present observed effect.

5.3.3.2 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 400 feet at the Altus AFB OU1 LF-04 site (Figure 4.3). Transverse dispersivity values are estimated as one-tenth of the longitudinal dispersivity values (Domenico and Schwartz, 1990).

5.3.3.3 Retardation

Retardation of CAHs relative to the advective velocity of the groundwater occurs when contaminant molecules are sorbed to organic carbon, silt, or clay in the aquifer matrix. Based on measured TOC concentrations near the water table at 11 locations across the site (see Table 4.1), an assumed bulk density of 1.4 kilograms per liter (kg/L), and published values of the soil sorption coefficient (K_{oc}) for TCE and DCE (as listed in Wiedemeier *et al.*, 1996) 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 CAH plume will migrate downgradient. Initially, the average calculated retardation coefficient of 4 was assigned to the model.

5.3.3.4 Biodegradation

As discussed in Section 4.5, first-order decay rates of 2×10^{-3} day^{-1} to 8×10^{-6} day^{-1} were calculated for site contaminants using site-specific data. These rates were used to define a range of possible values for model input. An initial conservative estimate of 8×10^{-6} days^{-1} was defined for the model domain. Also as noted in Section 4.5, reductive dechlorination of CAHs may be best represented using a second-order rate, but most common transport codes (including MT3D$^{\underline{96}®}$) can incorporate only a first-order rate. This impacts model calibration and may constrain the usefulness of predictions, but at this time there is no feasible alternative for simulating CAH transport under the influence of biodegradation. Provided that conservative values are used for other input parameters and a sensitivity analysis is performed, simulations incorporating a first-order rate constant will still be useful and meaningful.

5.4 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 superimposed upon the calibrated flow model helps demonstrate that contaminant loading and transport conditions are being appropriately simulated. Model input and output files for the calibrated model, Alternative 1, and Alternative 2 (Section 6) are included in Appendix E.

TABLE 5.2
CALCULATION OF RETARDATION COEFFICIENTS
OU1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB LF-04

Compound	K_{oc} (L/kg [a/])	Maximum Fraction Organic Carbon [b/]	Minimum Fraction Organic Carbon [b/]	Average Fraction Organic Carbon [b/]	Distribution Coefficient K_d (L/kg)			Bulk Density (kg/L) [d/]	Effective Porosity [d/]	Coefficient of Retardation		
					Maximum [c1/]	Minimum [c2/]	Average [c3/]			Maximum	Minimum	Average
TCE	87	0.00749	0.00022	0.0015	0.652	0.019	0.131	1.40	0.05	19.25	1.54	4.65
DCE	49	0.00749	0.00022	0.0015	0.367	0.011	0.074	1.40	0.05	11.28	1.30	3.06

[a/] From AFCEE technical protocol (Wiedemeier *et al.*, 1997).

[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.

5.4.1 Groundwater Flow Model

Groundwater elevation data collected in April 1997 and presented on Figure 3.3 were used to calibrate the flow model. Water level elevation data from 22 monitoring wells/points were used to compare measured and simulated heads for calibration. The selected locations were OU-1-03, WL018, WL019, WL020, WL021, WL022, WL060, WL062, TW1, TW2, TW3, TW4, TW5, TW6, TW7, TW8, TW9, TW10, TW11, TW13, TW14, and TW15.

The numerical flow model was calibrated by altering hydraulic conductivity, constant-head elevations at the model boundaries, and the river package parameters in a trial-and-error fashion until simulated heads approximated observed field values within a prescribed accuracy.

Figure 5.2 shows the calibrated water table. Calibrated model hydraulic conductivities ranged between 0.1 and 30 ft/day, with most cells having a hydraulic conductivity of 1 ft/day. The cells in the vicinity of the runway were assigned a hydraulic conductivity of 0.1 ft/day, because the subsurface was likely tamped and compressed during construction of the runway, resulting in a lower conductivity of those soils. Also, the cells in the vicinity of the brown clayey sand layer (see Figure 3.2) were assigned a hydraulic conductivity of 30 ft/day.

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:

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

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 the 22 comparison points was 1.11 feet, which corresponds to a calibration error of 7.6 percent (water levels dropped approximately 14.6 feet over the portion of the model domain containing the monitoring wells/points listed above).

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. The hydraulic mass balance for the calibrated model was adequate to accomplish the objectives of this modeling effort, with a 1.37 percent discrepancy.

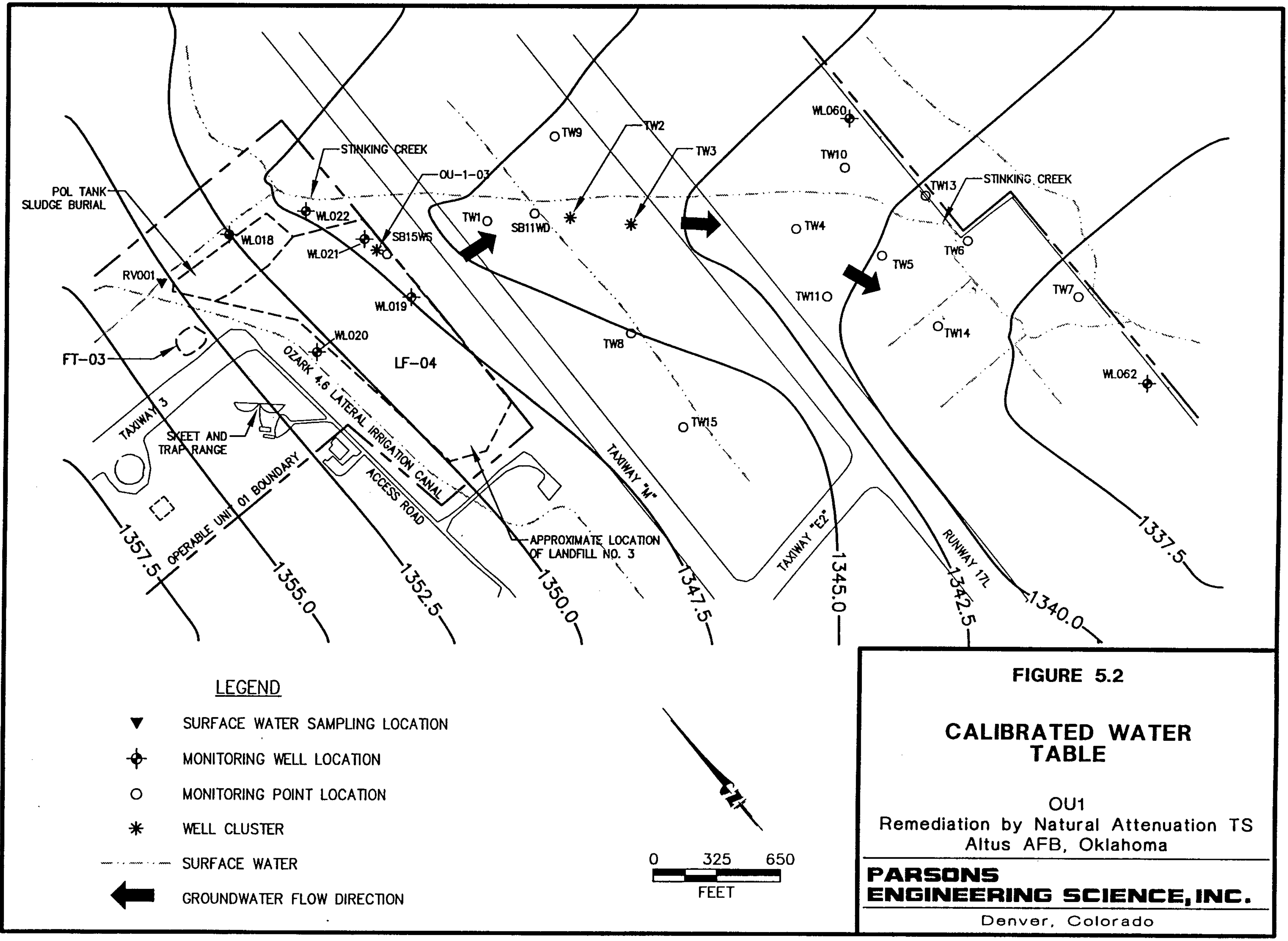

FIGURE 5.2

CALIBRATED WATER TABLE

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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5.4.2 Plume Calibration

After calibration of the 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. The transport parameters varied during plume calibration were the source concentration, the plume dispersivity, the CAH decay rate constant, and the distribution coefficient of contaminant sorbed to soil. Because the original estimates for these parameters resulted in a calculated plume that reasonably resembled the original plume, these parameters were not varied greatly.

The dissolved CAH concentrations obtained from April 1997 laboratory analytical data from 20 monitoring wells/points sampled by Parsons ES were used to calibrate the contaminant transport model. The calibration points were OU-1-03, WL018, WL019, WL020, WL022, WL060, WL062, TW1, TW2, TW3, TW4, TW5, TW6, TW7, TW8, TW9, TW10, TW14, TW15, and SB11.

The longitudinal dispersivity of 400 feet produced a reasonable simulated plume but was decreased to 40 feet in the source area because dispersivity is scale-dependent. This is the value used to produce the calibrated plume depicted on Figure 5.3.

The decay rate was varied during plume calibration, but because of the minimal decay estimated at the site, changes within the estimated range of possible decay rates did not seem to affect plume migration substantially. The calibrated model used the initially defined conservative value of 8×10^{-6} day^{-1}. Although this rate is expected to be overly conservative within the immediate source area, it is appropriate for the majority of the contaminant plume. Furthermore, use of this value yielded a good match between simulated and measured concentrations.

During the plume calibration, the retardation coefficient was varied, and a value of 1.8 was used in the calibrated model. This value is within the range estimated on the basis of observed TOC concentrations. Use of this value produced simulated concentrations similar to measured concentrations.

The calibrated plume calculated by the model (Figure 5.3) is similar, but not identical, to the observed April 1997 plume (Figure 4.3). Simulated CAH concentrations in the source area are slightly higher than observed April 1997 concentrations. The simulated CAH concentration at well OU-1-03 is 118 µmol/L, whereas the concentration observed at that well was 108 µmol/L. Simulated CAH concentrations upgradient from the source area are significantly lower than observed concentrations. The simulated CAH concentration at well WL018 is 4×10^{-8} µmol/L, whereas the concentration observed at that well was 0.019 µmol/L. Simulated CAH concentrations downgradient from the source area are slightly lower than observed April 1997 concentrations. The simulated CAH concentration at well TW-1 is 5.8 µmol/L, whereas the observed concentration at that well was 6.724 µmol/L. Simulated CAH concentrations midway downgradient from the source area to the toe of the plume are slightly higher than observed April 1997 concentrations. The simulated CAH concentration at well TW-4 is 0.73 µmol/L, whereas the observed concentration at that well was 0.424 µmol/L. Simulated CAH concentrations at the toe of the plume are similar to the observed April 1997

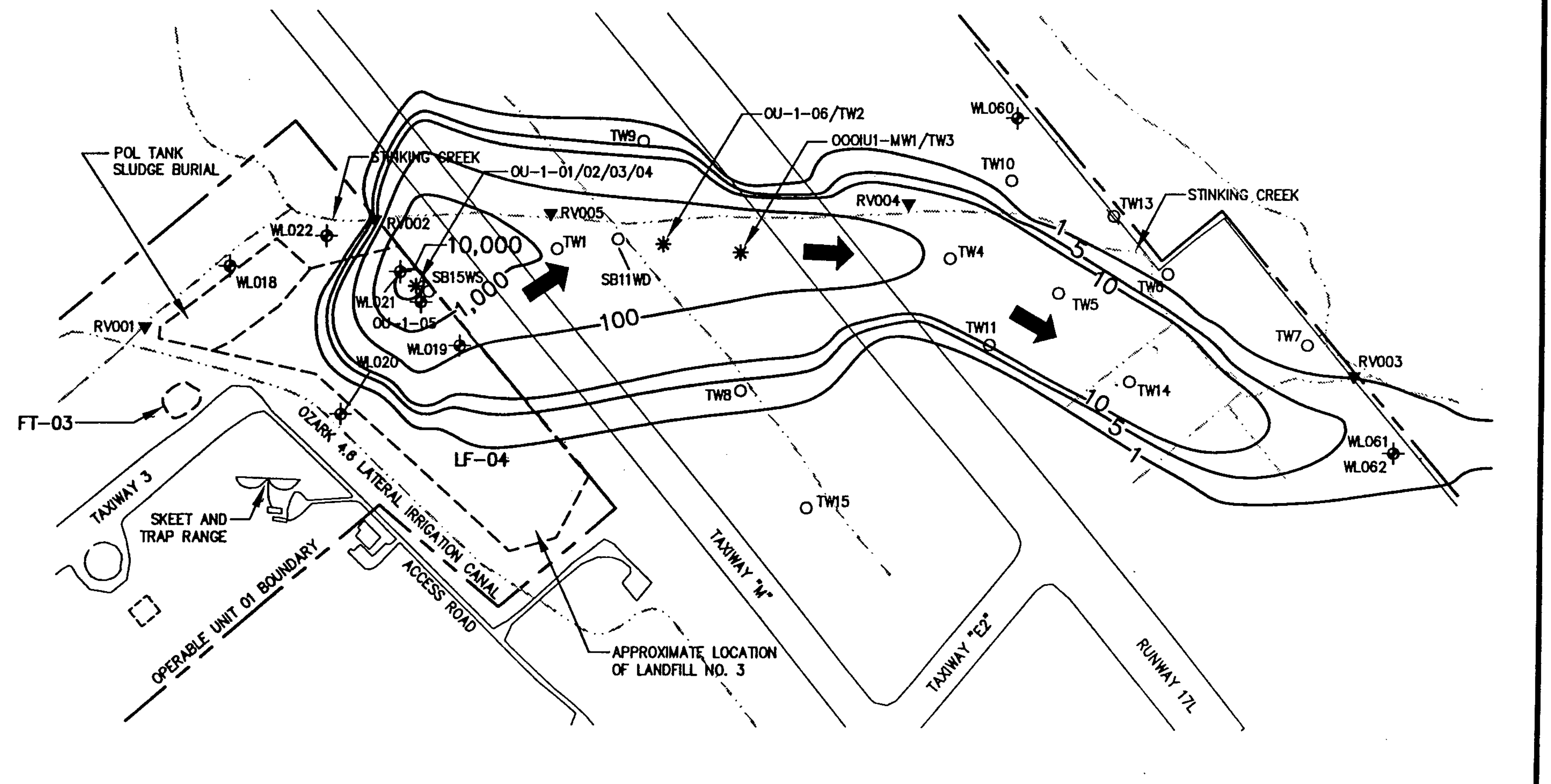


FIGURE 5.3

CALIBRATED CAH PLUME

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

concentrations. The simulated CAH concentration at well WL062 is 0.024 μmol/L, identical to the observed concentration at that well.

Higher simulated concentrations in the source area indicate that an adequate amount of mass is being introduced to the modeled system. Higher simulated concentrations midway through the plume shows that the model conservatively accomodates more mass than there is reason to believe is present. The similarity between the measured and simulated concentrations in the vicinity of well WL062 indicates that the calibrated model is adequately simulating migration of dissolved contaminant from the source area to the downgradient toe of the plume. This correlation is important because it facilitates accurate prediction of downgradient receptor impacts and of plume persistence by accurately simulating maximum CAH concentrations at the leading edge of the plume.

5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. The sensitivity analysis was conducted by varying hydraulic conductivity, the coefficient of retardation, the first-order decay rate, dispersivity, and the CAH injection rate.

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 41-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:

A. Hydraulic conductivity uniformly increased by a factor of 5;

B. Hydraulic conductivity uniformly decreased by a factor of 5;

C. Coefficient of retardation uniformly increased to 4.65;

D. Coefficient of retardation uniformly decreased to 1.3;

E. Dispersivity uniformly increased by 100 feet.;

F. Dispersivity uniformly decreased by 100 feet.;

G. First order decay rate increased by an order of magnitude;

H. First order decay rate increased to 2 x 10^{-3} day^{-1};

I. Recharge concentration source increased by a factor of 2; and

J. Recharge concentration source decreased by a factor of 2.

The results of the sensitivity analyses are discussed in the following subsections. As described in the following paragraphs, the parameter modifications listed above generally resulted in substantial changes in the resulting plumes, with the dispersivity modifications having the smallest effect.

5.5.1 Sensitivity to Variations in Hydraulic Conductivity

Hydraulic conductivity is an important aquifer characteristic that represents the ability of the water-bearing strata to transmit groundwater. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer. As a result, models used to estimate contaminant transport are particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume. Higher values of hydraulic conductivity result in a faster-moving plume. The effects of varying hydraulic conductivity are summarized in columns A and B of Table 5.3. Uniformly increasing the hydraulic conductivity by a factor of five increased the lateral dispersion of the plume such that the simulated total CAH molar concentration in the vicinity of source area monitoring well OU-1-03 was only 23 µmol/L, compared to the calibrated concentration of 118 µmol/L. The simulated CAH concentration in the vicinity of downgradient monitoring well WL062 increased to 0.8 µmol/L, compared to the calibrated concentration of 0.024 µmol/L. In contrast, decreasing the hydraulic conductivity by a factor of five slowed overall plume migration, and caused the contaminant mass to be concentrated within a smaller area. As a result, CAH levels in the vicinity of source area monitoring well OU-1-03 increased to 387 µmol/L, and the simulated CAH concentration in the vicinity of downgradient monitoring well WL062 decreased to 3×10^{-13} µmol/L.

5.5.2 Sensitivity to Variations in the Coefficient of Retardation

The effects of varying the coefficient of retardation are summarized in columns C and D of Table 5.3. Uniformly increasing the coefficient of retardation to 4.65 limited the downgradient migration of the plume. The simulated total CAH molar concentration in the vicinity of source area monitoring well OU-1-03 was 176 µmol/L, compared to the calibrated concentration of 118 µmol/L. The simulated CAH plume did not reach downgradient monitoring well WL062, where the calibrated CAH concentration was 0.024 µmol/L.

In contrast, decreasing the coefficient of retardation to 1.3 increased plume migration. As a result, the simulated CAH concentration at source area monitoring well OU-1-03 was unchanged, but the simulated CAH concentration in the vicinity of downgradient monitoring well WL062 increased to 0.04 µmol/L. Overall, varying the coefficient of retardation within a reasonable range has a limited effect on contaminant transport.

5.5.3 Sensitivity to Variations in Dispersivity

The effects of varying dispersivity are summarized in columns E and F of Table 5.3. Both longitudinal and transverse dispersivity were varied for this analysis, as the ratio of the two values was kept constant at 0.1. Increasing the dispersivity by 100 feet resulted in relatively lower concentrations in the source area. The simulated concentration at source area monitoring well OU-1-03 was 103 µmol/L, compared to a calibrated

TABLE 5.3
SUMMARY OF SENSITIVITY ANALYSIS RESULTS
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Well	Observed	Calibrated	A[a/]	B	C	D	E	F	G	H	I	J
OU-1-03	108	118	23	387	176	118	103	138	85	13	235	59
WL018	0.019	4E-08	2E-05	0	9E-30	4E-09	3E-07	3E-09	2E-08	0	9E-08	2E-08
WL019	4.133	1.18	1.5	0.003	0	1.4	1.7	0.6	0.4	0	2.4	0.6
WL020	0.007	5E-05	0.002	0	0	7E-05	3E-04	3E-06	5E-06	0	9E-05	2E-05
WL022	0.656	0	0.01	0	5E-13	0	0	0	0	0	0	0
WL060	0	0	0.03	3E-18	0	0	0	0	0	0	0	0
WL062	0.024	0.024	0.8	3E-13	0	0.04	0.04	0.009	0.009	0	0.05	0.01
TW1	6.724	5.8	2.4	0.4	3E-12	7	5.7	5.8	2.6	0	12	2.9
TW2	6.341	3	1.9	0.04	0	3.3	3.1	2.8	1.3	0	6	1.5
TW3	3.165	2.08	1.7	0.008	0	2.3	2.2	1.9	0.9	0	4.2	1
TW4	0.424	0.73	1.4	4E-05	0	0.9	0.84	0.6	0.3	0	1.5	0.4
TW5	0.016	0.4	1.3	7E-07	0	0.5	0.46	0.3	0.1	0	0.7	0.2
TW6	0	9E-04	0.4	1E-12	0	0.002	0.003	0	3E-04	0	0.002	4E-04
TW7	0	6E-04	0.4	5E-16	0	0.001	0.002	7E-05	2E-04	0	0.001	3E-04
TW8	3.717	0.02	0.4	6E-10	0	0.03	0.04	0.006	0.008	0	0.04	0.01
TW9	0.007	0.038	0.5	1E-08	0	0.05	0.08	0.01	0.01	0	0.08	0.02
TW10	0	0	0.2	1E-11	0	0	0	0	0	3E-06	0	0
TW14	0.007	0.2	1.2	0	0	0.3	0.3	0.1	0.08	0	0.4	0.1
TW15	0.113	2E-07	0.03	0	0	7E-07	6E-06	0	8E-08	0	5E-07	1E-07
SB11	3.886	3.997	2	0.1	0	3.5	4	3.9	1.7	0	8	2

[a/] Column headers refer to Section 5.5 Sensitivity Analysis labels.

concentration of 118 μmol/L. A corresponding increase in concentration downgradient from the source area was also observed, causing the simulated concentration at well WL062 to increase from 0.024 μmol/L in the calibrated model to 0.04 μmol/L.

Decreasing the dispersivity by 100 feet produced a plume with slightly higher concentrations in the source area. The simulated concentration at well OU-1-03 was 138 μmol/L, compared to the calibrated model concentration of 118. The CAH concentrations in the downgradient portion of the plume were lower. The simulated concentration at well WL062 was 0.009 μmol/L, compared to the observed concentration of 0.024 μmol/L at that well.

5.5.4 Sensitivity to Variations in the Anaerobic Decay Rate Constant

The effects of varying the first-order CAH decay rate are summarized in Table 5.3. Increasing this parameter by an order of magnitude results in more rapid degradation of dissolved contaminant. The resulting simulated concentrations at source area well OU-1-03 and at downgradient temporary well WL062 were lower than in the calibrated model (85 μmol/L and 0.009 μmol/L, respectively). Increasing the degradation rate to 2 x 10^{-3} day^{-1}, a rate that may be more appropriate within the source area of the plume, results in a much smaller plume. The simulated concentration at well OU-1-03 was 13 μmol/L, compared to the calibrated concentration of 118 μmol/L.

5.5.5 Sensitivity to Variations in Source Concentration Recharge Rate

The results of increasing and decreasing the CAH source concentration recharge rate by a factor of two are summarized in Table 5.3. Increasing the recharge rate concentration by a factor of two approximately doubles the simulated source area concentrations at well OU-1-03 to 235 mmol/L and substantially increases concentrations throughout the plume compared to field observations. The simulated concentration at downgradient well WL062 was 0.05 μmol/L, compared to the calibrated concentration of 0.024 at this well.

Decreasing the source concentration recharge rate by a factor of two approximately halved the calibrated concentrations at the source area well OU-1-03 to 59 μmol/L. Likewise, the simulated concentration at downgradient well WL062 was decreased by approximately a factor of 2 to 0.01 μmol/L. Furthermore, the overall size of the plume was reduced relative to the calibrated model dimensions.

5.5.6 Summary of Sensitivity Analysis Results

The results of the sensitivity analysis suggest that the calibrated model depicted in Figure 5.3 is reasonable. Varying the model parameters within the prescribed ranges generally caused the extent and magnitude of the dissolved plume to differ substantially from observed site conditions.

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the development and comparative analysis of two groundwater remedial alternatives for OU-1 at Altus AFB. The intent of this evaluation is to determine if RNA is an appropriate and cost-effective remedial approach to consider when developing final remedial strategies for the site, especially when combined with other innovative and conventional 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 demonstration project. Section 6.3 provides a brief description of each of these remedial alternatives. Section 6.4 provides a more detailed analysis, including modeling results, of the remedial alternatives using the defined evaluation criteria. The 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 groundwater contamination at the site were adapted from those recommended by the USEPA (1988) for selecting remedies for Superfund sites (OSWER Directive 9355.3-01). These criteria included (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 CAH concentrations in groundwater to levels that meet regulatory standards intended to be protective of human health and the environment.

6.1.1 Long-Term Effectiveness and Permanence

Each remedial approach or remedial alternative (which can be a combination of remedial approaches such as RNA and institutional controls) was analyzed to determine how effectively it will minimize groundwater plume expansion so that applicable groundwater quality standards can be achieved at a hypothetical downgradient POC. The expected remedial effectiveness based on case histories from other sites with similar conditions also is evaluated where feasible. The ability to minimize potential impacts on surrounding areas, facilities, and operations is considered. Also, the ability of each remedial alternative to protect both current and potential future receptors from potential exposures associated with site-related contamination in shallow groundwater is qualitatively assessed by conservatively evaluating the potential for completion of exposure pathways involving groundwater, either now or in the future. This evaluation criterion also includes permanence and the ability to reduce contaminant mass, toxicity, and volume. Time to implementation and estimated time until protection is achieved are described. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, also is evaluated.

6.1.2 Implementability

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

6.1.3 Cost

The total cost (present worth) of each remedial alternative was estimated for relative comparison following USEPA (1993) guidance. An estimate of capital costs, and operations and post-implementation costs for site monitoring and controls is included. An annual adjustment (discount) factor of 7 percent was assumed in present-worth calculations (USEPA, 1993). The discount rate is the difference between the rate of inflation and the cost of money.

6.2 FACTORS INFLUENCING ALTERNATIVES DEVELOPMENT

Several factors were considered during the identification and screening of remedial technologies for addressing shallow groundwater contamination at the site. Factors considered included the objectives of the AFCEE natural attenuation demonstration program; site-specific contaminant, groundwater, and soil properties; present and future land uses; and potential receptor 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 to the final remedial alternatives considered for the site.

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 naturally occurring subsurface attenuation processes that can be factored into overall site remediation plans. The objective of this program is to provide solid evidence of RNA of dissolved CAHs 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 that demonstrate that 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., vadose zone soil, soil gas, etc.), approaches and technologies have been evaluated based primarily on their potential impact on shallow groundwater and phreatic soils. Technologies that can reduce vadose zone contamination and partitioning of contaminants into groundwater also have been evaluated. Many of the source removal technologies evaluated in this section also will reduce soil and soil gas contamination, but it is important to emphasize that the remedial alternatives developed in this document are not necessarily intended to remediate all contaminated media.

Additional program objectives set forth by AFCEE include cost effectiveness and minimization of waste. Approaches and technologies that may meet these criteria include institutional controls, soil vapor extraction, biosparging/air sparging, limited groundwater pump and treat, and RNA. Soil excavation, slurry walls, sheet piling, carbon adsorption, *ex situ* biological or chemical treatment, and onsite/offsite disposal generally are not attractive technology candidates under this program.

6.2.2 Contaminant Properties

The site-related contaminants considered as part of this demonstration at OU-1 are TCE (the parent CAH) and *cis*-1,2-DCE (a biodegradation byproduct). The source(s) of this contamination have not been identified; potential sources include dense NAPL (DNAPL) and residual contamination adsorbed to soils in the vicinity of LF-04. The physiochemical characteristics of the individual CAH compounds will greatly influence the effectiveness and selection of a remedial technology.

The CAH compounds 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 susceptible 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. Henry's Law Constants reported for TCE range from 0.0086 to 10.2×10^3 atmosphere-cubic meters per mole (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 sorbs to soils, as it has a log K_{oc} of approximately 1.9 and a log octanol/water partition coeffiecient (K_{ow}) of approximately 2.6 (Montgomery, 1996). TCE biodegradation varies according to the prevailing groundwater geochemistry, as described in Section 4.2.

The second most frequently detected CAH at OU-1 is *cis*-1,2-DCE. *cis*-1,2-DCE is very volatile, with a vapor pressure of 200 mg Hg at 25°C and a Henry's Law Constant of about 0.0037 atm-m^3/mol (reported by Wiedemeier et al., 1996b). *cis*-1,2-DCE tends to be slightly more mobile than TCE, with less tendency to adsorb to the aquifer matrix material. The solubility of *cis*-1,2-DCE in water at 25°C is approximately 3,500 mg/L (Howard, 1990). The degradation of *cis*-1,2-DCE is discussed in Section 4.2.

On the basis of these physiochemical characteristics, natural attenuation, soil vapor extraction, biosparging/air sparging, limited groundwater extraction, and air stripping technologies could all be effective options for collecting, destroying, and/or treating CAH contaminants at OU-1.

6.2.3 Site-Specific Conditions

Two general categories of site-specific characteristics were considered when identifying remedial technologies for comparative evaluation as part of this demonstration project. The first category was physical characteristics such as groundwater depth, gradient, flow direction, and soil type, which influence the types of remedial technologies most appropriate for the site. The second category involved assumptions about future land uses and potential exposure pathways. Each of these catagories of site-specific characteristics has influenced the selection of remedial alternatives included in the comparative evaluation.

6.2.3.1 Groundwater and Soil Characteristics

Site geology and hydrogeology will 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. Slug tests conducted in the vicinity of OU-1 indicate a low to moderate conductivity within the shallow aquifer. Estimated conductivity values ranged from 8 to 52 ft/day. These values are higher than would be expected for the clay and shale present at the site, suggesting the presence of sandy seams and/or fractures that would increase the permeability of these deposits. Shallow groundwater migrates to the southeast, increasing the extent of contamination (i.e., the plume has expanded) but decreasing the average CAH concentration within the aquifer through dilution and biodegradation.

Although higher hydraulic conductivities can result in plume expansion and migration, this same characteristic also will enhance the effectiveness of other remedial technologies, such as groundwater and soil vapor extraction, air sparging, and RNA. For example, it should be less expensive and time-consuming to capture and treat the contaminant plume using a network of extraction wells in areas of high hydraulic conductivity. Contaminant recovery also may be maximized when contaminants are not significantly sorbed to and retarded by phreatic soil. The effectiveness of air sparging also may be increased in more conductive aquifers because of reduced entry pressures and increased radius of influence. Greater hydraulic conductivity also would increase the amount of contaminant mass traveling through an air sparging network within a given time period.

The movement of contaminants within the subsurface away from the source also may influence the effectiveness of natural biodegradation processes by distributing the contaminant mass into areas characterized by varying geochemical conditions. In addition, because CAH compounds are retarded relative to the advective flow velocity, relatively fresh groundwater containing DO may migrate through the plume area, further increasing the potential for aerobic biodegradation of less chlorinated ethenes such as DCE.

To satisfy the requirements of reductive dechlorination, which is the primary biodegradation mechanism for highly chlorinated CAHs such as TCE, the aquifer must provide an adequate and available carbon or energy source, relatively reducing conditions, suitably low concentrations of competing electron acceptors (e.g., DO), and proper ranges of pH and temperature. Dissolved TOC data collected as part of the field work phase of this demonstration project (Sections 3 and 4) indicate that there is adequate carbon in the source area. ORP data indicate that conditions are favorable for aerobic respiration, manganese reduction, and denitrification throughout the site. Concentrations of DO and nitrate/nitrite are low enough throughout all but the most downgradient toe of the plume not to inhibit reductive dechlorination of TCE.

Indigenous microorganisms capable of degrading CAHs tend to be common in most environmental settings; as many as 28 hydrocarbon-degrading isolates (bacteria and fungi) have been identified in different soil environments (Davies and Westlake, 1979; Jones and Eddington, 1968). 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). Therefore, microbe addition was not considered a viable remedial technology for this site.

6.2.3.2 Potential Exposure Pathways

A pathways analysis identifies the human and ecological receptors that could potentially come into contact with site-related contamination and the contaminant migration pathways through which these receptors might be exposed. To have a completed exposure pathway, there must be a source of contamination, a 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 if the approach will be sufficient and adequate to minimize plume expansion so that potential receptor exposure pathways involving shallow groundwater contaminants are incomplete.

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

The primary source of CAH contamination appears to be waste materials buried at LF-04. LF-04 is surrounded by flight aprons, taxiways, runways, a skeet and trap range, a communications building, and relatively undeveloped areas (Figure 2.1). In the hydraulically downgradient direction (southeast), these taxiways, runways, and undeveloped areas extend for at least 5,000 feet. Therefore, the current land use within and downgradient of the contaminant plume is entirely aviation/industrial.

Stinking Creek flows through the area hydraulically downgradient from LF-04. Surface water analysis indicates that TCE has been discharged to the creek. TCE concentrations in surface water ranged from 1.4 to 2.8 μg/L, with the highest concentration found east of Runway 17L (RV004) and the lowest concentration found at the most downgradient location (RV003) near the Base boundary. Stinking Creek may be acting as a hydrogeologic control, as TCE and DCE have not been identified in groundwater samples collected to the east of the creek. Depending on climate and groundwater elevations, Stinking Creek at times may act as a hydraulic divide, causing dissolved contamination to migrate parallel to the creek, and at other times, groundwater may discharge to the creek. Computer simulation results indicate that approximately 3 kg of CAHs will discharge to Stinking Creek during the calibration year 1997. During field work in April 1997, it was estimated that the flow velocity of Stinking Creek was approximately 0.25 meter per second and that the average cross-sectional area of the creek is 0.25 square meter, yielding an average volume of flow in the creek of 0.0625 cubic meters per second. A mass of 3 kg per year and a flow of 62.5 L per second yields a concentration of CAHs in surface water of less than 2 µg/L, similar to concentrations that were observed at the site. Discharge calculations are included in Appendix D.

Under reasonable current land use assumptions, potential receptors include Base worker populations and biota that may be exposed to contaminated surface water. Workers could be exposed to site-related contamination in phreatic soils or shallow groundwater if these materials are removed or exposed during construction excavations or remedial activities. Groundwater from the shallow aquifer is not currently used to meet any demands at Altus AFB. All Base potable water is supplied by the city of Altus. There are no private wells located on the Base. Two private wells, one reportedly located approximately 8,000 feet west and the other 4,000 feet north of LF-04, are used for domestic and livestock purposes (ES, 1985). Exposure pathways involving other environmental media such as vadose zone soils and soil gas in the source area were not considered as part of this project, but should be considered in overall site remediation decisions.

Assumptions about hypothetical future land uses also must be made to ensure that the remedial technology or alternative considered for shallow groundwater at the site is adequate and sufficient to provide long-term protection. The future use of OU-1 and the surrounding area is projected to be unchanged from the current uses described above. Therefore, potential future receptors are the same as those listed in the preceding paragraph. The potential future exposure pathways involving Base workers are identical to those under current conditions provided shallow groundwater is not used to meet industrial water demands. In summary, the use of RNA at this site will require that the source area be maintained as industrial property and that restrictions on shallow groundwater use be enforced in areas downgradient from the site until natural attenuation reduces contaminants to concentrations that meet regulatory standards. If source removal technologies such as soil vapor extraction or groundwater pump-and-treat are implemented, they will have some impact on the short- and long-term land use options and will require some level of institutional control and worker protection during remediation.

6.2.3.3 Remediation Goals for Groundwater and Surface Water

Potentially applicable state and federal water quality criteria are summarized in Table 6.1. State groundwater standards for TCE and 1,2-DCE are exceeded in most portions of the groundwater plume. Surface water quality standards for these CAHs are not exceeded in the sampled segments of the drainage ditch and Stinking Creek.

TABLE 6.1
REMEDIAL ACTION OBJECTIVES FOR GROUNDWATER AND SURFACE WATER
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Compound	USEPA MCL[a/] (µg/L)[b/]	USEPA Surface Water Quality Standard Fresh Chronic Criteria[c/]	Oklahoma Groundwater Standard[c/] (µg/L)	Oklahoma Surface Water Standard[d/] (µg/L)
Trichloroethene	5	21,900	0.3	3,094
1,2-Dichloroethene	70	NA[f/]	0.5	NA[f/]

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

[b/] µg/L = micrograms per liter.

[c/] Water Quality Criteria Summary, USEPA, 1991.

[d/] Oklahoma Department of Environmental Quality (DEQ), 1992. Numerical Water Quality Criteria for Groundwater in Oklahoma Regulation 1889 Section 785:45-7-2 Protective Measures and Corrective Actions.

[e/] Water Column Numerical Criteria to Protect Human Health for the Consumption of Fish Flesh and Water in Oklahoma Regulation 3305 Section 785:45-5-10 Public and Private Water Supplies (Oklahoma DEQ, 1995).

[f/] NA = Not Available.

Use of RNA assumes that compliance with promulgated water quality standards within the zone of institutional control is not necessary if site-related contamination does not pose an immediate threat to human health or the environment (i.e., exposure pathways are incomplete). Thus, the magnitude of required remediation in areas that can and will be placed under institutional control is different from the remediation that is required in areas that may be available for unrestricted groundwater use. The primary remedial action objective (RAO) for groundwater at and downgradient from OU-1 is limited plume expansion to prevent exposure of downgradient receptors to concentrations of CAH in groundwater and surface water that exceed regulatory standards or guidelines. This means that viable remedial alternatives must be able to achieve concentrations that minimize plume migration and/or expansion. Institutional controls are likely to be a necessary component of any groundwater remediation strategy for this site. The required duration of these institutional controls may vary depending on the effectiveness of the selected remedial technology at reducing contaminant mass and concentration in the groundwater, and the amount of contaminated groundwater discharging to surface water.

6.2.4 Summary of Remedial Technology Screening

Several remedial technologies were identified and screened for use in treating the groundwater at the site. Table 6.2 identifies the initial remedial technologies considered as part of this demonstration and those retained for detailed comparative analysis. Screening was conducted systematically by considering the program objectives of the AFCEE RNA demonstration, physiochemical properties of the CAH compounds, and

TABLE 6.2
INITIAL SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
B301 RNA TS
OFFUTT AFB, NEBRASKA

General Response Action	Technology Type	Process Option	Implementability and General Comments	Effectiveness	Relative Cost	Retain
Long-Term Monitoring	Periodic Groundwater and Surface Water Monitoring	Long-Term Monitoring Wells	Some existing wells are available to confirm the progress of remediation. Additional wells could be installed further downgradient to track any future migration of the plume.	Necessary for all remediation strategies	Low	Yes
Institutional Controls	Groundwater Use Control	Land Use Control/Regulate Well Permits	The plume currently lies within the Base boundary and the off-Base "clear area," both of which are under the Base jurisdiction.	Necessary component of LTM program	Low	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the current or predicted plume area.	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 to workers and other potentially affected populations.	Necessary for all remediation strategies	Low	Yes
Extraction/ Containment of Plume	Hydraulic Controls	Inteceptor Trench Collection	A groundwater extraction trench could be installed at the Base boundary to prevent dissolved contamination from migrating off-Base. Low hydraulic conductivity at Base boundary favors horizontal over vertical extraction well installation.	High	Moderate to High	Yes
		Groundwater Extraction Wells	Groundwater extraction wells could be installed near B301 to capture the most elevated CAH concentrations and lower the water table to expose and aerate contaminated zones as part of a dual-phase extraction system. Treatment of extracted water would be necessary.	Moderate	High	Yes
	Physical Controls	Slurry Walls/Grout Curtains	Could be installed as part of a funnel and gate system to direct plume through a relatively short treatment zone. However, solvents may permeate through slurry wall over time, and effective grout curtain would be difficult to construct in low-permeability soils. Funneling of groundwater may cause mounding and surface seepage.	Low to Moderate	High	No
		Sheet Piling	Could be installed as part of a funnel and gate system to direct plume through a relatively short treatment zone. May have more long-term integrity than slurry wall. Funneling of groundwater may cause mounding and surface seepage.	Moderate to High	High	No

TABLE 6.2 (Continued)
INITIAL SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
B301 RNA TS
OFFUTT AFB, NEBRASKA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
In Situ Groundwater Treatment	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Differs from biologically active zone in that oxygen and/or nutrients are injected in or downgradient from plume to limit plume migration by enhancing biodegradation and reducing contaminant concentrations as the plume moves downgradient from the source area. Limited radius of influence and short-circuiting are common problems.	Low to moderate	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 B301indicates that this is an ongoing remediation process in localized areas.	Low to High (varies spatially in study area)	Low	Yes
		Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of CAHs into air bubbles and into vadose zone. Limited radius of influence and short-circuiting are common problems, but installation in a gravel-filled trench could minimize these problems. Oxygenation of downgradient groundwater could potentially inhibit reductive dechlorination.	Low to moderate	Low	No
		Permeable Reaction Wall (Iron Filings Trench)	A permeable reaction wall can be installed at the Base Boundary to prevent dissolved CAHs from migrating off-Base. New, relatively unproven technology. Potential problems with clogging, and effective lifespan not known.	Moderate to High (if not clogged)	High	No
Aboveground Groundwater Treatment	Chemical/ Physical	Air Stripping	Cost-effective technology for removing varying concentrations of CAHs at higher flow rates. Potential permitting for air emissions.	High	Moderate	Yes
		Activated Carbon	Cost prohibitive for more concentrated CAHs or long remediation times. Creates a carbon disposal problem.	High	High (O&M)	No
		UV/Ozone Reactors	May require excessive retention times and large, expensive reactors.	Moderate	High	No

TABLE 6.2 (Continued))
INITIAL SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
B301 RNA TS
OFFUTT AFB, NEBRASKA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
	Chemical/ Physical (cont.)	Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)	Viable option when an IWWTP is readily available and capable of handling CAHs and hydraulic loading. IWWTP not available for this site.	High	Moderate	No
Treated Groundwater Disposal	Discharge to IWWTP or Sanitary Sewer	IWWTP	Viable option when an IWWTP is available and capable of handling CAHs and hydraulic loading. IWWTP is not available.	High	High	No
		Sanitary Sewer	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable. Sanitary sewer is potentially available, but may be cost-prohibitive.	High	Moderate to High	No
	Treated Groundwater Reinjection	Vertical Injection Wells	Not recommended due to clogging and high maintenance.	Moderate	High	No
		Injection Trenches	Require large trenches and can be subject to injection well permitting.	Moderate	High	No
	Discharge to Surface Waters	Storm Drains	Generally requires discharge permit.	High	Low	Yes
Source Removal/Soil Remediation	Excavation/ Treatment	Landfilling	Source has not been identified, and may be deep and beneath B301. If source is identified, less intrusive removal methods could be used.	High	High	No
		Ex situ soil vapor extraction	Excavation probably not feasible at this site (see Landfilling).	Moderate	High	No
		Thermal Desorption	Excavation probably not feasible at this site (see Landfilling).	Moderate	High	No

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

B301 RNA TS

OFFUTT AFB, NEBRASKA

General Response Action	Technology Type	Process Option	Implementability	Effectiveness	Relative Cost	Retain
	In Situ	Bioventing	Air injection/extraction to increase soil oxygen levels and stimulate biodegradation of residual contamination. Developed to remediate fuel contamination; limited effectiveness for CAHs.	Low	Low	No
		Soil Vapor Extraction	Vapor extraction has been successfully implemented at other sites. Requires source definition and off-gas treatment. Could be implemented as part of a dual-phase (groundwater and soil vapor) extraction system.	High	Moderate	Yes
		Surfactant Flushing	Additional pore volumes of water and/or surfactant solution are forced through aquifer material to enhance the partitioning of contaminants into the groundwater. Potential method to remove DNAPL, but first requires DNAPL location. Most effective in homogeneous sandy soils.	Low	High	No

other site-specific characteristics such as hydrogeology, land use assumptions, potential exposure pathways, and appropriate RAOs. 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 approaches and source removal technologies retained for development of remedial alternatives and comparative analysis include institutional controls, RNA combined with LTM, dual-phase extraction in the source area, and plume containment along the Base boundary and Stinking Creek, if necessary, via installation of an air sparging curtain.

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained from the screening process were combined into two remedial alternatives at OU-1. 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 and Surface Water Monitoring

RNA is achieved when naturally occurring attenuation mechanisms bring about a reduction in the total mass of a contaminant in the soil or dissolved in groundwater and surface water. 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 vicinity of LF-04 and will continue to reduce contaminant mass in the source area.

Implementation of Alternative 1 would require the use of institutional controls such as land use restrictions and LTM. Land use restrictions may include placing long-term restrictions on soil excavation in the source area (if significantly contaminated soils are detected in the future), on groundwater well installations within and downgradient of the plume area, and on use of Stinking Creek. 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.

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

6.3.2 Alternative 2--Dual-Phase Extraction in the Source Area, RNA, and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

Alternative 2 is identical to Alternative 1 except that a dual-phase (groundwater and soil vapor) extraction (DPE) system would be installed near the source area to remediate source area groundwater and phreatic soils by using low-vacuum extraction of groundwater and vadose zone gases.

DPE technology is most applicable at sites characterized by high concentrations of volatile contaminants and low soil permeabilities that would limit the effectiveness of conventional pump-and-treat systems in capturing contaminant plumes in groundwater. DPE involves lowering the water table via groundwater extraction while a vacuum is simultaneously applied to the extraction well. The vacuum increases liquid flow to the well and extracts vapors from the unsaturated portion of the formation. As the water table is lowered, more of the formation is exposed to the vacuum, causing an increase in the vapor flow to the well. The induced vapor flow volatilizes adsorbed and free-phase contaminants.

Radian (1996) conducted a DPE pilot test at the site in October 1996. OU-1-01 was used as the extraction well, and several nearby wells were used to monitor the effects of the extraction test. Results indicate a sustainable pumping rate of 3 to 5 gpm. A radius of influence of approximately 100 feet was measured during the test. Analytical results indicate that the average TCE extraction rate from soil vapor and groundwater was 112.5 pounds per year (lb/yr), and the average VOC extraction rate from soil vapor and groundwater was 189 lb/yr.

As with Alternative 1, institutional controls and LTM would be required. Sentry and LTM wells would be installed in the locations indicated in Section 7.2. At a minimum, groundwater monitoring would be conducted annually as part of this remedial alternative to evaluate the progress of source removal and natural attenuation processes.

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 and Surface Water Monitoring

6.4.1.1 Effectiveness

The Visual MODFLOW and MT3D^{96}® codes were used to simulate CAH plume migration if no engineered remedial actions are performed. The simulation assumes that the contaminant transport parameters are identical to those used in the calibrated model.

The prediction was run for 200 years beyond 1997. Although it is realistic to assume that the source strength will decrease over time through leaching and weathering/degradation, the rate of decrease cannot be predicted with confidence due to the lack of information regarding the nature and location of the source. Cohen and Mercer (1993) state that factors influencing NAPL dissolution and eventual depletion include the effective aqueous solubility of NAPL components, groundwater velocity, NAPL/water contact area, and the molecular diffusivity of the NAPL chemicals in water. The actual dissolution of NAPL will generally slow with time due to aging and reduction of the NAPL/water contact area (Powers *et al.*, 1991).

The contaminant source in this prediction is assumed to decrease at a rate of 2 percent per year for the 200 years of the predictive period (the source strength for each successive year was decreased by 2 percent from the previous year's value). This source reduction scenario reflects both the potential for generation of significant dissolved groundwater contamination for many years and the likelihood that the source strength will decrease over time.

Figure 6.1 presents the simulated migration of the plume over time as predicted by the model under the influence of RNA alone. Concentrations in the source area decline at a steady pace throughout the 200 year prediction period. The simulated concentrations over time at source area well OU-1-03 are shown on Figure 6.2. The simulated CAH concentration at this well in the year 2000 is approximately 15,000 μg/L, higher than the concentration of 13,800 μg/L observed in April 1997 (Table 4.2). The model predicts that the concentration at the well will decrease to approximately 1,000 μg/L by 2150 under the influence of RNA alone. The model also predicts that the plume will continue to expand for approximately 125 years. Simulated observation well OW-1 is located at the point of the highest concentration of dissolved CAHs along the Base boundary during the 200-year predictive period (Figure 6.1). A simulated concentration of dissolved CAHs above 5 μg/L reaches the Base boundary (at simulated observation well OW-1) during simulated calendar year 2000, and as plume expansion is simulated, concentrations at this well increase. Simulated dissolved CAH concentrations over time at well OW-1 are shown on Figure 6.3. The RNA-only model predicts a maximum dissolved CAH concentration at the Base boundary during the 200-year predictive period of 154 μg/L, in calendar year 2110. Simulated CAH concentrations at the Base boundary do not decrease below 5 μg/L within the 200-year simulation period.

The model also predicts that the CAH discharge to Stinking Creek may increase approximately 60 percent over the next 50 years, from 3 kilograms per year (kg/yr) in 1997, to 5 kg/yr in 2047. The model then predicts CAH discharge to remain relatively constant over the next 50 years (5 kg/yr in 2097). Thereafter, discharge decreases over the last 100 years of the model simulation to approximately 2 kg/yr in 2197. Based on these values, the concentration of CAHs in Stinking Creek will not reach or exceed regulatory limits within the 200-year prediction period.

6.4.1.2 Technical and Administrative Implementability

Alternative 1 is not technically difficult to implement. Installation of LTM and POC wells and periodic groundwater and surface water sampling and analysis are standard procedures. Long-term management efforts would be required to ensure that proper sampling procedures are followed. Periodic site reviews should be conducted to confirm the adequacy and completeness of LTM data and to verify the effectiveness of this remediation approach. However, there may be administrative concerns associated

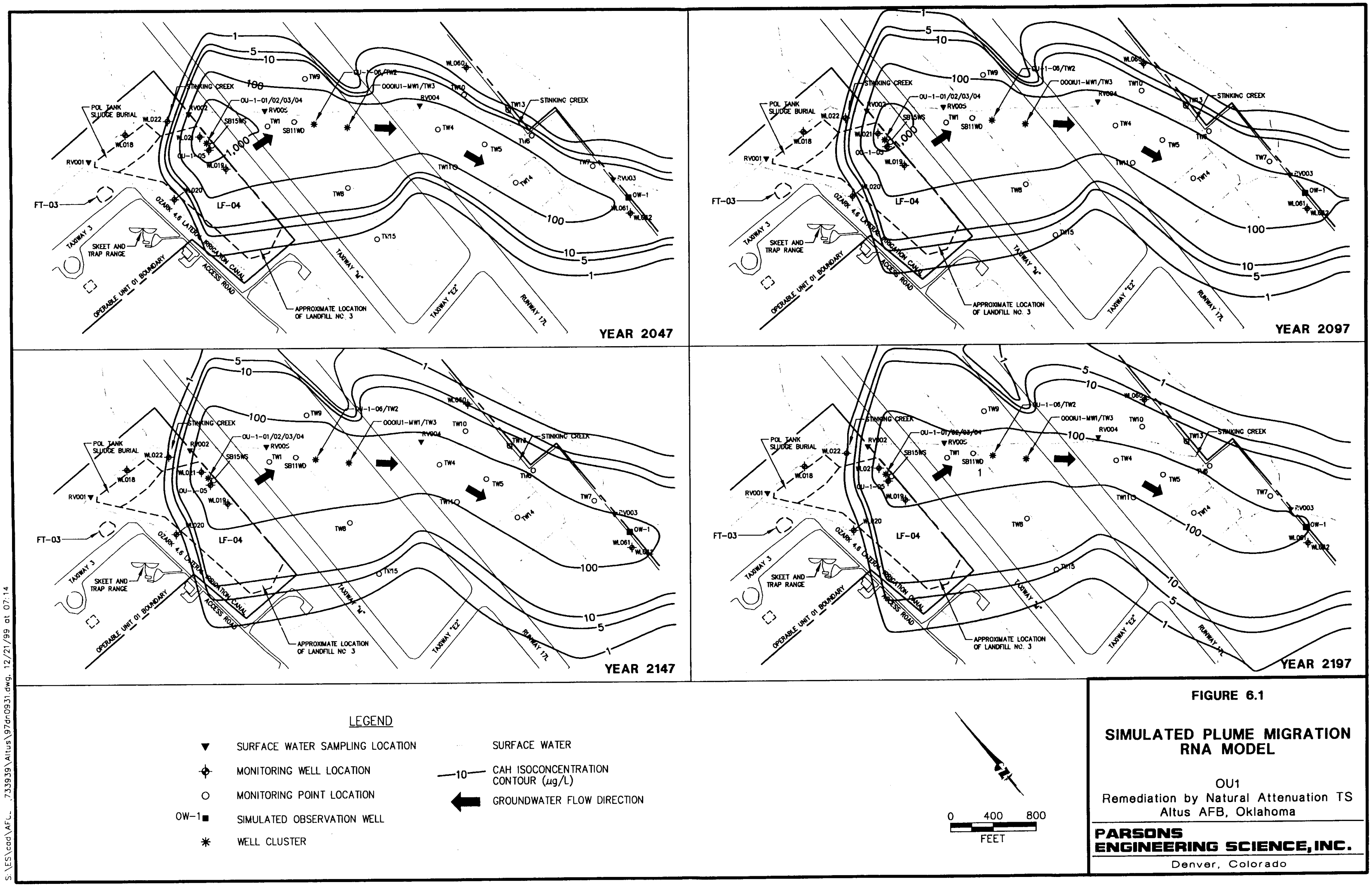


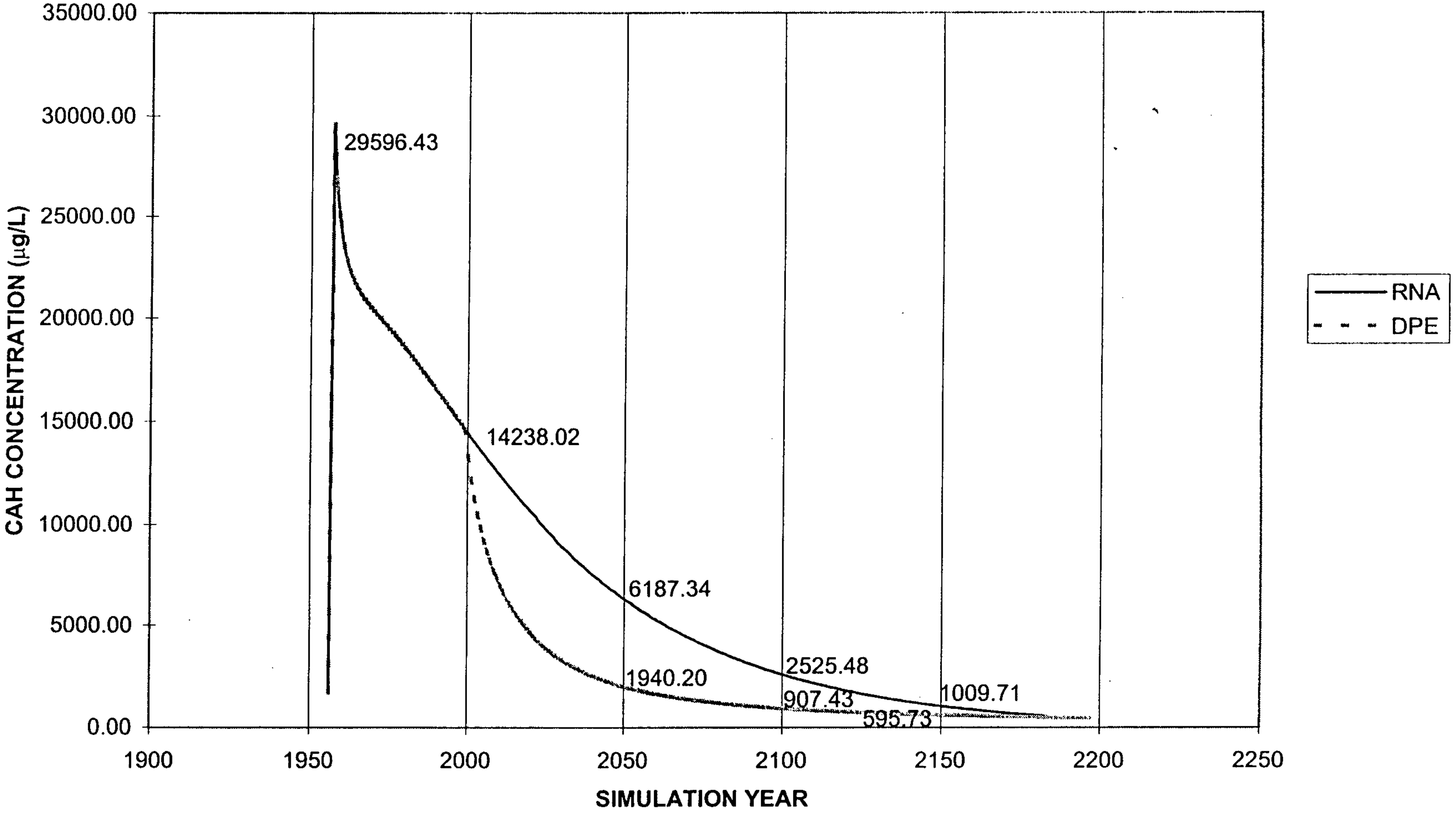
FIGURE 6.1

SIMULATED PLUME MIGRATION RNA MODEL

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

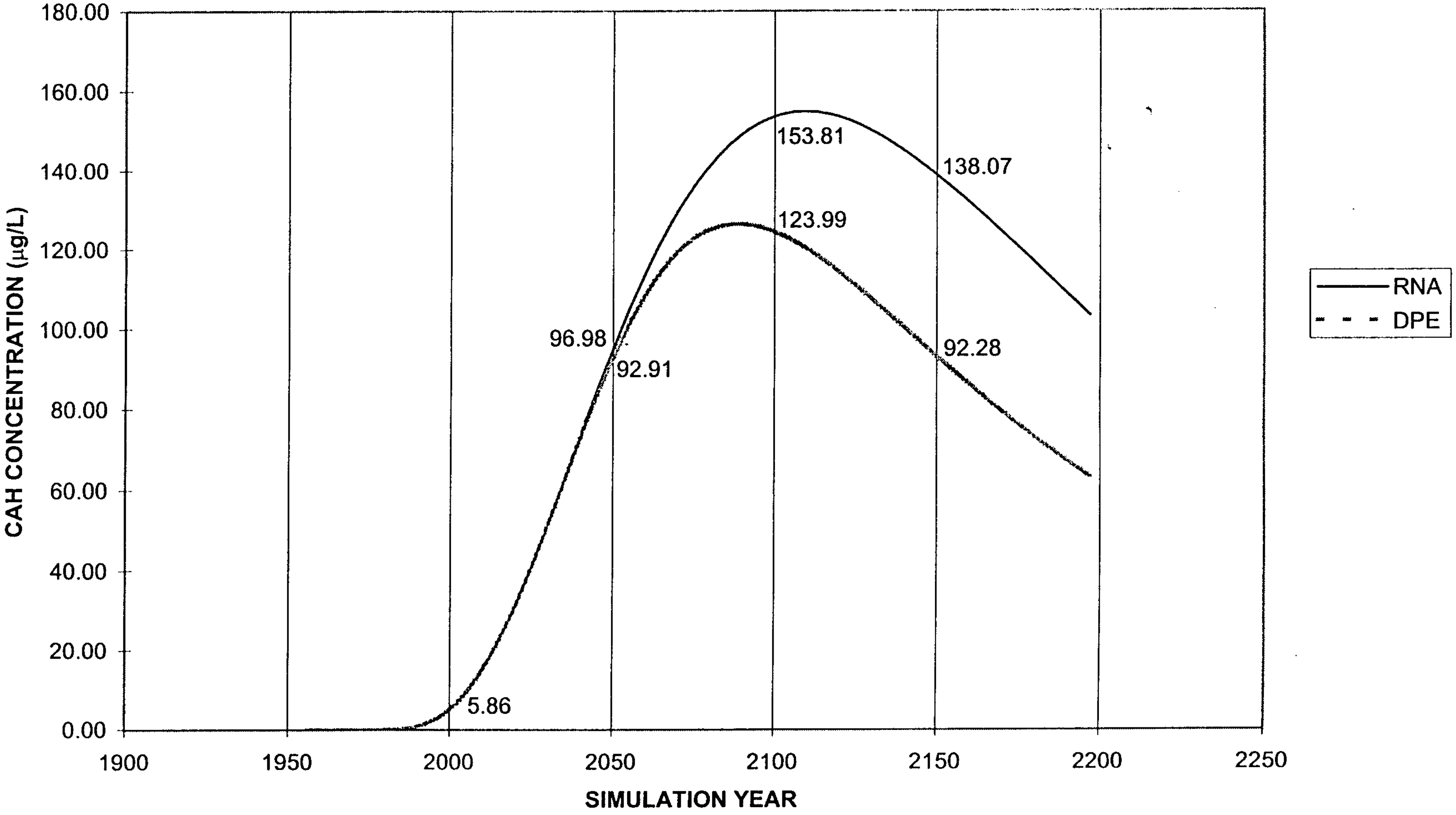
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

FIGURE 6.2
COMPARISON OF REMEDIAL ALTERNATIVES USING CAH CONCENTRATION VERSUS TIME AT SOURCE AREA WELL OU-1-03
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA



022/722450/ALTUS/Conc-tme.xls

FIGURE 6.3
COMPARISON OF REMEDIAL ALTERNATIVES USING CAH CONCENTRATION VERSUS TIME AT SIMULATED DOWNGRADIENT WELL OW-1
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA



with long-term enforcement of groundwater use restrictions. Given the assumptions regarding the future magnitude and duration of the contaminant source that are incorporated into the RNA-only model, substantially elevated CAH concentrations are predicted to persist in groundwater for more than 200 years. Furthermore, concentrations in excess of regulatory criteria may be exceeded at the Base boundary throughout much of the remediation time frame. Future land use within the plume area may be impacted by leaving contaminated soil and groundwater in place. Regulators, Base personnel, and the public will have to be informed of the benefits and limitations of the RNA option, but educational programs are not difficult to implement.

6.4.1.3 Cost

The present-worth cost of implementing Alternative 1 for a 30-year period beginning in 1998 is summarized in Table 6.3. Included in the total present-worth cost of $253,400 are the estimated costs for installing additional LTM wells, performing the recommended groundwater and surface water monitoring (see Section 7), maintaining institutional controls, public education, project management, and reporting. Cost calculations are contained in Appendix F.

TABLE 6.3
ESTIMATED ALTERNATIVE 1 COSTS
OU1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Capital Costs	**Present-Worth Cost**[a/]
Design/construct three LTM wells in 1998	**$12,700**
Monitoring Costs	**Present-Worth Cost**
Conduct annual monitoring of 11 wells and 5 surface water stations from 1998 to 2002	**$83,400**
Conduct biennial monitoring of 11 wells and 5 surface water stations from 2003 to 2028	**$82,800**
Site management (maintain institutional controls/public education) (30 years)	**$74,500**
Total Present Worth of Alternative 1 [a/]	**$253,400**

[a/] Based on an annual discount factor of 7 percent (USEPA, 1993). Costs assume that well installation and LTM are performed by local personnel.

6.4.2 Alternative 2 - DPE in Source Area, RNA, and Institutional Controls with Long-Term Groundwater and Surface Water Monitoring

6.4.2.1 Effectiveness

The predictive model used to simulate the effectiveness of Alternative 1 (Section 6.4.1.1) was modified to include a simulated DPE well near the suspected source area at LF-04. The DPE system is assumed to become operational in 1998.

According to the DPE pilot test results (Radian, 1996), this type of technology could be expected to remove 150 to 200 lb/yr of CAHs from the source area soil gas and groundwater. DPE was simulated by two modifications to the calibrated model. First, groundwater extraction and the resulting change in groundwater flow was simulated by a single extraction well. This well pumped 3 gal/min for a one year period for model year 42 (1998). The pumping rate was based on a sustainable rate derived from DPE pilot test results (Radian, 1996). Secondly, immediately following the 1-year pumping period, the contaminant source terms were reduced by 90 percent to simulate the DPE source reduction. The remaining source mass was then degraded at 2 percent per year as in Alternative 1.

The plume migration simulated by the DPE alternative model is shown on Figure 6.4. The combination of source reduction and groundwater extraction west of LF-04 reduces the dissolved CAH concentration at well OU-1-03 (source area well) to below 5,000 µg/L by year 2018 (Figure 6.2); therefore, maximum CAH concentrations within the plume and available to discharge to Stinking Creek are substantially reduced relative to the Alternative 1 simulations (Section 6.4.1).

CAH concentrations at simulated downgradient observation well OW-1 during the 200-year predictive period under the influence of Alternative 2 DPE are shown on Figure 6.3. The maximum dissolved CAH concentration predicted to reach simulated well OW-1 is 128 µg/L in calendar year 2088. Because it may take decades before the effects of source reduction are fully realized at the Base boundary, this peak concentration is only 20 percent lower and occurs only 22 years earlier than for the simulation considering RNA alone. However, dissolved CAH concentrations are predicted to decrease in subsequent years at a faster rate than predicted for RNA alone as the plume recedes toward the source area.

Model results indicate that the mass of CAHs discharging to Stinking Creek from the aquifer throughout the site in 2047 is less than 4 kg/yr, in 2097 is approximately 3 kg/yr, in 2147 is approximately 2 kg/yr, and in 2197 is approximately 1 kg/yr. Based on these simulated values of mass entering the creek, concentrations of CAHs in surface water will not exceed regulatory limits (Table 6.1).

6.4.2.2 Technical and Administrative Implementability

The implementability issues described for Alternative 1 in Section 6.4.1.2 also are applicable for Alternative 2. However, administrative concerns regarding the length of LTM and institutional controls should be lessened due to more rapid depletion of significantly elevated dissolved CAH concentrations. Regulatory and community acceptance of this alternative should be more positive than with Alternative 1 due to the more aggressive plume remediation activities.

Alternative 2, as simulated by the numerical model, should not be difficult to implement technically or administratively. However, the precise nature and location of the contaminant source to be remediated has not been defined.

The DPE system simulated by the DPE alternative predictive model would not require construction of an extraction well, because well OU-1-01, installed for the DPE pilot test conducted by Radian (1996), could be used for a full-scale system. Implementation would require the installation of a submersible pump with controls, an aboveground vacuum blower, an air stripper, and the associated piping. State and/or local regulations

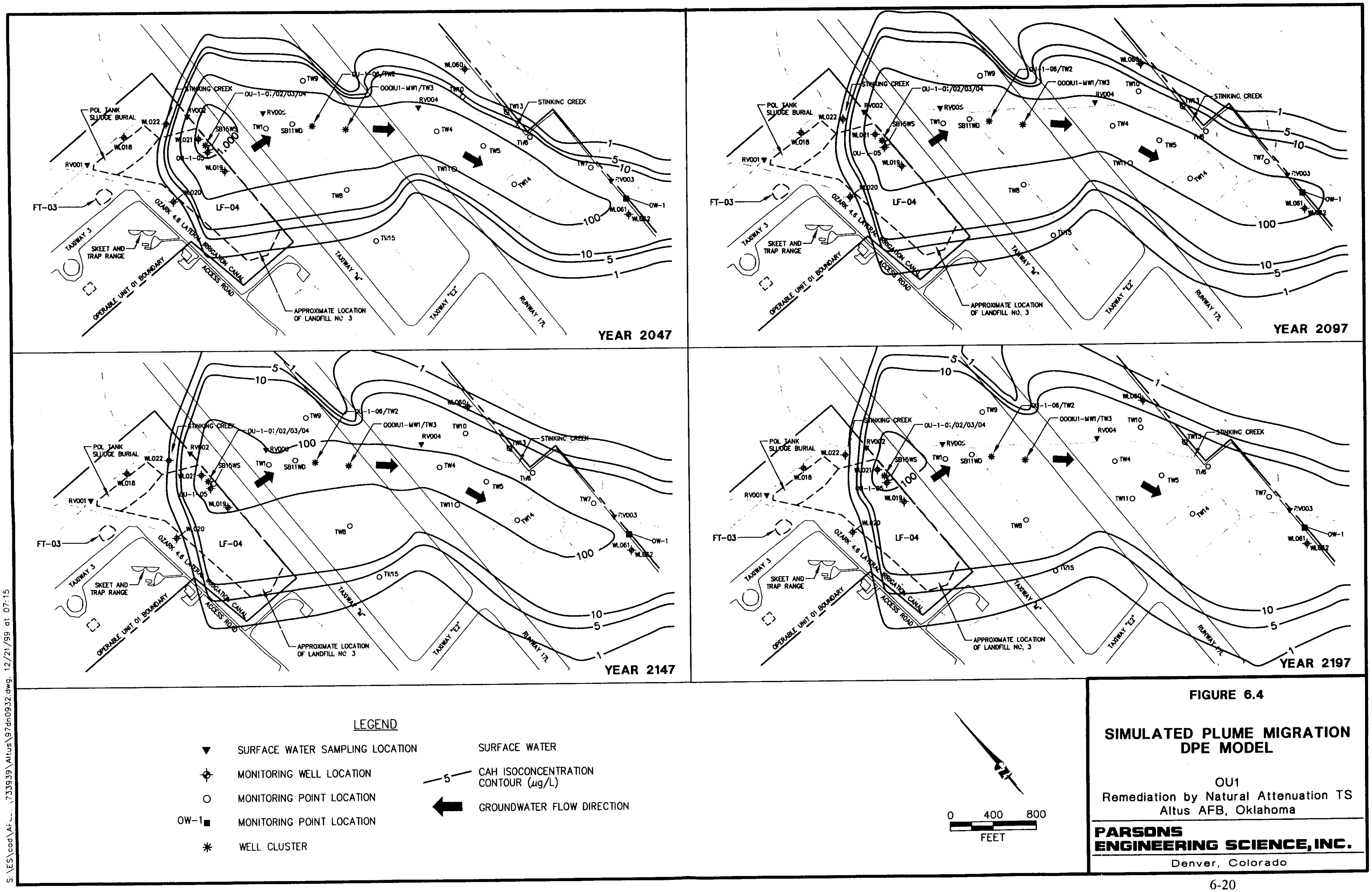


FIGURE 6.4

SIMULATED PLUME MIGRATION
DPE MODEL

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

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may require a vapor treatment system to meet air discharge requirements. However, such equipment was assumed to be unnecessary in determining the cost for this alternative. Standard mechanical and electrical construction and equipment would be used; special construction techniques and special-order equipment should not be necessary. All equipment needed for this alternative is commercially available.

Submersible pumps and air strippers generally are highly reliable when properly maintained. The most frequent reliability problems occur with pump controls, which must be carefully set to minimize pump cycling. Assuming a 3-year-long operating period, the submersible pump should not have to be replaced. The most significant maintenance requirement for this system will be regular maintenance of the air stripper and monitoring of effluent to ensure that surface water discharge and air emissions standards are attained. Blower systems are very reliable and require only minimal maintenance. Air filters provide blower protection and generally require replacement every 90 to 180 days. Installation and operation of a full-scale DPE system would require an increased commitment of labor and other resources to maintain and monitor the system. Weekly system checks are recommended, during which operating data such as vaccum pressure and flow rate should be recorded. Periodic effluent water and vapor sampling and analysis would be required to demonstrate compliance with discharge/emissions requirements.

Administrative implementation of this alternative will require that appropriate air/water discharge permits are obtained, and that future development plans protect the DPE system. All system components (above- and below-grade) should be protected against damage in the event that construction or maintenance work is performed in the area.

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 approximately $469,800. The cost of Alternative 2 is greater than Alternative 1 due to the addition of the DPE system. It is assumed that the DPE system would be operated for 3 years after installation. Annual LTM would continue for a total of 5 years to build a historical groundwater and surface water quality database, and biennial LTM would be performed for at least an additional 25 years to monitor temporal changes in CAH concentrations. Cost calculations are contained in Appendix F.

6.5 RECOMMENDED REMEDIAL APPROACH

Two alternatives have been evaluated for remediation of the shallow groundwater at OU-1. Components of the alternatives evaluated include groundwater and soil vapor extraction, aboveground treatment of groundwater, RNA with LTM of groundwater and surface water, and institutional controls. Table 6.5 summarizes the results of the evaluation based upon effectiveness, implementability, and cost criteria.

TABLE 6.4
ESTIMATED ALTERNATIVE 2 COSTS
OU1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Capital Costs	**Present-Worth Cost** [a/]
Design/construct three LTM wells in 1998	**$12,700**
Design/install 1-well groundwater extraction system in 1998	**$15,400**
Design/install vapor extraction system in 1998	**$58,000**
Design/install groundwater treatment system in 1998	**$82,100**
Monitoring and O&M Costs	**Present-Worth Cost** [a/]
Conduct annual monitoring of 11 wells and 5 surface water stations from 1998 to 2002	**$83,400**
Conduct biennial monitoring of 11 wells and 5 surface water stations from 2003 to 2028	**$82,800**
Site management (maintain institutional controls/public education) (30 years)	**$74,500**
Operate/maintain DPE system (3 years)	**$159,300**
Total Present Worth of Alternative 2 [a/]	**$568,200**

[a/] Based on an annual discount factor of 7 percent (USEPA, 1993). Costs assume that well installation, LTM, and O&M are performed by local personnel.

TABLE 6.5
SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION
GROUNDWATER REMEDIATION
REMEDIATIO BY NATURAL ATTENUATION
OFFUTT AFB, NEBRASKA

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 plume may migrate significantly depending on TCE decay rate in Papillion Creek valley. Potentially lengthy LTM period required.	Readily implementable. Groundwater and surface water quality monitoring required for an estimated minimum of 30 years, and potentially much longer. Institutional controls, includng land and ground water use controls, may be required for more than 100 years; elevated dissolved TCE concentrations may persist for more than 200 years. Minimal exposure to potential receptors if institutional controls are implemented and discharge to surface water bodies does not exceed aquatic life criteria. If significant plume migration occurs and completion of exposure pathways is possible, then additional remedial work may be required.	**$259,000**
Alternative 2 - Dual-Phase Extraction - Natual Attenuation - Long-Term Monitoring - Institutional Controls	Similar to Alternative 1, with the addition of a dual-phase extraction (DPE) system near B301 to remove TCE source and highest dissolved TCE concentrations. Even if the source is substantially reduced, significant plume migration in the Papillion Creek valley may still occur, but to a lesser degree than with Alternative 1. Contaminant mass, volume, and toxicity will be reduced more rapidly than in Alternative 1.	The DPE system simulated by the numerical model may not signifcantly affect the TCE source if the source is located beneath B301 and/or if it consists of DNAPL. In addition, locating the source may be technically difficult. Therefore, potentially significant implementability concerns are associated with Alternative 2. Long-term site management, groundwater use controls, and monitoring would be required as elevated TCE concentrations may persist for more than 200 years. If future plume migration in the off-Base area is unacceptable, then additional remedial work may be required.	**$1,070,000**
Alternative 3 - Groundwater Extraction at Base Boundary - Dual-Phase Extraction - Natual Attenuation - Long-Term Monitoring - Institutional Controls	Similar to Alternative 2, with the addition of a Base boundary groundwater extraction trench to reduce off-Base migration of dissolved CAHs. Contaminant mass, volume, and toxicity will be reduced more rapidly than in Alternatives 1 and 2. Less likely that sigificant plume migration will occur compared to Alternatives 1 and 2. CAH discharge to off-Base drainage ditches would be reduced.	Implementability concerns associated with Alternative 2 also are relevant for Alternative 3. Base boundary plume interception is readily implementable, especially if discharge of treated effluent to surface water is permitted. However, without successful source reduction, operation of a Base boundary system for an indefinite time period would be required. Long-term management, groundwater use controls, and monitoring required as elevated TCE concentrations may persist for more than 200 years..	**$1,670,000**

Alternative 1 makes maximum use of natural attenuation mechanisms to reduce plume migration and toxicity. Alternative 2 would reduce plume longevity and provide additional protection against further plume migration, but would still rely on RNA to reduce plume toxicity in the downgradient portions of the affected area. Implementation of Alternative 2 would potentially decrease the time frame required for remediation, but would require greater capital and O&M expenditures.

Each of the alternatives has long-term implementability concerns. Implementation of either alternative may require a very lengthy LTM period, and maintenance of institutional controls in the plume area would be required. However, if future LTM results indicate that the plume is either stable or receding, and that potential receptor exposure pathways will not be completed, then the frequency of LTM sampling events could be reduced. Alternative 2 would be the most acceptable to the public and regulatory agencies because it represents a more aggressive remedial approach.

If groundwater discharge to Stinking Creek is unacceptable or if an unacceptable CAH concentration is observed to migrate beyond the Base boundary, plume interception along the creek at the Base boundary via installation of an air sparging curtain could reduce or eliminate further discharge to the creek or off-Base migration of dissolved CAHs. Without concurrent source reduction, however, the interception system would have to be operated indefinitely.

On the basis of this evaluation, implementation of Alternative 2 is recommended. The degree to which RNA will prevent further downgradient migration of the CAH plume is not known with certainty, but will become more apparent as successive LTM sampling events are performed. Model results suggest that state surface water quality criteria will not be exceeded in Stinking Creek during the next 200 years. In addition, the shallow groundwater at the site is not used as a drinking water or irrigation source. As described above, if LTM results demonstrate that the plume is stable or receding and that potential receptor exposure pathways will not be completed in the future, then the frequency of LTM could potentially be reduced (e.g., to once every 5 years).

Installation of an air sparging curtain at the Base boundary or along Stinking Creek is not recommended at this time because it is not certain that the contaminant plume will migrate beyond the Base boundary at concentrations of regulatory concern or endanger potential receptors. If future LTM data indicate that more significant amounts of contamination are discharging to Stinking Creek or that biodegradation rates near the Base boundary are not sufficient to prevent significant downgradient plume migration, or if shortening of the LTM period is required, then a plume containment/interception technology should be considered as a contingency.

SECTION 7

LONG-TERM MONITORING PLAN

7.1 OVERVIEW

In keeping with the requirements of the preferred remedial alternative for the Altus AFB OU-1 site (Section 6), a long-term groundwater and surface water monitoring plan was developed. The purpose of this component of the preferred remedial alternative for the site is to assess site conditions over time and the effectiveness of naturally occurring processes at reducing contaminant mass and minimizing contaminant migration, and to evaluate the need for additional remediation.

The LTM plan for the site presented in this section describes a monitoring scheme for the next 30 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 30-year period. The LTM plan consists of identifying the locations of LTM wells 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;
- Evaluate the TCE and DCE degradation rate and assess the effectiveness of naturally occurring processes at reducing contaminant mass and minimizing contaminant migration;
- Assess the need for additional remedial action; 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. In the event that data collected under this LTM program indicate that naturally occurring processes are insufficient to adequately protect human health and the environment, contingency controls to more aggressively remediate the dissolved plume would be necessary.

7.2 GROUNDWATER MONITORING NETWORK AND SAMPLING FREQUENCY

Annual LTM of a minimum of 11 site monitoring wells, including 8 existing wells, is recommended. The existing wells include WL018, OU-1-03, OU-1-05, OU-1-06, 000IU1-MW1, WL060, WL061, and WL062. Three additional wells are proposed for the locations shown on Figure 7.1. Well WL018 is located upgradient from the majority of the plume; well WL060 and an additional proposed well are located cross-gradient from the plume; and the remaining eight wells are located along the primary plume flowpath, with four each in the shallower and deeper zones of the surficial aquifer. Performance of annual sampling for 5 years (1998 through 2002) is recommended to build a historical water quality database for the site. Following each LTM sampling event, an assessment should be made as to whether the plume appears to be stable or expanding, and whether installation of additional LTM wells further downgradient is required to track plume migration.

Following completion of the 5-year annual LTM period, biennial (every other year) LTM for an additional 25 years (2003 through 2027) was assumed to assess temporal changes in plume magnitude and extent. The actual duration and frequency of the monitoring events will be adjusted based on LTM results.

Estimates of the groundwater/CAH migration rate and direction should be progressively refined as new wells are installed to aid in plume definition and tracking. Estimates of the CAH decay rate also can be refined as new data are obtained to update plume fate and transport predictions.

7.3 SURFACE WATER MONITORING NETWORK AND SAMPLING FREQUENCY

Annual sampling of a minimum of five surface water stations during the 5-year annual LTM period described above for groundwater is recommended. The five stations, located along Stinking Creek, are RV001, RV002, RV003, RV004, and RV005 (Figure 7.1). The need for additional surface water quality monitoring following completion of the 5-year annual monitoring period should be assessed on the basis of the monitoring results. Biennial monitoring of five surface water stations for 25 years starting in year 2004 was assumed for costing purposes.

7.4 ANALYTICAL PROTOCOL

All LTM wells should be sampled and analyzed to determine compliance with chemical-specific remediation goals and to verify the effectiveness of RNA at the site. Groundwater level measurements should be made during each sampling event. Groundwater samples from LTM wells should be analyzed for the parameters listed in Table 7.1. Surface water samples should be analyzed for VOCs using USEPA Method 8260A.

7.5 PERIODIC LTM PLAN REVIEW

The LTM plan should be periodically reviewed and revised as appropriate on the basis of available groundwater quality data. For example, if the sampling results obtained during the 25-year biennial sampling period demonstrate that the plume is in equilibrium (not receding or 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. If sampling results indicate that geochemical conditions in the plume area (e.g., nitrate, sulfate, and ferrous iron

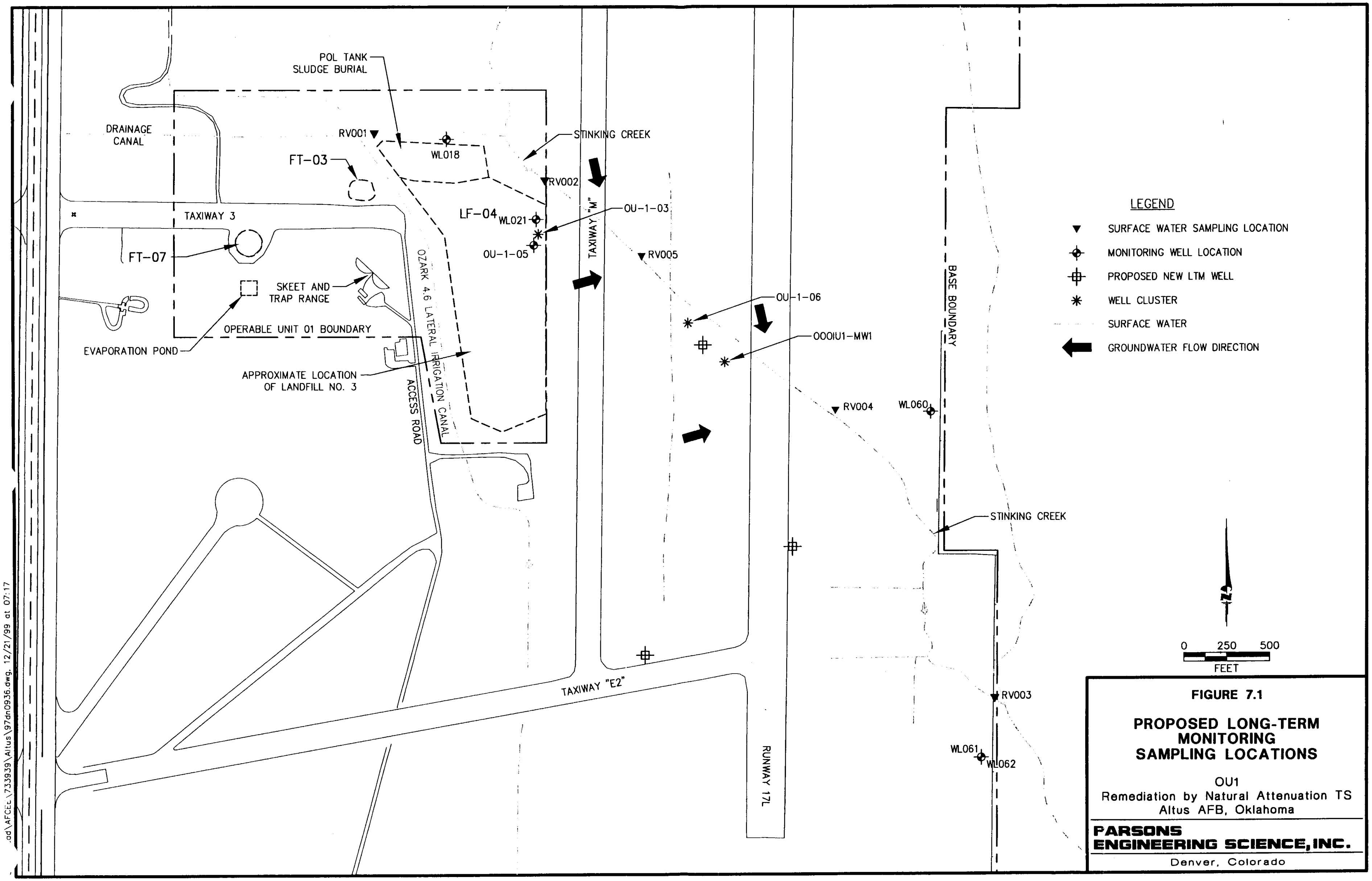

FIGURE 7.1

PROPOSED LONG-TERM MONITORING SAMPLING LOCATIONS

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 7.1
LONG-TERM GROUNDWATER MONITORING ANALYTICAL PROTOCOL
B301 RNA TS
OFFUTT AFB, NEBRASKA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Ferrous Iron (Fe^{2+})	Colorimetric A3500-Fe D or Hach 25140-25	Filter if turbid	May indicate an anaerobic degradation process due to the depletion of oxygen, nitrate, and manganese	Each sampling event	Collect 100 mL of water in a glass container; for Method A3500-FeD, acidify with hydrochloric acid per method	Field
Temperature	E170.1, direct-reading meter	Measure at well-head	Purging adequacy; 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	Purging adequacy; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Each sampling event	Measure at well-head using a flow-through cell	Field
pH	E150.1/SW9040, direct-reading meter	Measure at well-head	Purging adequacy; aerobic and anaerobic processes are pH-sensitive	Each sampling event	Measure at well-head using a flow-through cell	Field
Conductivity	E120.1/SW9050, direct-reading meter	Measure at well-head	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 or measure at wellhead using flow-through cell	Field
Nitrate (NO_3^{-1})	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook[a/] 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; analyze within 48 hours	Fixed-base
Alkalinity	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook[a/] method; method SW9056 is an equivalent procedure	Measure of the groundwater to buffer changes in pH.	Each sampling event	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C; analyze within 48 hours	Fixed-based or field (for Hach Method)

TABLE 7.1 (Concluded)
LONG-TERM GROUNDWATER MONITORING ANALYTICAL PROTOCOL
B301 RNA TS
OFFUTT AFB, NEBRASKA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Sulfate (SO_4^{2-})	IC method E300 or method SW9056 or Hach SulfaVer 4 method	Method E300 is a Handbook method; method SW9056 is an equivalent procedure. Hach method is Photometric	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)
Oxidation-Reduction Potential (ORP)	A2580 B, direct-reading meter	Measurements are made with electrodes; results are displayed on 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 redox potential of groundwater may range from more than 200 mV to less than -400 mV	Each sampling event	Measure at well-head using a flow-through cell	Field
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 National Risk Management Research 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	GS/MS method SW8260A or GC Method SW8010	Handbook methods	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/ Handbook refers to "AFCEE Handbook to Support the Installation Restoration Program (IRP) Remedial Investigation / Feasibility Study (RI/FS)."

concentrations) are stable over time, then the sampling frequency for these parameters could be reduced.

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 in the vicinity of LF-04 at OU1, Altus AFB, Oklahoma. The finite-difference models MODFLOW and MT3D$^{\underline{96}®}$ 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, groundwater, surface water, and sediment samples were collected from the site and analyzed. Physical and chemical data collected under this program were supplemented (where necessary) with data collected during previous site characterization events and accepted literature values. Additional data collected in April 1999 were not available for analysis in this TS, but are evaluated in Appendix H.

The chlorinated solvent plume at OU-1 exhibits conditions of anaerobic reductive dechlorination, where the primary source of biologically available organic carbon is anthropogenic fuel hydrocarbons (BTEX). Typical of these conditions is a decrease in concentrations of TCE, an increase in cis-1,2-DCE, and eventually the accumulation of VC. Some of these characteristics are observed at the OU-1 site. Much of the TCE has been effectively degraded to cis-1,2-DCE by reductive dechlorination. However, the occurrence of this process is limited to the general source area and core of the TCE plume. As a result, the parent CAH (TCE) still comprises the majority of the contamination present in groundwater throughout most of the plume. The lack of VC in groundwater at OU-1 indicates that reductive dechlorination is not proceeding past the initial step that involves the transformation of TCE to DCE. Within the source area, VC would be expected to accumulate because the anaerobic degradation rate of VC is slow relative to TCE and cis-1,2-DCE. Because VC is not observed, further reductive dechlorination of DCE does not appear to occur at the site. The stability of the cis-1,2-DCE plume observed in April 1999 suggests that cis-1,2-DCE may degrade by aerobic oxidation or cometabolism (which do not produce VC) further downgradient under more aerobic conditions.

Additional data collected in April 1999 indicate the TCE and cis-1,2-DCE plumes are stable with little change in the extent of TCE and cis-1,2-DCE, although some vertical expansion was observed. The contaminant plume also shows indications of less reducing conditions in 1999 with an increase in nitrate concentrations, an increase in redox potential, and a decrease in methane concentrations. It is not clear whether any of these conditions are related to a drop of 3 to 4 feet in groundwater levels from April 1997 to April 1999.

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 dissolved CAH plume. 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.

Remedial Alternative 1 incorporates natural attenuation, but does not include engineered remediation. The model used to simulate this alternative incorporates the conservative assumption that contaminant dissolution from mobile and/or 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) for the 200 years of the predictive period. The results of this simulation suggest that it is not likely that surface water will be significantly impacted by contamination, but that dissolved CAH concentrations substantially in excess of 5 µg/L may persist in the groundwater for more than 200 years.

The model used to simulate remedial Alternative 2 assumes that partial source removal via application of an engineered remedial technology such as DPE would significantly reduce contaminant dissolution from NAPL within a 3-year operational period. Results of this model indicate that source reduction would result in a more rapid decrease in dissolved CAH concentrations within the plume relative to Alternative 1. The model predicts that dissolved CAH concentrations in excess of 5 µg/L may persist in the groundwater for more than 200 years, but that concentrations will begin to decrease sooner than if no engineered remedial technology is used.

Implementation of Alternative 2 (DPE, RNA, institutional controls, and LTM) should be considered, at least in the short term. The degree to which RNA will prevent further downgradient migration of the plume is not known with certainty, but will become more apparent as successive LTM sampling events are performed. In any event, model results suggest that surface water criteria and aquatic life standards will not be exceeded in Stinking Creek during the next 200 years.

Observed BTEX and CAH plume behavior in April 1999 (Appendix H) have not exceeded the conservative predictions made using the numerical and analytical models developed in this TS report. To assess the effectiveness of naturally occurring processes at reducing contaminant mass and minimizing contaminant migration, groundwater from a minimum of eight existing and three proposed monitoring wells should continue to be sampled annually for 5 years to build a historical groundwater quality database for the site. A minimum of five surface water stations also should be sampled annually during this 5-year period. Following completion of the 5-year annual LTM period, the LTM program should be reassessed. If the annual sampling results indicate that temporal changes in plume magnitude and extent could be adequately monitored by less-frequent sampling events, then the frequency of LTM could be reduced appropriately. The number and location of wells and surface water stations selected for continued monitoring should be determined on the basis of results from the initial, 5-year LTM period.

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 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., plume containment along Stinking Creek and/or at the Base boundary) should be implemented.

SECTION 9

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APPENDIX A

PERTINENT TABLES AND FIGURES FROM PREVIOUS REPORTS

DATA FROM USGS, 1992

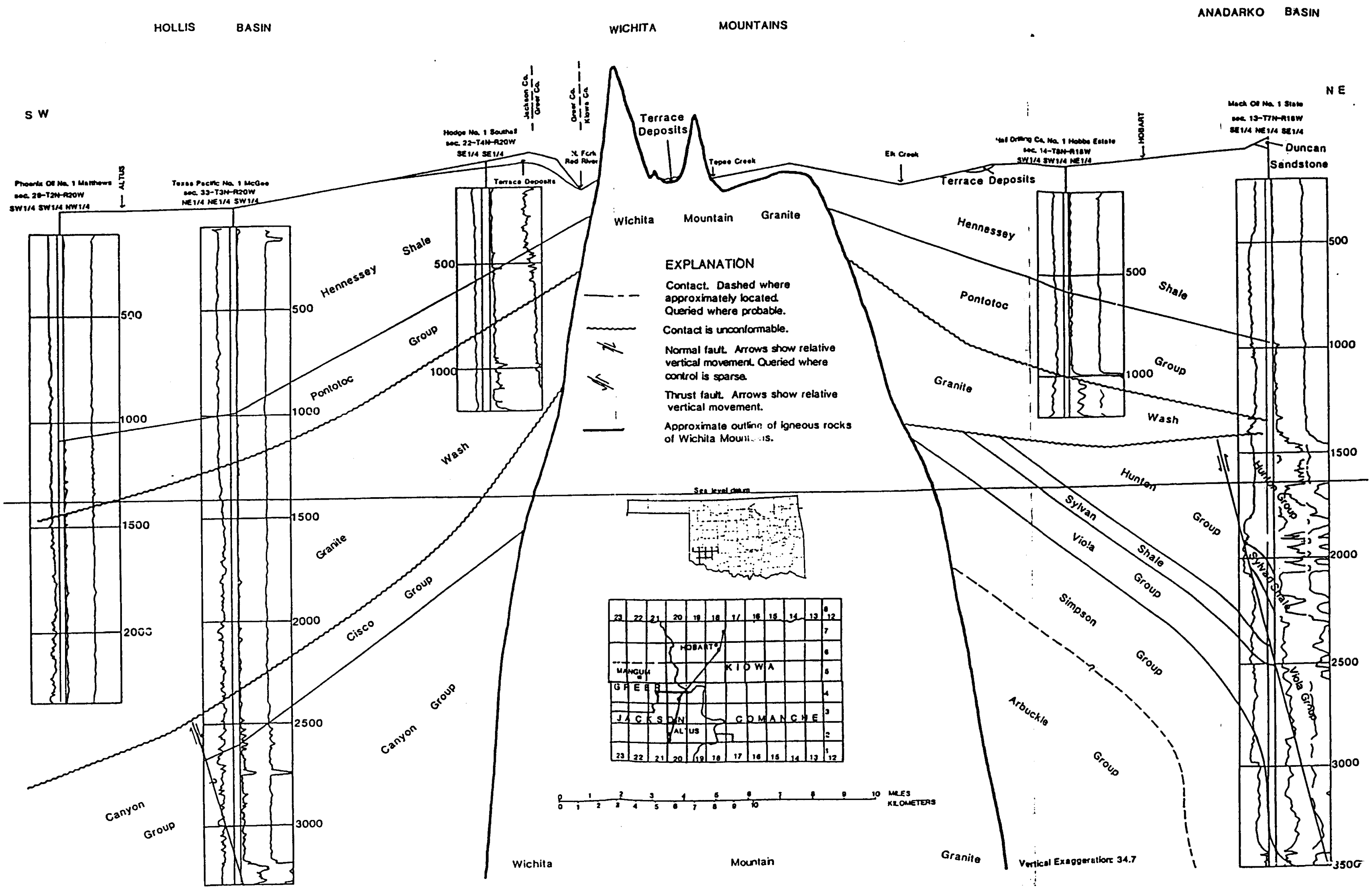


Figure 2.2.1.2—GEOLOGIC SECTION SHOWING POSSIBLE SUBSURFACE CORRELATIONS AND LAND-SURFACE FEATURES IN KIOWA, GREER, AND JACKSON COUNTIES, OKLAHOMA

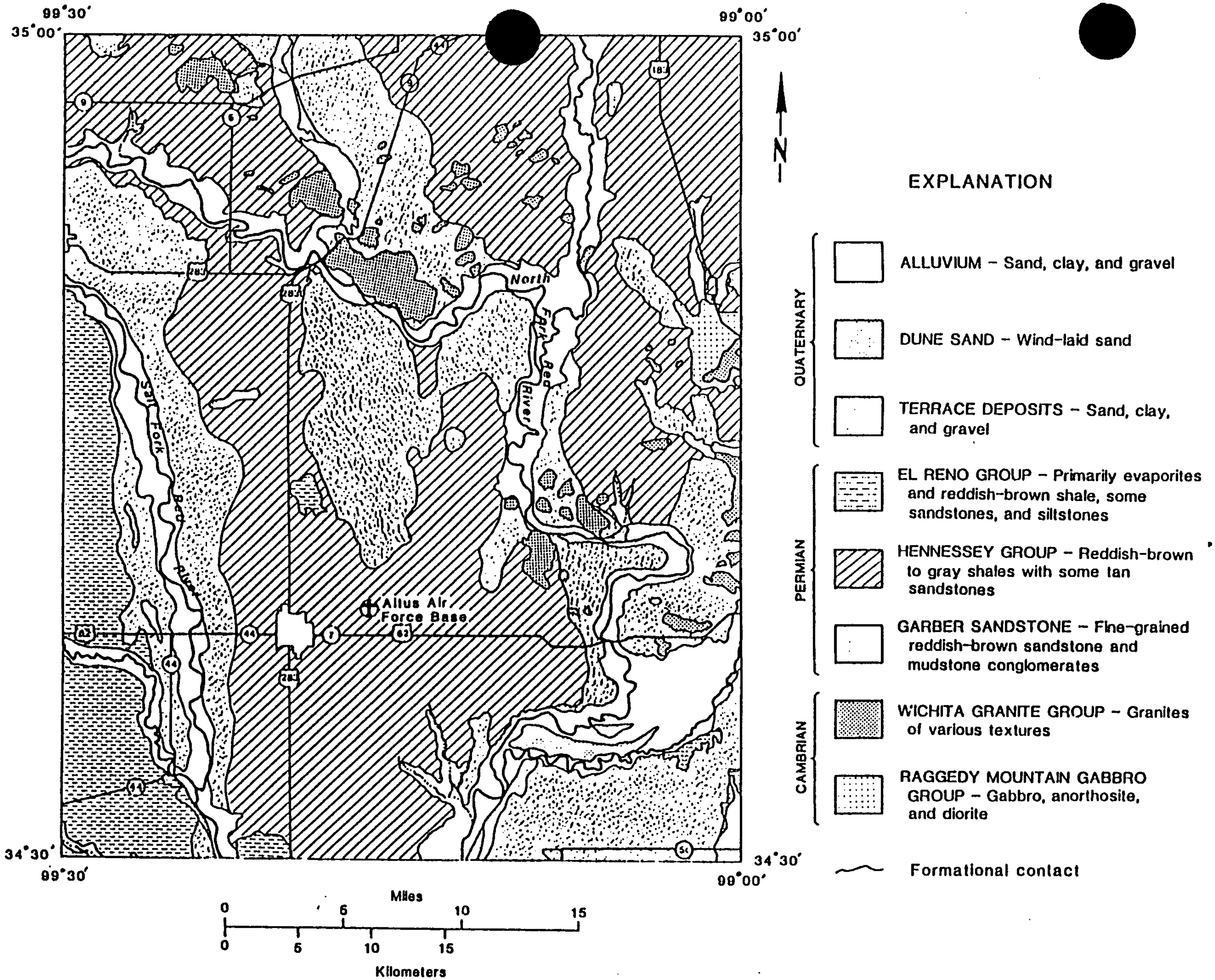


Figure 2.2.2.1--Geologic map ,of Altus Air Force Base and vicinity.

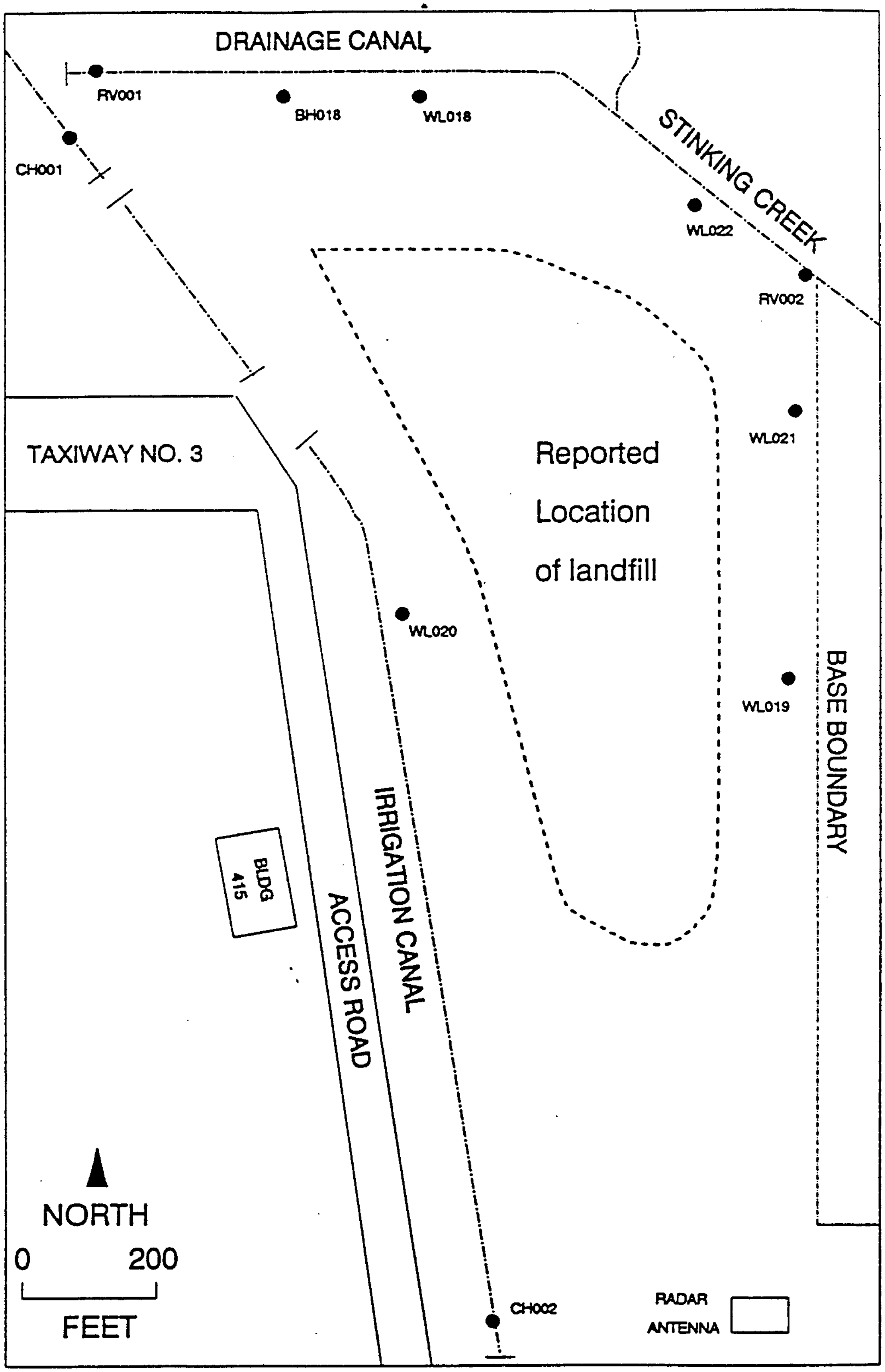


Figure 4.1.4.2.--Site 04 borehole, monitoring well, and surface sediment-sampling station locations.

Table 4.1.4.3.1.—Analytical Results for Site 04—Continued

				Standards, Criteria and Action Levels					
					Field Number	4010430331	4010430332	4010430329	4010430330
					Location	CH001	CH002	RV001	RV002
					Sample Depth				
					Sample Date	890801	890801	890801	890801
Parameter	Method	Units	Detection Limit	Federal	State	Results	Results	Results	Results
Water Temperature	E170.1	Celsius	—	—	—	25.6	26.3	25.1	27.4
pH	E150.1	SU	—	—	—	8.25	8.28	7.43	7.8
Specific Conductance	E120.1	(us)/cm/cm	—	—	—	1980.	1980.	3140.	3370.
Bicarbonate	A403	mg/L	—	—	—	166.	166.	302.	304.
Carbonate	A403	mg/L	—	—	—	0.	0.	0.	0.
Chloride	325.3	mg/L	3.0	250. (c)	250.(e)	249.	249.	326.	366.
Fluoride	340.2	mg/L	0.1	2.0(c)	2.0(e)	1.0	0.4	1.0	1.0
Sulfate	375.4	mg/L	5.0	250. (c)	250. (e)	598.	540.	1200.	1250.
Total Dissolved Solids	E160.1	mg/L	10.	500. (c)	500. (e)	1320.	1380.	2500.	2680.
Arsenic	E206.2	mg/L	0.005	0.05(a)	0.05(d)	—	—	—	0.005
Barium	E200.7	mg/L	0.01	1.0(a)	1.0(d)	0.12	0.12	0.04	0.10
Calcium	E200.7	mg/L	0.1	—	—	174.	171.	328.	338.
Magnesium	E200.7	mg/L	0.2	—	—	71.	70.	95.	107.
Manganese	E200.7	mg/L	0.01	0.05(c)	0.05(e)	—	—	0.25	0.32
Potassium	E200.7	mg/L	5.0	—	—	—	6.0	—	—
Sodium	E200.7	mg/L	0.9	—	—	198.	195.	343.	378.
1,2-Dichloroethane	E601	ug/L	0.50	5.0(a)	5.0(e)	—	—	—	0.93
1,1,1-Trichloroethane	E601	ug/L	0.20	200. (a)	0.3(b)	1.8	0.65	0.36	—
bis(2-Ethylhexyl) phthalate	E625	ug/L	10.	—	—	—	15.	—	—

Table 4.1.4—Analytical Results for site 04—Continued

					Field Number	4010410291	4010410292	4010410375	4010410297	4010410373
					Location	WL020	WL020(dup)	WL020	WL021	WL021
					Sample Depth					
					Sample Date	890628	890628	910228	890718	910228
				Standards, Cnriteria and Action Levels						
Parameter	Method	Units	Detection Limit	Federal	State	Results	Results	Results	Results	Results
Water Temperature	E170.1	Celsius	—	—	—	18.2	—	—	18.7	—
pH	E150.1	SU	—	—	—	7.43	7.01	—	6.95	—
Specific Conductance	E120.1	(us)/cm/cm	—	—	—	3660.	—	—	4770.	—
Bicarbonate	A403	mg/L	—	—	—	379.	370.	—	422.	—
Carbonate	A403	mg/L	—	—	—	0.	0.	—	0.	—
Chloride	A429	mg/L	0.5	250. (b)	250. (d)	—	—	—	498.	—
Fluoride	A429	mg/L	0.5	2.0(b)	2.0(d)	—	—	—	2.5	—
Nitrate as N	A429	mg/L	0.5	10. (a)	10. (c)	—	—	—	1.7	—
Sulfate	A429	mg/L	0.5	250. (b)	250. (d)	—	—	—	2390.	—
Chloride	325.3	mg/L	3.0	250. (b)	250. (d)	403.	403.	—	—	—
Fluoride	340.2	mg/L	0.1	2.0(b)	2.0(d)	1.6	0.8	—	—	—
Sulfate	375.4	mg/L	5.0	250. (b)	250. (d)	1320.	1280.	—	—	—
Total Dissolved Solids	E160.1	mg/L	10.	500. (b)	500. (d)	2840.	2830.	—	4660.	—
Arsenic	E206.2	mg/L	0.005	0.05(a)	0.05(c)	—	0.006	—	—	—
Barium	E200.7	mg/L	0.01	1.0(a)	1.0(c)	0.01	0.01	—	—	—
Calcium	E200.7	mg/L	0.1	—	—	396.	396.	—	473.	—
Magnesium	E200.7	mg/L	0.2	—	—	122.	118.	—	155.	—
Manganese	E200.7	mg/L	0.01	0.05(b)	0.05(d)	—	—	—	0.16	—
Sodium	E200.7	mg/L	0.9	—	—	334.	324.	—	509.	—
Total Petroleum Hydrocarbons	E418.1	mg/L	1.0	—	—	—	1.0	—	—	—
trans-1,2-Dichloroethene	E601	ug/L	1.2	—	—	—	—	—	5.8	11.
Trichloroethene	E601	ug/L	0.60	5.0(a)	5.0(c)	1.9	2.4	3.9	—	—
Trichloroethene	E601	ug/L	1.5	5.0(a)	5.0(c)	—	—	—	25.	1.5

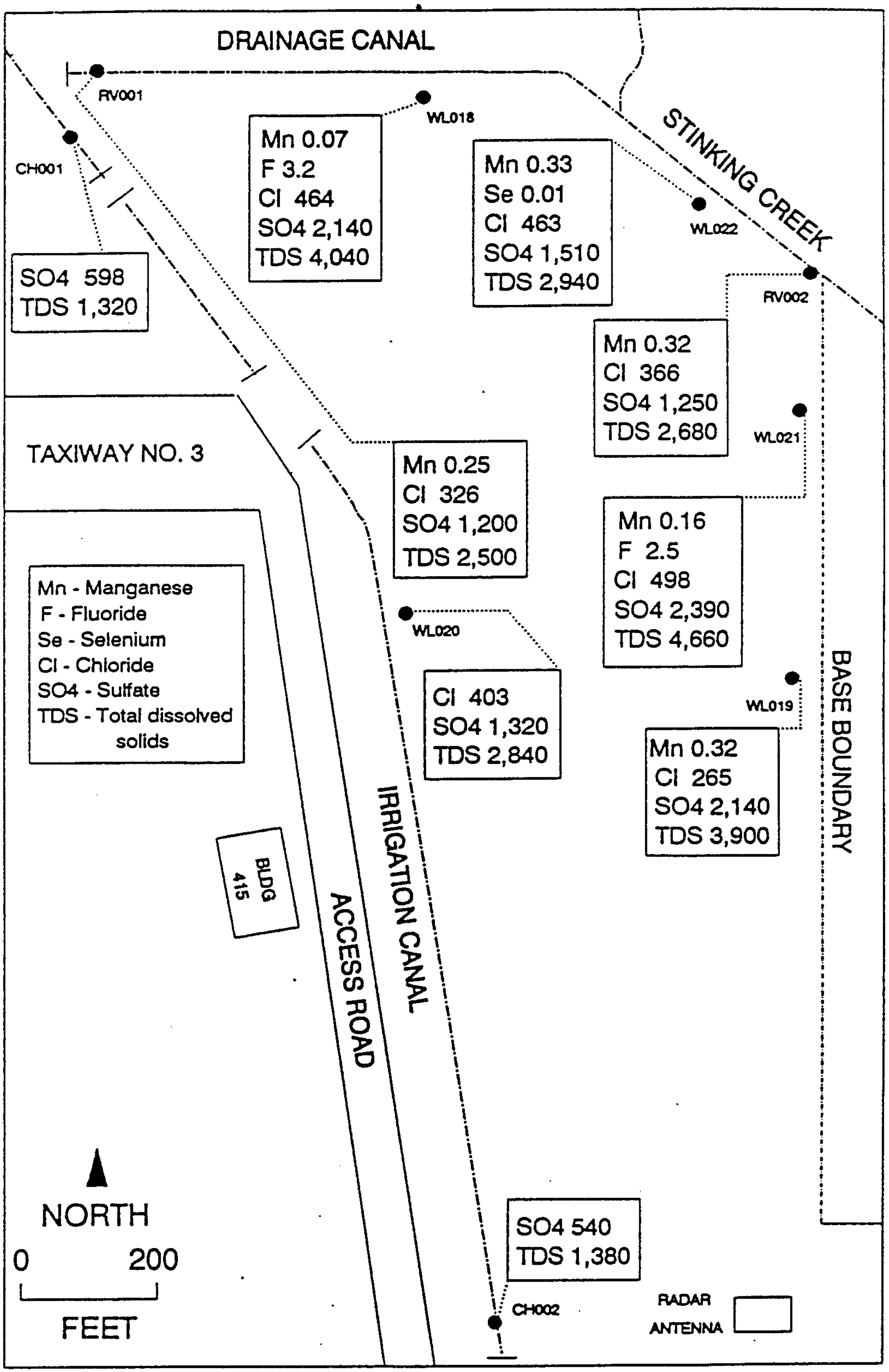


Figure 4.1.4.3.2.--Concentration of selected inorganic constituents in the surface waters and shallow ground water at Site 04 July 1989. Concentrations are in mg/L.

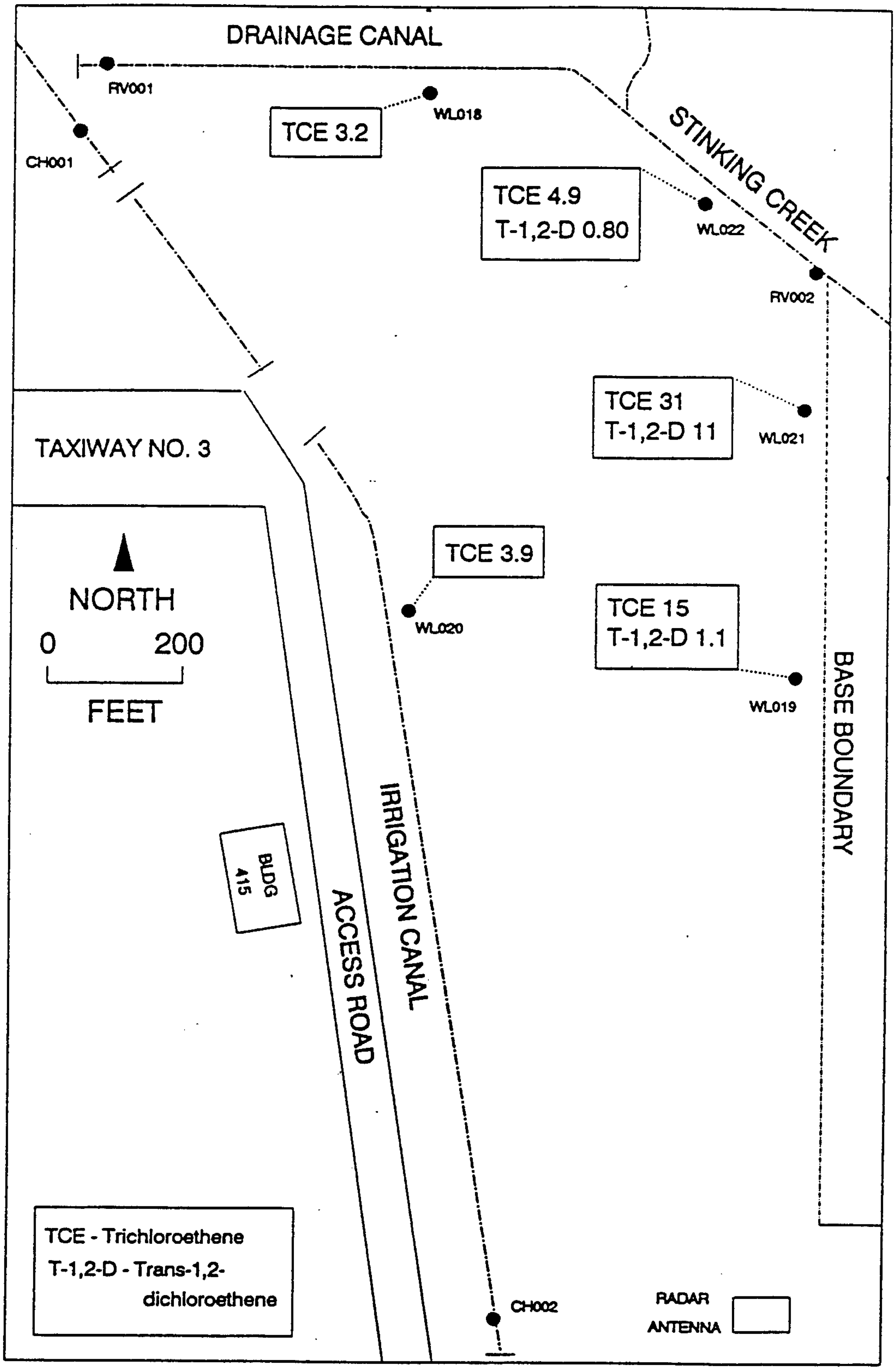


Figure 4.1.4.3.4.–Concentration of target organic compounds in the shallow ground water at Site 04, February 1991. Concentrations are in ug/L.

DATA FROM USACE, 1992

SAMPLE NUMBER	MW 49	MW 50
LAB NO.	2-1180	2-1185
DATE SAMPLED	4-14-92	4-14-92
CATIONS/ANIONS (mg/L)		
pH	7.26	7.22
Conductivity	4520	11250
Alkalinity Carbonate Bicarbonate	< 10 240	< 10 370
Hardness	1630	3020
Chloride	640	2520
Nitrate as N	0.60	< 0.20
Sulfate	1810	3930
Phosphate	< 0.50	< 0.50
Fluoride	0.65	1.10
TDS	3990	10400
METALS (µg/L)		
Arsenic	1.9	< 1.0
Barium	17	14
Cadmium	< 10	< 10
Calcium	435	657
Chromium	< 10	< 10
Iron	1327	277
Lead	< 5	< 5
Magnesium	131	336
Manganese	32	40
Mercury	< 0.20	< 0.20
Potassium	6.97	7.9
Selenium	3.8	27
Silver	< 10	< 10
Sodium	465	1100
VOLATILE ORGANICS (µg/L)		
Trichloroethene	111	
trans-1,2-Dichloroethane		J 1.9
Benzene		43
SEMIVOLATILE ORGANICS (µg/L)		
Di-n-butyl phthalate	10	

J - ESTIMATED VALUE

ppm

ppb

Table 1 - Summary of Soil Analytical Results

SITE	COE (1) Sample No.	VOA ug/Kg	SVOA ug/Kg	Metals mg/Kg	TRPH mg/Kg	TCLP mg/L
LF-3	4-5	1,2 Dichloroethene - 29.4	ND	Ba- 537 Cr- 27.1 Pb- 32.2	24	NT
LF-2	9-2	ND	Di-n-butyl phthalate 1500	Ba- 248 Cr- 34.1 Pb- 42.7	400	Ba-0.3
LF-4	11-3	ND	Di-n-butyl phthalate 1400	Ba- 194 Cr- 28.6 Pb- 32.9	190	Ba-0.8
LF-4	11-4	ND	ND	Ba- 123 Cr- 29.7 Pb- 20.6	ND	NT
LF-4	11-8	ND	(2)	Ba- 145 Cr- 29.5 Pb- 18.0	1200	NT
LF-4	11-13	ND	ND	Ba- 325 Cr- 26.5 Pb- 17.0	ND	NT
HF-3	14-6	ND	NT	Ba- 283 Cr- 34.7 Pb-22.2	ND	Ba-1.1
HF-3	14-7	ND	NT	Ba- 164 Cr- 29.8 Pb- 29.6	ND	NT
POL TANK SL LF	19-1	ND	ND	Ba- 183 Cr- 39.4 Pb- 25.8	ND	Ba-0.4 Pb-.03
POL TANK SL LF	19-15	ND	ND	Ba- 80.3 Cr- 19.2 Pb- 11.9 Hg- 0.21	ND	Ba-1.9

Notes:

1. The COE Sample No. is the IRP site number, as listed on Figure 1, and the trench the sample was taken from.

2. Sample 11-8 SVOA (ug/Kg) results: Acenaphthene- 1030, Fluorene- 1010, Phenanthrene- 11200, Anthracene- 2360, Fluoranthene- 14700, Pyrene- 11800, Benzo(a)anthracene- 5520, Benzo(b)Fluoranthene- 5630, Benzo(k)Fluoranthene- 2150, Benzo(a)pyrene- 4230, Indeno(1,2,3-cd)pyrene- 1650, Benzo(g,h,i)perylene- 1650, Chrysene- 5810.

3. ND=Not Detected, NT=Not Tested, VOA=Volatile Organics, SVOA=Semivolatile Organics, TRPH=Total Recoverable Petroleum Hydrocarbons, TCLP=Toxicity Characteristic Leaching Procedure.

DATA FROM TARGET, 1993

TABLE 3

ANALYTE CONCENTRATIONS IN HEADSPACE OF GROUND WATER VIA GC/FID (µg/l)

Drainage Canal water

SAMPLE	DEPTH (FT.)	BENZENE	TOLUENE	ETHYL-BENZENE	XYLENES	TOTAL FID VOLATILES*
REPORTING LIMIT		1.0	1.0	1.0	1.0	10
DC-1-W	12	<1.0	<1.0	<1.0	<1.0	<10
DC-3-W	13	<1.0	<1.0	<1.0	<1.0	<10
DC-5-W	15	<1.0	<1.0	<1.0	<1.0	<10
DC-9-W	13	<1.0	<1.0	<1.0	<1.0	<10
DC-10-W	16	<1.0	<1.0	<1.0	<1.0	<10
DC-11-W	24	<1.0	<1.0	<1.0	<1.0	<10
DC-13-W	18	<1.0	<1.0	<1.0	<1.0	<10
DC-15-W	15	<1.0	<1.0	<1.0	<1.0	<10
DC-18-W	18	<1.0	<1.0	<1.0	<1.0	<10
DC-20-W	18	<1.0	<1.0	<1.0	<1.0	<10
DC-22-W	13	<1.0	<1.0	<1.0	<1.0	<10
DC-24-W	14	<1.0	<1.0	<1.0	<1.0	<10
DC-28-W	6	<1.0	<1.0	<1.0	<1.0	<10
DC-30-W	15	<1.0	<1.0	<1.0	<1.0	<10
DC-32-W	12	<1.0	<1.0	<1.0	<1.0	<10
DC-34-W	13	<1.0	<1.0	<1.0	<1.0	<10
DC-35-W	12	<1.0	<1.0	<1.0	<1.0	<10
DC-36-W	14	<1.0	<1.0	<1.0	<1.0	<10
DC-56-W	18	<1.0	<1.0	<1.0	<1.0	100
DC-57-W	12	<1.0	<1.0	<1.0	<1.0	68
DC-58-W	12	<1.0	<1.0	<1.0	<1.0	162
DC-59-W	15	<1.0	<1.0	<1.0	<1.0	33
DC-60-W	15	<1.0	<1.0	<1.0	<1.0	16
DC-61-W	15	<1.0	<1.0	<1.0	<1.0	<10
DC-62-W	13	<1.0	<1.0	<1.0	<1.0	<10
DC-63-W	15	<1.0	<1.0	<1.0	<1.0	<10
DC-64-W	18	<1.0	<1.0	<1.0	<1.0	25
DC-78-W	17	<1.0	<1.0	<1.0	<1.0	<10
DC-79-W	13	<1.0	<1.0	<1.0	<1.0	<10
DC-80-W	12	<1.0	<1.0	<1.0	<1.0	38
DC-81-W	12	<1.0	<1.0	<1.0	<1.0	24
DC-83-W	12	<1.0	<1.0	<1.0	<1.0	32
DC-84-W	18	<1.0	<1.0	<1.0	<1.0	12
DC-85-W	18	<1.0	<1.0	<1.0	<1.0	11

* *CALCULATED USING THE SUM OF THE AREAS OF ALL INTEGRATED CHROMATOGRAM PEAKS AND THE INSTRUMENT RESPONSE FACTOR FOR TOLUENE*

TABLE 3 (CONT.)

ANALYTE CONCENTRATIONS IN HEADSPACE OF GROUND WATER VIA GC/FID (µg/l)

SAMPLE	DEPTH (FT.)	BENZENE	TOLUENE	ETHYL-BENZENE	XYLENES	TOTAL FID VOLATILES*
REPORTING LIMIT		1.0	1.0	1.0	1.0	10
DC-86-W	18	<1.0	<1.0	<1.0	<1.0	<10
DC-87-W	18	<1.0	<1.0	<1.0	<1.0	<10
DC-88-W	18	<1.0	<1.0	<1.0	<1.0	<10
DC-89-W	18	<1.0	<1.0	<1.0	<1.0	<10
2-10-W	18	<1.0	<1.0	<1.0	<1.0	20
2-38-W	21	<1.0	<1.0	<1.0	<1.0	<10
2-52-W	16	<1.0	<1.0	<1.0	<1.0	53
2-54-W	16	<1.0	<1.0	<1.0	<1.0	<10
2-57-W	15	<1.0	<1.0	<1.0	<1.0	<10
2-58-W	21	<1.0	<1.0	<1.0	<1.0	11
2-70-W	15	<1.0	<1.0	<1.0	<1.0	17
3-W-3	12	<1.0	<1.0	<1.0	<1.0	56
3-39-W	18	<1.0	<1.0	<1.0	<1.0	24
04-1-W	18	<1.0	<1.0	<1.0	<1.0	<10
04-2-W	15	<1.0	<1.0	<1.0	<1.0	<10
04-3-W	16	<1.0	<1.0	<1.0	<1.0	<10
4-5-W	13	<1.0	<1.0	<1.0	<1.0	351
4-6-W	13	<1.0	<1.0	<1.0	<1.0	54
4-65-W	20	<1.0	<1.0	<1.0	<1.0	98
4-66-W	18	<1.0	<1.0	<1.0	<1.0	61
4-67-W	15	<1.0	<1.0	<1.0	<1.0	<10
4-68-W	19	<1.0	<1.0	<1.0	<1.0	<10
4-69-W	15	<1.0	<1.0	<1.0	<1.0	<10
4-70-W	17	<1.0	<1.0	<1.0	<1.0	39
4-72-W	18	<1.0	<1.0	<1.0	<1.0	<10
4-73-W	17	<1.0	<1.0	<1.0	<1.0	<10
4-74-W	20	<1.0	<1.0	<1.0	<1.0	21
4-75-W	15	<1.0	<1.0	<1.0	<1.0	<10
4-76-W	19	<1.0	<1.0	<1.0	<1.0	<10
4-77-W	18	<1.0	<1.0	<1.0	<1.0	<10
4-92-W	16	<1.0	<1.0	<1.0	<1.0	<10
4-93-W	16	<1.0	<1.0	<1.0	<1.0	<10
4-94-W	21	<1.0	<1.0	<1.0	<1.0	<10

** CALCULATED USING THE SUM OF THE AREAS AKS AND THE INSTRUMENT RESPONSE FACTOR FOR TOLUEN*

[redacted]

TABLE 4 (CONT.)

ANALYTE CONCENTRATIONS IN HEADSPACE OF GROUND WATER VIA GC/ECD (μg/l)

	7	oklahoma 10ppb	100		70				5		5
SAMPLE	11DCE	CH2Cl2	t12DCE	11DCA	c12DCE	CHCl3	111TCA	CCl4	TCE	112TCA	PCE
REPORTING LIMIT	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
DC-84-W	<1.0	<1.0	<1.0	<1.0	1.3	<1.0	<1.0	<1.0	24	<1.0	<1.0
DC-85-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	20	<1.0	<1.0
DC-86-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	7.2	<1.0	<1.0
DC-87-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	9.0	<1.0	<1.0
DC-88-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	9.4	<1.0	<1.0
DC-89-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	11	<1.0	<1.0
2-10-W	1.2	<1.0	6.2	<1.0	3.8	<1.0	<1.0	<1.0	17	<1.0	2.9
2-38-W	3.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.9	<1.0	<1.0
2-52-W	<1.0	50	301	<1.0	<1.0	<1.0	<1.0	<1.0	14	<1.0	5.4
2-54-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-57-W	<1.0	<1.0	<1.0	<1.0	1.9	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-58-W	93	10	49	<1.0	1.7	<1.0	<1.0	<1.0	10	<1.0	1.4
2-70-W	37	<1.0	<1.0	<1.0	2.1	<1.0	<1.0	<1.0	28	<1.0	9.4
3-W-3	<1.0	<1.0	6.0	<1.0	181	<1.0	<1.0	<1.0	34	<1.0	<1.0
[illegible]-W	<1.0	<1.0	1.6	<1.0	48	<1.0	<1.0	<1.0	4.7	<1.0	<1.0
04-1-W	<1.0	<1.0	<1.0	<1.0	3.7	<1.0	<1.0	<1.0	1.8	<1.0	<1.0
04-2-W	<1.0	<1.0	<1.0	<1.0	4.5	<1.0	<1.0	<1.0	2.7	<1.0	<1.0
04-3-W	<1.0	<1.0	<1.0	<1.0	2.4	<1.0	<1.0	<1.0	8.6	<1.0	<1.0
4-5-W	<1.0	<1.0	18	<1.0	168	<1.0	<1.0	<1.0	1,086	<1.0	<1.0
4-6-W	<1.0	<1.0	36	<1.0	85	<1.0	<1.0	<1.0	115	<1.0	<1.0
4-65-W	<1.0	<1.0	19	<1.0	46	<1.0	<1.0	<1.0	112	<1.0	<1.0
4-66-W	<1.0	<1.0	3.4	<1.0	14	<1.0	<1.0	<1.0	77	<1.0	<1.0
4-67-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	2.7	<1.0	<1.0
4-68-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
4-69-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
4-70-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	51	<1.0	<1.0
4-72-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	12	<1.0	<1.0
4-73-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
4-74-W	<1.0	<1.0	<1.0	<1.0	1.3	<1.0	<1.0	<1.0	28	<1.0	<1.0
4-75-W	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

11DCE = 1,1-dichloroethene
11DCA = 1,1-dichloroethane
111TCA = 1,1,1-trichloroethane
112TCA = 1,1,2-trichloroethane
CH2Cl2 = methylene chloride
c12DCE = cis-1,2-dichloroethene
CCl4 = carbon tetrachloride
PCE = tetrachloroethene
t12DCE = trans-1,2-dichloroethene
CHCl3 = chloroform
TCE = trichloroethene

TABLE 1

ANALYTE CONCENTRATIONS IN SOIL GAS VIA GC/FID (µg/l)

SAMPLE	DEPTH (FT.)	BENZENE	TOLUENE	ETHYL-BENZENE	XYLENES	TOTAL FID VOLATILES*
REPORTING LIMIT		1.0	1.0	1.0	1.0	10
DC-1	9	<1.0	<1.0	<1.0	<1.0	<10
DC-1-5'	5	<1.0	<1.0	<1.0	<1.0	<10
DC-2	9	<1.0	<1.0	<1.0	<1.0	<10
DC-3	6	<1.0	<1.0	<1.0	<1.0	<10
DC-4	6	<1.0	<1.0	<1.0	<1.0	<10
DC-5	6	<1.0	<1.0	<1.0	<1.0	<10
DC-6	6	<1.0	<1.0	<1.0	<1.0	<10
DC-7	12	<1.0	<1.0	<1.0	<1.0	<10
DC-8	6	<1.0	<1.0	<1.0	<1.0	<10
DC-9	6	<1.0	<1.0	<1.0	<1.0	<10
DC-10	17	<1.0	2.5	1.1	5.1	10
DC-11	18	<1.0	<1.0	<1.0	1.0	<10
DC-12	18	<1.0	<1.0	<1.0	<1.0	<10
DC-13	18	<1.0	<1.0	<1.0	<1.0	<10
DC-14	15	<1.0	<1.0	<1.0	1.3	<10
DC-15	15	<1.0	<1.0	<1.0	<1.0	<10
DC-16	15	<1.0	<1.0	<1.0	<1.0	<10
DC-17	15	<1.0	<1.0	<1.0	<1.0	<10
DC-27	6	<1.0	<1.0	<1.0	<1.0	<10
DC-28	6	<1.0	<1.0	<1.0	<1.0	<10
2-1	5	<1.0	<1.0	<1.0	<1.0	<10
2-2	5	<1.0	<1.0	<1.0	<1.0	125
2-3	5	<1.0	<1.0	<1.0	<1.0	<10
2-4	5	<1.0	<1.0	<1.0	<1.0	<10
2-5	5	108	320	143	153	31,150
2-6	5	<1.0	<1.0	<1.0	<1.0	<10
2-7	5	<1.0	<1.0	<1.0	<1.0	<10
2-8	5	<1.0	15	1.1	<1.0	1,127
2-9	8	<1.0	<1.0	<1.0	<1.0	<10
2-10	5	<1.0	<1.0	<1.0	<1.0	<10
2-11	5	<1.0	<1.0	<1.0	<1.0	<10
2-12	8	<1.0	<1.0	<1.0	<1.0	<10
2-13	5	<1.0	<1.0	<1.0	<1.0	<10
2-14	5	<1.0	<1.0	<1.0	<1.0	<10

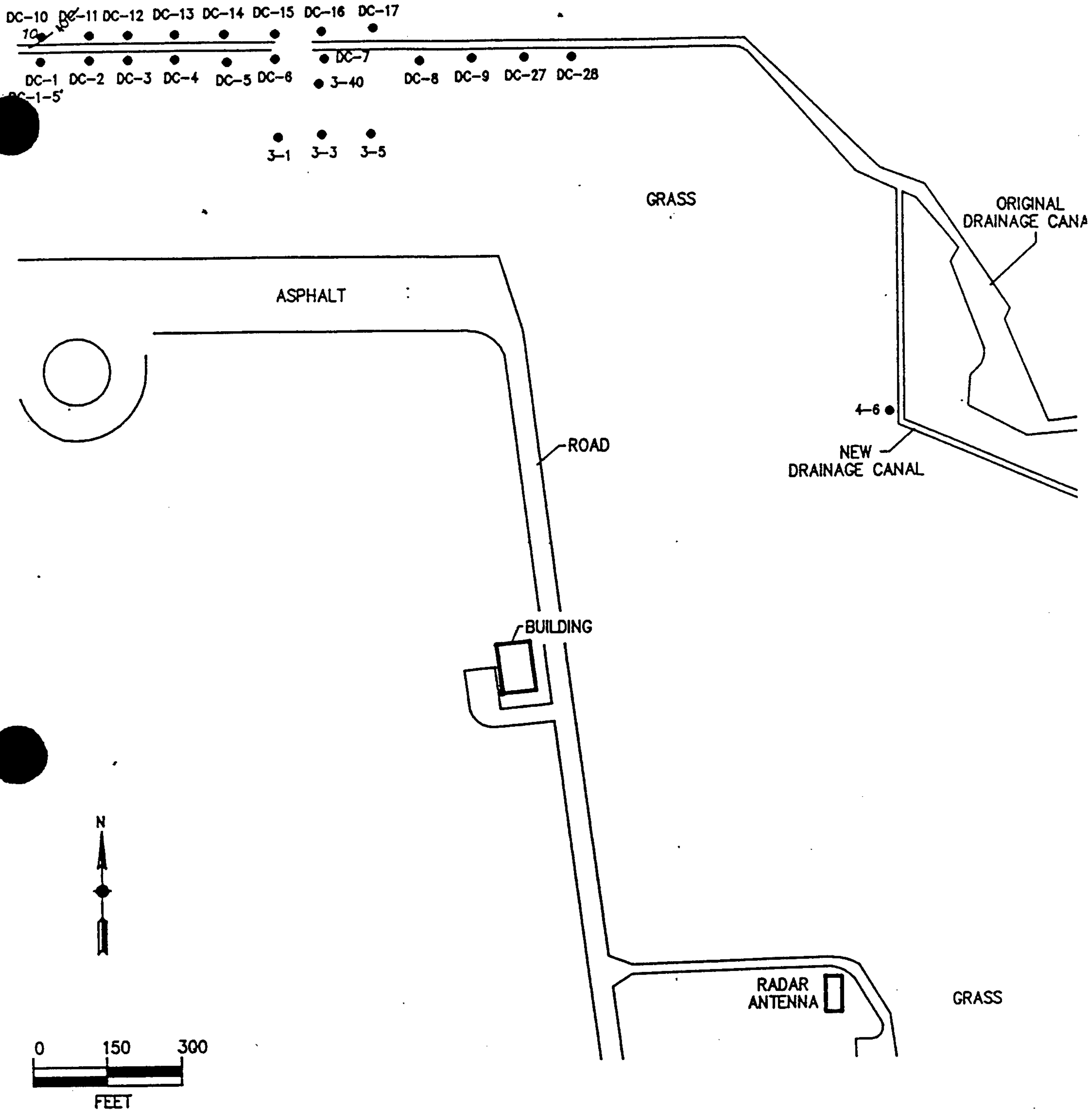
** CALCULATED USING THE SUM OF THE AREAS OF ALL INTEGRATED CHROMATOGRAM PEAKS AND THE INSTRUMENT RESPONSE FACTOR FOR TOLUENE*

TABLE 2

ANALYTE CONCENTRATIONS IN SOIL GAS VIA GC/ECD (µg/l)

SAMPLE	11DCE	CH2Cl2	t12DCE	11DCA	c12DCE	CHCl3	111TCA	CCl4	TCE	112TCA	PCE
REPORTING LIMIT	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
DC-1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-1-5'	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-2	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-4	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-5	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-6	<1.0	<1.0	<1.0	<1.0	7.7	<1.0	<1.0	<1.0	1.2	<1.0	<1.0
DC-7	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-8	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-9	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-10	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-11	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-12	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-13	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
14	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
D[illegible]	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
D[illegible]	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-17	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-27	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DC-28	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	9.0	<1.0	<1.0
2-2	<1.0	<1.0	5.6	<1.0	46	<1.0	<1.0	<1.0	342	<1.0	<1.0
2-3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	8.1	<1.0	<1.0
2-4	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	4.9	<1.0	<1.0
2-5	25	<1.0	279	<1.0	981	3.9	<1.0	<1.0	22,980	<1.0	14
2-6	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	5.0	<1.0	<1.0
2-7	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-8	5.3	<1.0	135	<1.0	124	<1.0	<1.0	<1.0	918	<1.0	1.2
2-9	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
2-10	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

11DCE = 1,1-dichloroethene
11DCA = 1,1-dichloroethane
111TCA = 1,1,1-trichloroethane
112TCA = 1,1,2-trichloroethane
CH2Cl2 = methylene chloride
c12DCE = cis-1,2-dichloroethene
CCl4 = carbon tetrachloride
PCE = tetrachloroethene
t12DCE = trans-1,2-dichloroethene
CHCl3 = chloroform
TCE = trichloroethene



● SOIL GAS SAMPLE LOCATION

○ NOT SAMPLED (UNCOLLECTABLE)

FIGURE 10. Total FID Volatiles in Soil Gas (calc'd $\mu g/l$)

IRP SITES 03, 04, 07
SKEET & TRAP RANGE &
DRAINAGE CANAL
ALTUS AIR FORCE BASE
OKLAHOMA

TARGET ENVIRONMENTAL SERVICES, INC.

This map is integral to a written report and should be viewed in that context.

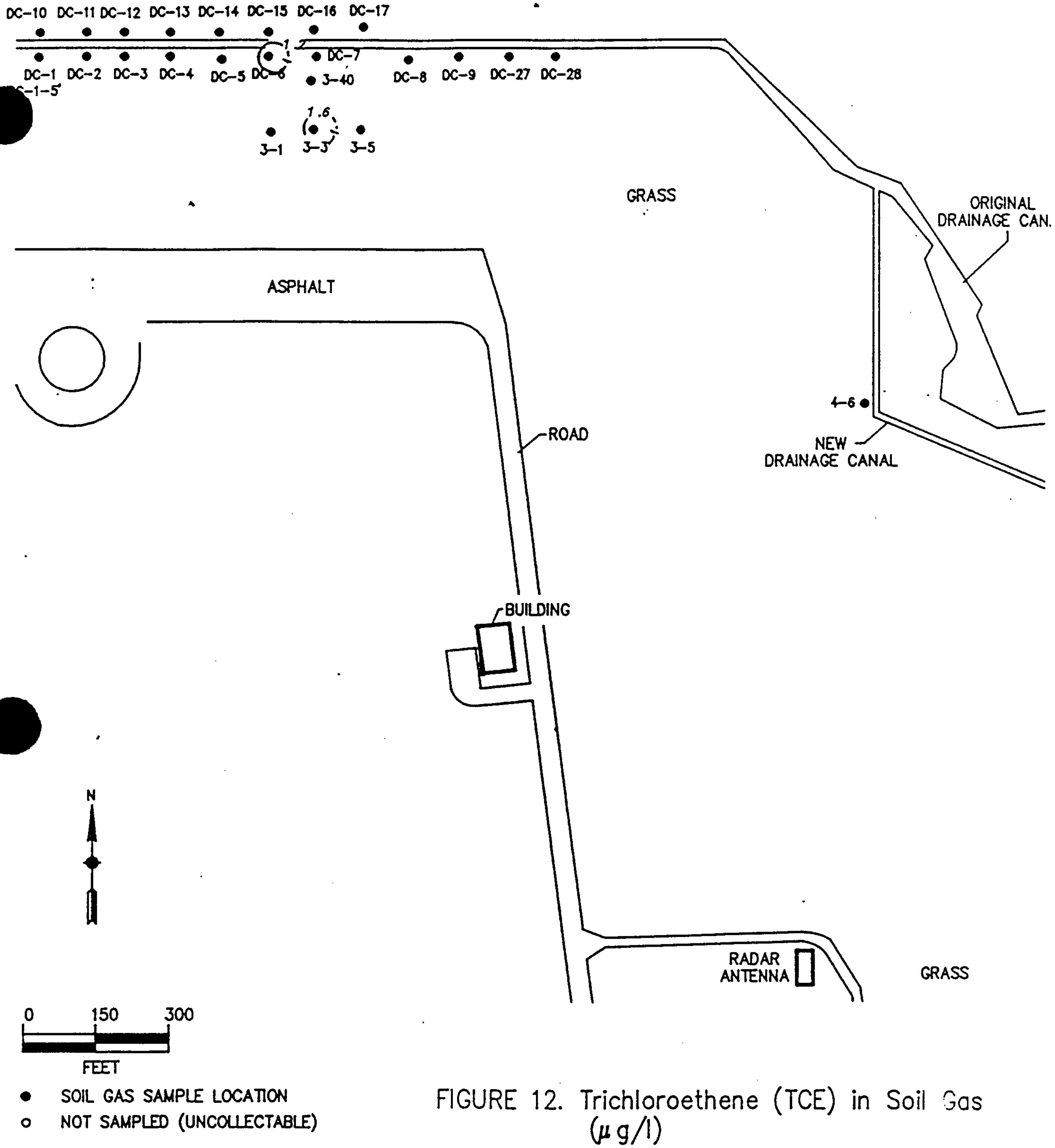


FIGURE 12. Trichloroethene (TCE) in Soil Gas (μg/l)

TARGET ENVIRONMENTAL SERVICES, INC.

This map is integral to a written report and should be viewed in that context.

IRP SITES 03, 04, 07
SKEET & TRAP RANGE &
DRAINAGE CANAL
ALTUS AIR FORCE BASE
OKLAHOMA

IRP SITES 03, 04, 07
SKEET & TRAP RANGE & DRAINAGE CANAL
ALTUS AIR FORCE BASE
OKLAHOMA

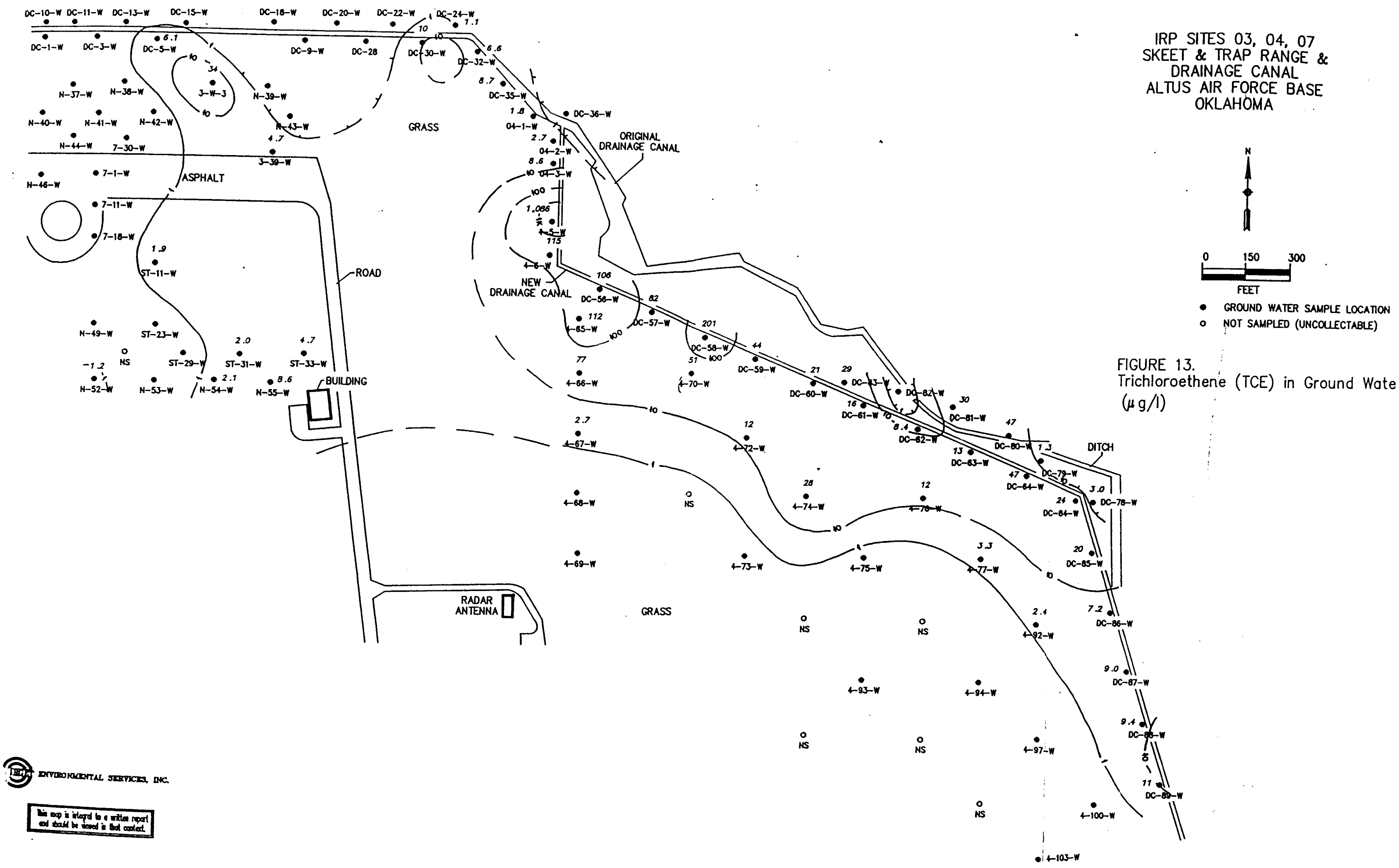


FIGURE 13.
Trichloroethene (TCE) in Ground Wate
(µg/l)

IRP SITES 03, 04, 07
SKEET & TRAP RANGE & DRAINAGE CANAL
ALTUS AIR FORCE BASE
OKLAHOMA

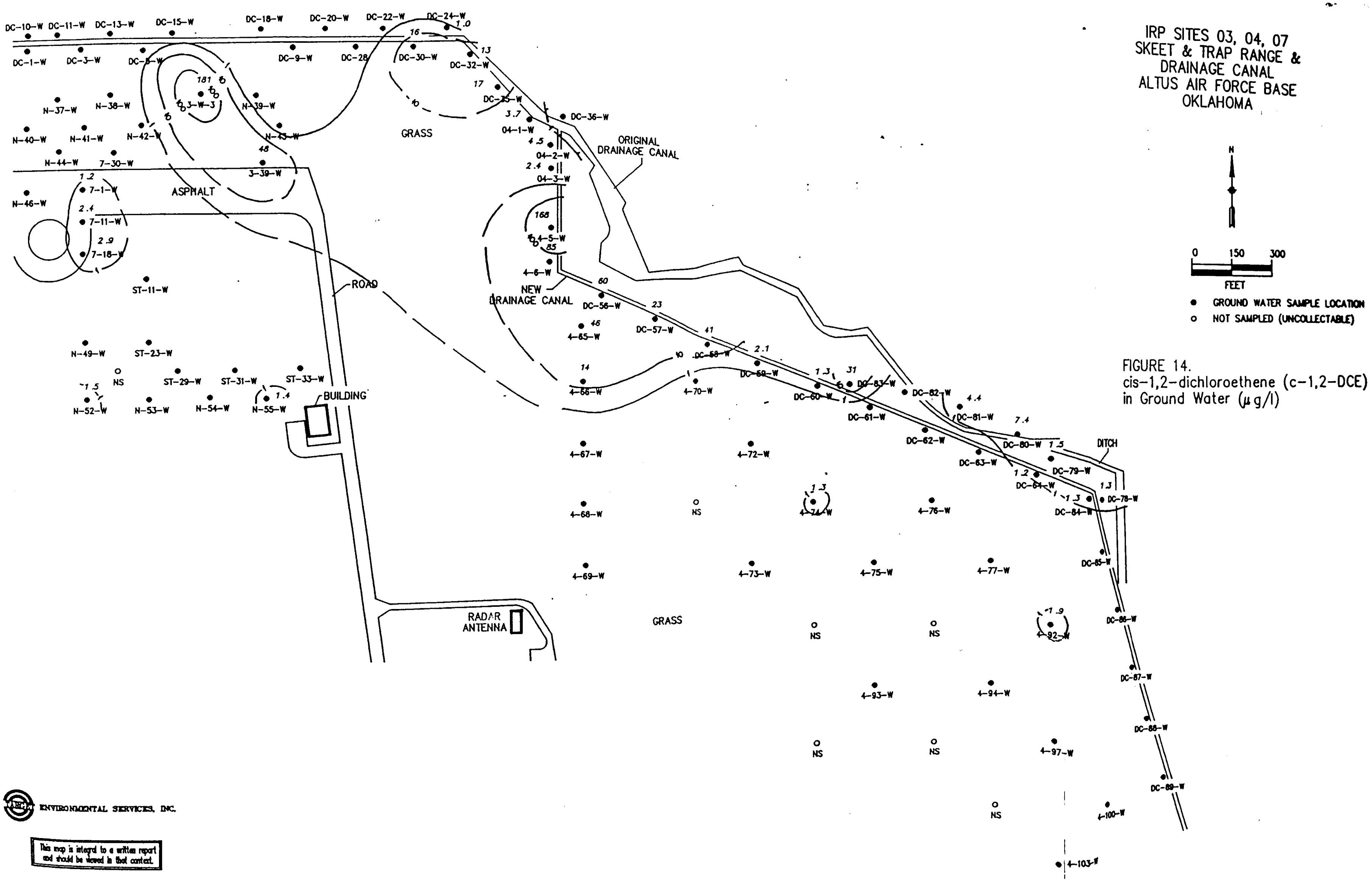
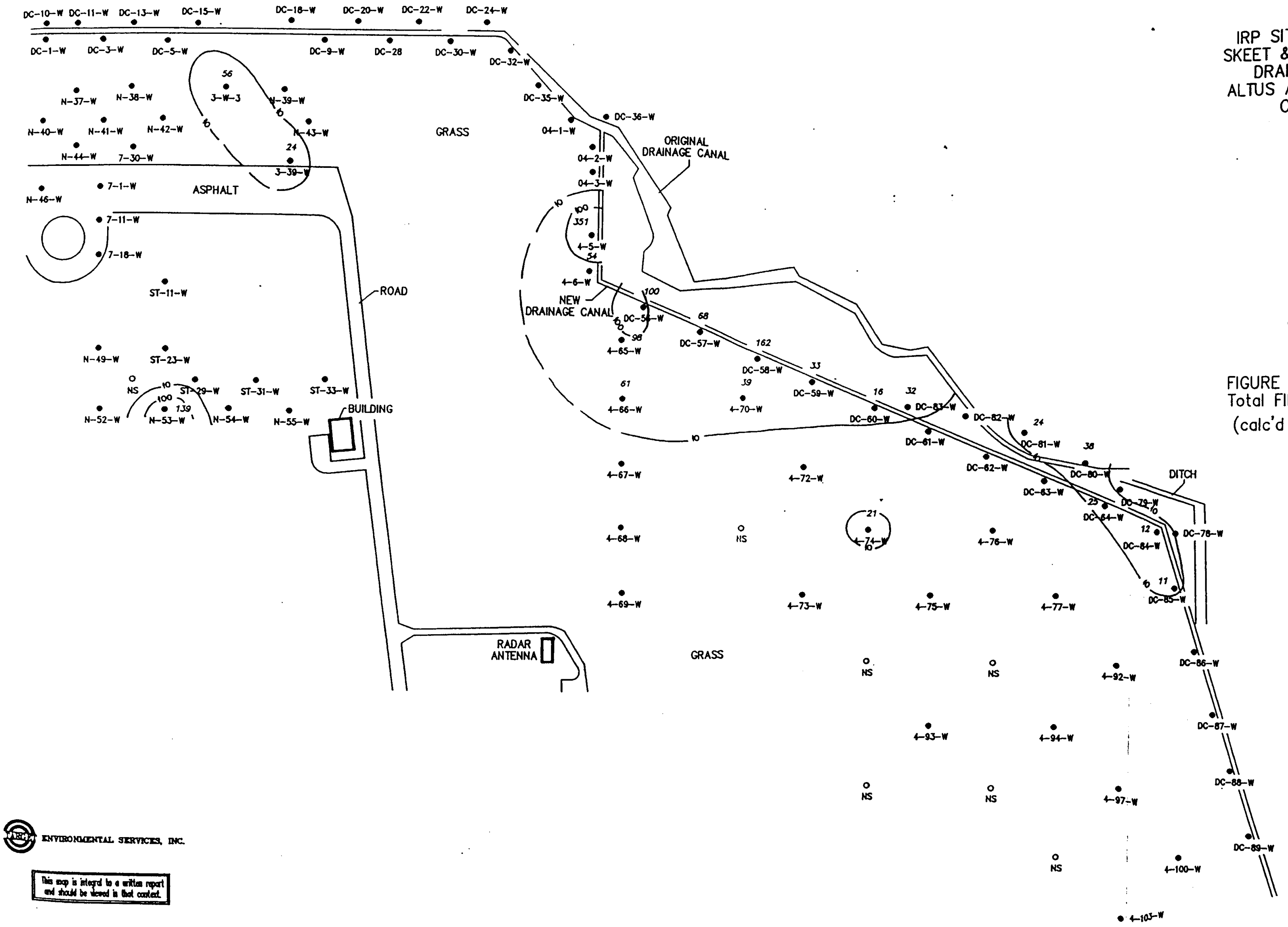


FIGURE 14.
cis-1,2-dichloroethene (c-1,2-DCE) in Ground Water (µg/l)

ENVIRONMENTAL SERVICES, INC.

This map is integral to a written report and should be viewed in that context.

IRP SITES 03, 04, 07
SKEET & TRAP RANGE &
DRAINAGE CANAL
ALTUS AIR FORCE BASE
OKLAHOMA



N

0 150 300
FEET

- ● GROUND WATER SAMPLE LOCATION
- ○ NOT SAMPLED (UNCOLLECTABLE)

FIGURE 15.
Total FID Volatiles in Ground Wate
(calc'd μg/l)

ENVIRONMENTAL SERVICES, INC.

This map is integral to a written report and should be viewed in that context.

DATA FROM USGS, 1996

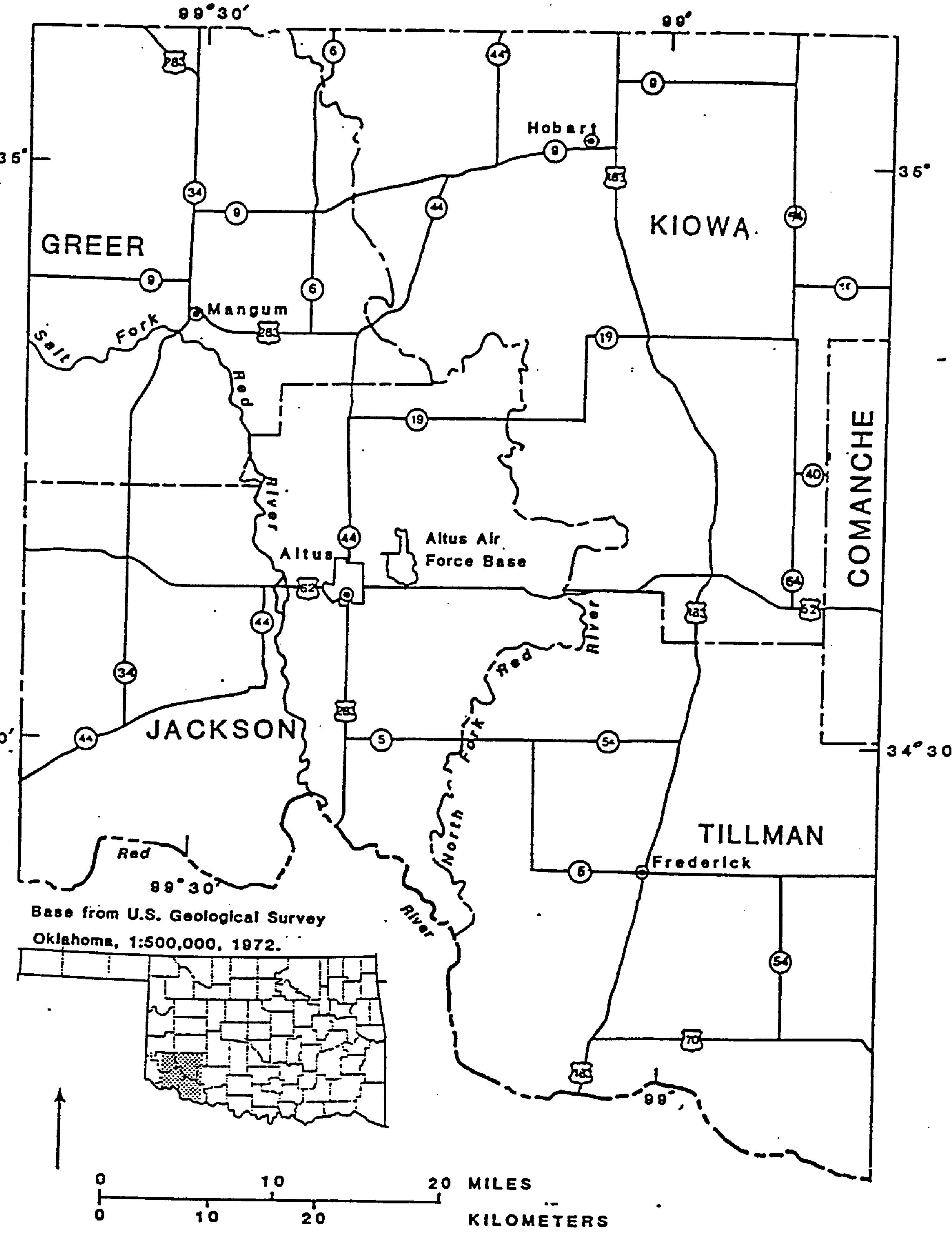
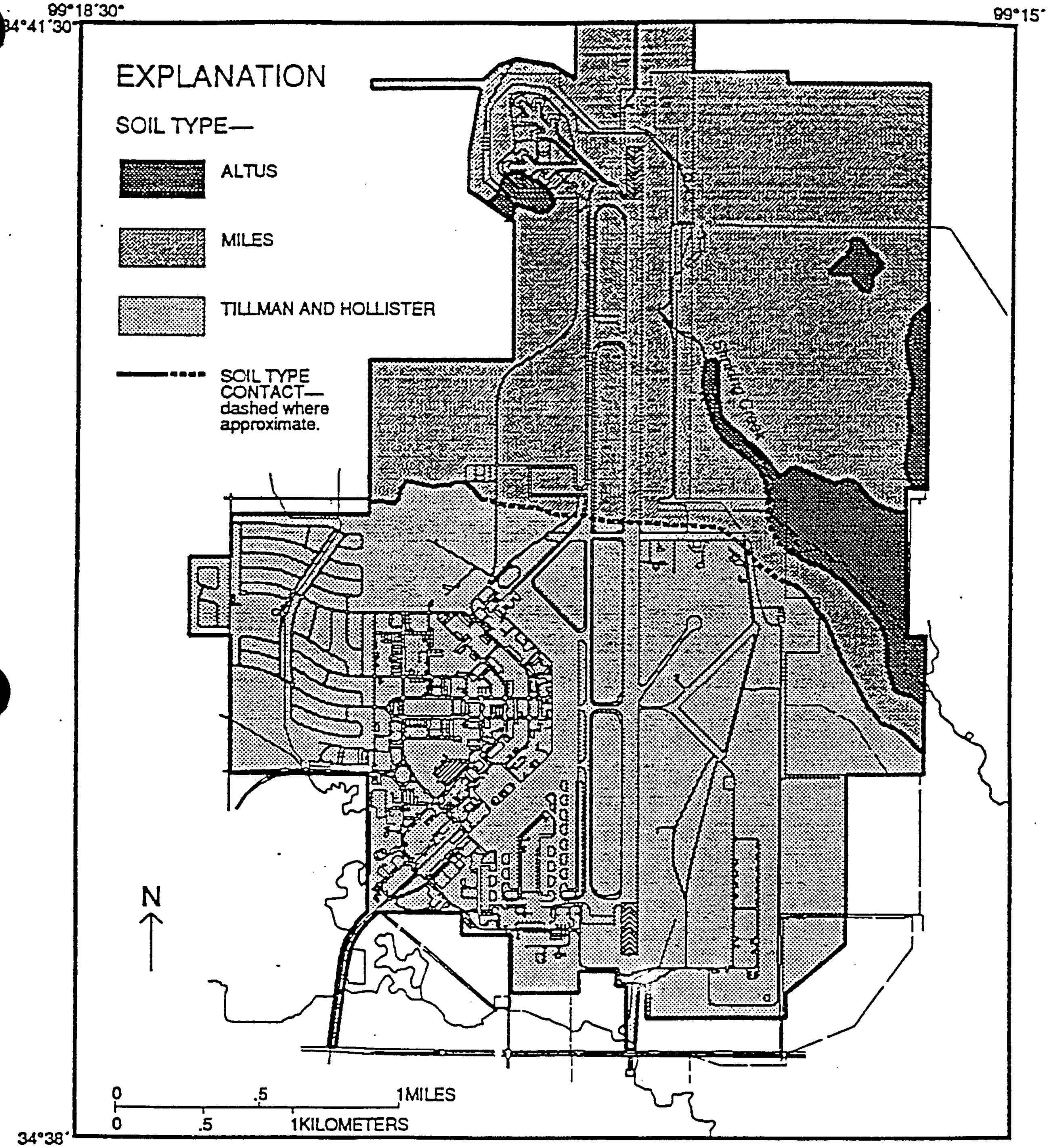


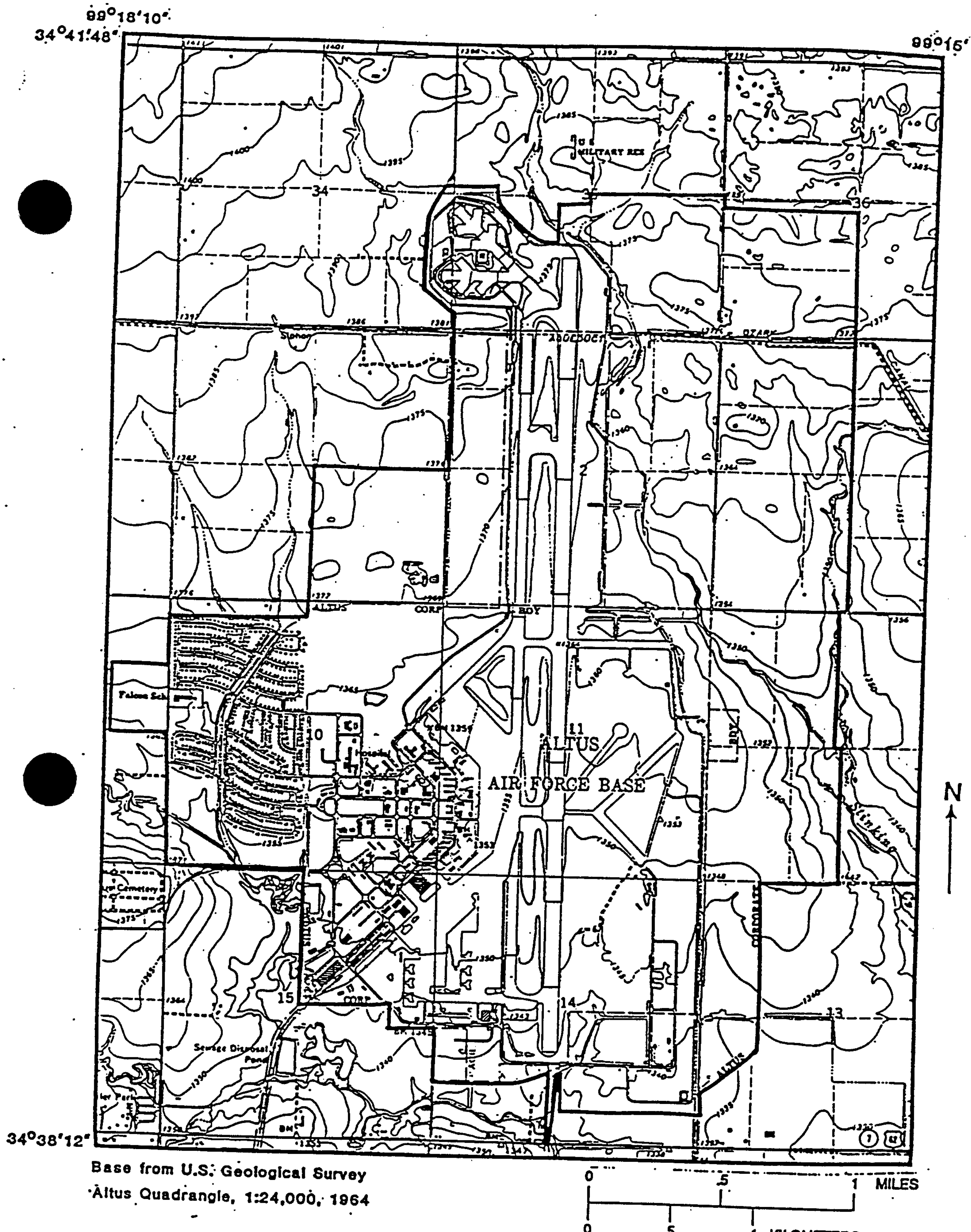
Figure 1-2.-Location map of Altus AFB, Oklahoma.



Base from U.S. Army Corps of Engineers Intergraph map, 1986

Modified from O.F. Bailey and R.D. Graft, 1961
Prepared by D.L. Runkle and J.R. Cederstrand, USGS, 1995

Figure 2–4.––Soil map for Altus AFB, Oklahoma.



Base from U.S. Geological Survey
Altus Quadrangle, 1:24,000, 1964

Figure 2-9.-Topographic map of Altus AFB, Oklahoma.

Table 4.4 Laboratory analytical results for major and trace elements in an unfiltered surface-water sample from Stinking Creek at Altus AFB, Oklahoma

[Column heading for samples lists stream-sampling identification, sample date, and field sample number. Analytical method SW6010 from U.S. Environmental Protection Agency, 1986; mg/L, milligrams per liter]

Constituent	Method	Units	Maximum contaminant level[1]	RV003 08/30/~~93~~ 94 4010430622	
				Minimum reporting limit	Concentration
Aluminum	SW6010	mg/L	0.05-0.2[2]	0.20	2.1
Calcium	SW6010	mg/L	--	5.0	184
Iron	SW6010	mg/L	0.3[2]	0.040	2.0
Magnesium	SW6010	mg/L	--	5.0	76.4
Manganese	SW6010	mg/L	0.05[2]	0.010	0.053
Potassium	SW6010	mg/L	--	5.0	7.6
Sodium	SW6010	mg/L	--	5.0	233
Zinc	SW6010	mg/L	5[2]	0.010	0.016

[1] The maximum permissible level of contaminant in water that is delivered to any user of a public water supply.

[2] The secondary maximum contaminant levels permissible in water delivered to any public water supply. Current as of June 1994.

4.1.1.2.2 Bottom-sediment analysis of Stinking Creek near the eastern Base boundary

A bottom-sediment sample from Stinking Creek, RV003, (plate 1) was collected August 30, 1994, and analyzed for VOCs, sVOCs, major elements, trace elements, and percent soil moisture. Only laboratory analytical results for chemical constituents detected at concentrations greater than the reporting limits are presented in table 4.5. The sediment results in this table are based on dry weight. VOCs, sVOCs, antimony, cadmium, cobalt, mercury, molybdenum, selenium, silver, or thallium were not detected in the bottom-sediment sample.

Table 4.9. Field analytical results of VOCs in ground-water samples from boreholes in LF-04, Operable Unit 01, Altus AFB, Oklahoma [ug/L, micrograms per liter; --, not detected].

Site ID	Date	Borehole depth (in feet)	Vinyl chloride	trans 1,2-Dichloro-ethene	cis 1,2-Dichloro-ethene	Benzene	Trichloro-ethene	toluene	Tetrachloro-ethene	meta-xylene	Unknowns expressed as Benzene
Hole 1	11/12/92	15	--	1.5	10	--	12	--	--	--	--
Hole 2	11/12/92	15	--	11	51	--	31	1.2	--	--	5.2
Hole 3	11/12/92	15	--	6.6	18	-	16	--	--	--	--
Hole 4	11/12/92	18	--	3.7	15	--	89	--	--	--	1.7
Hole 5	11/12/92	15	--	150	1600	1.8	3900	--	9.1	--	60
Hole 6	11/12/92	15	--	250	1700	--	5800	--	--	--	--
Hole 7	11/12/92	20	--	4.1	28	--	710	5.3	5.4	--	--
Hole 8	11/12/92	20	--	45	460	--	760	--	--	--	--
Hole 9	11/12/92	21	--	12	140	--	1000	--	--	--	--
Hole 10	11/12/92	18	--	0.7	41	--	770	--	--	--	34
Hole 11	11/12/92	21	--	6.4	38	--	820	--	--	--	9
Hole 12	11/12/92	20	--	1.1	6.9	--	620	--	--	--	9.3
Hole 13	11/12/92	23	--	--	0.4	--	0.5	--	0.2	--	3.4
Hole 14	11/16/92	24	--	--	--	--	310	--	--	--	--
Hole 15	11/16/92	25	--	--	--	--	110	--	--	--	8.8
Hole 16	11/16/92	25	--	--	--	--	--	--	--	--	5.5

Table 4.10. Laboratory analytical results for VOCs in ground-water samples from boreholes in LF-04, Operable Unit 01, Altus AFB, Oklahoma-Continued

Constituent	Method	Units	Maximum contaminant level[1]	Hole 08		Hole 09		Hole 10		Hole 11	
				11/12/92 4010410542 0-20 ft		11/12/92 4010410543 0-21ft		11/12/92 4010410548 0-18 ft		11/12/92 4010410544 0-21 ft	
				Minimum reporting limit	Concentration	Minimum reporting limit	Concentration	Minimum reporting limit	Concentration	Minimum reporting limit	Concentration
1,2-Dichloroethene (total)	SW8240	ug/L	70/100[2]	33	790	62	340	84	–	50	–
Trichloroethene (Trichloroethylene)	SW8240	ug/L	5	33	1200	62	2200	84	1900	50	1700

Constituent	Method	Units	Maximum contaminant level[1]	Hole 12		Hole 14		Hole 15	
				11/12/92 4010410546 0-20 ft		11/16/92 4010410551 0-24 ft		11/16/92 4010410552 0-25 ft	
				Minimum reporting limit	Concentration	Minimum reporting limit	Concentration	Minimum reporting limit	Concentration
Chloromethane	SW8240	ug/L	–	88	200	47	–	14	–
1,2-Dichloroethene (total)	SW8240	ug/L	70/100[2]	31	–	17	–	5.0	–
Trichloroethene (Trichloroethylene)	SW8240	ug/L	5	31	1100	17	560	50	65

---

[1] The maximum permissible level of contaminant in water delivered to any user of a public water supply. Current as of June 1994.

[2] Dual numbers are the respective levels of the cis/trans isomers of 1,2-dichoroethene.

Table 4.15. Laboratory analytical results for VOCs in ground-water samples from monitoring wells in Operable Unit 01, Altus AFB, Oklahoma-Continued

Constituent	Method	Units	Maximum contaminant level[1]	WL021		WL022		WL068	
				09/13/93 4010410649 3-27 ft		09/02/93 4010410647 3/26 ft		08/31/93 4019910625 8-25 ft	
				Minimum reporting limit	Concentration	Minimum reporting limit	Concentration	Minimum reporting limit	Concentration
1,2-Dichloroethene (total)	SW8240	ug/L	70/100[2]	5.0	7.1	5.0	100	5.0	7.7
Trichloroethene (Trichloroethylene)	SW8240	ug/L	5	5.0	14	5.0	42	5.0	94

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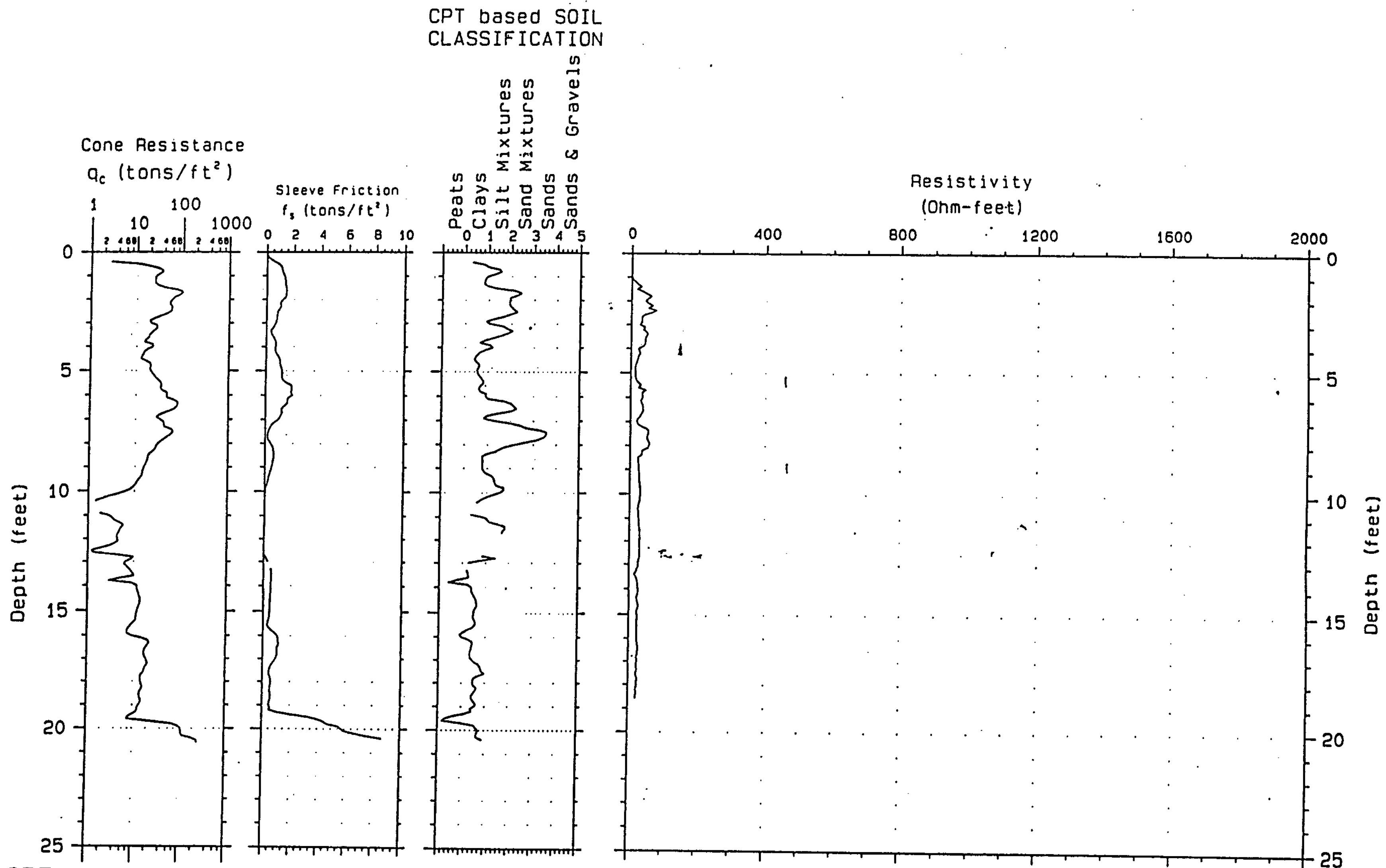
[1] The maximum permissible level of contaminant in water delivered to any user of a public water supply. Current as of June 1994.

[2] Dual numbers are the respective levels of the cis/trans isomers of 1,2-dichoroethene.

Water-level measurements in monitoring wells at Altus AFB from September 1992 to April 1994—Continued

Well name and location	Water-level measurement date	Water-level measurement time	Water-level in feet below land surface
	09-16-1993	1005	6.62
WL019, LF-04	09-16-1992	1620	4.97
	10-29-1992	1407	5.66
	12-01-1992	1031	3.36
	12-16-1992	–	2.02
	01-27-1993	0800	2.92
	02-26-1993	0945	2.95
	03-30-1993	1612	2.11
	09-13-1993	1245	9.46
	09-16-1993	1110	9.60
WL020, LF-04	09-16-1992	1625	9.81
	10-29-1992	1415	11.09
	12-16-1992	–	6.87
	01-27-1993	0750	7.57
	02-26-1993	0950	7.56
	03-30-1993	1620	7.18
	09-02-1993	1055	11.93
	09-16-1993	1120	12.57
WL021, LF-04	09-16-1992	1615	2.72
	10-29-1992	1424	3.30
	12-01-1992	1021	1.43
	12-16-1992	–	.69
	01-27-1993	0810	1.24
	02-26-1993	0940	1.23
	03-30-1993	1605	.64
	09-13-1993	1230	2.47
	09-16-1993	1100	7.56
WL022, LF-04	09-16-1992	1610	2.42
	10-29-1992	1431	2.98
	12-01-1992	1011	1.10
	12-16-1992	–	.20
	01-27-1993	0815	.61
	02-26-1993	0935	.58
	03-30-1993	1515	.22
	09-02-1993	1430	5.48
	09-16-1993	1020	5.51
WL023, LF-09	09-16-1992	1450	4.70
	10-29-1992	1538	7.76
	12-01-1992	–	4.82
	12-16-1992	–	3.19
	01-27-1993	No water-level meausured. Well destoyed	

DATA FROM USACE, 1996



CPT: R02
STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
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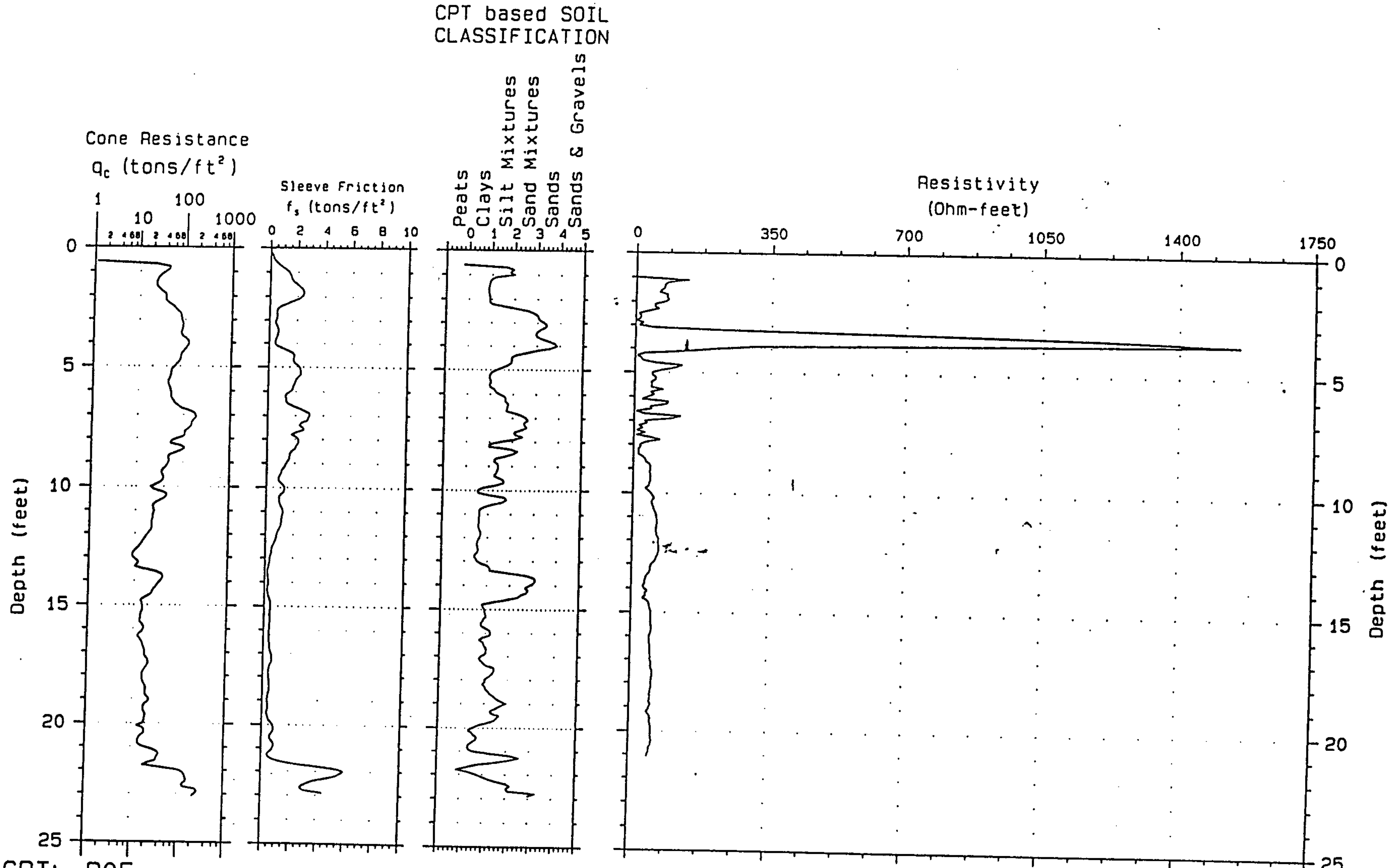
Project: Altus AFB



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STATE COORDINATES:

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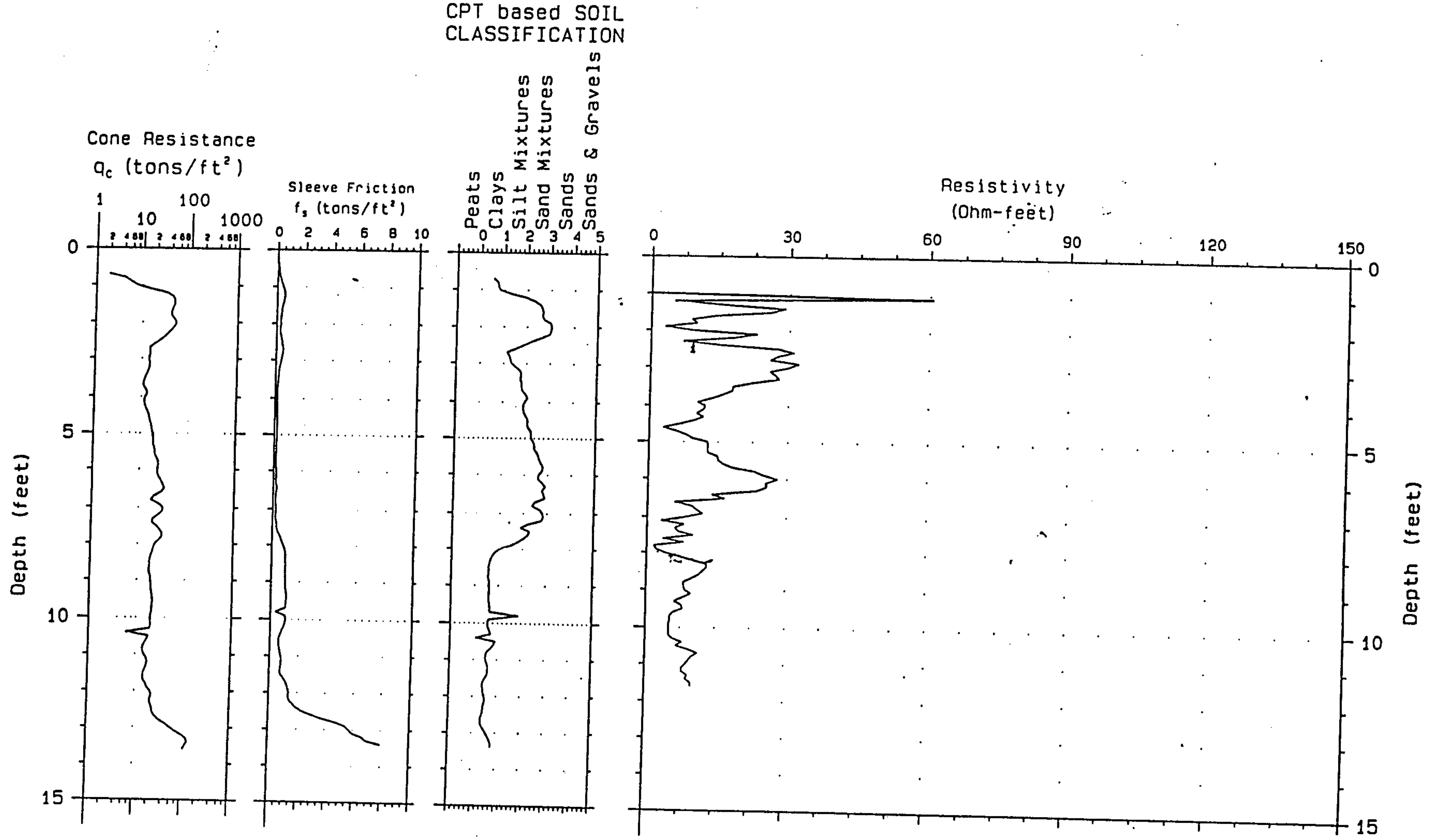
Project: Altus AFB



CPT: R07
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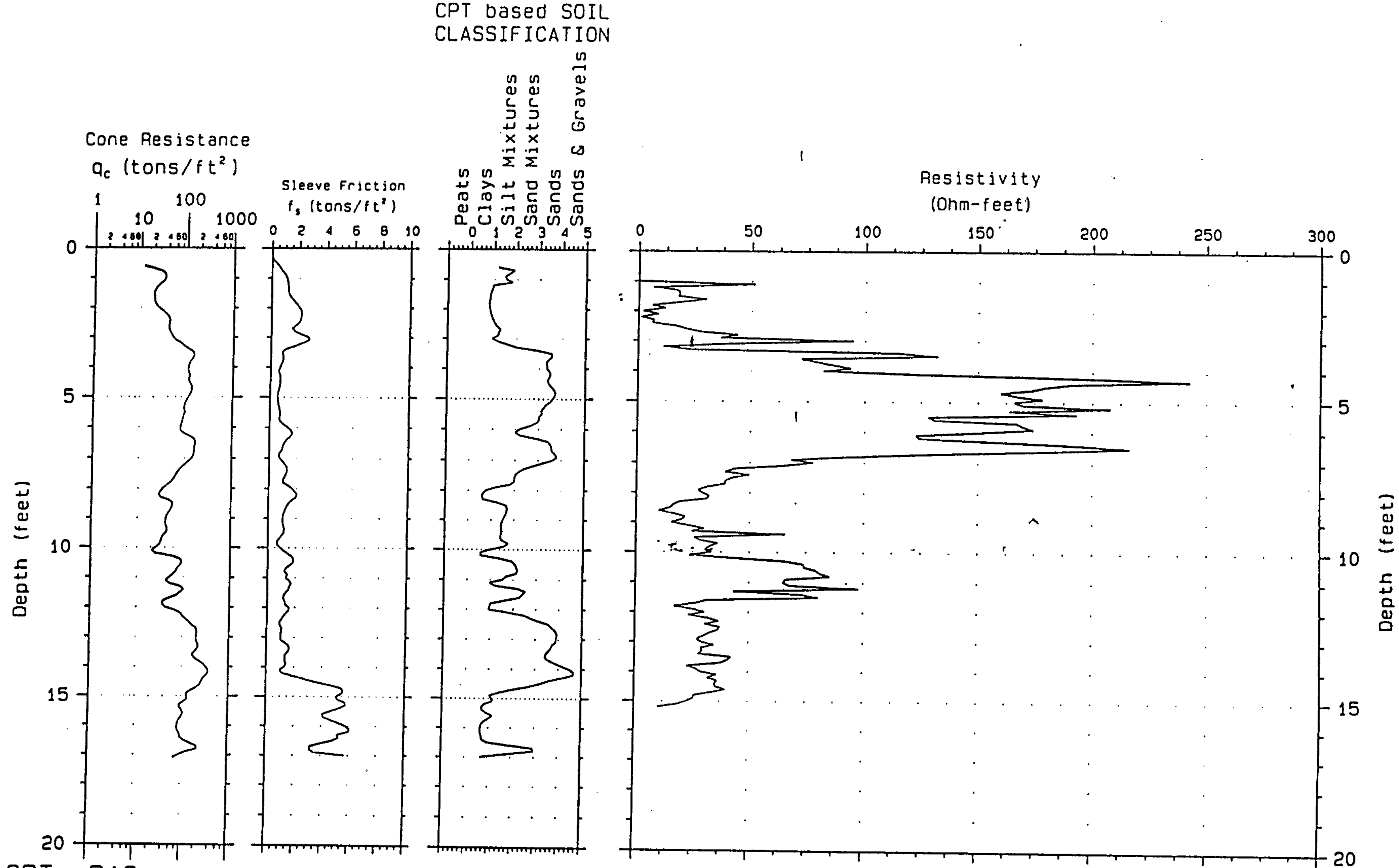
Project: Altus AFB

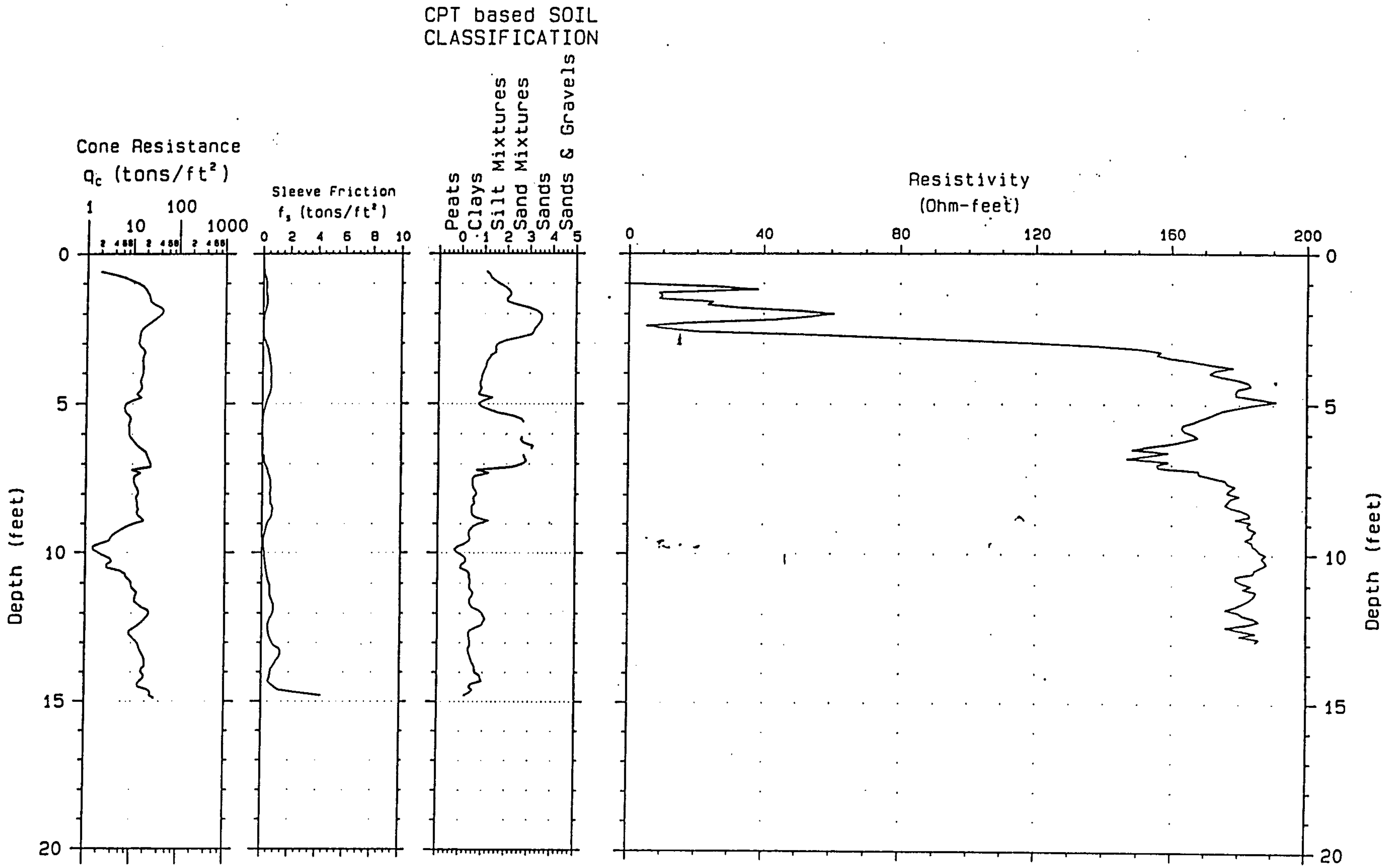


Project: Altus AFB

CPT: R12

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
0	0	0

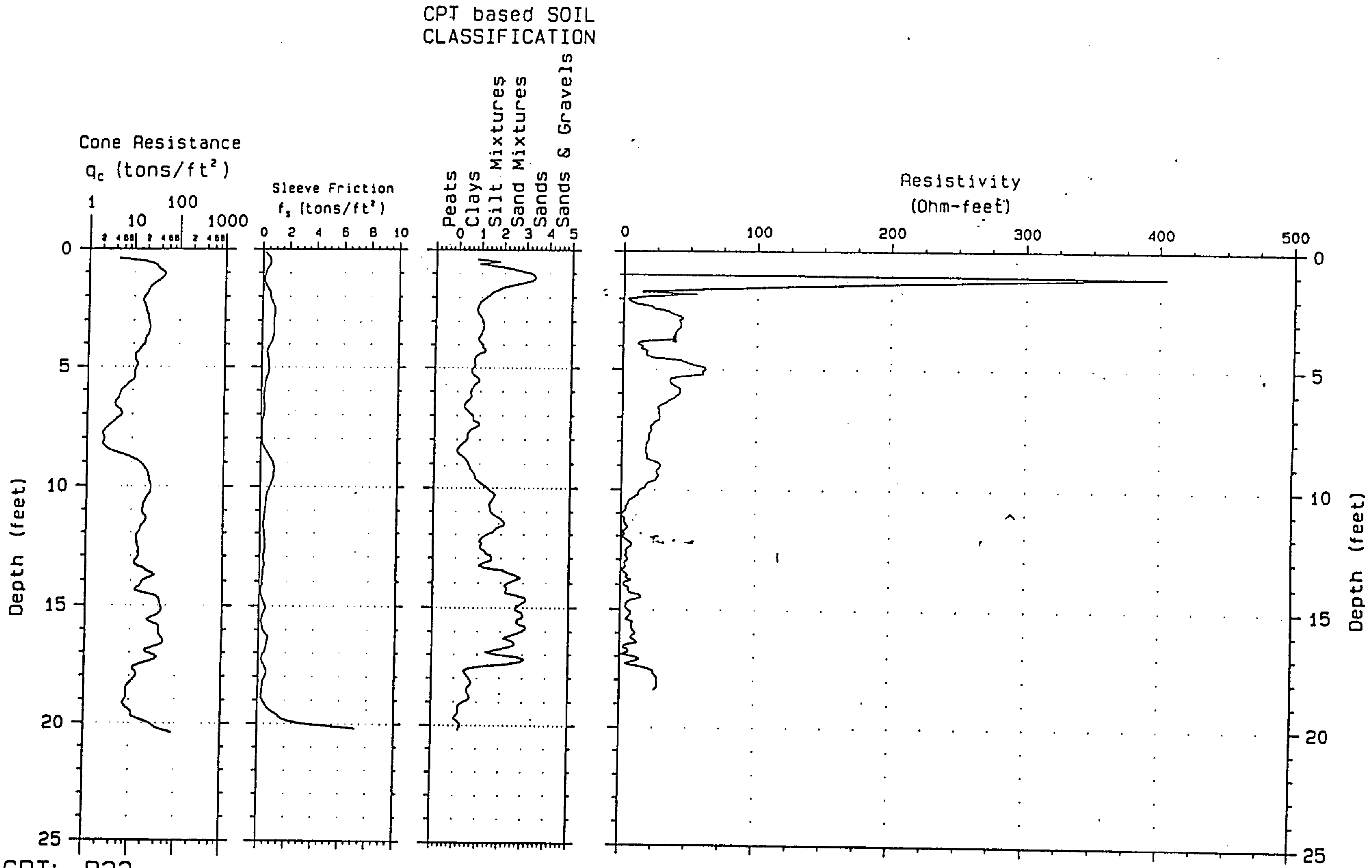


CPT: R14

STATE COORDINATES:

Project: Altus AFB

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
0	0	0

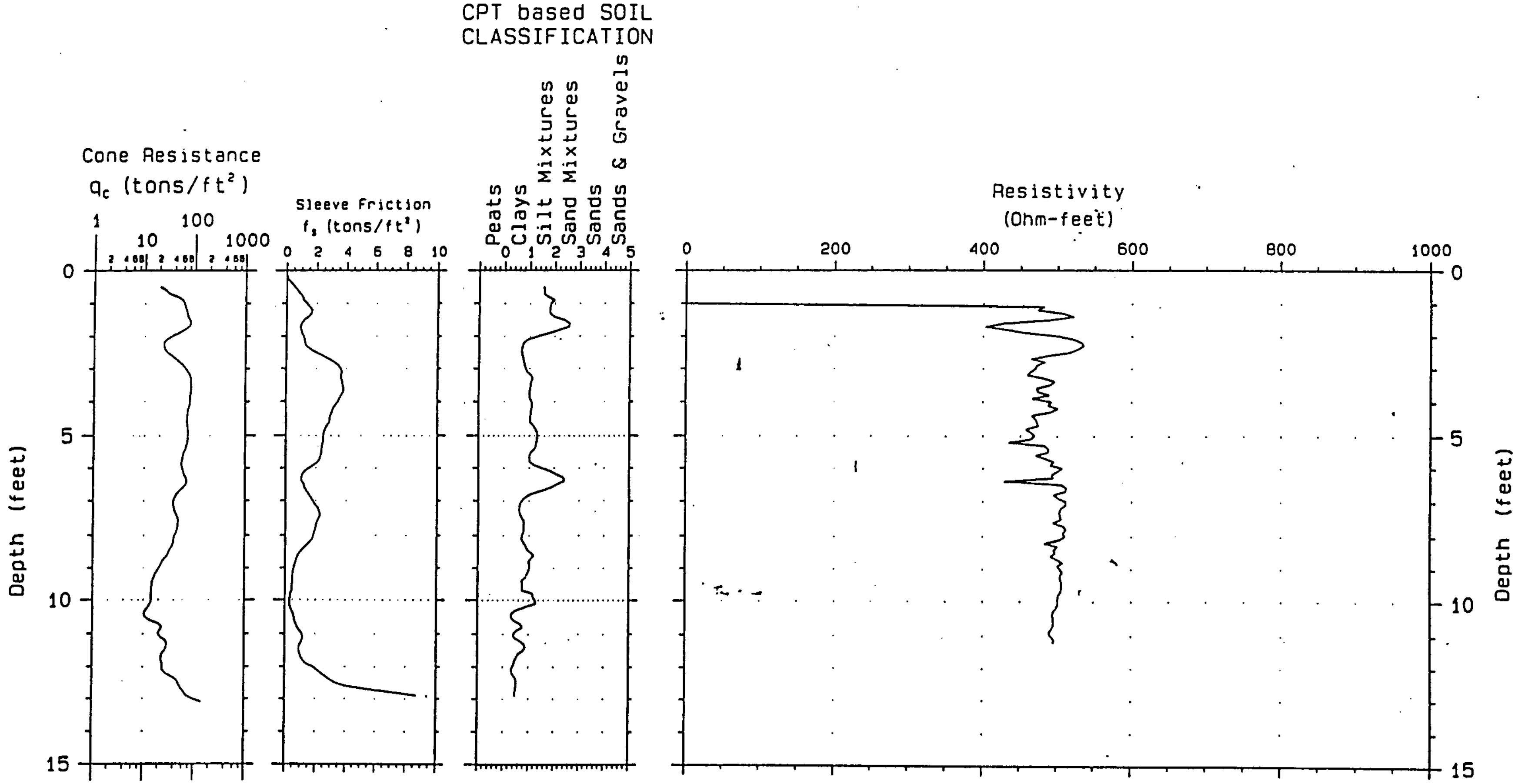


CPT: R22

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
0	0	0

Project: Altus AFB

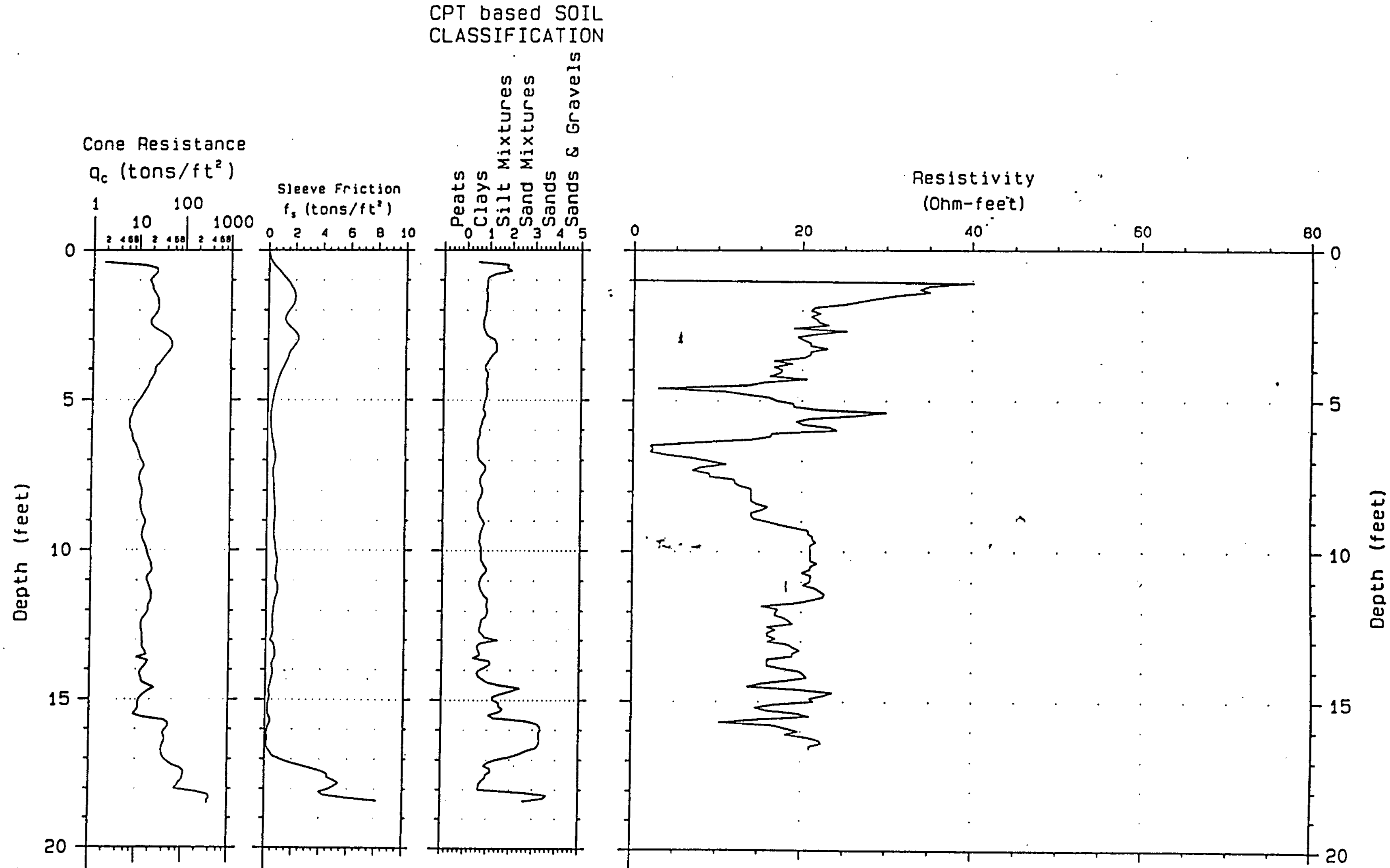


CPT: R24

Project: Altus AFB

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
0	0	0



Project: Altus AFB

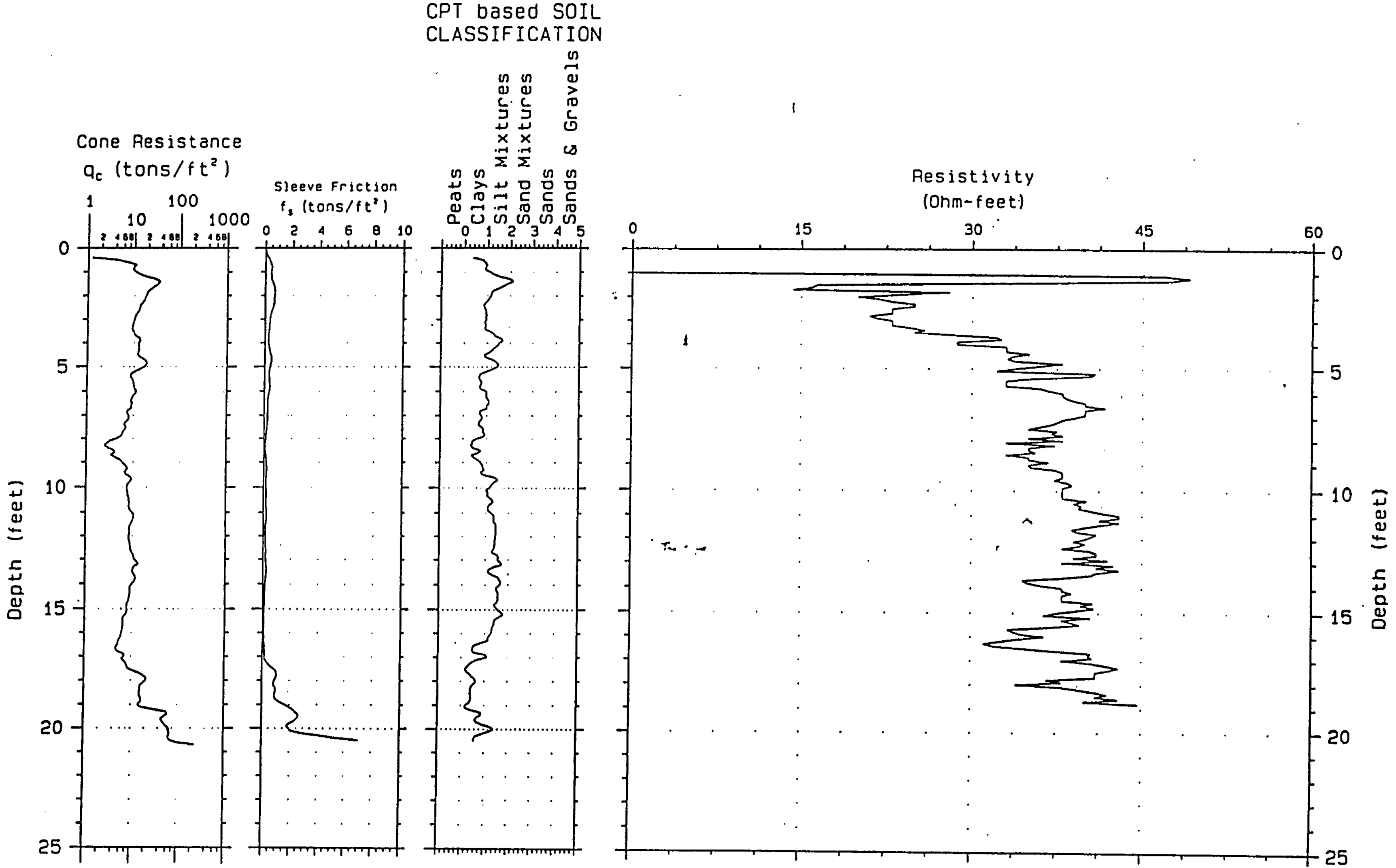
CPT: R28

STATE COORDINATES:

EASTING (ft.) 0

NORTHING (ft.) 0

ELEVATION (ft.) 0

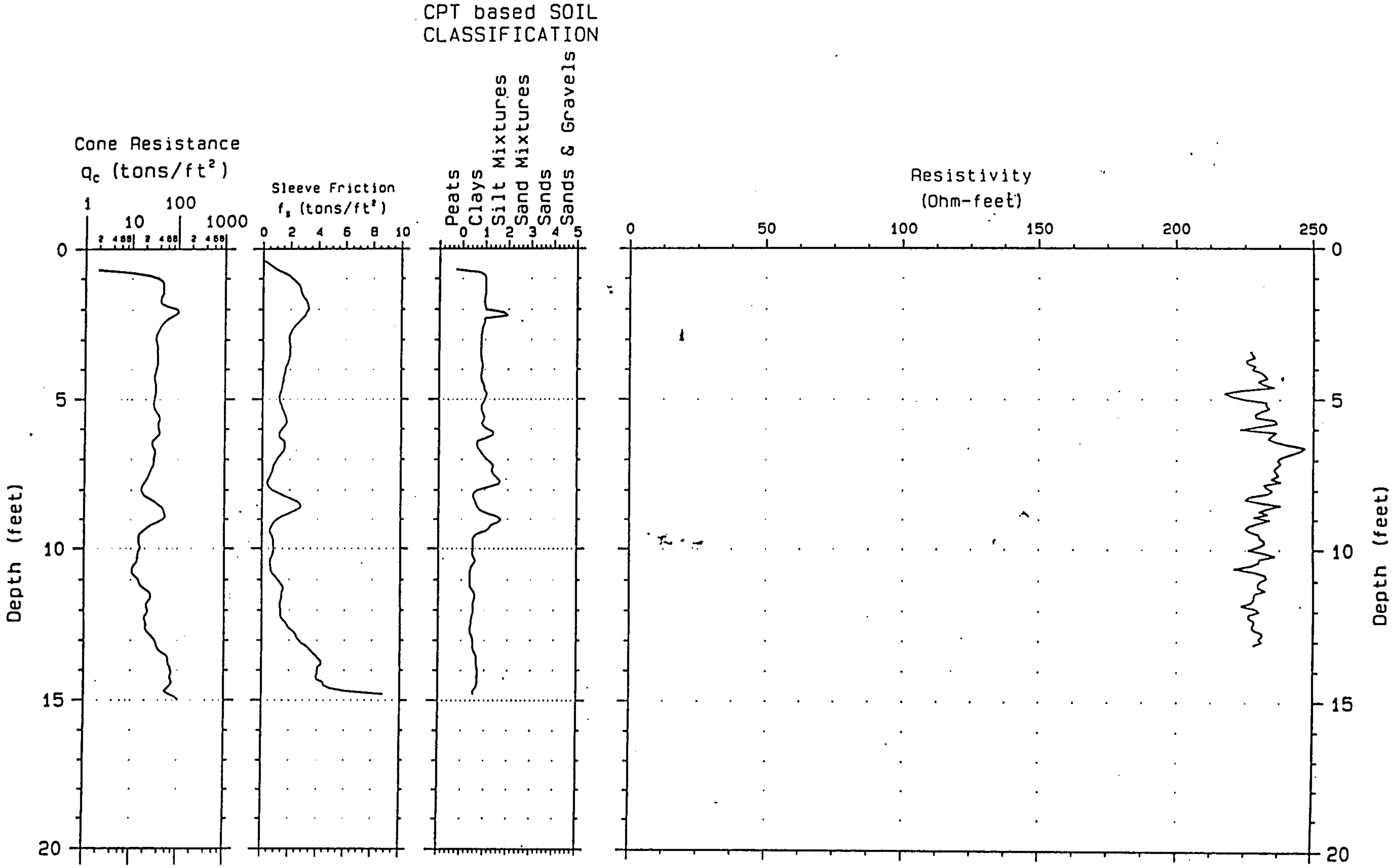


CPT: R30

Project: Altus AFB

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
0	0	0

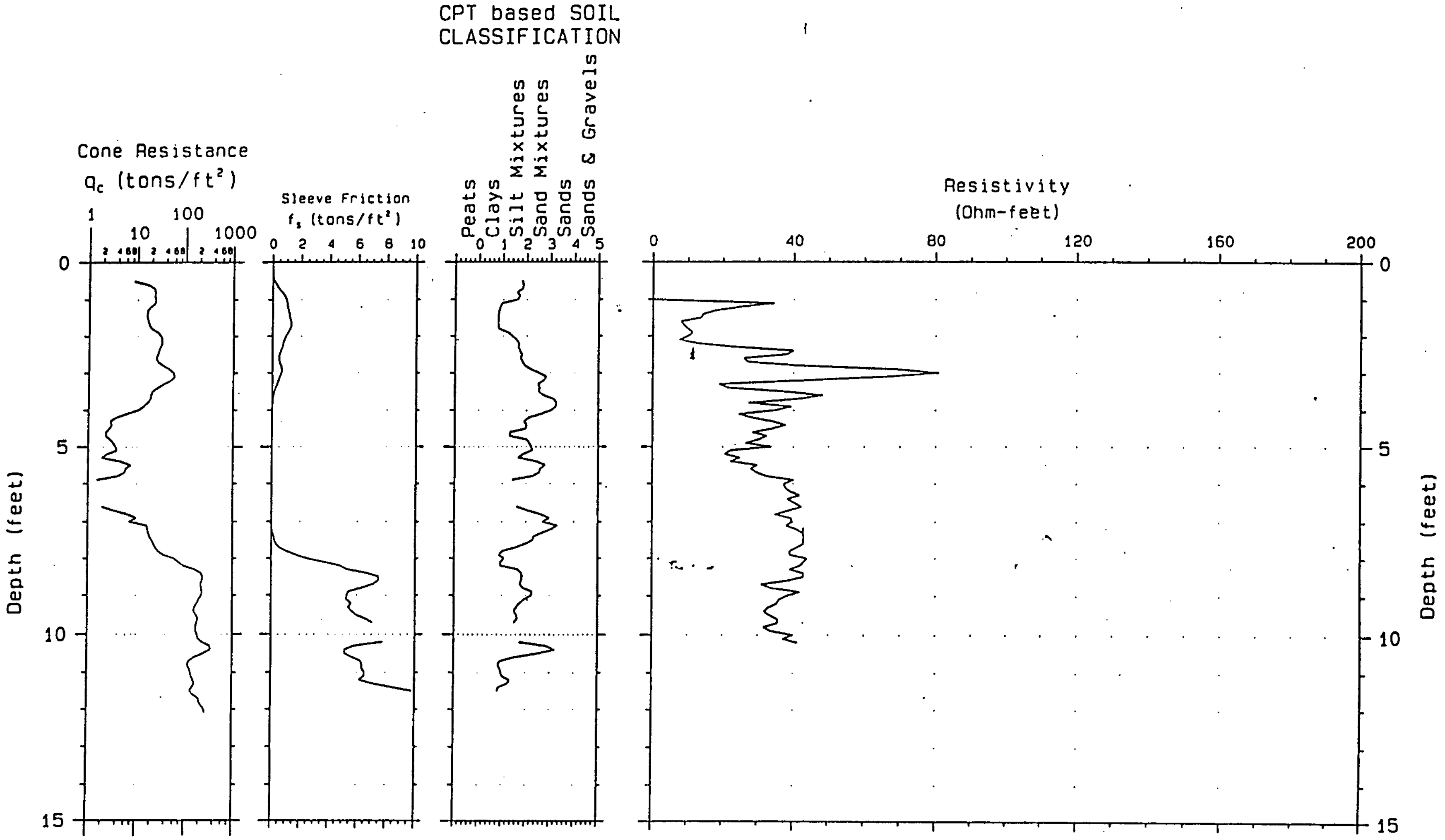


CPT: R42

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
0	0	0

Project: Altus AFB

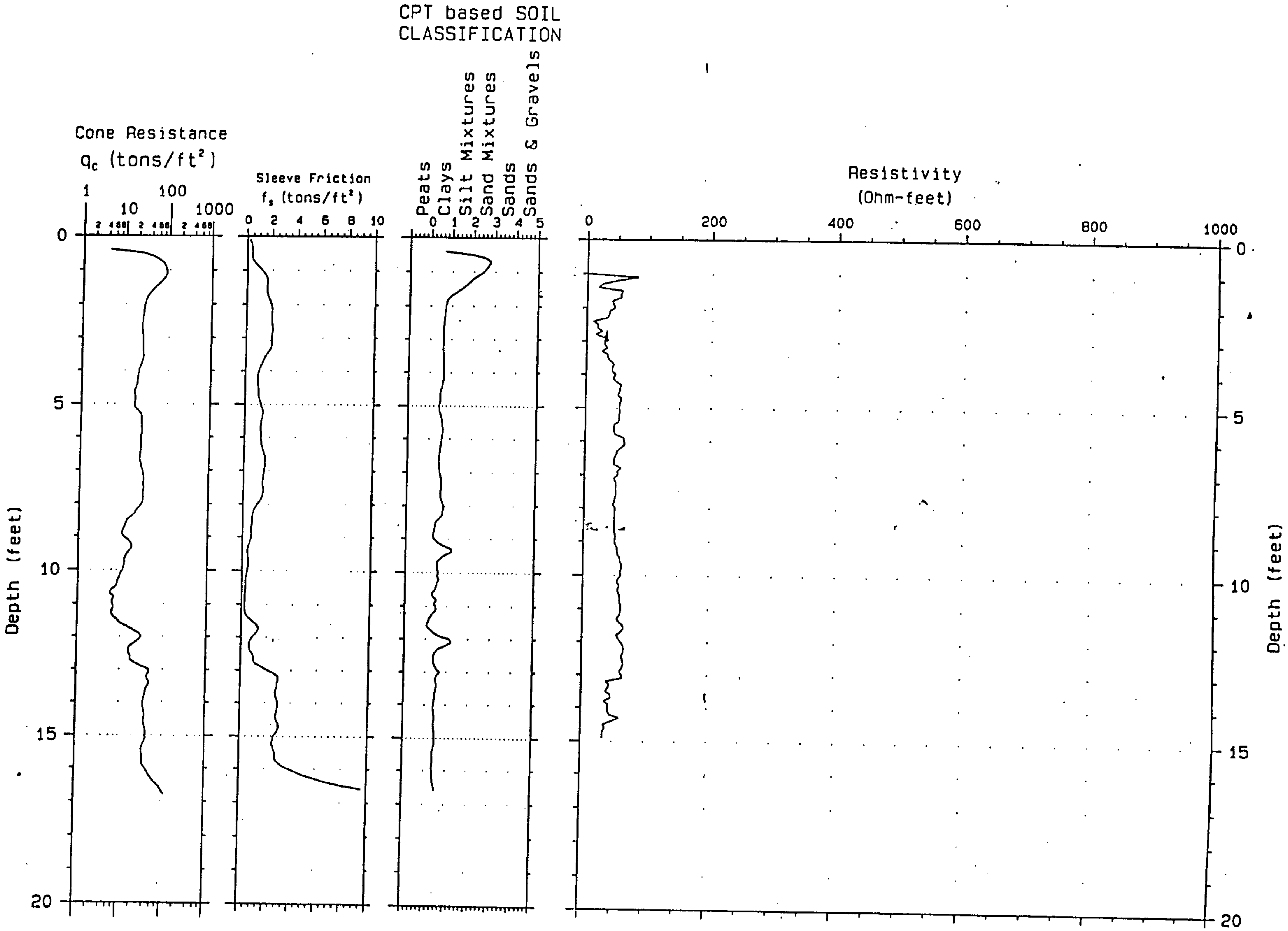


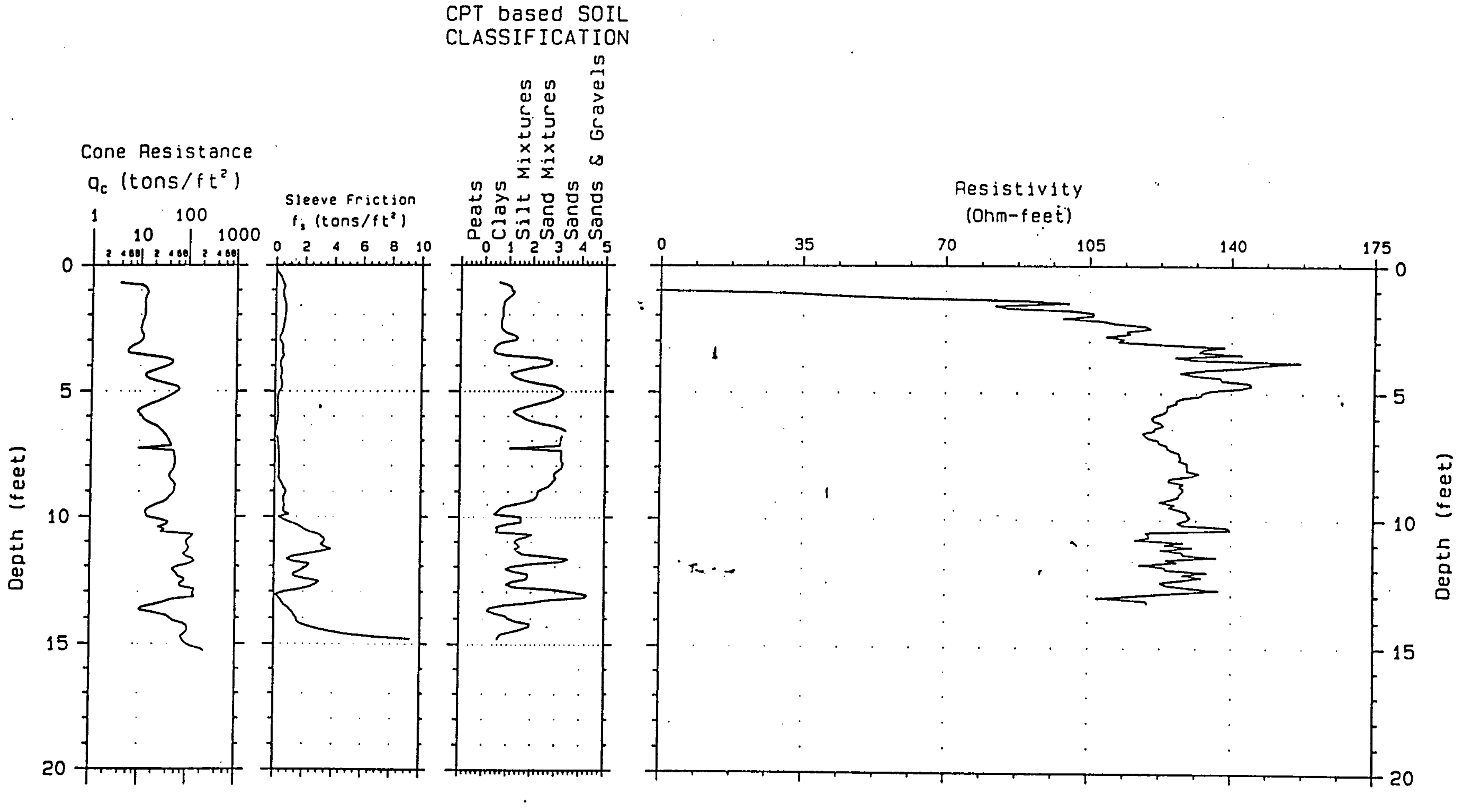
CPT: R44

STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
0	0	0

Project: Altus AFB

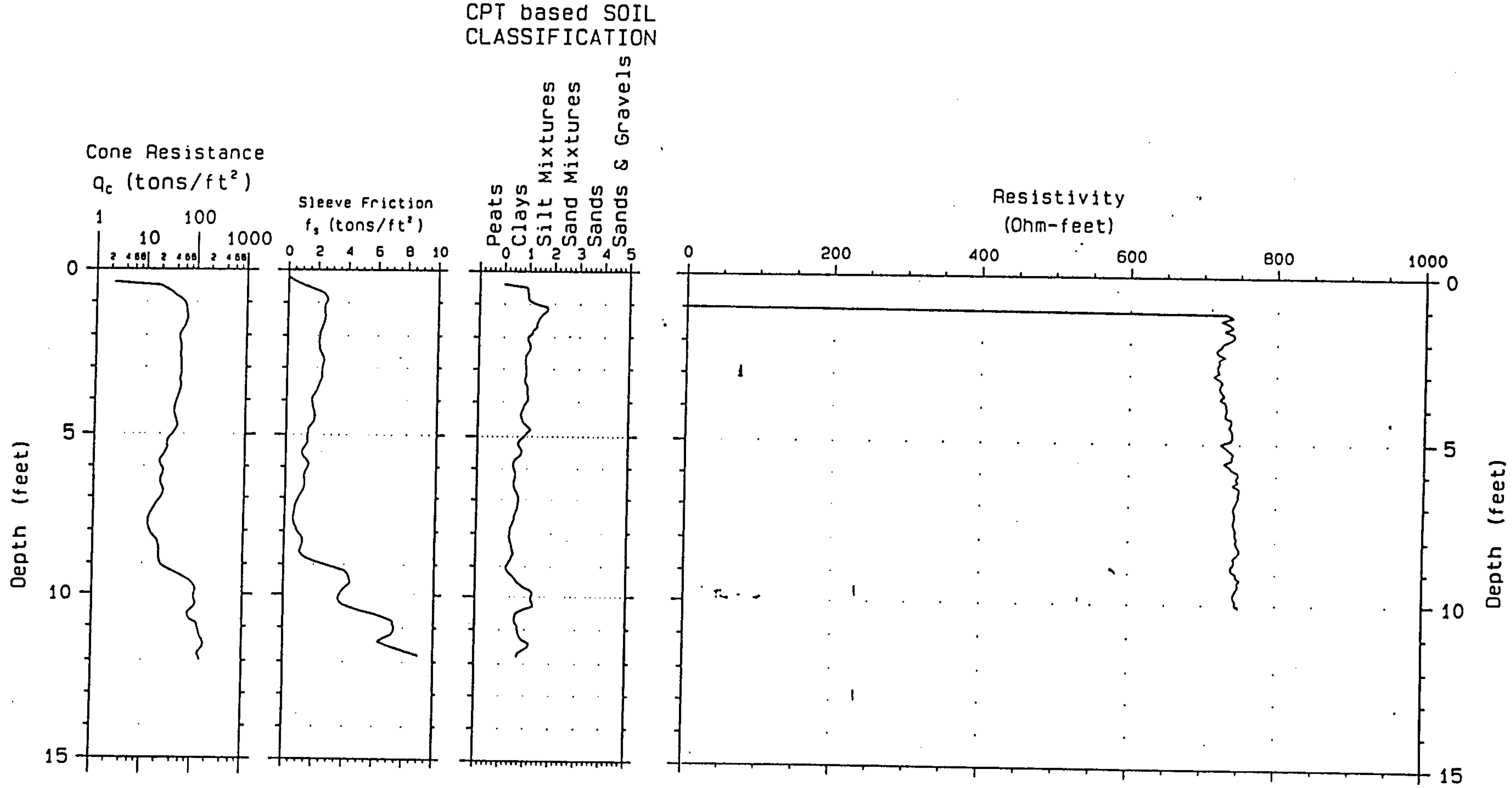

CPT based SOIL CLASSIFICATION
Cone Resistance
q_c (tons/ft^2)
1
10
100
1000
Sleeve Friction
f_s (tons/ft^2)
0 2 4 6 8 10
Peats
Clays
Silt Mixtures
Sand Mixtures
Sands
Sands & Gravels
0 1 2 3 4 5
Resistivity
(Ohm-feet)
0 200 400 600 800 1000
Depth (feet)
0 5 10 15 20



CPT: R37
STATE COORDINATES:

EASTING (ft.)	NORTHING (ft.)	ELEVATION (ft.)
0	0	0

Project: Altus AFB



CPT: R39

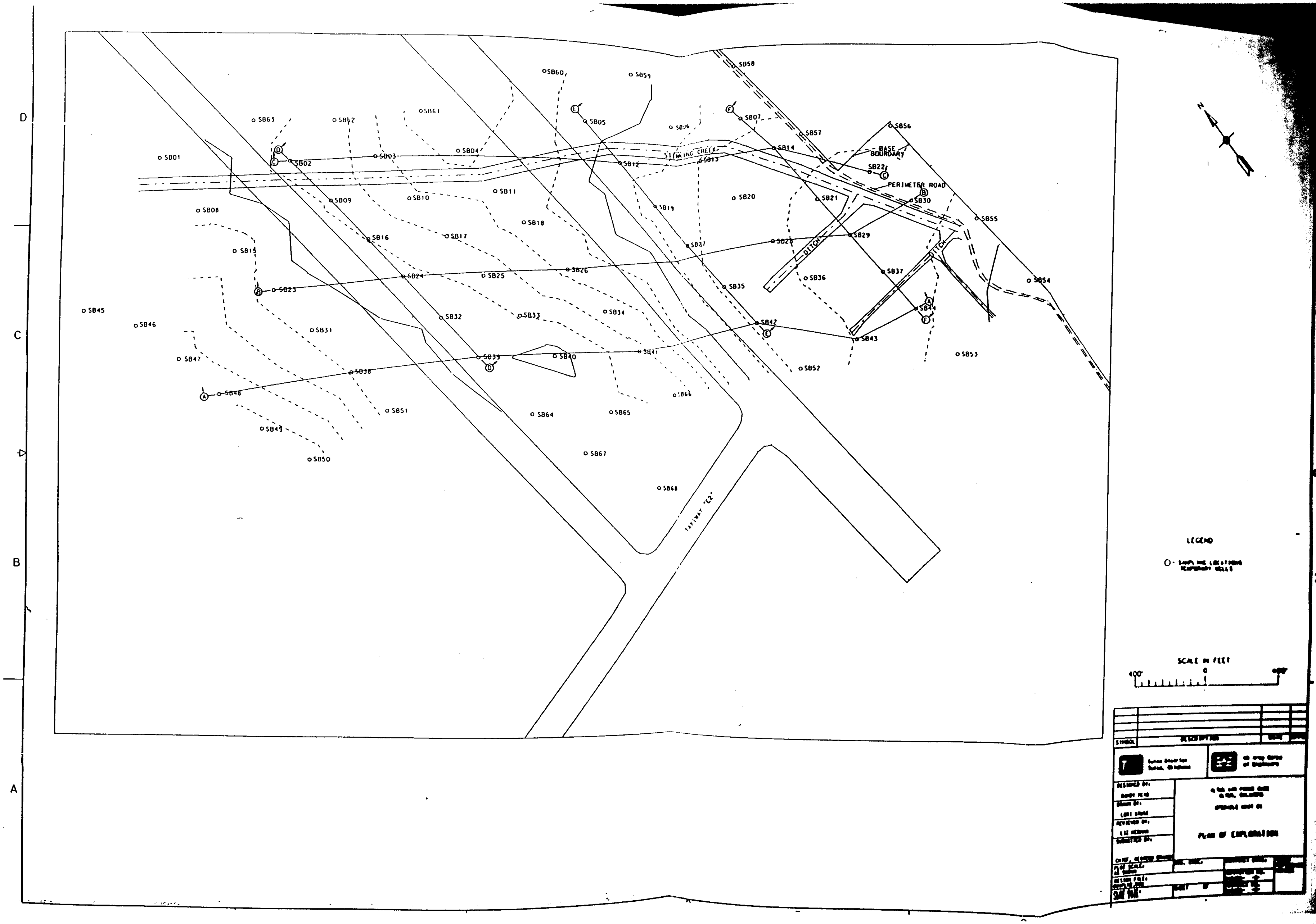
STATE COORDINATES:

EASTING (ft.) 0

NORTHING (ft.) 0

ELEVATION (ft.) 0

Project: Altus AFB


SB01
SB02
SB03
SB04
SB05
SB06
SB07
SB08
SB09
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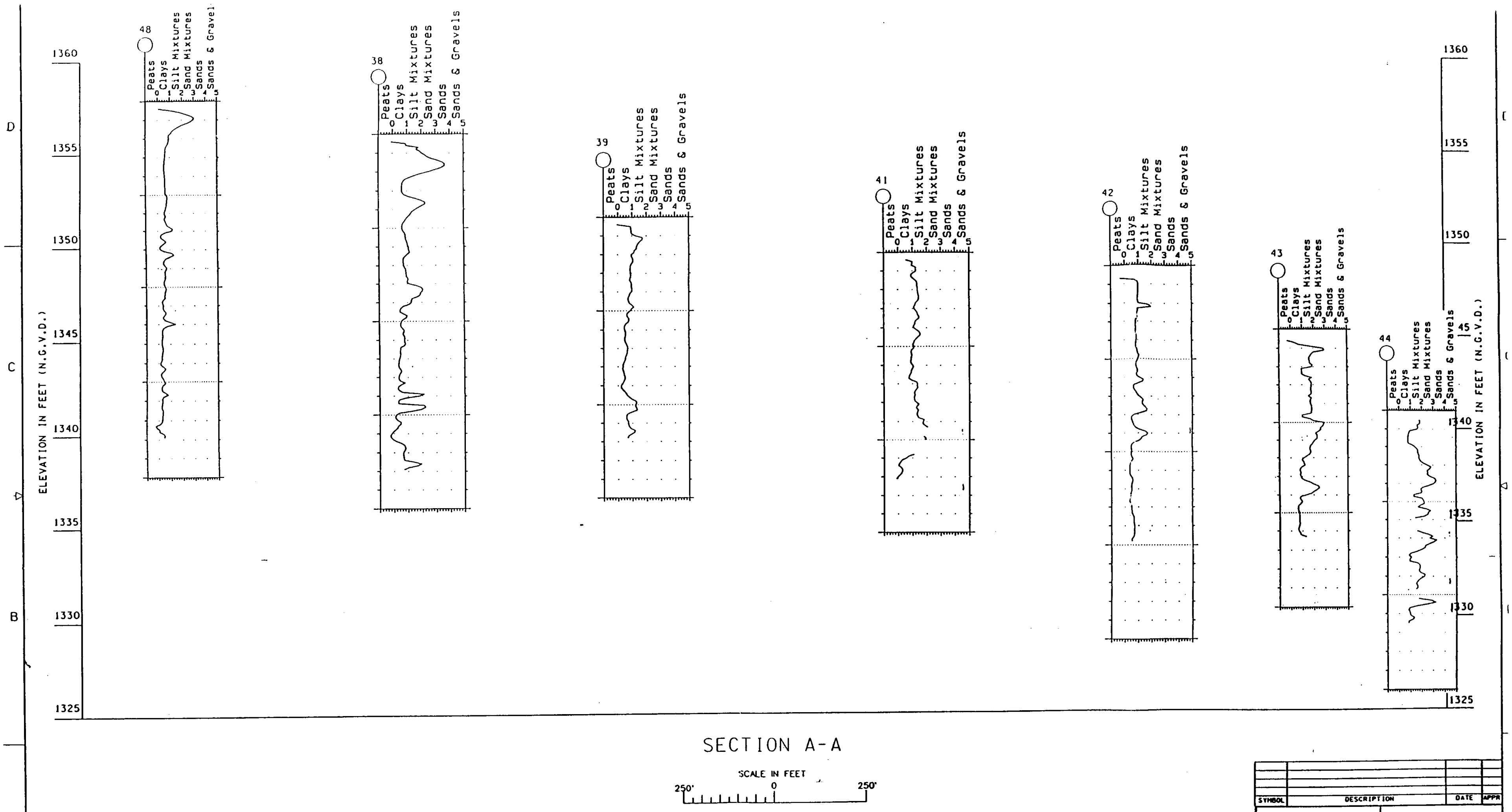
SB59
SB60
SB61
SB62
SB63
SB64
SB65
SB66
SB67
SB68
A
B
C
D
E
F
STINKING CREEK
DITCH
BASE BOUNDARY
PERIMETER ROAD
TAXIWAY "E2"
N
LEGEND
SCALE IN FEET
400'
0
SYMBOL
DESCRIPTION
DESIGNED BY:
DRAWN BY:
REVIEWED BY:
SUBMITTED BY:
PLAN OF EXPLORATION
SHEET
D
C
B
A



SECTION A-A

SYMBOL	DESCRIPTION	DATE	APPR

Tulsa District
Tulsa, Oklahoma

US Army Corps
of Engineers

DESIGNED BY:
RANDY HEAD
DRAWN BY:
LORI KRUSE
REVIEWED BY:
LIZ HERMAN
SUBMITTED BY:

CHIEF, GEOTECH BRANCH

ALTUS AIR FORCE BASE
ALTUS, OKLAHOMA

OPERABLE UNIT 01

GEOLOGICAL SECTION A-A

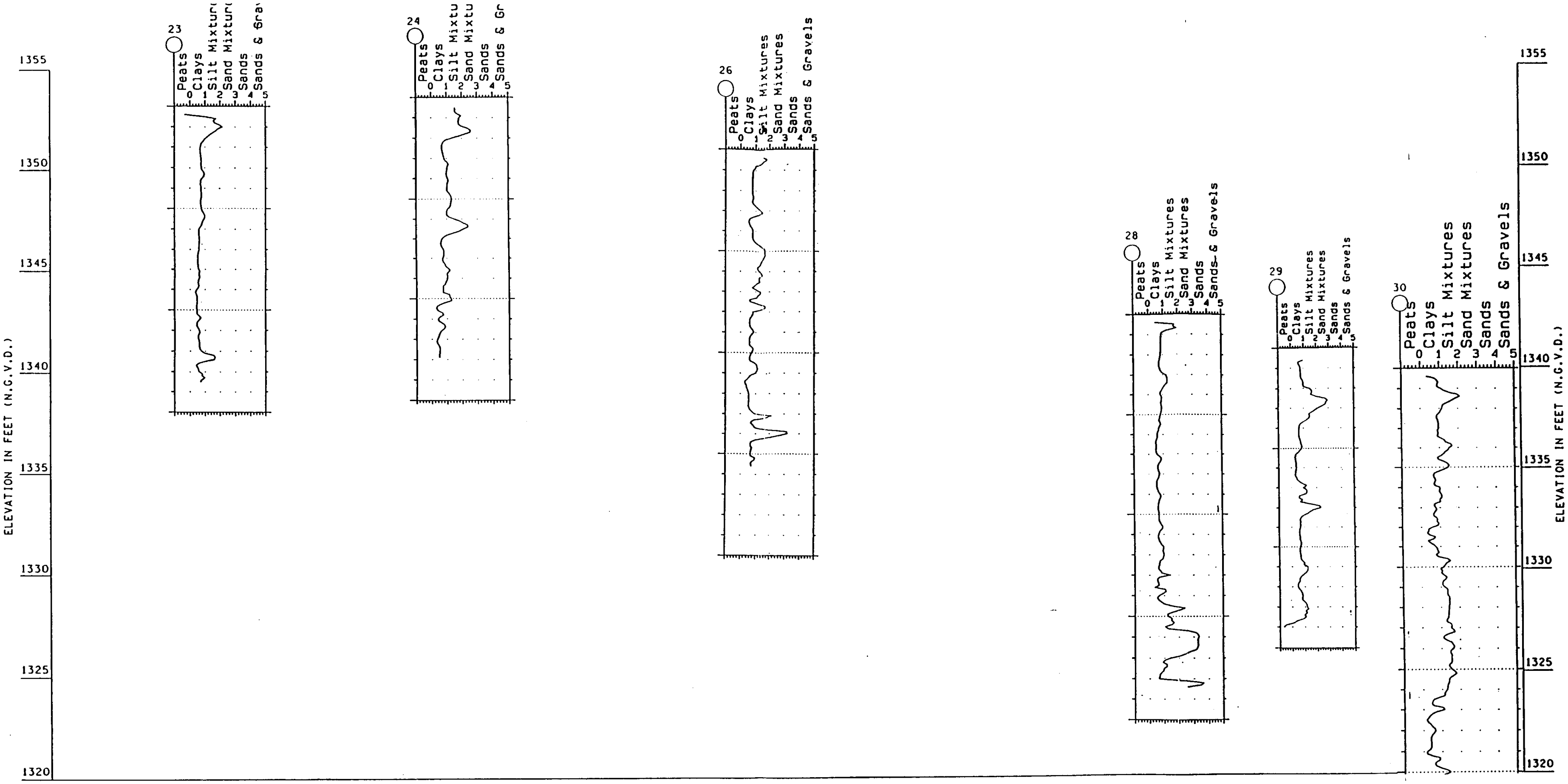
PLOT SCALE:
AS SHOWN
DESIGN FILE:
OU1SECT.DGN
PLOT DATE:
JUNE 1996

DWG. CODE:

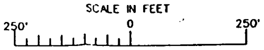
SHEET OF

CONTRACT DATE:
INVITATION NO.
DACA56- -B-
CONTRACT NO.
DACA56- -C-

SHEET
REFERENCE
NUMBER



SECTION B-B



SYMBOL	DESCRIPTION	DATE	APPR

Tulsa District
Tulsa, Oklahoma

US Army Corps
of Engineers

DESIGNED BY:
RANDY MEAD
DRAWN BY:
LORI KRUSE
REVIEWED BY:
LIZ HERMAN
SUBMITTED BY:

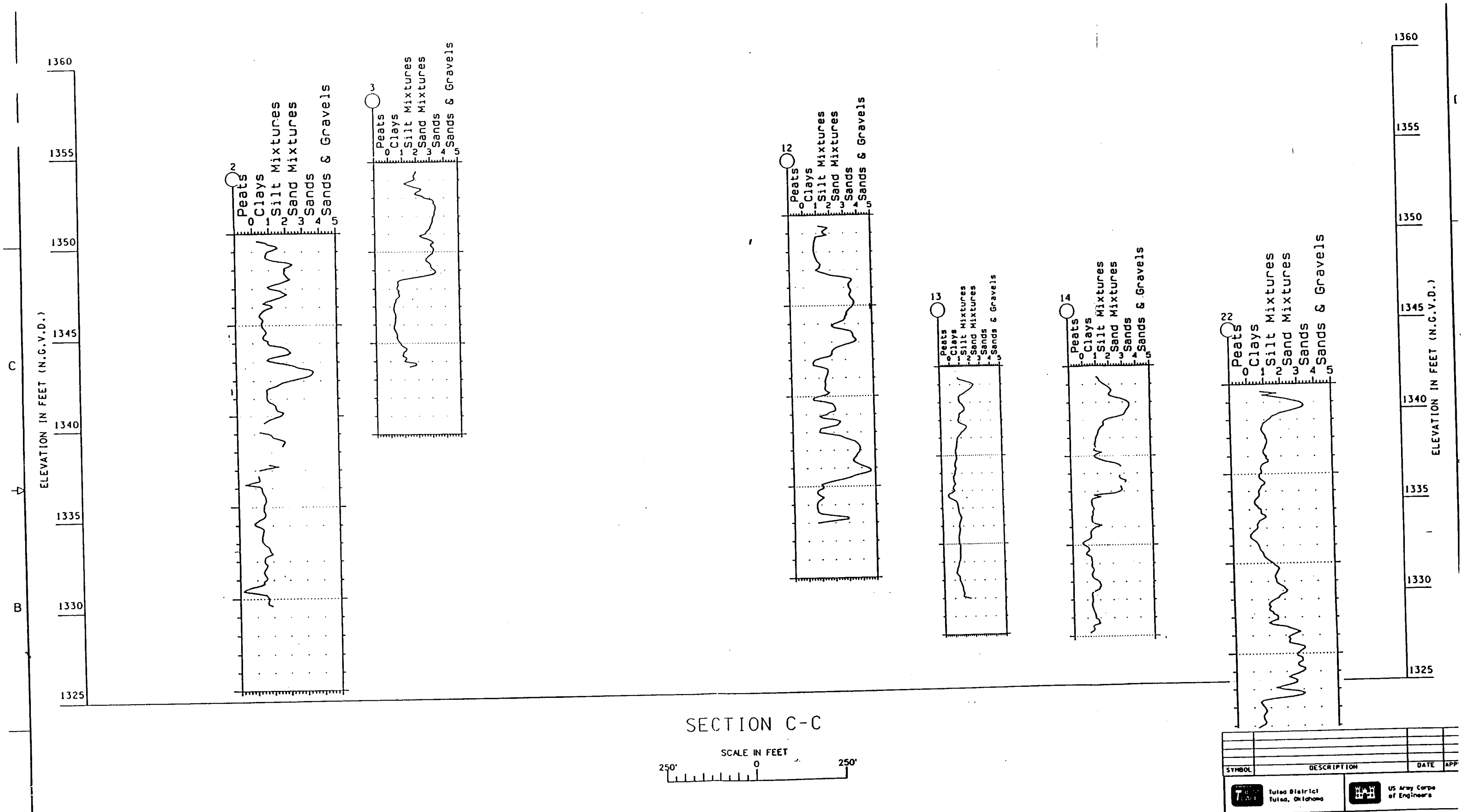
CHIEF, GEOTECH BRANCH

ALTUS AIR FORCE BASE
ALTUS, OKLAHOMA

OPERABLE UNIT 01

GEOLOGICAL SECTION B-B

PLOT SCALE:
AS SHOWN
DWG. CODE:
CONTRACT DATE:
SHEET REFERENCE NUMBER
DESIGN FILE:
OU1SECT.DGN
INVITATION NO.
DACA56- -B-
PLOT DATE:
JUNE 1996
SHEET OF
CONTRACT NO.
DACA56- -C-



SECTION C-C

SYMBOL	DESCRIPTION	DATE	APP

Tulsa District
Tulsa, Oklahoma

US Army Corps
of Engineers

DESIGNED BY:
RANDY MEAD
DRAWN BY:
LORI KRUSE
REVIEWED BY:
LIZ HERMAN
SUBMITTED BY:

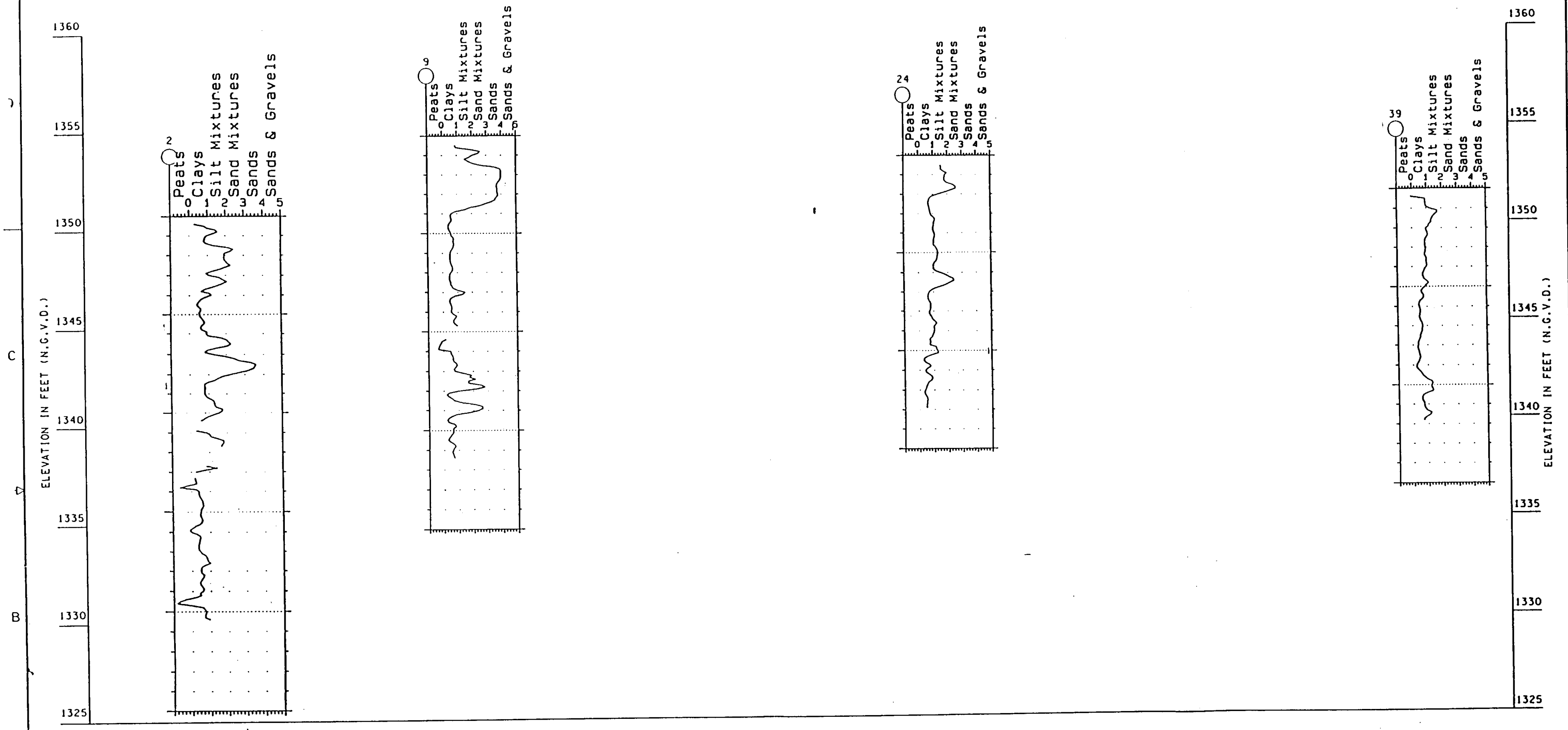
CHIEF, GEOTECH BRANCH

ALTUS AIR FORCE BASE
ALTUS, OKLAHOMA

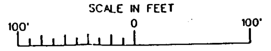
OPERABLE UNIT 01

GEOLOGICAL SECTION C-C

PLOT SCALE:
AS SHOWN
DWG. CODE:
CONTRACT DATE:
SHEET
REFEREN
NUMBER
DESIGN FILE:
OU1SECT.DGN
INVITATION NO.
DACA56- -B-
PLOT DATE:
JUNE 1996
SHEET OF
CONTRACT NO.
DACA56- -C-



SECTION D-D



SYMBOL	DESCRIPTION	DATE	APPR

Tulsa District
Tulsa, Oklahoma

US Army Corps
of Engineers

DESIGNED BY:
RANDY MEAD
DRAWN BY:
LORI KRUSE
REVIEWED BY:
LIZ HERMAN
SUBMITTED BY:

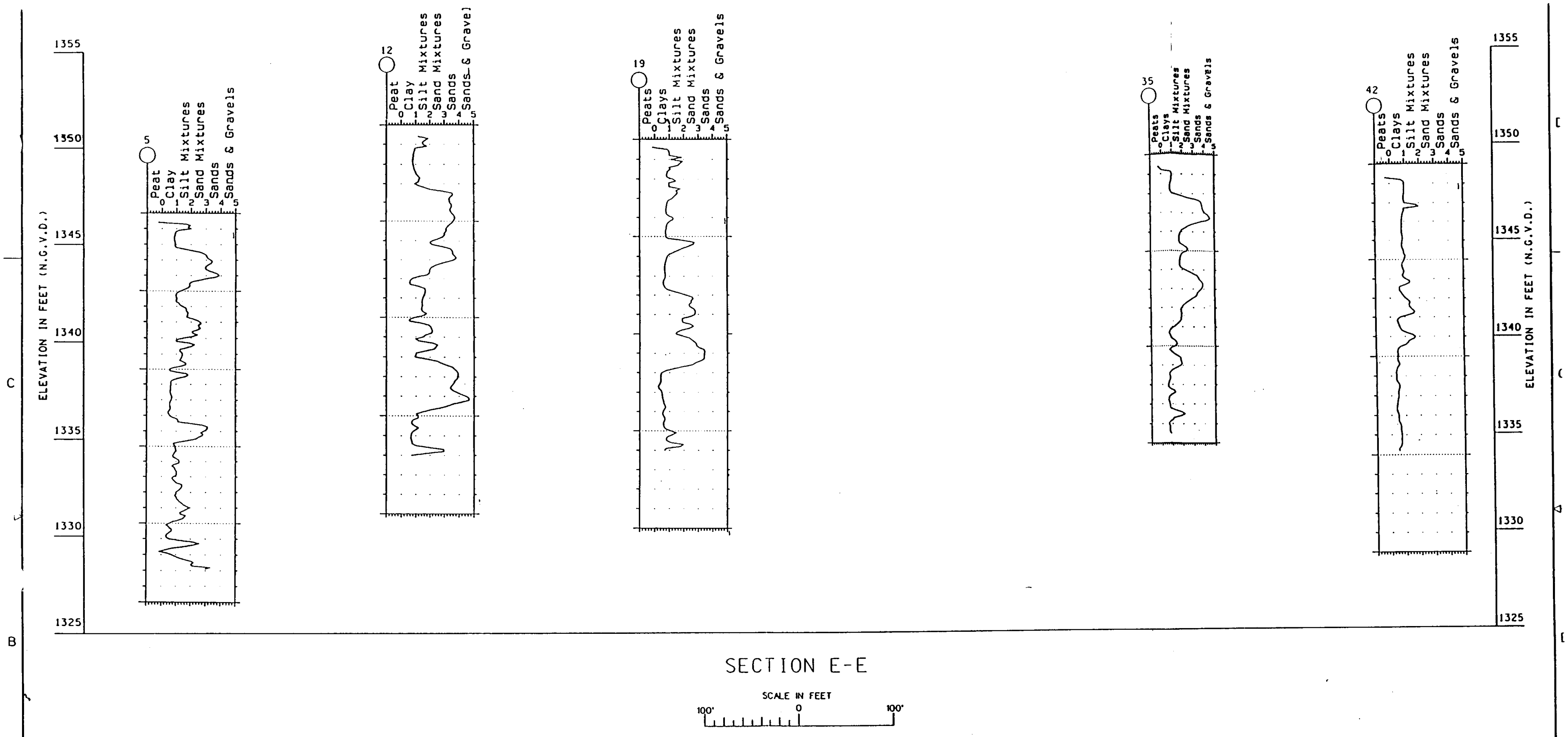
CHIEF, GEOTECH BRANCH

ALTUS AIR FORCE BASE
ALTUS, OKLAHOMA

OPERABLE UNIT 01

GEOLOGICAL SECTION D-D

PLOT SCALE:
AS SHOWN
DWG. CODE:
CONTRACT DATE:
SHEET REFERENCE NUMBER
DESIGN FILE:
OU1SECT.DGN
INVITATION NO.
DACA56- -B-
PLOT DATE:
JUNE 1996
SHEET OF
CONTRACT NO.
DACA56- -C-



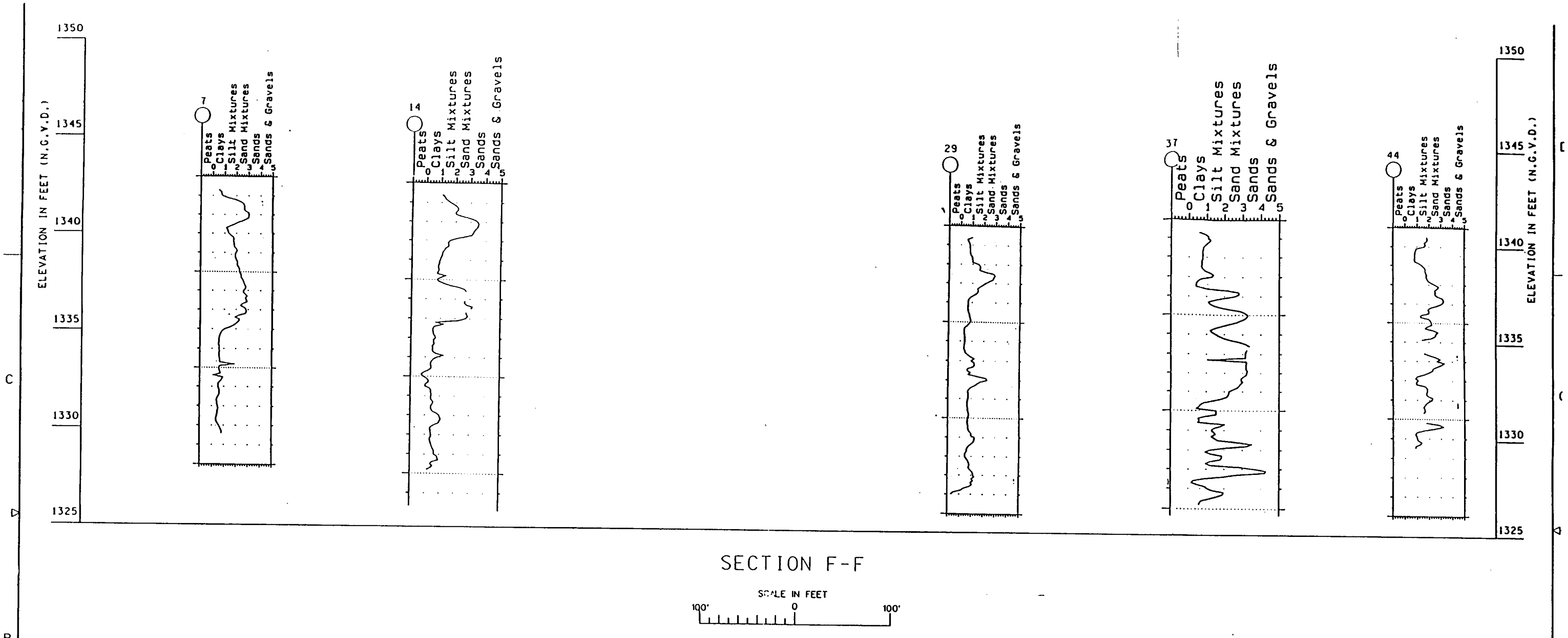
SECTION E-E

SYMBOL	DESCRIPTION	DATE	APPR

Tulsa District
Tulsa, Oklahoma

US Army Corps
of Engineers

DESIGNED BY: RANDY HEAD	ALTUS AIR FORCE BASE ALTUS, OKLAHOMA OPERABLE UNIT 01 GEOLOGICAL SECTION E-E		
DRAWN BY: LORI KRUSE			
REVIEWED BY: LIZ HERMAN			
SUBMITTED BY: CHIEF, GEOTECH BRANCH			
PLOT SCALE: AS SHOWN	DWG. CODE:	CONTRACT DATE:	SHEET REFERENCE NUMBER
DESIGN FILE: OU1SECT.DGN		INVITATION NO. DACA56- -B-	
PLOT DATE: JUNE 1996	SHEET OF	CONTRACT NO. DACA56- -C-	



SECTION F-F

SYMBOL	DESCRIPTION	DATE	APPR

Tulsa District
Tulsa, Oklahoma

US Army Corps
of Engineers

DESIGNED BY:
RANDY MEAD
DRAWN BY:
LORI KRUSE
REVIEWED BY:
LIZ NERMAN
SUBMITTED BY:

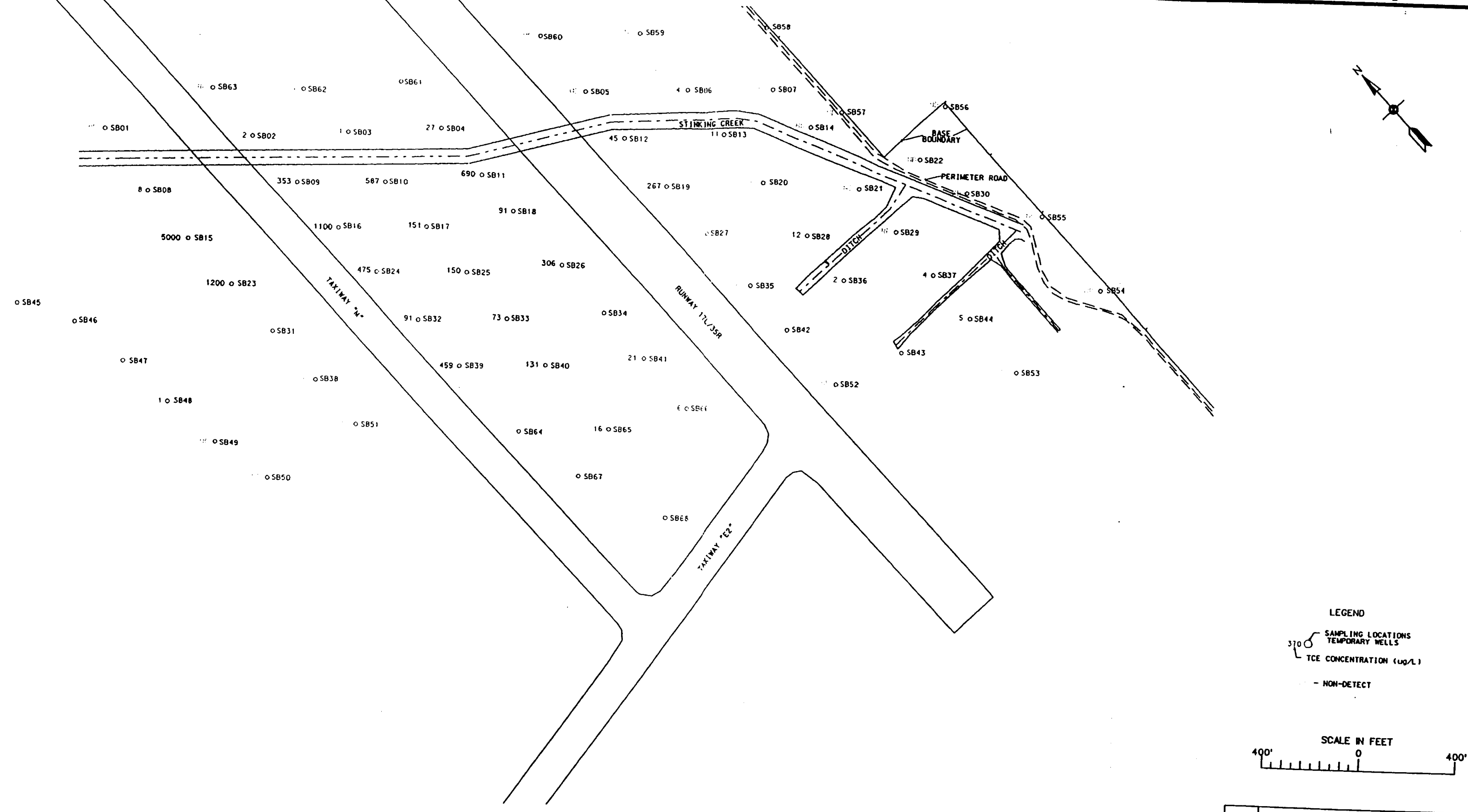
CHIEF, GEOTECH BRANCH

ALTUS AIR FORCE BASE
ALTUS, OKLAHOMA

OPERABLE UNIT 01

GEOLOGICAL SECTION F-F

PLOT SCALE: AS SHOWN	DWG. CODE:	CONTRACT DATE:	SHEET REFERENCE NUMBER
DESIGN FILE: OUISECT.DGN		INVITATION NO. DACA56- -B-	
PLOT DATE: JUNE 1996	SHEET OF	CONTRACT NO. DACA56-	



SYMBOL	DESCRIPTION	DATE	APPR

TULSA DISTRICT
TULSA, OKLAHOMA

US ARMY CORPS
OF ENGINEERS

DESIGNED BY: RANDY HEAD
DRAWN BY: R. HEAD/L. KRUSE
REVIEWED BY: LIZ HERMAN
SUBMITTED BY:
CHIEF, GEOTECH BRANCH

ALTUS AIR FORCE BASE
ALTUS, OKLAHOMA

OPERABLE UNIT #1

FIGURE 4.3
TCE CONCENTRATION MAP

PLOT SCALE: AS SHOWN
DWG. CODE:
CONTRACT DATE:
SHEET REFERENCE NUMBER
DESIGN FILE: OU1TCE.DGN
INVITATION NO. DACA56- -B-
PLOT DATE:
SHEET OF
CONTRACT NO.

APPENDIX B

GEOLOGIC LOGS; MONITORING POINT/WELL INSTALLATION, DEVELOPMENT, AND SAMPLING RECORDS; SURVEY DATA; AND SLUG TEST ANALYSIS RESULTS

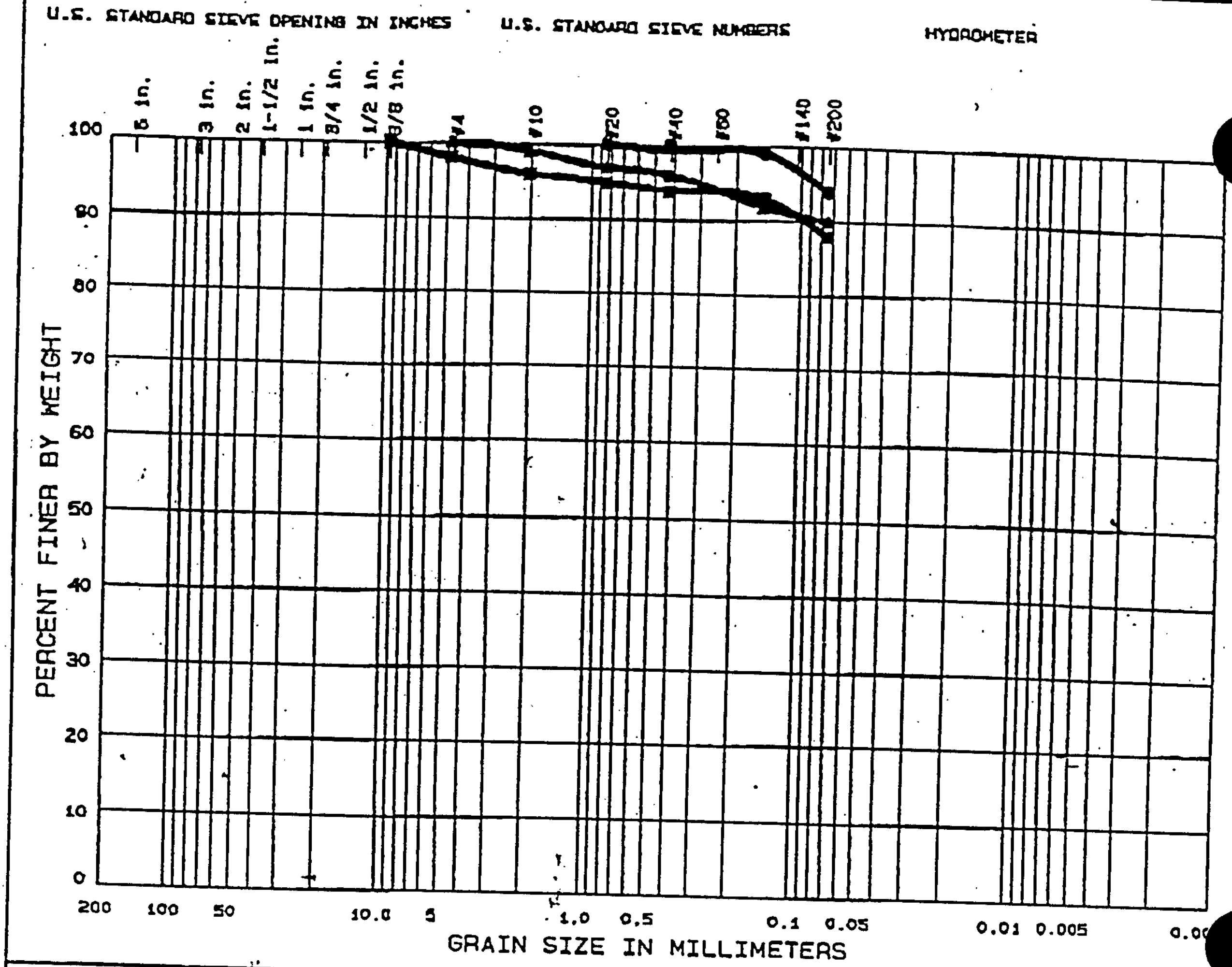
HOLE NO. OU01-15

DRILLING LOG	DIVISION SOUTHWEST	INSTALLATION ALTUS AFB	SHEET 1 OF 1 SHEETS
1. PROJECT OPERABLE UNIT 01		10. SIZE AND TYPE OF BIT MOSTAP	
2. LOCATION (Coordinates or Station) 158397.00 486709.00		11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MSL	
3. DRILLING AGENCY COE-TULSA DISTRICT		12. MANUFACTURER'S DESIGNATION OF DRILL SCAPS	
4. HOLE NO. (As shown on drawing title and file number)	OU01-15	13. OVERBURDEN SAMPLES	DISTURBED / UNDISTURBED
5. NAME OF DRILLER JEFF LACQUEMENT		14. TOTAL NUMBER CORE BOXES	0
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.		15. ELEVATION GROUND WATER	7.0'
		16. DATE HOLE	STARTED 04/00/1996 / COMPLETED 04/00/1996
7. THICKNESS OF OVERBURDEN	11.0	17. ELEVATION TOP OF HOLE	1352.0
8. DEPTH DRILLED INTO ROCK	7.5	18. TOTAL CORE RECOVERY FOR BORING	0.0 %
9. TOTAL DEPTH OF HOLE	18.5	STEVE BREWER	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1347.0	2 4	▨	LEAN CLAY (CL) (0.0 - 5.0) WITH SAND, REDDISH BROWN, MOIST, ROOTS.			TYPE MOSTAP, ZONE 0.0- 18.5
1344.5	6	▨	LEAN CLAY (CL) (5.0 - 7.5) REDDISH BROWN, MOIST, CALCAREOUS, ROOTS.		J-1	
1341.0	8 10	▨	LEAN CLAY (CL) (7.5 - 11.0) REDDISH BROWN WITH LIGHT GRAY SPOTS, VERY MOIST, CALCAREOUS, GRAVELS TO 1/2".		J-2	
1339.4	12	≡	CLAY-SHALE (SH) (11.0 - 12.6) REDDISH BROWN WITH DARK GRAY, FREE WATER, CALCAREOUS, GRAVEL AND COARSE SNAD CONSISTS OF HARD SHALE FRAGMENTS.		J-3	
1335.3	14 16	≡	CLAY-SHALE (SH) (12.6 - 16.7) REDDISH BROWN WITH LIGHT GRAY TO REDDISH BROWN, VERY MOIST, SLIGHTLY CALCAREOUS TO NON-CALCAREOUS.		J-4 J-5 J-6	
1334.4		▧	GYPSUM (GY) (16.7 - 17.6) CRYSTALS TO 1 1/4".		J-7	
1333.5	18	≡	CLAY-SHALE (SH) (17.6 - 18.5) WEATHERED, REDDISH BROWN, MOIST, NON-CALCAREOUS, STRINGERS OF GYPSUM, SAND SIZES CONSISTS OF GYPSUM CRYSTALS.		J-8	
	20					

SAMPLE	DEPTH
J-1	5.0- 6.5
J-2	8.5- 10.0
J-3	11.5- 12.6
J-4	12.6- 13.0
J-5	14.5- 15.0
J-6	15.0- 16.0
J-7	17.4- 17.6
J-8	17.6- 18.5

PROJECT OPERABLE UNIT 01 | HOLE NO. OU01-15



	% COBBLES	% GRAVEL	% SAND	% SILT OR CLAY
●	0.0	0.0	6.0	94.0
▲	0.0	0.0	10.0	90.0
■	0.0	2.0	10.0	88.0

	Sample No.	Elev or Depth	Nat W%	LL	PL	PI	C_c	C_u
●	96/1390	5.0-6.5	19.6	28	14	14		
▲	96/1391	8.5-10.0	23.6	38	20	18		
■	96/1392	11.5-12.6	28.7	33	18	15		

CLASSIFICATION

● LEAN CLAY (CL)

▲ LEAN CLAY (CL)

■ CLAY-SHALE/SHALE

Remarks:

Project ALTUS AFB

Area

Lab No. CESWD-ETE-GL RPT No. 16555

Boring No. OU-01 15

Date JUNE 1996

GRADATION CURVES

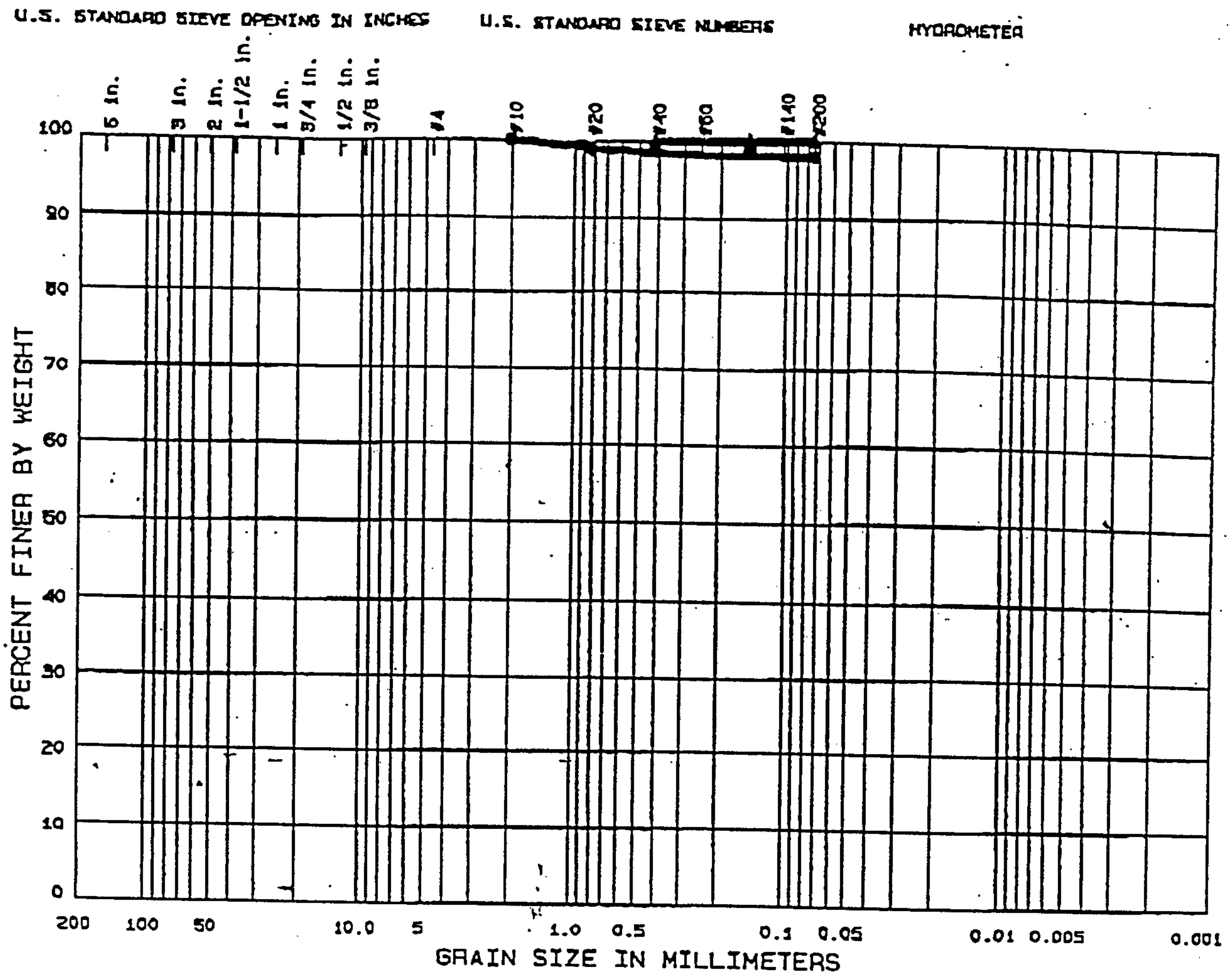
W.O. No.

Req. No.

Contract No.

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

W.O. No.
Req. No.
Contract No.



	% COBBLES	% GRAVEL	% SAND	% SILT OR CLAY
●	0.0	0.0	2.0	98.0
▲	0.0	0.0	0.0	100.0

	Sample No.	Elev or Depth	Nat W%	LL	PL	PI	C_c	C_u
●	96/1393	12.6-13.0	20.3	34	19	15		
▲	96/1394	14.5-15.0	24.4	38	19	19		

CLASSIFICATION

● LEAN CLAY (CL)

▲ LEAN CLAY (CL)

Remarks:

Project ALTUS AFB

Area

Lab No. CESWD-ETE-GL RPT No. 16555

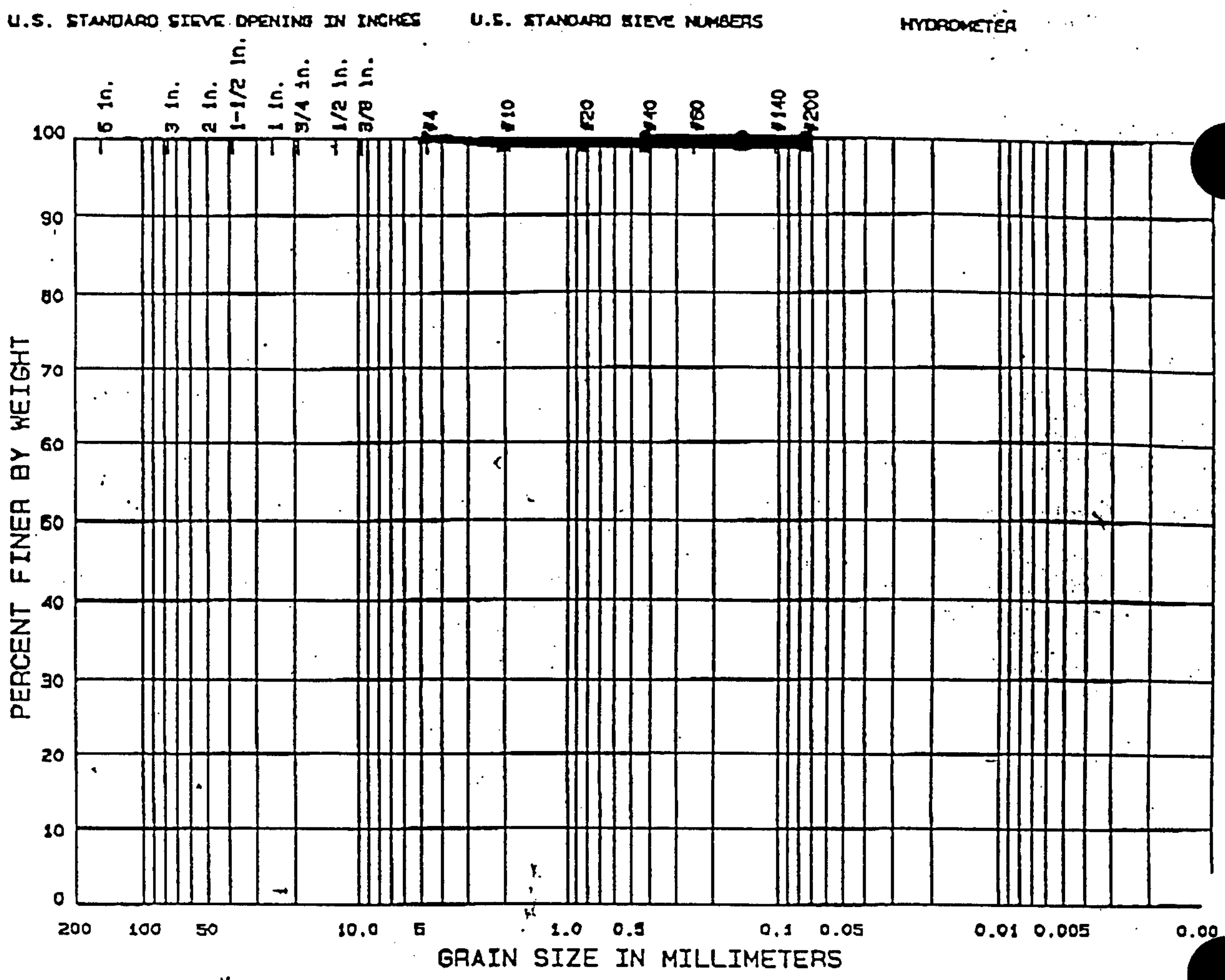
Boring No. OU-01 15

Date JUNE 1996

GRADATION CURVES

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

W.O. No.
Req. No.
Contract No.



% COBBLES		% GRAVEL	% SAND	% SILT OR CLAY
●	0.0	0.0	0.0	100.0
▲	0.0	0.0	1.0	99.0

	Sample No.	Elev or Depth	Nat W%	LL	PL	PI	C_c	C_u
●	96/1395	15.0-16.0	25.1	44	23	21		
▲	96/1397	17.6-18.5	15.5	47	25	22		

CLASSIFICATION

● LEAN CLAY (CL)

▲ SHALE

Remarks:

Project ALTUS AFB

Lab No. CESWD-ETE-GL RPT No. 16555

Area

Boring No. OU-01 15

Date JUNE 1996

GRADATION CURVES

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

HOLE NO. OU01-16

DRILLING LOG	DIVISION SOUTHWEST	INSTALLATION ALTUS AFB	SHEET 1 OF 1 SHEETS

1. PROJECT OPERABLE UNIT 01
2. LOCATION (Coordinates or Station) 1588881.00 486315.00
3. DRILLING AGENCY COE-TULSA DISTRICT
4. HOLE NO. (As shown on drawing title and file number) OU01-16
5. NAME OF DRILLER JEFF LACQUEMENT
6. DIRECTION OF HOLE ☑ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN 12.5
8. DEPTH DRILLED INTO ROCK 3.5
9. TOTAL DEPTH OF HOLE 16.0
10. SIZE AND TYPE OF BIT MOSTAP
11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MSL
12. MANUFACTURER'S DESIGNATION OF DRILL SCAPS
13. OVERBURDEN SAMPLES DISTURBED UNDISTURBED
14. TOTAL NUMBER CORE BOXES 0
15. ELEVATION GROUND WATER 10.9'
16. DATE HOLE STARTED 04/00/1996 COMPLETED 04/00/1996
17. ELEVATION TOP OF HOLE 1354.1
18. TOTAL CORE RECOVERY FOR BORING 0.0 %

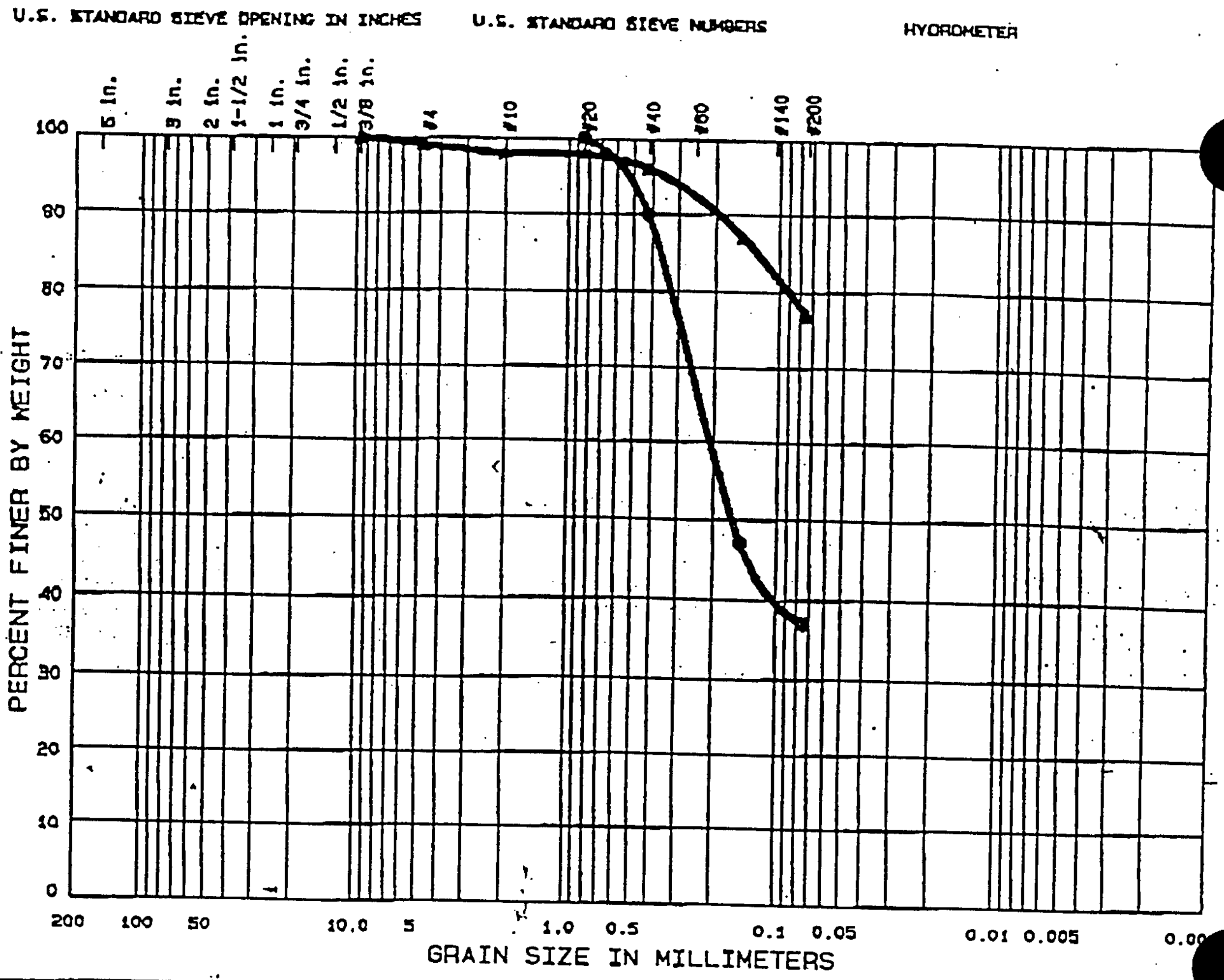
STEVE BREWER

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1349.1	2 4	○ ○ ○	SAND (SM) (0.0 - 5.0) SILTY, BROWN, MOIST, NON-CALCAREOUS, ROOTS.		J-1	TYPE MOSTAP ZONE 0.0- 16.0 SAMPLE DEPTH J-1 1.9- 3.0 J-2 7.0- 7.4 J-3 14.8- 15.0 J-4 15.0- 15.9
1341.6	6 8 10 12	▨	LEAN CLAY (CL) (5.0 - 12.5) WITH SAND, REDDISH BROWN WITH YELLOW, MOIST, CALCAREOUS WITH CALCAREOUS NODULES.		J-2	
1339.1	14	— —	CLAY-SHALE (SH) (12.5 - 15.0) REDDISH BROWN WITH LIGHT GRAY, MOIST, NON-CALCAREOUS, SAND SIZES CONSISTS OF HARD OLIVE-GRAY SILT FRAGMENTS.		J-3	
1338.1	16	— —	CLAY-SHALE (SH) (15.0 - 16.0) REDDISH BROWN, MOIST, CALCAREOUS WITH CALCAREOUS NODULES,SCATTERED BLACK STAINS		J-4	
	18 20					

PROJECT OPERABLE UNIT 01 HOLE NO. OU01-16

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

W.O. No.
Req. No.
Contract No.



	% COBBLES	% GRAVEL	% SAND	% SILT OR CLAY
●	0.0	0.0	63.0	37.0
▲	0.0	1.0	22.0	77.0

	Sample No.	Elev or Depth	Nat W%	LL	PL	PI	C_c	C_u
●	96/1398	1.9-3.0	4.0	18	17	1		
▲	96/1399	7.0-7.4	13.4	30	12	18		

CLASSIFICATION

● SILTY SAND (SM)

▲ LEAN CLAY WITH SAND (CL)

Remarks:

Project ALTUS AFB

Lab No. CESWD-ETE-GL RPT No. 16555

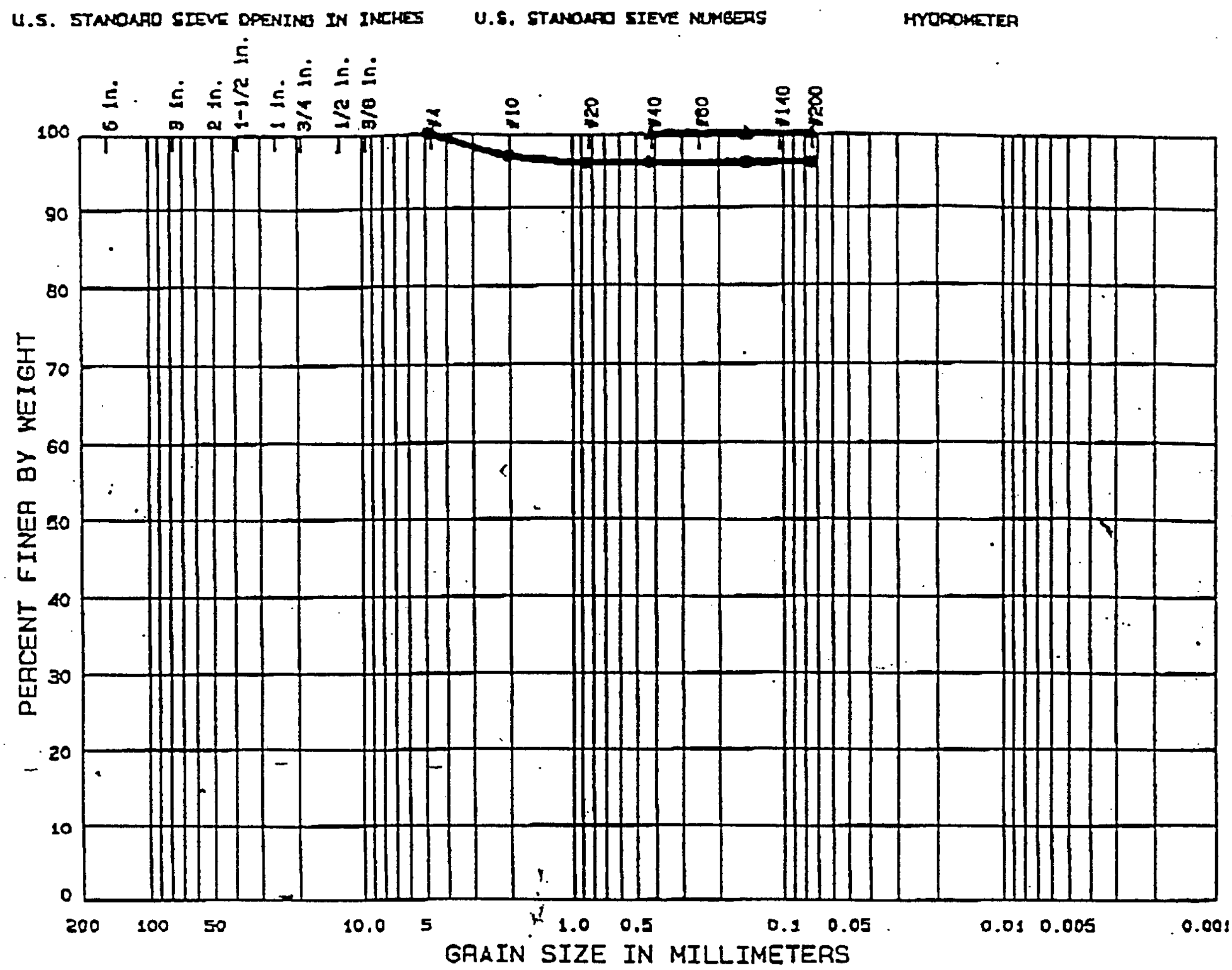
Area

Boring No. OU-01 16

Date JUNE 1996

GRADATION CURVES

W.O. No.
Req. No.
Contract No.



	% COBBLES	% GRAVEL	% SAND	% SILT OR CLAY
●	0.0	0.0	4.0	96.0
▲	0.0	0.0	0.0	100.0

	Sample No.	Elev or Depth	Nat W%	LL	PL	PI	C_c	C_u
●	96/1400	14.8-15.0	16.2					
▲	96/1401	15.0-15.9	19.9	46	23	23		

CLASSIFICATION

● CLAY-SHALE

▲ CLAY-SHALE

Remarks:

Project ALTUS AFB

Lab No. CESWD-ETE-GL RPT No. 16555

Area

Boring No. OU-01 16

Date JUNE 1996

GRADATION CURVES

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

HOLE NO. OU01-19

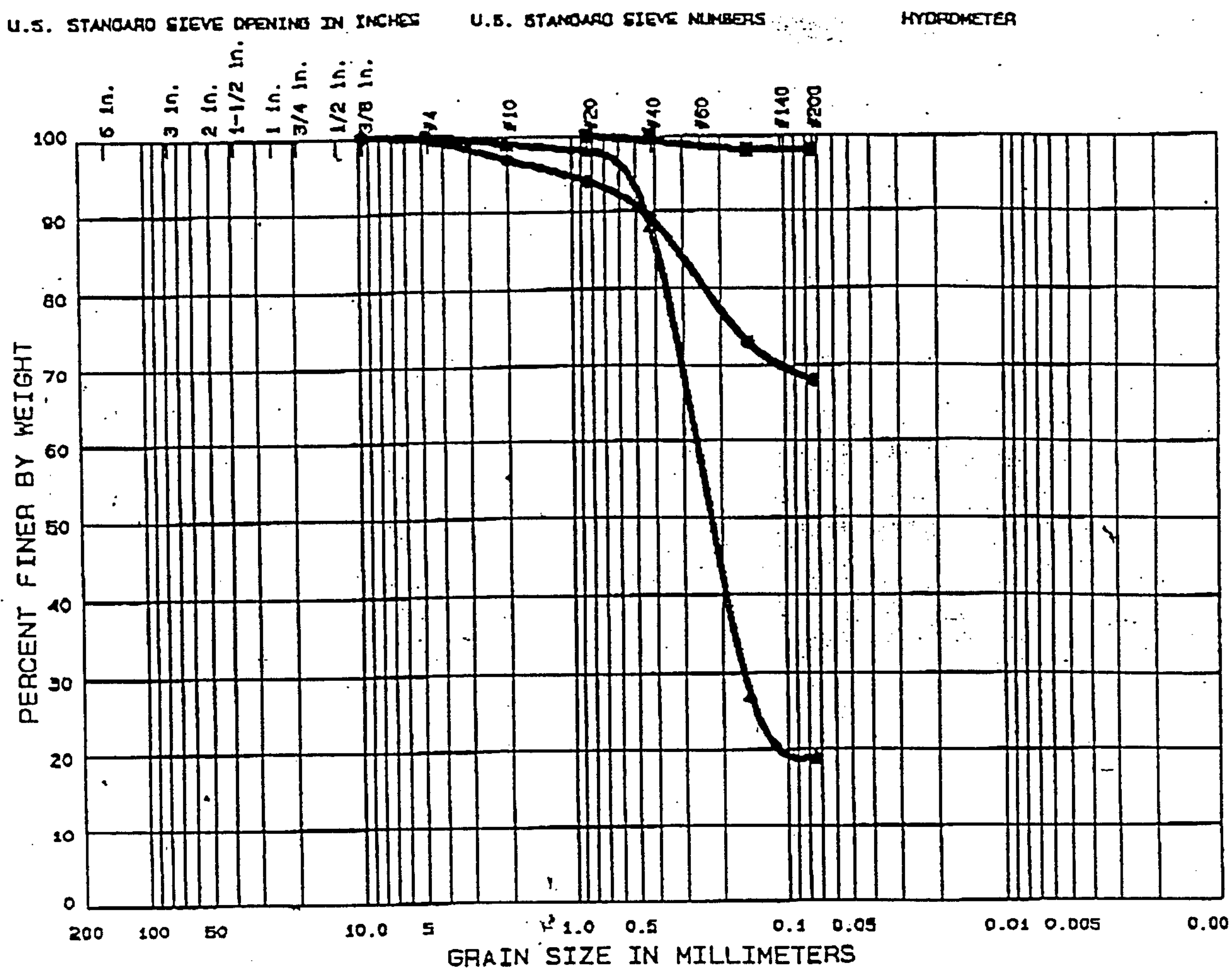
DRILLING LOG	DIVISION SOUTHWEST	INSTALLATION ALTUS AFB	SHEET 1 OF 1 SHEETS
1. PROJECT OPERABLE UNIT 01		10. SIZE AND TYPE OF BIT MOSTAP	
2. LOCATION (Coordinates or Station) 1589991.00 485510.00		11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MSL	
3. DRILLING AGENCY COE-TULSA DISTRICT		12. MANUFACTURER'S DESIGNATION OF DRILL SCAPS	
4. HOLE NO. (As shown on drawing title and file number)	OU01-19	13. OVERBURDEN SAMPLES	DISTURBED / UNDISTURBED
5. NAME OF DRILLER JEFF LACQUEMENT		14. TOTAL NUMBER CORE BOXES	0
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.		15. ELEVATION GROUND WATER 12.6'	
		16. DATE HOLE	STARTED 04/00/1996 COMPLETED 04/00/1996
7. THICKNESS OF OVERBURDEN 14.5		17. ELEVATION TOP OF HOLE	1350.5
8. DEPTH DRILLED INTO ROCK 5.5		18. TOTAL CORE RECOVERY FOR BORING	0.0 %
9. TOTAL DEPTH OF HOLE 20.0		STEVE BREWER	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
1343.0	2 4 6	▨	LEAN CLAY (CL) (0.0 - 7.5) SANDY, REDDISH BROWN WITH YELLOW, MOIST, CALCAREOUS WITH CALCAREOUS NODULES, SOME GYPSUM CRYSTALS.		J-1	TYPE MOSTAP ZONE 0.0- 20.0 SAMPLE DEPTH J-1 6.0- 7.5 J-2 10.5- 11.5 J-3 11.5- 12.5 J-4 17.0- 18.4 J-5 19.1- 19.6
1339.0	8 10	○	SAND (SC) (7.5 - 11.5) CLAYEY, REDDISH BROWN, VERY MOIST, VERY SILTY, CALCAREOUS.		J-2	
1336.0	12 14	▨	LEAN CLAY (CL) (11.5 - 14.5) REDDISH BROWN WITH LIGHT GRAY SPOTS, VERY MOIST, CALCAREOUS, SOME GYPSUM CRYSTALS.		J-3	
1332.0	16 18	☰	CLAY-SHALE (SH) (14.5 - 18.5) REDDISH BROWN WITH LIGHT GRAY SPOTS, MOIST, CALCAREOUS, SCATTERED BLACK STAINS, SOME SAND.		J-4	
1330.5	20	☰	CLAY-SHALE (SH) (18.5 - 20.0) WEATHERED, REDDISH BROWN, MOSIT, CALCAREOUS, SAND-SIZES CONSISTS OF HARD SHALE PARTICLES.		J-5	

PROJECT	HOLE NO.
OPERABLE UNIT 01	OU01-19

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

W.O. No.
Req. No.
Contract No.



% COBBLES	% GRAVEL	% SAND	% SILT OR CLAY
● 0.0	0.5	31.5	68.0
▲ 0.0	0.0	81.0	19.0
■ 0.0	0.0	2.0	98.0

	Sample No.	Elev or Depth	Nat W%	LL	PL	PI	C_c	C_u
●	96/1402	6.0-7.5	11.6	30	12	18		
▲	96/1403	10.5-11.5	14.9	19	10	9		
■	96/1404	11.2-12.5	22.4	47	22	25		

CLASSIFICATION

● SANDY LEAN CLAY (CL)

▲ CLAYEY SAND (SC)

■ LEAN CLAY (CL)

Remarks:

Project ALTUS AFB

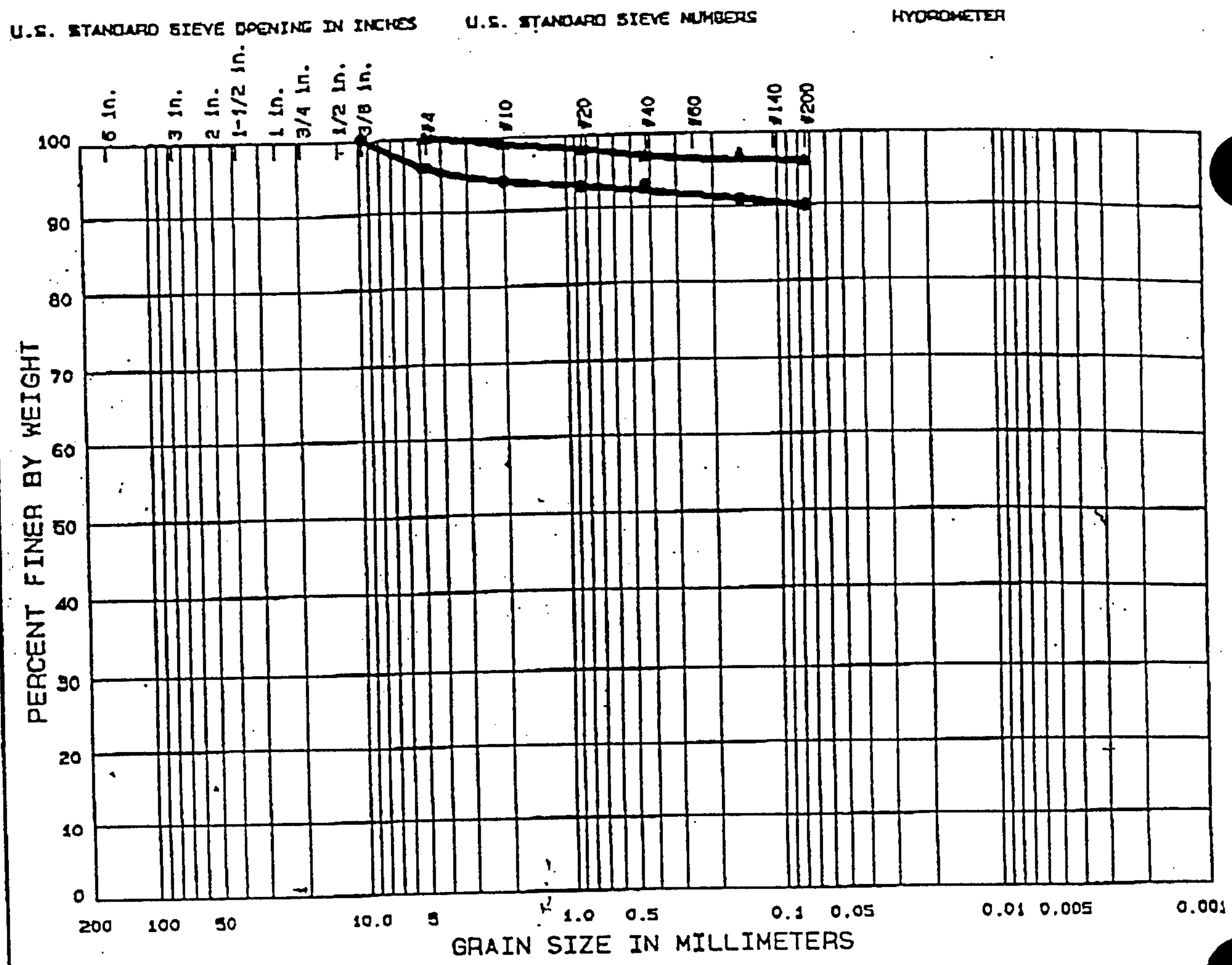
Lab No. CESWD-ETE-GL RPT No. 16555

Area

Boring No. OU-01 19 Date JUNE 1996

GRADATION CURVES

W.O. No.
Req. No.
Contract No.



%	COBBLES	% GRAVEL	% SAND	% SILT OR CLAY
●	0.0	4.0	6.0	90.0
▲	0.0	0.0	4.0	96.0

	Sample No.	Elev or Depth	Nat W%	LL	PL	PI	C_c	C_u
●	96/1405	17.0-18.4	17.3	37	20	17		
▲	96/1406	19.1-19.6	13.6	33	18	15		

CLASSIFICATION

● CLAY-SHALE/SHALE

▲ SHALE

Remarks:

Project ALTUS AFB

Lab No. CESWD-ETE-GL RPT No. 16555

Area

Boring No. OU-01 19

Date JUNE 1996

GRADATION CURVES

DEPARTMENT OF THE ARMY, SOUTHWESTERN DIVISION LABORATORY
CORPS OF ENGINEERS, 4815 CASS STREET, DALLAS, TX 75235

GEOLOGIC BORING LOG

BORING NO.: TW1
CLIENT: AFCEE
OB NO.: 722450360[illegible]
OCATION: Altus AFB
OLOGIST: RN/CM
ENTS:

CONTRACTOR: EDA
RIG TYPE: Geoprobe
DRLG METHOD: Geoprobe
BORING DIA.: 2.25"
DRLG FLUID: None

DATE SPUD: 4/14 245pm
DATE CMPL: 4/15/97
ELEVATION:
TEMP: 55°
WEATHER: ~~55°~~ Windy, sunny

Elev (ft)	Depth (ft)	Profile	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Pend Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1											
			CL	red-brown silty CLAY trace quartz sand (med grained)		3.5' bgs			13.0			
	5											
			ML	red-brown clayey SILT (gradational change from clay to silt from 5.5' to 6.5' bgs)		7' bgs			15.6			
	10					10' bgs			3.6			
						12' bgs			3.4			
						13.5'			3.5			
	15											
				BoH ~16' bgs								
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

FIGURE 3.3

GEOLOGIC BORING LOG

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

GEOLOGIC BORING LOG

BORING NO.: TW2
CLIENT: AFCEE
JOB NO.: 722450.36020
LOCATION: Altus AFB OU1
GEOLOGIST: CM
COMENTS:

CONTRACTOR: EPA
RIG TYPE: Geoprobe
DRLG METHOD: Geoprobe
BORING DIA.: 2.25"
DRLG FLUID: none

DATE SPUD: 4/15/97
DATE CMPL: 4/15/97
ELEVATION:
TEMP: 65°F
WEATHER: Sunny, breezy

Elev (ft)	Depth (ft)	Profile	USCS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Pend Res	PID (ppm)	TLV (ppm)	TOTAL BTEX (ppm)	TPH (ppm)
	1		OL	dark brown SILT		1' bgs			6.5			
			ML	red-brown clayey SILT		3' bgs			4.7			
	5		CL	gradational change to red-brown silty CLAY		5' bgs			3.1			
						7' bgs			3.4			
	10		SM	red silty fine gr. SAND								
						13.5'			5.8			
	15			very hard - top of red clay (weathered shale??) or shale itself... no core collected								
				BCH ~ 14' bgs								
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

FIGURE 3.3

GEOLOGIC BORING LOG

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

GEOLOGIC BORING LOG

BORING NO.: TW3
CONTRACTOR: USEPA
DATE SPUD: 4/15/97
CLIENT: AFCEE
RIG TYPE: Geoprobe
DATE CMPL.: 4/15/97
OB NO.: 722450.36020
DRLG METHOD: Geoprobe
ELEVATION:
LOCATION: Altus AFB OU1
BORING DIA.: 2.25"
TEMP: 65°F
LOGIST: CM
DRLG FLUID: none
WEATHER: sunny, breezy
ENTS:

Elev (ft)	Depth (ft)	Profile	USCS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Pand Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1											
			ML	mottled red and brown clayey SILT			2'		4.2			
							4'		5.4			
	5											
			OL	dark brown SILT			6'		5.2			
			CL	red-brown silty CLAY			8'		5.6			
	10											
			CL	brown sandy CLAY			10'		5.3			
			SC	sand is fine to med grained brown clayey SAND			12'		5.4			
				BOH ~13' bgs								
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

Water level drilled

FIGURE 3.3

GEOLOGIC BORING LOG

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

GEOLOGIC BORING LOG

BORING NO.: TW7
CLIENT: AFCEE
JOB NO.: 722450.36020
LOCATION: Altus AFB OU1
GEOLOGIST: Cindy Merrill
COMENTS:

CONTRACTOR: USEPA
RIG TYPE: GEOPROBE
DRLG METHOD: GEOPROBE W/CORES
BORING DIA.: 2.25"
DRLG FLUID: none

DATE SPUD: 4/10/97
DATE CMPL.: 4/10/97
ELEVATION: ?
TEMP: 50°F
WEATHER: overcast

Elev (ft)	Depth (ft)	Profile	USCS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Pend Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1											
			CL	red-brown silty CLAY	S1	3.5'			8.2			
	5											
			SM	light brown silty qtz SAND	S2	6.5'			10.1			
	10											
			CH	stiff, very hard red-brown CLAY	S3	11.5'			10.5			
				BOH ~12' bgs								
	15											
	20											
	25											
	30											
	35											

NOTES

bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE

D – DRIVE
C – CORE
G – GRAB

▽ Water level drilled

FIGURE 3.3

GEOLOGIC BORING LOG

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

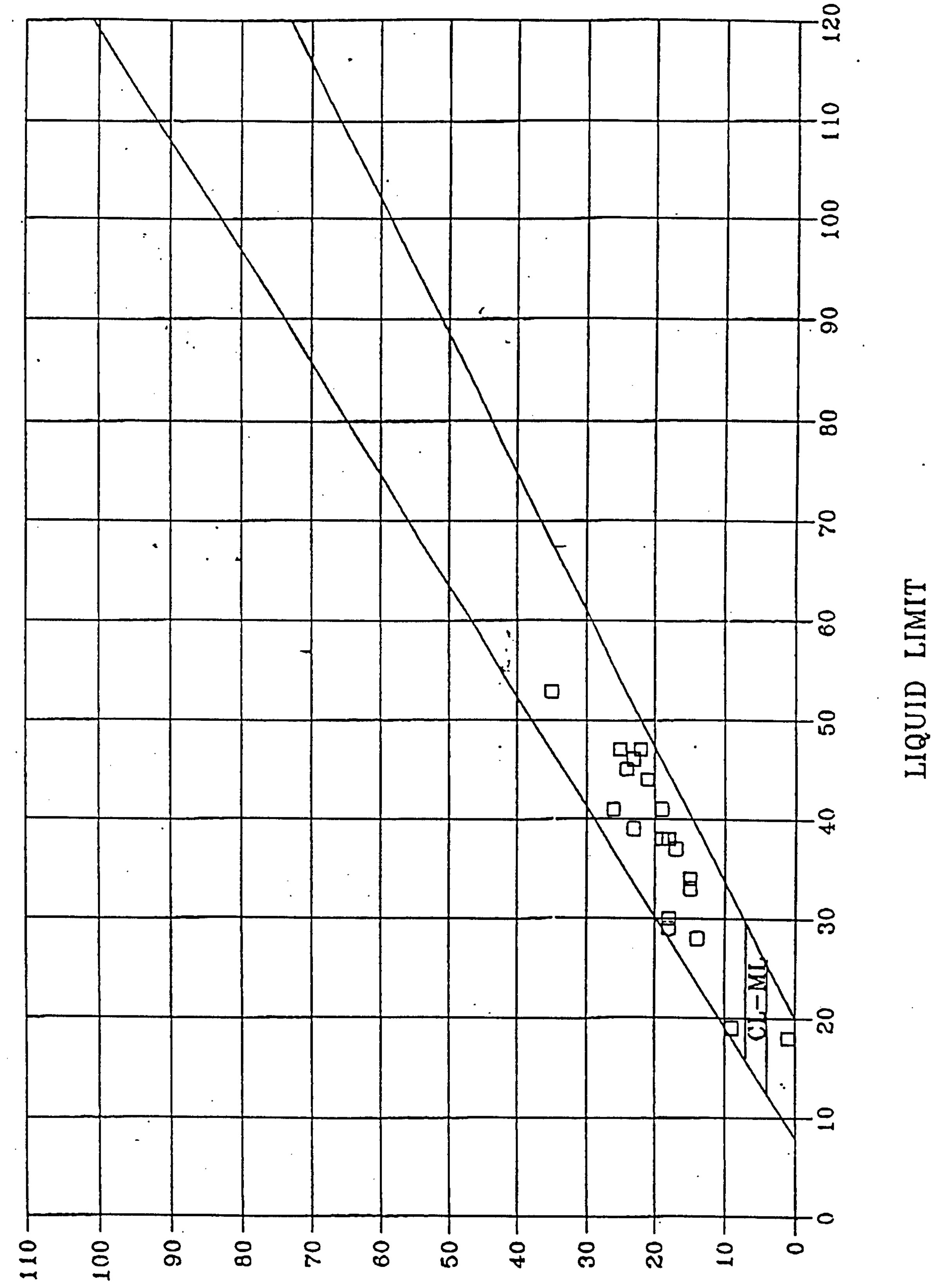
TABLE 1

RESULTS OF TESTS OF DISTURBED AND UNDISTURBED SOIL SAMPLES

NOTE: * ALL SOIL SAMPLES THAT DO NOT HAVE COMPLETE LABORATORY TEST DATA
WERE VISUALLY CLASSIFIED ONLY.

SWDED-GL REPORT NO. 16555 ALTUS AFB

BORING	NO.	SWD NO.	FLD NO.	DEPTH , FT	GR	SA	FI	LL	PL	PI	LS	WC, %	PCF	MAJOR TESTS	DESCRIPTION OF MATERIAL
OU-01	15	96\ 1390	JAR-1	5.0 - 6.5	0	6	94	28	14	14		19.6			CL - LEAN CLAY, REDDISH BROWN, MOIST, CALCAREOUS, ROOTS.
OU-01	15	96\ 1391	JAR-2	8.5 - 10.0	0	10	90	38	20	18		23.6			CL - LEAN CLAY, REDDISH BROWN WITH LIGHT GRAY SPOTS, VERY MOIST, CALCAREOUS, GRAVELS TO 1/2", CLAY-SHALE CHARACTERISTICS, SOME COARSE SAND CONSISTS OF HARD SHALE FRAGMENTS.
OU-01	15	96\ 1392	JAR-3	11.5 - 12.6	2	10	88	33	18	15		28.7			- CLAY-SHALE/SHALE, REDDISH BROWN WITH DARK GRAY, FREE WATER, CALCAREOUS, GRAVELS AND COARSE SAND CONSISTS OF HARD SHALE FRAGMENTS.
OU-01	15	96\ 1393	JAR-4	12.6 - 13.0	0	2	98	34	19	15		20.3			CL - LEAN CLAY, REDDISH BROWN WITH LIGHT GRAY, VERY MOIST, SLIGHTLY CALCAREOUS, CLAY-SHALE CHARACTERISTICS, SOME SHALE FRAGMENTS.
OU-01	15	96\ 1394	JAR-5	14.5 - 15.0	0	0	100	38	19	19		24.4			CL - LEAN CLAY, REDDISH BROWN WITH LIGHT GRAY, VERY MOIST, NON-CALCAREOUS, CLAY-SHALE CHARACTERISTICS, SOME SAND.
OU-01	15	96\ 1395	JAR-6	15.0 - 16.0	0	0	100	44	23	21		25.1			CL - LEAN CLAY, REDDISH BROWN, VERY MOIST, NON-CALCAREOUS, CLAY-SHALE CHARACTERISTICS.
OU-01	15	96\ 1396	JAR-7	17.4 - 17.6											- GYPSUM, CRYSTALS TO 1 1/4", SAMPLE UNSUITABLE FOR TESTING.
OU-01	15	96\ 1397	JAR-8	17.6 - 18.5	0	1	99	47	25	22		15.5			- SHALE, WEATHERED, REDDISH BROWN, MOIST, NON-CALCAREOUS, STRINGERS OF GYPSUM, SAND-SIZES CONSISTS OF GYPSUM CRYSTALS.
OU-01	16	96\ 1398	JAR-1	1.9 - 3.0	0	63	37	18	17	1		4.0			SM - SILTY SAND, BROWN, MOIST, NON-CALCAREOUS, ROOTS.
OU-01	16	96\ 1399	JAR-2	7.0 - 7.4	1	22	77	30	12	18		13.4			CL - LEAN CLAY WITH SAND, REDDDISH BROWN WITH YELLOW, MOIST, CALCAREOUS WITH CALCAREOUS NODULES.
OU-01	16	96\ 1400	JAR-3	14.8 - 15.0	0	4	96					16.2			- CLAY-SHALE, REDDISH BROWN WITH LIGHT GRAY, MOIST, NON-CALCAREOUS, SAND-SIZES CONSISTS OF HARD OLIVE-GRAY SILT FRAGMENTS, NON-CALCAREOUS, INSUFFICIENT AMOUNT OF MATERIAL FOR ATTERBERG LIMIT TESTS.
OU-01	16	96\ 1401	JAR-4	15.0 - 15.9	0	0	100	46	23	23		19.9			- CLAY-SHALE, REDDISH BROWN, MOIST, CALCAREOUS WITH CALCAREOUS NODULES, SCATTERED BLACK STAINS.
OU-01	19	96\ 1402	JAR-1	6.0 - 7.5	0	32	68	30	12	18		11.6			CL - SANDY LEAN CLAY, REDDISH BROWN WITH YELLOW, MOIST, CALCAREOUS WITH CALCAREOUS NODULES, SOME GYPSUM CRYSTALS.
OU-01	19	96\ 1403	JAR-2	10.5 - 11.5	0	81	19	19	10	9		14.9			CL - CLAYEY SAND, REDDISH BROWN, VERY MOIST, VERY SILTY, CALCAREOUS.
OU-01	19	96\ 1404	JAR-3	11.2 - 12.5	0	2	98	47	22	25		22.4			CL - LEAN CLAY WITH SAND, REDDISH BROWN WITH LIGHT GRAY SPOTS, VERY MOIST, CALCAREOUS, CLAY-SHALE CHARACTERISTICS, SOME GYPSUM CRYSTALS.
OU-01	19	96\ 1405	JAR-4	17.0 - 18.4	4	6	90	37	20	17		17.3			- CLAY-SHALE/SHALE, REDDISH BROWN WITH LIGHT GRAY SPOTS, MOIST, CALCAREOUS, SCATTERED BLACK STAINS, SOME SAND.
OU-01	19	96\ 1406	JAR-5	19.1 - 19.6	0	4	96	33	18	15		13.6			- SHALE, WEATHERED, REDDISH BROWN, MOIST, CALCAREOUS, SAND-SIZES CONSISTS OF HARD SHALE PARTICLES.



ALTUS AFB

PLASTICITY CHART
PLATE #

CESWD-ETE-GL RPT No. 16555

HTW DRILLING LOG

HOLE No. OU-1-VP1

1. COMPANY NAME Radian International LLC	2. DRILLING SUBCONTRACTOR AEI Corporation	SHEET 1 OF 1 SHEETS

3. PROJECT Altus AFB TPVE Testing	4. LOCATION OU-1-VP1
5. NAME OF DRILLER Ron Newton	6. MANUFACTURER'S DESIGNATION OF DRILL Stratastar 10
7. SIZE AND TYPES OF DRILLING AND SAMPLING EQUIPMENT 8 3/4 O.D. Borehole 5' Core barrel Samples	8. HOLE LOCATION 5' West of OU-1-02
	9. SURFACE ELEVATION 1352.036 (BH) 1351.845 (TOC)
	10. DATE STARTED 9-10-96 / 11. DATE COMPLETED 9-10-96
12. OVERBURDEN THICKNESS —	15. DEPTH GROUNDWATER ENCOUNTERED —
13. DEPTH DRILLED INTO ROCK —	16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED NA
14. TOTAL DEPTH OF HOLE 5.2'	17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY) NA

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES
NONE	—	—	—

20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY %
NONE	—	—	—	—	—	

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR
Vapor probe	—	—	Vapor probe	

24. CHECKED BY: —	25. NAME OF INSPECTOR Gerald T Mullin

ELEV. a	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
		dark reddish brown (5YR 3/2), silty clay, slightly friable, low plasticity, organic matter from 0-1.7', 10%-15% Fe nodules	1.3				Rec 5.2/5.2
	1						
			1.3				
	2	yellowish red (5YR 5/8), slightly silty clay	1.2				
	3						
			1.4				
	4						
			1.5				
	5	50% Fe nodules from 4.8'-5.0'					
		TD = 5.2'					

MRK FORM JUN 89 55	PROJECT NAME & NO. Altus AFB TPUE Testi	HOLE No. OU-1-VP1

HTW DRILLING LOG

HOLE No. OU-1-UP2

1. COMPANY NAME Radian International LLC

2. DRILLING SUBCONTRACTOR AEI Corporation

SHEET 1 OF 1 SHEETS

3. PROJECT Altus AFB TVUE Testing

4. LOCATION OU-1-UP2

5. NAME OF DRILLER Ron Newton

6. MANUFACTURER'S DESIGNATION OF DRILL Stratastar 10

7. SIZE AND TYPES OF DRILLING AND SAMPLING EQUIPMENT 8 3/4" OD Borehole
5' Core barrel Samples

8. HOLE LOCATION 5' North of OU-1-03

9. SURFACE ELEVATION BM = 1352.739 TOC = 1352.547

10. DATE STARTED 9-10-96

11. DATE COMPLETED 9-10-96

12. OVERBURDEN THICKNESS —

15. DEPTH GROUNDWATER ENCOUNTERED —

13. DEPTH DRILLED INTO ROCK —

16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED NA

14. TOTAL DEPTH OF HOLE 5.2

17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY) NA

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES
NONE	—	—	—

20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY %
NONE	—	—	—	—	—	

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR
Vapor probe	—	—	vapor probe	

24. CHECKED BY: —

25. NAME OF INSPECTOR Gerald T Mullin

ELEV. a	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
		dark reddish brown (5YR 3/2), silty clay, slightly friable, low plasticity, organic matter from 0-0.5'					Rec 5.2/5.2
	1						
	2						
	3	yellowish red (5YR 5/8), slightly silty clay, low plasticity, 5% Fe nodules					
	4						
	5	T.D. = 5.2'					

PROJECT NAME & NO. Altus AFB TVUE Test...

HOLE No. OU-1-UP2

HTW DRILLING LOG

HOLE No. OU-1-VP3

1. COMPANY NAME Radian International LLC	2. DRILLING SUBCONTRACTOR AEI Corporation	SHEET 1 OF 1 SHEETS

3. PROJECT Altus AFB TPVE Testing	4. LOCATION OU-1-VP3
5. NAME OF DRILLER Ron Newton	6. MANUFACTURER'S DESIGNATION OF DRILL Stratastar 10
7. SIZE AND TYPES OF DRILLING AND SAMPLING EQUIPMENT 8 3/4" O.D. Borehole 5' Core barrel Sample	8. HOLE LOCATION 5' West of OU-1-04
	9. SURFACE ELEVATION BM=1352.349 TOC=1352.091
	10. DATE STARTED 9-11-96 / 11. DATE COMPLETED 9-11-96
12. OVERBURDEN THICKNESS —	15. DEPTH GROUNDWATER ENCOUNTERED —
13. DEPTH DRILLED INTO ROCK —	16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED NA
14. TOTAL DEPTH OF HOLE 5.2'	17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY) NA

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES
NONE	—	—	—

20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY %
NONE	—	—	—	—	—	

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR
Vapor probe	—	—	Vapor probe	

24. CHECKED BY: —	25. NAME OF INSPECTOR Gerald T. Mullin

ELEV. a	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
	0–1	dark reddish brown (5YR 3/4), silty clay, organic matter from 0-0.8', man made fill mottled throughout 0-1.5', Fe and FeO nodules comprise 15% of core					Rec 5.2/5.2
	2–5	yellowish red (5YR 5/8), slightly silty clay, dense, slightly friable					
		T.D. = 5.2'					

MRK FORM 55 JUN 89	PROJECT NAME & NO. Altus AFB TPVE Testing	HOLE No. OU-1-VP3

HTW DRILLING LOG

HOLE No. OU-1-01

SHEET 1 OF 2 SHEETS

1. COMPANY NAME Radian International	2. DRILLING SUBCONTRACTOR AEI Corporation
3. PROJECT Altus AFB TPVE Testing	4. LOCATION OU-1-01
5. NAME OF DRILLER Ron Newton	6. MANUFACTURER'S DESIGNATION OF DRILL Strata star 10
7. SIZE AND TYPES OF DRILLING AND SAMPLING EQUIPMENT 10 3/4" O.D. Borehole 5' Core barrel Samples	8. HOLE LOCATION 25' due south of WL 021
	9. SURFACE ELEVATION BM = 1351.958 TOC = 1354.501
	10. DATE STARTED 9-9-96 / 11. DATE COMPLETED 9-9-96
12. OVERBURDEN THICKNESS —	15. DEPTH GROUNDWATER ENCOUNTERED 3.3' / standing water @ 5.2' in hole
13. DEPTH DRILLED INTO ROCK —	16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED —
14. TOTAL DEPTH OF HOLE 25'	17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY) 6.08 BTOC - 9-12-96

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES
None			—

20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY %
None	—	—	—	—	—	—

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR
Extraction Well	—	—	Extraction	Gerald T Mullin

24. CHECKED BY: —

25. NAME OF INSPECTOR Gerald T. Mullin

ELEV. a	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
1354.501		yellowish red (5YR 5/8) silty clay, slightly moist, friable, organic matter from 0-1'	PID NOT Available				Rec 3.3/5.0
51	1	dark reddish brown (5YR 3/2) silty-very fine grained sandy clay, slightly moist, friable					
50	2						
49	3	yellowish red (5YR 5/8), slightly silty clay, moist, infrequent Fe nodules mottled throughout 2-3.3' (10% of core)					→ section not recovered is most likely same as 5.0-5.6'
48	4	NOT RECOVERED					
47	5	yellowish red (5YR 5/8), silty sand, saturated, infrequent pebble and cobbles					Rec 5.0/5.0
46	6	yellowish red (5YR 5/8) silty-very fine grained sandy clay, moist, moderate plasticity,					
45	7						
44	8	olive (5Y 5/4), round calcareous inclusions (0.5-1.5 cm diameter) mottled throughout 7.5-10' comprising 15% of core sample → blocky clay-shale chunks from 8.5-9'	Screen ↓				
43	9	Saturated					
42	10						

MRK FORM 55 JUN 89

PROJECT NAME & NO. Altus AFB TPVE Testing

HOLE No. OU-1-01

HTW DRILLING LOG

HOLE No. OU-1-01

PROJECT Altus AFB TPVE Testing

INSPECTOR Gerald T Mullin

SHEET 2 OF 2 SHEETS

V.	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
							Rec 5/5
41	11	yellowish red (5YR 5/8), clay shale, weathered, dry					
40	12	→ becoming more clay-like					
39	13	yellowish red (5YR 5/8), clay, moderate-high plasticity, moist, mottled with olive (5Y 5/8) round calcareous inclusions comprising 30% of core sample					
38	14	yellowish red (5YR 5/8) clay shale, hard, dry					
40							
37	15						
		yellowish red (5YR 5/2) sandy-pea gravel clay, very moist					Rec 5/5
36	16						
		yellowish red (5YR 5/8), clay shale, very dense, moist, 10% olive (5Y 5/8) calcareous inclusions					
35	17	saturated from 17.2-17.9					
34	18						
		→ gypsum xtls (2-3cm diameter) from 18.5-19.0					
33	19	yellowish red (5YR 5/8) clay shale-shale, slightly moist, 15%-20% olive (5Y 5/8) calcareous inclusions					
35							
32	20						Rec 5/5
		→ 0.5' gypsum xtl layer from 20.5-21.0'					
31	21						
		→ becoming shale-like	↑				
30	22	→ 0.5cm thick gypsum seam	screen				
29	23						
31							
28	24	yellowish red (5YR 5/8) shale, dry, very hard, parting is horizontal and on mm scale					
27	25	T.D = 25.0. 3' sluff in = 22.0 T.D. when PVC was emplaced					

MRK FORM 55-2 JUN 89

PROJECT

HOLE No. OU-1-01

HTW DRILLING LOG

HOLE No. OU-1-02

1. COMPANY NAME Radian International	2. DRILLING SUBCONTRACTOR AEI Corporation	SHEET 1 OF 2 SHEETS

3. PROJECT Altus AFB TPVE Testing	4. LOCATION OU-1-02
5. NAME OF DRILLER Ron Newton	6. MANUFACTURER'S DESIGNATION OF DRILL Statesta- 10
7. SIZE AND TYPES OF DRILLING AND SAMPLING EQUIPMENT 8 3/4" O.D. Borehole 5' core barrel samples	8. HOLE LOCATION 10' South of OU-1-01
	9. SURFACE ELEVATION BM=1352.097 TOC=1354.607
	10. DATE STARTED 9-10-96 / 11. DATE COMPLETED 9-10-96
12. OVERBURDEN THICKNESS —	15. DEPTH GROUNDWATER ENCOUNTERED ~5.4'
13. DEPTH DRILLED INTO ROCK —	16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED —
14. TOTAL DEPTH OF HOLE 25'	17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY) 6.27' BTOC 9-13-96

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES
NONE	—	—	—

20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY %
NONE	—	—	—	—	—	

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR
Piezometer	—	—	Piezometer	

24. CHECKED BY: —

25. NAME OF INSPECTOR

ELEV. a	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
1354.607		dark reddish brown (2.5 YR 3/4), silty clay, organic matter from 0-1.5'	Background = 1.8				Rec = 3.7/5.0
51.1	1		0.6				
50.1	2		0.9				
49.1	3	Yellow red (5YR 5/8), silty clay, friable, 5% Fe nodules	0.7				
48.1	4	NOT RECOVERED					
47.1	5	as above and slightly moist	2.5				
46.1	6	saturated and containing some organic matter	3.7				Rec = 3.3/5.0
45.1	7	moist and becoming hard → pea gravel and sand layer from 7.2' - 7.8'	11.1				
44.1	8	yellow red (5YR 5/8) clay shale, hard, slightly moist					
43.1	9	NOT RECOVERED					
42.1	10						

MRK FORM 55 JUN 89

PROJECT NAME & NO.

HOLE No. OU-1-02

HTW DRILLING LOG

HOLE No. OU-1-02

PROJECT Altus AFB TPVE Testing

INSPECTOR Gerald T. Mullin

SHEET 2 OF 2 SHEETS

. a	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
		Saturated and containing blocky shale, 10% olive (5Y 5/4) calcareous inclusions	5.9				Rec = 2.5/5.0
41.1	11		1.4				
40.1	12	red (2.5 YR 4/8) clay shale, very hard, blocky	1.3				
39.1	13	NOT RECOVERED					
38.1	14				/		
37.1	15	light greenish gray (5G 7/1), calcareous layer, dry, friable, silty	1.3				
36.1	16	yellowish red (5YR 5/8), clay shale-shale, dry, extremely hard, weathered, speckled with olive (5Y 5/4) calcareous inclusions that became large (3 cm diameter) from 17'-17.7'	1.0				Rec = 2.7/5.0
35.1	17						
34.1	18	gypsum xtl layer NOT RECOVERED	1.2				
3.1	19						
32.1	20	yellow red (5YR 5/8) shale, hard, dry, weathered, 10% calcareous inclusions gypsum xtl layer	2.3				Rec = 5/5
31.1	21		3.5				
30.1	22	→ friable from 22.2-23.8	2.6				
29.1	23		3.5				
28.1	24		3.7				
27.1	25	gypsum xtl layer TD = 25.0' → gypsum xtls 3 cm in diameter in shoe	4.1				

HTW DRILLING LOG

HOLE No. OU-1-03

1. COMPANY NAME Radian International
2. DRILLING SUBCONTRACTOR AEI Corporation
SHEET 1 OF 2 SHEETS
3. PROJECT Altus AFB TPUE Testing
4. LOCATION OU-1-03
5. NAME OF DRILLER Ron Newton
6. MANUFACTURER'S DESIGNATION OF DRILL Stratastar 10
7. SIZE AND TYPES OF DRILLING AND SAMPLING EQUIPMENT 8 3/4" O.D. Borehole; 5' core barrel sample
8. HOLE LOCATION 25' west of OU-1-01
9. SURFACE ELEVATION BM=1352.716 TOC=1355.039
10. DATE STARTED 9-10-96
11. DATE COMPLETED 9-10-96
12. OVERBURDEN THICKNESS –
15. DEPTH GROUNDWATER ENCOUNTERED ~ 4.8'
13. DEPTH DRILLED INTO ROCK –
16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED –
14. TOTAL DEPTH OF HOLE 25.5'
17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY) 6.72' BTOC 9-13-96

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES
NONE	–	–	–

20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY %
NONE	–	–	–	–	–	

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR
Piezometer	–	–	Piezometer	

24. CHECKED BY: –
25. NAME OF INSPECTOR

ELEV. a	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
		dark reddish brown (5 YR 3/2), silty clay, slightly moist, friable, organic matter from 0-0.8'	PID Not Available				Rec 5/5
	1						
	2						
	3	Yellow red (5 YR 5/8), slightly silty clay, Fe nodules (10%), low-moderate plasticity					
	4						
	5	→ moist, moderate-high plasticity, slightly silty					
	6						Rec 5/5
	7						
	8	yellow red (5 YR 5/8), sandy clay with pea gravel, slightly moist-moist					
	9						
	10						

MRK FORM 55 JUN 89 PROJECT NAME & NO. HOLE No.

HTW DRILLING LOG

HOLE No.	OU-1-03
PROJECT	Altus AFB TPVE Testing
INSPECTOR	
SHEET 2 OF 2 SHEETS	

	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
		→ becoming more clayey, slightly moist, ~20% olive (5Y5/4) calcareous inclusions from 10.7'-15.0'					Rec = 5/5
	11						
		yellow red (5YR5/8) clay shale, weathered, dry					
	12	moist from 12.0-12.4					
		→ becoming very hard and dry					
	13						
	14						
		yellow red (5 YR5/8), clay, moist					
	15						
		light greenish gray (5 G 7/1), calcareous layer, dry					Rec = 3.2/5.0
	16	red (2.5 YR 4/8) clay shale-shale, very hard, dense, speckled with 5% calcareous inclusions					
	17						
	18						
		NOT RECOVERED					
	19						
	20	as above and moist from 20'-20.8'					Rec 4.8/5.0
	21	red (2.5 YR 4/8), shale, dry, very hard, weathered					
		gypsum xtl layer					
	22	gypsum xtl layer					
		very moist from 22.2'-23.6'					
	23						
	24	dark red (2.5 YR 3/6), shale, extremely hard, dense, 10% olive (5Y 5/4), calcareous inclusions, dry					
	25						
	26	TD=25.5 - drill refusal					Rec = 0.5/0.5

MRK FORM 55-2 JUN 89

PROJECT Altus AFB TPVE Testing

HOLE No. OU-1-03

HTW DRILLING LOG

HOLE No. OU-1-04

1. COMPANY NAME Radian International LLC	2. DRILLING SUBCONTRACTOR AEI Corporation
SHEET 1 OF 2 SHEETS	
3. PROJECT Altus AFB TPVE Testing	4. LOCATION OU-1-04
5. NAME OF DRILLER Ron Newton	6. MANUFACTURER'S DESIGNATION OF DRILL Stratastar 10
7. SIZE AND TYPES OF DRILLING AND SAMPLING EQUIPMENT 8¾" O.D. Borehole 5' Core barrel Samples	8. HOLE LOCATION 50' South of OU-1-01
	9. SURFACE ELEVATION BM=1352.218 TOC=1354.510
	10. DATE STARTED 9-11-96
	11. DATE COMPLETED 9-11-96
12. OVERBURDEN THICKNESS –	15. DEPTH GROUNDWATER ENCOUNTERED ~4.8'
13. DEPTH DRILLED INTO ROCK –	16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED –
14. TOTAL DEPTH OF HOLE 25'	17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY) 6.17' BTOC 9-13-96

18. GEOTECHNICAL SAMPLES	DISTURBED	UNDISTURBED	19. TOTAL NUMBER OF CORE BOXES
NONE	–	–	–

20. SAMPLES FOR CHEMICAL ANALYSIS	VOC	METALS	OTHER (SPECIFY)	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY %
NONE	–	–	–	–	–	

22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR
Piezometer	–	–	Piezometer	

24. CHECKED BY: –

25. NAME OF INSPECTOR

ELEV. a	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
1354.510		dark reddish brown (5YR 2.5/2) silty clay, organic matter from 0-1.3'	background ~ 0.8 0				Rec 4.8/5.0
51	1		0				
50	2						
		yellowish red (5 YR 5/8), slightly silty clay, mottled with 15% Fe nodules, somewhat friable	1.8				
49	3		1.6				
48	4	becoming moist	3.4				
47	5	NOT RECOVERED					
		Yellowish red (5 YR 5/8), slightly silty clay, saturated	10.6				
46	6		15.4				
45	7						Rec 3.6/5.0
44	8	as above and only slightly moist, somewhat friable and speckled with 10% calcareous inclusions	12.0				
43	9	NOT RECOVERED					
42	10						

MRK FORM 55 JUN 89

PROJECT NAME & NO. Altus AFB TPVE Testing

HOLE No. OU-1-04

HTW DRILLING LOG

HOLE No. OU-1-04

PROJECT Altus AFB TPVE Testing

INSPECTOR Gerald T. Mullin

SHEET 2 OF 2 SHEETS

	DEPTH b	DESCRIPTION OF MATERIALS c	FIELD SCREENING RESULTS d	GEOTECH SAMPLE OR CORE BOX No. e	ANALYTICAL SAMPLE No. f	BLOW COUNTS g	REMARKS h
		red (2.5 YR 4/8), clay shale, hard, blocky, 15% calcareous inclusions	5.9				Rec= 2.6/5.0
41	11		4.8				
40	12	extremely hard at 12.5 gypsum xtl layer NOT RECOVERED	6.9				
39	13						
38	14						
37	15	light greenish gray (5G 7/1), calcareous layer, dry, friable, silty	0.7				Rec=3.0/5.0
36	16	yellowish red (5 YR 5/8), clay shale - shale, hard, dense, speckled with olive (5 Y 5/4), calcareous inclusions	0				
35	17	gypsum xtl layer gypsum xtl layer	0				
34	18	yellow red (5 YR 5/8), shale, extremely hard, 10% calcareous inclusions NOT RECOVERED					
	19						
32	20	yellow red (5 YR 5/8), sandy clay → most likely sluff	3.2				
31	21	gypsum xtl layer					Rec 5.0/5.0
30	22	yellowish red (5 YR 5/8), shale, 10% calcareous inclusions	2.5				
29	23		1.6				
28	24	Shale becomes weathered and somewhat sandy from 23.3'-24.8'	0.7				
27	25		0.2				
		TD=25					

MRK FORM JUN 89 55-2

PROJECT Altus AFB TPVE Testing

HOLE No. OU-1-04

GEOLOGIC BORING LOG

BORING NO.: OU-1-05
CONTRACTOR: USEPA
DATE SPUD: 4/8/97 2:00p
CLIENT: AFCEE
RIG TYPE: Giddings
DATE CMPL.: 4/9/97 11:30a
JOB NO.: 722450.36020
DRLG METHOD: Hollow Stem Auger
ELEVATION:
LOCATION: Altus AFB OU-1
BORING DIA.: 6.5"
TEMP: 45°F
GEOLOGIST: Cindy Merrill
DRLG FLUID: none
WEATHER: Windy, rain
COMENTS:

Elev (ft)	Depth (ft)	Pro-file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Pend Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1		OL	loose grey clayey SILT								
						4.5			7.0			
	5		CL	red-brown silty CLAY		7.5			21.5			
	10			no samples collected 4' to BOH sampler will not penetrate								
	15											
	20											
	25			formable								
			CH	stiff red-brown CLAY								
	30					30.			0			
				BOH								
	35											

NOTES
bgs – Below Ground Surface
GS – Ground Surface
TOC – Top of Casing
NS – Not Sampled
SAA – Same As Above

SAMPLE TYPE
D – DRIVE
C – CORE
G – GRAB

▼ Water level drilled

FIGURE 3.3

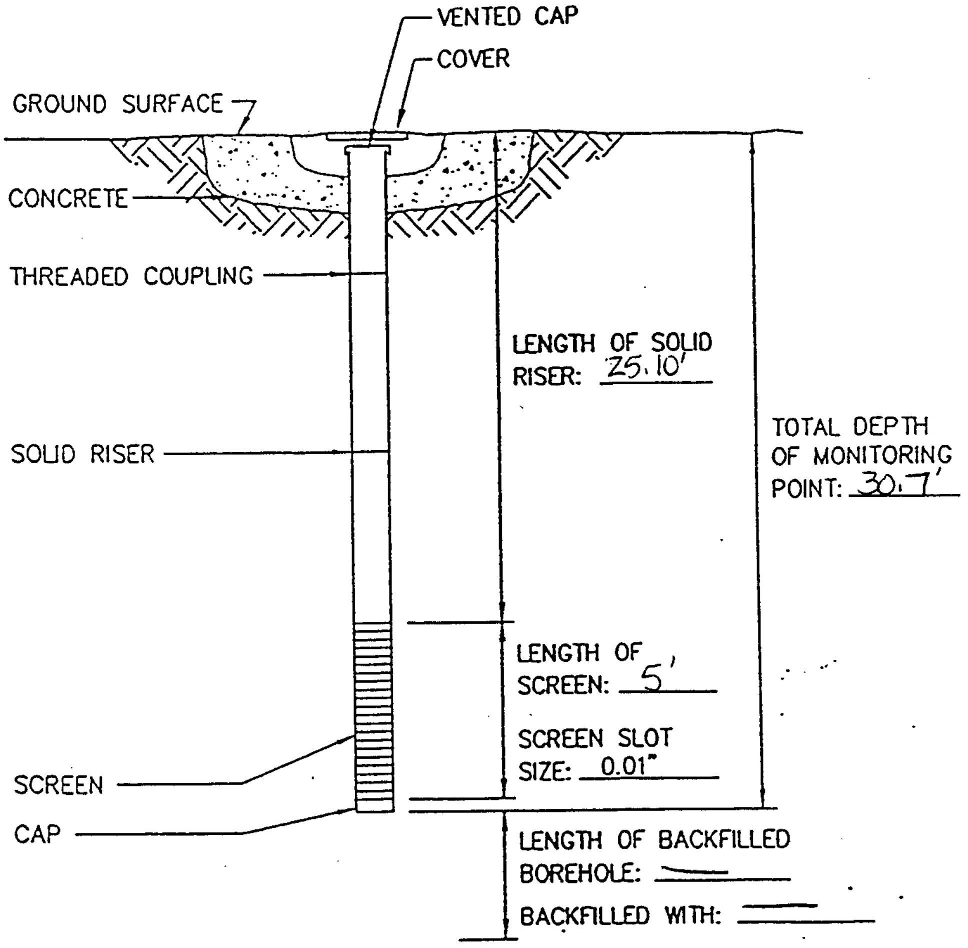
GEOLOGIC BORING LOG

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1
MONITORING POINT NUMBER OU-1-05
JOB NUMBER 722450.36020
INSTALLATION DATE 4/9/97
LOCATION
TUM ELEVATION
GROUND SURFACE ELEVATION
ATUM FOR WATER LEVEL MEASUREMENT TOC
[illegible]EN DIAMETER & MATERIAL 2" ID Schedule 40 PVC
SLOT SIZE 0.010"
[illegible]R DIAMETER & MATERIAL 2" ID Schedule 40 PVC
BOREHOLE DIAMETER 4.25"
Boring Method: Hollow Stem Auger
ES REPRESENTATIVE Cindy Merrill



LENGTH OF SOLID RISER: 25.10'

TOTAL DEPTH OF MONITORING POINT: 30.7'

LENGTH OF SCREEN: 5'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: —

BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 7.95 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 30.7 FEET BELOW DATUM.

GROUND SURFACE FEET

FIGURE 3.4

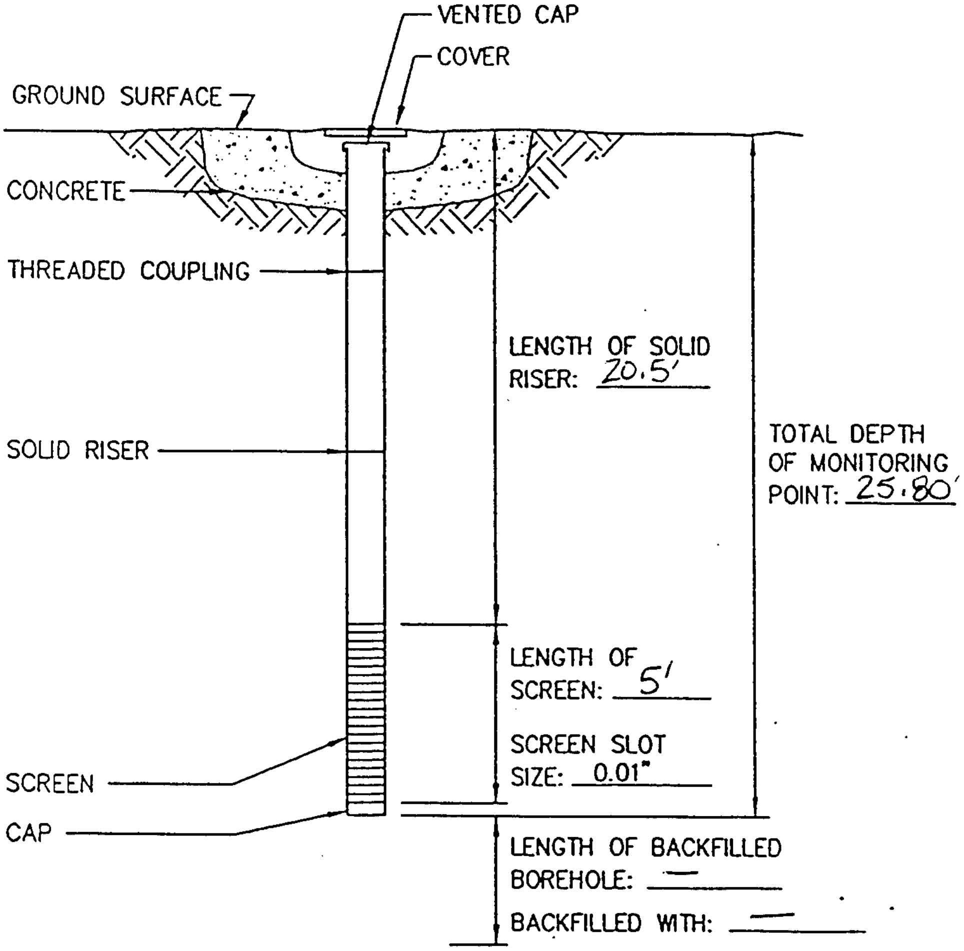
MONITORING POINT
INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1
MONITORING POINT NUMBER OU-1-06
JOB NUMBER 722450.36020
INSTALLATION DATE 4/15/97
LOCATION
DATUM ELEVATION
GROUND SURFACE ELEVATION
DATUM FOR WATER LEVEL MEASUREMENT TOC
SCREEN DIAMETER & MATERIAL 2" ID Schedule 40 PVC
SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 2" ID Schedule 40 PVC
BOREHOLE DIAMETER 4.25"
Boring Method: Hollow Stem Auger
ES REPRESENTATIVE Cindy Merrill



LENGTH OF SOLID RISER: 20.5'

TOTAL DEPTH OF MONITORING POINT: 25.80'

LENGTH OF SCREEN: 5'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: —

BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 13.07 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 25.80 FEET BELOW DATUM.

GROUND SURFACE FEET

FIGURE 3.4

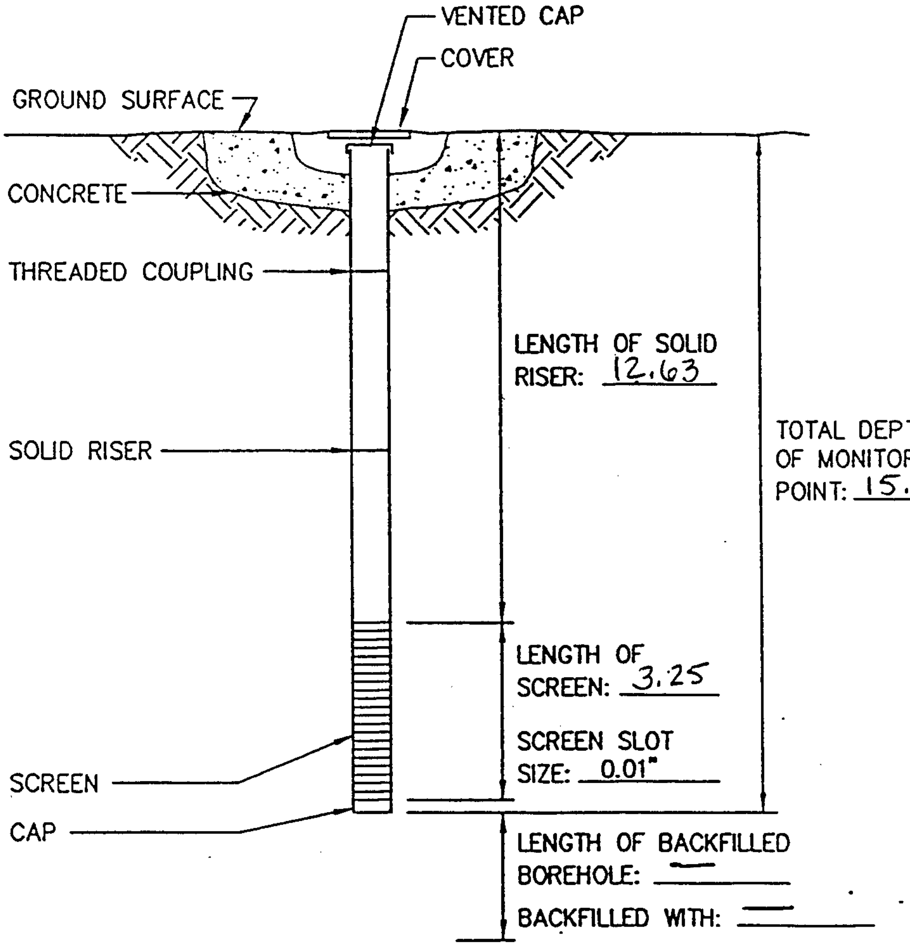
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW1
JOB NUMBER 722450.36020 INSTALLATION DATE 4/14/97 LOCATION
)ATUM ELEVATION GROUND SURFACE ELEVATION
DATUM FOR WATER LEVEL MEASUREMENT TOC
EEN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC SLOT SIZE 0.010"
SER DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC BOREHOLE DIAMETER 2" OD
Boring Method: Geoprobe with Core Barrel ES REPRESENTATIVE Rob Nagel



LENGTH OF SOLID RISER: 12.63
TOTAL DEPTH OF MONITORING POINT: 15.88
LENGTH OF SCREEN: 3.25
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: —
BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 11.01 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 15.88 FEET BELOW DATUM.
GROUND SURFACE FEET

FIGURE 3.4

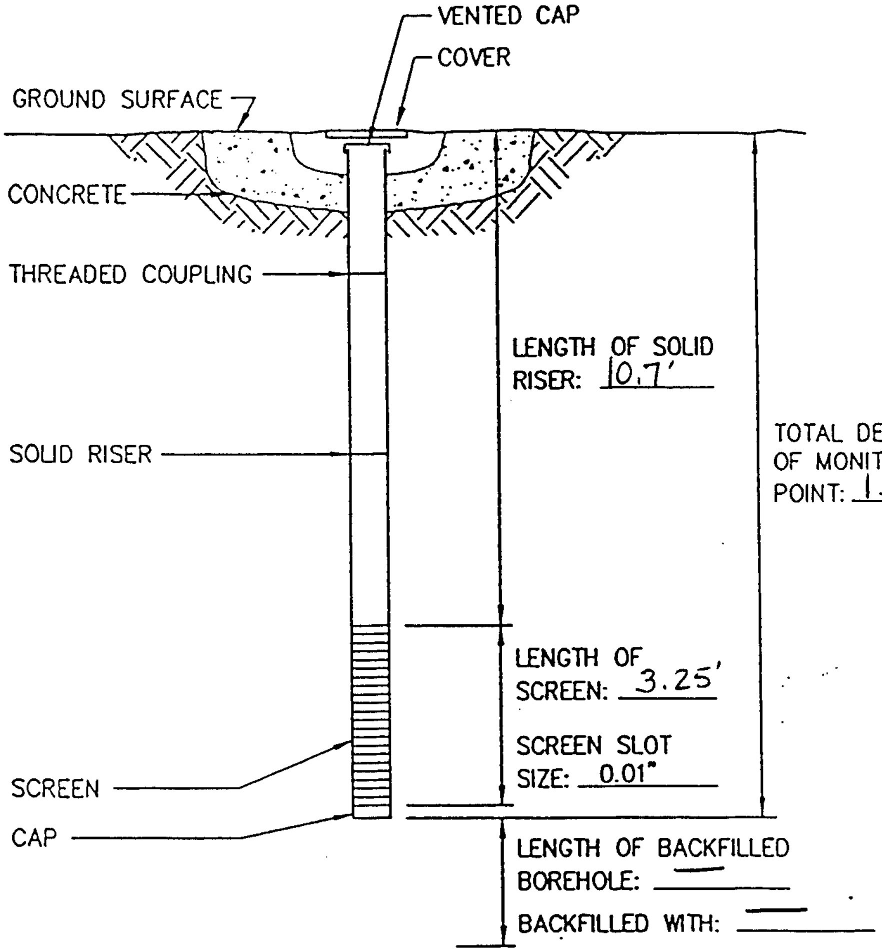
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW2
JOB NUMBER 722450.36020 INSTALLATION DATE 4/15/97 LOCATION ______
DATUM ELEVATION ______ GROUND SURFACE ELEVATION ______
DATUM FOR WATER LEVEL MEASUREMENT TOC
SCREEN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC BOREHOLE DIAMETER 2"OD
Boring Method: Geoprobe with Core Barrel ES REPRESENTATIVE Cindy Merrill



LENGTH OF SOLID RISER: 10.7'

TOTAL DEPTH OF MONITORING POINT: 13.95'

LENGTH OF SCREEN: 3.25'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: —

BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 4.78 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 13.95 FEET BELOW DATUM.

GROUND SURFACE ______ FEET

FIGURE 3.4

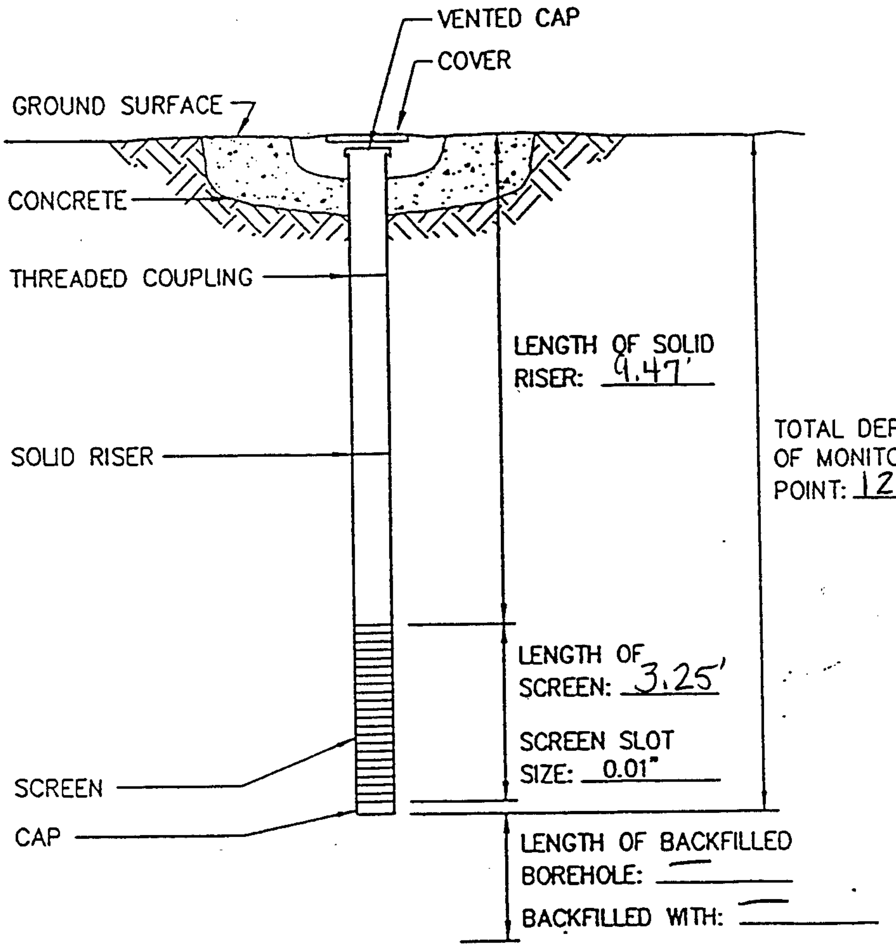
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW3
JOB NUMBER 722450.36020 INSTALLATION DATE 4/15/97 LOCATION
TUM ELEVATION GROUND SURFACE ELEVATION
UM FOR WATER LEVEL MEASUREMENT TOC
EN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC BOREHOLE DIAMETER 2" OD
Boring Method: Geoprobe with Core Barrel ES REPRESENTATIVE Bob Nagel



LENGTH OF SOLID RISER: 9.47'
TOTAL DEPTH OF MONITORING POINT: 12.72'
LENGTH OF SCREEN: 3.25'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: —
BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 9.69 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 12.72 FEET BELOW DATUM.
GROUND SURFACE FEET

FIGURE 3.4

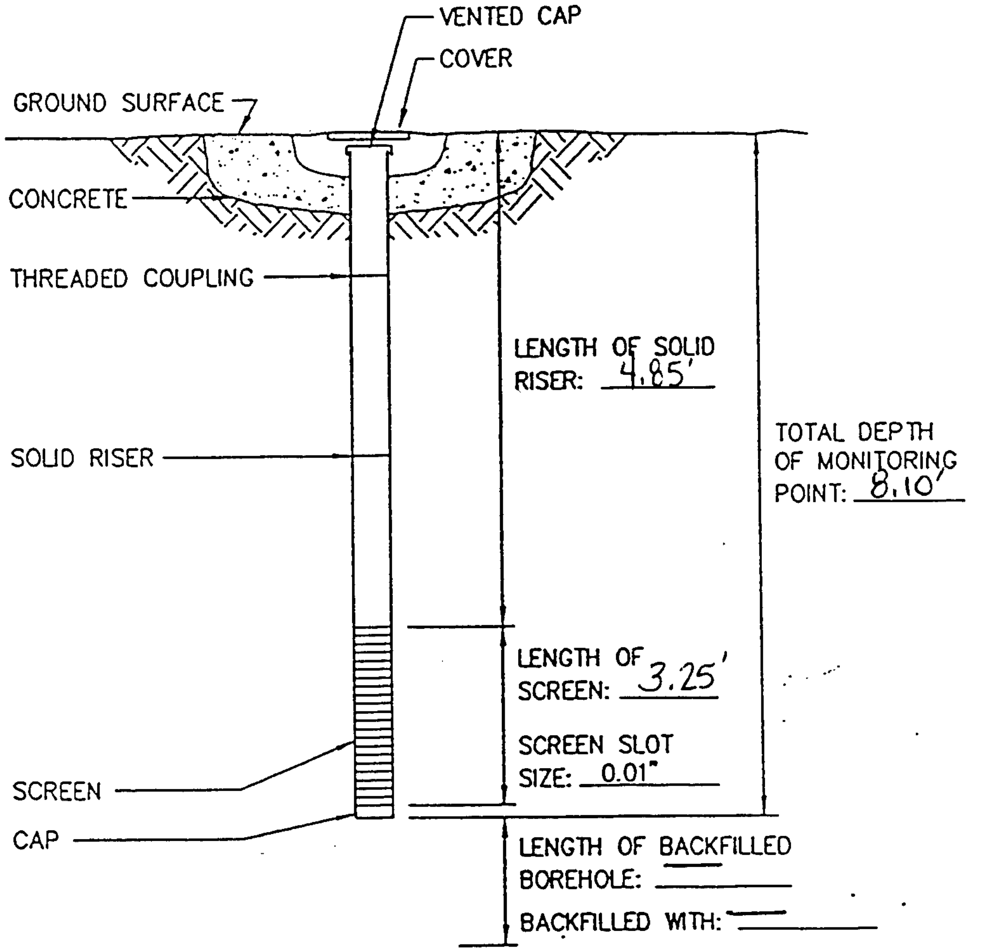
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW4
JOB NUMBER 722450.36020 INSTALLATION DATE 4/16/97 LOCATION
ATUM ELEVATION GROUND SURFACE ELEVATION
DATUM FOR WATER LEVEL MEASUREMENT TOC
SCREEN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC BOREHOLE DIAMETER 1/2"
Boring Method: Hand-Driven ES REPRESENTATIVE Rob Nagel



LENGTH OF SOLID RISER: 4.85'

TOTAL DEPTH OF MONITORING POINT: 8.10'

LENGTH OF SCREEN: 3.25'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE:

BACKFILLED WITH:

(NOT TO SCALE)

STABILIZED WATER LEVEL 7.24 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 8.10 FEET BELOW DATUM.

GROUND SURFACE FEET

FIGURE 3.4

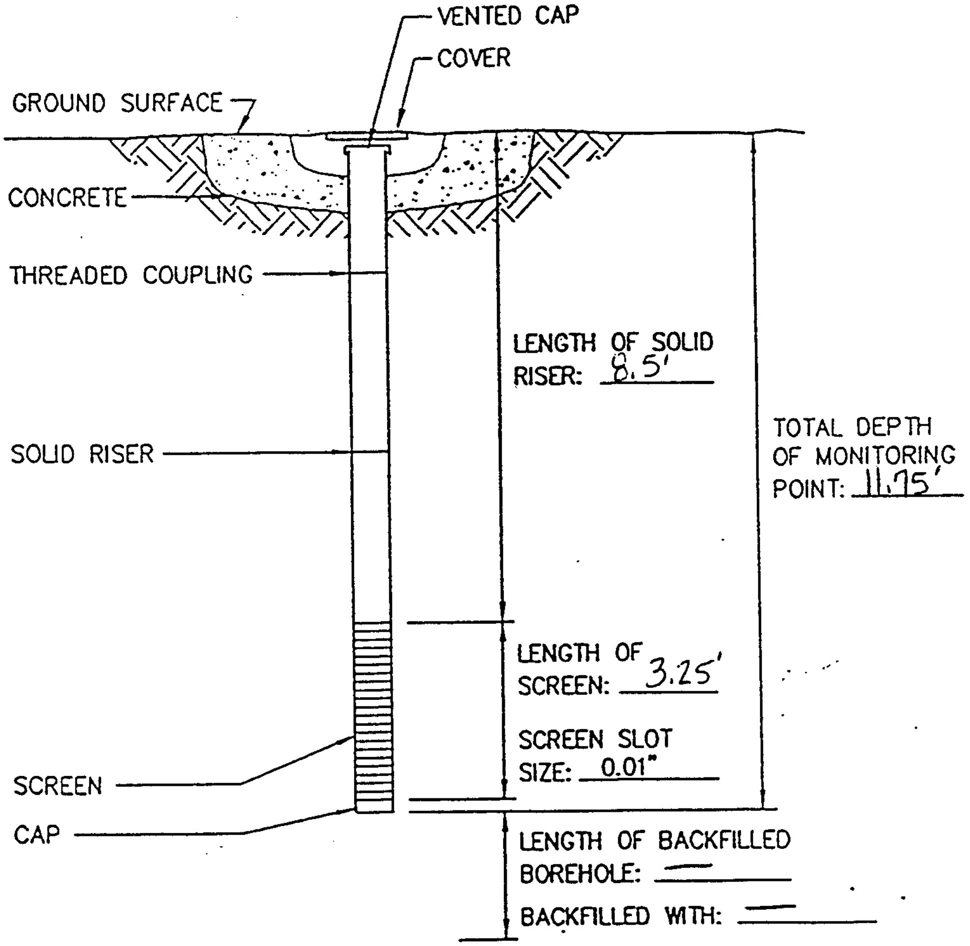
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW5
JOB NUMBER 722450.36020 INSTALLATION DATE 4/15/97 LOCATION
ATUM ELEVATION GROUND SURFACE ELEVATION
UM FOR WATER LEVEL MEASUREMENT TOC
EN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC BOREHOLE DIAMETER 1/2"
Boring Method: Hand-Driven ES REPRESENTATIVE Rob Nagel



LENGTH OF SOLID RISER: 8.5'

TOTAL DEPTH OF MONITORING POINT: 11.75'

LENGTH OF SCREEN: 3.25'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: —

BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 4.00 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 11.75' FEET BELOW DATUM.

GROUND SURFACE ______ FEET

FIGURE 3.4

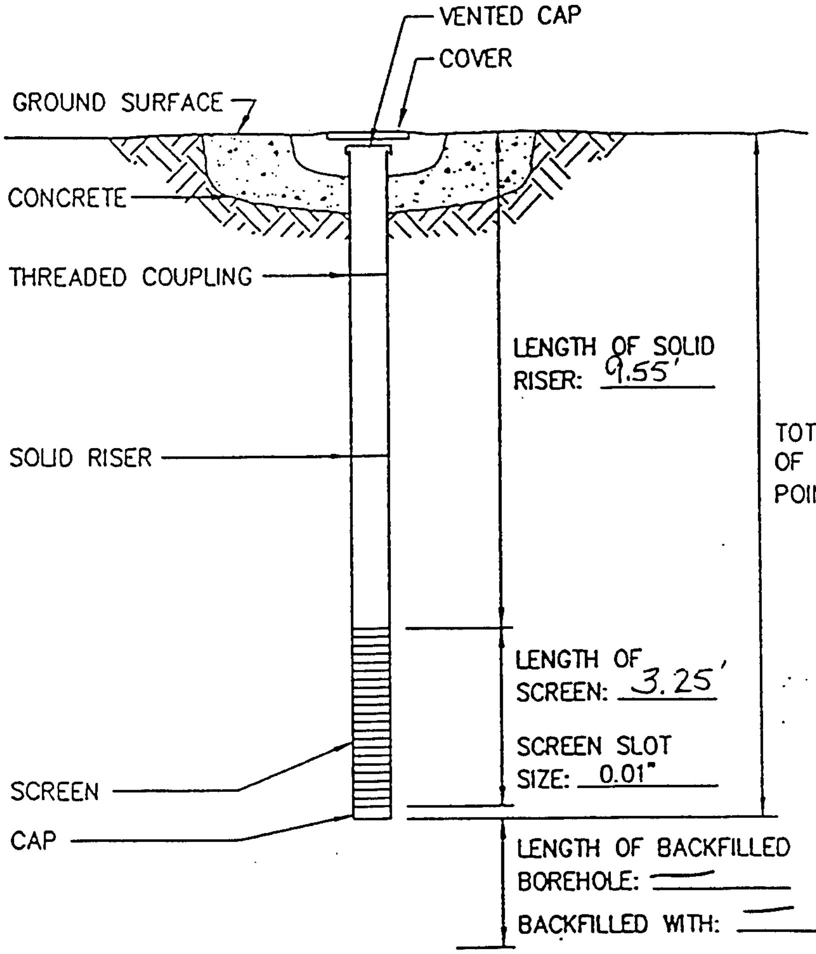
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1
MONITORING POINT NUMBER TW6
JOB NUMBER 722450.36020
INSTALLATION DATE 4/9/97
LOCATION
ATUM ELEVATION
GROUND SURFACE ELEVATION
DATUM FOR WATER LEVEL MEASUREMENT TOC
SCREEN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC
SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC
BOREHOLE DIAMETER 1"
Boring Method: Geoprobe (no core barrel)
ES REPRESENTATIVE Cindy Merrill



LENGTH OF SOLID RISER: 9.55'
TOTAL DEPTH OF MONITORING POINT: 12.8'
LENGTH OF SCREEN: 3.25'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: —
BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 3.29 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 12.8 FEET BELOW DATUM.
GROUND SURFACE FEET

FIGURE 3.4

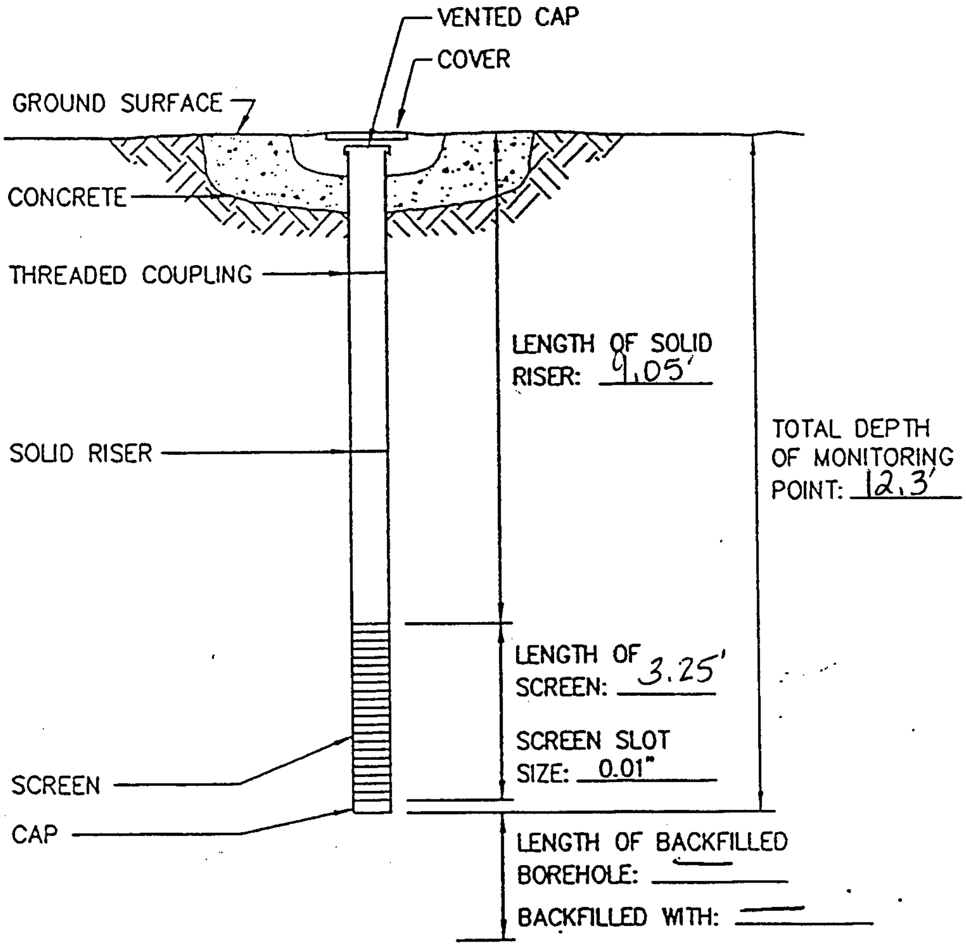
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW7
JOB NUMBER 722450.36020 INSTALLATION DATE 4/10/97 LOCATION
ATUM ELEVATION GROUND SURFACE ELEVATION
ATUM FOR WATER LEVEL MEASUREMENT TOC
EEN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC BOREHOLE DIAMETER 1"
Boring Method: Geoprobe (no core barrel) ES REPRESENTATIVE Cindy Merritt



LENGTH OF SOLID RISER: 9.05'
TOTAL DEPTH OF MONITORING POINT: 12.3'
LENGTH OF SCREEN: 3.25'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: —
BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 3.02 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 12.3 FEET BELOW DATUM.
GROUND SURFACE FEET

FIGURE 3.4

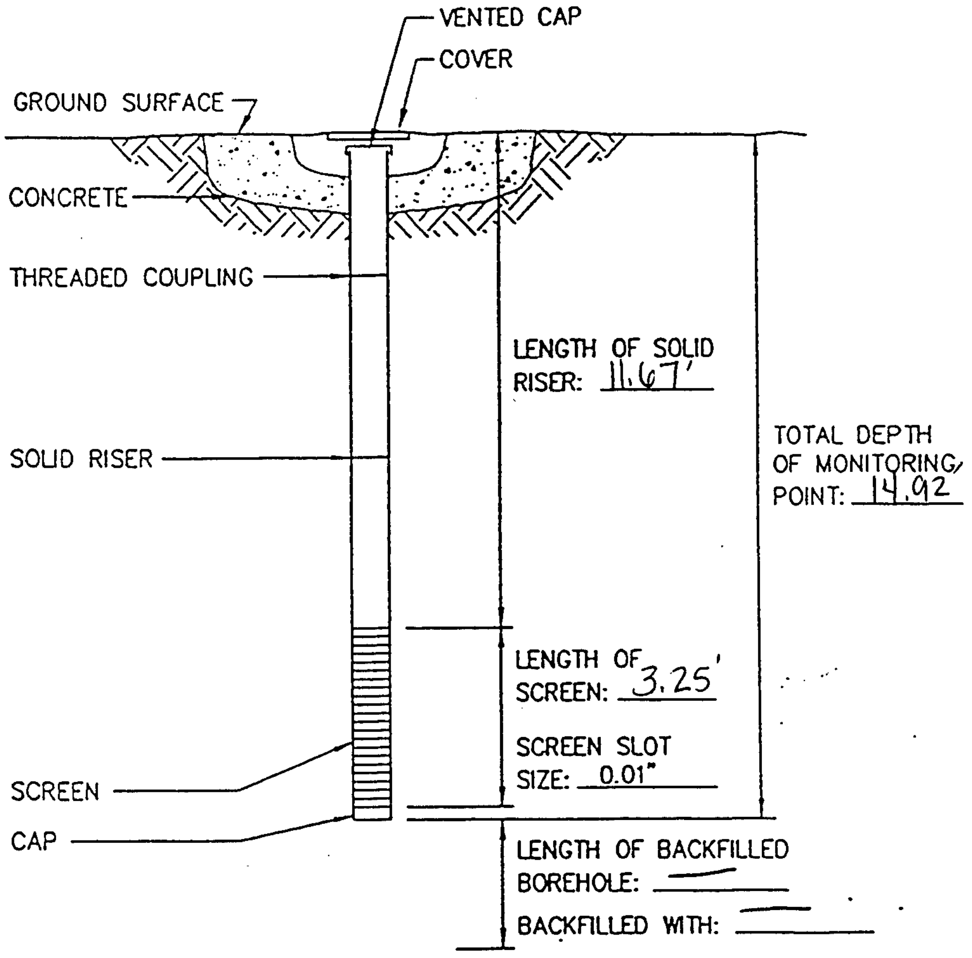
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW8
JOB NUMBER 722450.36020 INSTALLATION DATE 4/14/97 LOCATION
ATUM ELEVATION GROUND SURFACE ELEVATION
DATUM FOR WATER LEVEL MEASUREMENT TOC
SCREEN DIAMETER & MATERIAL ½" ID Schedule 40 PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL ½" ID Schedule 40 PVC BOREHOLE DIAMETER 1"
Boring Method: Geoprobe (no core barrel) ES REPRESENTATIVE Cindy Merrill



LENGTH OF SOLID RISER: 11.67'
TOTAL DEPTH OF MONITORING POINT: 14.92
LENGTH OF SCREEN: 3.25'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: —
BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 3.16 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 14.92 FEET BELOW DATUM.
GROUND SURFACE FEET

FIGURE 3.4

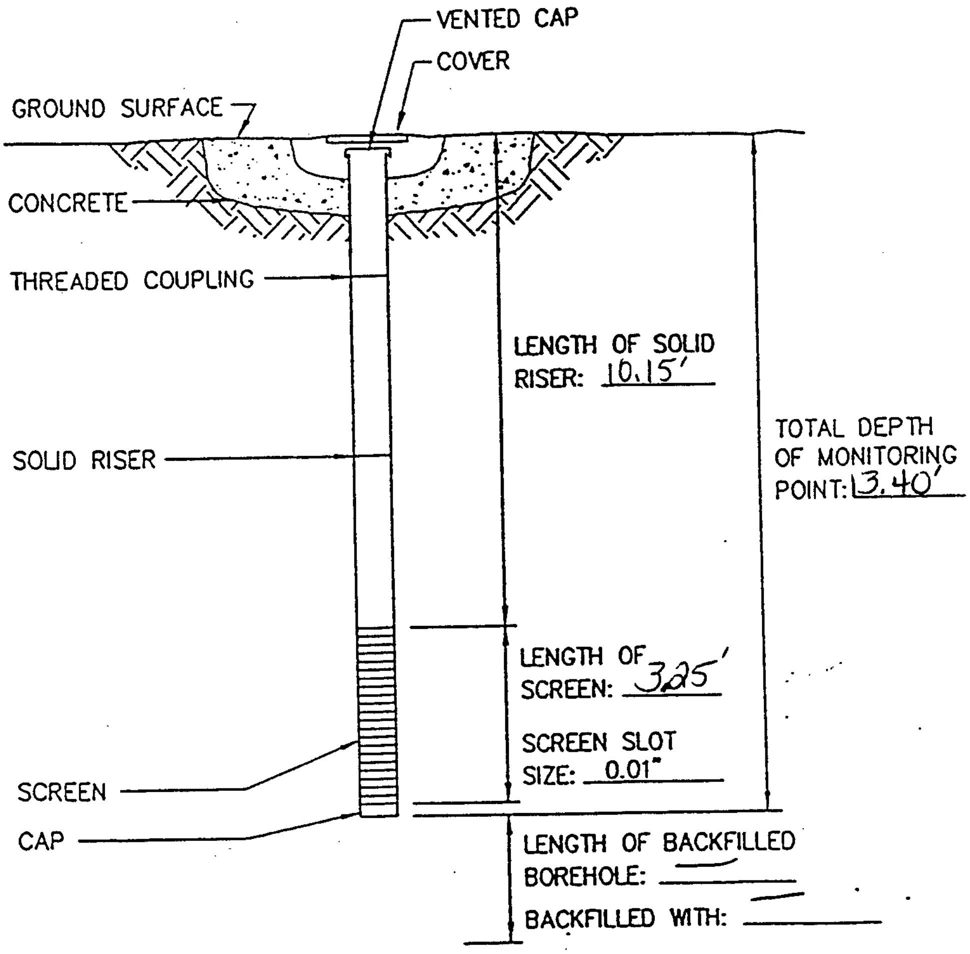
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW9
OB NUMBER 722450.36020 INSTALLATION DATE 4/15/97 LOCATION
ATUM ELEVATION GROUND SURFACE ELEVATION
UM FOR WATER LEVEL MEASUREMENT TOC
EN DIAMETER & MATERIAL ½" ID Schedule 40 PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL ½" ID Schedule 40 PVC BOREHOLE DIAMETER 1"
Boring Method: Geoprobe (no core barrel) ES REPRESENTATIVE Cindy Merrill



LENGTH OF SOLID RISER: 10.15'
TOTAL DEPTH OF MONITORING POINT: 13.40'
LENGTH OF SCREEN: 3.25'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: —
BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 8.82 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 13.40 FEET BELOW DATUM.
GROUND SURFACE FEET

FIGURE 3.4

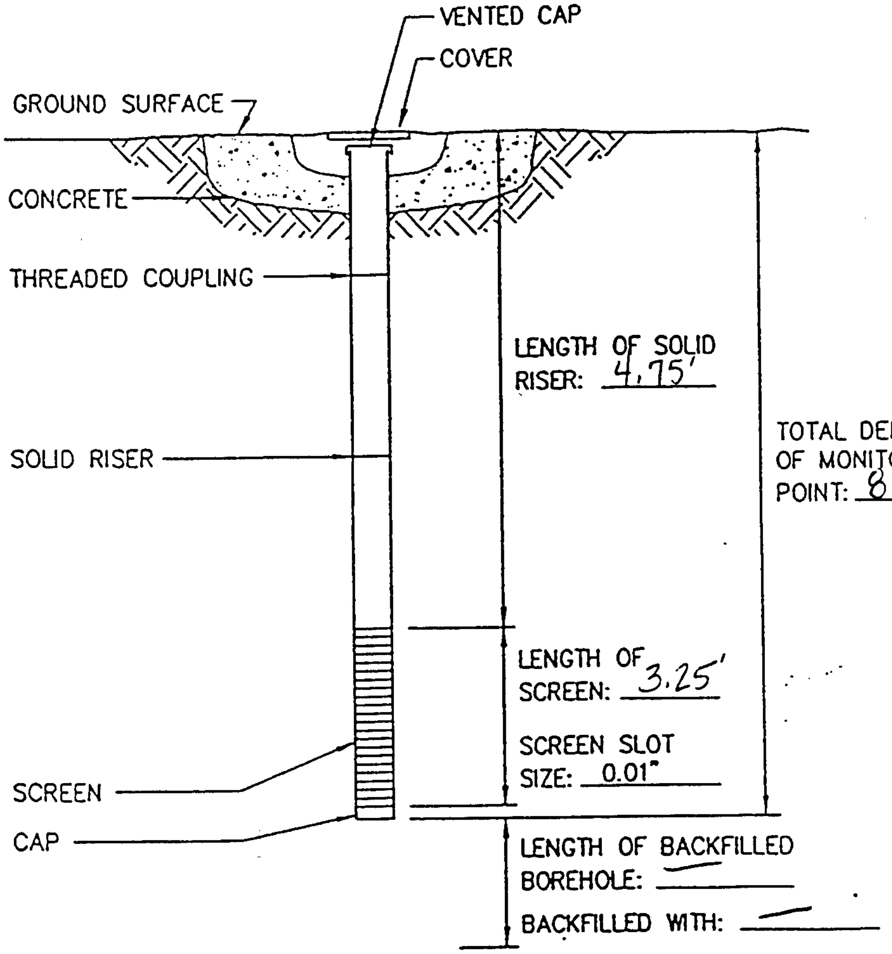
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW10
JOB NUMBER 722450.36020 INSTALLATION DATE 4/10/97 LOCATION
ATUM ELEVATION GROUND SURFACE ELEVATION
DATUM FOR WATER LEVEL MEASUREMENT TOC
SCREEN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC BOREHOLE DIAMETER 1/2"
Boring Method: Hand-Driven ES REPRESENTATIVE Cindy Merrill



LENGTH OF SOLID RISER: 4.75'

TOTAL DEPTH OF MONITORING POINT: 8.0'

LENGTH OF SCREEN: 3.25'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: —

BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 1.75 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 8.0 FEET BELOW DATUM.
GROUND SURFACE FEET

FIGURE 3.4

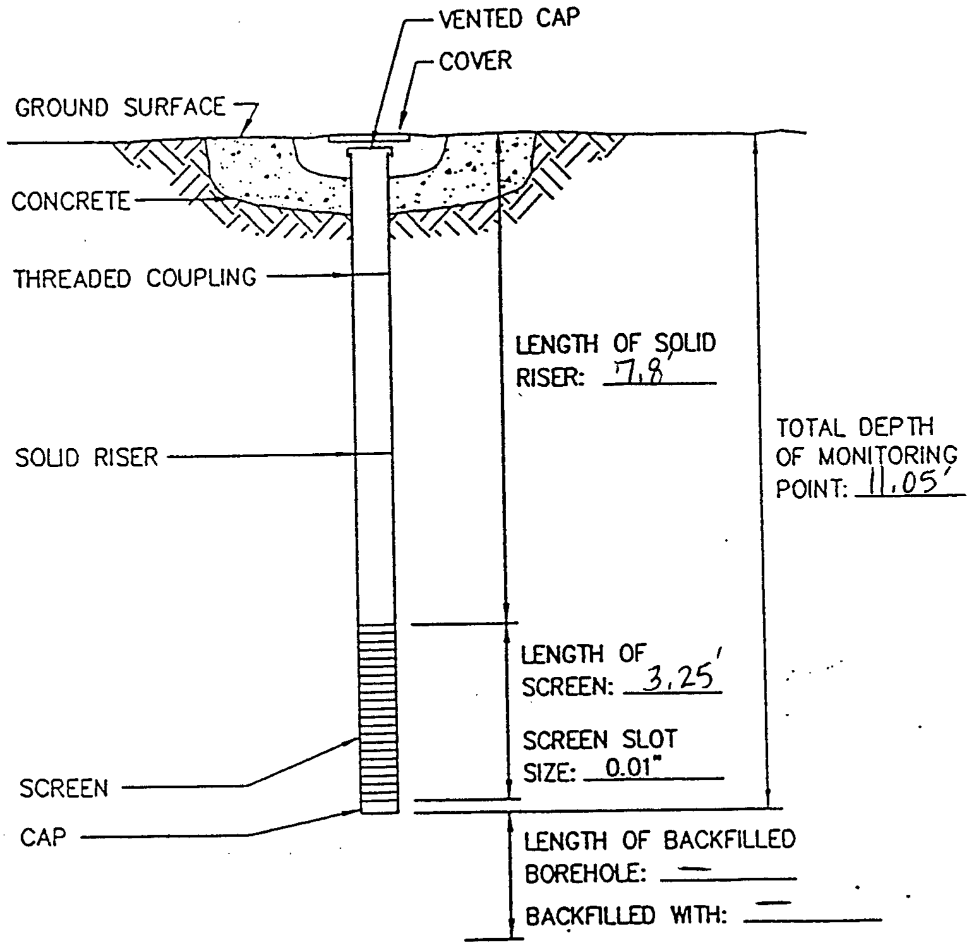
MONITORING POINT
INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS
ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW 11
JOB NUMBER 722450.36020 INSTALLATION DATE 4/10/97 LOCATION
.TUM ELEVATION GROUND SURFACE ELEVATION
DATUM FOR WATER LEVEL MEASUREMENT TOC
EN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC BOREHOLE DIAMETER 1/2"
Boring Method: Hand-Driven ES REPRESENTATIVE Bob Nagel



LENGTH OF SOLID RISER: 7.8'

TOTAL DEPTH OF MONITORING POINT: 11.05'

LENGTH OF SCREEN: 3.25'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: —

BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 10.50 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 11.05 FEET BELOW DATUM.
GROUND SURFACE FEET

FIGURE 3.4

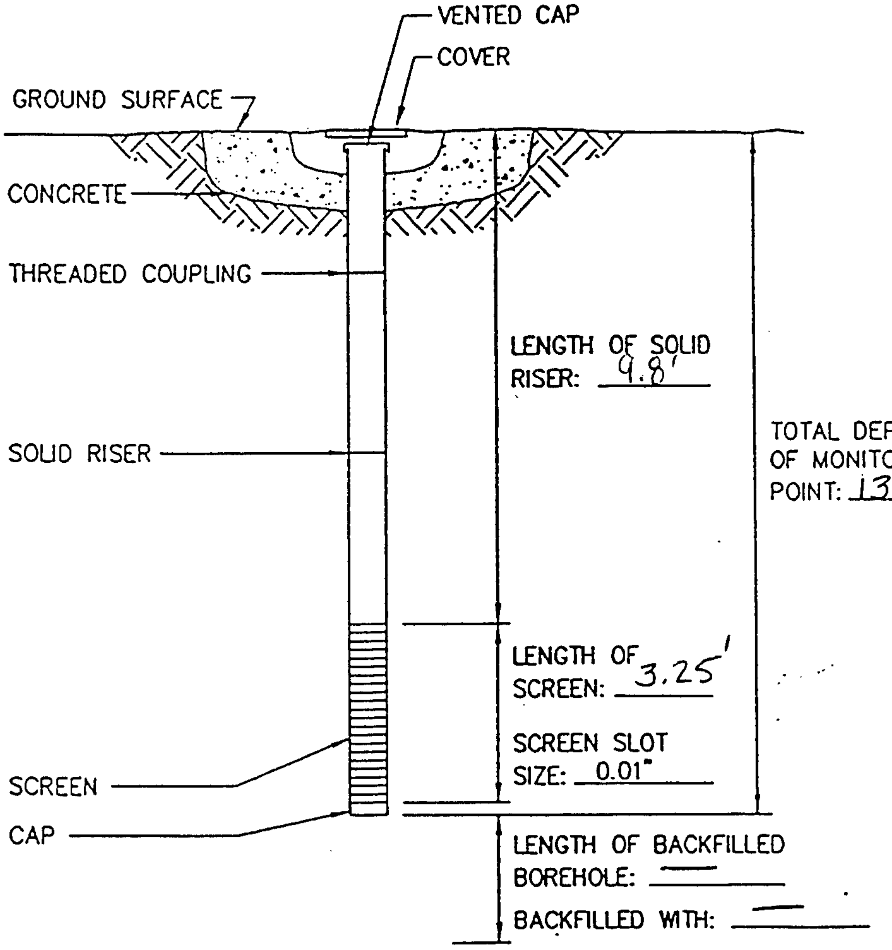
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW13
JOB NUMBER 722450.36020 INSTALLATION DATE 4/9/97 LOCATION
ATUM ELEVATION GROUND SURFACE ELEVATION
DATUM FOR WATER LEVEL MEASUREMENT TOC
SCREEN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC BOREHOLE DIAMETER 1"
Boring Method: Geoprobe (no core barrel) ES REPRESENTATIVE Cindy Merrill



LENGTH OF SOLID RISER: 9.8'
TOTAL DEPTH OF MONITORING POINT: 13.05'
LENGTH OF SCREEN: 3.25'
SCREEN SLOT SIZE: 0.01"
LENGTH OF BACKFILLED BOREHOLE: —
BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 2.59 FEET BELOW DATUM.
TOTAL MONITORING POINT DEPTH 13.05 FEET BELOW DATUM.
GROUND SURFACE FEET

FIGURE 3.4

MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1 MONITORING POINT NUMBER TW14

JOB NUMBER 722450.36020 INSTALLATION DATE 4/10/97 LOCATION

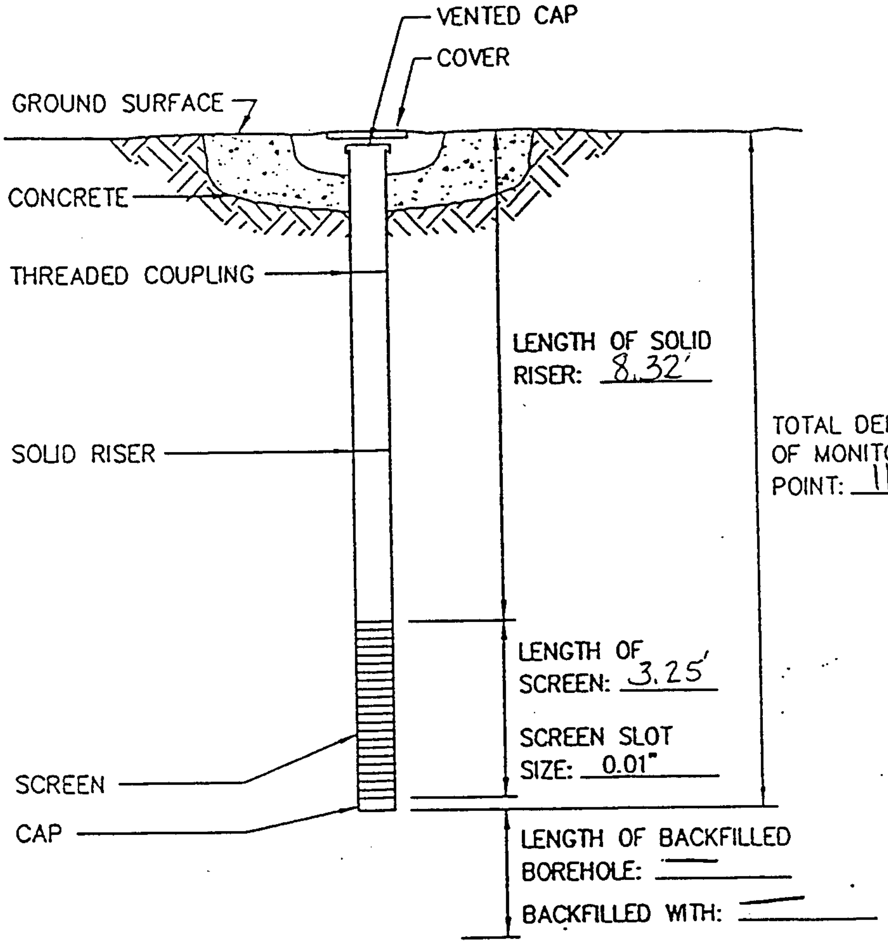
ATUM ELEVATION GROUND SURFACE ELEVATION

ATUM FOR WATER LEVEL MEASUREMENT TOC

EN DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC SLOT SIZE 0.010"

R DIAMETER & MATERIAL 1/2" ID Schedule 40 PVC BOREHOLE DIAMETER 1/2"

Boring Method: Hand-Driven ES REPRESENTATIVE Rob Nagel



LENGTH OF SOLID RISER: 8.32'

TOTAL DEPTH OF MONITORING POINT: 11.57'

LENGTH OF SCREEN: 3.25'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: —

BACKFILLED WITH: —

(NOT TO SCALE)

STABILIZED WATER LEVEL 4.48 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 11.57 FEET BELOW DATUM.

GROUND SURFACE FEET

FIGURE 3.4

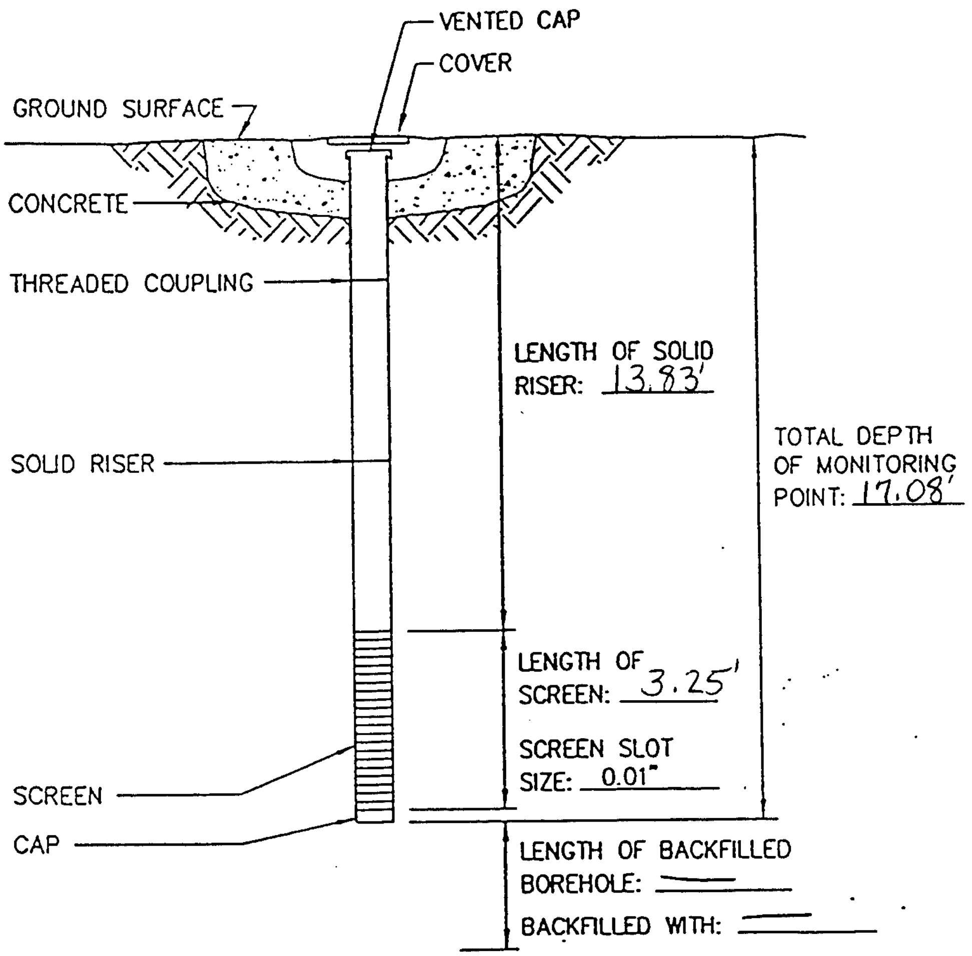
MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

MONITORING POINT INSTALLATION RECORD

JOB NAME Altus AFB OU-1
MONITORING POINT NUMBER TW15
JOB NUMBER 722450.36020
INSTALLATION DATE 4/14/97
LOCATION
ATUM ELEVATION
GROUND SURFACE ELEVATION
DATUM FOR WATER LEVEL MEASUREMENT TOC
SCREEN DIAMETER & MATERIAL ½" ID Schedule 40 PVC
SLOT SIZE 0.010"
RISER DIAMETER & MATERIAL ½" ID Schedule 40 PVC
BOREHOLE DIAMETER 1"
Boring Method: Geoprobe (no core barrel)
ES REPRESENTATIVE Cindy Merrill



LENGTH OF SOLID RISER: 13.83'

TOTAL DEPTH OF MONITORING POINT: 17.08'

LENGTH OF SCREEN: 3.25'

SCREEN SLOT SIZE: 0.01"

LENGTH OF BACKFILLED BOREHOLE: ——

BACKFILLED WITH: ——

(NOT TO SCALE)

STABILIZED WATER LEVEL 2.21 FEET BELOW DATUM.

TOTAL MONITORING POINT DEPTH 17.08 FEET BELOW DATUM.

GROUND SURFACE FEET

FIGURE 3.4

MONITORING POINT INSTALLATION RECORD

OU1
Remediation by Natural Attenuation TS
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.

Denver, Colorado

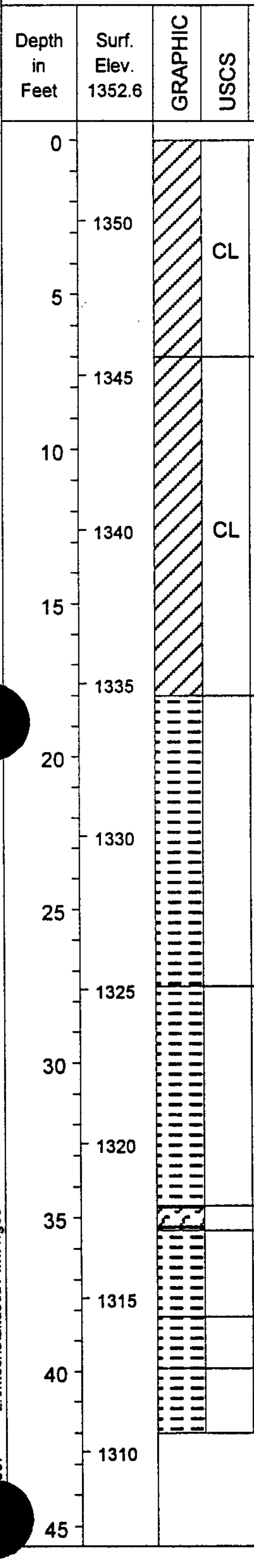
PARSONS
PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado (303) 831-8100

LOG OF BORING 000IU1-MW1

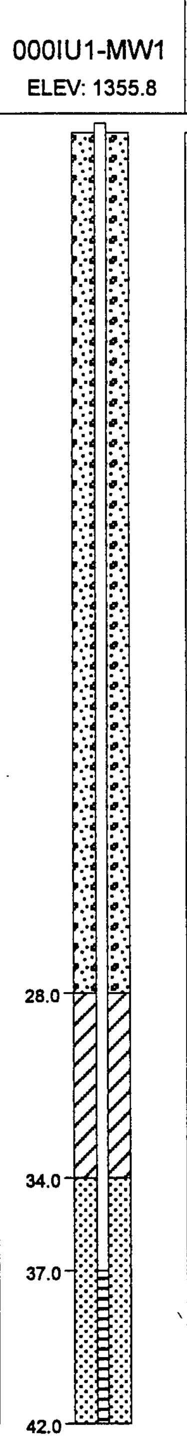
(Page 1 of 1)

OPERABLE UNIT 1
ALTUS AFB, OKLAHOMA

Date Completed	: 5/20/97	Northing	:
Drilling Method	: Hollow Stem Auger	Easting	:
Drilling Contractor	: Associated Env.	Ground Elevation	: 1352.6 (feet msl)
Boring Logged By	: Woodward-Clyde	TOC Elevation	: 1355.8 (feet msl)



USCS	DESCRIPTION
CL	Reddish-brown, medium stiff, lean CLAY, low plasticity, moist
CL	Dark brownish-gray, soft, lean CLAY, low plasticity, trace fine sand, very moist
	Red to reddish-brown weathered SHALE, blocky texture with fissile structure, dry
	Reddish-brown SHALE, dry
	Light greenish-gray SILTSTONE
	Reddish-brown SHALE, dry
	Fracture zone, very weathered, water bearing



Well Construction Information

WELL CASING
Casing Material : Sched.40 PVC
Casing Diameter : 2" ID
Joint Type : threaded

WELL SCREEN
Screen Material : Sched.40 PVC
Screen Diameter : 2" ID
Screen Slot Size : 0.010 "
Screen Joint Type : threaded

ANNULUS
Cement Grout : 0 - 28'
Bentonite Pellets : 28' - 34'
20-40 Silica Sand : 34' - 42'
Borehole Diameter: 8"

NOTES

L:\ntech3\altus\iu1-mw1.ge3 997

Woodward-Clyde

One Old Mill Building
101 South 108th Avenue
Omaha, Nebraska 68154

Tel. No. (402) 334 8181
Fax No. (402) 334-1984

FAX TRANSMITTAL

DATE: 23 June 97

PROJECT NO. TT13

No. of pages 8
(including cover sheet)

TO: Rob Nagel
PARSONS

FAX NO.: 303-831-8208

FROM: Denny Jorgenson
Woodward-Clyde Omaha

☐ ***URGENT***
Please deliver at once
___ **Reply requested**
_X_ **Information only**
___ **For your files**
___ **For your distribution**

REGARDING: 000IU1-MW1 Well Logs

REMARKS :

HTRW DRILLING LOG

DISTRICT Tulsa USACE

HOLE NUMBER 000IU1-MW 1

SHEET 1 OF SHEETS 6

1. COMPANY NAME Woodward-Clyde

2. DRILL SUBCONTRACTOR Associated Environmental Industries

PROJECT Altus AFB-TCE Vertical Extent Eval.

4. LOCATION Altus AFB Oklahoma

5. NAME OF DRILLER Ron Newton

6. MANUFACTURER'S DESIGNATION OF DRILL Failing F-10

7. SIZES AND TYPES OF DRILLING AND SAMPLING EQUIPMENT
6 5/8" ID, 11" OD HSA
8" PVC Casing
7 7/8" Rotory Bit
2" PVC Casing and Screen
NX Core Barrel - 5 ft. long

8. HOLE LOCATION See Figure Below

9. SURFACE ELEVATION G.L. = 1352.6 TOC = 1355.80

10. DATE STARTED 5/13/97

11. DATE COMPLETED 5/20/97

12. OVERBURDEN THICKNESS 18 ft.

15. DEPTH GROUNDWATER ENCOUNTERED 26 ft. during drilling

13. DEPTH DRILLED INTO ROCK 24 ft.

16. DEPTH TO WATER AND ELAPSED TIME AFTER DRILLING COMPLETED 9.60 ft below ~~TOC~~ GL KW 5/20/97

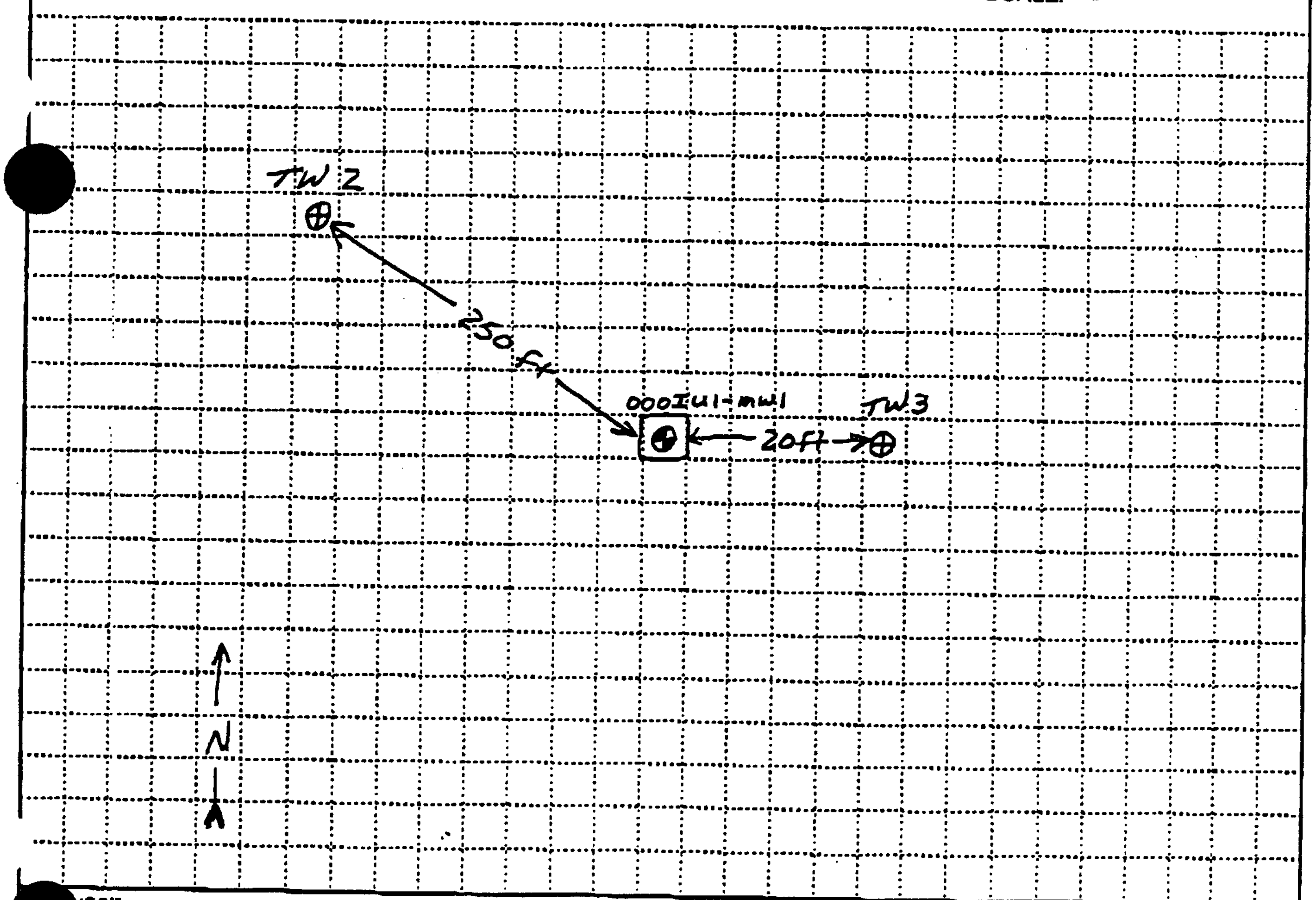
14. TOTAL DEPTH OF HOLE 42 ft.

17. OTHER WATER LEVEL MEASUREMENTS (SPECIFY) 13.29 ft below TOC 5/29/97

18. GEOTECHNICAL SAMPLES	DISTURBED —	UNDISTURBED 2	19. TOTAL NUMBER OF CORE BOXES 1			
20. SAMPLES FOR CHEMICAL ANALYSIS	VOC Soil-1/Water-1	METALS Soil-1/Water-1	OTHER (SPECIFY) Water NA-1	OTHER (SPECIFY)	OTHER (SPECIFY)	21. TOTAL CORE RECOVERY 76%
22. DISPOSITION OF HOLE	BACKFILLED	MONITORING WELL X	OTHER (SPECIFY)	23. SIGNATURE OF INSPECTOR		

LOCATION SKETCH/COMMENTS

SCALE:



ECT Altus AFB-TCE Vertical Extent Eval.

HOLE NO. 000IU1-MW 1

ENG FORM 5056-R, AUG 94

(Proponent: CECW-EG)

HTRW DRILLING LOG

(CONTINUATION SHEET)

HOLE NUMBER: 000IU1-MW1

PROJECT: Altus AFB - TCE Vertical Extent Evaluation

INSPECTOR:

SHEET 2 OF 6 SHEETS

ELEV. (a)	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)
	0	Lean Clay (CL) - dk brown, roots -	BZ=ND BKgd=ND				Topsoil
		Lean Clay (CL) - med. stiff, moist, reddish brown, low plastic w/ thin plastic zones. Fill					Fill
	1						
	2						
	3						
	4						
	5		BZ=ND				
	6						
	7	Lean Clay (CL) soft, very moist, dark brownish gray, low plastic, trace of fine sand. Alluvium					Alluvium
	8						
	9						
	10		BZ=ND				

PROJECT: Altus AFB - TCE Vertical Extent Eval.

HOLE NO. 000IU1-MW1

ENG FORM 5056A-R, AUG 94

(Proponent: CECW-EG)

HTRW DRILLING LOG (CONTINUATION SHEET)

OJECT Altus AFB- TCE Vertical Extent Evaluation

INSPECTOR

HOLE NUMBER 000IU1-MW1

SHEET 3 OF 6 SHEETS

[illegible]V.	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)
		Lean Clay (CL) - med. stiff, moist, reddish brown, low plastic, Residual Clay					Residual Clay
	11						
	12						
	13						
	14						
	15		BZ=ND				
	16						
	17						
	18	Shale - tougher drilling, dry, red to reddish brown, blocky texture w/ fissile structure, weathered.					Weathered Shale
	19						
	20		BZ=ND				

PR[illegible]CT Altus AFB - TCE Vertical Extent Eval.

HOLE NO. 000IU1-MW1

ENG FORM 5056A-R, AUG 94

(Proponent: CECW-EG)

HTRW DRILLING LOG

(CONTINUATION SHEET)

HOLE NUMBER: 000IU1-MW1

PROJECT: Altus AFB - TCE Vertical Extent Evaluation

INSPECTOR:

SHEET 4 OF 6 SHEETS

ELEV. (a)	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)
		Weathered Shale (as above)	BZ=ND				Weathered Shale
		← cuttings becoming moist.					
	21						
	22						
	23	← cutting dry again. tougher drilling.					
	24						
	25		BZ=ND				
	26	← wet zone - containing small pieces of shale					
	27						
		Shale Bedrock - tough drilling, hard consistency, dry, reddish brown, Shale					Shale
	28						
	29						set surface casing.
	30		BZ=ND				Stopped at 30 ft. 5/13/97

PROJECT: Altus AFB - TCE Vertical Extent Eval.

HOLE NO.: 000IU1-MW1

ENG FORM 5056A-R, AUG 94

(Proponent: CECW-EG)

HTRW DRILLING LOG (CONTINUATION SHEET)

ROJECT Altus AFB - TCE Vertical Extent Evaluation	INSPECTOR	HOLE NUMBER 000IUI-MW1 SHEET 5 OF SHEETS 6

	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)
Fractures	31	NCR - No Core Recovery	Bkgd=ND BZ=ND	Core Box #1		Core Run #1	Started 5/16/97 R= 1.0'/3.0' RQD= 0.4'/3.0'
	32	Shale - Dark red, hard. Core broken up during extraction from core barrel.	HS=ND	Geotech			
	33	NCR				Core Run #2	R= 4.3'/5.0' RQD= 1.5'/5.0'
	34	Shale ← Thin horizontal siltstone layer					
	35	Siltstone - light greenish gray.	BZ=ND				Siltstone
	36	Shale } Gypsum Inclusion Zone					Shale
	37		HS=ND		VOCs metals VOCs Metals VOCs metals	} Lab Duplicate # 000IUI-SM-MW01-045 @ 9:50 } COE split	
	38	← Fracture zone from 38.2 to 39.9 ft. Very weathered - appears to be water bearing				Core Run #3	R= 3.1'/3.1' RQD= 1.8'/3.1'
	39	} Large gypsum inclusion					Drill rig lost circulation - Lost 300 gallons water from pit.
	40		BZ=ND				

31
32
33
34
35
36
37
38
39
40

JECT Altus AFB - TCE Vertical Extent Eval.	HOLE NO. 000IUI-MW1

HTRW DRILLING LOG (CONTINUATION SHEET)

PROJECT	AHus AFB- TCE Vertical Extent Evaluation
INSPECTOR	
HOLE NUMBER	000IU1-MW1
SHEET 6 OF 6 SHEETS	

~~ELEV.~~ (a)	DEPTH (b)	DESCRIPTION OF MATERIALS (c)	FIELD SCREENING RESULTS (d)	GEOTECH SAMPLE OR CORE BOX NO. (e)	ANALYTICAL SAMPLE NO. (f)	BLOW COUNT (g)	REMARKS (h)
Fracture:		Shale (as above)					Shale
	41			Geotech			End of Coring
			BZ=ND				
	42						Bottom of Boring @ 42 ft. Installed Monitoring Well (5/16/97)

PROJECT AHus AFB-TCE Vertical Extent Eval.

HOLE NO. 000IU1-MW1

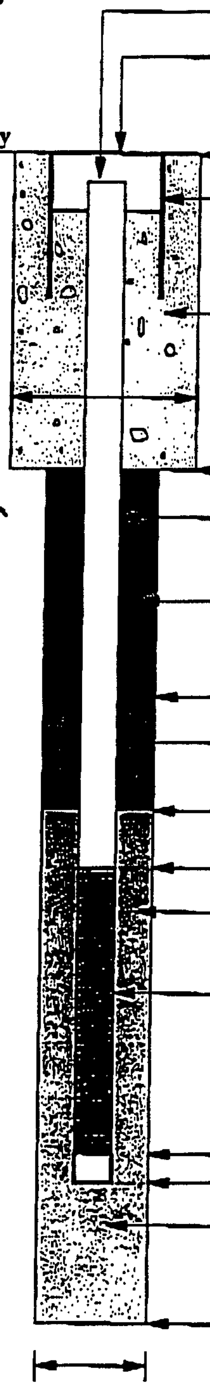
MONITORING WELL CONSTRUCTION LOG

Project Name Altus AFB-TCE Vertical Extent Eval.
Location Altus AFB operable Unit No. 1
Installed By Associated Environmental Industries
Inspected By K. Wunder, K. Wofford
Method of Installation 7 7/8" Rotary Wash Boring
Remarks 8" PVC surface casing set from ground surface to 30 ft. bgs.

Piez/Well No. 000IU1-MW1
Project No. TT13
Date 5/16/97 **Time** —

* Monitoring well completed with an aboveground protective cover.

	AGS	Elevation (feet)
Elevation of top of riser *	3.2	1355.80
Depth of riser ~~below~~ above ground *	3.5	
Ground Elevation	—	1352.6



Generalized Stratigraphy

Lean Clay (CL) - Fill
7 Lean Clay (CL) - Alluvium
18 Shale
42

I.D./Type of surface casing 6-inch Steel Cover

Type of surface seal Concrete

Diameter of surface seal 8-inch

	BGS	Elevation (feet)
Depth of surface seal	3.0	
Depth to top of seal	28.0	
Depth of top of filter pack	34.0	
Depth of top of screen	37.0	
Depth of bottom of screen	41.8	
Depth of bottom of plugged blank section	42.0	
Depth of bottom of boring	42.0	1310.6

I.D./Type of riser pipe 2-inch, Schedule 40 PVC

Type of backfill Cement/Bentonite Grout

Type of seal Bentonite Chips

Type of filter pack 20-40 gradation silica sand

I.D./Type of screen 2-inch, Schedule 40 PVC

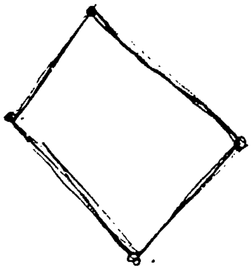
Screen slot size 0.010-inch factory slot

Type of backfill below observation well 20-40 gradation sand.

Diameter of boring 7 7/8-inches

TABLE 2.2
GROUND ELEVATIONS
OU-1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA

Location	Northing	Easting	Elev
OU-1-01			1351.96
OU-1-02			1352.10
OU-1-03			1352.72
OU-1-04			1352.22
OU-1-05	486773.68	1588381.48	1352.21
OU-1-06	486323.05	1589280.83	1348.00
OU-1-TW1	486584.82	1588939.63	1356.00
OU-1-TW2	486323.44	1589275.34	1348.00
OU-1-TW3	486098.62	1589497.14	1353.09
OU-1-TW4	485541.26	1590128.53	1346.62
OU-1-TW5	485158.54	1590372.25	1343.23
OU-1-TW6	484937.95	1590755.45	1341.74
OU-1-TW7	484360.33	1591003.01	1340.07
OU-1-TW8	485669.38	1589143.29	1350.04
OU-1-TW9	486693.59	1589483.8	1352.97
OU-1-TW10	485624.43	1590515.69	1342.80
OU-1-TW11	485173.72	1590028.15	1348.52
OU-1-TW13	485253.02	1590737.22	1342.37
OU-1-TW14	484700.65	1590361.81	1342.52
OU-1-TW15	485132.97	1589045.83	1349.72
000IU1-MW1	486098.62	1589477.14	1352.6
WL018			1353.14
WL019	486525.54	1588389.35	1354.12
WL020	486919.68	1588397.22	1359.08
WL021			1351.94
WL022			
WL060	485796.53	1590693.81	1344.67
WL061			1337.07
WL062			1338.21
SB10WS			1355.64
SB10WD			1355.64
SB11WS			1351.88
SB11WD			1351.88
SB15WS			1355.11
SB15WD			1355.11
SB16WS			1357.71
SB16WD			1357.71
Feet above mean sea level.			
Feet below top of casing.			



Location: Altus AFB, OK

Date: 3 Oct, 1996

Survey Data

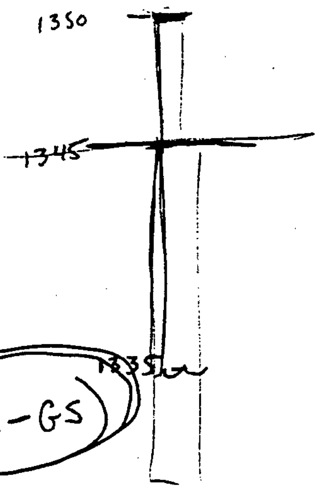
Operable Unit 01

Location Name	Well Depth	Horizontal Angle Degree	Minute	Distance ft	Verticle Distance ft	TOC Elev (ft msl)
S SB10W	12	89	30	639.16	-1.30	1355.32
D SB10W	21.3	89	31	638.86	-1.35	1355.27
SB10W	Ground Elev	89	25	639.20	-0.98	1355.64
S SB11W	11.75	96	2	764.74	-4.96	1351.66
D SB11W	20	96	1	764.80	-5.04	1351.58
SB11W	Ground Elev	95	57	764.57	-4.74	1351.88
S SB15W	7	9	10	367.64	-1.61	1355.01
D SB15W	18.2	9	11	367.36	-1.61	1355.01
SB15W	Ground Elev	9	10	368.24	-1.51	1355.11
S SB16W	12.25	98	13	509.07	0.90 0.90	1357.52
D SB16W	24.1	98	12	509.47	0.80 0.80	1357.42
SB16W	Ground Elev	98	7	509.17	1.09 1.09	1357.71
04-7-01		356	46	271.27	-2.10	1354.52
04-1-02		356	40	261.34	-1.98	1354.64
06-1-VP		355	33	260.88	-1.97	1354.65

Notes on site: Rod and Instr Hgt 5.70 North is 0 degrees The angle is right, setup point is Corps of Engineers Monument Number WL 019

Surveyed in using SOKKIA Set 6 by SCAPS crew Kansas City District Corps of Engineers, D. Veldhuis operator

TOC(WL019) = 1356.62



(TOC - DTW)

DTW - (TOC - GS)

10 - (5) ✓

5 - (50 - 51)

5 + 1

ENGINEERING-SCIENCE, INC.

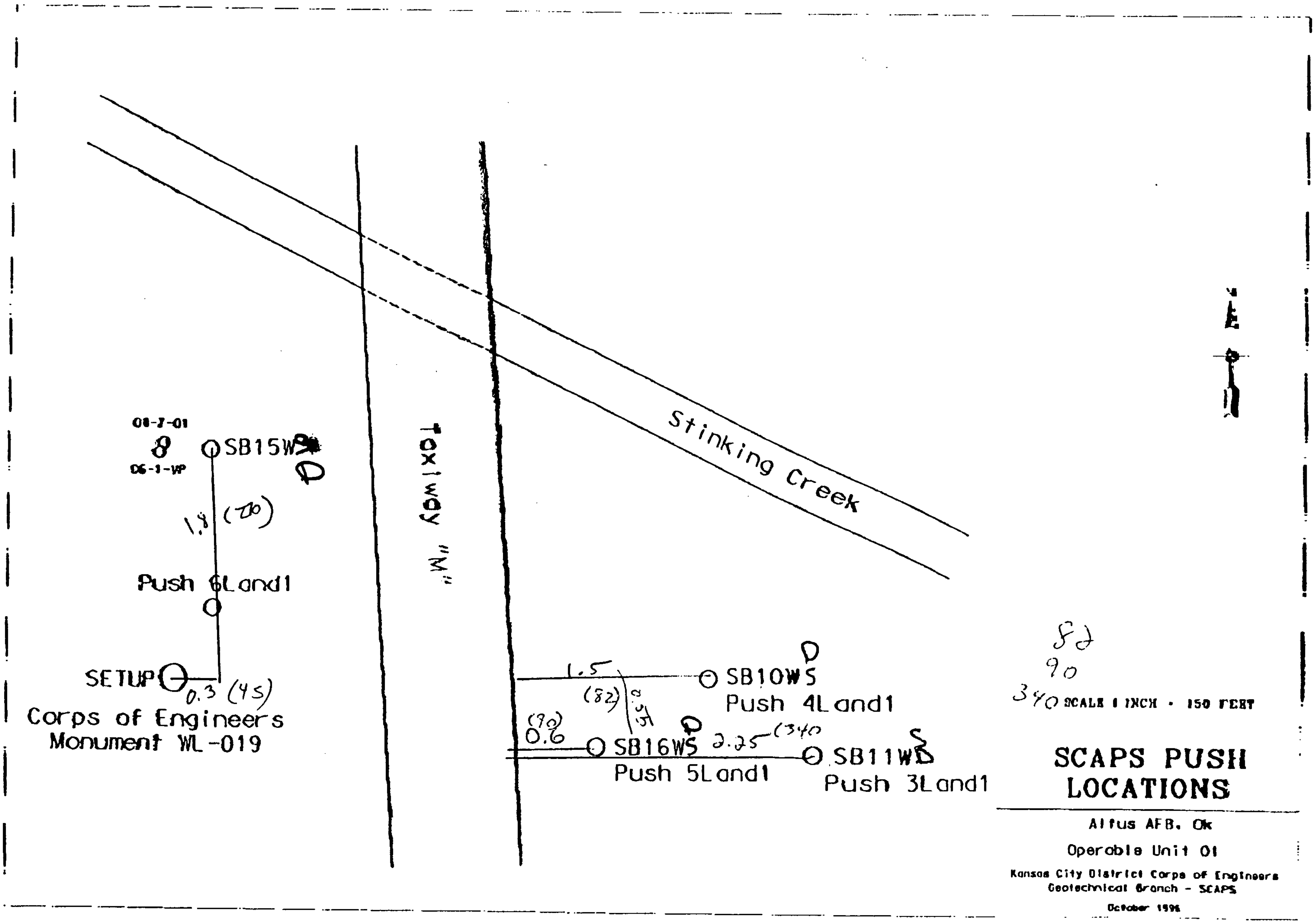
Quality Improvement Process Awareness

SB11WD onto SB15WS map

TS sampling

all onto site map

one symbol for each location label SB10W(S,D)



SCALE 1 INCH = 150 FEET

SCAPS PUSH LOCATIONS

Altus AFB. Ok

Operable Unit 01

Kansas City District Corps of Engineers
Geotechnical Branch - SCAPS

October 1996

SURVEY DATA FOR OPERABLE UNIT 01

SCAPS POINT	NORTH COORD.	EAST COORD.	GROUND ELEV. (FT)	TOP OF RISER ELEV. (FT)
1	487273	1588452	1350.8	1351.7
2	486833	1588878	1355.0	1355.6
3	486575	1589178	1347.1	1347.7
4	486321	1589471	1351.4	1352.0
5	486021	1590010	1351.9	1352.6
6	485738	1590323	1343.2	1343.8
7	485489	1590587	1343.0	1343.6
8	486965	1588407	1350.8	1351.7
9	486568	1588883	1354.8	1355.2
10	486319	1589152	1348.6	1349.4
11	486066	1589466	1351.8	1352.3
12	485773	1590000	1351.3	1351.9
13	485498	1590312	1342.9	1343.5
14	485269	1590599	1342.7	1343.5
15	486709	1588397	1352.0	1352.5
16	486315	1588881	1354.1	1354.9
17	486068	1589151	1349.4	1350.0
18	485868	1589458	1351.2	1351.9
19	485510	1589991	1350.5	1351.1
20	485241	1590300	1343.1	1343.6
21	484947	1590574	1341.1	1341.8
22	484863	1590841	1341.4	1341.9
23	486449	1588402	1353.2	1353.8
24	486076	1588875	1353.6	1354.3
25	485816	1589148	1349.1	1349.8
26	485570	1589457	1351.0	1351.6

27	485254	1589983	1349.7	1350.2
28	484954	1590286	1342.8	1343.5
29	484712	1590564	1341.0	1341.5
30	484628	1590889	1340.1	1340.5
31	486195	1588398	1354.8	1355.6
32	485816	1588870	1352.2	1353.0
33	485567	1589142	1349.5	1350.1
34	485309	1589452	1350.5	1351.2
35	484969	1589971	1349.6	1350.4
36	484716	1590272	1343.4	1344.1
37	484479	1590556	1341.4	1342.0
38	485929	1588391	1356.1	1356.7
39	485560	1588867	1351.6	1352.3
40	485319	1589129	1348.9	1349.6
41	485061	1589444	1349.6	1350.4
42	484733	1589965	1348.9	1349.6
43	484338	1590248	1345.5	1346.2
44	484245	1590550	1341.0	1341.5
45	486999	1587702	1359.6	1360.3
46	486784	1587825	1359.1	1359.8
47	486531	1587861	1357.7	1358.5
48	486283	1587883	1357.9	1358.3
49	486025	1587914	1358.1	1358.6
50	485768	1587970	1358.4	1358.9
51	485682	1588388	1356.9	1357.6
52	484429	1589960	1348.9	1349.4
53	483951	1590541	1342.5	1343.2
54	483958	1591021	1337.9	1338.5
55	484345	1591052	1338.1	1338.7

56	484950	1591062	1342.5	1342.9
57	485225	1590732	1341.5	1342.5
58	485694	1590740	1343.1	1344.0
59	486042	1590337	1345.4	1345.9
60	486316	1590029	1353.5	1354.1
61	486574	1589478	1351.5	1352.1
62	486829	1589160	1348.7	1349.4
63	487088	1588889	1356.2	1356.9
64	485197	1588863	1350.4	1350.9
65	484948	1589141	1346.8	1347.3
66	484790	1589434	1348.3	1348.9
67	484891	1588916	1348.1	1348.7
68	484520	1589060	1350.2	1351.0

ALTUS

Well location	screened interval in feet below ground
02F392	15.8-18.8
02F392	4.0-7.0
SB15	15.7-18.7
SB15	21.1-24.1
SB 15	17.0 -20.0
SB 15 & near ditch	18 -21.0
05LAND1 (near SB16)	9.3-12.3
06LAND1 (near SB15)	4.0-7.0
near SB11	8.8-11.8
near SB10	9-12.0

303-831-8100
303-831-8208

MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Location Altus AFB - OU 1
Well Identification OU-1-05

Job Name: AFCEE-RNA
by RN/[✓ CM]
Date: 4/9/97
Measurement Datum TOC

Pre-Development Information

Time (Start): 1:03p

Water Level: 7.67' below TOC

Total Depth of Well: 30.3

30.3
7.7
22.6
0.163
678
1356
226
3.6838

3.7
x 10
37.0 gallons

Water Characteristics

Color red - brown   Clear [✓ Cloudy]
Odor: [✓ None]   Weak   Moderate   Strong
Any Films or Immiscible Material no
pH NM   Temperature (°C) 22.6
Specific Conductance ~~(µS/cm)~~ 2030 umhos
Dissolved Oxygen (mg/L) 0.2
Redox (mV) -23

1:35 Pumped dry in 4 minutes
let sit 1/2 hour to recharge

Pumped dry again
2:15p let sit 1/2 hour

Interim Water Characteristics

Gallons Removed
Time:
pH
Temperature (°C)
Specific Conductance(µS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

Continued to pump dry and allow recharge periodically until 4/17/97 — water is clear this morning

Post-Development Information

Time (Finish): 8:18a 4/17/97

Water Level: 7.95' below TOC

Total Depth of Well: 30.70' below TOC

Approximate Volume Removed: approx. 40 gallons over 8 days

Water Characteristics

Color   [✓ Clear] Cloudy
Odor: [✓ None]   Weak   Moderate   Strong
Any Films or Immiscible Material None
pH 7.87   Temperature (°C) 15.7
Specific Conductance (µS/cm) 4680
Dissolved Oxygen (mg/L) 0.7
Redox (mV) 210

Comments:

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MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA
Location Altus AFB - OU 1
by RN/CM
Date: 4/16
Well Identification OU-1-06
Measurement Datum TOC

Pre-Development Information
Time (Start): 1017

Water Level: 8.25-TOC
Total Depth of Well: 23'

Water Characteristics

Color red-brown Clear [✓ Cloudy]
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material no
pH 7.46 Temperature (°C) 17.7
Specific Conductance (μS/cm) 5060
Dissolved Oxygen (mg/L)
Redox (mV) 116.5

1047 - Dry
2.5 gallons purged

Interim Water Characteristics

Gallons Removed
Time:

pH

Temperature (°C)

Specific Conductance(μS/cm)

Dissolved Oxygen (mg/L)

Redox (mV)

Continued to pump dry periodically throughout day (4/16) and allow recharge

Post-Development Information
Time (Finish): 9:50a 4/17/97 (beginning of sampling)

Water Level: 13.07' Below TOC
Total Depth of Well: 25.80' below TOC

Approximate Volume Removed: approx. 20 gallons removed 4/16

Water Characteristics

Color red-brown Clear [✓ Cloudy]
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material none
pH NM Temperature (°C) 18.1
Specific Conductance (μS/cm) 7040
Dissolved Oxygen (mg/L) 1.5
Redox (mV) 134.4

Comments:

$$\begin{array}{r} 23 \\ -\ 6 \\ \hline 17 \\ \hline 2 \end{array} = 8.5$$

$$\begin{array}{r} 8.5 \\ \times\ 3.3 \\ \hline 255 \\ 2550 \\ \hline 28.00 \end{array}$$ gallons

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MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Location Altus AFB - OU 1
Well Identification TW1

Job Name: AFCEE-RNA
by RN/CM Date: 4/15/97
Measurement Datum TOC

Mike Cook
(EPA)
developed

Pre-Development Information

Time (Start): 3:00 p

Water Level: 12.2

Total Depth of Well: 15.88

Water Characteristics

Color ______ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material —
pH — Temperature (°C) 18.2
Specific Conductance (μS/cm) 4600
Dissolved Oxygen (mg/L) 4.0
Redox (mV) 180

Interim Water Characteristics

Gallons Removed 2.5 gal
Time: 3:30p

pH —

Temperature (°C) 18.0

Specific Conductance(μS/cm) 4610

Dissolved Oxygen (mg/L) 4.0

Redox (mV) 169

Post-Development Information

Time (Finish): 4:00p

Water Level: 12.2' below TOC

Total Depth of Well: 15.88' below TOC

Approximate Volume Removed: 3.0 gal

Water Characteristics

Color ______ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material ______
pH 6.9 Temperature (°C) 18.5
Specific Conductance (μS/cm) 4610
Dissolved Oxygen (mg/L) 4.1
Redox (mV) 165

Comments:

MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA
Location Altus AFB - OU 1
by RN/CM
Date: 4/16/97
Well Identification TW2
Measurement Datum TOC

Pre-Development Information
Time (Start): 3:00p

Water Level: 4.38'
Total Depth of Well: ~14' bgs

Water Characteristics

Color red-brown Clear [✓ Cloudy]
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material NO
pH 7.7 Temperature (°C) 21
Specific Conductance (µS/cm) 8000
Dissolved Oxygen (mg/L) 4.9
Redox (mV) 76.9

Interim Water Characteristics

Gallons Removed approx. 0.25
Time: 4:30p

pH 7.91

Temperature (°C) 21.0

Specific Conductance(µS/cm) 8000

Dissolved Oxygen (mg/L) 4.9

Redox (mV) 42.8

Well is dry - even though I pumped at lowest flow rate possible.

Post-Development Information
Time (Finish): 10:13a

Water Level: —
Total Depth of Well: 13.95' below TOC

Approximate Volume Removed: approx. 4 gallons

Water Characteristics

Color clear [✓ Clear] Cloudy
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material none
pH NM Temperature (°C) 18.5
Specific Conductance (µS/cm) 8630
Dissolved Oxygen (mg/L) 3.5
Redox (mV) 135

Comments:

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MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Location Altus AFB - OU 1
Well Identification TW3
Job Name: AFCEE-RNA
by RN/CM Date: 4/15/97
Measurement Datum

Pre-Development Information

Time (Start): 3:20p

Water Level: 9.69

Total Depth of Well: 12.72

Water Characteristics

Color Red-brown
Clear [✓ Cloudy]
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material none
pH NM
Temperature (°C) 18.2
Specific Conductance (µS/cm) 6770
Dissolved Oxygen (mg/L) 0.3
Redox (mV) 120

Interim Water Characteristics

Gallons Removed 1.5

Time: 330p

pH NM

Temperature (°C) 18.2

Specific Conductance(µS/cm) 6820

Dissolved Oxygen (mg/L) 0.2

Redox (mV) 106

Post-Development Information

Time (Finish): 3:35

Water Level: —

Total Depth of Well: 12.72

Approximate Volume Removed: 2.0 gal

Water Characteristics

Color
Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material
pH 6.9
Temperature (°C) 18.3
Specific Conductance (µS/cm) 6820
Dissolved Oxygen (mg/L) 0.1
Redox (mV) 103

Comments:

MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA
Location Altus AFB - OU 1
by RN/CM
Date: 4/16/97
Well Identification TW4
Measurement Datum TOC
Mike Cook/EPA

Pre-Development Information

Time (Start): 1130a

Water Level: ~ 6.5' bgs
Total Depth of Well: 8.10

Water Characteristics

Color red-brown
Clear [✓ Cloudy]
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material
pH
Temperature (°C)
Specific Conductance (µS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

Well pumped dry too quickly to measure parameters

Interim Water Characteristics

Gallons Removed
Time:
pH
Temperature (°C)
Specific Conductance(µS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

Well does not produce enough water to fill VOAs - Cannot collect sample or develop properly

Post-Development Information

Time (Finish):
Water Level:
Total Depth of Well:
Approximate Volume Removed:

Water Characteristics

Color
Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material
pH
Temperature (°C)
Specific Conductance (µS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

Comments:

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MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Location Altus AFB - OU 1
Well Identification TW5
Job Name: AFCEE-RNA
by RN/CM
Date: 4/16/97
Measurement Datum
Mike Cook/EPA
Time (Start): 1100a

Pre-Development Information

Water Level: 5.2
Total Depth of Well: 11.75

Water Characteristics

Color Clear [✓ Cloudy]
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material no
pH
Temperature (°C) 16.1
Specific Conductance (µS/cm)
Dissolved Oxygen (mg/L) 0.2
Redox (mV) 202

Interim Water Characteristics

Gallons Removed 2.0
Time: 1130

pH 6.9

Temperature (°C) 16.3

Specific Conductance(µS/cm) 4180

Dissolved Oxygen (mg/L) 0.2

Redox (mV) 180

Post-Development Information

Time (Finish): 1130

Water Level:
Total Depth of Well:

Approximate Volume Removed: 2.0 gallons

Water Characteristics

Color [✓ Clear] Cloudy
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material no
pH 6.9
Temperature (°C) 16.3
Specific Conductance (µS/cm) 4180
Dissolved Oxygen (mg/L) 0.2
Redox (mV) 180

Comments:

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MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA
Location Altus AFB - OU 1
by RN/CM
Date: 4/10/97
Well Identification OU-1-TW6
Measurement Datum Ground Surface

Pre-Development Information

Time (Start): 1048

Water Level: 4.0' bls

Total Depth of Well: 13.75' bls

Water Characteristics

Color ______ Clear [✓ Cloudy]
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material no
pH ______ Temperature (°C) ______
Specific Conductance (µS/cm) ______
Dissolved Oxygen (mg/L) ______
Redox (mV) ______

purged dry after < 1 minute

1100 Obtained samples -VOAs, Inorganics, On-site analysis - still cloudy

1108 Dry

Interim Water Characteristics

Gallons Removed 0.5

Time: 1120

1112 Obtained remaining samples and final readings

pH 7.43

Temperature (°C) 15.3

Specific Conductance(µS/cm) 3400

Dissolved Oxygen (mg/L) 0.9

Redox (mV) 131

1121 going dry

112 Obtain samples. For duplicate VOAs

Post-Development Information

Time (Finish): 1120

Water Level: ______

Total Depth of Well: 13.75

Approximate Volume Removed: ______

Water Characteristics

Color ______ Clear Cloudy
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material ______
pH ______ Temperature (°C) ______
Specific Conductance (µS/cm) ______
Dissolved Oxygen (mg/L) ______
Redox (mV) ______

Comments:

MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA
Location Altus AFB - OU 1
by RN/CM
Date: 4/13/97
Well Identification OU-1-TW7
Measurement Datum Ground surface

Pre-Development Information

Time (Start): 538 pm

Water Level: 3.65

Total Depth of Well: NA (could not get probe down)

Water Characteristics

Color dk brown Clear [✓ Cloudy]
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material none
pH 7.55 Temperature (°C) 14.8
Specific Conductance (µS/cm) 5020
Dissolved Oxygen (mg/L) 1.0
Redox (mV) 40.1

went dry after 1 minute, will wait and pump at lower rate

Interim Water Characteristics

Gallons Removed

Time:

pH

Temperature (°C)

Specific Conductance(µS/cm)

Dissolved Oxygen (mg/L)

Redox (mV)

Post-Development Information

Time (Finish):

Water Level:

Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color ~~cloud~~ slightly cloudy brown Clear Cloudy
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material no
pH Temperature (°C)
Specific Conductance (µS/cm) 5000
Dissolved Oxygen (mg/L)
Redox (mV)

10 5.33

Comments:

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MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Location Altus AFB - OU 1
Well Identification TW8

Job Name: AFCEE-RNA Mike Cook/EPA
by RN/CM Date: 4/15/97
Measurement Datum TOC

Pre-Development Information

Time (Start): 11:00 a

Water Level: 4.2

Total Depth of Well: 14.92

Water Characteristics

Color ______ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material none
pH ______ Temperature (°C) 16.6
Specific Conductance (µS/cm) 5580
Dissolved Oxygen (mg/L) 0.1
Redox (mV) 185

Interim Water Characteristics

Gallons Removed 2.0

Time: 11:15 a

pH NM

Temperature (°C) 16.8

Specific Conductance(µS/cm) 5540

Dissolved Oxygen (mg/L) 0.0

Redox (mV) 160

Post-Development Information

Time (Finish): 1130 a

Water Level: 3.16

Total Depth of Well: 14.92

Approximate Volume Removed: 3 gal

Water Characteristics

Color ______ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material ______
pH 6.9 Temperature (°C) 16.9
Specific Conductance (µS/cm) 5550
Dissolved Oxygen (mg/L) 0.0
Redox (mV) 150

Comments:

MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA
Location Altus AFB - OU 1
by RN/CM
Date: 4/15/97
Well Identification TW9
Measurement Datum

Pre-Development Information
Time (Start):

Water Level: 9.1
Total Depth of Well: 13.40

Water Characteristics

Color Red-brown
Clear [✓ Cloudy]
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material None
pH
Temperature (°C)
Specific Conductance (µS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

Pumps dry before parameters can be measured in flow through cell

Interim Water Characteristics

Gallons Removed
Time:

pH

Temperature (°C)

Specific Conductance(µS/cm)

Dissolved Oxygen (mg/L)

Redox (mV)

Need smaller flowthrough

Post-Development Information
Time (Finish): 4:45

Water Level: — NM
Total Depth of Well: — NM

Approximate Volume Removed:

Water Characteristics

Color
[✓ Clear] Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material
pH 7.4
Temperature (°C) 21.0
Specific Conductance (µS/cm) 2670
Dissolved Oxygen (mg/L) 2.4
Redox (mV) 33

Comments:

MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA
Location Altus AFB - OU 1
by RN/[✓ CM]
Date: 4/
Well Identification TW10
Measurement Datum = Ground Surface

Pre-Development Information
Time (Start):

Water Level: ~~1.45~~ 1.45' bgs
Total Depth of Well:

Water Characteristics

Color reddish-brown
Clear [✓ Cloudy]
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material none
pH
Temperature (°C)
Specific Conductance (μS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

not enough water to measure parameters

Interim Water Characteristics

Gallons Removed
Time:

pH

Temperature (°C)

Specific Conductance(μS/cm)

Dissolved Oxygen (mg/L)

Redox (mV)

Post-Development Information
Time (Finish): 12:40p

Water Level: NM
Total Depth of Well: NM

Approximate Volume Removed:

Measured w/smaller flow-through

Water Characteristics

Color
Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material
pH
Temperature (°C) 18.2
Specific Conductance (μS/cm) 3720
Dissolved Oxygen (mg/L) 4.3
Redox (mV) 140

Comments:

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MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA
Location Altus AFB - OU 1
by RN/CM
Date: 4/16/97
Well Identification TW11
Measurement Datum TOC

Pre-Development Information
Time (Start): 1030a

Water Level: 10.5
Total Depth of Well: 11.05

Water Characteristics

Color________ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material ________
pH________ Temperature (°C)________
Specific Conductance (µS/cm)________
Dissolved Oxygen (mg/L)________
Redox (mV)________

Well Pumps dry almost immediately

Interim Water Characteristics

Gallons Removed________
Time:________

pH________

Temperature (°C)________

Specific Conductance(µS/cm)________

Dissolved Oxygen (mg/L)________

Redox (mV)________

Post-Development Information
Time (Finish):________

Water Level:________
Total Depth of Well:________

Approximate Volume Removed: ________

Water Characteristics

Color________ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material ________
pH________ Temperature (°C)________
Specific Conductance (µS/cm)________
Dissolved Oxygen (mg/L)________
Redox (mV)________

Comments:

MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA
Location Altus AFB - OU 1
by RN/CM
Date: 4/10/97
Well Identification OU-1-TW13
Measurement Datum ground surface

Pre-Development Information

Time (Start): 1136

Water Level:

Total Depth of Well: 14.0 ' bls

Water Characteristics

1155

Color brown-red Clear [✓ Cloudy] getting a little clearer
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material no
pH 6.63 Temperature (°C) 15.2
Specific Conductance (µS/cm) 4200
Dissolved Oxygen (mg/L) 1.4
Redox (mV) 127

Interim Water Characteristics

Gallons Removed 1

Time: 1206

pH 6.96

Temperature (°C) 15.0

Specific Conductance(µS/cm) 4300

Dissolved Oxygen (mg/L) 0.2

Redox (mV) 74

Post-Development Information

Time (Finish): 1215

Water Level:

Total Depth of Well:

Approximate Volume Removed: 1.5 gal

Water Characteristics

Color Slightly cloudy Clear Cloudy
Odor: [✓ None] Weak Moderate Strong
Any Films or Immiscible Material no.
pH 7.08 Temperature (°C) 15.0
Specific Conductance (µS/cm) 4300
Dissolved Oxygen (mg/L) 0.1
Redox (mV) 63

Comments:

Sampled 1220

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MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA Mike Cook/EPA
Location Altus AFB - OU 1
by RN/CM
Date:
Well Identification TW14
Measurement Datum

Pre-Development Information
Time (Start):

Water Level:
Total Depth of Well:

Water Characteristics

Color Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material
pH Temperature (°C)
Specific Conductance (μS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

Well Pumps dry

Interim Water Characteristics

Gallons Removed
Time:

pH

Temperature (°C)

Specific Conductance(μS/cm)

Dissolved Oxygen (mg/L)

Redox (mV)

Post-Development Information
Time (Finish):

Water Level:
Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material
pH Temperature (°C)
Specific Conductance (μS/cm)
Dissolved Oxygen (mg/L)
Redox (mV)

Comments:

MONITORING POINT DEVELOPMENT RECORD

Job Number: 722450.36020
Job Name: AFCEE-RNA
Location Altus AFB - OU 1
by RN/CM
Date: 4/15/97
Well Identification TW15
Measurement Datum TOC

Pre-Development Information
Time (Start): 9:00 a

Water Level: 4.0
Total Depth of Well: 17.08

Water Characteristics

Color ______ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material ______
pH NM Temperature (°C) 15.3
Specific Conductance (µS/cm) 5540
Dissolved Oxygen (mg/L) 0.0
Redox (mV) 255

Interim Water Characteristics

Gallons Removed 3 gal
Time: 9:30 a

pH NM

Temperature (°C) 16.8

Specific Conductance(µS/cm) 5530

Dissolved Oxygen (mg/L) 0.5

Redox (mV) 226

Post-Development Information
Time (Finish): 9:45 a

Water Level: NM
Total Depth of Well: NM

Approximate Volume Removed: 3.5 gal

Water Characteristics

Color ______ Clear Cloudy
Odor: None Weak Moderate Strong
Any Films or Immiscible Material ______
pH ______ Temperature (°C) 16.6
Specific Conductance (µS/cm) 5530
Dissolved Oxygen (mg/L) 0.5
Redox (mV) 220

Comments:

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL OU-1-01
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/8 at 1055 a.m./p.m.
SAMPLE COLLECTED BY: CM/[✓ KN] of Parsons ES
WEATHER: rain, windy,
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 4" ID Sched 40 PVC

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 isopropanol + distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with: —

WATER DEPTH 6.10' FT. BELOW DATUM
Measured with: ORS (by Cybix)
TD= 22.0 Purge Vol. = 15.6 gallons

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: red-brown silty
Odor: none
Other Comments: —

4 [ ] WELL EVACUATION:
Method: Grundfos
Volume Removed: 36 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

$$\begin{array}{r} 22 \\ -\ 6 \\ \hline 16 \\ \times 2 \\ \hline 32 \end{array}$$

Groundwater Sampling Record

Monitoring Well No. 041-01 (Continued)

5 ☐ SAMPLE EXTRACTION METHOD:

☐ Bailer made of:
☒ Pump, type: Peristaltic
☐ Other, describe:

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐ ON-SITE MEASUREMENTS:

Time	1202	1207				Measured with
Temp (°C)	13.6	13.6				Orion 840
pH						
Cond (µS/cm)	3890	3880				Orion 140
DO (mg/L)	0.0	0.0				Orion 840
Redox (mV)	+150	+140				Orion 290A
gallons purged	30	36				

7 ☐ SAMPLE CONTAINERS (material, number, size):

8 ☐ ON-SITE SAMPLE TREATMENT:

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

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

9 ☐ CONTAINER HANDLING:

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

10 ☐ OTHER COMMENTS: 4" Ø well EPA containers

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL OU1-02
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/8 at 1055 [✓ a.m.]/p.m. 1140 sample
SAMPLE COLLECTED BY: CM/[✓ KN] of [✓ Parsons] ES
WEATHER: rainy 50° windy
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ID. Sched 40 PVC

MONITORING WELL CONDITION:
[X] 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 ~~[illegible]~~ isopropanol + distilled water
Items Cleaned (List): probes

2 [ ] PRODUCT DEPTH – FT. BELOW DATUM
Measured with: –

WATER DEPTH 6.25 FT. BELOW DATUM
Measured with: ORS (by Cybix)
TD = 25.0 Purge Vol. 9.17 gallons

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

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 9 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: None
Other comments:

Groundwater Sampling Record

Monitoring Well No. OU-1-02 (Continued)

5 ☐ SAMPLE EXTRACTION METHOD:

☐ Bailer made of:
☒ Pump, type: Peristaltic
☐ Other, describe:

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐ ON-SITE MEASUREMENTS:

Time	1110	1125	1138			Measured with
Temp (°C)	14.1	14.0	14.0			Orion 840
pH						
Cond (µS/cm)	4070	[illegible]	4030			Orion 140
DO (mg/L)	0.0	0.1	0.0			Orion 840
Redox (mV)	—	198	197			Orion 250A
gallons purged	1.5	5	9			

7 ☐ SAMPLE CONTAINERS (material, number, size):

8 ☐ ON-SITE SAMPLE TREATMENT:

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

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

9 ☐ CONTAINER HANDLING:

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

10 ☐ OTHER COMMENTS: EPA handled samples

2.5
− 6
19/2 = 9.5

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL 041-03
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [✓] Special Sampling;
DATE AND TIME OF SAMPLING: 4/12 at 12 [✓ a.m.]/p.m.
SAMPLE COLLECTED BY: CMRN of Parsons ES
WEATHER: cold, windy, drizzle
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ID Sched 40 PVC

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 isopropanol & distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with: —

WATER DEPTH 6.82 ft FT. BELOW DATUM
Measured with: Solinst
TD = 25.5 Purge Vol 9 gallons

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: M murky
Odor: none
Other Comments: —

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 7.5 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. 041-03 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

- [ ] Bailer made of:
- [X] Pump, type: Peristaltic
- [ ] Other, describe:

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

6 [ ] ON-SITE MEASUREMENTS:

Time	1438	1452	1503	1508		Measured with
Temp (°C)	14.5	14.3	14.3	14.1		Orion 840
pH						
Cond (µS/cm)	4050	4060	4070	4090		Orion 140
DO (mg/L)	0.4	0.1	0.1	0.1		Orion 840
Redox (mV)	176	164	155	151		Orion 290A
gallons purged	2	4	5	7		

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

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration:

Method ______ Containers: ______
Method ______ Containers: ______
Method ______ Containers: ______

[ ] Preservatives added:

Method ______ Containers: ______
Method ______ Containers: ______
Method ______ Containers: ______
Method ______ Containers: ______

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL 041-04
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/12/97 at 1530 a.m./p.m.
SAMPLE COLLECTED BY: CM/RN of Parsons ES
WEATHER: windy, cold
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ID Sched 40 PVC

MONITORING WELL CONDITION:
[X] 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 isopropanol and distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with: —

WATER DEPTH 6.72' FT. BELOW DATUM
Measured with: Solinst
TD=25.0' Purge Vol 9 gallons

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: murky
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 8 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. 041-4 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	1526	1600	1614			Measured with
Temp (°C)	13.8	13.5	13.6			Orion 840
pH						
Cond (µS/cm)	4260	3410	3380			Orion 140
DO (mg/L)	0.5	0.3	0.2			Orion 840
Redox (mV)	177	188	188			Orion 270A
gallons purged	3	6	8			

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

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration:

Method Containers:
Method Containers:
Method Containers:

[ ] Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL OU-1-05
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/17/97 at 8:30 [✓ a.m.]/p.m.
SAMPLE COLLECTED BY: [✓ CM]/RN of Parsons ES Mike Cook/EPA
WEATHER: clear, breezy 45°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ID sched 40 PVC stickup

MONITORING WELL CONDITION:
[ ] LOCKED: ☒ UNLOCKED Pad not set, yet.
WELL NUMBER (IS - [✓ IS NOT]) APPARENT
STEEL CASING CON~~DITION IS~~: not set yet
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM ([✓ IS] - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

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

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: –

WATER DEPTH 7.95 FT. BELOW DATUM
Measured with: Solinst water level meter
TD= 30.70 Purge Vol 11 gallons

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: clear
Odor: none
Other Comments: –

4 [✓] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 11 gallons
Observations: Water (slightly - very) cloudy
Water level (rose - [✓ fell] - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. DU-1-05 (Continued)

5 ☐ SAMPLE EXTRACTION METHOD:

☐ Bailer made of:
☒ Pump, type: Peristaltic
☐ Other, describe:

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐ ON-SITE MEASUREMENTS:

Time	8:18	8:23	8:28			Measured with
Temp (°C)	15.7	15.8	16.6			Orion 840
pH	7.87	8.15	8.05			Orion 290A
Cond (µS/cm)	4680	4650	4620			Orion 140
DO (mg/L)	0.7	0.5	0.3			Orion 840
Redox (mV)	210	199	200.9			Orion 290A
gallons purged	~½	5 gal	10 gal			

7 ☐ SAMPLE CONTAINERS (material, number, size):

8 ☐ ON-SITE SAMPLE TREATMENT:

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

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

9 ☐ CONTAINER HANDLING:

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

10 ☐ OTHER COMMENTS: EPA sampled

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL OU-1-06
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/17/97 at 10:30 [✓ a.m.]/p.m.
SAMPLE COLLECTED BY: [✓ CM]/RN of Parsons ES
WEATHER: sunny, breezy, 60°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ID sched 40 PVC stickup

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

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 13.07 FT. BELOW DATUM
Measured with: Solinst
TD = 25.80 Purge Vol 6.2 gallons

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: reddish-brown
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 6 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - [✓ fell] - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. OU-1-06 (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	9:58	10:03	10:07	10:25		Measured with
Temp (°C)	18.1	17.7		17.5		Orion 840
pH	NM	NM		NM		Orion 290A
Cond (µS/cm)	7040	7080		7060		Orion 140
DO (mg/L)	1.5	1.5		1.3		Orion 840
Redox (mV)	134.4	[illegible] 98.5		-25		Orion 290A
gallons purged	2	4		6		

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

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration:

Method	Containers:
Method	Containers:
Method	Containers:

[ ] Preservatives added:

Method	Containers:
Method	Containers:
Method	Containers:
Method	Containers:

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA sampled

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW-1
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4-15-97 at 400 a.m./[✓ p.m]
SAMPLE COLLECTED BY: CM/[✓ RN] of Parsons ES Mike Cook of EPA
WEATHER:
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC - Stick up

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: not set yet
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM (IS - [✓ IS NOT]) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [ ] EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water
Items Cleaned (List): probes

2 [ ] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 12.2 ft FT. BELOW DATUM
Measured with: Solinst
TD = 15.88 Purge Vol. = 2 gallons

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic Pump
Volume Removed: 3 gallons
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW-1 (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [✓] ON-SITE MEASUREMENTS:

Time	3:00 pm	3:30pm	4:00pm			Measured with
Temp (°C)	18.2	18.0	18.5			Orion 840
pH				6.9		Orion 290A
Cond (µS/cm)	4600	4610	4610			Orion 140
DO (mg/L)	4.0	4.0	4.1			Orion 840
Redox (mV)	180	169	165			Orion 290A
gallons purged	2.0	2.5	3.0			

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

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: well pumps DRY after about
- 800ml -

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW 2
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling:
DATE AND TIME OF SAMPLING: 4/16 at 1040 [✓ a.m.]/~~p.m.~~
SAMPLE COLLECTED BY: [✓ CM]/[✓ RN] of Parsons ES
WEATHER: Windy 65°
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC ½" ID sched 40 PVC flush mount

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 isopropanol + distilled water
Items Cleaned (List): probes

2 [✓] PRODUCT DEPTH — FT. BELOW DATUM
Measured with:

WATER DEPTH 4.38 FT. BELOW DATUM
Measured with: Solinst
TD = 13.95 Purge Vol = 4.68 gallons

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: red-brown
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Peristaltic Pump
Volume Removed: 5 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - [✓ fell] - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW2 (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	10:13	10:17	10:30			Measured with
Temp (°C)	18.5	18.3	18.3			Orion 840
pH	NM	NM	NM			Orion 290A
Cond (µS/cm)	8630	8650	8640			Orion 140
DO (mg/L)	3.5	3.3	3.3			Orion 840
Redox (mV)	135	119	108			Orion 290A
gallons purged	2	3	5			

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

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 Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW3
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/15/97 at 3:45 a.m. [✓ p.m.]
SAMPLE COLLECTED BY [✓ CM]/RN of Parsons ES
WEATHER: sunny, breezy, 70°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC - not at final elevation however; will be cut off at ground surface when pad is built.

MONITORING WELL CONDITION:

[ ] LOCKED: [X] UNLOCKED no pad yet - brand new well
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: not set
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM (IS - [✓ IS NOT]) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe): PVC cut, marked w/datum marker, covered w/ protective steel - pad set - should be completed later today.

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alconox, distilled water
Items Cleaned (List):

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH ~~approximately [illegible] ft bgs~~ 9.69' ~~FT. BELOW DATUM~~
Measured with: water level meter
TD = 13.72bgs ~~[illegible]~~ 1/2" ID Purge Vol. 0.4 gallons

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: silty brown-red
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Peristaltic Pump
Volume Removed: 0.5 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water ~~level~~ (rose - [✓ fell] - no change)
Water odors: none
Other comments: —

Groundwater Sampling Record

Monitoring Well No. TW3 (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:
[X] Pump, type: Masterflex Peristaltic
[ ] Other, describe:

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

6 [ ] ON-SITE MEASUREMENTS: * on site lab

Time	3:25p	3:30p	3:35p			Measured with
Temp (°C)	18.2	18.2	18.3			Orion 840
pH	NM	NM	NM	6.9*		—
Cond (µS/cm)	6770	6820	6820			Orion 140
DO (mg/L)	0.3	0.2	0.1			Orion 840
Redox (mV)	120	106	103			Orion 290A
gallons purged	~1.0	~1.5	~2.0			bucket

7 [ ] SAMPLE CONTAINERS (material, number, size): EPA sampled - full set.

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 Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW4
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/16/97 at 11:30 [✓ a.m.]/p.m.
SAMPLE COLLECTED BY [✓ CM]/RN of Parsons ES & Don Kampbell of EPA
WEATHER: partly cloudy, 50°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC (not set yet)

MONITORING WELL CONDITION:

- [ ] LOCKED: [X] UNLOCKED
- WELL NUMBER (IS - [✓ IS NOT]) APPARENT
- STEEL CASING CONDITION IS: not set in pad
- INNER PVC CASING CONDITION IS: good
- WATER DEPTH MEASUREMENT DATUM (IS - [✓ IS NOT]) APPARENT
- [ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
- [ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

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

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH est. 6.5' bgs ~~FT. BELOW DATUM~~
Measured with: water level meter

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: silty red-brown
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Peristaltic Pump
Volume Removed:
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW4 (Continued)

5 ☐ SAMPLE EXTRACTION METHOD:

☐ Bailer made of:
☒ Pump, type: Peristaltic
☐ Other, describe:

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐ ON-SITE MEASUREMENTS: Not enough water

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

7 ☐ SAMPLE CONTAINERS (material, number, size):

8 ☐ ON-SITE SAMPLE TREATMENT:

☐ Filtration:

Method Containers:
Method Containers:
Method Containers:

☐ Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 ☐ CONTAINER HANDLING:

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

10 ☐ OTHER COMMENTS: EPA sampled (DK)
1 VOA filled

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW-5
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4-16-97 at 11:45 a.m./p.m.
SAMPLE COLLECTED BY: CM/[✓ RN] of Parsons ES
WEATHER:
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC - Stickup

MONITORING WELL CONDITION:
[ ] LOCKED: ☒ UNLOCKED
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: not set yet
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 isopropanol and distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with:

WATER DEPTH 5.2 FT. BELOW DATUM
Measured with: Solinst

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 2 gallons
Observations: Water (slightly - very) [✓ cloudy]
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW-5 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:
[X] Pump, type: masterflex
[ ] Other, describe:

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

6 [ ] ON-SITE MEASUREMENTS:

Time	11:00	11:30				Measured with
Temp (°C)	16.1	16.3				Orion 840
pH			6.9			Orion 290A
Cond (µS/cm)		4180				Orion 140
DO (mg/L)	.2	.2				Orion 840
Redox (mV)	202	180				Orion 290A
gallons purged	1.5	1.9)				

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

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

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA sampled - full set.

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW6
(Identification)

REASON FOR SAMPLING: ☒ Regular Sampling; ☐ Special Sampling;
DATE AND TIME OF SAMPLING: 4/10/97 at 11 15 [✓ a.m.]/p.m.
SAMPLE COLLECTED BY: CM/[✓ RN] of Parsons ES
WEATHER:
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC ½" ID Schedule 40 PVC flush mount

MONITORING WELL CONDITION:

☐ LOCKED: ☒ UNLOCKED
WELL NUMBER (IS - [✓ IS NOT]) APPARENT
STEEL CASING CONDITION IS: not set yet
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 Isopropanol and distilled water
Items Cleaned (List): Probes

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

WATER DEPTH 4.0 FT. BELOW DATUM
Measured with: Solinst

3 ☐ WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 ☐ WELL EVACUATION:
Method: Peristaltic Pump
Volume Removed: 0.5 gallons
Observations: Water (slightly - very) [✓ cloudy]
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW6 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:
[X] Pump, type: Masterflex Peristaltic
[ ] Other, describe:

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

6 [ ] ON-SITE MEASUREMENTS: too little sample to get additional readings - kept going dry

Time	11:20					Measured with
Temp (°C)	15.3					Orion 840
pH	7.43					Orion 290A
Cond (µS/cm)	3400					Orion 840
DO (mg/L)	0.9					Orion 840
Redox (mV)	131					Orion 290A
gallons purged	0.5					

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

[ ] Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handeed samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW7
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/16/97 at ________ a.m./p.m.
SAMPLE COLLECTED BY [✓ CM]/RN of Parsons ES
WEATHER: partly cloudy, sprinkles, 50°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
[ ] LOCKED: ☒ UNLOCKED
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: not set yet; will be this afternoon
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM (~~IS~~ - [✓ IS NOT]) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alcohol. distilled water
Items Cleaned (List): water level probe

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 0.5' FT. BELOW DATUM
Measured with: Solinst
TD ~13.5 13' WC

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: red-brown silt
Odor: none
Other Comments: —

4 [ ] WELL EVACUATION:
Method: Peristaltic Pump
Volume Removed: ~ 2 cups
Observations: Water ([✓ slightly] - very) cloudy
Water ~~level~~ (rose - [✓ fell] - no change)
Water odors: none
Other comments: —

Groundwater Sampling Record

Monitoring Well No. TW7 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of: -
[X] Pump, type: Peristaltic
[ ] Other, describe:

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

6 [ ] ON-SITE MEASUREMENTS: Not enough water to measure

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

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

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

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: ~~EPA Sampled~~ 1/2 voa only - no samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW-8
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4-15-97 at 11:30 [✓ a.m.]/p.m.
SAMPLE COLLECTED BY: CM/[✓ RN] of Parsons ES Mike Cook/EPA
WEATHER:
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC - Stick up

MONITORING WELL CONDITION:

[ ] LOCKED: ☒ UNLOCKED
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: ~~good~~ not completed
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 isopropanol and water
Items Cleaned (List): probes

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with: —

WATER DEPTH 4.2 FT. BELOW DATUM
Measured with: Solinst
TD= 14.92

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 3 gallon
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW8 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:
[ ] Pump, type: master flex-Peristaltic
[ ] Other, describe:

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

6 [ ] ON-SITE MEASUREMENTS:

Time	11:00	11:15	11:30			Measured with
Temp (°C)	16.6	16.8	16.9			Orion 840
pH				6.90		Orion 290A
Cond (µS/cm)	5580	5540	5550			Orion 140
DO (mg/L)	.1	.0	.0			Orion 840
Redox (mV)	185	160	150			Orion 290A
gallons purged	1.5	2.0	2.9			

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

[ ] Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: full set of samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW 9
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling; sampled for VOCs
DATE AND TIME OF SAMPLING: 4/15/97 at 445 a.m. [✓ p.m.]
SAMPLE COLLECTED BY: CM/RN of Parsons ES
WEATHER: sunny, windy 65-70°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC ½" ~~ID~~ PVC

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED but bolted
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM ([✓ IS] - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water
Items Cleaned (List): water level probe

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: –

WATER DEPTH 9.10 FT. BELOW DATUM
Measured with: water level probe
TD [illegible] 13.40' Purge Vol 0.67 gallons

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: silty (red-brown)
Odor: none
Other Comments: –

4 [✓] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 1 Liter
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - [✓ fell] - no change)
Water odors: none
Other comments: –

Groundwater Sampling Record

Monitoring Well No. TW9 (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS: Not enough Water to measure...

Time	445					Measured with
Temp (°C)	21.0					Orion 840
pH	–	7.4*				Orion 290A
Cond (µS/cm)	2670					Orion 140
DO (mg/L)	2.9					Orion 840
Redox (mV)	33					Orion 290A
gallons purged	↑					

* on site lab

dry for second time - water clearing

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

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

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA sampled.

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW10
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/16/97 at 1:00 a.m./[✓ p.m.]
SAMPLE COLLECTED BY: [✓ CM]/RN of Parsons ES
WEATHER: partly cloudy, windy 55°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): ground surface

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED
WELL NUMBER (IS - [✓ IS NOT]) APPARENT
STEEL CASING CONDITION IS: not set yet
INNER PVC CASING CONDITION IS: good ½" ID PVC
WATER DEPTH MEASUREMENT DATUM (IS - [✓ IS NOT]) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water
Items Cleaned (List): water level probe

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 2.25' bgs FT. BELOW DATUM
Measured with: water level meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 1 Liter
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW10 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS: Not enough water -

Time	12:40					Measured with
Temp (°C)	18.2					Orion 840
pH	—					Orion 290A
Cond (µS/cm)	3720					Orion 140
DO (mg/L)	4.3					Orion 840
Redox (mV)	140					Orion 290A
gallons purged	—					

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

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

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA Sampled (DK) full set

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW11
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/16/97 at ________ a.m./p.m.
SAMPLE COLLECTED BY: CM/RN of Parsons ES
WEATHER: partly cloudy, windy, 50°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): [illegible] ground surface

MONITORING WELL CONDITION:

[ ] LOCKED: [X] UNLOCKED
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: not set yet
INNER PVC CASING CONDITION IS: good ½" ID PVC
WATER DEPTH MEASUREMENT DATUM ([✓ IS] - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water
Items Cleaned (List): water level probe

2 [ ] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH ~6.5' bgs FT. BELOW DATUM
Measured with: water level meter

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW11 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS: Not enough water

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

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

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration:

Method Containers:
Method Containers:
Method Containers:

[ ] Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: No sample

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW13
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/10/97 at 12:20 a.m./[✓ p.m.]
SAMPLE COLLECTED BY: CM/[✓ RN] of Parsons ES
WEATHER:
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC - Stick up

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: no completed yet
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 isopropanol and distilled water
Items Cleaned (List): Probes

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 2.59 FT. BELOW DATUM
Measured with: Solinst

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: red-brown silty
Odor: none
Other Comments: —

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 1.5 gal
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW13 (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	11:55	12:06	12:15			Measured with
Temp (°C)	15.2	15.0	15.0			Orion 840
pH	6.63	6.96	7.04			Orion 290A
Cond (µS/cm)	4200	4300	4300			Orion 140
DO (mg/L)	1.4	0.2	0.1			Orion 840
Redox (mV)	127	74	63			Orion 290A
gallons purged	0.5	1	1.5			

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

[ ] Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW14
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/16/97 at 9:00 [✓ a.m.]/p.m.
SAMPLE COLLECTED BY: CM[✓ R]N of Parsons ES - Mike Cook - EPA
WEATHER: partly cloudy, cool, windy
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
[ ] LOCKED: ☑ UNLOCKED
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: not completed yet
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 isopropanol, distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with: —

WATER DEPTH 4.48 FT. BELOW DATUM
Measured with:
TD 11.57

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: —
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW14 (Continued)

5 ☐ SAMPLE EXTRACTION METHOD:

☐ Bailer made of:
☐ Pump, type:
☐ Other, describe:

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐ ON-SITE MEASUREMENTS: Not enough water

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

7 ☐ SAMPLE CONTAINERS (material, number, size):

8 ☐ ON-SITE SAMPLE TREATMENT:

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

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

9 ☐ CONTAINER HANDLING:

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

10 ☐ OTHER COMMENTS: No Sample Collected

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL TW - 15
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4-15-97 at 9:30 [✓ a.m.]/p.m.
SAMPLE COLLECTED BY: CM/[✓ RN] of Parsons ES
WEATHER:
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC - Stick up

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED
WELL NUMBER ([✓ IS] / IS NOT) APPARENT
STEEL CASING CONDITION IS: not completed yet
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 Isopropanol, distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with: —

WATER DEPTH 4.0 FT. BELOW DATUM
Measured with: Slope meter -
TD = 17.08

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 4 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. TW - 15 (Continued)

5 ☐ SAMPLE EXTRACTION METHOD:

☐ Bailer made of:
☐ Pump, type: masterflex - peristaltic
☐ Other, describe:

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐ ON-SITE MEASUREMENTS:

Time	9:00	9:15	9:30	9:45		Measured with
Temp (°C)	15.3	16.8	16.8	16.6		Orion 840
pH					6.95	Orion 290A
Cond (µS/cm)	5540	5530	5530	5530		Orion 140
DO (mg/L)	0	.4	.5	.5		Orion 840
Redox (mV)	255	226	226	220		Orion 290A
gallons purged	2 gal	2.5 gal	3.0 gal	3.5 gal		

7 ☐ SAMPLE CONTAINERS (material, number, size):

8 ☐ ON-SITE SAMPLE TREATMENT:

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

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

9 ☐ CONTAINER HANDLING:

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

10 ☐ OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

4/9/97

GROUND WATER SAMPLING RECORD - MONITORING WELL WL-018
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/9 at 235 a.m./[✓ p.m.] sampled 145
SAMPLE COLLECTED BY: CM/[✓ RN] of Parsons ES
WEATHER: Cloudy cool
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ID PVC (sched 40) stickup

MONITORING WELL CONDITION:
[✓] LOCKED: [ ] UNLOCKED
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM ([✓ IS] - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alcohol, distilled water
Items Cleaned (List):

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 8.05' FT. BELOW DATUM
Measured with: Solinst Water level meter
TD = 24.4' Purge Vol. = 8 gallons

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: clear
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Peristaltic Pump
Volume Removed: 8 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: None
Other comments:

Groundwater Sampling Record

Monitoring Well No. WL-018 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:
[X] Pump, type: peristaltic
[ ] Other, describe:

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

6 [ ] ON-SITE MEASUREMENTS:

Time	1305	1315	1330	1340		Measured with
Temp (°C)	14.5	14.7	14.7	14.6		Orion 840
pH	7.29	7.21	7.12	7.08		Orion 290A
Cond (µS/cm)	3900	3800	3800	3800		Orion 140
DO (mg/L)	0.8	0.4	0.4	0.4		Orion 840.
Redox (mV)	181	174	167	165		Orion 290A
gallons purged	2	4	6	8		

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

[ ] Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL WL-019
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/8/97 at 945 [✓ a.m.]/p.m.
SAMPLE COLLECTED BY: CM/[✓ KN] of Parsons ES
WEATHER:
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ID sched 40 PVC stick-up

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 isopropanol + distilled water
Items Cleaned (List): probes

2 [ ] PRODUCT DEPTH - FT. BELOW DATUM
Measured with: -

WATER DEPTH 3.85' FT. BELOW DATUM
Measured with: Solinst
TD: 23.0' Purge Vol. 7 gallons

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

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 8 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. WL-019 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	0920	0930	0944			Measured with
Temp (°C)	14.5	14.9	14.8			Orion 840
pH						
Cond (µS/cm)	4150	4190	4130			Orion 140
DO (mg/L)	0.0	0.0	0.0			Orion 840
Redox (mV)	222	192	192			Orion 290A
gallons purged	2	5	7			

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

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

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL WL-020
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling:
DATE AND TIME OF SAMPLING: 4/9/97 at 215 a.m./[✓ p.m.] 300 sampled
SAMPLE COLLECTED BY: CM/[✓ RN] of Parsons ES
WEATHER: 40° cloudy
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ID sched 40 PVC stick up

MONITORING WELL CONDITION:
[X] 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 isopropanol + distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with: —

WATER DEPTH 13.41 FT. BELOW DATUM
Measured with: Solinst
TD = 26.1' Purge Vol. 6.2 gallons

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

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 8 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

26
−10
16/2 = 8

Groundwater Sampling Record

Monitoring Well No. WL-020 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	240	245	253	259		Measured with
Temp (°C)	16.1	16.2	16.3	16.3		Orion 840
pH	7.15	7.11	7.05	7.13		Orion 290A
Cond (µS/cm)	3100	3100	3000	3000		Orion 140
DO (mg/L)	3.1	3.1	3.5	3.6		Orion 840
Redox (mV)	165	163	160	158		Orion 290A
gallons purged	4.5	5	7	8		

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

[ ] Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL WL ~~[illegible]~~ - 021
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/8/97 at 1640 a.m./[✓ p.m.]
SAMPLE COLLECTED BY: CM/RN of Parsons ES
WEATHER: cold [illegible] cloudy, windy
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 2" ID sched 40 PVC stick up

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 new tubing
Items Cleaned (List):

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with: —

WATER DEPTH 6.73' FT. BELOW DATUM
Measured with: Solinst
TD=23.6' Purge Vol. 8.2 gallons

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

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 7.5 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. WL-021 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:
[✓] Pump, type: perisaltalic
[ ] Other, describe:

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

6 [ ] ON-SITE MEASUREMENTS:

Time	1710	1740				Measured with
Temp (°C)	12.6	12.9				Orion 840
pH						
Cond (µS/cm)	4050	4080				Orion 190
DO (mg/L)	0.3	0.0				Orion 840
Redox (mV)		174				Orian 290-A
gallons purged	2	7				

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

[ ] Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL OW022
WL- (Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/9/97 at 1026 [✓ a.m.]/p.m. 1110 sample
SAMPLE COLLECTED BY: CM/KN of Parsons ES
WEATHER: 40° windy
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 isopropanol + distilled water
Items Cleaned (List):

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with: —

WATER DEPTH 7.44' FT. BELOW DATUM
Measured with: Solinst
TD = 23.5 Purge Vol. 7.9 gallons

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

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 9 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

21
4
17
2 = 8.5

Groundwater Sampling Record

Monitoring Well No. WL-022 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:

[X] Pump, type: Peristaltic

[ ] Other, describe:

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

6 [ ] ON-SITE MEASUREMENTS:

Time	1043	1049	1059	1104	1107	Measured with
Temp (°C)	13.3	13.2	13.2	13.2	13.3	Orion 840
pH	6.55	6.60	6.77	6.81	6.84	Orion 290A
Cond (µS/cm)	4960	4960	4940	4930	4930	Orion 140
DO (mg/L)	0.0	0.0	0.0	0.0	0.0	Orion 840
Redox (mV)	-80	-171	-182	-180	-179	Orion 290A
gallons purged	4	5	7	8	8.5	

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

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration:

Method Containers:
Method Containers:
Method Containers:

[ ] Preservatives added:

Method Containers:
Method Containers:
Method Containers:
Method Containers:

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL WL-060
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/10 at 925 [✓ a.m.]/p.m. 1000 sample
SAMPLE COLLECTED BY: CM/[✓ RM] of Parsons ES
WEATHER: 50 cloudy
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 isopropanol + distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH - FT. BELOW DATUM
Measured with: -

WATER DEPTH 5.93 FT. BELOW DATUM
Measured with: Solinst
TD= 13.5' Purge Vol. 3.7 gallons

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

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 5.5 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

$$\begin{array}{r} 13.5 \\ -\ 2.5 \\ \hline 11.0 \end{array} \quad \frac{11.0}{2} = 5.5$$

Groundwater Sampling Record

Monitoring Well No. WL-060 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	934	938	942	946	951	Measured with
Temp (°C)	14.4	14.4	14.4	14.4	14.4	Orion 840
pH	7.43	7.41	77.1	740	7.39	Orion 250A
Cond (µS/cm)	4800	4800	4800	4800	4800	Orion 140
DO (mg/L)	0.4	0.3	0.3	0.3	0.3	Orion 840
Redox (mV)	147	142	139	138	136	Orion 250A
gallons purged	1	2	3	4	5	

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

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

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL WL-061
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/9/97 at 545 a.m./[✓ p.m.]
SAMPLE COLLECTED BY: CM/RN of Parsons ES
WEATHER: 40° cloudy, drizzle
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC

MONITORING WELL CONDITION:
[X] 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 Isopropanol + distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH — FT. BELOW DATUM
Measured with: —

WATER DEPTH 5.48 FT. BELOW DATUM
Measured with: Solinst
TD = 34.0' Purge Vol. 13.9 gallons

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 15 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

34
3
31/2 = 15.5 gallons

Groundwater Sampling Record

Monitoring Well No. WL-061 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	505	510	523	535	545	Measured with
Temp (°C)	16.4	16.4	16.4	16.4	16.4	Orion 840
pH	5.96	7.20	7.86	7.68		Orion 290A
Cond (µS/cm)	5700	5700	5700	5700	5700	Orion 140
DO (mg/L)	1.2	1.2	1.2	1.1	1.2	Orion 840
Redox (mV)	150	155	149	155	151	Orion 290A
gallons purged	7	9	11	13	15	

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

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

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL WL-062
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/9 at 357 ~~a.m.~~ [✓ p.m.] 445 sample
SAMPLE COLLECTED BY: CM [✓ RN] of Parsons ES
WEATHER: 40 rain
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 isopropanol + distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH – FT. BELOW DATUM
Measured with: –

WATER DEPTH 5.65 FT. BELOW DATUM
Measured with: Solinst
TD= 19.0' Purge Vol. 6.5 gallons

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 8 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments:

19
- 3
16/2 = 8 gallons

Groundwater Sampling Record

Monitoring Well No. WL-062 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	427	432	437	441		Measured with
Temp (°C)	13.7	13.7	13.7	13.7		Orion 840
pH	7.00	7.09	712	7.12		Orion 290A
Cond (µS/cm)	6100	6200	6100	6100		Orion 140
DO (mg/L)	7.0	0.9	0.0	0.0		Orion 840
Redox (mV)	146	143	142	140		Orion 290A
gallons purged	5	6	7	8		

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

8 [ ] ON-SITE SAMPLE TREATMENT:

[ ] Filtration:
Method ____ Containers: ____
Method ____ Containers: ____
Method ____ Containers: ____

[ ] Preservatives added:
Method ____ Containers: ____
Method ____ Containers: ____
Method ____ Containers: ____
Method ____ Containers: ____

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

D 21.3
S 12.0

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL SB10S
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/10/97 at 340 a.m./[✓ p.m.]
SAMPLE COLLECTED BY: [✓ CM]/RN of Parsons ES
WEATHER: overcast, light rain, 50°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 1/2" ID PVC

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED bolted
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM ([✓ IS] - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alconox, isopropyl, distilled water;
Items Cleaned (List): water level probe

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 8.70 FT. BELOW DATUM
Measured with: water level probe
TD 12.0' below TOC Purge Vol 0.4059 gal

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

4 [✓] WELL EVACUATION:
Method: Masterflex Peristaltic
Volume Removed: <1 gal
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - [✓ fell] - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. SB 10 S (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

[ ] Bailer made of:
[X] Pump, type: peristaltic
[ ] Other, describe:

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

6 [✓] ON-SITE MEASUREMENTS: Not enough water

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

7 [ ] SAMPLE CONTAINERS (material, number, size): No samples

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 Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL SB10 D
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/10/97 at 340 a.m./[✓ p.m.]
SAMPLE COLLECTED BY: [✓ CM]/RN of Parsons ES
WEATHER: Overcast, light rain, 50° F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 1/2" ID PVC

MONITORING WELL CONDITION:
[ ] LOCKED: [✓] UNLOCKED bolted
WELL NUMBER (IS - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM ([✓ IS] - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alconox isopropyl, distilled water
Items Cleaned (List): water level meter

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 9.20' FT. BELOW DATUM
Measured with:
TD 21.3' below TOC Purge Vol 1.5 gal

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Clear
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Peristaltic
Volume Removed: <0.5 gal
Observations: Water ([✓ slightly] - very) cloudy
Water ~~level~~ (rose - [✓ fell] - no change)
Water odors: None
Other comments: —

Groundwater Sampling Record

Monitoring Well No. SB 10 D (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [✓] ON-SITE MEASUREMENTS: Not enough water

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

7 [ ] SAMPLE CONTAINERS (material, number, size): No samples collected

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:

S 11.75
D 20.0

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL SB11S
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/10/97 at 4:20 a.m./[✓ p.m.]
SAMPLE COLLECTED BY [✓ CM/RN] of Parsons ES
WEATHER: steady rain 45°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 1/2" ID PVC

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED bolted
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: Good
INNER PVC CASING CONDITION IS: Good
WATER DEPTH MEASUREMENT DATUM ([✓ IS] - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alconox, isopropyl, distilled water
Items Cleaned (List): water level probe

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 5.5' FT. BELOW DATUM
Measured with: water level meter

TD 11.75' TOC Purge Vol 0.769 gal

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance:
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method:
Volume Removed:
Observations: Water (slightly - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. SB11S (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS: Not enough water to measure

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

7 [ ] SAMPLE CONTAINERS (material, number, size): ~~EPA sampled~~ Not enough water

No Samples

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 Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL SB11 D
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/10/97 at 4:30 a.m./[✓ p.m.]
SAMPLE COLLECTED BY: CM/RN of Parsons ES
WEATHER: steady rain 45°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 1/2" ID PVC

MONITORING WELL CONDITION:
[ ] LOCKED: [✓] UNLOCKED bolted
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM ([✓ IS] - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off
1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alc., isop alc, di H2O
Items Cleaned (List): water level probe

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 6.0' FT. BELOW DATUM
Measured with: water level meter
TD 20.0' TOC Purge Vol 1.722 gal

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: slightly cloudy
Odor:
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 1 + gallon
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors:
Other comments:

Groundwater Sampling Record

Monitoring Well No. SB11D (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	4:45p	4:58p	4:59			Measured with
Temp (°C)	17.1	17.2	17.1			Orion 840
pH	7.63	7.70	7.68			Orion 290A
Cond (µS/cm)	5300	5280	5290			Orion 140
DO (mg/L)	1.1	2.2	1.9			Orion 840
Redox (mV)	87.3	75.4	75.6			Orion 290A
gallons purged	<1.0	1.0	1.0			

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

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 Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL SB15W5 (7.0 TD)
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/8 at 510 a.m./[✓ p.m.] 530 Sampled
SAMPLE COLLECTED BY: CM/[✓ RN] of Parsons ES
WEATHER: 40° windy cloudy
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 isopropanol + distilled water
Items Cleaned (List): Probes

2 [ ] PRODUCT DEPTH FT. BELOW DATUM
Measured with: –

WATER DEPTH 4.10 FT. BELOW DATUM
Measured with: solinst

3 [ ] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: Cloudy red-brown
Odor: none
Other Comments:

4 [ ] WELL EVACUATION:
Method: Peristaltic
Volume Removed: 2 gallons
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - fell - no change)
Water odors: none
Other comments: 1/2" PVC

7
~~18.7~~
4.1
13.6/8 = 1.5 gallons

Groundwater Sampling Record

Monitoring Well No. SB1SW4 (Continued)

5 [ ] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS:

Time	513	520	528	530		Measured with
Temp (°C)	11.9	12.1	12.2	12.2		Orion 840
pH						
Cond (µS/cm)	3200	3640	3810	3810		Orion 140
DO (mg/L)	1.1	0.4	0.4	0.4		Orion 840
Redox (mV)	162	154	153	151		Orion 890A
gallons purged	0.75	1.2	1.5	1.7		

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

8 [ ] ON-SITE SAMPLE TREATMENT:

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

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

9 [ ] CONTAINER HANDLING:

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

10 [ ] OTHER COMMENTS: EPA handled samples

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL SB165
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/10/97 at 3:20 a.m./[✓ p.m.]
SAMPLE COLLECTED BY: [✓ CM/RN] of Parsons ES
WEATHER: overcast, windy 50°F
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC ½" ID PVC

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED but bolted
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM ([✓ IS] - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alconox, isopropyl, distilled water
Items Cleaned (List): water level probe

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 9.3 FT. BELOW DATUM
Measured with: Water level meter

TD 12.25 Purge vol 0.36 gal

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: silty brown
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Masterflex Peristaltic Pump
Volume Removed: < 1 gal
Observations: Water (slightly - [✓ very]) cloudy
Water level (rose - [✓ fell] - no change)
Water odors: none
Other comments: —

Groundwater Sampling Record

Monitoring Well No. SB16S (Continued)

5 [✓] SAMPLE EXTRACTION METHOD:

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

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

6 [ ] ON-SITE MEASUREMENTS: Not enough water to measure

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

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

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:

2" ID → 0.163
1/2" ID → 0.041

GROUNDWATER SAMPLING RECORD

Sampling Location Altus AFB - OU 1
Sampling Dates 4/07/97 - 4/17/97

GROUND WATER SAMPLING RECORD - MONITORING WELL SB16D
(Identification)

REASON FOR SAMPLING: [X] Regular Sampling; [ ] Special Sampling;
DATE AND TIME OF SAMPLING: 4/10/97 at 3:02 a.m. [✓ p.m.]
SAMPLE COLLECTED BY: CM/RN of Parsons ES
WEATHER: cloudy - overcast 50°F storm moving in
DATUM FOR WATER DEPTH MEASUREMENT (Describe): TOC 1/2" ID PVC

MONITORING WELL CONDITION:
[ ] LOCKED: [X] UNLOCKED but bolted
WELL NUMBER ([✓ IS] - IS NOT) APPARENT
STEEL CASING CONDITION IS: good
INNER PVC CASING CONDITION IS: good
WATER DEPTH MEASUREMENT DATUM ([✓ IS] - IS NOT) APPARENT
[ ] DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR
[ ] MONITORING WELL REQUIRED REPAIR (describe):

Check-off

1 [✓] EQUIPMENT CLEANED BEFORE USE WITH alconox, alcohol, Distilled water,
Items Cleaned (List): water level meter

2 [✓] PRODUCT DEPTH NA FT. BELOW DATUM
Measured with: —

WATER DEPTH 10.10' below TOC FT. BELOW DATUM
Measured with: water level meter
TD 24.1 Purge Vol ~~[illegible]~~ 1.722 gallons

3 [✓] WATER-CONDITION BEFORE WELL EVACUATION (Describe):
Appearance: clear
Odor: none
Other Comments: —

4 [✓] WELL EVACUATION:
Method: Masterflex Peristaltic Pump
Volume Removed: <1 gal
Observations: Water ([✓ slightly] - very) cloudy
Water level (rose - [✓ fell] - no change)
Water odors: none
Other comments:

Groundwater Sampling Record

Monitoring Well No. SB16D (Continued)

5 ☑ SAMPLE EXTRACTION METHOD:

☐ Bailer made of: -
☒ Pump, type: Peristaltic
☐ Other, describe:

Sample obtained is ☒ GRAB; ☐ COMPOSITE SAMPLE

6 ☐ ON-SITE MEASUREMENTS: Not enough water to measure

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

7 ☐ SAMPLE CONTAINERS (material, number, size): EPA sampled

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:

Aquifer Slug Test Data Sheet

Location Altus AFB - OU 1
Job No. 722450.36020
Water Level 4.86' TOC
Measuring Datum TOC
Weather sunny, breezy
Comments

Client AFCEE
Field Scientist [✓ CM]/RN
Total Well Depth 22'
Elevation of Datum 1354.50' msl
Temp 65°F

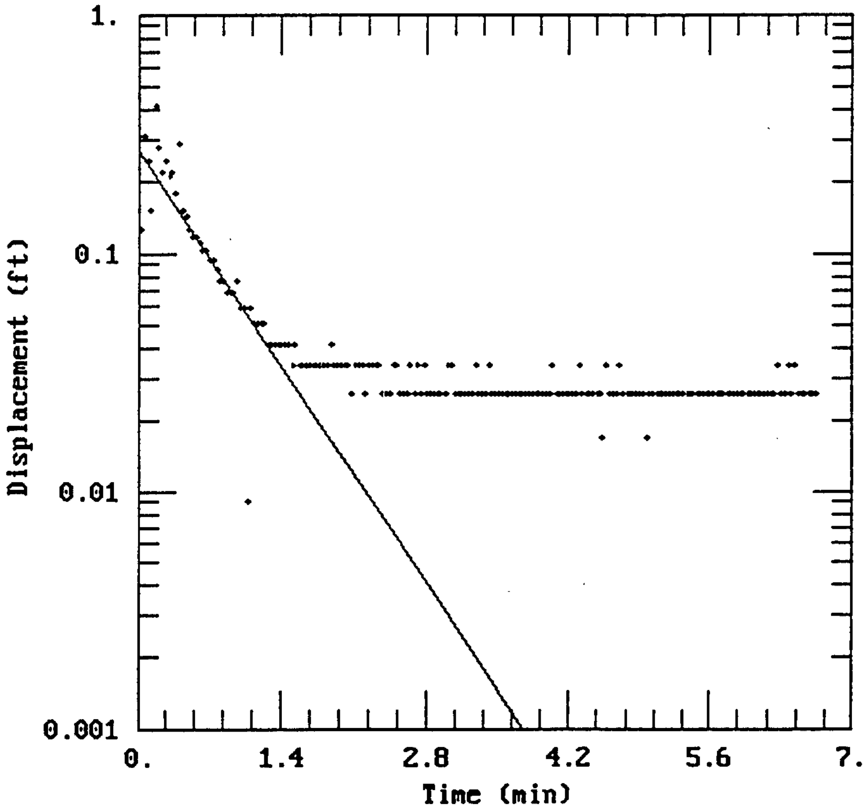
Well ID ~~WL01~~ OU-1-01
Date 4/14/97

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name OU_1_01A	Comments
6:22p	6:32p	21.317	21.351	Fall	~~WL01A~~	
6:35p	6:36p	21.351	21.351	Rise	OU-1_01B	
6:37p	6:48p	21.343	21.368	Fall	OU-1_01C	
6:49p	6:59p	21.359	21.359	Rise	OU_1_01D	
7:02p	7:14p	21.368	21.376	Fall	OU-1_01E	
7:15p	7:19p	21.368	21.368	Rise	OU_1_01F	

Kavg

LIENT: AFCEE	COMPANY: Parsons Engineering Science
OCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
OU_1_01A.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/14/97
test well: NA
obs. well: OU-1-01

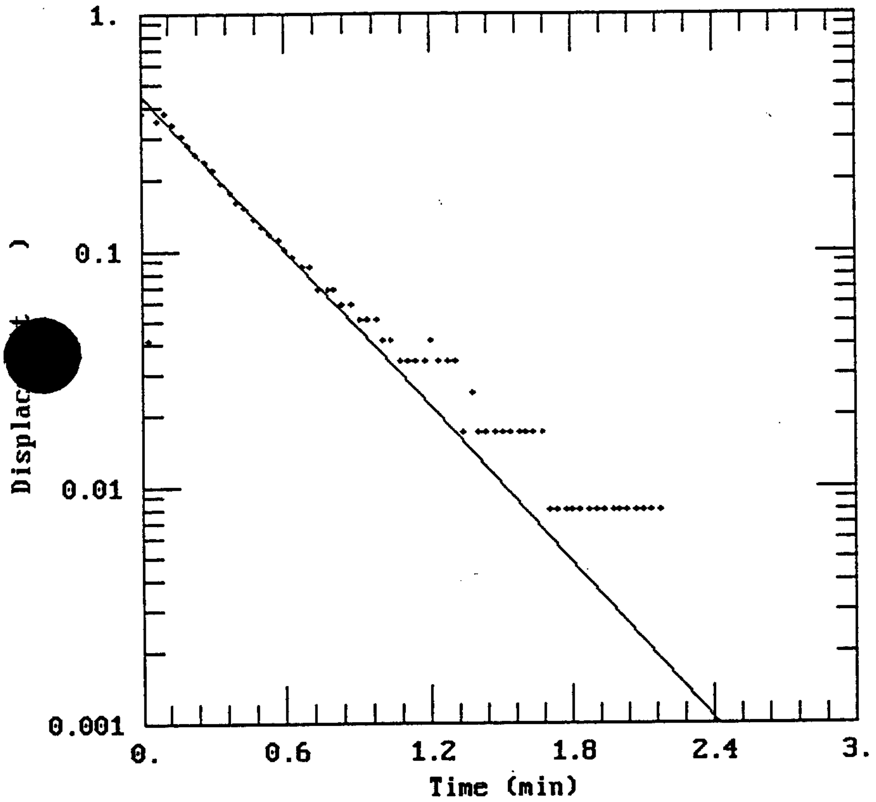
TEST DATA:
H0= 0.313 ft
r_c= 0.167 ft
r_w= 0.5 ft
L = 15. ft
b = 25. ft
H = 19.25 ft

PARAMETER ESTIMATES:
K = 0.01003 ft/min
y0 = 0.269 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
OU_1_01B.DAT
06/05/97

AQUIFER MODEL:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/14/97
test well: NA
obs. well: OU-1-01

TEST DATA:
H0= 0.38 ft
r_c= 0.167 ft
r_w= 0.5 ft
L = 15. ft
b = 25. ft
H = 19.25 ft

PARAMETER ESTIMATES:
K = 0.01693 ft/min
y0 = 0.4509 ft

AQTESOLV

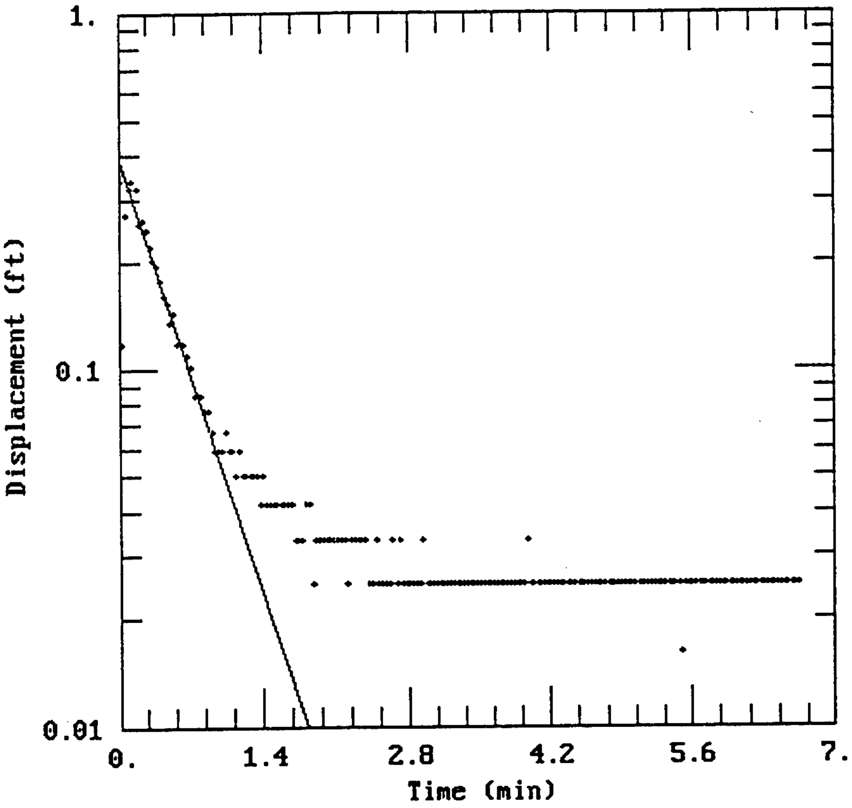
IENT: AFCEE

COMPANY: Parsons Engineering Science

CATION: Altus AFB, Altus, Oklahoma

PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
OU_1_01C.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/14/97
test well: NA
obs. well: OU-1-01

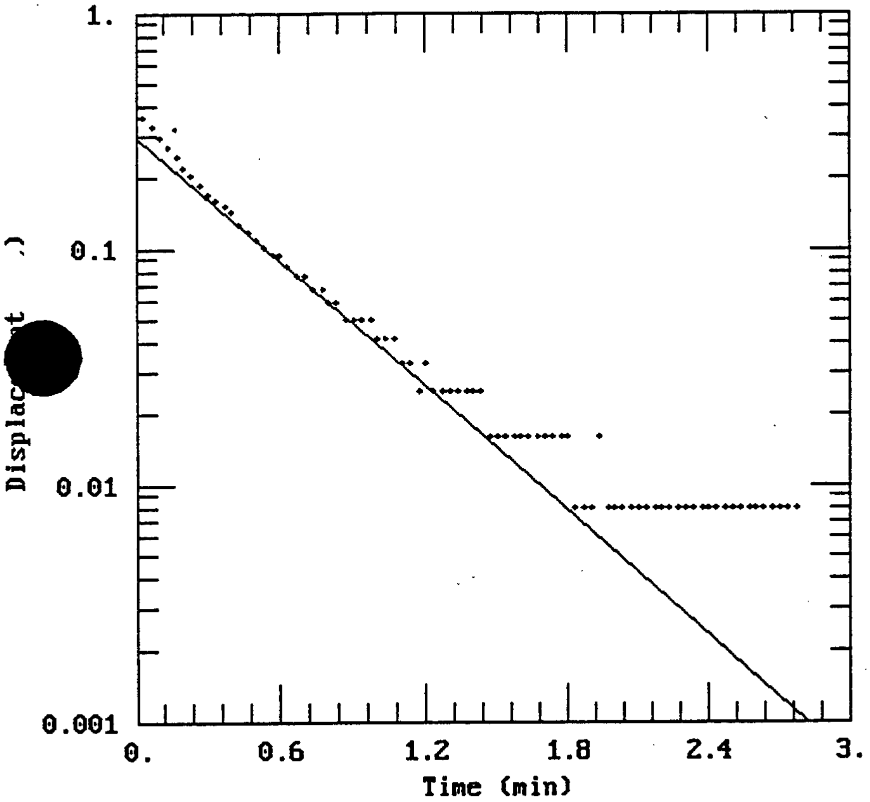
TEST DATA:
H0= 0.337 ft
r_c= 0.167 ft
r_w= 0.5 ft
L = 15. ft
b = 25. ft
H = 19.25 ft

PARAMETER ESTIMATES:
K = 0.01342 ft/min
y0 = 0.3876 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
OU_1_01D.DAT
06/05/97

AQUIFER MODEL:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/14/97
test well: NA
obs. well: OU-1-01

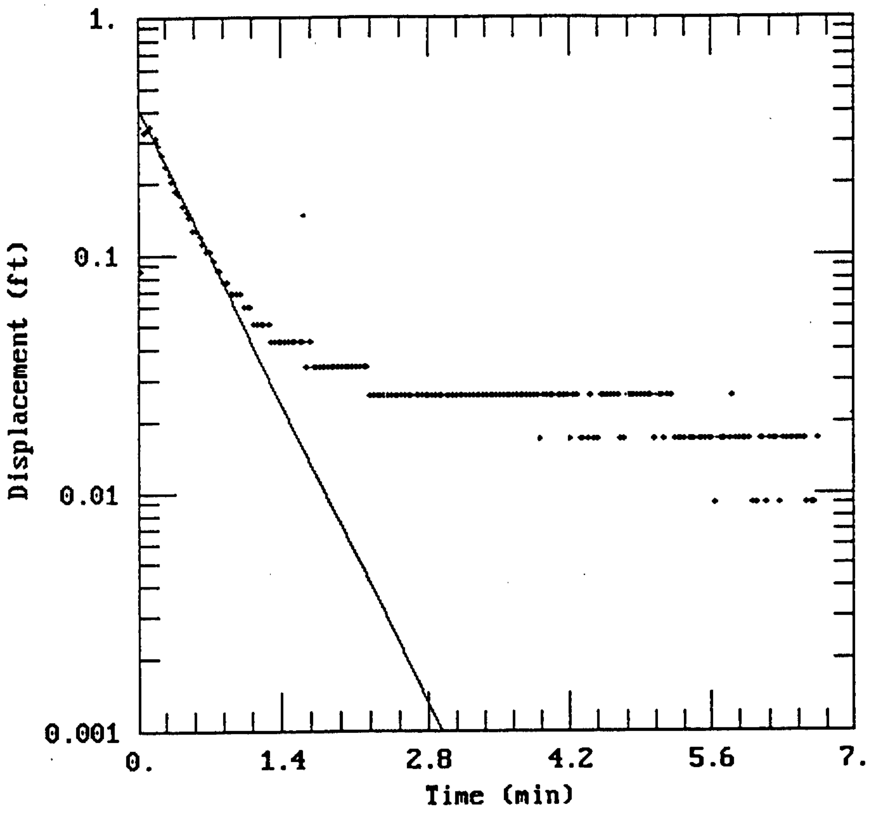
TEST DATA:
H0= 0.363 ft
r_c= 0.167 ft
r_w= 0.5 ft
L = 15. ft
b = 25. ft
H = 19.25 ft

PARAMETER ESTIMATES:
K = 0.0135 ft/min
y0 = 0.2945 ft

AQTESOLV

IENT: AFCEE	COMPANY: Parsons Engineering Science
CATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
OU_1_01E.DAT
06/05/97

AQUIFER MODEL:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/14/97
test well: NA
obs. well: OU-1-01

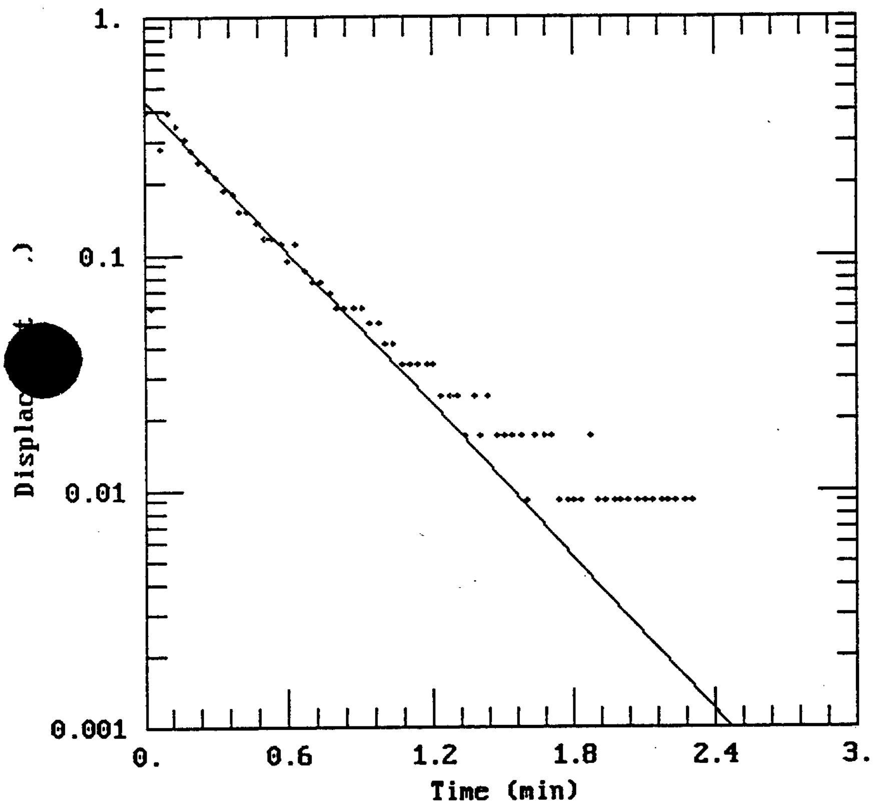
TEST DATA:
H0= 0.347 ft
r_c= 0.167 ft
r_w= 0.5 ft
L = 15. ft
b = 25. ft
H = 19.25 ft

PARAMETER ESTIMATES:
K = 0.01383 ft/min
y0 = 0.4151 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
OU_1_01F.DAT
06/05/97

AQUIFER MODEL:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/14/97
test well: NA
obs. well: OU-1-01

TEST DATA:
$H0 = 0.397$ ft
$r_c = 0.167$ ft
$r_w = 0.5$ ft
$L = 15.$ ft
$b = 25.$ ft
$H = 19.25$ ft

PARAMETER ESTIMATES:
$K = 0.01654$ ft/min
$y0 = 0.4419$ ft

AQTESOLV

Aquifer Slug Test Data Sheet

Location Altus AFB - OU 1
Client AFCEE
Well ID WL060
Job No. 722450.36020
Field Scientist CM/RN
Date 4/13/97
Water Level
Total Well Depth 13.5' below TOC
Measuring Datum TOC
Elevation of Datum 1346.81
Weather sunny, [illegible]
Temp 50°F
Comments

Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments	
5:44 p	5:50 p	14.220	14.220	Fall	WL060A		>16.1
5:51 p	6:00 p	14.211	14.144	Rise	WL060B		<12.1
6:01 p	6:09 p	14.135	14.177	Fall	~~WL060C~~	DID NOT SAVE	>16.5
6:10 p	6.20 p	14.152	14.101	Rise	WL060D		<12.158
6:21 p	6:30 p	14.093	14.135	Fall	WL060E		>16.4
6:31 p		14.118		Rise	WL060F		

K_{avg} = 0.0029 ft/min
= 4 ft/day

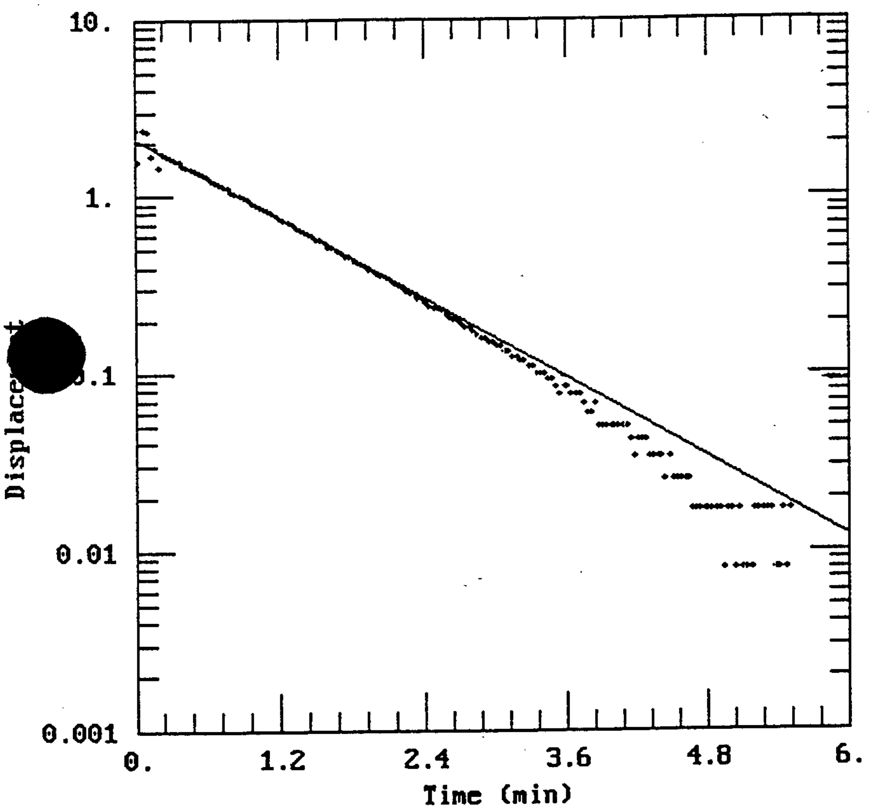
CLIENT: AFCEE

COMPANY: Parsons Engineering Science

LOCATION: Altus AFB, Altus, Oklahoma

PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL060A.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL060

TEST DATA:
$H0= 2.349$ ft
$r_c= 0.083$ ft
$r_w= 0.333$ ft
$L = 5.$ ft
$b = 11.5$ ft
$H = 10.$ ft

PARAMETER ESTIMATES:
$K = 0.005789$ ft/min
$y0 = 2.086$ ft

AQTESOLV

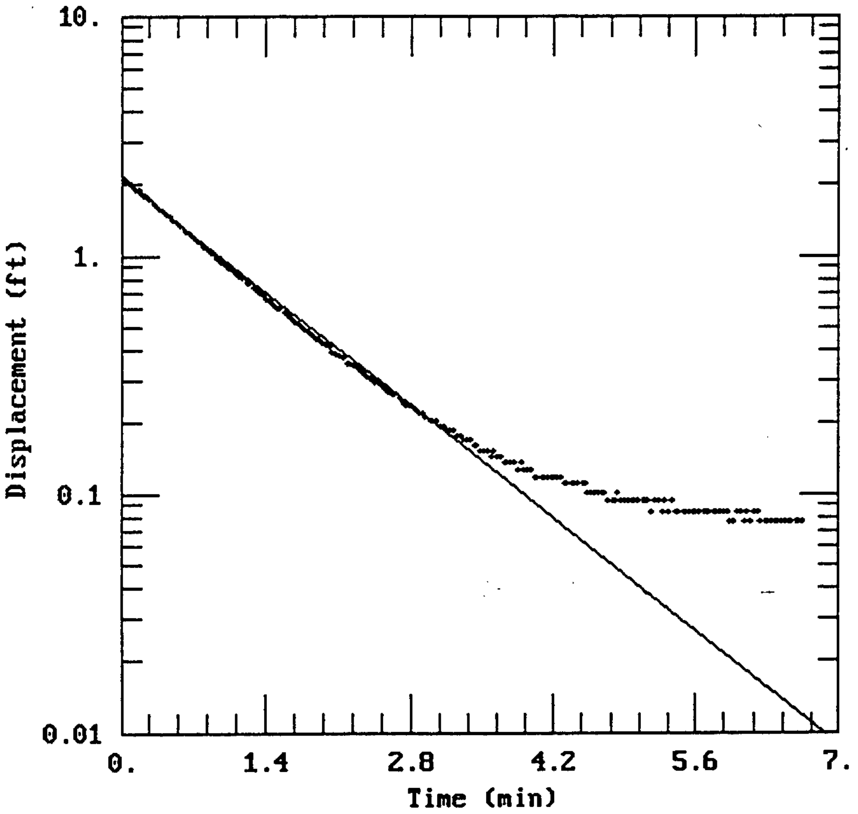
IENT: AFCEE

COMPANY: Parsons Engineering Science

CATION: Altus AFB, Altus, Oklahoma

PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL060B.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL060

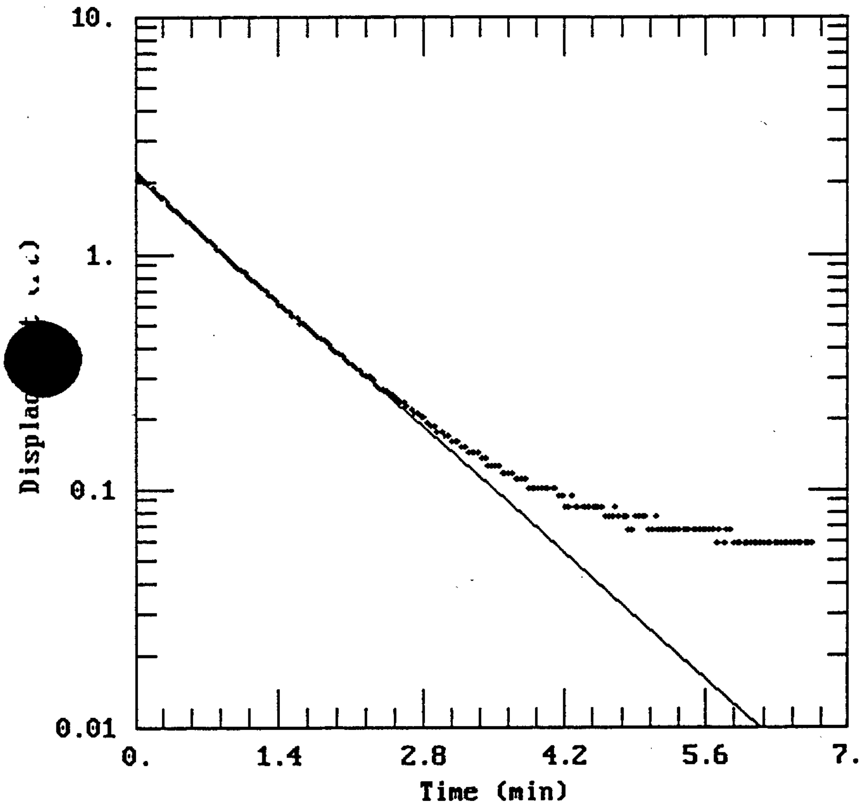
TEST DATA:
H0= 2.112 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 5. ft
b = 11.5 ft
H = 10. ft

PARAMETER ESTIMATES:
K = 0.005237 ft/min
y0 = 2.053 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL060D.DAT
06/05/97

AQUIFER MODEL:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL060

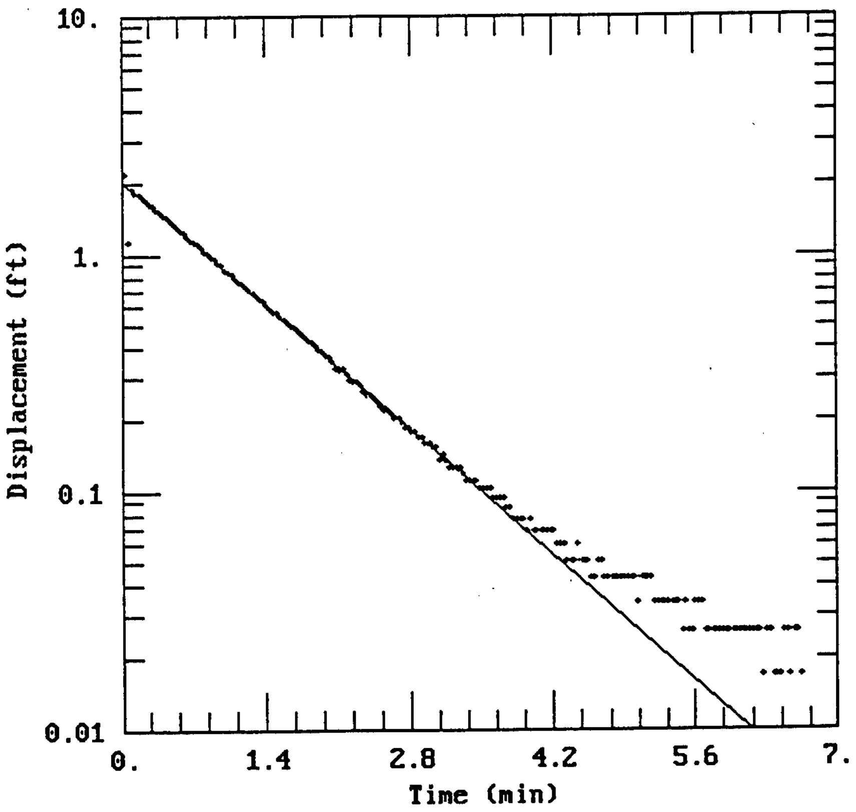
TEST DATA:
H_0 = 2.146 ft
r_c = 0.083 ft
r_w = 0.333 ft
L = 5. ft
b = 11.5 ft
H = 10. ft

PARAMETER ESTIMATES:
K = 0.00588 ft/min
y_0 = 2.096 ft

AQTESOLV

IENT: AFCEE	COMPANY: Parsons Engineering Science
CATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL060E.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL060

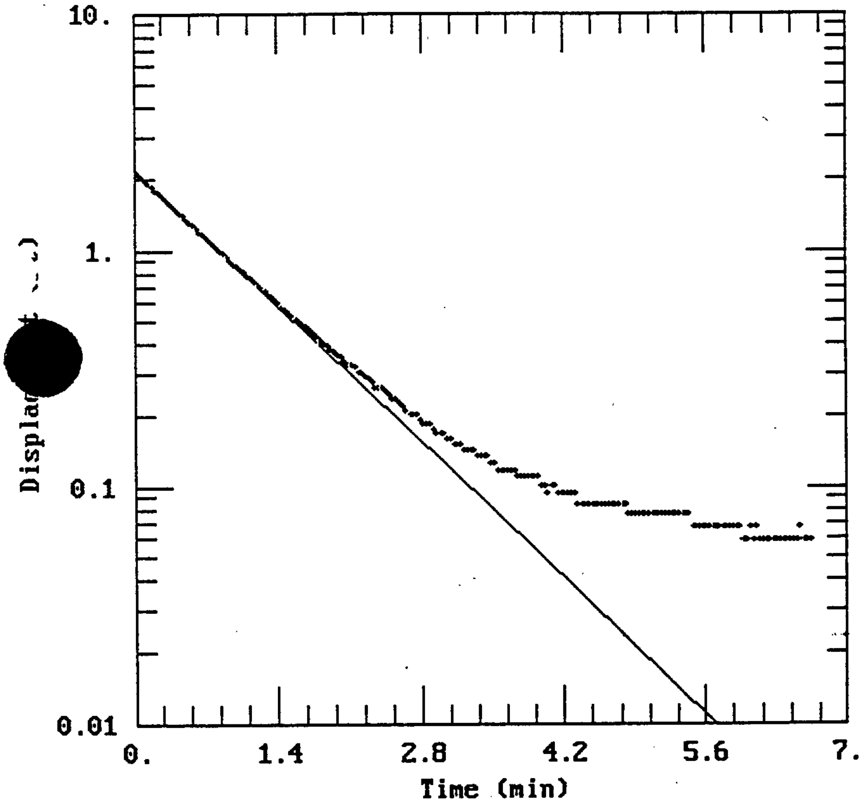
TEST DATA:
H0= 2.206 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 5. ft
b = 11.5 ft
H = 10. ft

PARAMETER ESTIMATES:
K = 0.005819 ft/min
y0 = 2.019 ft

AQTESOLV

CLIENT: AFCEE
COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma
PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL060F.DAT
06/05/97

AQUIFER MODEL:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL060

TEST DATA:
H0= 2.112 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 5. ft
b = 11.5 ft
H = 10. ft

PARAMETER ESTIMATES:
K = 0.006341 ft/min
y0 = 2.136 ft

AQTESOLV

90% recovery

28.829 ↑ 29.5 = 0.7

x 90%

0.63

29.50
\- 0.63
28.87

Aquifer Slug Test Data Sheet

Location Altus AFB - OU 1
Client AFCEE
Well ID WL061
Job No. 722450.36020
Field Scientist CM/RN
Date 4/13/97
Water Level 4.96' below TOC
Total Well Depth 34.0'
Measuring Datum TOC
Elevation of Datum 1340.92 msl
Weather sunny, breezy
Temp 40°F
Comments

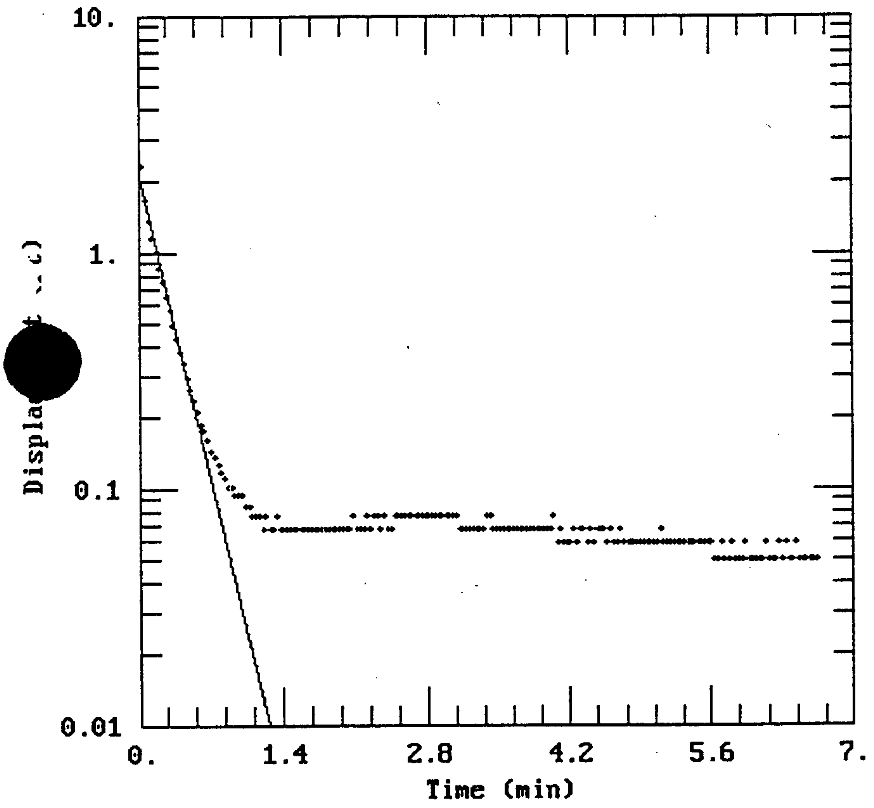
Beginning Time	Ending Time	Initial Head Reading (before slug)	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments
1:12 p	1:39 p	28.896	28.896	Fall	WL061A	
1:40 p	2:07 p	28.898	28.829	Rise	WL061B	
2:08 p	2:28 p	28.829	28.879	Fall	WL061C	
2:29 p	2:46 p	28.879	28.87	Rise	WL061D	
2:52 p	2:59	28.879	28.871	Fall	WL061E	
3:00 p	3:08	28.871	28.829	Rise	WL061F	

30.8
28.8
2.0
x 90%
1.8

K_{AVG} = 0.014 ft/min
= 20 ft/day

CLIENT: AFCEE	COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL061A.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL061

TEST DATA:
H0= 2.298 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 5. ft
b = 35. ft
H = 31. ft

PARAMETER ESTIMATES:
K = 0.03286 ft/min
y0 = 2.096 ft

AQTESOLV

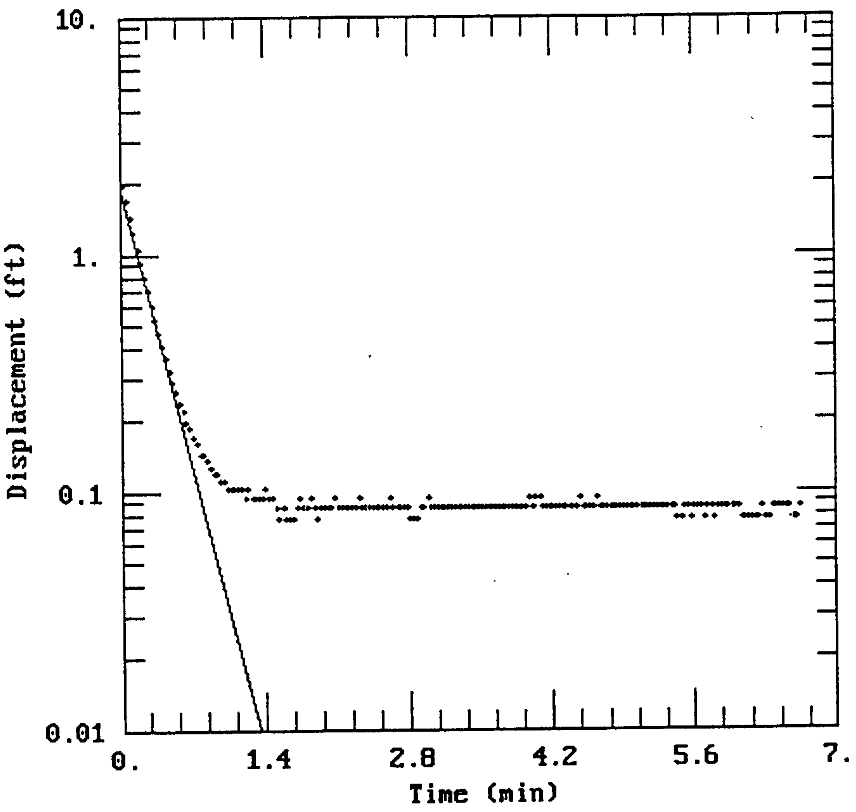
IENT: AFCEE

CATION: Altus AFB, Altus, Oklahoma

COMPANY: Parsons Engineering Science

PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL061B.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL061

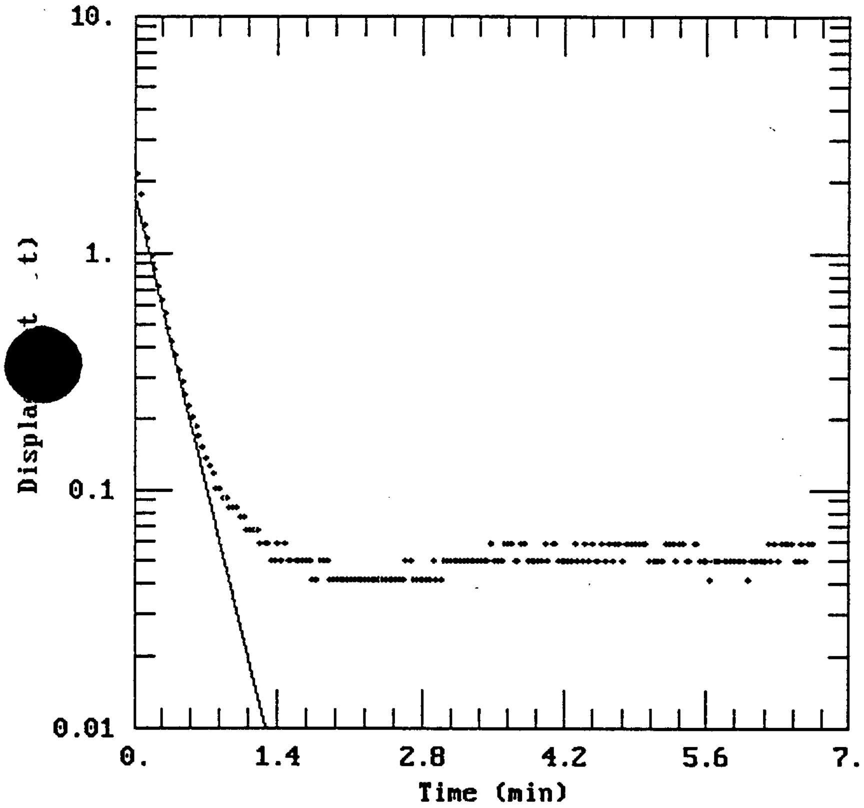
TEST DATA:
$H0= 1.952$ ft
$r_c= 0.083$ ft
$r_w= 0.333$ ft
$L = 5.$ ft
$b = 35.$ ft
$H = 31.$ ft

PARAMETER ESTIMATES:
$K = 0.03018$ ft/min
$y0 = 1.872$ ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL061C.DAT
06/05/97

AQUIFER MODEL:
Unconfined
SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL061

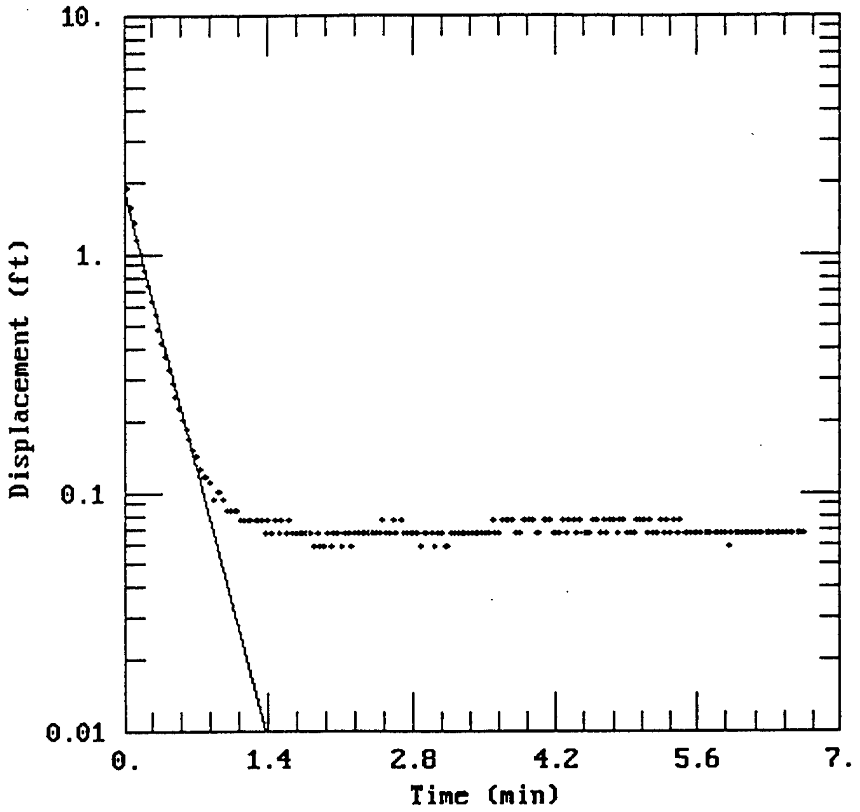
TEST DATA:
H0= 2.163 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 5. ft
b = 35. ft
H = 31. ft

PARAMETER ESTIMATES:
K = 0.03076 ft/min
y0 = 1.711 ft

AQTESOLV

LIENT: AFCEE	COMPANY: Parsons Engineering Science
OCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL061D.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL061

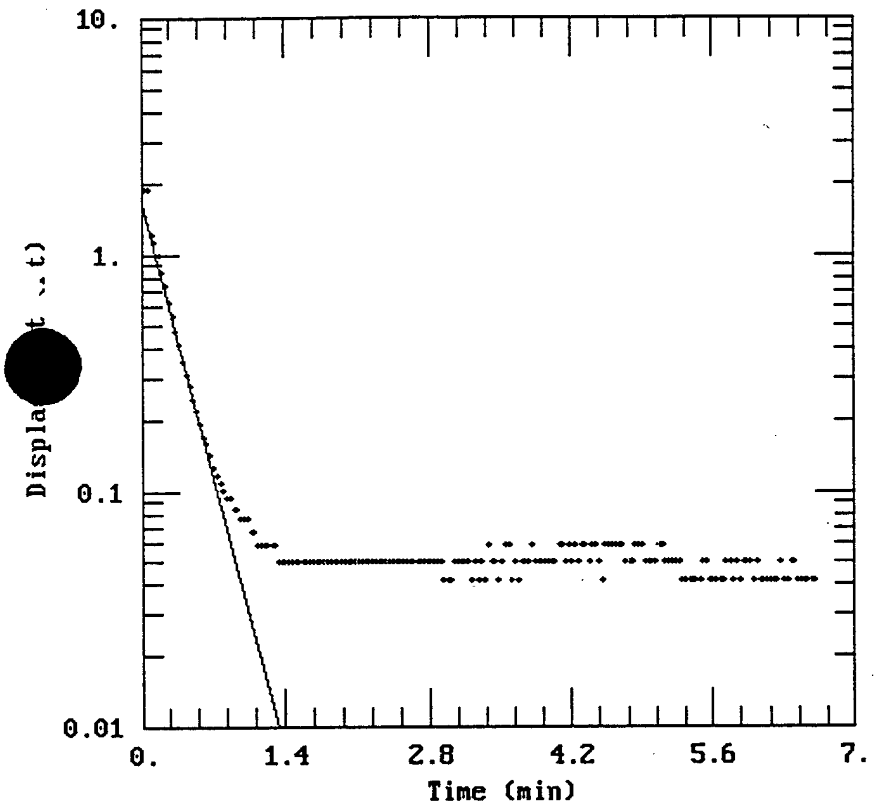
TEST DATA:
H0= 1.875 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 5. ft
b = 35. ft
H = 31. ft

PARAMETER ESTIMATES:
K = 0.02926 ft/min
y0 = 1.796 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL061E.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL061

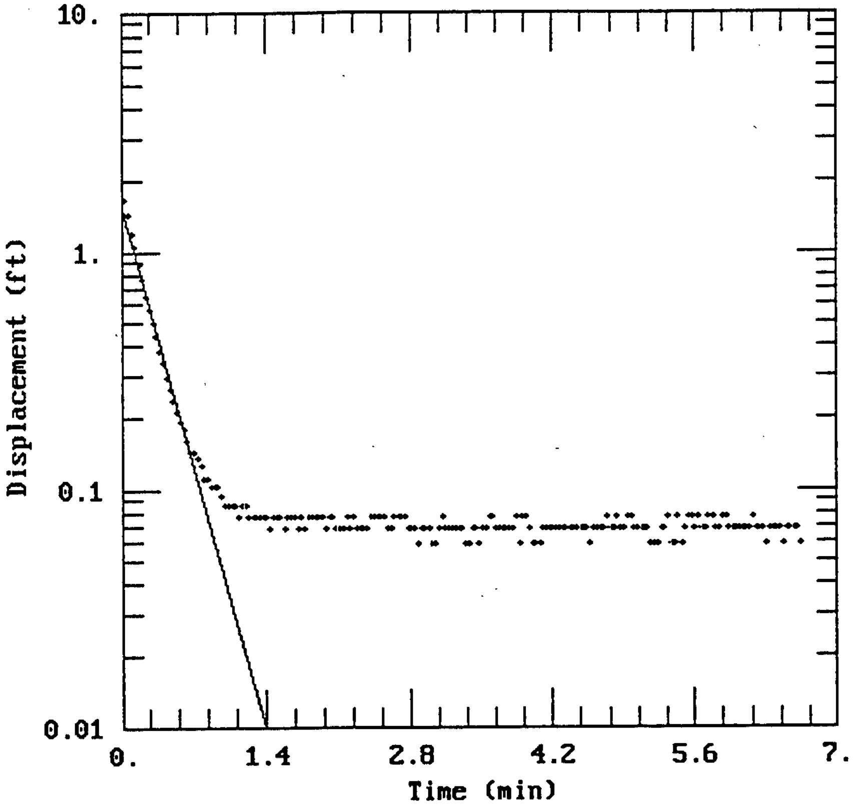
TEST DATA:
H0= 1.892 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 5. ft
b = 35. ft
H = 31. ft

PARAMETER ESTIMATES:
K = 0.02947 ft/min
y0 = 1.632 ft

AQTESOLV

IENT: AFCEE	COMPANY: Parsons Engineering Science
CATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL061F.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL061

TEST DATA:
H0= 1.648 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 5. ft
b = 35. ft
H = 31. ft

PARAMETER ESTIMATES:
K = 0.02775 ft/min
y0 = 1.521 ft

AQTESOLV

Aquifer Slug Test Data Sheet

Location Altus AFB - OU 1
Job No. 722450.36020
Water Level
Measuring Datum TOC
Weather sunny, breezy
Comments

Client AFCEE
Field Scientist CM/RN
Total Well Depth 19' below TOC
Elevation of Datum 1340.80' msl
Temp 50°F

Well ID WL062
Date 4/13/97

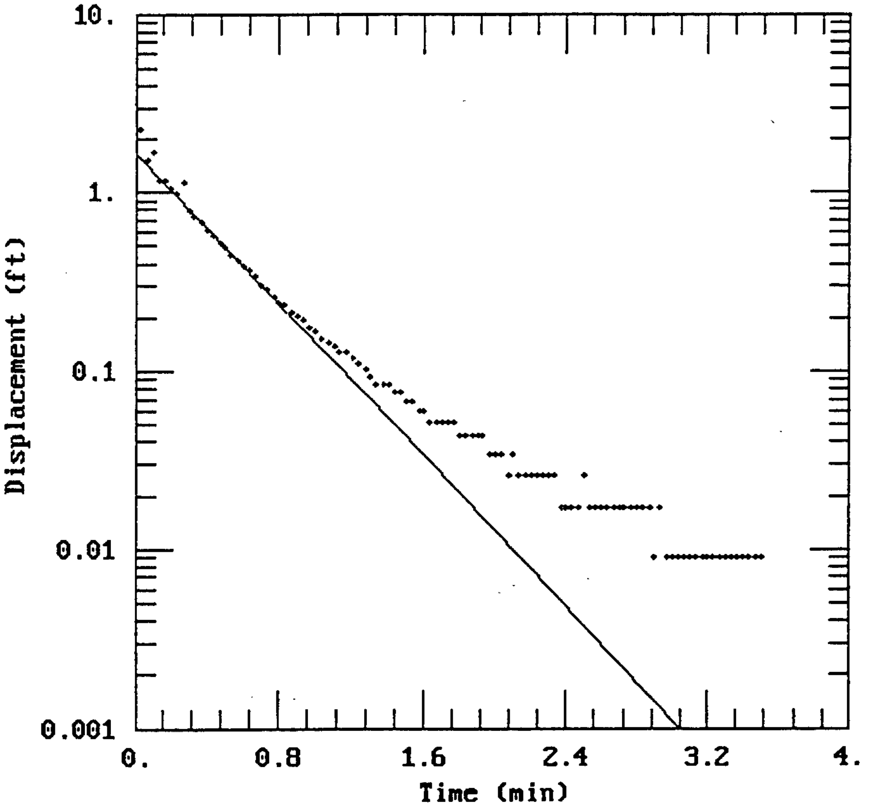
Beginning Time	Ending Time	Initial Head Reading	Ending Head Reading	Test Type (Rise/Fall)	File Name	Comments	
3:22p	3:26	17.363	17.363	Fall	WL062A		
3:27p	3:34	17.363	17.346	Rise	WL062B		
3:35	3:40	17.338	17.363	Fall	WL062C		18359
3:41	3:48	17.363	17.329	Rise	WL062D		
3:49	3:53p	17.321	17.354	Fall	WL062E		18757
4:01p	4:09p	17.169	17.126	Rise	WL062F		

Kavg = 0.0045 ft/min
= 6.5 ft/day

m:\forms\slug.doc 3/27/97

IENT: AFCEE	COMPANY: Parsons Engineering Science
CATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL062A.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL062

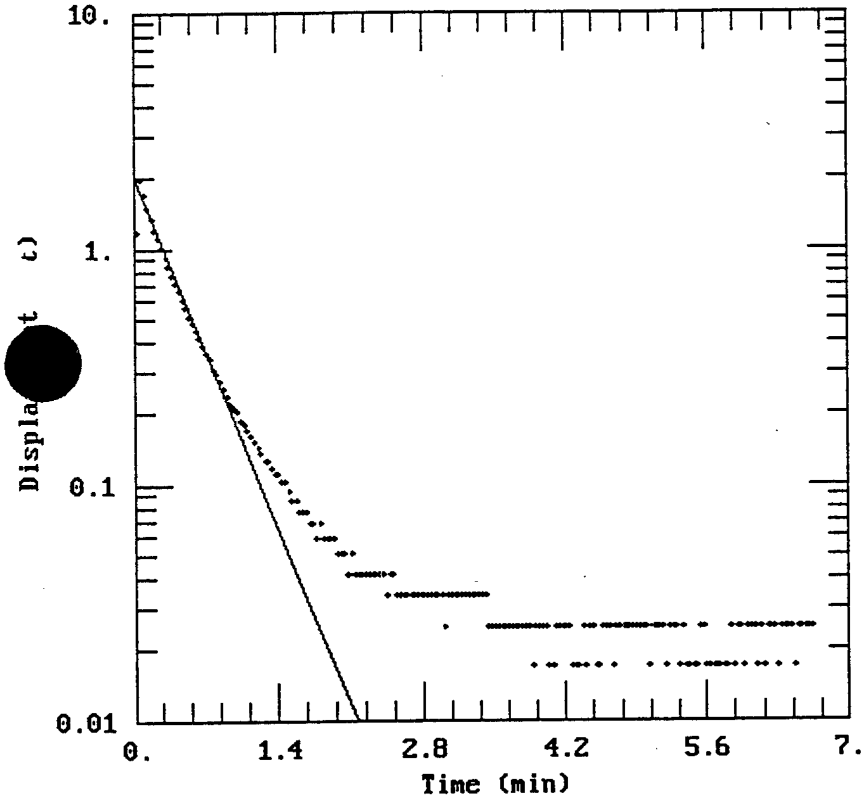
TEST DATA:
H0= 2.256 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 10. ft
b = 20. ft
H = 16. ft

PARAMETER ESTIMATES:
K = 0.01002 ft/min
y0 = 1.645 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL062B.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL062

TEST DATA:
H0= 1.969 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 10. ft
b = 20. ft
H = 16. ft

PARAMETER ESTIMATES:
K = 0.01016 ft/min
y0 = 2.002 ft

AQTESOLV

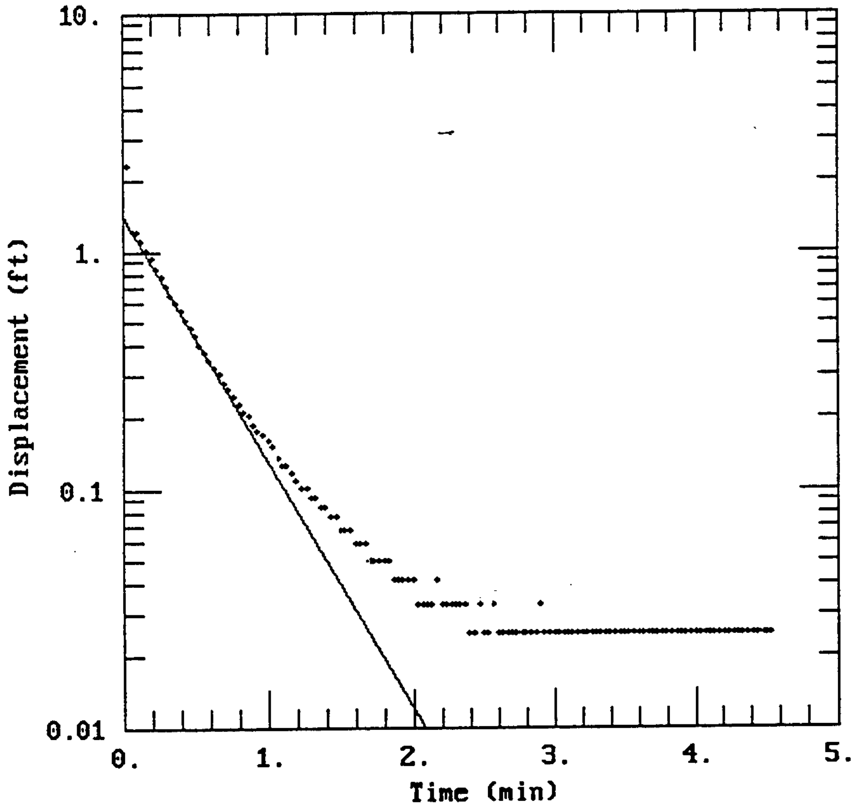
LIENT: AFCEE

COMPANY: Parsons Engineering Science

OCATION: Altus AFB, Altus, Oklahoma

PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL062C.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL062

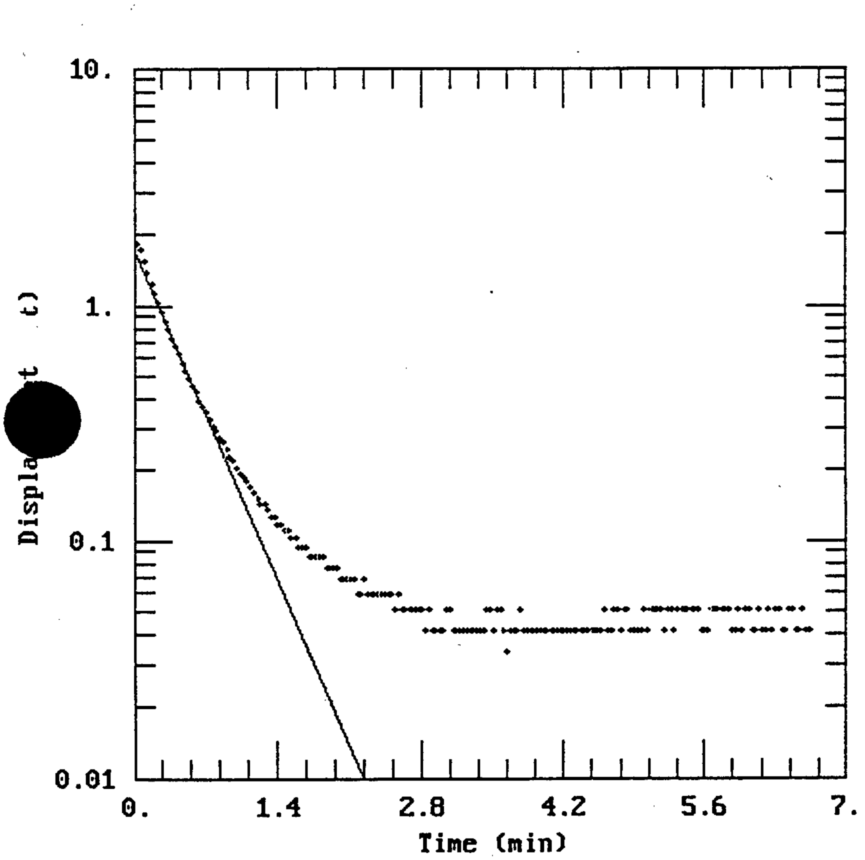
TEST DATA:
H0= 2.298 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 10. ft
b = 20. ft
H = 16. ft

PARAMETER ESTIMATES:
K = 0.009809 ft/min
y0 = 1.404 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL062D.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL062

TEST DATA:
H0= 1.808 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 10. ft
b = 20. ft
H = 16. ft

PARAMETER ESTIMATES:
K = 0.009457 ft/min
y0 = 1.691 ft

AQTESOLV

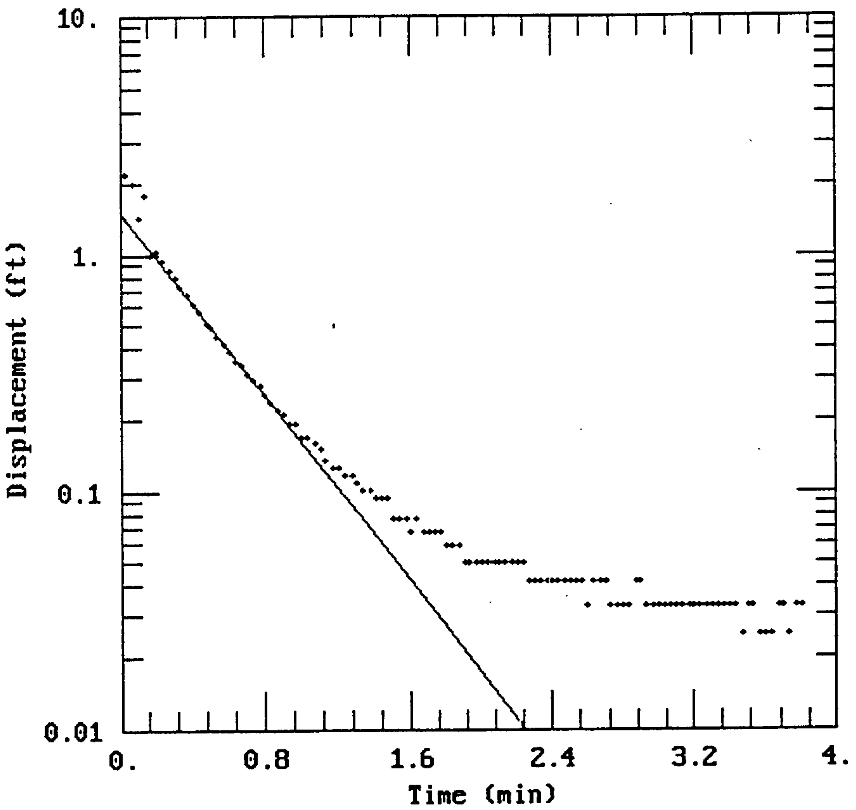
IENT: AFCEE

COMPANY: Parsons Engineering Science

CATION: Altus AFB, Altus, Oklahoma

PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL062E.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL062

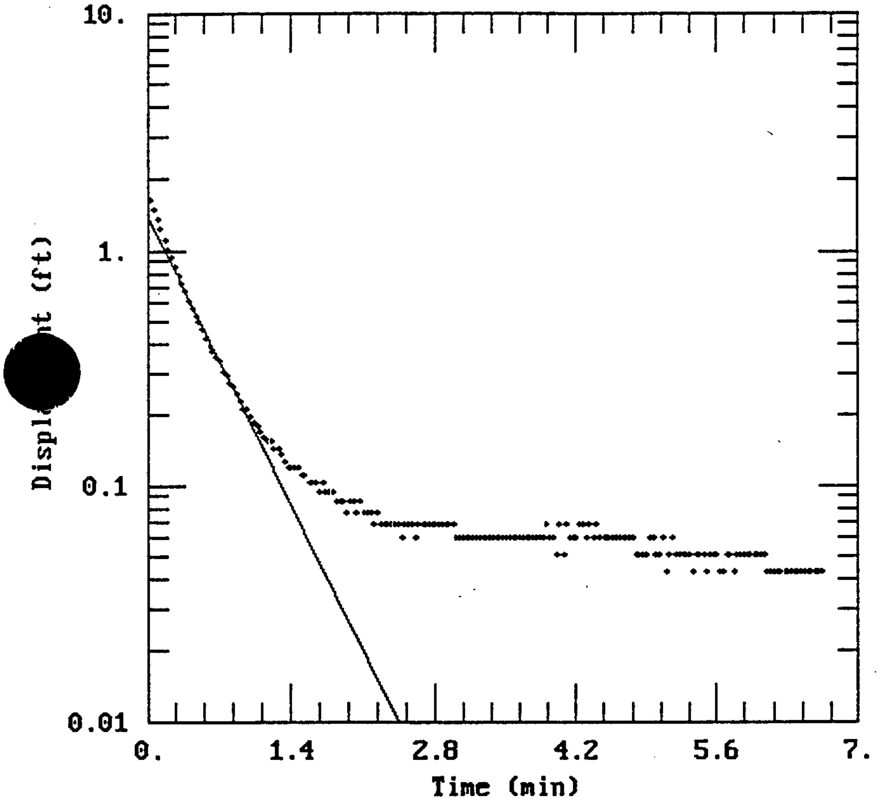
TEST DATA:
H0= 2.196 ft
r_c= 0.083 ft
r_w= 0.333 ft
L = 10. ft
b = 20. ft
H = 16. ft

PARAMETER ESTIMATES:
K = 0.009229 ft/min
y0 = 1.498 ft

AQTESOLV

CLIENT: AFCEE	COMPANY: Parsons Engineering Science
LOCATION: Altus AFB, Altus, Oklahoma	PROJECT: 722450.36050

Slug Test Data Analysis



DATA SET:
WL062F.DAT
06/05/97

AQUIFER MODEL:
Unconfined

SOLUTION METHOD:
Bouwer-Rice

PROJECT DATA:
test date: 4/13/97
test well: NA
obs. well: WL062

TEST DATA:
$H0 = 1.64$ ft
$r_c = 0.083$ ft
$r_w = 0.333$ ft
$L = 10.$ ft
$b = 20.$ ft
$H = 16.$ ft

PARAMETER ESTIMATES:
$K = 0.008388$ ft/min
$y0 = 1.387$ ft

AQTESOLV

APPENDIX C

LABORATORY ANALYTICAL DATA

MAN
TECH

May 21, 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 11 Altus soils submitted May 1, 1997 under Service Request #SF-3-260. Sample analysis was begun May 9, 1997 and completed May 21, 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

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 ALTUS SOILS SF-3-260

SAMPLE	SOIL FILTRATE % O.C.	SOLIDS % TOC	TOTAL SOIL % TOC	MEAN %TOC	STD DEV
TW-1,3.5',1-1	.016	.069	.085	.085	
1-2	.028	.056	.084		
TW-1,7',1-1	.019	.075	.094	.097	
1-2	.021	.079	.100		
TW-1,10',1-1	.015	.073	.088	.100	
1-2	.011	.101	.112		
TW-2,3',1-1	.018	.007	.025	.062	.046
1-2	.034	.013	.047		
1-3	.024	.089	.113		
TW-2,7',1-1	.019	.096	.115	.099	
1-2	.007	.075	.082		
TW-2,13.5',1-1	.017	.006	.023	.022	
1-2	.013	.008	.021		
TW-3,6',1-1	.040	.713	.753	.749	
1-2	.048	.696	.744		
TW-3,12',1-1	.017	.036	.053	.056	
1-2	.018	.040	.058		
TW-7,6.5',1-1	.027	.034	.061	.059	
1-2	.026	.031	.054		
TW-7,11.5',1-1	.017	.261	.278	.256	
1-2	.022	.212	.234		
OU-1-06,1-1	.014	.012	.026	.064	.045
1-2	.016	.036	.052		
1-3	.024	.089	.113		
LECO STD		.930			
WSO38	4.88				

Leco soil std t.v.=.90+/-.04
WSO38 std t.v.=4.92

Ref: 97-MAB4/vg
April 15,1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, Ok 74820

THRU: S.A. Vandegrift

Dear Don:

As per Service Request #SFTA-3-121, dissolved hydrogen analysis was performed onsite at Altus AFB, OK, using a RGA3 Reduction Gas Analyzer. The analysis began on April 7, 1997 and was completed April 11, 1997. A six place (0.0 to 10.0 PPM) external standard curve was used to quantitate the samples. The following data represents the concentration in the dissolved phase.

ALTUS AFB, OK

Well	H_2 Concentration (nM)
OU1-02	0.14
OU1-01	2.15
OU1-03	2.24
OU1-04	1.12
WL-021	0.42
SB-15S	0.27
SB-15D	No sample-low flow
WL-019	0.38
WL-022	0.66
WL-018	0.16
WL-020	0.35
WL-062	0.19
WL-061	0.29
WL-060	0.66
SB-11S	No sample-low flow
SB-11D	No sample-low flow
SB-16S	No sample-low flow
SB-16D	No sample-low flow
SB-10S	No sample-low flow
SB-10D	No sample-low flow

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

If you have any questions, please feel free to contact me at your convenience.

Sincerely,

Mark Blankenship

Mark Blankenship

xc: R.L. Cosby
G.B. Smith
J.L. Seeley

MANTECH ENVIRONMENTAL
TECHNOLOGY

Ref: 97-BN21/vg

April 17, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection & Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

Please find attached the analytical results for Service Request #SF-3-260 requesting the analysis of field samples from Altus AFB to be analyzed by purge-and-trap/GC-PID for Benzene, Toluene, Ethylbenzene, p-, m-, & o-xylene, 1,3,5-, 1,2,4-, & 1,2,3-Trimethylbenzene, and Total Fuel Carbon. We obtained the 16 samples in capped, 40 mL VOA autosampler vials April 14, 1997, and they were analyzed April 15 and 16, 1997. The samples were acquired and processed using the Millennium data system. A 5 place external standard curve (1-1000 ppb) was used to quantitate sample concentration for the compounds of interest. Since all but one sample had no analytes present, only that sample is reported for total fuel carbon.

RSKSOP-133, "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column-Dual Detector for Ground Water Samples" was used for these analyses. Autosampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Sincerely,

Bryan Newell

Bryan Newell

xc: R.L. Cosby
J.T. Wilson
G.B. Smith
J.L. Seeley SV for
L. Black

ManTech Environmental Research Services Corporation
R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SF-3-260 BTEXXXTMB and Fuelcarbon Analysis for Dr. Kampbell

UNITS = ng/ml Analyst: B. Newell

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND
QC, OBSERVED, PPB	18.4	18.3	19.1	18.3	19.1	18.7	19.6	19.5	18.3
QC, TRUE VALUE, PPB	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
10 PPB	10.0	9.5	10.5	9.4	9.5	9.4	10.0	9.4	10.2
SB-11-D	ND	ND	ND	ND	ND	ND	ND	ND	ND
SB-11-D FD	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-6	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-13	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-018	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-019	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-020	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-021	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-021 FD	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-022	BLQ	ND	ND	ND	ND	ND	ND	ND	ND
WL-060	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-061	ND	ND	ND	ND	ND	ND	ND	ND	ND
100 PPB	101.9	98.2	107.3	98.9	100.3	99.2	104.9	99.9	107.8
WL-062	ND	ND	ND	ND	ND	ND	ND	ND	ND
OU1-01	ND	1.4	ND	ND	ND	ND	ND	ND	ND
OU1-02	ND	ND	ND	ND	ND	ND	ND	ND	ND
OU1-03	ND	ND	ND	ND	ND	ND	ND	ND	ND
OU1-04	ND	ND	ND	ND	ND	ND	ND	ND	ND
SB1SWS	ND	ND	ND	ND	ND	ND	ND	ND	ND
500 PPB	502.5	480.9	523.6	486.5	495.8	483.1	516.3	495.0	535.6
LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND
QC, OBSERVED, PPB	18.6	18.5	19.3	18.6	19.7	18.7	19.4	19.0	18.9
QC, TRUE VALUE, PPB	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
QC, OBSERVED, PPB	20.1	19.6	20.2	19.8	20.1	19.7	20.5	19.8	19.7
10 PPB	10.7	10.1	11.0	9.8	9.8	9.8	10.6	9.7	10.7
LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND
1 PPB	1.1	1.0	1.1	1.1	1.0	0.9	1.0	0.9	1.1

SampleName	TOTAL FUEL CARBON
OU1-01	883

ND denotes None Detected.
[illegible] denotes Below Limit of Quantitation.

Ref: 97-LH11/vg

April 17, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift

Dear Don:

As requested in Service Request #SF-3-260, gas analysis was performed for methane, ethylene, and ethane on samples from Altus AFB. The samples were received on April 14, 1997. The analyses were performed on April 15, 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 C Hopkins

Lisa Hopkins

xc: R.L. Cosby
J.T. Wilson
G.B. Smith
J.L. Seeley

ManTech Environmental Research Services Corporation
R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	Methane	Ethylene	Ethane
100ppm CH4	92.6	**	**
100ppm C2H4	**	98.0	**
100ppm C2H6	**	**	99.4
HPHe	**	**	**
Lab Blank	**	**	**
OU1-01	0.006	**	**
OU1-02	0.007	**	**
OU1-03	0.008	**	**
OU1-04	0.002	**	**
TW-6	*	**	**
TW-6 Lab Dup	**	**	**
5B-11-D	**	**	**
TW-13	**	**	**
5B-15-WS	0.001	**	**
WL-019	0.037	**	**
WL-018	*	**	**
WL-018 Field Dup	**	**	**
10ppm CH4	9.2	**	**
WL-020	**	**	**
WL-021	0.001	**	**
WL-022	0.078	**	**
WL-060	0.001	**	**
WL-061	**	**	**
WL-061 Lab Dup	**	**	**
WL-062	**	**	**
100ppm CH4	96.1	**	**
100ppm C2H4	**	90.7	**
100ppm C2H6	**	**	94.2

Lower Limit of Quantitation

	Methane	Ethylene	Ethane
	0.001	0.003	0.002

Units for the samples are in mg/L.
Units for the standards are parts per million.

** denotes None Detected.
* denotes Below Limit of Quantitation.

MANAGEMENT
TECHNOLOGY

April 23, 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 28 Altus liquids submitted April 17, 1997 under Service Request #SF-3-260. Sample analysis was begun April 17, 1997 and completed April 23, 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

ManTech Environmental Research Services Corporation
R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

KAMPBELL ALTUS LIQUIDS SF-3-260

SAMPLE	MG/L TOC
TW-3	2.48
TW-5	2.07
TW-5, REP 2	2.66
TW-6	29.8
TW-9	14.2
TW-10	1.06
TW-13	1.55
DUP	1.58
TW-15	.290
TW-15, REP 2	.263
OU1-01	4.19
OU1-02	3.10
OU1-03	45.8
OU1-04	17.0
OU1-05	1.44
OU1-06	2.53
WL-018, REP 1	16.1
WL-018, REP 2	16.7
WL-019	3.56
WL-020	15.7
WL-021	3.67
WL-022	8.35
WL-060	1.18
WL-061	.330
WL-062	1.04
SB-11D	6.30
SB15WS	3.90
WSO38	4.82

WSO38 std. t.v.=4.92

Ref: 97-BN25/vg

April 23, 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

Dear Don:

Please find attached the analytical results for Service Request #SF-3-260 requesting the analysis of field samples from Altus AFB to be analyzed by purge-and-trap/GC-PID for Benzene, Toluene, Ethylbenzene, p-, m-, & o-xylene, 1,3,5-, 1,2,4-, & 1,2,3-Trimethylbenzene, and Total Fuel Carbon. We obtained the 18 samples in capped, 40 mL VOA autosampler vials April 18, 1997, and they were analyzed April 21 and 22, 1997. The samples were acquired and processed using the Millennium data system. A 5 place external standard curve (1-1000 ppb) was used to quantitate sample concentration for the compounds of interest. Since only a few samples had analytes present, only those samples are reported for total fuel carbon.

RSKSOP-133, "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column-Dual Detector for Ground Water Samples" was used for these analyses. Autosampling was performed using a Dynatech Precision autosampler system in line with a Tekmar LSC 2000 concentrator.

Sincerely,

Bryan Newell

Bryan Newell

xc:
R.L. Cosby
J.T. Wilson
G.B. Smith
J.L. Seeley
L. Black

ManTech Environmental Research Services Corporation
R.S. Kerr Environmental Research Laboratory, P.O. Box 1198. 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

SF-3-260 BTEXXXTMB and Total Fuel Carbon for Dr. Kampbell

Units = ng/ml Analyst: B. Newell

SampleName	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND
QC, OBSERVED, PPB	17.3	17.1	17.8	17.0	17.9	17.1	18.0	17.4	17.2
QC, TRUE VALUE, PPB	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
10 PPB	9.0	8.7	9.4	8.6	9.0	8.6	9.0	8.7	9.4
TW-1	BLQ	7.8	2.6	3.4	7.0	3.6	1.1	4.5	BLQ
TW-1 Field Dup	BLQ	6.9	2.4	3.0	6.2	3.1	BLQ	3.8	BLQ
TW-2	1.1	16.9	4.1	4.5	10.3	6.1	1.1	4.3	1.0
TW-2 Field Dup	1.4	21.6	4.9	5.3	12.2	7.4	1.2	5.0	1.0
TW-3	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-5	ND	2.1	BLQ	BLQ	1.8	1.0	ND	1.1	ND
TW-8	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-9	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
TW-10	ND	2.5	ND	ND	ND	ND	ND	ND	ND
TW-15	ND	ND	ND	ND	ND	ND	ND	ND	ND
OU1-05	ND	ND	ND	ND	ND	ND	ND	ND	ND
OU1-06	ND	1.8	BLQ	BLQ	1.7	1.0	ND	1.0	ND
OU1-06 Field Dup	ND	1.8	BLQ	BLQ	1.7	BLQ	ND	1.0	ND
RIN1	ND	ND	ND	ND	ND	ND	ND	ND	ND
1 PPB	1.0	1.0	1.0	0.9	1.0	0.9	1.0	0.9	1.0
RIN2	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRIP BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND
RV-001	ND	ND	ND	ND	ND	ND	ND	ND	ND
RV-002	ND	ND	ND	ND	ND	ND	ND	ND	ND
RV-003	ND	ND	ND	ND	ND	ND	ND	ND	ND
RV-004	ND	ND	ND	ND	ND	ND	ND	ND	ND
RV-005	ND	ND	ND	ND	ND	ND	ND	ND	ND
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND
1 PPB	1.0	0.9	0.9	0.9	1.0	0.9	0.9	0.9	0.9

SampleName	TOTAL FUEL CARBON
TW-1	166.1
TW-1 Field Dup	169.6
TW-2	239.3
TW-2 Field Dup	239.6
TW-5	7.6
TW-10	2.2
OU1-06	84.7
OU1-06 Field Dup	83.2

ND denotes None Detected.
[illegible] denotes Below Limit of Quantitation.

ALTUS AIR FORCE BASE
Field Data

Sample	Date	pH	Total Alkalinity mg/l $CaCo_3$	Carbon Dioxide mg/l	Ferrous Iron	Hydrogen Sulfide mg/l
OU1-02	4-08-97	6.8	386	420	<.05	
OU1-01	4-08-97	6.8	379	210	<.05	
OU1-03	4-08-97	6.8	383	262	<.05	
OU1-04	4-08-97	6.8	446	264	<.05	
WL-021	4-08-97	6.8	415	402	<.05	
SB15WS	4-08-97	6.9	332	256	<.05	
WL-019	4-09-97	6.8	418	212	<.05	
WL-022	4-09-97	7.0	422	344	<.05	<.1
WL-018	4-09-97	7.0	283	184	<.05	
WL-020	4-09-97	7.0	250	114	<.05	
WL-062	4-09-97	7.0	272	240	<.05	
WL-061	4-09-97	7.1	157	82	<.05	
WL-060	4-10-97	7.1	311	120	<.05	
TW-6	4-10-97	7.2	325	264	<.05	
TW-13	4-10-97	7.1	320	128	<.05	
SB11-D	4-10-97	6.9	256	204	<.05	
TW-15	4-15-97		205	80	<.05	
TW-8	4-15-97		319	160	<.05	
TW-1	4-15-97		320	306	<.05	
TW-3	4-15-97	6.9	417	320	<.05	
TW-9	4-15-97	6.9	408	160	<.05	
TW-5	4-16-97	6.9	405	180	<.05	
TW-10	4-16-97	6.9	504		<.05	
OU1-05	4-17-97		220	100	<.05	

MAN TECH

Ref: 97-JRD26/vg
97-LP46/vg
97-MW29/vg

April 29, 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 25 Altus AFB samples submitted to MERSC as part of Service Request #SF-3-260. The samples were received April 14 and 18 and analyzed April 14, 17, 18 and 21, 1997. The methods used for analysis were EPA Methods 353.1 for NO_2 and NO_3 and 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,

Justin Daniel
Justin R. Daniel

Lynda Pennington by JRD
Lynda Pennington

Mark White
Mark White

xc: R.L. Cosby
G.B. Smith
J.L. Seeley

ManTech Environmental Research Services Corporation
R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	mg/L Cl^-	mg/L $SO_4^=$	mg/L $NO^-_2 + NO^-_3(N)$	mg/L NH_3
SB-11-D	517	2230	1.41	<.05
SB-11-D Dup	507	2220	-----	-----
TW-6	260	1240	0.79	<.05
TW-13	400	1580	1.42	<.05
WL-018	384	1500	0.72	<.05
WL-019	320	1900	<.05	<.05
WL-020	321	1070	0.45	<.05
WL-020 Dup	-----	------	0.47	<.05
WL-021	341	2010	<.05	<.05
WL-022	398	2180	0.37	<.05
WL-060	537	2010	4.11	<.05
WL-061	811	2340	1.50	<.05
WL-061 Dup	816	2350	-----	-----
WL-062	830	2480	1.41	<.05
OU1-01	330	1780	<.05	<.05
OU1-02	341	1690	<.05	<.05
OU1-03	384	1780	<.05	<.05
OU1-03 Dup	-----	------	<.05	<.05
OU1-04	207	1440	0.17	<.05
SB15WS	406	1820	<0.05	<0.05
Blank	<.1	<.1	<.05	<.05
AQC	34.8	44.4	2.02	10.2
AQC T.V.	34.8	44.0	2.10	10.1
Spike Rec.	100%	100%	90%	100%
TW-2	952	3620	<0.05	<0.05
TW-1	378	2170	<0.05	<0.05
TW-3	699	2880	<0.05	<0.05
TW-3 Dup	-----	------	<0.05	<0.05
TW-5	579	1460	0.37	<0.05
TW-8	724	1920	0.99	<0.05
TW-9	230	680	7.80	<0.05
TW-10	417	1150	2.29	<0.05
TW-10 Dup	411	1140	-----	-------
TW-15	687	2160	2.23	<0.05
OU1-05	390	2080	2.37	<0.05
OU1-06	657	3050	1.00	<0.05
Blank	<.1	<.1	<0.05	<0.05
AQC	34.4	43.9	2.05	9.87
AQC T.V.	34.8	44.0	2.10	10.0
Spike Rec.	-----	-----	95%	101%
	-----	-----	100%	101%

Ref: 97JAD21

April 24, 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-3-260, headspace GC/MS analysis of 40 Altus AFB water samples for chlorinated volatile organics was completed. The samples were received on April 14,18, 1997 and analyzed on April 18-19, 1997. RSKSOP-148 (Determination of Volatile Organic Compounds in Water by Automated Headspace Gas Chromatography/Mass Spectrometry (Saturn II Ion Trap Detector) was used for this analysis.

An internal standard calibration method was established for the 15 compounds. The standard curves were prepared from 1.0 to 4000 ppb. The lower calibration limits were 1.0 ppb.

A dilution corrected quantitation report for the samples, lab duplicates, field duplicates, QC standards and lab blanks is presented in tables 1-3.

If you should have any questions, please feel free to contact me.

Sincerely,

John Allen Daniel

John Allen Daniel

xc: R.L. Cosby
G.B. Smith
D.D. Fine
J.L. Seeley
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-3-260 from Altus AFB.

Concentration = ppb

Compound	SB-11-D	TW-6	TW-6 Field Dup	TW-13	WL-018	WL-019	WL-020	WL-021	WL-022	WL-060	WL-061
VINYL CHLORIDE	ND	ND	ND	ND	ND	---	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	---	ND	ND	ND	ND	1.0	ND	---	---	ND	ND
T-1,2-DICHLOROETHENE	6.8	ND	ND	ND	ND	27.4	ND	3.4	4.3	ND	ND
1,1-DICHLOROETHANE	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	31.8	ND	ND	ND	---	207	ND	15.7	31.7	ND	ND
CHLOROFORM	---	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	457	ND	ND	ND	1.3	224	---	41.8	36.2	ND	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	1.1	---	---	---	---	---	ND	ND	ND	ND	ND

	WL-061 Lab Dup	WL-062	OU1-01	OU1-01 1/10 Dil Field Dup	OU1-02	OU1-02 1/10 Dil Field Dup	OU1-03	OU1-03 1/10 Dil Field Dup	OU1-04	OU1-04 Field Dup	SB15WS
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	---	ND
1,1-DICHLOROETHENE	ND	ND	4.3	---	3.8	---	3.5	---	1.9	2.1	1.9
T-1,2-DICHLOROETHENE	ND	ND	33.3	34.0	19.2	18.0	16.3	15.0	148	154	23.7
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	ND	1340	1320	1130	1160	1080	1060	756	778	444
CHLOROFORM	ND	ND	---	ND	1.1	ND	1.9	ND	ND	ND	---
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	3.2	*****	8,910	*****	11,400	*****	12,700	1670	1690	3520
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	---	ND	---	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	---
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate Dil = Dilution ***** = Above Calibration Limit(4000 ppb)

Table 2. Quantitation Report fo[illegible].R. # SF-3-260 from Altus AFB.

Concentration = ppb

Compound	SB15WS Lab Dup	TW-1	TW-3	TW-5	TW-8	TW-9	TW-10	TW-15	OU1-05	OU1-06	RIN-1
VINYL CHLORIDE	---	---	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	1.9	1.8	2.1	ND	---	ND	ND	ND	---	---	ND
T-1,2-DICHLOROETHENE	23.4	22.9	20.0	ND	---	ND	ND	ND	1.1	8.1	ND
1,1-DICHLOROETHANE	ND	ND	---	ND	---	ND	ND	ND	ND	---	ND
C-1,2-DICHLOROETHENE	443	118	28.7	---	2.1	ND	ND	---	63.2	37.9	ND
CHLOROFORM	---	ND	ND	ND	---	ND	ND	ND	ND	---	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	3540	690	347	---	483	---	ND	13.6	ND	360	ND
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

	RIN-2	FIELD-BLK	TRIP BLK	RV001	RV001 Lab Dup	RV-002	RV003	RV004	RV005	TW-2	TW-2 Lab Dup
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.1	1.1
T-1,2-DICHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	16.4	17.3
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	---	---
C-1,2-DICHLOROETHENE	ND	ND	ND	---	---	---	---	---	---	54.1	54.1
CHLOROFORM	ND	---	3.6	ND	ND	ND	ND	ND	ND	---	---
1,1,1-TRICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CARBON TETRACHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	ND	ND	ND	---	1.4	2.8	1.6	736	757
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	---	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	ND	ND	ND	ND	---	ND	ND	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = None Detected --- = Below Calibration Limit(1.0 ppb) Dup = Duplicate

Table 3. Quantitation Report for S.R. # SF−3−260 from Altus AFB.

Concentration = ppb

Compound	TW−4	TW−7	TW−14P	QC0417A 20 ppb	QC0417B 200 ppb	QC0417C 20 ppb	QC0417D 200 ppb	QC0417E 20 ppb	QC0417F 200 ppb	QC0417G 20 ppb	QC0417H 200 ppb
VINYL CHLORIDE	ND	ND	ND	18.3	179	18.8	179	18.5	182	18.7	179
1,1−DICHLOROETHENE	ND	ND	ND	22.3	220	21.7	218	21.5	224	22.8	214
T−1,2−DICHLOROETHENE	1.4	ND	ND	19.6	192	20.0	199	20.1	198	20.0	178
1,1−DICHLOROETHANE	ND	ND	ND	21.3	200	21.1	199	21.7	194	21.1	209
C−1,2−DICHLOROETHENE	2.0	ND	ND	20.8	193	18.9	201	20.2	194	20.2	199
CHLOROFORM	ND	−−−	ND	21.4	199	19.8	204	21.0	194	19.9	208
1,1,1−TRICHLOROETHANE	ND	ND	ND	20.8	202	21.4	204	20.8	211	21.2	209
CARBON TETRACHLORIDE	ND	ND	ND	20.1	197	20.0	193	20.5	198	20.5	194
1,2−DICHLOROETHANE	ND	ND	ND	22.0	202	19.7	215	21.6	192	20.6	214
TRICHLOROETHENE	51.1	ND	−−−	17.6	183	17.8	180	17.6	183	18.1	176
TETRACHLOROETHENE	ND	ND	ND	17.8	197	18.4	194	18.4	191	18.2	166
CHLOROBENZENE	ND	ND	ND	21.0	212	20.9	213	21.3	207	20.4	203
1,3−DICHLOROBENZENE	ND	ND	−−−	19.1	208	19.8	211	20.1	209	19.3	173
1,4−DICHLOROBENZENE	ND	ND	ND	19.0	213	20.9	215	21.4	208	19.7	176
1,2−DICHLOROBENZENE	ND	ND	ND	20.9	214	21.0	218	21.4	211	20.2	201

	QC0417I 20 ppb	QC0417J 200 ppb	BL0417A
VINYL CHLORIDE	19.0	175	ND
1,1−DICHLOROETHENE	22.7	214	ND
T−1,2−DICHLOROETHENE	20.6	197	ND
1,1−DICHLOROETHANE	20.3	197	ND
C−1,2−DICHLOROETHENE	19.0	195	ND
CHLOROFORM	19.3	200	ND
1,1,1−TRICHLOROETHANE	21.2	205	ND
CARBON TETRACHLORIDE	20.8	194	ND
1,2−DICHLOROETHANE	17.8	199	ND
TRICHLOROETHENE	17.9	186	ND
TETRACHLOROETHENE	19.7	195	ND
CHLOROBENZENE	19.6	212	ND
1,3−DICHLOROBENZENE	19.1	205	ND
1,4−DICHLOROBENZENE	19.8	215	ND
1,2−DICHLOROBENZENE	18.7	214	ND

ND = None Detected −−− = Below Calibration Limit(1.0 ppb) QC = Quality Control Std. Dup = Duplicate BL = Blank

MANAGEMENT
TECHNOLOGY

Ref: 97-LH13/vg

April 29, 1997

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

As requested in Service Request #SF-3-260, gas analysis was performed for methane, ethylene, and ethane on samples from Altus AFB. The samples were received on April 18, 1997. The analyses were performed on April 22, 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 C Hopkins

Lisa Hopkins

xc:
R.L. Cosby
J.T. Wilson
G.B. Smith
J.L. Seeley

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Sample	Methane	Ethylene	Ethane
100ppm CH4	105.2	**	**
100ppm C2H4	**	91.7	**
100ppm C2H6	**	**	97.2
HPHe	**	**	**
Lab Blank	**	**	**
TW-1	0.058	**	**
OU1-TW-2	0.008	**	**
TW-3	0.021	**	**
TW-5	0.058	**	**
TW-8	0.011	**	**
TW-8 Lab Dup	0.011	**	**
TW-9	0.001	**	**
TW-10	**	**	**
OU1-05	0.001	**	**
OU1-06	0.005	**	**
TW-15	**	**	**
TW-15 Field Dup	**	**	**
10ppm CH4	8.7	**	**
100ppm CH4	96.9	**	**
100ppm C2H4	**	91.7	**
100ppm C2H6	**	**	95.6
Lower Limit of Quantitation	0.001	0.003	0.002

Units for the samples are in mg/L.
Units for the standards are parts per million.

** denotes None Detected.
* denotes Below Limit of Quantitation.

MAN
TECH

Ref: 97-DF20

May 1, 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-3-260, GC/MS analysis for phenols and aliphatic/aromatic acids was done on three water samples from Altus AFB. These samples were labeled: WL-022, OU1-01 and OU1-02. The samples were received on March 14, 1997 and were extracted and derivatized by Amy Zhao on Mar. 17, 1997. The extracts were analyzed by GC/MS on March 19, 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 Altus AFB water samples. 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 Fine

Dennis D. Fine

xc: J. Seeley SV for
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 Altus AFB Service Request SF-3-260.

		Concentration ppb							% Recovery	
	File Name:	830WL022.TXT	831OU101.TXT	832OU102.TXT	819METHB.TX	840MTHBL.TX	829EXTBL.TXT	850EXTBL.TXT	828EXTRE.TXT	849EXTRE.TXT
Compound	Sample Name:	WL-022	OU1-01	OU1-02	Method Blank	Method Blank	Extraction Blank	Extraction Blank	50 ppb Extr. % Recovery	50 ppb Extr. % Recovery
Propanoic Acid		***	***	***	***	12	***	6	9	13
2-Methylpropanoic Acid		***	***	***	***	***	***	***	30	26
Trimethylacetic Acid		10	9	10	***	***	11	***	95	79
Butyric Acid		***	***	***	***	***	***	3	30	27
2-Methylbutyric Acid		***	***	***	***	***	***	***	68	66
3-Methylbutryic Acid		***	***	***	***	***	***	***	67	64
3,3-Dimethylpropanoic Acid		***	***	***	*	*	***	***	89	95
Pentanoic Acid		***	***	3	***	***	***	4	75	74
2,3-Dimethybutyric Acid		***	***	***	***	***	***	***	89	94
2-Ethylbutyric Acid		***	***	***	***	***	***	***	90	97
2-Methylpentanoic Acid		***	***	***	***	***	***	***	94	99
3-Methylpentanoic Acid		*	*	***	*	*	***	***	93	93
4-Methylpentanoic Acid		*	*	***	*	*	***	***	92	96
Hexanoic Acid		4	5	10	***	3	5	10	102	138
2-Methylhexanoic Acid		*	*	*	*	*	*	*	94	112
Phenol		4	4	***	***	***	3	*	83	91
Cyclopentanecarboxylic Acid		*	*	*	*	*	***	*	80	77
5-Methylhexanoic Acid		*	*	*	*	*	***	*	94	108
o-Cresol		***	***	***	***	*	***	*	91	107
2-Ethylhexanoic Acid		35	33	35	***	***	***	***	98	126
Heptanoic Acid		***	***	4	***	***	3	4	101	129
m-Cresol		***	***	***	***	*	***	***	90	108
p-Cresol		*	*	*	*	*	***	*	90	102
1-Cyclopentene-1-carboxylic Acid		*	*	*	*	*	***	***	78	66
o-Ethylphenol		*	*	*	*	*	*	*	91	111
Cyclopentaneacetic Acid		*	*	*	*	*	*	*	98	101
2,6-Dimethyphenol		*	*	*	*	*	*	*	74	80
2,5-Dimethylphenol		*	*	*	*	*	*	*	86	99
Cyclohexanecarboxylic Acid		*	*	*	*	*	***	*	97	102
3-Cyclohexene-1-carboxylic Acid		*	***	*	*	*	*	*	90	85
2,4-Dimethylphenol		*	*	*	*	*	*	*	68	69
3,5-Dimethylphenol & m-Ethylphenol		*	*	*	*	*	3	*	92	113
Octanoic Acid		***	***	8	***	***	5	8	106	146
2,3-Dimetholphenol		*	*	*	*	*	*	*	83	99
p-Ethylphenol		*	*	*	*	*	*	*	97	110
Benzoic Acid		4	5	4	***	***	9	10	117	95
3,4-Dimethyphenol		*	*	*	*	*	*	*	90	102
m-Methylbenzoic Acid		*	*	*	*	*	*	*	90	73
1-Cyclohexene-1-carboxylic Acid		*	*	*	*	*	***	*	99	100
Cyclohexaneacetic Acid		*	*	*	*	*	***	*	98	111
2-Phenylpropanoic Acid		*	*	*	*	*	*	*	104	107
o-Methylbenzoic Acid		*	*	*	*	*	***	***	104	99
Phenylacetic Acid		*	***	***	*	*	***	***	110	101
m-Tolylacetic Acid		*	*	*	*	*	*	*	111	113
o-Tolylacetic Acid		*	*	***	*	*	*	*	114	115
2,6-Dimethylbenzoic Acid		*	*	***	*	*	***	*	103	117
p-Tolylacetic Acid		*	*	*	*	*	*	*	110	122
p-Methylbenzoic Acid		*	*	*	*	*	***	*	108	98
3-Phenylpropanoic Acid		*	*	*	*	*	*	*	106	97
2,5-Dimethylbenzoic Acid		*	*	*	*	*	*	*	105	108
Decanoic Acid		***	*	4	***	***	3	4	105	131
2,4-Dimethylbenzoic Acid		*	*	*	*	*	*	*	108	113
3,5-Dimethylbenzoic Acid		*	*	*	*	*	*	*	111	111
2,3-Dimethylbenzoic Acid		*	*	*	*	*	*	*	107	102
4-Ethylbenzoic Acid		*	*	*	*	*	*	*	107	99
2,4,6-Trimethylbenzoic Acid		*	*	*	*	*	*	*	108	103
3,4-Dimethylbenzoic Acid		*	*	*	*	*	***	*	108	102
2,4,5-Trimethylbenzoic Acid		*	*	*	*	*	*	*	108	111

*** indicates concentration of extract was below lowest calibration standard (3 ppb)
* indicates not found.

Printer: 3:52 PM 5/1/97

Table I. Quantitative Report and QC Data for Phenols and Aliphatic and Aromatic Acids in Water Samples from Altus AFB Service Request SF-3-260.

	% Recovery	
File Name:	835100AA.TX	842100AA.TX
Compound Sample Name:	100 ppb Std. % Recovery	100 ppb Std. % Recovery
Propanoic Acid	103	111
2-Methylpropanoic Acid	104	112
Trimethylacetic Acid	106	112
Butyric Acid	102	110
2-Methylbutyric Acid	105	113
3-Methylbutryic Acid	105	112
3,3-Dimethylpropanoic Acid	103	111
Pentanoic Acid	103	111
2,3-Dimethybutyric Acid	104	110
2-Ethylbutyric Acid	100	108
2-Methylpentanoic Acid	103	109
3-Methylpentanoic Acid	105	111
4-Methylpentanoic Acid	105	110
Hexanoic Acid	104	113
2-Methylhexanoic Acid	103	108
Phenol	101	113
Cyclopentanecarboxylic Acid	104	112
5-Methylhexanoic Acid	105	111
o-Cresol	104	110
2-Ethylhexanoic Acid	105	110
Heptanoic Acid	104	111
m-Cresol	104	112
p-Cresol	104	112
1-Cyclopentene-1-carboxylic Acid	103	111
o-Ethylphenol	105	111
Cyclopentaneacetic Acid	103	110
2,6-Dimethyphenol	103	111
2,5-Dimethylphenol	104	108
Cyclohexanecarboxylic Acid	104	111
3-Cyclohexene-1-carboxylic Acid	104	112
2,4-Dimethylphenol	105	111
3,5-Dimethylphenol & m-Ethylphenol	105	110
Octanoic Acid	104	110
2,3-Dimetholphenol	108	110
p-Ethylphenol	102	112
Benzoic Acid	105	111
3,4-Dimethyphenol	105	111
m-Methylbenzoic Acid	102	106
1-Cyclohexene-1-carboxylic Acid	104	112
Cyclohexaneacetic Acid	104	110
2-Phenylpropanoic Acid	104	108
o-Methylbenzoic Acid	103	111
Phenylacetic Acid	102	106
m-Tolylacetic Acid	100	103
o-Tolylacetic Acid	97	106
2,6-Dimethylbenzoic Acid	106	113
p-Tolylacetic Acid	92	97
p-Methylbenzoic Acid	101	107
3-Phenylpropanoic Acid	100	102
2,5-Dimethylbenzoic Acid	102	106
Decanoic Acid	100	105
2,4-Dimethylbenzoic Acid	102	103
3,5-Dimethylbenzoic Acid	105	108
2,3-Dimethylbenzoic Acid	104	108
4-Ethylbenzoic Acid	102	105
2,4,6-Trimethylbenzoic Acid	103	107
3,4-Dimethylbenzoic Acid	101	105
2,4,5-Trimethylbenzoic Acid	102	107

*** indicates concentration of extract was below lowest calibration standard (3 ppb)

* indicates not found.

Printer: 3:51 PM 5/1/97

Ref: 97-DF26
May 19, 1996

Dr. Don Kampbell
National Risk Management Research Laboratory
Subsurface Protection and Remediation Division
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SV

Dear Don:

As requested in Service Request SF-3-260, GC/MS analysis for semi-volatile compounds was done on one water sample from Altus AFB. This sample was labeled: OU1-01. The sample was received on April 14, 1997. Base/neutral extractions of the water sample was completed on April 14, 1997. The GC/MS analysis of the sample was completed on May 14, 1997. EPA method 8270A with the modifications listed below was used for this analysis.

The liquid/liquid extraction was done by Brad Scroggins according to the standard operating procedure for base/neutral extraction. After the pH of one liter of each water sample was adjusted to slightly above 11.0 with 10N NaOH, the water sample was extracted three times with 60 ml of methylene chloride. After the methylene chloride fraction was passed through a Na_2SO_4 column, it was concentrated using the Savant Evaporation Station to a final volume near 1.0 ml.

For quantitative analysis, 5.0 μl of a 400 ppm internal standard mixture of benzene-d_6, toluene-d_8, ethylbenzene-d_{10}, p-xylene-d_{10}, o-xylene-d_{10}, p-dichlorobenzene-d_2, naphthalene-d_8, acenaphthene-d_{10}, phenanthrene-d_{10}, chrysene-d_{12} and perylene-d_{12} in methylene chloride was added to 200 μl of each standard or sample. The Hewlett Packard 7673 autoinjector delivered 1.0 μl of the methylene chloride extract with splitless injection onto a 60 meter, 0.25 mm DB5-MS capillary column with 0.5 μm film thickness. The column was temperature programmed from 40°C to 100°C at 30°C/min and then to 300°C at 6°C/min. The Finnigan 4615 GC/MS was scanned from 42 to 650 m/z in 0.5 sec.

ManTech Environmental Research Services Corporation
R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Research Drive
Ada, Oklahoma 74821-1189 405-436-8660 FAX 405-436-8501

Chromatograms of the extract of the sample and an extraction blank are attached.

If you should have any questions, please feel free to contact me.

Sincerely,

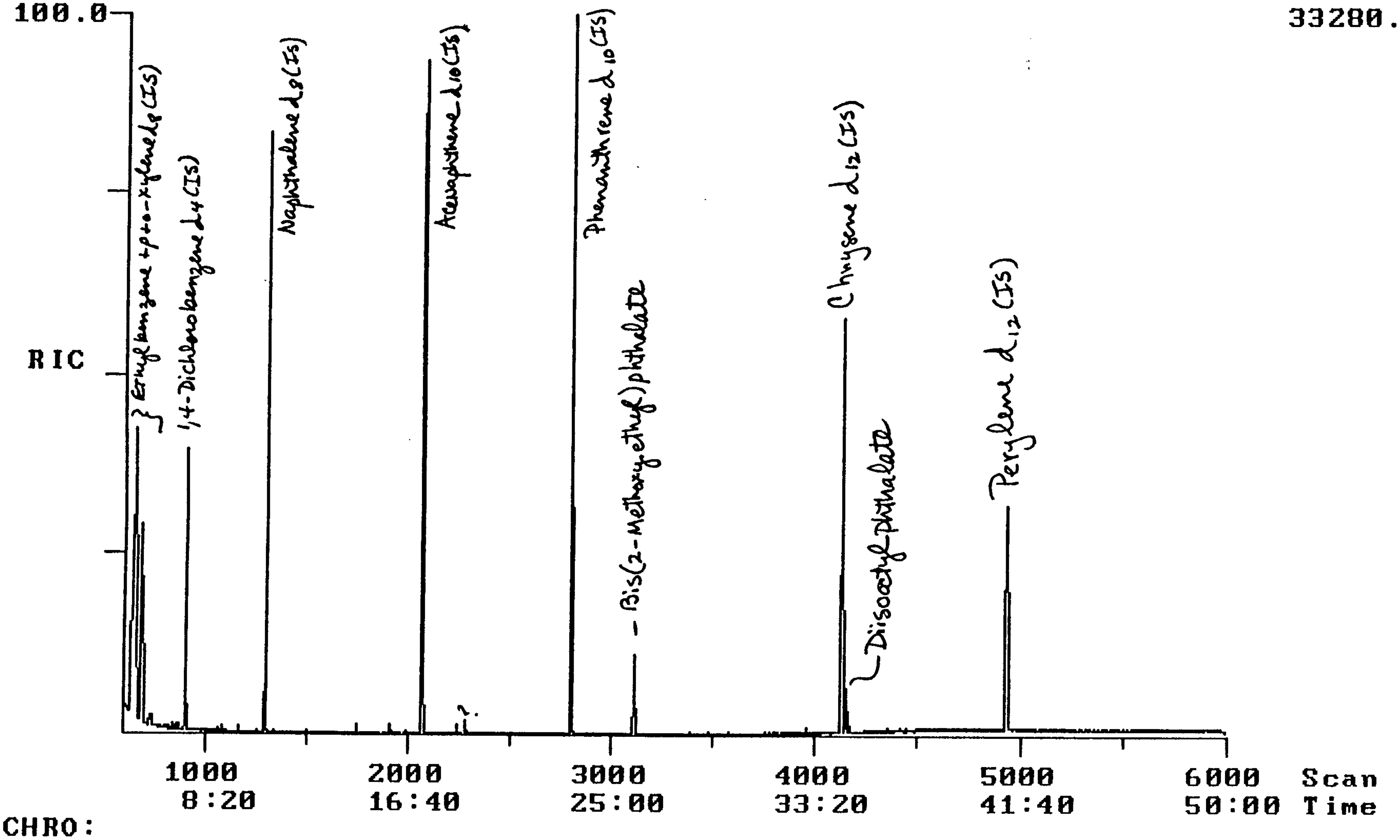
Dennis D Fine

Dennis D. Fine

xc: J. Seeley
G. Smith
R. Cosby
D. Fine
J. Wilson

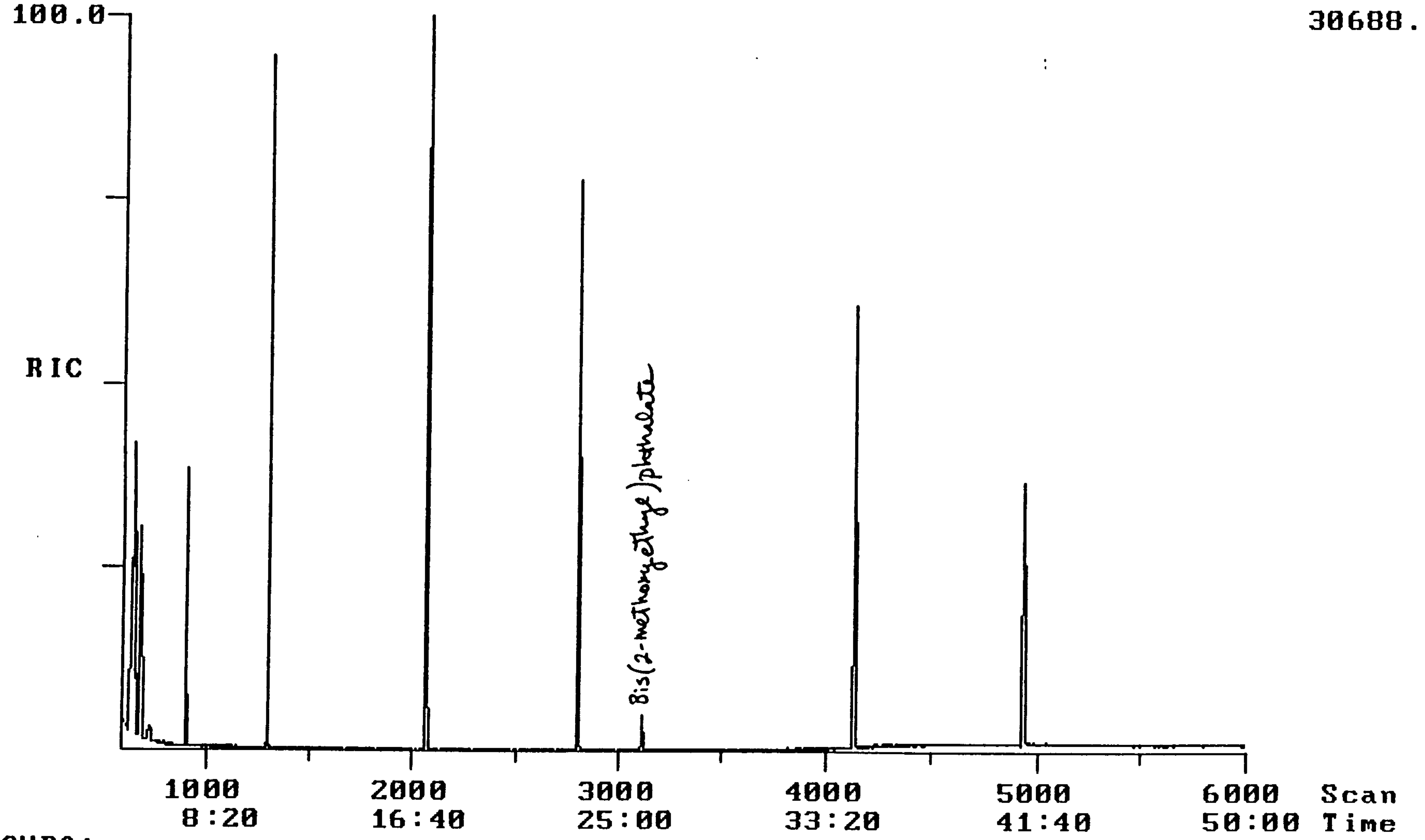
b067W

```
RIC                                    Data: 1150U101 #1          Scans  600 to 6000
05/14/97 21:54:00                      Cali: CAL57 #3
Sample: 1UL SEMIVOL LIQ/LIQ EXTR ALTUS AFB SAMPLE OU1-01
Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
Range: G   1,6000  Label: N  0, 4.0  Quan: A  0, 1.0 J  0  Base: U 20,  3
```



CHRO:

```
RIC                                      Data: 114MTHBLK #1        Scans  600 to 6000
05/14/97 20:51:00                        Cali: CAL57 #3
Sample: 1UL SEMIVOL EXT LIQ/LIQ METHOD BLANK
Conds.: 40C TO 100C 30C/MIN TO 300C 6C/MIN SPLITLESS 2-DB5MS30.25.25
Range: G   1,6000  Label: N  0, 4.0  Quan: A  0, 1.0 J  0  Base: U 20,  3
```



CHRO:

FACSIMILE ELECTRO MAIL TRANSMITTAL

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SECTION I - TO BE COMPLETED BY ORIGINATOR

CLASSIFICATION: Unclassified

☐ FOR OFFICIAL USE ONLY

TRANSMISSION: ☐ IMMEDIATE ☒ ROUTINE

PAGE 1 OF 24 PAGES

TO (Office Symbol, Point of Contact, and Address): ROB NAGEL

FAX NO. DSN:

FAX NO. COMMERCIAL: (303) 831-8208

ELECTRONIC MAIL ADDRESS (E-Mail):

VOICE NO. DSN:

VOICE NO. COMMERCIAL:

SUBJECT: DEEP BORING RESULTS

FROM (Office Symbol, Point of Contact, and Address):

JENNIFER ROCK
97 CES/CEVR
401 L AVE
ALTUS AFB, OK 73523-5138

FAX NO. DSN: 866-5841

FAX NO. COMMERCIAL: (405) 481-5841

ELECTRONIC MAIL ADDRESS (E-Mail):

VOICE NO. DSN: 866-7346

VOICE NO. COMMERCIAL: (405) 481-7346

REMARKS:

RELEASER'S SIGNATURE: Jennifer Rock

DATE: 19 JUN 97

TIME:

SECTION II - TO BE COMPLETED BY ELECTRO MAIL OPERATOR

DATE TRANSMITTED:

TIME TRANSMITTED:

TRANSMITTER'S SIGNATURE:

DATE ADDRESSEE CONTACTED:

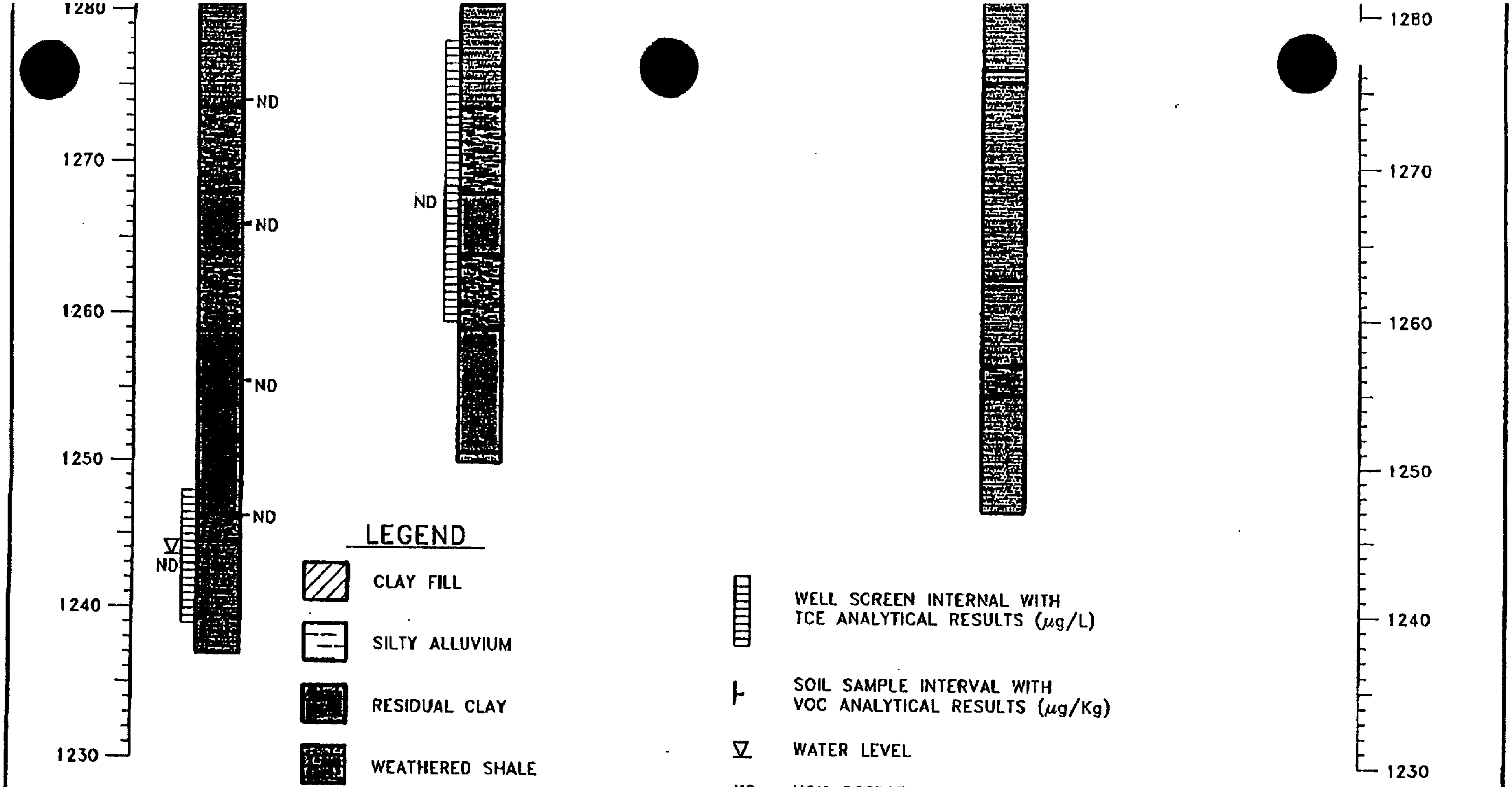
TIME ADDRESSEE CONTACTED:

CONTACTOR'S SIGNATURE:

FORM 3535, FEB 95 *(EF-V1)* (PerFORM PRO)

PREVIOUS EDITION IS OBSOLETE.

				17:20	18:00				38'	45'
		Water		27-May				Soil	16-May	
		mg/L	arsenic	<0.005	<0.005				7.9	6.1
		mg/L	barium	0.02	<0.01				130	87
		mg/L	cadmium	<0.005	<0.005				2.3	2.9
		mg/L	chromium	<0.01	<0.01				23	28
		mg/L	lead	<0.005	<0.005				34	38
		mg/L	mercury	<0.002	<0.002				<0.1	<0.1
		mg/L	selenium	<0.005	<0.005				<0.5	<0.5
		mg/L	silver	<0.01	<0.01				<1.0	<1.0
		mg/L	organic carbon	45	52					
		mg/L	alkalinity	230	210					
		mg/L	sulfide	<1						
			Nitrate	18	19					
			chloride	620	1500					
		mg/L	sulfate	2100	5300					
	8280a	μg/L	TCE	<1.0	1.3					



LEGEND

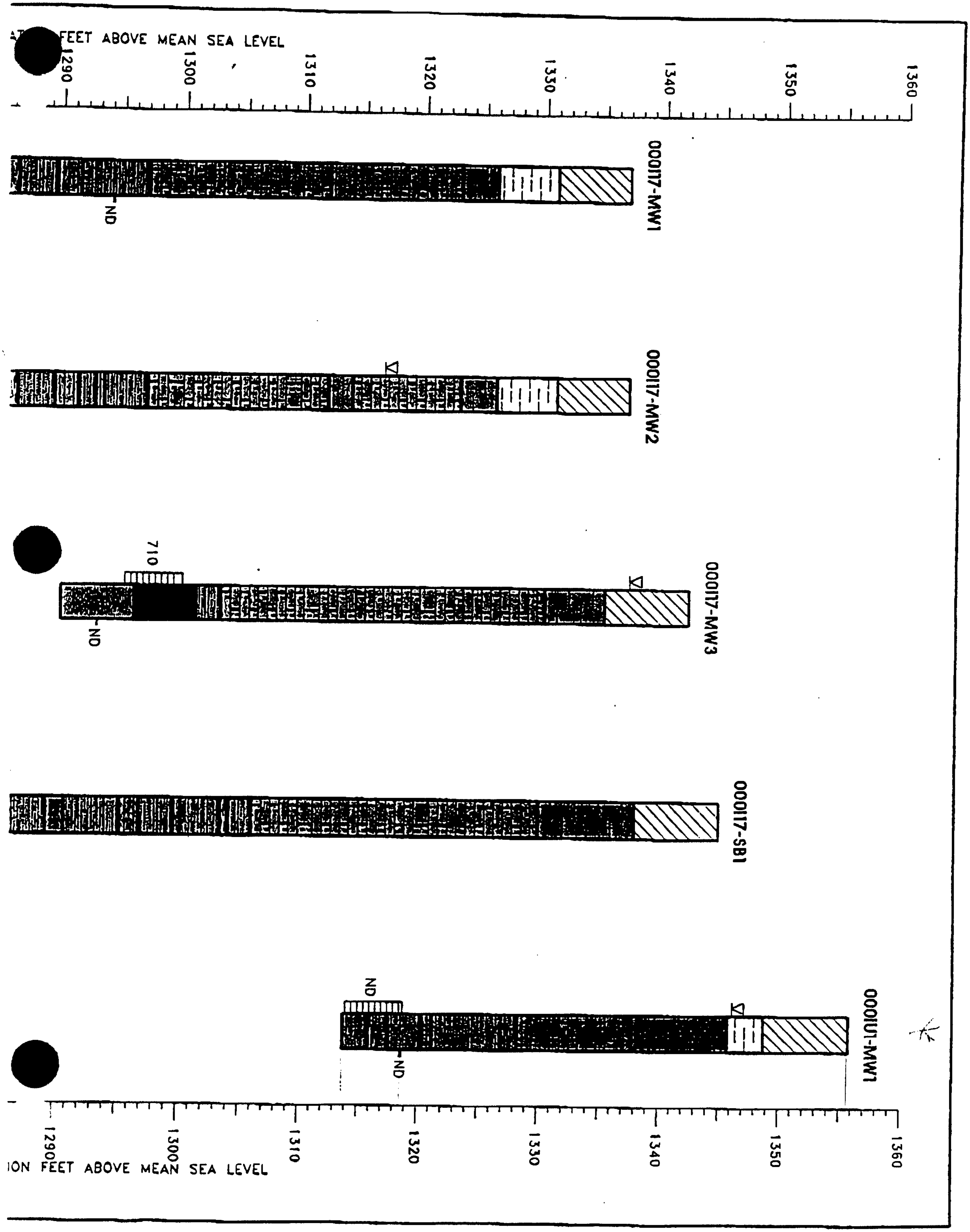
- ▨ CLAY FILL
- ☐ SILTY ALLUVIUM
- ■ RESIDUAL CLAY
- ■ WEATHERED SHALE
- ■ FRACTURED SILTSTONE WITH GYPSUM LAYERS AND INCLUSION ZONES
- ■ FRACTURED SHALE WITH GYPSUM LAYERS AND INCLUSION ZONES
- ■ HIGHLY FRACTURED SHALE WITH GYPSUM LAYERS AND INCLUSION ZONES
- ■ MASSIVE SHALE WITH MINIMAL FRACTURING
- ■ NO CORE RECOVERED

- ▤ WELL SCREEN INTERNAL WITH TCE ANALYTICAL RESULTS (µg/L)
- ⊢ SOIL SAMPLE INTERVAL WITH VOC ANALYTICAL RESULTS (µg/Kg)
- ▽ WATER LEVEL
- ND NON-DETECT

VERTICAL SCALE
10 5 0 10
HORIZONTAL SCALE

DRN BY: BAG	DATE: 06/13/97	SIMPLIFIED BORING LOGS TCE VERTICAL EXTENT EVALUATION ALTUS AIR FORCE BASE	FIG. NO: 3-1
PROJ #: TT13	REVISION: 1		

I:\altus\H83\hk3\borings.dgn


FEET ABOVE MEAN SEA LEVEL
1290
1300
1310
1320
1330
1340
1350
1360
000117-MW1
ND
000117-MW2
000117-MW3
710
ND
000117-SB1
0001U1-MW1
ND
ND
ION FEET ABOVE MEAN SEA LEVEL

CHEMRON
INCORPORATED

10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-8121

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 512285141
Date Sampled: 05/27/97
Date Received: 05/29/97
Sample Matrix: Water
Chemron ID #: 64670
Report Date: 06/05/97
Chemron's Job#: 10489

Sample Description:
19735 Altus AFB Tulsa Yerc Altus OK
0001U1-MW0001-001 05-27-97 17:20

CHEMICAL ANALYSIS REPORT

Analyte	PQL	Units	Results	Method	Preparation Batch	Digestion Date	Digestion Time	Analysis Date	Analysis Time
Total Arsenic	.005	MG/L	< .005U,M	7060A	985	06/02/97	10:00	06/04/97	13:53
Total Barium	.01	MG/L	.02	3005/6010A	985	06/02/97	10:00	06/05/97	10:29
Total Cadmium	.005	MG/L	< .005U	3005/6010A	985	06/02/97	10:00	06/05/97	10:29
Total Chromium	.01	MG/L	< .01 U	3005/6010A	985	06/02/97	10:00	06/05/97	10:29
Total Lead	.005	MG/L	< .005U M	7421	985	06/02/97	10:00	06/04/97	10:08
Total Mercury	.0002	MG/L	< .0002 U	7470	0602	06/02/97	14:30	06/02/97	14:30
Total Selenium	.005	MG/L	< .005 U M	7740	985	06/02/97	10:00	06/03/97	15:46
Total Silver	.01	MG/L	< .01 U	3005/6010A	985	06/02/97	10:00	06/05/97	09:42

Approved By:

PQL - Practical Quantitation Limit

CHEMRON
INCORPORATED

10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-8121

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 512285141
Date Sampled: 05/27/97
Date Received: 05/29/97
Sample Matrix: Water
Chemron ID #: 64671
Report Date: 06/05/97
Chemron's Job#: 10489

Sample Description:
19735 Altus AFB Tulsa Ferc Altus OK
D001U1-MW1001-D01 05-27-97 18:00

CHEMICAL ANALYSIS REPORT

Analyte	PQL	Units	Results	Method	Preparation Batch	Digestion Date	Digestion Time	Analysis Date	Analysis Time
Total Arsenic	.005	MG/L	< .005 U,M	7060A	985	06/02/97	10:00	06/04/97	13:53
Total Barium	.01	MG/L	< .01 U	3005/6010A	985	06/02/97	10:00	06/05/97	10:29
Total Cadmium	.005	MG/L	< .005 U	3005/6010A	985	06/02/97	10:00	06/05/97	10:29
Total Chromium	.01	MG/L	< .01 U	3005/6010A	985	06/02/97	10:00	06/05/97	10:29
Total Lead	.005	MG/L	< .005 U,M	7421	985	06/02/97	10:00	06/04/97	10:08
Total Mercury	.0002	MG/L	< .0002 U	7470	0602	06/02/97	14:30	06/02/97	14:30
Total Selenium	.005	MG/L	< .005 U,M	7740	985	06/02/97	10:00	06/03/97	15:46
Total Silver	.01	MG/L	< .01 U	3005/6010A	985	06/02/97	10:00	06/05/97	09:42

Approved By: ____________

PQL - Practical Quantitation Limit

CHEMRON
INCORPORATED

10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-8121

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 5143
Date Sampled: 05/27/97
Date Received: 05/29/97
Sample Matrix: Water
Chemron ID #: 64675
Report Date: 06/05/97
Chemron's Job#: 10489

Sample Description:
19735 Altus AFB Tulsa Terc Altus OK
ODOIU1-MW0001-RN 05-27-97 18:00

CHEMICAL ANALYSIS REPORT

Analyte	PQL	Units	Results	Method	Preparation Batch	Digestion Date	Digestion Time	Analysis Date	Analysis Time
Total Arsenic	.005	MG/L	< .005 U M	7060A	985	06/02/97	10:00	06/04/97	13:53
Total Barium	.01	MG/L	< .01 U	3005/6010A	985	06/02/97	10:00	06/05/97	10:29
Total Cadmium	.005	MG/L	< .005 U	3005/6010A	985	06/02/97	10:00	06/05/97	10:29
Total Chromium	.01	MG/L	< .01 U	3005/6010A	985	06/02/97	10:00	06/05/97	10:29
Total Lead	.005	MG/L	< .005 U,M	7421	985	06/02/97	10:00	06/04/97	10:09
Total Mercury	.0002	MG/L	< .0002 U	7470	0602	06/02/97	14:30	06/02/97	14:30
Total Selenium	.005	MG/L	< .005 U,M	7740	985	06/02/97	10:00	06/03/97	15:46
Total Silver	.01	MG/L	.01 U	3005/6010A	985	06/02/97	10:00	06/05/97	09:42

Approved By:

PQL - Practical Quantitation Limit

CHEMRON
INCORPORATED

10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-8

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 5122&5141
Report Date: 06/05/97
Chemron's Job#: 10489

Date & Time Received:
05/29/97, 09:00

Date Sampled:
05/27/97

CHEMICAL ANALYSIS REPORT
MG/L

Chemron #	Sample Description	Sample Matrix	Date Analyzed	ORGANI CARBO
64670	19735 Altus AFB Tulsa Terc Altus OK 000IU1-MW0001-001 05-27-97 17:20	Water	06/02/97	45.
64671	19735 Altus AFB Tulsa Terc Altus OK 000IU1-MW1001-001 05-27-97 18:00	Water	06/02/97	52.
64672	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0001-001 05-28-97 07:35	Water	06/02/97	19
64673	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0002-001 05-28-97 07:50	Water	06/02/97	11.
64674	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0003-001 05-28-97 11:20	Water	06/02/97	38.

Approved By: ____________________

Analytical Methods: 415.1

* Dissolved Organic Carbon

CHEMRON
INCORPORATED

10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-8121

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 5122&5141
Report Date: 06/04/97
Chemron's Job #: 10489

Date & Time Received:
05/29/97, 09:00

Date Sampled:
05/27/97

CHEMICAL ANALYSIS REPORT

Chemron #	Sample Description	Sample Matrix	Date Analyzed	Alkalinity MG/L CaCO3
64670	19735 Altus AFB Tulsa Terc Altus OK 000IU1-MW0001-001 05-27-97 17:20	Water	06/04/97	230.
64671	19735 Altus AFB Tulsa Terc Altus OK 000IU1-MW1001-001 05-27-97 18:00	Water	06/04/97	210.
[illegible]2	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0001-001 05-28-97 07:35	Water	06/04/97	75.
64673	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0002-001 05-28-97 07:50	Water	06/04/97	50.
64674	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0003-001 05-28-97 11:20	Water	06/04/97	130.

Approved By: ______________________

Analytical Methods: 310.1/SM 2320 B

CHEMRON
INCORPORATED

10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-81

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 5122&5141
Report Date: 06/04/97

Date & Time Received:
05/29/97, 09:00

Date Sampled:
05/27/97

CHEMICAL ANALYSIS REPORT

Chemron #	Sample Description	Sample Matrix	Date Analyzed	Sulfide (MG/L)
64670	19735 Altus AFB Tulsa Terc Altus 000IU1-MW0001-001 05-27-97 1	Water	06/02/97	< 1
64672	19735 Altus AFB Tulsa Terc Altus 000I17-MW0001-001 05-28-97 0	Water	06/02/97	< 1
64673	19735 Altus AFB Tulsa Terc Altus 000I17-MW0002-001 05-28-97 0	Water	06/02/97	< 1.
64674	19735 Altus AFB Tulsa Terc Altus 000I17-MW0003-001 05-28-97 1	Water	06/02/97	< 1.

Approved By: ______________________

Analytical Method: Standard Methods 376.1

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10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-8121

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 5122&5141
Report Date: 06/03/97
Chemron's Job ID: 10489

Date & Time Received:
05/29/97, 09:00

Date Sampled:
05/27/97

CHEMICAL ANALYSIS REPORT

(MG/L)

Chemron #	Sample Description	Sample Matrix	Date Analyzed	Nitrate
64670	19735 Altus AFB Tulsa Terc Altus OK 000IU1-MW0001-001 05-27-97 17:20	Water	05/30/97	18.
6[illegible]71	19735 Altus AFB Tulsa Terc Altus OK 000IU1-MW1001-001 05-27-97 18:00	Water	05/30/97	19.
64672	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0001-001 05-28-97 07:35	Water	05/30/97	33.
64673	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0002-001 05-28-97 07:50	Water	05/30/97	6.5
64674	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0003-001 05-28-97 11:20	Water	05/30/97	11.

Approved By: ______________________

Analytical Methods: 300

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10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-812

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 5122&5141
Report Date: 06/04/97
Chemron's Job ID: 10489

Date & Time Received:
05/29/97, 09:00

Date Sampled:
05/27/97

CHEMICAL ANALYSIS REPORT

(MG/L)

Chemron #	Sample Description	Sample Matrix	Date Analyzed	Chlorid
64670	19735 Altus AFB Tulsa Terc Altus OK 000IU1-MW0001-001 05-27-97 17:20	Water	06/04/97	620.
64671	19735 Altus AFB Tulsa Terc Altus OK 000IU1-MW1001-001 05-27-97 18:00	Water	06/04/97	1500[illegible]
64672	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0001-001 05-28-97 07:35	Water	06/04/97	64400.
64673	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0002-001 05-28-97 07:50	Water	06/04/97	112000
64674	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0003-001 05-28-97 11:20	Water	06/04/97	3500.

Approved By: ______________________

Analytical Methods: 300.

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10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-8121

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 5122&5141
Report Date: 06/04/97

Date & Time Received:
05/29/97, 09:00

Date Sampled:
05/27/97

CHEMICAL ANALYSIS REPORT

Chemron #	Sample Description	Sample Matrix	Date Analyzed	Sulfate (MG/L)
64670	19735 Altus AFB Tulsa Terc Altus OK 000IU1-MW0001-001 05-27-97 17:20	Water	06/04/97	2100.
1671	19735 Altus AFB Tulsa Terc Altus OK 000IU1-MW1001-001 05-27-97 18:00	Water	06/04/97	5300.
[illegible]72	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0001-001 05-28-97 07:35	Water	06/04/97	6200.
[illegible]73	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0002-001 05-28-97 07:50	Water	06/04/97	2800.
64674	19735 Altus AFB Tulsa Terc Altus OK 000I17-MW0003-001 05-28-97 11:20	Water	06/04/97	2600.

Approved By: ____________________

Analytical Method: 300

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Client:
OHM Southwest Region
225 West Airtex
Houston TX 77090

Report Date: 05/31/97
COC # 5123
Job I.D. # 10430
Chemron Sample # 64408
Sample Matrix: Soil
Sampling Date: 05/16/97
SamplingTime: 09:33
Analysis Date: 05/22/97
Analysis Time: 21:35
QC Batch: PV052297

Sample Description:
Project No. 19735
Project Name/Loc: 19735 Altus AFB Terc Altus AFB
Client Sample ID: 000IU1-SM-MW01-038' 05-16-97 09:33

VOLATILE ORGANIC ANALYSIS REPORT

EPA SW-846 Method 8260a

ANALYTE	PQL	Units	RESULTS		
Acetone	20	ug/Kg	<	20	(U)
Acrolein	100	ug/Kg	<	100	(U)
Acrylonitrile	100	ug/Kg	<	100	(U)
Benzene	5	ug/Kg	<	5	(U)
Bromobenzene	5	ug/Kg	<	5	(U)
Bromochloromethane	5	ug/Kg	<	5	(U)
Bromodichloromethane	5	ug/Kg	<	5	(U)
Bromoform	5	ug/Kg	<	5	(U)
Bromomethane	10	ug/Kg	<	10	(U)
2-Butanone	5	ug/Kg	<	5	(U)
Carbon Disulfide	5	ug/Kg	<	5	(U)
Carbon Tetrachloride	5	ug/Kg	<	5	(U)
Chlorobenzene	5	ug/Kg	<	5	(U)
Chlorodibromomethane	5	ug/Kg	<	5	(U)
Chloroethane	5	ug/Kg	<	5	(U)
2-Chloroethyl Vinyl Ether	5	ug/Kg	<	5	(U)
Chloroform	5	ug/Kg	<	5	(U)
Chloromethane	5	ug/Kg	<	5	(U)
2-Chlorotoluene	5	ug/Kg	<	5	(U)
4-Chlorotoluene	5	ug/Kg	<	5	(U)
1,2-Dibromo-3-Chloropropane	5	ug/Kg	<	5	(U)
1,2-Dibromomethane	5	ug/Kg	<	5	(U)
Dibromomethane	5	ug/Kg	<	5	(U)
1,1-Dichloroethane	5	ug/Kg	<	5	(U)
1,2-Dichloroethane	5	ug/Kg	<	5	(U)
1,1-Dichloroethene	5	ug/Kg	<	5	(U)
1,2-Dichlorobenzene	5	ug/Kg	<	5	(U)

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Chemron Sample # 64408

QC Batch: PV052297

ANALYTE	PQL	Units	RESULTS		
1,3-Dichlorobenzene	5	ug/Kg	<	5	(U)
1,4-Dichlorobenzene	5	ug/Kg	<	5	(U)
Dichlorodifluoromethane	5	ug/Kg	<	5	(U)
Cis-1,2-Dichloroethene	5	ug/Kg	<	5	(U)
Trans-1,2-Dichloroethene	5	ug/Kg	<	5	(U)
1,2-Dichloropropane	5	ug/Kg	<	5	(U)
1,3-Dichloropropane	5	ug/Kg	<	5	(U)
1,1-Dichloropropane	5	ug/Kg	<	5	(U)
Cis-1,3-Dichloropropene	5	ug/Kg	<	5	(U)
Trans-1,3-Dichloropropene	5	ug/Kg	<	5	(U)
Ethylbenzene	5	ug/Kg	<	5	(U)
2-Hexanone	10	ug/Kg	<	10	(U)
Hexachlorobutadiene	5	ug/Kg	<	5	(U)
Methylene Chloride	5	ug/Kg	<	5	(U)
4-Methyl-2-Pentanone	5	ug/Kg	<	5	(U)
Naphthalene	5	ug/Kg	<	5	(U)
Styrene	5	ug/Kg	<	5	(U)
1,1,1,2-Tetrachloroethane	5	ug/Kg	<	5	(U)
1,1,2,2-Tetrachloroethane	5	ug/Kg	<	5	(U)
Tetrachloroethene	5	ug/Kg	<	5	(U)
Toluene	5	ug/Kg	<	5	(U)
1,2,3-Trichlorobenzene	5	ug/Kg	<	5	(U)
1,2,4-Trichlorobenzene	5	ug/Kg	<	5	(U)
1,1,1-Trichloroethane	5	ug/Kg	<	5	(U)
1,1,2-Trichloroethane	5	ug/Kg	<	5	(U)
Trichloroethene	5	ug/Kg	<	5	(U)
Trichlorofluoromethane	5	ug/Kg	<	5	(U)
Vinyl Acetate	5	ug/Kg	<	5	(U)
Vinyl Chloride	5	ug/Kg	<	5	(U)
o-'Xylene	5	ug/Kg	<	5	(U)
m,p-'Xylenes	5	ug/Kg	<	5	(U)

Approved by :

CHEMRON
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10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-812

Client:	Report Date: 05/31/97
OHM Southwest Region	COC # 5123
225 West Airtex	Job I.D. # 10430
Houston TX 77090	Chemron Sample # 64409
	Sample Matrix: Soil
	Sampling Date: 05/16/97
Sample Description:	SamplingTime: 09:50
Project No. 19735	Analysis Date: 05/22/97
Project Name/Loc: 19735 Altus AFB Terc Altus AFB	Analysis Time: 22:19
Client Sample ID: 000IU1-SM-MW01-045' 05-16-97 09:50	QC Batch: PV052297

VOLATILE ORGANIC ANALYSIS REPORT

EPA SW-846 Method 8260a

ANALYTE	PQL	Units	RESULTS	
Acetone	20	ug/Kg	< 20	(U)
Acrolein	100	ug/Kg	< 100	(U)
Acrylonitrile	100	ug/Kg	< 100	(U)
Benzene	5	ug/Kg	< 5	(U)
Bromobenzene	5	ug/Kg	< 5	(U)
Bromochloromethane	5	ug/Kg	< 5	(U)
Bromodichloromethane	5	ug/Kg	< 5	(U)
Bromoform	5	ug/Kg	< 5	(U)
Bromomethane	10	ug/Kg	< 10	(U)
2-Butanone	5	ug/Kg	< 5	(U)
Carbon Disulfide	5	ug/Kg	< 5	(U)
Carbon Tetrachloride	5	ug/Kg	< 5	(U)
Chlorobenzene	5	ug/Kg	< 5	(U)
Chlorodibromomethane	5	ug/Kg	< 5	(U)
Chloroethane	5	ug/Kg	< 5	(U)
2-Chloroethyl Vinyl Ether	5	ug/Kg	< 5	(U)
Chloroform	5	ug/Kg	< 5	(U)
Chloromethane	5	ug/Kg	< 5	(U)
2-Chlorotoluene	5	ug/Kg	< 5	(U)
4-Chlorotoluene	5	ug/Kg	< 5	(U)
1,2-Dibromo-3-Chloropropane	5	ug/Kg	< 5	(U)
1,2-Dibromomethane	5	ug/Kg	< 5	(U)
Dibromomethane	5	ug/Kg	< 5	(U)
1,1-Dichloroethane	5	ug/Kg	< 5	(U)
1,2-Dichloroethane	5	ug/Kg	< 5	(U)
1,1-Dichloroethene	5	ug/Kg	< 5	(U)
1,2-Dichlorobenzene	5	ug/Kg	< 5	(U)

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Chemron Sample # 64409

QC Batch: PV052297

ANALYTE	PQL	Units	RESULTS		
1,3-Dichlorobenzene	5	ug/Kg	<	5	(U)
1,4-Dichlorobenzene	5	ug/Kg	<	5	(U)
Dichlorodifluoromethane	5	ug/Kg	<	5	(U)
Cis-1,2-Dichloroethene	5	ug/Kg	<	5	(U)
Trans-1,2-Dichloroethene	5	ug/Kg	<	5	(U)
1,2-Dichloropropane	5	ug/Kg	<	5	(U)
1,3-Dichloropropane	5	ug/Kg	<	5	(U)
1,1-Dichloropropane	5	ug/Kg	<	5	(U)
Cis-1,3-Dichloropropene	5	ug/Kg	<	5	(U)
Trans-1,3-Dichloropropene	5	ug/Kg	<	5	(U)
Ethylbenzene	5	ug/Kg	<	5	(U)
2-Hexanone	10	ug/Kg	<	10	(U)
Hexachlorobutadiene	5	ug/Kg	<	5	(U)
Methylene Chloride	5	ug/Kg	<	5	(U)
4-Methyl-2-Pentanone	5	ug/Kg	<	5	(U)
Naphthalene	5	ug/Kg	<	5	(U)
Styrene	5	ug/Kg	<	5	(U)
1,1,1,2-Tetrachloroethane	5	ug/Kg	<	5	(U)
1,1,2,2-Tetrachloroethane	5	ug/Kg	<	5	(U)
Tetrachloroethene	5	ug/Kg	<	5	(U)
Toluene	5	ug/Kg	<	5	(U)
1,2,3-Trichlorobenzene	5	ug/Kg	<	5	(U)
1,2,4-Trichlorobenzene	5	ug/Kg	<	5	(U)
1,1,1-Trichloroethane	5	ug/Kg	<	5	(U)
1,1,2-Trichloroethane	5	ug/Kg	<	5	(U)
Trichloroethene	5	ug/Kg	<	5	(U)
Trichlorofluoromethane	5	ug/Kg	<	5	(U)
Vinyl Acetate	5	ug/Kg	<	5	(U)
Vinyl Chloride	5	ug/Kg	<	5	(U)
o-Xylene	5	ug/Kg	<	5	(U)
m,p-Xylenes	5	ug/Kg	<	5	(U)

Approved by :

CHEMRON
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10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-8121

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 5123
Date Sampled: 05/16/97
Date Received: 05/17/97

Sample Matrix: Soil
Chemron ID #: 64408
Report Date: 05/30/97
Chemron's Job#: 10430

Sample Description:
19735 Altus AFB Terc Altus AFB
0001U1-SM-MW01-038' 05-16-97_09:33

CHEMICAL ANALYSIS REPORT

Analyte	MDL	Units	Results	Method	Preparation Batch	Digestion Date	Digestion Time	Analysis Date	Analysis Time
Total Arsenic	0.5	MG/KG	7.9	7060A	983	05/30/97	0800	05/31/97	1000
Total Barium	1.0	MG/KG	130.	3050/6010A	983	05/30/97	0800	05/30/97	1400
Total Cadmium	0.5	MG/KG	2.3	3050/6010A	983	05/30/97	0800	05/30/97	1400
Total Chromium	1.0	MG/KG	23.	3050/6010A	983	05/30/97	0800	05/30/97	1400
Total Lead	1.5	MG/KG	34.	3050/6010A	983	05/30/97	0800	05/30/97	1400
Total Mercury	0.1	MG/KG	<.1 U	7471	0521	05/21/97	1500	05/21/97	1500
Total Selenium	0.5	MG/KG	<0.5 U	7740	983	05/30/97	0800	05/30/97	1300
Total Silver	1.0	MG/KG	<1.0 U	3050/6010A	983	05/30/97	0800	05/30/97	1630

Approved By: ______________________

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10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-8121

Client: OHM Southwest Region
225 West Airtex
Houston, TX 77090

Client's Job #: 19735
COC #: 5123
Date Sampled: 05/16/97
Date Received: 05/17/97

Sample Matrix: Soil
Chemron ID #: 64409
Report Date: 05/30/97
Chemron's Job#: 10430

Sample Description:
19735 Altus AFB Ierc Altus AFB
0001U1-SM-HN01-045' 05-16-97 09:50

CHEMICAL ANALYSIS REPORT

Analyte	MDL	Units	Results	Method	Preparation Batch	Digestion Date	Digestion Time	Analysis Date	Analysis Time
Total Arsenic	0.5	MG/KG	6.1	7060A	983	05/30/97	0800	05/31/97	1000
Total Barium	1.0	MG/KG	87.	3050/6010A	983	05/30/97	0800	05/30/97	1400
Total Cadmium	0.5	MG/KG	2.9	3050/6010A	983	05/30/97	0800	05/30/97	1400
Total Chromium	1.0	MG/KG	28.	3050/6010A	983	05/30/97	0800	05/30/97	1400
Total Lead	1.5	MG/KG	38.	3050/6010A	983	05/30/97	0800	05/30/97	1400
Total Mercury	0.1	MG/KG	<.1 U	7471	0521	05/21/97	1500	05/21/97	1500
Total Selenium	0.5	MG/KG	<0.5 U	7740	983	05/30/97	0800	05/30/97	1300
Total Silver	1.0	MG/KG	<1.0 U	3050/6010A	983	05/30/97	0800	05/30/97	1630

Approved By: ____________________

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Client:
OHM Southwest Region
225 West Airtex
Houston TX 77090

Report Date: 06/03/97
COC # 512286141
Job I.D. # 10489
Chemron Sample # 84670
Sample Matrix: Water
Sampling Date: 05/27/97
SamplingTime: 17:20
Analysis Date: 06/02/97
Analysis Time: 19:31
QC Batch: PV060297

Sample Description:
Project No. 19735
Project Name/Loc: 19735 Altus AFB Tulsa Tac Altus OK
Client Sample ID: 0001U1-MWU001-001 05-27-97 17:20

VOLATILE ORGANIC ANALYSIS REPORT
EPA SW-846 Method 8260a

ANALYTE	PQL	Units	RESULTS	
Acetone	10	ug/L	< 10	(U)
Acrolein	20	ug/L	< 20	(U)
Acrylonitrile	20	ug/L	< 20	(U)
Benzene	1.0	ug/L	< 1.0	(U)
Bromobenzene	1.0	ug/L	< 1.0	(U)
Bromochloromethane	1.0	ug/L	< 1.0	(U)
Bromodichloromethane	1.0	ug/L	< 1.0	(U)
Bromoform	1.0	ug/L	< 1.0	(U)
Bromomethane	1.0	ug/L	< 1.0	(U)
2-Butanone	5.0	ug/L	< 5.0	(U)
Carbon Disulfide	2.0	ug/L	< 2.0	(U)
Carbon Tetrachloride	1.0	ug/L	< 1.0	(U)
Chlorobenzene	1.0	ug/L	< 1.0	(U)
Chlorodibromomethane	1.0	ug/L	< 1.0	(U)
Chloroethane	2.0	ug/L	< 2.0	(U)
2-Chloroethyl Vinyl Ether	5.0	ug/L	< 5.0	(U,M)
Chloroform	1.0	ug/L	< 1.0	(U)
Chloromethane	2.0	ug/L	< 2.0	(U)
2-Chlorotoluene	1.0	ug/L	< 1.0	(U)
4-Chlorotoluene	1.0	ug/L	< 1.0	(U)
1,2-Dibromo-3-Chloropropane	2.0	ug/L	< 2.0	(U)
1,2-Dibromomethane	5.0	ug/L	< 5.0	(U)
Dibromomethane	2.0	ug/L	< 2.0	(U)
1,1-Dichloroethane	1.0	ug/L	< 1.0	(U)
1,2-Dichloroethane	1.0	ug/L	< 1.0	(U)
1,1-Dichloroethene	1.0	ug/L	< 1.0	(U)
1,2-Dichlorobenzene	1.0	ug/L	< 1.0	(U)

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Chemron Sample # 64670

QC Batch: PV080297

ANALYTE	PQL	Units	RESULTS		
1,3-Dichlorobenzene	1.0	ug/L	<	1.0	(U)
1,4-Dichlorobenzene	1.0	ug/L	<	1.0	(U)
Dichlorodifluoromethane	1.0	ug/L	<	1.0	(R,U)
Cis-1,2-Dichloroethene	1.0	ug/L	<	1.0	(U)
Trans-1,2-Dichloroethene	1.0	ug/L	<	1.0	(U)
1,2-Dichloropropane	1.0	ug/L	<	1.0	(U)
1,3-Dichloropropane	1.0	ug/L	<	1.0	(U)
1,1-Dichloropropane	1.0	ug/L	<	1.0	(U)
Cis-1,3-Dichloropropene	1.0	ug/L	<	1.0	(U)
Trans-1,3-Dichloropropene	1.0	ug/L	<	1.0	(U)
Ethylbenzene	1.0	ug/L	<	1.0	(U)
2-Hexanone	5.0	ug/L	<	5.0	(U)
Hexachlorobutadiene	1.0	ug/L	<	1.0	(U)
Methylene Chloride	1.0	ug/L	<	1.0	(U)
4-Methyl-2-Pentanone	5.0	ug/L	<	5.0	(U)
Naphthalene	1.0	ug/L	<	2.0	(U)
Styrene	1.0	ug/L	<	1.0	(U)
1,1,1,2-Tetrachloroethane	1.0	ug/L	<	1.0	(U)
1,1,2,2-Tetrachloroethane	1.0	ug/L	<	1.0	(U)
Tetrachloroethene	1.0	ug/L	<	1.0	(U)
Toluene	1.0	ug/L	<	1.0	(U)
1,2,3-Trichlorobenzene	1.0	ug/L	<	1.0	(U)
1,2,4-Trichlorobenzene	1.0	ug/L	<	1.0	(U)
1,1,1-Trichloroethane	1.0	ug/L	<	1.0	(U)
1,1,2-Trichloroethane	1.0	ug/L	<	1.0	(U)
Trichloroethene	1.0	ug/L	<	1.0	(U)
Trichlorofluoromethane	1.0	ug/L	<	1.0	(U)
Vinyl Acetate	5.0	ug/L	<	5.0	(U)
Vinyl Chloride	2.0	ug/L	<	2.0	(U)
o-Xylene	1.0	ug/L	<	1.0	(U)
m,p-Xylenes	1.0	ug/L	<	1.0	(U)

Approved by : ______________

CHEMRON
INCORPORATED

10526 Gulfdale • San Antonio, Texas 78216-3601 • (210) 340-8121

Client:
OHM Southwest Region
225 West Airtex
Houston TX 77090

Report Date: 06/03/97
COC # 5143
Job I.D. # 10489
Chemron Sample # 64675
Sample Matrix: Water
Sampling Date: 05/27/97
SamplingTime: 18:00
Analysis Date: 06/02/97
Analysis Time: 22:29
QC Batch: PV060297

Sample Description:
Project No. 19735
Project Name/Loc: 19735 Altus AFB Tulsa Terc Altus OK
Client Sample ID: 000IU1-MW0001-RN 05-27-97 18:00

VOLATILE ORGANIC ANALYSIS REPORT

EPA SW-846 Method 8260a

ANALYTE	PQL	Units	RESULTS		
Acetone	10	ug/L	<	10	(U)
Acrolein	20	ug/L	<	20	(U)
Acrylonitrile	20	ug/L	<	20	(U)
Benzene	1.0	ug/L	<	1.0	(U)
Bromobenzene	1.0	ug/L	<	1.0	(U)
Bromochloromethane	1.0	ug/L	<	1.0	(U)
Bromodichloromethane	1.0	ug/L	<	1.0	(U)
Bromoform	1.0	ug/L	<	1.0	(U)
Bromomethane	1.0	ug/L	<	1.0	(U)
2-Butanone	5.0	ug/L	<	5.0	(U)
Carbon Disulfide	2.0	ug/L	<	2.0	(U)
Carbon Tetrachloride	1.0	ug/L	<	1.0	(U)
Chlorobenzene	1.0	ug/L	<	1.0	(U)
Chlorodibromomethane	1.0	ug/L	<	1.0	(U)
Chloroethane	2.0	ug/L	<	2.0	(U)
2-Chloroethyl Vinyl Ether	5.0	ug/L	<	5.0	(U,M)
Chloroform	1.0	ug/L	<	1.0	(U)
Chloromethane	2.0	ug/L	<	2.0	(U)
2-Chlorotoluene	1.0	ug/L	<	1.0	(U)
4-Chlorotoluene	1.0	ug/L	<	1.0	(U)
1,2-Dibromo-3-Chloropropane	2.0	ug/L	<	2.0	(U)
1,2-Dibromomethane	5.0	ug/L	<	5.0	(U)
Dibromomethane	2.0	ug/L	<	2.0	(U)
1,1-Dichloroethane	1.0	ug/L	<	1.0	(U)
1,2-Dichloroethane	1.0	ug/L	<	1.0	(U)
1,1-Dichloroethene	1.0	ug/L	<	1.0	(U)
1,2-Dichlorobenzene	1.0	ug/L	<	1.0	(U)

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Chemron Sample # 84876

QC Batch: PV060297

ANALYTE	PQL	Units	RESULTS		
1,3-Dichlorobenzene	1.0	ug/L	<	1.0	(U)
1,4-Dichlorobenzene	1.0	ug/L	<	1.0	(U)
Dichlorodifluoromethane	1.0	ug/L	<	1.0	(R,U)
Cis-1,2-Dichloroethene	1.0	ug/L	<	1.0	(U)
Trans-1,2-Dichloroethene	1.0	ug/L	<	1.0	(U)
1,2-Dichloropropane	1.0	ug/L	<	1.0	(U)
1,3-Dichloropropane	1.0	ug/L	<	1.0	(U)
1,1-Dichloropropane	1.0	ug/L	<	1.0	(U)
Cis-1,3-Dichloropropene	1.0	ug/L	<	1.0	(U)
Trans-1,3-Dichloropropene	1.0	ug/L	<	1.0	(U)
Ethylbenzene	1.0	ug/L	<	1.0	(U)
2-Hexanone	5.0	ug/L	<	5.0	(U)
Hexachlorobutadiene	1.0	ug/L	<	1.0	(U)
Methylene Chloride	1.0	ug/L	<	1.0	(U)
4-Methyl-2-Pentanone	5.0	ug/L	<	5.0	(U)
Naphthalene	1.0	ug/L	<	2.0	(U)
Styrene	1.0	ug/L	<	1.0	(U)
1,1,1,2-Tetrachloroethane	1.0	ug/L	<	1.0	(U)
1,1,2,2-Tetrachloroethane	1.0	ug/L	<	1.0	(U)
Tetrachloroethene	1.0	ug/L	<	1.0	(U)
Toluene	1.0	ug/L	<	1.0	(U)
1,2,3-Trichlorobenzene	1.0	ug/L	<	1.0	(U)
1,2,4-Trichlorobenzene	1.0	ug/L	<	1.0	(U)
1,1,1-Trichloroethane	1.0	ug/L	<	1.0	(U)
1,1,2-Trichloroethane	1.0	ug/L	<	1.0	(U)
Trichloroethene	1.0	ug/L		1.3	
Trichlorofluoromethane	1.0	ug/L	<	1.0	(U)
Vinyl Acetate	5.0	ug/L	<	5.0	(U)
Vinyl Chloride	2.0	ug/L	<	2.0	(U)
o-Xylene	1.0	ug/L	<	1.0	(U)
m,p-Xylenes	1.0	ug/L	<	1.0	(U)

Approved by : ____________

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Client:
OHM Southwest Region
226 West Airtex
Houston TX 77090

Report Date: 06/03/97
COC # 512285141
Job I.D. # 10489
Chemron Sample # 64871
Sample Matrix: Water
Sampling Date: 05/27/97
Sampling Time: 18:00
Analysis Date: 06/02/97
Analysis Time: 18:47
QC Batch: PV060297

Sample Description:
Project No. 19735
Project Name/Loc: 19735 Altus AFB Tulsa Terc Altus OK
Client Sample ID: 0001U1-MW1001-001 05-27-97 18:00

VOLATILE ORGANIC ANALYSIS REPORT
EPA SW-846 Method 8260a

ANALYTE	PQL	Units	RESULTS	
Acetone	10	ug/L	< 10	(U)
Acrolein	20	ug/L	< 20	(U)
Acrylonitrile	20	ug/L	< 20	(U)
Benzene	1.0	ug/L	< 1.0	(U)
Bromobenzene	1.0	ug/L	< 1.0	(U)
Bromochloromethane	1.0	ug/L	< 1.0	(U)
Bromodichloromethane	1.0	ug/L	< 1.0	(U)
Bromoform	1.0	ug/L	< 1.0	(U)
Bromomethane	1.0	ug/L	< 1.0	(U)
2-Butanone	5.0	ug/L	< 5.0	(U)
Carbon Disulfide	2.0	ug/L	< 2.0	(U)
Carbon Tetrachloride	1.0	ug/L	< 1.0	(U)
Chlorobenzene	1.0	ug/L	< 1.0	(U)
Chlorodibromomethane	1.0	ug/L	< 1.0	(U)
Chloroethane	2.0	ug/L	< 2.0	(U)
2-Chloroethyl Vinyl Ether	5.0	ug/L	< 5.0	(U,M)
Chloroform	1.0	ug/L	< 1.0	(U)
Chloromethane	2.0	ug/L	< 2.0	(U)
2-Chlorotoluene	1.0	ug/L	< 1.0	(U)
4-Chlorotoluene	1.0	ug/L	< 1.0	(U)
1,2-Dibromo-3-Chloropropane	2.0	ug/L	< 2.0	(U)
1,2-Dibromomethane	5.0	ug/L	< 5.0	(U)
Dibromomethane	2.0	ug/L	< 2.0	(U)
1,1-Dichloroethane	1.0	ug/L	< 1.0	(U)
1,2-Dichloroethane	1.0	ug/L	< 1.0	(U)
1,1-Dichloroethene	1.0	ug/L	< 1.0	(U)
1,2-Dichlorobenzene	1.0	ug/L	< 1.0	(U)

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Chemron Sample # 04671 **QC Batch: PV060297**

ANALYTE	PQL	Units	RESULTS		
1,3-Dichlorobenzene	1.0	ug/L	<	1.0	(U)
1,4-Dichlorobenzene	1.0	ug/L	<	1.0	(U)
Dichlorodifluoromethane	1.0	ug/L	<	1.0	(R,U)
Cis-1,2-Dichloroethene	1.0	ug/L	<	1.0	(U)
Trans-1,2-Dichloroethene	1.0	ug/L	<	1.0	(U)
1,2-Dichloropropane	1.0	ug/L	<	1.0	(U)
1,3-Dichloropropane	1.0	ug/L	<	1.0	(U)
1,1-Dichloropropane	1.0	ug/L	<	1.0	(U)
Cis-1,3-Dichloropropene	1.0	ug/L	<	1.0	(U)
Trans-1,3-Dichloropropene	1.0	ug/L	<	1.0	(U)
Ethylbenzene	1.0	ug/L	<	1.0	(U)
2-Hexanone	5.0	ug/l	<	5.0	(U)
Hexachlorobutadiene	1.0	ug/L	<	1.0	(U)
Methylene Chloride	1.0	ug/L	<	1.0	(U)
4-Methyl-2-Pentanone	5.0	ug/L	<	5.0	(U)
Naphthalene	1.0	ug/L	<	2.0	(U)
Styrene	1.0	ug/L	<	1.0	(U)
1,1,1,2-Tetrachloroethane	1.0	ug/L	<	1.0	(U)
1,1,2,2-Tetrachloroethane	1.0	ug/L	<	1.0	(U)
Tetrachloroethene	1.0	ug/L	<	1.0	(U)
Toluene	1.0	ug/L	<	1.0	(U)
1,2,3-Trichlorobenzene	1.0	ug/L	<	1.0	(U)
1,2,4-Trichlorobenzene	1.0	ug/L	<	1.0	(U)
1,1,1-Trichloroethane	1.0	ug/L	<	1.0	(U)
1,1,2-Trichloroethane	1.0	ug/L	<	1.0	(U)
Trichloroethene	1.0	ug/L	<	1.0	(U)
Trichlorofluoromethane	1.0	ug/L	<	1.0	(U)
Vinyl Acetate	5.0	ug/L	<	5.0	(U)
Vinyl Chloride	2.0	ug/L	<	2.0	(U)
o-Xylene	1.0	ug/l	<	1.0	(U)
m,p-Xylenes	1.0	ug/L	<	1.0	(U)

Approved by : ______________

APPENDIX D

MODEL INPUT PARAMETERS, RELATED CALCULATIONS, AND SENSITIVITY ANALYSIS RESULTS

Altus AFB OU1 | Hydraulic Gradient | C. Nagel 9/30/97

Flow Path	GW Elev'	Δh	Δl	i
OU-1-03	1348.67'			
		3.87'	580'	0.007
TW1	1344.80'			
		1.82'	420'	0.004
TW2	1342.98'			
		3.68'	1150'	0.0032
TW4	1339.30'			
		0.41'	450'	0.0009
TW5	1338.89'			
		3.49'	1500'	0.002
WL062	1335.40'			

AVG 0.00342

Calculation of model simulated average concentration of CAHs in surface water (Stinking Creek) in 1997

Estimated Average Width of Stinking Creek	1 m
Estimated Average Depth of Stinking Creek	0.25 m
Average Cross-sectional Area of Stinking Creek	0.25 m^2
Measured Flow Velocity of Stinking Creek	0.25 m/sec
Estimated Flow through Stinking Creek	62.5 L/sec
Discharge Mass (based on computer simulation)	3194 g/yr (0.0001 g/sec)
Average Concentration (based on computer simulated discharge mass and estimated volumetric flow of Stinking Creek)	1.65E-06 g/L 1.65E-03 mg/L 1.64852 µg/L

FIRST-ORDER DECAY RATE CALCULATION USING THE METHOD OF BUSCHECK AND ALCANTAR (1995)

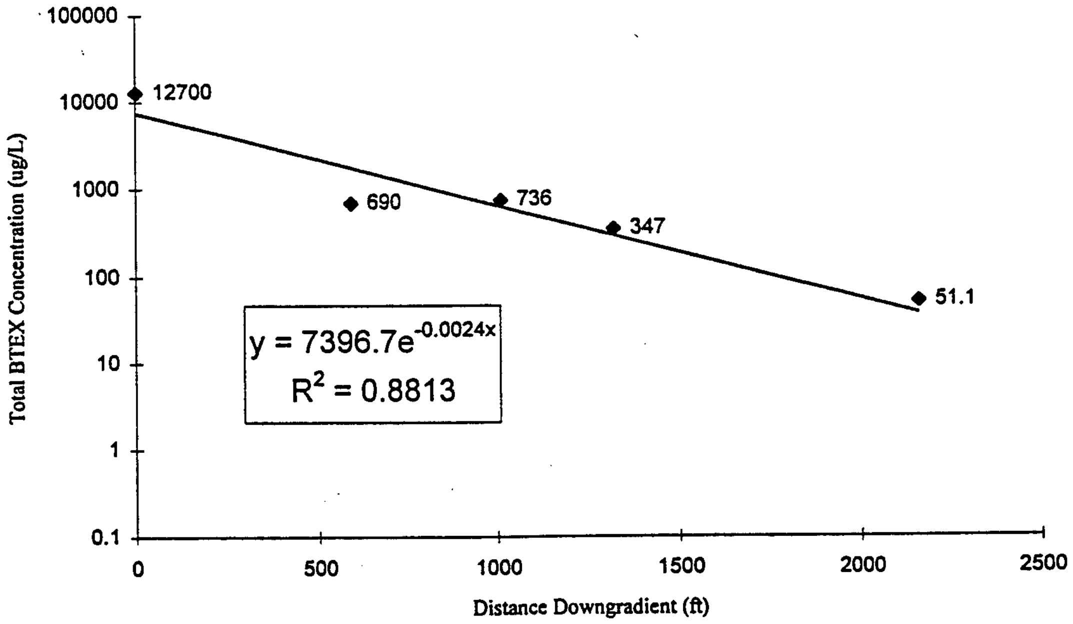
OU-1

REMEDIATION BY NATURAL ATTENUATION TS

ALTUS AFB, OKLAHOMA

Point	Distance (ft) Downgradient	TCE (µg/L) June-July 1996
OU-1-03	0	12700
TW1	590	690
TW-2	1010	736
TW-3	1320	347
TW4	2160	51.1

PLOT OF TCE CONCENTRATION VERSUS DISTANCE



$$\lambda = v_c/4\alpha_x([1+2\alpha_x(k/v_x)]^2-1)$$

where	$v_c = 0.4$	ft/day
	$\alpha_x = 400$	feet
	$k/v = 0.0024$	
therefore	$\lambda = 1.88E-03$	days^{-1}
	6.87E-01	years^{-1}

REDUCTIVE DECHLORINATION RATE
MOUTOUX METHOD (1995)
entire flow path (april 97)
B301 RNA TS
OFFUTT AFB, NEBRASKA

Step 1: Enter Observed Contaminant Concentration (µg/L)

Well	PCE	TCE	DCE	VC	Ethene	Total CAHs
OU-1-03	0	12700	1099.8	0	0	13799.8
TW1	0	690	142.7	0	0	832.7
TW2	0	736	71.6	0	0	807.6
TW3	0	347	50.8	0	0	397.8
TW4	0	51.1	3.4	0	0	54.5

Step 2: Compute Molar Concentrations (micromoles/Liter)

Well	M_{PCE}	M_{TCE}	M_{DCE}	M_{VC}	M_{Ethene}	Total M_{CAHs}
OU-1-03	0	96.67	11.35	0.00	0.00	108.01
TW1	0	5.25	1.47	0.00	0.00	6.72
TW2	0	5.60	0.74	0.00	0.00	6.34
TW3	0	2.64	0.52	0.00	0.00	3.17
TW4	0	0.39	0.04	0.00	0.00	0.42

Step 3: Compute Carbon Equivalents

Well	Total M_{CAHs}	x 2	= Ceqi
OU-1-03	108.01		216.02
TW1	6.72		13.45
TW2	6.34		12.68
TW3	3.17		6.33
TW4	0.42		0.85

Step 4: Compute Chlorine Equivalents

Well	$M_{PCE} \times 4$	$M_{TCE} \times 3$	$M_{DCE} \times 2$	M_{VC}	$\Sigma = Cleq_i$
OU-1-03	0	290.00	22.69	0	312.69
TW1	0	15.76	2.94	0	18.70
TW2	0	16.81	1.48	0	18.28
TW3	0	7.92	1.05	0	8.97
TW4	0	1.17	0.07	0	1.24

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	$C_{i,corr}$
OU-1-03				13799.8
TW1	13799.8	0.060	16.064	13256.9
TW2	13256.9	0.978	1.060	13745.2
TW3	13745.2	0.491	2.003	13511.3
TW4	13511.30	0.138	7.465	13906.2

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REDUCTIVE DECHLORINATION RATE
MOUTOUX METHOD (1995)
entire flow path (april 97)
B301 RNA TS
OFFUTT AFB, NEBRASKA

Step 6: Plot Exponential Trendline of Contaminant Concentration vs. Time

Well	Distance From Source (ft)	CAH avg. velocity (ft/day)	CAH Travel Time (day)	$C_{i,corr}$
OU-1-03	0	0.4	0	13799.8
TW1	590	0.4	1475	13256.9
TW2	1010	0.4	2525	13745.2
TW3	1320	0.4	3300	13511.3
TW4	2160	0.4	5400	13906.2

Reductive Dechlorination Rate

$C = C_0e^{-kt}$ 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: $y = 13683e^{-8E-06x}$

k = 8.0E-06 days^{-1}
k = 2.9E-03 years^{-1}

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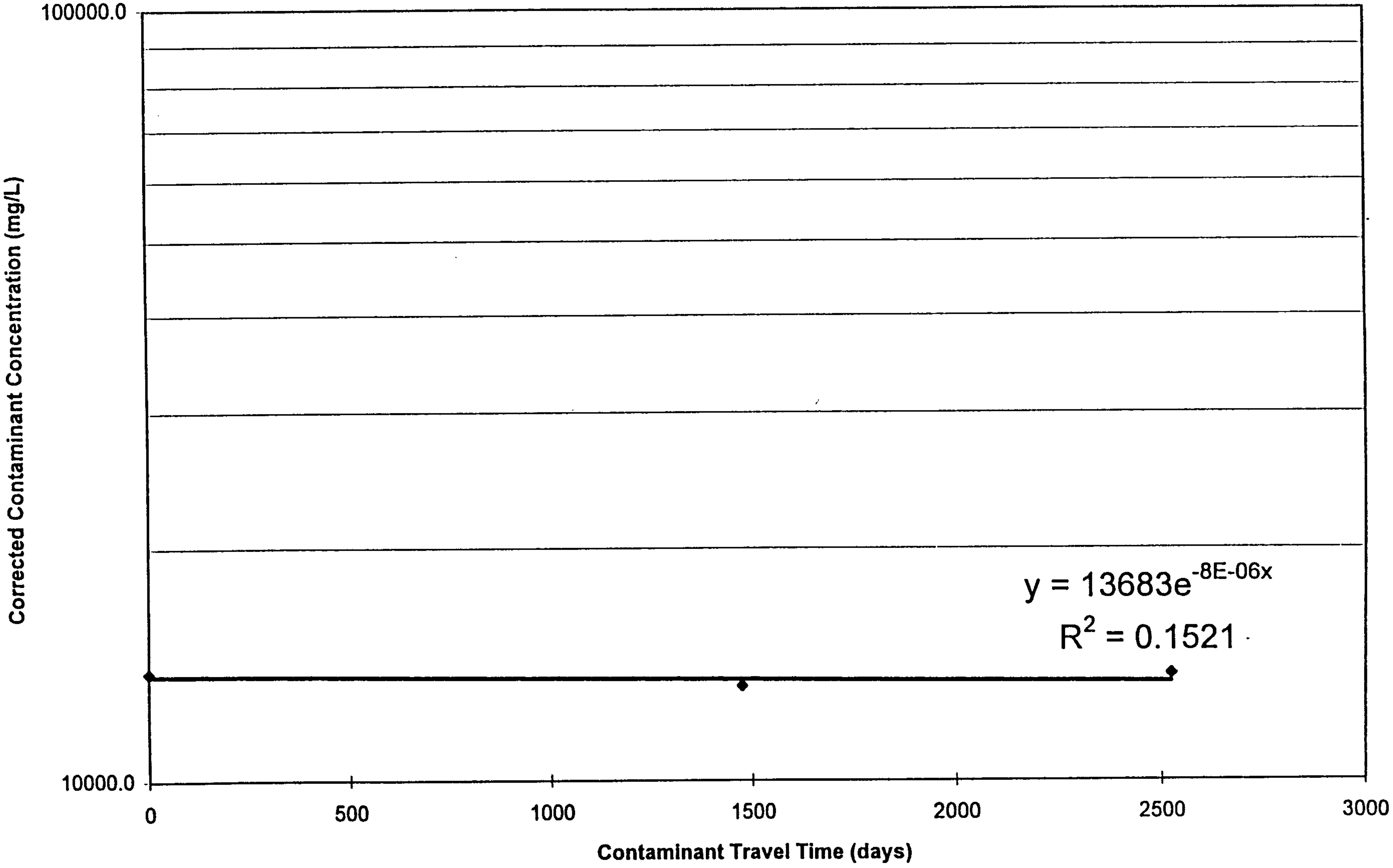
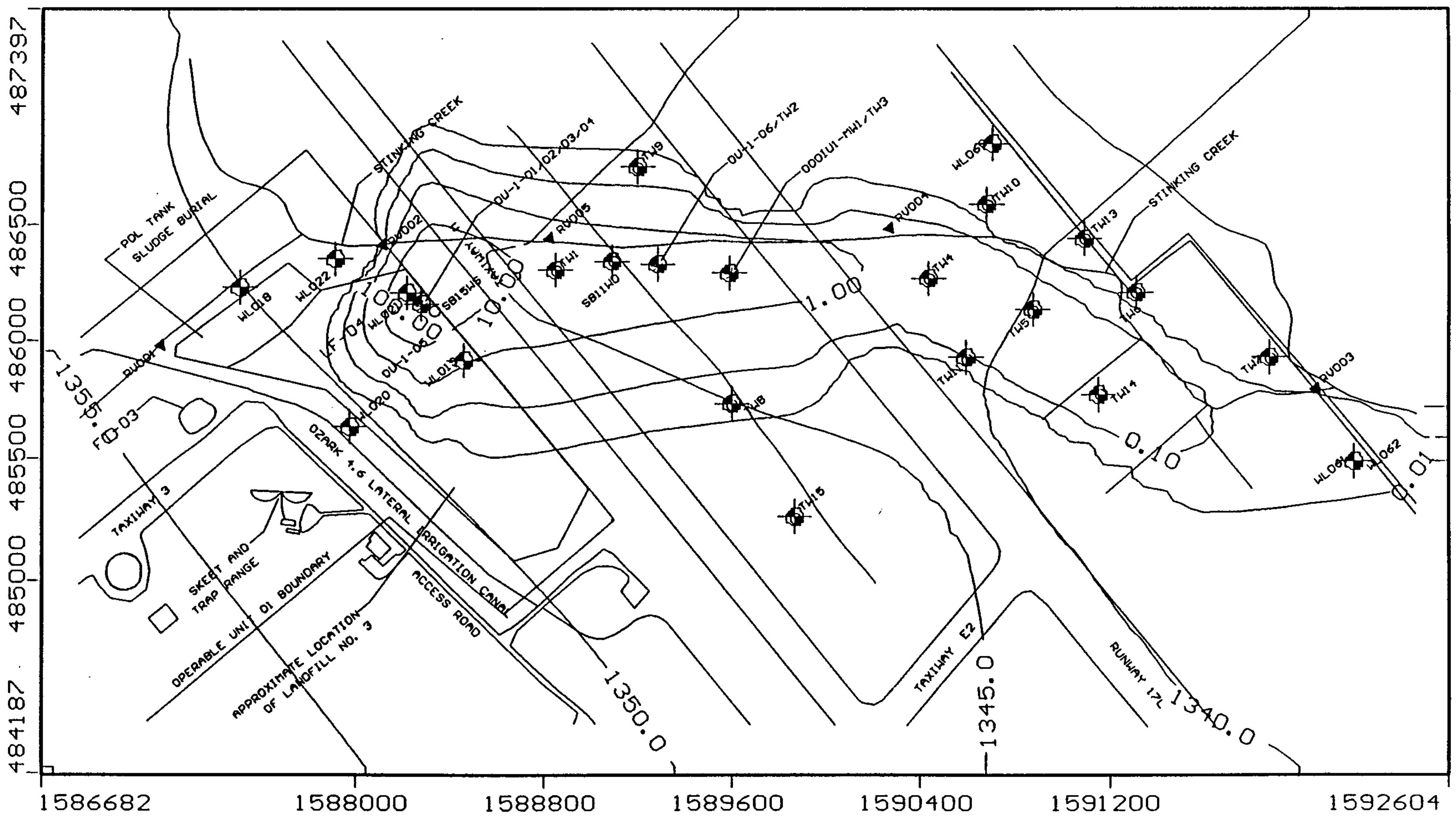
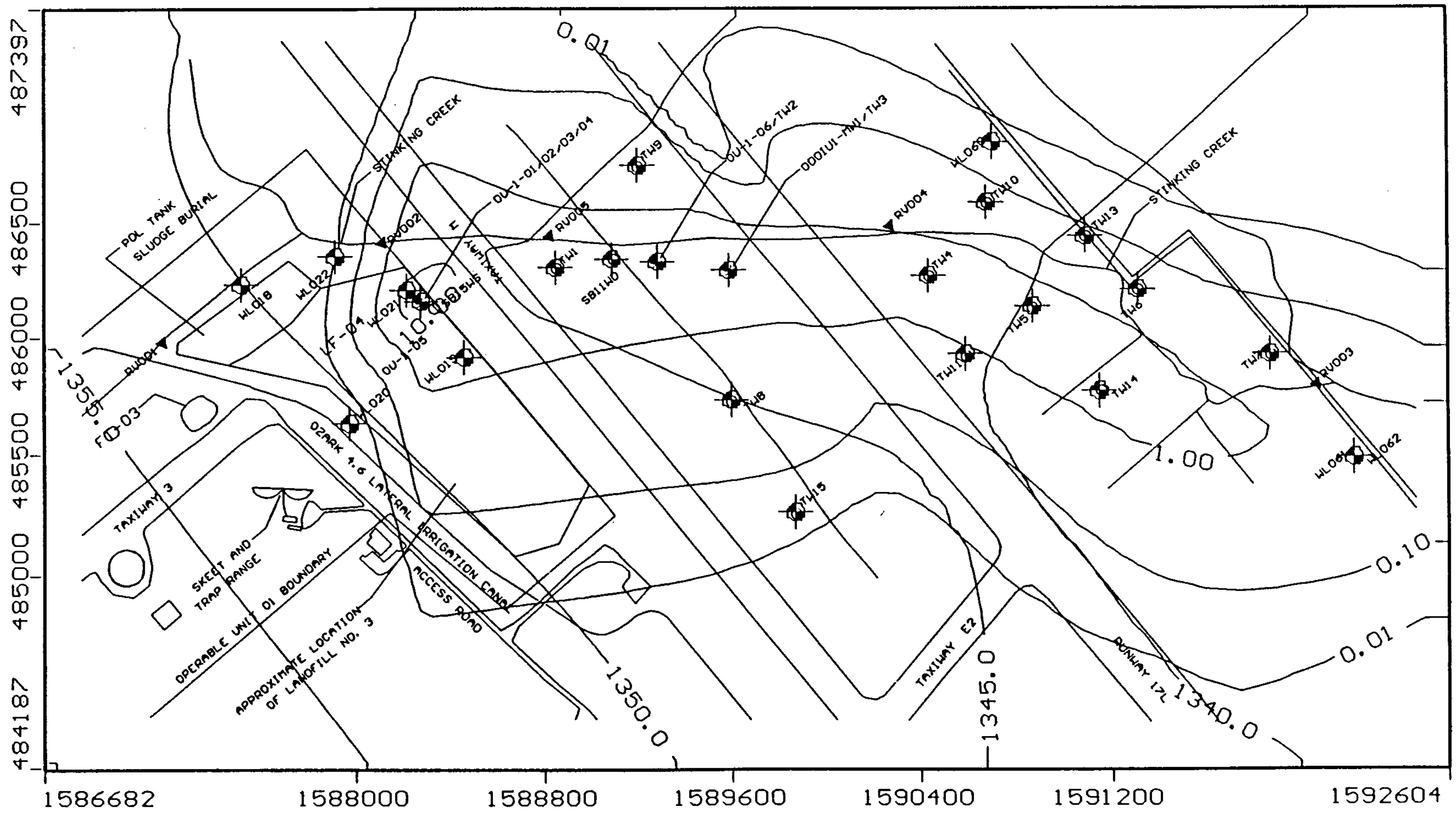
REDUCTIVE DECHLORINATION RATE
OU-1-03 > TW2 > SB11WD > TW3 > WL062
OU1
REMEDIATION BY NATURAL ATTENUATION TS
ALTUS AFB, OKLAHOMA



Note: Min. Average Contaminant Travel Velocity = 0.13 ft/day = 46 ft/year

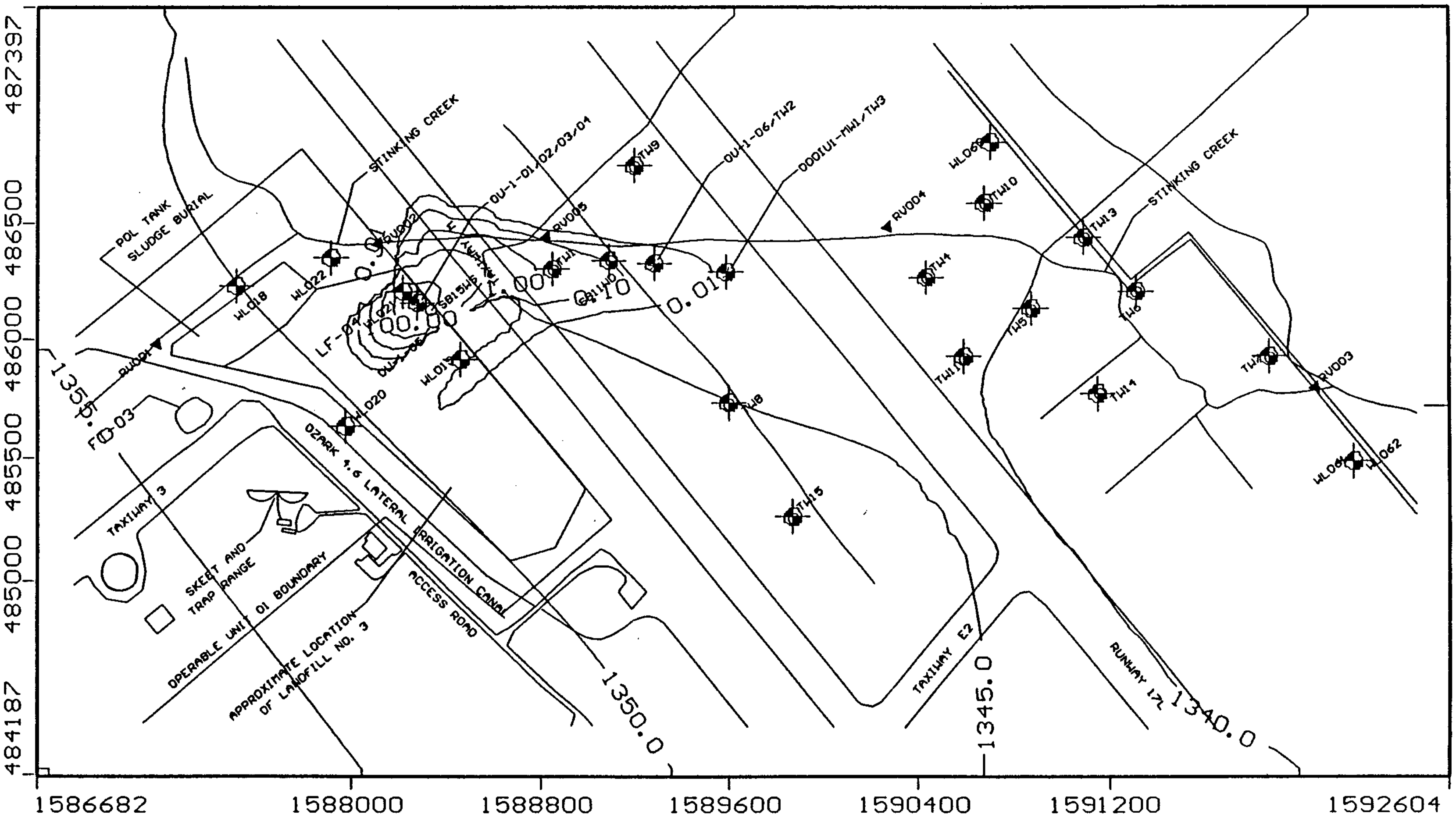


Parsons Eng. Science, Inc. Project: Altus AFB OU-1 Description: Calibrated Plume Modeller: Parsons ES 9 Oct 97	Visual MODFLOW v.2.20, (c) 1995 Waterloo Hydrogeologic Software NC: 74 NR: 52 NL: 1 Current Layer: 1



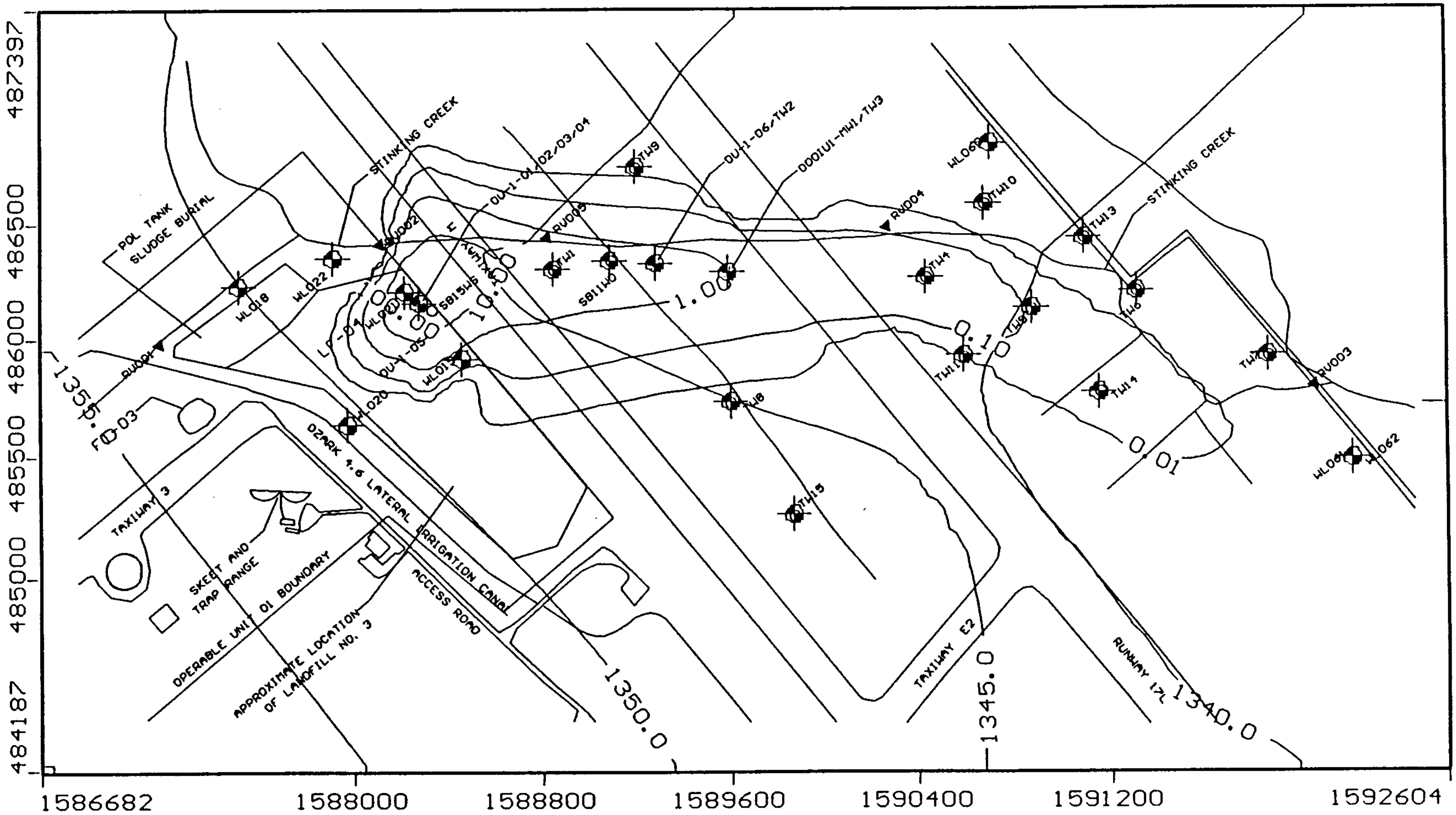
Parsons Eng. Science, Inc.
Project: Altus AFB OU-1
Description: Sensitivity Analysis A
Modeller: Parsons ES
9 Oct 97

Visual MODFLOW v.2.20, (c) 1995
Waterloo Hydrogeologic Software
NC: 74 NR: 52 NL: 1
Current Layer: 1

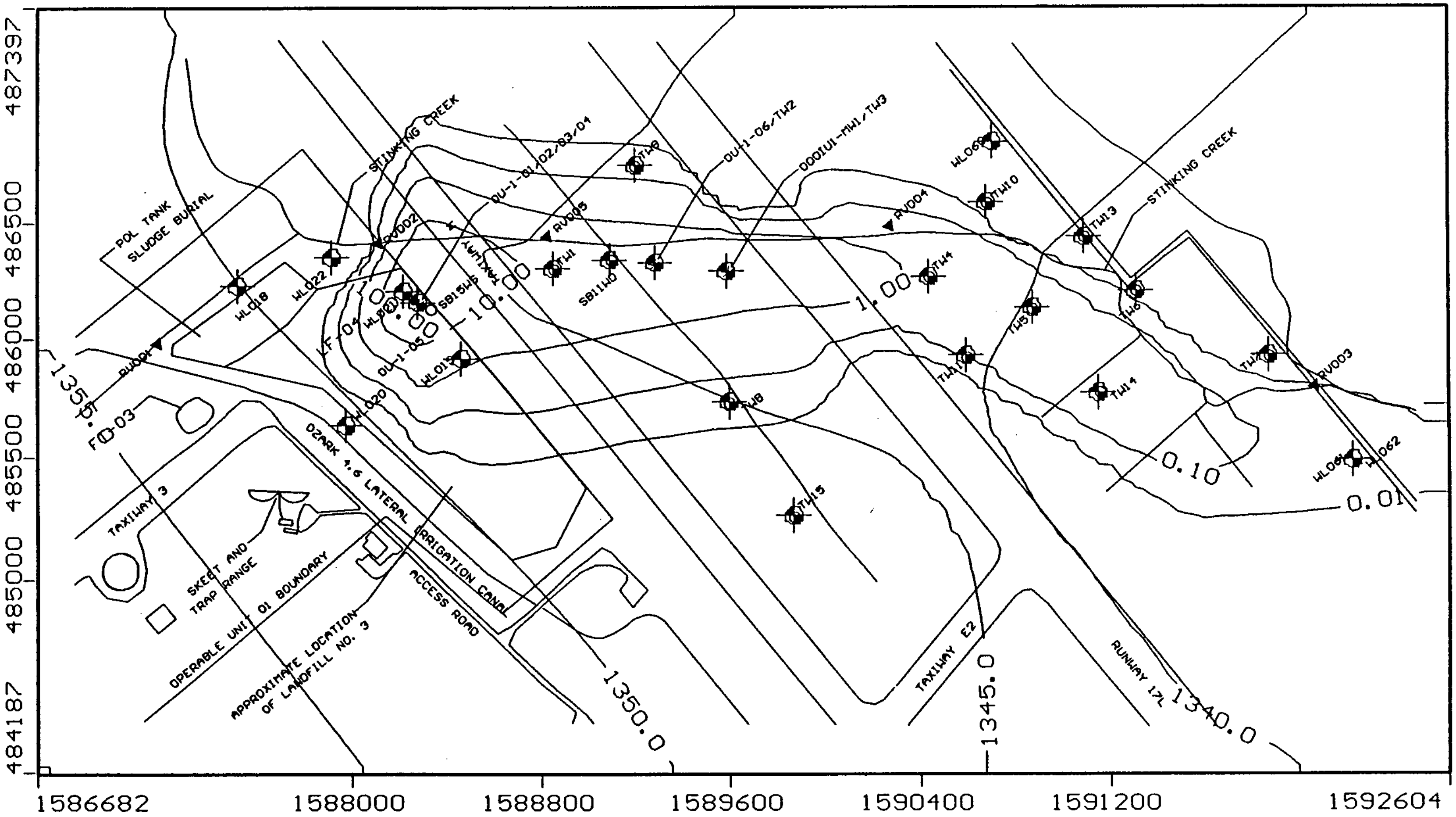


Parsons Eng. Science, Inc.
Project: Altus AFB OU-1
Description: Sensitivity Analysis B
Modeller: Parsons ES
9 Oct 97

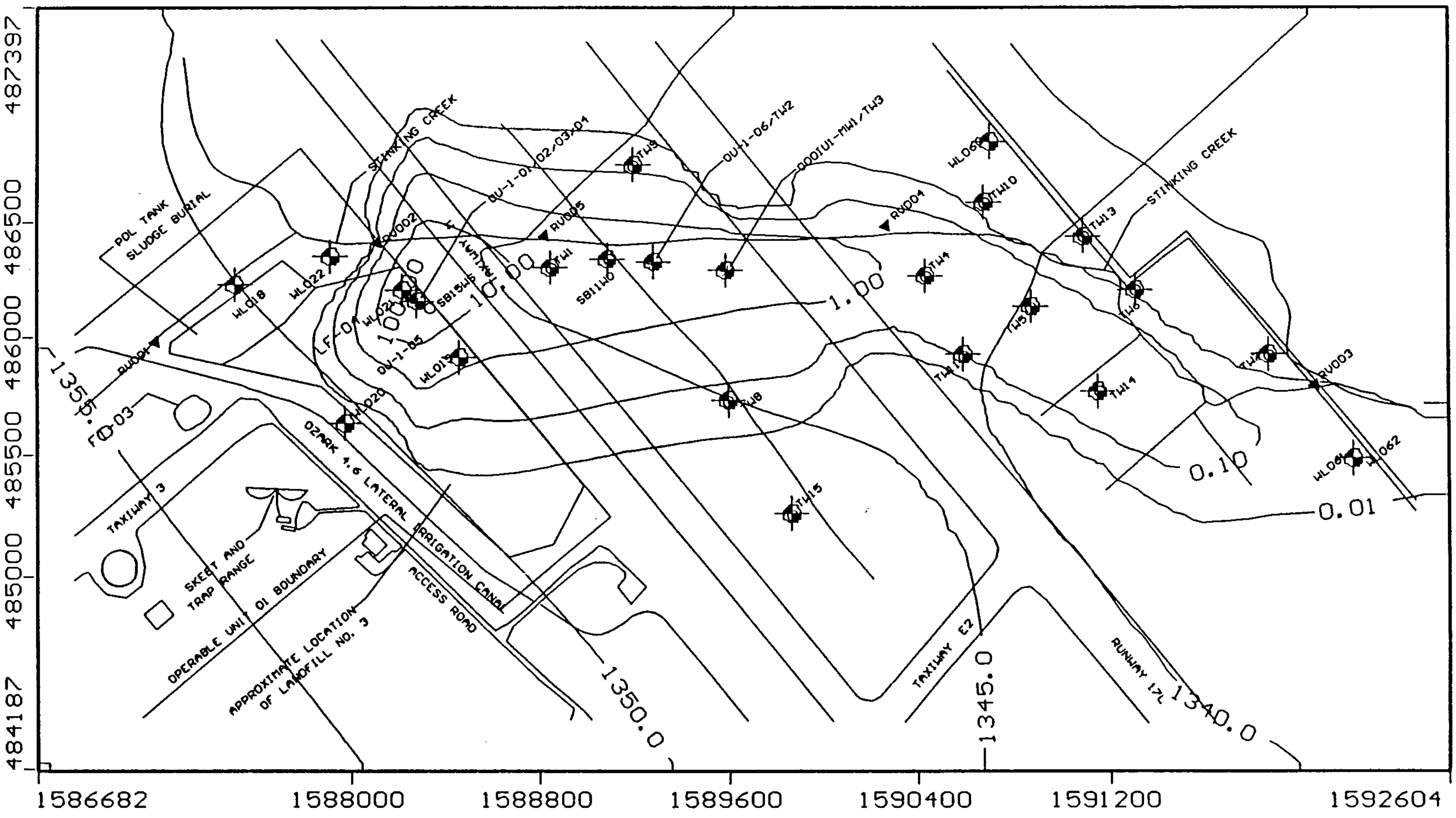
Visual MODFLOW v.2.20, (c) 1995
Waterloo Hydrogeologic Software
NC: 74 NR: 52 NL: 1
Current Layer: 1



Parsons Eng. Science, Inc. Project: Altus AFB OU–1 Description: Sensitivity Analysis C Modeller: Parsons ES 9 Oct 97	Visual MODFLOW v.2.20, (c) 1995 Waterloo Hydrogeologic Software NC: 74 NR: 52 NL: 1 Current Layer: 1

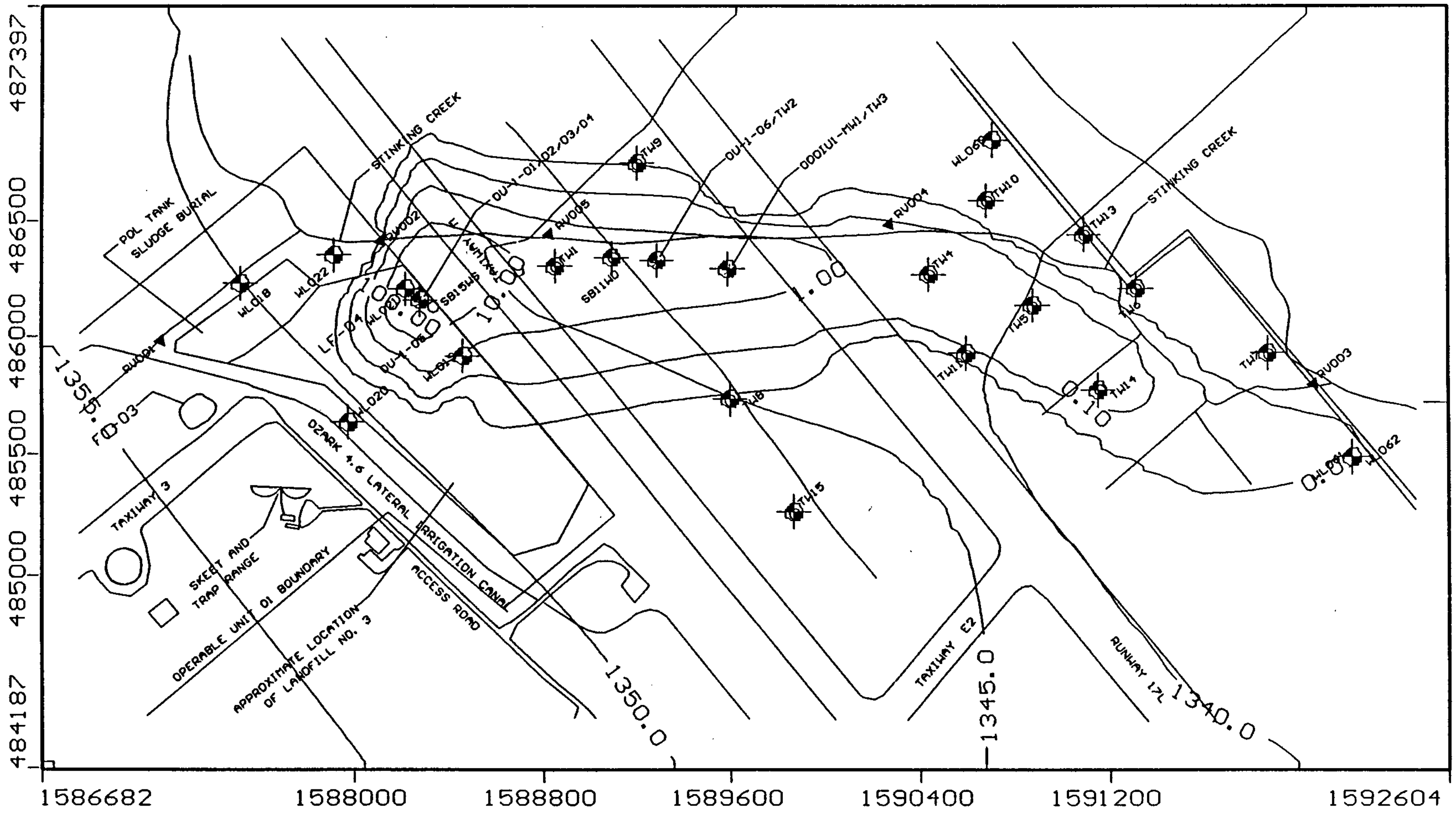


Parsons Eng. Science, Inc. **Project: Altus AFB OU–1** **Description: Sensitivity Analysis D** **Modeller: Parsons ES** **9 Oct 97**	**Visual MODFLOW v.2.20, (c) 1995** **Waterloo Hydrogeologic Software** **NC: 74 NR: 52 NL: 1** **Current Layer: 1**



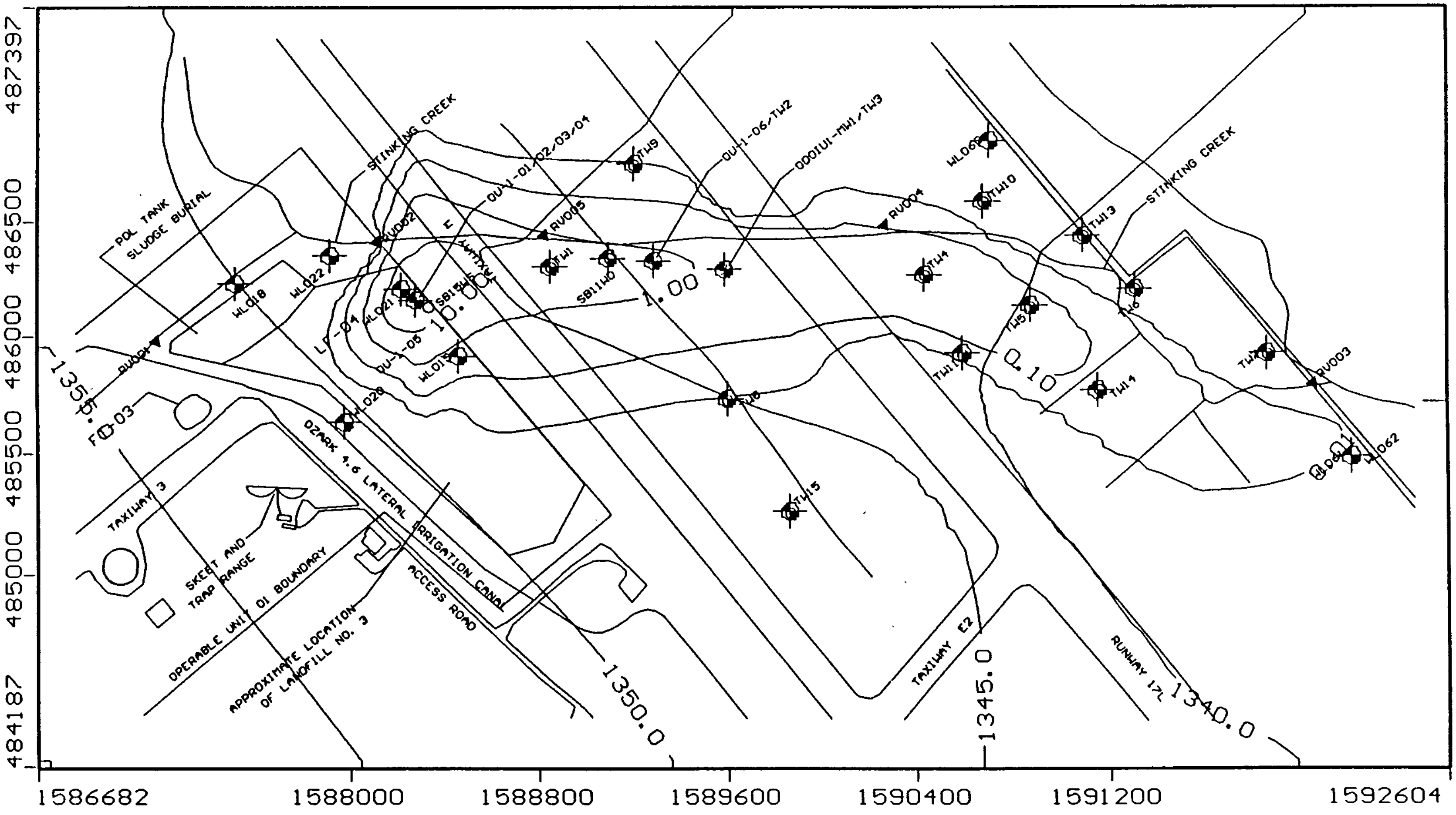
Parsons Eng. Science, Inc.
Project: Altus AFB OU-1
Description: Sensitivity Analysis E
Modeller: Parsons ES
9 Oct 97

Visual MODFLOW v.2.20, (c) 1995
Waterloo Hydrogeologic Software
NC: 74 NR: 52 NL: 1
Current Layer: 1



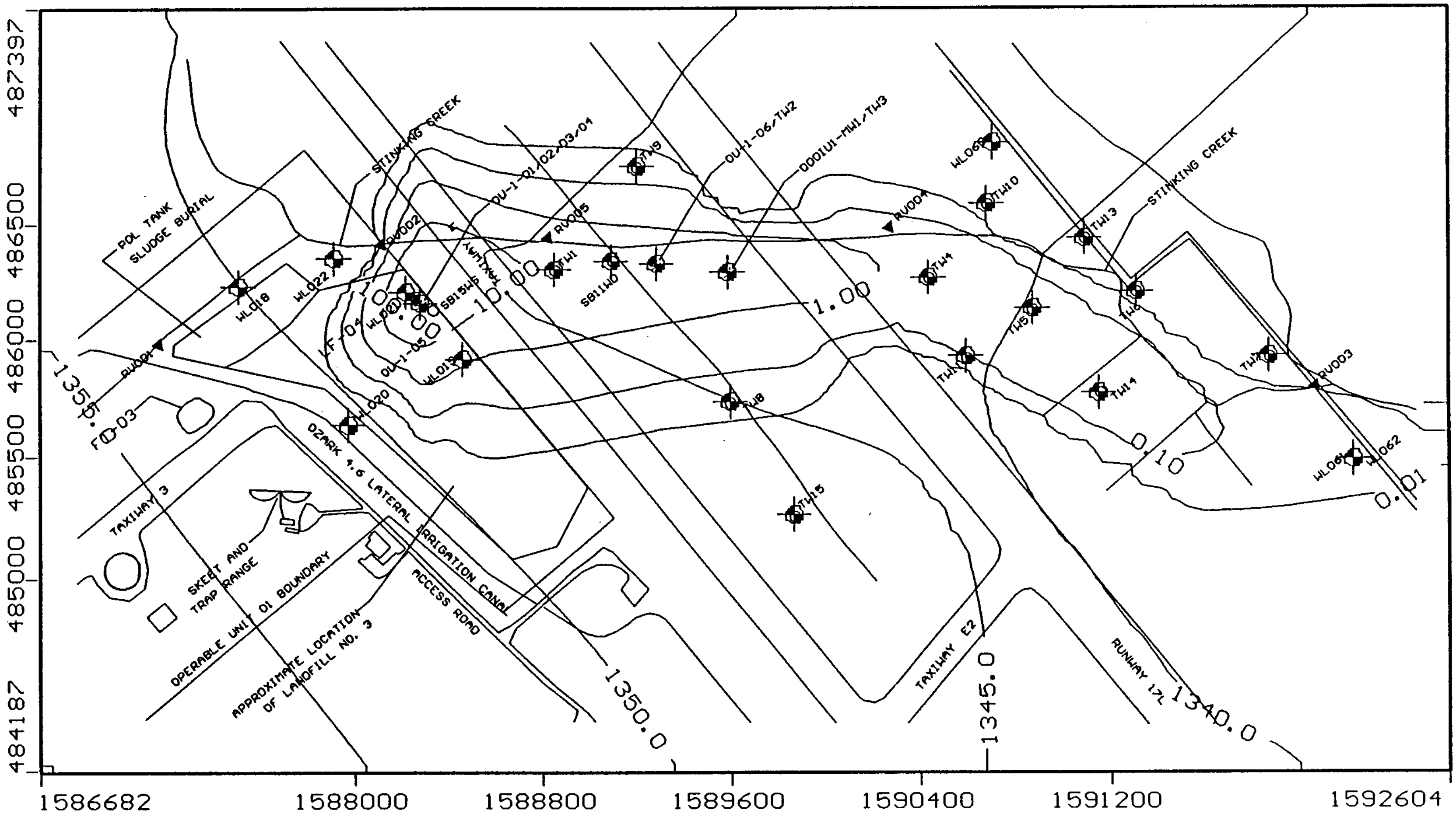
Parsons Eng. Science, Inc.
Project: Altus AFB OU-1
Description: Sensitivity Analysis F
Modeller: Parsons ES
9 Oct 97

Visual MODFLOW v.2.20, (c) 1995
Waterloo Hydrogeologic Software
NC: 74 NR: 52 NL: 1
Current Layer: 1



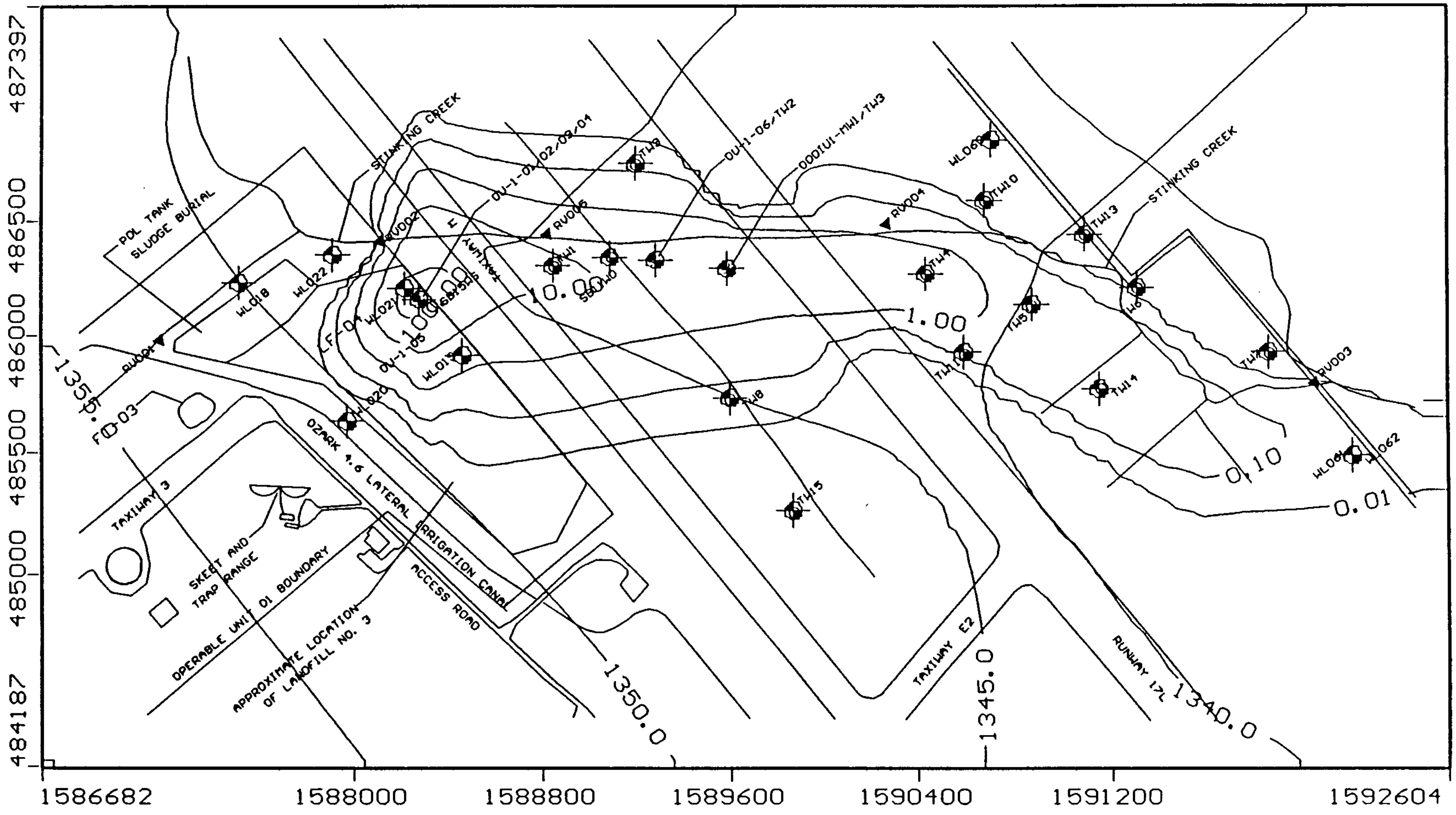
Parsons Eng. Science, Inc.
Project: Altus AFB OU-1
Description: Sensitivity Analysis G
Modeller: Parsons ES
9 Oct 97

Visual MODFLOW v.2.20, (c) 1995
Waterloo Hydrogeologic Software
NC: 74 NR: 52 NL: 1
Current Layer: 1



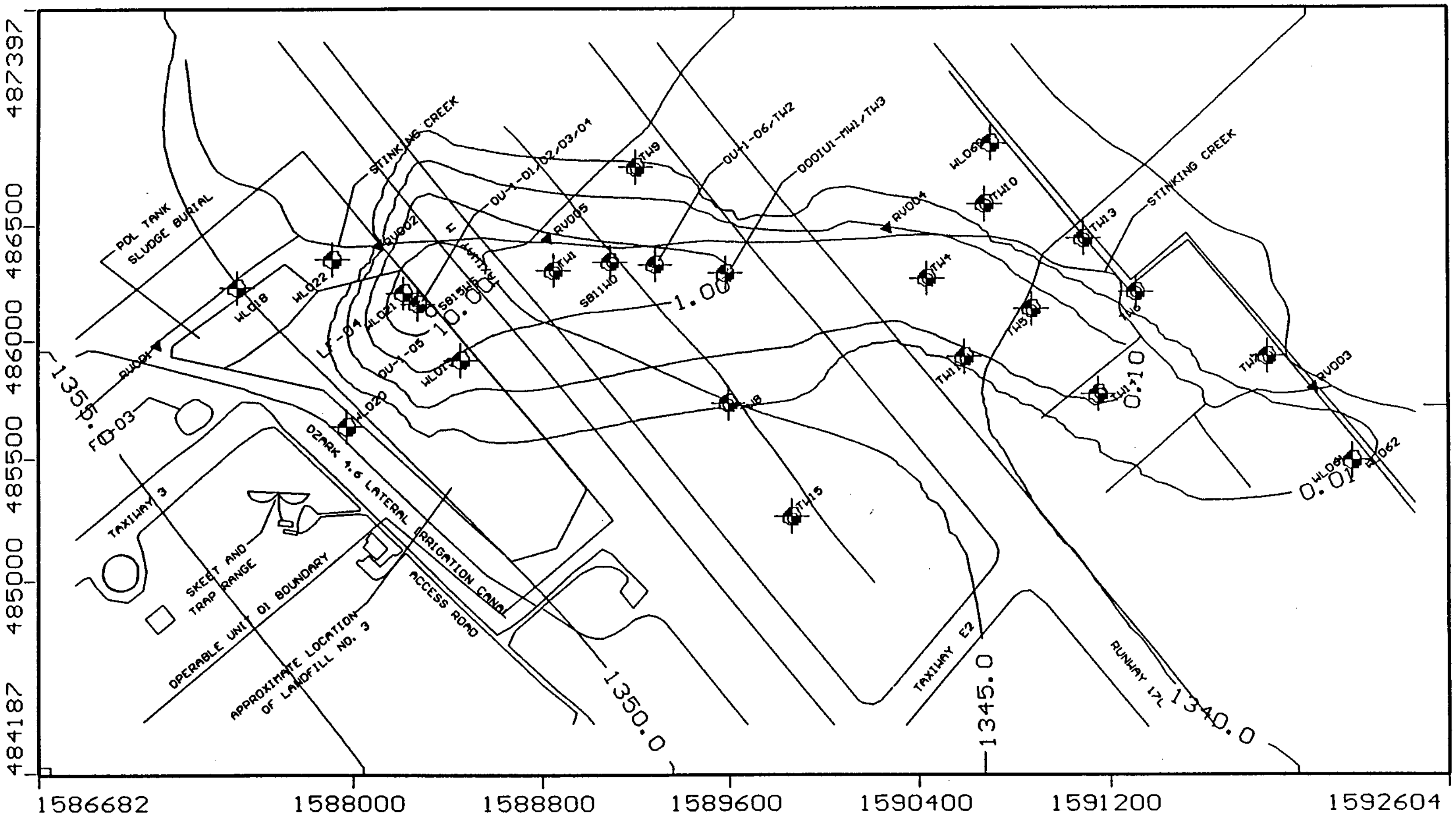
Parsons Eng. Science, Inc.
Project: Altus AFB OU–1
Description: Sensitivity Analysis H
Modeller: Parsons ES
9 Oct 97

Visual MODFLOW v.2.20, (c) 1995
Waterloo Hydrogeologic Software
NC: 74 NR: 52 NL: 1
Current Layer: 1



Parsons Eng. Science, Inc.
Project: Altus AFB OU-1
Description: Sensitivity Analysis I
Modeller: Parsons ES
9 Oct 97

Visual MODFLOW v.2.20, (c) 1995
Waterloo Hydrogeologic Software
NC: 74 NR: 52 NL: 1
Current Layer: 1

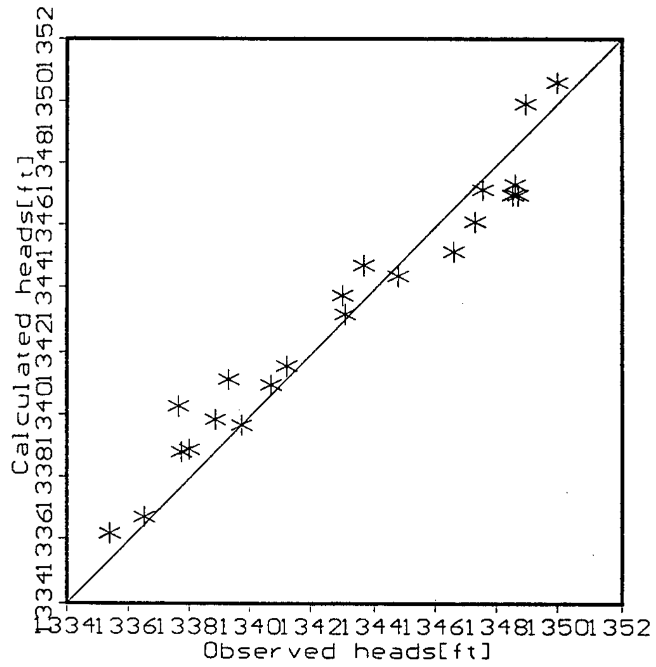


Parsons Eng. Science, Inc.
Project: Altus AFB OU-1
Description: Sensitivity Analysis J
Modeller: Parsons ES
9 Oct 97

Visual MODFLOW v.2.20, (c) 1995
Waterloo Hydrogeologic Software
NC: 74 NR: 52 NL: 1
Current Layer: 1

Calculated versus Simulated Hydraulic Heads
Altus AFB OU-1 Flow Calibration

Observation Name	bserved Heads[ft	Calc Heads[ft]	Residual (ft)
WL018	1,348.95	1,349.86	-0.91
WL022	1,347.58	1,347.15	0.43
WL021	1,348.51	1,346.98	1.53
OU-1-03	1,348.67	1,347.00	1.67
WL020	1,350.01	1,350.59	-0.58
WL019	1,348.63	1,347.28	1.35
TW1	1,344.80	1,344.40	0.40
TW9	1,343.73	1,344.73	-1.00
TW8	1,346.62	1,345.15	1.47
TW15	1,347.30	1,346.09	1.21
TW2	1,342.98	1,343.74	-0.76
TW3	1,343.11	1,343.15	-0.04
WL060	1,341.16	1,341.57	-0.41
TW10	1,340.67	1,340.95	-0.28
TW4	1,339.30	1,341.09	-1.79
TW5	1,338.89	1,339.80	-0.91
TW11	1,337.68	1,340.26	-2.58
TW13	1,339.74	1,339.66	0.08
TW6	1,338.04	1,338.85	-0.81
TW14	1,337.74	1,338.78	-1.04
TW7	1,336.51	1,336.69	-0.18
WL062	1,335.40	1,336.18	-0.78



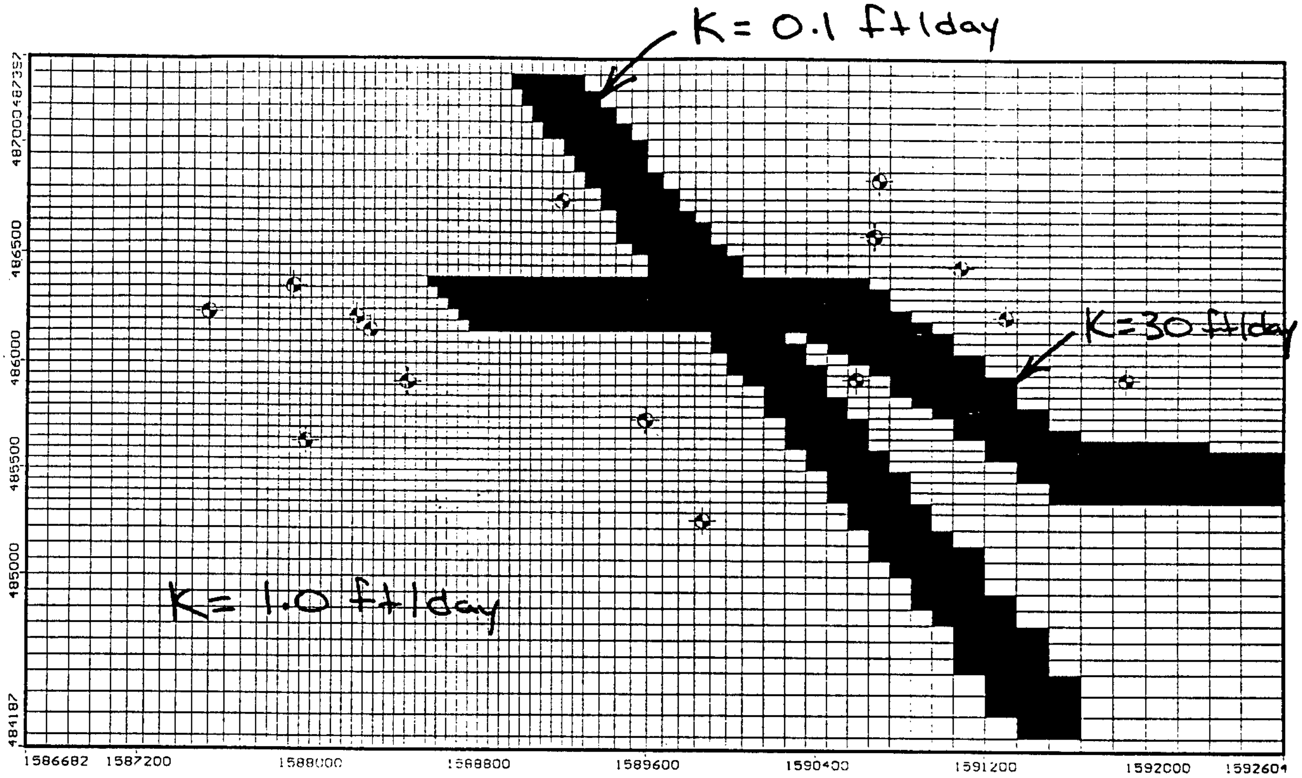
Period: 1
Step: 1

Mean error: 0.179466 Mean abs. err: 0.917839 RMS error: 1.10679

Parsons Eng Science, Inc – Denver, CO
Project: Altus AFB OU–1
Description: Flow Calibration
Modeller: Parsons ES
29 Oct 99

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 74 NR: 52 NL: 1
Current Layer: 1

DISTRIBUTION OF HYDRAULIC CONDUCTIVITY



Parsons Eng Science, Inc – Denver, CO
Project: Altus AFB OU-1
Description: Hydraulic Conductivity
Modeller: Parsons ES
28 Sep 99

Visual MODFLOW v.2.50, (C) 1995–1997
Waterloo Hydrogeologic Software
NC: 74 NR: 52 NL: 1
Current Layer: 1

APPENDIX E

MODEL INPUT AND OUTPUT FILES
SLUG TEST FILES

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 E
MODFLOW/MT3D MODEL
INPUT AND OUTPUT FILES

alt1_in.zip	Alternative 1 Prediction Input Files
alt1_out.zip	Alternative 1 Prediction Output Files
alt2_in.zip	Alternative 2 Prediction Input Files
alt2_out.zip	Alternative 2 Prediction Output Files

To decompress these files, 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. Only 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

APPENDIX F

REMEDIAL ALTERNATIVE COST CALCULATIONS

LTM Well Installation Cost Estimate
Altus AFB OU-1
722450.36050

sign/Construct 3 LTM Wells		Description	Unit	Qty.	Unit Price	Subtotal	Total
st calculations		Mobilization	ea	1	$ 1,000	$ 1,000	
Number of wells:	3	Well Installation	ln ft	60	$ 75	$ 4,500	
Depth (ft) each:	20	Soil Disposal	drum	3	$ 100	$ 300	
							$ 5,800

Billing Category Cost Code/(Billing Category)		Billing Rate	Task 1 (hrs)	Install New LTM/POC Wells ($)	Task 2 (hrs)	Subcontracting ($)	Task 3 (hrs)	Reporting & PM ($)
Word Processor	88/(15)	$30	0	$0	5	$150	5	$150
CADD Operator	58/(25)	$47	0	$0	0	$0	5	$235
Technician	42/(50)	$40	8	$320	0	$0	0	$0
Staff Level	16/(65)	$57	30	$1,710	20	$1,140	15	$855
Project Level	12/(70)	$65	8	$520	12	$780	5	$325
Senior Level	10/(80)	$85	2	$170	2	$170	2	$170
Principal	02/(85)	$97	0	$0	0	$0	0	$0
Total Labor (hrs | $)			48	$2,720	39	$2,240	32	$1,735

ODCs	Task 1	Task 2	Task 3
Phone	$20	$20	$0
Photocopy	$10	$0	$10
Mail	$0	$10	$20
Computer	$0	$50	$50
D	$0	$0	$50
	$0	$20	$20
Travel	$150	$0	$0
Per Diem	$0	$0	$0
Eqpt. & Supplies	$200	$0	$0
Total ODCs	$380	$100	$150

Outside Services	Task 1	Task 2	Task 3
LTM/POC Well Installation Costs	$ 5,800	$0	$0
Surveying	$500	$0	$0
Other: Maintain Institutional Controls	$0	$0	$0
Total Outside Services	$6,300	$0	$0

Proposal Estimate	Task 1	Task 2	Task 3
Labor	$2,720	$2,240	$1,735
ODC's	$380	$100	$150
Outside Services	$6,300	$0	$0
Total by Task	$9,400	$2,340	$1,885

Total Labor	$6,695
Total ODCs	$630
Total Outside Services	$6,300
Total Project	$13,625

Task 1: Install New LTM/POC Wells
Task 2: Subcontracting/Permitting
Task 3: Reporting/PM per Event.

Remedial Alternative 1 Cost Estimate
Altus AFB OU-1
722450.36050

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apital Costs

Design/Construct 3 LTM Wells in 1998	P/F i=7% n=1	Present Worth Cost	$12,734

Monitoring Costs (11 groundwater samples, 5 surface water samples, 9 QA/QC samples)

Labor				
Field Work	60 hours x	$60	/hour	$3,600
Data Management	40 hours x	$60	/hour	$2,400
Data Validation	20 hours x	$60	/hour	$1,200
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
Analytical				
CAHs	25	$150	/each	$3,750
Methane/Ethene	16	$100	/each	$1,600
Field Parameters	16	$20	/each	$320
Supplies		$700	lump sum	$700
Travel		$300	lump sum	$300
		Total for each Sampling Event		$20,330

Annual Monitoring, 1998-2002 (5 events)

P/A i=7%, n=5 PWF = 4.100197436

Annual Monitoring (5 yrs) Present Worth Cost $83,357

Biennial Monitoring, 2003-2028 (13 events)

P/A i=7%, n=7	2004	$12,661
P/A i=7%, n=9	2006	$11,058
P/A i=7%, n=11	2008	$9,659
P/A i=7%, n=13	2010	$8,436
P/A i=7%, n=15	2012	$7,369
P/A i=7%, n=17	2014	$6,436
P/A i=7%, n=19	2016	$5,621
P/A i=7%, n=21	2018	$4,910
P/A i=7%, n=23	2020	$4,289
P/A i=7%, n=25	2022	$3,746
P/A i=7%, n=27	2024	$3,272
P/A i=7%, n=29	2026	$2,858
P/A i=7%, n=31	2028	$2,496

Biennial Monitoring (25 yrs) Present Worth Cost $82,809

Site Management (30 years)

Annual Cost $6,000

P/A i=7% n=30 PWF = 12.40904118

Site Management Present Worth Cost $74,454

TOTAL PRESENT WORTH COST OF ALTERNATIVE 1 $253,354

Remedial Alternative 2 Cost Estimate
Altus AFB OU-1
722450.36050

tem Installation Costs

Installation of the Vapor Extraction System

Design/Procure System	150 hours x	$70	/hour	$10,500
Blower/Shed/Accessories		$20,000	lump sum	$20,000
Asphalt cutting/trenching	600 ft x	$10	ft	$6,000
Electrical Subcontractor		$5,000	lump sum	$5,000
Per Diem	20 days x	$100	/day	$2,000
Travel (1 round trip)		$1,000	lump sum	$1,000
O & M Manual Preparation	40 hours x	$65	/hour	$2,600
Emissions Permitting		$2,000	lump sum	$2,000
Installation/startup Labor	200 hours x	$65	/hour	$13,000
		VES Installation Subtotal		$62,100

Installation of Groundwater Extraction System

Pumps	1	$1,000	each	$1,000
System Controls	1	$4,500	lump sum	$4,500
Per Diem in Field	20 days	$100	/day	$2,000
Travel (included in SVE system)	0	$0	lump sum	$0
Electrical Subcontractor	1	$5,000	lump sum	$5,000
Surface Well Completion	2	$2,000	ea	$4,000
		GES Installation Subtotal		$16,500

Design/Construct GW Treatment System

Labor--Design/Procure	250 hours	$70	/hr	$17,500
Labor--Construct	200 hours	$65	/hr	$13,000
Mechanical Subcontractor	1	$12,000	lump sum	$12,000
Prefilter	1	$3,000	lump sum	$3,000
Air Stripper	1	$10,000	lump sum	$10,000
Electrical Controls	1	$3,000	lump sum	$3,000
Piping/Valves/supplies	1	$2,500	lump sum	$2,500
Per Diem	20 days	$100	/day	$2,000
Travel	2 round trip	$1,000	/trip	$2,000
Equipment Rental	1	$2,000	lump sum	$2,000
Analytical for Startup (8 VOCs)	8	$150	/ea	$1,200
Prefabricated Heated Building	1	$15,000	lump sum	$15,000
O&M Manual Preparation	40 hours	$65	hr	$2,600
Discharge Permitting		$2,000	lump sum	$2,000
		GWTS Installation Subtotal		$87,800

(assuming installation in 1998)

Vapor Extraction System	$62,100	P/A i=7%, n=1	$58,037
Groundwater Extraction System	$16,500	P/A i=7%, n=1	$15,421
Groundwater Treatment System	$87,800	P/A i=7%, n=1	$82,056
		System Installation Present Worth Cost	$155,514

Remedial Alternative 2 Cost Estimate
Altus AFB OU-1
722450.36050

[illegible]eration and Maintenance Costs

Labor			
Weekly System Checks (4 hr x 52 wk/yr x $60/hr)		$12,480	
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	
VOCs (H2O)	(2/mo x 12 mo x $150/ea)	$3,600	
misc.	(2/mo x 12 mo x $100/ea)	$2,400	
Sample ship.	(4/mo x 12 mo x $30/ea) (assume 2 labs)	$1,440	
Supplies			
Filters	(lump sum)	$1,000	
pumps	(lump sum)	$600	
misc.	(lump sum)	$1,000	
Travel (52 trips from Omaha per year @ $20/ea)		$1,040	
Electricity		$5,000	
Site Management		$6,000	
	Annual O&M Cost	$60,720	
Present Worth O & M (3-year operation period)			
Annual Cost	$60,720		
	1998 n=1	$56,748	
	1999 n=2	$53,035	
	2000 n=3	$49,566	
	O&M Present Worth Cost		$159,348
	Total Present Worth LTM Program (from Alternative 1)		$253,354
	TOTAL PRESENT WORTH OF ALTERNATIVE 2		$568,216

APPENDIX G

RESPONSE TO COMMENTS

PARSONS

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29 October 1999

Mr. Jerry Hansen
AFCEE/ERT
3207 North Road, Bldg 532
Brooks AFB, TX 78235-5363

Subject: Responses to AFCEE Comments on the Draft Remediation by Natural Attenuation Treatability Study for Operable Unit 1, Altus AFB, OK (Contract F41624-92-D-8036)

Dear Mr. Hansen:

This letter provides responses to comments received on the Draft Remediation by Natural Attenuation (RNA) Treatability Study (TS) for Operable Unit 1 (OU1), Altus Air Force Base (AFB), Oklahoma. The draft RNA TS was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) and Altus AFB. The intent of the RNA TS was to determine the role of natural attenuation in remediating chlorinated solvents in groundwater at OU1. The draft RNA TS was submitted to AFCEE and Altus AFB in November 1997. Comments on the draft RNA TS were received from AFCEE as reviewed by Jon Atkinson, dated February 9, 1998. The Base has declined to comment. Responses to these comments were prepared by Parsons ES and are presented herein.

Responses to AFCEE Comments: February 9, 1998

Comment 1) Pages 11 and 12, Sec 1.3, Para 1, Line 13: Most likely, VOCs were detected at levels lower than 2 μg/L, not 2 mg/L.

Parsons ES Response: *The text will be changed to indicate that VOCs in surface water samples were detected at concentrations less than 2 μg/L.*

Comment 2) Page 12 and 13, Sec 1.3, Para 1, Line 13. Here and throughout the report (e.g., p. 4-25), suggest rounding all analytical results to two significant figures (e.g., 110 ug/L) to better reflect accuracy/certainty of the measurements.

Parsons ES Response: *The accuracy of analytical results will be reported to no more than three significant figures to better reflect the accuracy/uncertainty of the measurements.*

Comment 3) Pages 2-1 and 2-5, Sec 2, Para 3, Sent 2: Appendix B, not A, should be referenced here.

Parsons ES Response: *The reference will be changed to Appendix B.*

Comment 4) Page 2-12, Sec 2.1.3.3: Suggest annotating the outside and inside diameter of the hollow stem augers.

Parsons ES Response: *The outside (8.25-inches) and inside (4.25-inches) diameters of the hollow stem augers will be annotated in Section 2.1.3.3.2, Installation.*

Comment 5) Pages 2-18 and 2-19, Sec 2.6:

a. Sent 2: Suggest inserting "Oklahoma state" in front of "plane."

b. Sent 3: Although the text states that horizontal locations were surveyed to the nearest 0.1 foot, northings and eastings in Appendix B, Table 2.2 are reported to the nearest 0.01 foot. This discrepancy should be resolved.

Parsons ES Response:

a. "Oklahoma State" will be inserted in front of "plane."

b. The text will be changed to indicate that the horizontal locations were surveyed to the nearest 0.01 foot.

Comment 6) Pages 3-1 and 3-3, Sec 3.1.2: Recommend adding a brief discussion of the method and equipment used to measure stream flow. Because stream flow was evidently measured as velocity (L/T), not discharge rate (L3/T), suggest in sentences four and five changing "flow" to "flow velocity" to enhance clarity. Suggest adding a range in discharge rate for Stinking Creek.

Parsons ES Response: *A brief discussion of the method used to measure stream flow velocity will be included in Section 3.1.2 and "velocity" will be inserted after "flow". The average flow velocity for Stinking Creek will be calculated and added to the text. Discharge rates can not be calculated because of insufficient field data. Therefore, discharge rates are not provided in the text.*

Comment 7) Page 3-5, Sec 3.3, Para 2: the stated base-wide horizontal gradient is notably flat. Based on Figure 3.3 and Section 3.3.2.1 (p. 3-7), the hydraulic gradient at the site along stinking creek is 0.003. Recommend, therefore, that the accuracy of the annotated base-wide gradient be verified.

Parsons ES Response: *The base-wide hydraulic gradient was checked using USGS data collected in 1993. The base-wide hydraulic gradient should be corrected to 0.0033 foot/foot. The text will be modified accordingly.*

Comment 8) Page 3-10, Sec 3.3.2.2, Sent 2:

a. Because these measured K values are high for clay and shale lithologies, K values were calculated using the slug test analysis graphs for wells OU-1-01 and WL061. Hand calculations yielded K values ranging from 4.8 to 8.2 ft/day and from 8.6 to 10. ft/day for OU-101 and WL061, respectively. Additionally, test data obtained electronically from Parsons for well OU-1-01 were input into AQTESOLV, Version 1.10.

   Results obtained using only early time data ranged from 4.0 to 6.9 ft/day. Early time data were used because the slug tests were essentially aquifer recovery tests and early time data are most reliable for calculating Ks from recovery test data.

b. The high end of the range in average K values, 52 ft/day, is not confirmed by slug test analysis results contained in Appendix B, the average K value for well WL061 is 43 ft/day, not 52 ft/day.

c. Suggest reporting K values to two significant figures to attain consistency in the number of significant figures used.

Parsons ES Response:

a. *Upon reviewing the slug testing data, Parsons ES selected curve fits that were representative of the formation response. Given that values of hydraulic conductivity (K) range over several magnitudes of order, the estimated K values are appropriate given the accuracy of the slug test method. Estimated results within the same order of magnitude are considered reasonable.*

Parsons ES agrees that the calculated K values appear to be high compared to literature values for clay and shale. However, the clay and shale horizons at OU-1 are highly weathered and are expected to have higher K values (wells OU-1-01, WL060, and WL061). Monitoring well WL062 is screened across clayey sand, for which the K value is within the range of reported literature values. Parsons ES believes use of the listed K values (Table 3.3) are suitable for conservative model input.

More importantly, the K values used in the model are representative of the lower range of estimated values from the field data and provide a reasonable calibration for the transport model. Values of K input in the groundwater flow model ranged from 0.1 ft/day to 30 ft/day, with the vast majority of cells being assigned a K of 0.1 ft/day to 1.0 ft/day. The distribution of K values equal to 30 ft/day is limited to a flow path along Stinking Creek. Parsons ES believes this is appropriate considering that fluvial deposits along the creek are expected to have a higher hydraulic conductivity than surrounding weathered clay and shale, and that the creek deposits represent a potential preferential flowpath. The distribution of K values used in the model will be shown on a printout included in Appendix D.

b. Table 3.3 will be corrected to indicate the hydraulic conductivity for well WL061 is 43 ft/day.

c. K values will be reported to two significant figures as suggested.

Comment 9) Page 3-12, Table 3.3: Assuming the current K values are erroneous, revised values for K and groundwater flow velocity will need to be tabulated here.

Parsons ES Response: *K values are considered reasonable, therefore, K values and groundwater flow velocities will not be revised (for rationale, see response to Comment 8a.).*

Comment 10) Page 3-13, Sec 3.3.2.4:

a. Assuming the current K values are excessively high, groundwater flow velocities will need to be revised downward.

b. Recommend reporting average groundwater velocities to two significant figures instead of four or five to better reflect accuracy/certainty of the measurements and to be consistent with the reporting convention for K values.

<u>*Parsons ES Response:*</u>

a. K'values are considered appropriate, therefore groundwater flow velocities will not be revised (for rationale, see response to Comment 8a.).

b. K values will be reported to two significant figures as recommended.

Comment 11) Page 4-2, Sec 4.1.2, Line 7: "stinking creek" should be "Stinking Creek."

<u>*Parsons ES Response:*</u> *The text will be changed as indicated.*

Comment 12) Page 4-10, Fig 4.2: The chemical compound designated "DCE Oxide" is more correctly named"1-chloro-1-ethoxide."

<u>*Parsons ES Response:*</u> *The text will be changed as indicated.*

Comment 13) Page 4-49, Sec 4.6, Table 4.7: To enhance clarity, suggest expanding the title by insert "CAH Degradation" in front of "Screening".

<u>*Parsons ES Response:*</u> *The title will be changed as indicated.*

Comment 14) Page 5-1, Sec 5.1, Para 2, Sent 2: For clarity, suggest inserting "steady-state" in front of "groundwater flow model."

<u>*Parsons ES Response:*</u> *The text will be changed as indicated.*

Comment 15) Page 5-8, Sec 5.3.2.2: Appendix E contains MODFLOW Recharge files, in spite of the statement here that recharge was not defined for the modeling effort. This apparent discrepancy should be resolved.

Parsons ES Response: *An overall rate of recharge was not specified for calibration of the flow model. However, recharge was specified in four model cells near the western boundary of LF-04 to simulate partitioning of CAHs to groundwater (Section 5.3.3.1). The specified rate of recharge for these four cells was low (0.065 inches per year), so there was minimal effect on the flow calibration.*

The text in Section 5.3.2.2 will be changed to "Therefore, no recharge or evapotranspiration was defined for the site, except for low rates of recharge at four cells located near the western boundary of LF-04 to help simulate partitioning of CAHs to groundwater (Section 5.3.3.1).

Comment 16) Page 5-8, ec 5.3.3, Line 6: "migrograms" should be "micrograms."

Parsons ES Response: *The text will be changed as indicated.*

.Comment 17) Page 5-12, Sec 5.4:

a. Suggest the text briefly explain why two sets of MODFLOW and MT3D input files are included in Appendix E.

b. Additionally, recommend explaining why the flow rate for the single well in MODFLOW file DPE.WEL is set to zero.

c. How was dual-phase extraction simulated in MODFLOW and MT3D?

Parsons ES Response:

a. The two sets of input and output files in Appendix E are for Alternative 1 and Alternative 2. Note that both alternatives are identical up to 1997 (model year 41), the date for model calibration, and only differ after that date. To avoid confusion, model input and output files for the calibration model will be added to Appendix E. The text will be expanded to indicate that MODFLOW and MT3D input files for the calibrated model, Alternative 1, and Alternative 2 are included in Appendix E.

b. The single well in MODFLOW file DPE.WEL was used to simulate groundwater extraction of a dual-phase extraction (DPE) system. The flow rate for the well is set to 0 gallons per minute (gal/min) for model year 41 to 42, 3 gal/min for model *year 42 to 43 (the simulated extraction period), and then set to 0 gal/min for the remainder of the model simulation. The text will be expanded to indicate how the DPE system was simulated as indicated in the following response.*

c. *DPE was simulated by two modifications to the calibrated model. First, groundwater extraction and the resulting change in groundwater flow was simulated by a single extraction well. This well pumped 3 gal/min for a one year period for model year 42 (1998). The pumping rate was based on a sustainable rate derived from DPE pilot test results (Radian, 1996). Secondly, immediately following the 1-year pumping period, the contaminant source terms were reduced by 90 percent to simulate the DPE source reduction (as described in Section 6.4.2.1). The remaining source mass was then degraded at 2 percent per year as in Alternative 1. This description of simulating the DPE system will be added to Section 6.4.2.1.*

Comment 18) Pages 5-12 and 5-14, Sec 5.4.1, Para 3: Given the measured K values most likely are about three to four times higher than actual K values and that that clayey sand probably does not possess Ks approaching 30 ft/day, suggest reducing maximum modeled K values to about 15 ft/day. This reduction would require recalibration of the MODFLOW and MT3D models.

<u>Parsons ES Response:</u> *The K values used in the model are representative of the estimated K values from the field data and provide a reasonable calibration for the transport model. Therefore, the maximum K value used in the model will not be reduced.*

Comment 19) Page 5-14, Sec 5.4.1, Para 3, Sent 2: Based on the MODFLOW input files provided in Appendix E, the MODFLOW-calculated hydrologic balance error is 1.37 percent, not zero as stated here. Suggest this 1.37 percent error be annotated here.

<u>Parsons ES Response:</u> *The text will be changed as indicated.*

Comment 20) Page 5-13, Fig 5.2: Recommend plotting residual (observed-calculated) head values for the 22 calibration wells. To reduce clutter, suggest deleting all other well and surface-water monitoring locations.

Parsons ES Response: *Residual head values will be listed and plotted for the 22 calibration wells and included in Appendix D. Other monitoring locations will be removed from Figure 5.2.*

Comment 21) Page 5-16, Fig 5.3: in the legend, should the concentration unit of measurement for CAHs be umol/L instead of ug/L?

Parsons ES Response: *The CAH concentration should be shown in umol/L. Figure 5.3 will be changed accordingly.*

Comment 22) Page 6-6, Sec 6.2.3.1, Para 1:

a. Sent 5: These K values should be reduced based on reanalysis of the slug-test data.

b. Sent 6: Assuming reanalysis of slug-test data results in much lower K values, this sentence can be deleted.

Parsons ES Response:

a. K values are considered appropriate (for rationale, see response to Comment 8a.).

c. The sentence will not be deleted.

Comment 23) Page 6-19, Sec 6.4.1.1, Para 3, Sent 1: The use of "geometric rate" infers a geometric progression. Reducing source strength by 2 percent yearly is no where near a decrease characterized by a geometric progression. Consequently, suggest deleting "geometric."

Parsons ES Response: *The text will be changed as suggested.*

Comment 24) Pages 7-4 and 7-5, Table 7.1: Suggest adding alkalinity because BTEX occurs in the contaminant plume and alkalinity is an analyte in Table 2.1 of *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Dissolved in Groundwater.* To more fully measure the impact of biodegradation processes on geochemistry of site groundwater, suggest that major cations also be added to the list of analytes.

Parsons ES Response: *Table 7.1 will be amended to include alkalinity. While analysis of major cations may be useful to note changes in general groundwater chemistry, they are not necessary to document biodegradation. To adhere to the objectives of the LTM plan and to minimize cost, Parsons ES does not recommend adding the major cations to Table 7.1.*

Comment 25) Page 9-1, Sec 9: The 1993 AFCEE Handbook has been reformatted and renamed the *Model Field Sampling Plan*. Version 1.1 (March 1997) should be referenced.

Parsons ES Response: *The reference will be changed as indicated.*

Comment 26) Appendix A-4: Recommend that slug-test data logger output (elapsed time vs. water level) be added in electronic format to Appendix B. This will provide supporting information for the time-drawdown graphs and allow independent evaluation of the pumping test data.

Parsons ES Response: *The slug test data logger output will be provided in electronic format with model input and output files in Appendix E.*

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 722450.16000

REFERENCES:

Air Force Center for Environmental Excellence (AFCEE), 1997, Model Field Sampling Plan, Version 1.10, March.

Radian International, LLC. (Radian), 1996, TPVE Technology Evaluation Report, Altus AFB, OK. December (Preliminary Draft).

APPENDIX H

FINAL REMEDIATION BY NATURAL ATTENUATION TREATABILITY STUDY ADDENDUM

FINAL
ADDENDUM TO THE TREATABILITY STUDY IN SUPPORT OF REMEDIATION BY NATURAL ATTENUATION FOR OPERABLE UNIT 1

at

ALTUS AIR FORCE BASE
OKLAHOMA

December 1999

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

and

ALTUS AIR FORCE BASE
OKLAHOMA

Prepared by:

Parsons Engineering Science, Inc.
1700 Broadway, Suite 900
Denver, Colorado 80290

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LIST OF ACRONYMS AND ABBREVIATIONS

1,2-DCB	1,2-dichlorobenzene
µg/L	micrograms per liter
AETC	Air Education Training Command
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
AMC	Air Mobility Command
bls	below land surface
BTEX	benzene, toluene, ethylbenzene, and xylenes
CAH	chlorinated aliphatic hydrocarbon
DCE	dichloroethene
DO	dissolved oxygen
Fe^{2+}	ferrous iron
Fe^{3+}	ferric iron
FT-03	Fire Training Area 3
FT-07	Fire Training Area 4
ft/day	feet per day
ft/ft	foot per foot
ft/yr	feet per year
LF-04	Landfill Number 4
LTM	long-term monitoring
MAC	Military Aircraft Command
mg/L	milligrams per liter
MTBE	methyl tert-butyl ether
mV	millivolts
N	nitrogen
NH_3	ammonia
NRMRL	National Risk Management Research Laboratory
ORP	oxidation-reduction potential
OU1	Operable Unit 1
Parsons ES	Parsons Engineering Science, Inc.
POL	petroleum, oil and lubricant
RNA	Remediation by Natural Attenuation
SAC	Strategic Air Command
TAC	Tactical Air Command
TCE	trichloroethene
TMBs	trimethylbenzenes
TOC	total organic carbon
TS	Treatability Study
USEPA	United States Environmental Protection Agency
USGS	United States Geologic Survey
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 Treatability Study (TS) in Support of Remediation by Natural Attenuation (RNA) for Operable Unit 1 (OU1), Altus Air Force Base (AFB), Oklahoma, (Parsons ES, 1999). 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 aliphatic hydrocarbons (CAHs, or chlorinated solvents).

1.1 Scope and Objectives

This addendum documents the effectiveness of natural attenuation at OU-1 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 April 1997 for the TS. The focus of this addendum is to evaluate changes in concentrations of CAHs, CAH plume extent, and natural attenuation mechanisms through time. Concentrations of fuel hydrocarbons including 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 are presented in Attachment A.

1.2 Site Background

Altus AFB occupies an area of over 2,500 acres in eastern Jackson County, Oklahoma. It is bordered by the city of Altus on the west, Highway 62 on the south, and agricultural land on the north and east. In 1942, Altus AFB became operational as an Air Force flight-training base, and was later turned over for use as a municipal airport after completion of the European phase of World War II (United States Geological Survey [USGS], 1996). Altus AFB was reactivated under the Tactical Air Command (TAC) in January 1953. Since then, Altus AFB has been transferred between:

The Strategic Air Command (SAC) (1953-1961),

The 577th Strategic Missile Squadron (1961-1965),

The Military Aircraft Command (MAC) (1968-1992),

The Air Mobility Command (AMC) (1992-1993), and

The Air Education Training Command (AETC) (1993).

Throughout this time, the Base generated waste material including garbage, wood, metal, paper, shop waste, construction debris, concrete, brush, and drums of paint waste. Landfill Number 4 (LF-04) received waste material from 1956 to 1983. From 1956 to 1965, the waste was commonly buried in trenches with an east-west orientation and depths ranging from 6 to 8 feet below land surface (bls). After 1965, the waste was buried 6 feet bls in trenches with a north-south orientation. Petroleum, oil, and lubricant (POL) sludge waste was buried 3 feet bls at the northern and northwestern edges of LF-04.

LF-04 is only one portion of OU-1. Other investigated sites within OU-1 include Fire Training Area 3 (FT-03), Fire Training Area 4 (FT-07), and the Skeet and Trap Range. Since these sites are located upgradient from LF-04, groundwater contamination potentially migrating toward LF-04 also was evaluated. The source of contamination at OU-1 is most likely associated with waste disposal activities at LF-04 and related activities at the other sites within OU-1. To date, no engineered remediation has been implemented at the site. Natural attenuation is the only process acting to reduce dissolved CAH concentrations and mass. Additional site information, including site background, geology, and hydrogeology, is available in the TS (Parsons ES, 1999).

2.0 MONITORING RESULTS

In April 1999 researchers from the USEPA NRMRL measured groundwater levels at 29 monitoring well/points, and collected 26 groundwater samples and 2 surface water samples. Monitoring wells/points OU-1-TW4, OU-1-TW6, OU-1-TW7, OU-1-TW9, OU-1-TW13, WL060, and SB15WS; and surface water sampling locations RV003, RV004, and RV005; were not sampled in April 1999. Samples were analyzed in the field for temperature, pH, conductivity, dissolved oxygen (DO), oxidation-reduction potential (ORP), alkalinity, hydrogen sulfide, and ferrous iron. Additional sample volumes were analyzed at the USEPA NRMRL in Ada, Oklahoma, for BTEX, trimethylbenzenes (TMBs), methyl tertiary-butyl ether (MTBE), CAHs, chlorobenzene, sulfate, chloride, nitrate+nitrite as nitrogen (N), ammonia (NH_3), methane, ethene, ethane, and total organic carbon (TOC). Analytical methods for April 1999 are summarized in Table 1, while field and laboratory analytical results are included in Attachment A.

2.1 Groundwater Flow Direction and Gradient

Groundwater elevation data are summarized in Table 2, and Figure 1 presents contoured groundwater elevation data for April 1997 and April 1999. In April 1999, the depth to groundwater in the immediate vicinity of LF-04 ranged from 8 to 12 feet bls. Groundwater levels in the vicinity of LF-04 in April 1999 were approximately 3 to 4 feet lower than in April 1997. The inferred flow direction was toward the east and southeast, with a possible convergent divide along Stinking Creek suggesting either discharge to the creek or a preferential groundwater flow pathway along the creek channel. The flow of groundwater toward Stinking Creek may be attributed to recharge from precipitation, which then discharges to the creek. It is also possible that groundwater flows parallel to the creek, or with the creek acting as a divergent divide, during more arid seasons. The horizontal hydraulic gradient was approximately 0.003 foot per foot (ft/ft) along the primary contaminant plume axis in 1999. The groundwater elevations, horizontal hydraulic gradient, and flow direction are similar to those observed in April 1997.

Using hydraulic conductivity of 8 to 52 feet per day (ft/day), a lateral hydraulic gradient of 0.003 ft/ft, and an estimated effective porosity of 0.05 for clay and 0.03 for shale, the

TABLE 1
SUMMARY OF GROUNDWATER ANALYTICAL METHODS
APRIL 1999
OU1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Analyte	Method	Field (F) or Fixed-Base Laboratory (L)
Oxidation-Reduction Potential	Direct Reading Meter	F
Dissolved Oxygen	Direct Reading Meter	F
Conductivity	Direct Reading Meter	F
Temperature	Direct Reading Meter	F
pH	Direct Reading Meter	F
Ferrous Iron (Fe^{2+})	Colorimetric, Hach Method 8146 or equivalent	F
Hydrogen Sulfide	Colorimetric, Hach Method 8131 or equivalent	F
Alkalinity (Carbonate [CO_3^{2-}] and Bicarbonate [HCO_3^-])	Titrimetric, Hach Method 8221 or equivalent	F
Nitrate + Nitrite	Lachat FIA Method 10-107-04-2-A	L
Ammonia	Lachat FIA Method 10-107-06-1	L
Chlorides	Waters Capillary Electrophoresis Method N-601	L
Sulfate	Waters Capillary Electrophoresis Method N-601	L
Methane, Ethane and Ethene	RSKSOP-175[a/] and RSKSOP-194	L
Total Organic Carbon	RSKSOP-102	L
BTEX, TMBs, and MTBE[b/]	RSKSOP-122	L
CAHs[c/] and Chlorobenzenes	RSKSOP-148	L

[a/] RSKSOP = Robert S. Kerr Laboratory (now known as NRMRL) standard operating procedure.

[b/] BTEX = benzene, toluene, ethylbenzene and xylenes; TMBs = trimethylbenzenes; MTBE = methyl tertiary-butyl ether.

[c/] CAHs = chlorinated aliphatic hydrocarbons.

TABLE 2
SUMMARY OF GROUNDWATER ELEVATIONS
OU-1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Location	Ground Surface Elevation (ft amsl)$^{a/}$	Top of Casing Elevation (ft asml)	April 1997		April 1999	
			Depth to Water (ft btoc)$^{b/}$	Water Elevation (ft amsl)	Depth to Water (ft btoc)	Water Elevation (ft amsl)
OU-1-01	1351.96	1354.50	5.29	1349.21	9.1	1345.40
OU-1-02	1352.10	1354.10	5.43	1348.67	9.3	1344.80
OU-1-03	1352.72	1355.04	5.84	1349.20	9.7	1345.34
OU-1-04	1352.22	1354.51	5.35	1349.16	9.2	1345.31
OU-1-05	1352.21	1354.43	7.95	1346.48	9.6	1344.83
OU-1-06	1348.00	1350.43	13.07	1337.36	8.4	1342.03
OU-1-TW1	1356.00	1355.81	11.01	1344.80	12.3	1343.51
OU-1-TW2	1348.00	1347.76	4.78	1342.98	5.8	1341.96
OU-1-TW3	1353.09	1352.80	9.69	1343.11	11.6	1341.20
OU-1-TW4	1346.62	1346.54	7.24	1339.30	DRY	NM$^{c/}$
OU1-TW5	1343.23	1342.89	4.00	1338.89	DRY	NM
OU-1-TW6.	1341.74	1341.33	3.29	1338.04	NM	NM
OU-1-TW7	1340.07	1339.53	3.02	1336.51	NM	NM
OU-1-TW8	1350.04	1349.78	3.16	1346.62	5.9	1343.88
OU-1-TW9	1352.97	1352.55	8.82	1343.73	NM	NM
OU-1-TW10	1342.80	1342.42	1.75	1340.67	4.0	1338.42
OU-1-TW11	1348.52	1348.18	10.50	1337.68	10.5	1337.68
OU-1-TW13	1342.34	1342.33	2.59	1339.74	NM	NM
OU-1-TW14	1342.52	1342.22	4.48	1337.74	5.9	1336.32
OU-1-TW15	1349.72	1349.51	2.21	1347.30	5.2	1344.31
000IU1-MW1D	NM	NM	NM	NM	16.1	NM

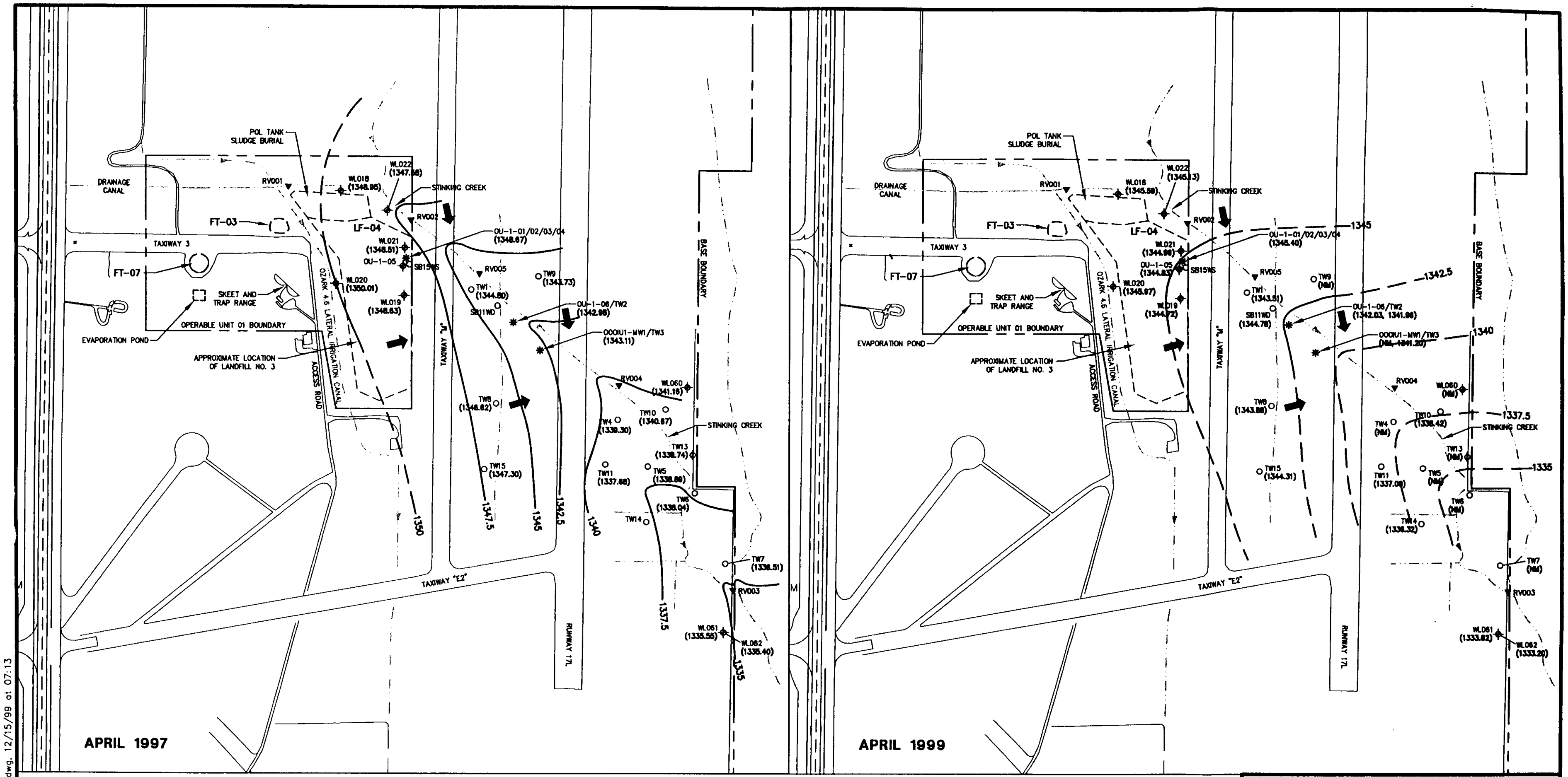
TABLE 2 (Concluded)
SUMMARY OF GROUNDWATER ELEVATIONS
OU-1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Location	Ground Surface Elevation (ft amsl)[a]	Top of Casing Elevation (ft asml)	April 1997 Depth to Water (ft btoc)[b]	April 1997 Water Elevation (ft amsl)	April 1999 Depth to Water (ft btoc)	April 1999 Water Elevation (ft amsl)
WL018	1353.52	1356.39	7.44	1348.95	10.8	1345.59
WL019	1353.48	1356.62	7.99	1348.63	11.9	1344.72
WL020	1359.48	1362.37	12.36	1350.01	16.4	1345.97
WL021	1351.35	1354.36	5.85	1348.51	9.4	1344.96
WL022	1351.23	1354.53	6.95	1347.58	9.4	1345.13
WL060S	1344.21	1346.81	5.65	1341.16	NM	NM
WL061D	1338.23	1340.92	5.37	1335.55	7.3	1333.62
WL062S	1338.26	1340.80	5.40	1335.40	7.6	1333.20
SB10WS	1355.64	1355.32	8.51	1346.81	NM	NM
SB10WD	1355.64	1355.27	9.16	1346.11	NM	NM
SB11WS	1351.88	1351.66	5.45	1346.21	6.9	1344.76
SB11WD	1351.88	1351.58	5.84	1345.74	6.8	1344.78
SB15WS	1355.11	1355.01	3.37	1351.64	NM	NM
SB15WD	1355.11	1355.01	4.14	1350.87	6.8	1348.21
SB16WS	1357.71	1357.52	8.85	1348.67	DRY	NM
SB16WD	1357.71	1357.42	8.95	1348.47	11.5	1345.92

[a] ft amsl = Feet above mean sea level.

[b] ft btoc = Feet below top of casing.

[c] NM = Not measured.



LEGEND

▼	SURFACE WATER SAMPLING LOCATION	- · - · -	SURFACE WATER
⌖	MONITORING WELL LOCATION	➡	GROUNDWATER FLOW DIRECTION
○	MONITORING POINT LOCATION	NM	NOT MEASURED
✳	WELL CLUSTER		

FIGURE 1

GROUNDWATER ELEVATION CONTOUR MAPS

OU1
RNA TS Addendum
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

advective groundwater flow velocity in the overburden clay was calculated to be 0.5 to 1.0 ft/day (180 to 360 feet per year [ft/yr]) in 1997 (Parsons ES, 1999). The advective groundwater flow velocity in the weathered shale is calculated to be 2.0 to 5.2 ft/day (730 to 1,900 ft/yr).

Vertical hydraulic gradients for April 1999 could only be estimated from three of the six well clusters used for previous calculations, as shown in Table 3. Gradients for well clusters SB10WS/D, SB15WS/D, and SB16WS/D could not be estimated in April 1999 because one (or both) of the well pairs was either not measured or was dry. The downward vertical gradient measured for well pair WL062/WL061 in April 1999 (-0.023 ft/t) was higher than that measured in April 1999 (-0.008). Well clusters SB11WS/D and OU-1-TW2/OU-1-06 exhibited downward gradients in April 1997, but displayed slight upward gradients in April 1999.

2.2 Dissolved BTEX Contamination

Results of dissolved fuel hydrocarbon compounds and MTBE in groundwater for April 1997 and 1999 at OU-1 are summarized in Table 4. Detection of fuel hydrocarbons in 1997 and 1999 include BTEX, 1,3,5-TMB, 1,2,4-TMB, and 1,2,3-TMB. MTBE was not detected in any groundwater sample collected in April 1999. Total fuel carbon was detected in 6 of 34 groundwater samples collected in April 1997 at concentrations ranging from 2.2 to 883 micrograms per liter (µg/L), but was not analyzed for in April 1999. Concentration isopleth maps for total BTEX in groundwater for April 1997 and April 1999 are presented on Figure 2.

Temporal and spatial changes in dissolved BTEX indicate that concentrations in the source area are decreasing. This is demonstrated by a decrease in total dissolved BTEX concentrations at wells OU-1-06, OU-1-TW1, and OU-1-TW2 from April 1997 to April 1999. BTEX concentrations decreased from 4.5 µg/L at OU-1-06, 24.4 µg/L at OU-1-TW1, and 43.0 µg/L at OU-1-TW2 in April 1997, to below detection at each location in April 1999. These wells are immediately downgradient from the source area. In addition, a comparison of the extent of the April 1999 BTEX plume to the extent of the April 1997 BTEX plume shown on Figure 2 shows a significant reduction.

Because of the limited occurrence and low concentrations of fuel hydrocarbons detected at the site in April 1999, natural attenuation of BTEX compounds is not analyzed further. However the presence of low levels of anthropogenic carbon (fuel hydrocarbons) within the general source area may impact biodegradation of CAHs (Section 3.0).

2.3 Dissolved Chlorinated Solvent Contamination

Concentrations of CAHs detected in groundwater samples collected since July 1989 are summarized in Table 5. Trichloroethene (TCE); dichloroethene (DCE) isomers 1,1-DCE, cis-1,2-DCE, and trans-1,2-DCE; and chloroform were detected in groundwater samples collected over the five sampling events. Distributions of TCE and cis-1,2-DCE are shown on Figures 3 and 4, respectively.

TABLE 3
VERTICAL GRADIENT CALCULATIONS
OU-1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Well	Groundwater Elevation (ft amsl[a/]) Apr-97	Groundwater Elevation (ft amsl[a/]) Apr-99	Bottom of Screen Elevation (ft amsl)	Top of Screen Elevation (ft amsl)	Saturated Screen Midpoint Elevation (ft amsl)	Apr-97 Vertical Gradient [b/] (ft/ft)	Apr-99 Vertical Gradient [b/] (ft/ft)
WL062	1335.40	1333.20	1319.7	1329.7	1324.7		
WL061	1335.55	1333.62	1303.6	1308.6	1306.1	-0.008 [c/]	-0.023
SB10WS	1346.81	NM	1343.6	1346.6	1345.1		
SB10WD	1346.11	NM	1334.6	1337.6	1336.1	0.078	NA
SB11WS	1346.21	1344.76	1340.1	1343.1	1341.6		
SB11WD	1345.74	1344.78	1331.9	1334.9	1333.4	0.057	-0.002
SB15WS	1351.64	NM	1348.1	1351.1	1349.6		
SB15WD	1350.87	1348.21	1336.8	1339.8	1338.3	0.068	NA
SB16WS	1348.67	DRY	1345.4	1348.4	1346.9		
SB16WD	1348.47	1345.92	1333.6	1336.6	1335.1	0.017	NA
OU-1-TW2	1342.98	1341.96	1333.8	1337.0	1335.4		
OU-1-06	1337.36	1342.03	1324.9	1329.9	1327.4	0.703	-0.009

a/ ft amsl = Feet above mean sea level.

b/ Vertical gradient =

$$\frac{\text{Difference in groundwater elevations of clustered wells}}{\text{Difference in elevations of midpoints of saturated portions of well screens}}$$

Calculations were completed using April 1997 monitoring well construction data.

c/ A negative value indicates upward gradient, and a positive value indicates downward gradient.

TABLE 4

FUEL HYDROCARBONS AND MTBE[a/] DETECTED IN GROUNDWATER AND SURFACE WATER

OU-1

RNA TS ADDENDUM

ALTUS AFB, OKLAHOMA

Sample Location	Date	MTBE (µg/L)[d/]	Total Fuel Carbon (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	Xylenes (µg/L)	BTEX[b/] (µg/L)	1,3,5-TMB[c/] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
OU-1-01	Apr-99	ND[e/]	NA[f/]	1.0	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	883	ND	1.4	ND	ND	1.4	ND	ND	ND
OU-1-02	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-03	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-04	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-05	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-06	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	84.7	ND	1.8	<1[g/]	2.7	4.5	ND	1.0	ND
OU-1-TW1	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	166	<1	7.8	2.6	14.0	24.4	1.1	4.5	<1
OU-1-TW2	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	239	1.1	16.9	4.1	20.9	43.0	1.1	4.3	1.0
OU-1-TW3	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU1-TW5	Apr-97	NA	7.6	ND	2.1	<1	2.8	4.9	ND	1.1	ND
OU-1-TW6	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-TW7	Apr-97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
OU-1-TW8	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-TW9	Apr-97	NA	NA	ND	<1	ND	ND	ND	ND	ND	ND

TABLE 4 (Continued)
FUEL HYDROCARBONS AND MTBE[a/] DETECTED IN GROUNDWATER AND SURFACE WATER
OU-1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Sample Location	Date	MTBE (µg/L)[d/]	Total Fuel Carbon (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	Xylenes (µg/L)	BTEX[b/] (µg/L)	1,3,5-TMB[c/] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
OU-1-TW10	Apr-97	NA	2.2	ND	2.5	ND	ND	2.5	ND	ND	ND
OU-1-TW13	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-TW14	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
OU-1-TW15	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
000IU1-MW1	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	NA	NA	NA
WL018	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL019	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL020	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL021	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL022	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	<1	ND	ND	ND	ND	ND	ND	ND
WL060	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
WL061	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND

TABLE 4 (Concluded)
FUEL HYDROCARBONS AND MTBE[a/] DETECTED IN GROUNDWATER AND SURFACE WATER
OU-1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Sample Location	Date	MTBE (µg/L)[d/]	Total Fuel Carbon (µg/L)	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	Xylenes (µg/L)	BTEX[b/] (µg/L)	1,3,5-TMB[c/] (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)
WL062	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
SB11WS	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
SB11WD	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
SB15WS	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
SB15WD	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
SB16WD	Apr-99	ND	NA	ND	<1	ND	ND	ND	ND	ND	ND
RV001	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
RV002	Apr-99	ND	NA	ND	ND	ND	ND	ND	ND	ND	ND
	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
RV003	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
RV004	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND
RV005	Apr-97	NA	NA	ND	ND	ND	ND	ND	ND	ND	ND

[a/] MTBE = Methyl tertiary-butyl ether.

[b/] BTEX = Benzene, toluene, ethylbenzene and xylenes.

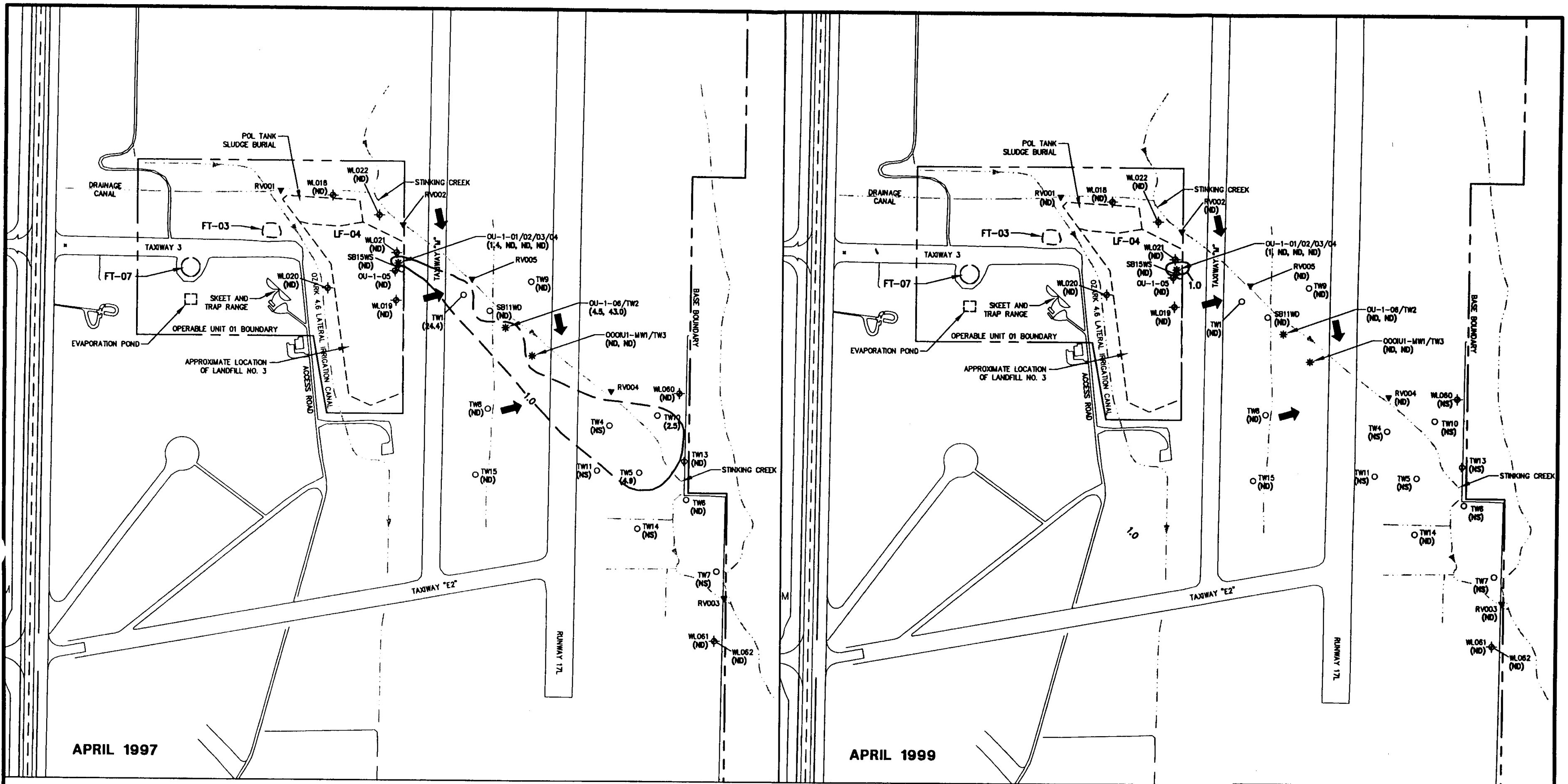
[c/] TMB = Trimethylbenzene.

[d/] µg/L = micrograms per Liter.

[e/] ND = Compound not detected.

[f/] NA = Not analyzed.

[g/] < 1 = Compound detected below limit of quantitation.



LEGEND

▼ SURFACE WATER SAMPLING LOCATION

⌖ MONITORING WELL LOCATION

○ MONITORING POINT LOCATION

✳ WELL CLUSTER

-·-·- SURFACE WATER

—1.0— LINE OF EQUAL BTEX CONCENTRATION (μg/L) (DASHED WHERE INFERRED)

(1.4) BTEX CONCENTRATION (μg/L)

(NS) NOT SAMPLED

(ND) NOT DETECTED AT OR ABOVE LABORATORY DETECTION LIMITS

➡ GROUNDWATER FLOW DIRECTION

FIGURE 2

DISTRIBUTION OF BTEX IN SHALLOW GROUNDWATER

OU1
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Altus AFB, Oklahoma

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Denver, Colorado

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TABLE 5
CHLORINATED ORGANIC COMPOUNDS DETECTED IN GROUNDWATER AND SURFACE WATER
OU1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Sample Location	Date	TCE (µg/L)$^{a/}$	*cis-1,2*-DCE (µg/L)	*trans-1,2*-DCE (µg/L)	1,1-DCE (µg/L)	1,2-DCB (µg/L)	Chloroform (µg/L)
OU-1-01	Apr-99	2,680	265	6.1	<1$^{b/}$	<1	<1
	Apr-97	8,910	1,340	33.3	4.3	ND$^{c/}$	<1
	Sep-96	11,900	1,680	51.0	6.18	NA	1.45
OU-1-02	Apr-99	6,110	590	12.0	1.9	<1	1.0
	Apr-97	11,400	1,130	19.2	3.8	ND	1.1
OU-1-03	Apr-99	4,200	378	6.3	1.2	<1	<1
	Apr-97	12,700	1,080	16.3	3.5	ND	1.9
OU-1-04	Apr-99	719	98.2	19.3	<1	<1	<1
	Apr-97	1,670	756	148	1.9	ND	ND
OU-1-05	Apr-99	495	46.2	<1	<1	ND	<1
	Apr-97	ND	63.2	1.1	<1	ND	ND
OU-1-06	Apr-99	187	16.2	2.8	<1	ND	ND
	Apr-97	360	37.9	8.1	<1	ND	<1
OU-1-TW1	Apr-99	48.3	247	66.0	1.7	<1	ND
	Apr-97	690	118	22.9	1.8	ND	ND
OU-1-TW2	Apr-99	716	61.9	14.3	1.1	ND	<1
	Apr-97	736	54.1	16.4	1.1	ND	ND
OU-1-TW3	Apr-99	61.0	17.3	13.4	<1	<1	ND
	Apr-97	347	28.7	20.0	2.1	ND	ND
OU-1-TW4	Apr-97	51.1	2.0	1.4	ND	ND	ND
OU1-TW5	Apr-99	<1	ND	ND	ND	ND	ND
	Apr-97	<1	<1	ND	ND	ND	ND
OU-1-TW6	Apr-97	ND	ND	ND	ND	<1	ND
OU-1-TW7	Apr-97	ND	ND	ND	ND	ND	<1
OU-1-TW8	Apr-99	290	1.7	<1	<1	<1	ND
	Apr-97	483	2.1	<1	<1	ND	<1
OU-1-TW9	Apr-97	<1	ND	ND	ND	ND	ND
OU-1-TW10	Apr-99	ND	ND	ND	ND	ND	ND
	Apr-97	ND	ND	ND	ND	ND	ND
OU-1-TW13	Apr-97	ND	ND	ND	ND	<1	ND
OU-1-TW14	Apr-99	<1	ND	ND	ND	ND	ND
	Apr-97	<1	ND	ND	ND	ND	ND
OU-1-TW15	Apr-99	5.5	ND	ND	ND	ND	ND
	Apr-97	13.6	<1	ND	ND	ND	ND
000IU-MW1	Apr-99	36.5	<1	ND	ND	<1	ND
	Apr-97	ND	ND	ND	ND	ND	ND

TABLE 5 (Continued)
CHLORINATED ORGANIC COMPOUNDS DETECTED IN GROUNDWATER AND SURFACE WATER
OU1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Sample Location	Date	TCE (µg/L)$^{a/}$	*cis-1,2*-DCE (µg/L)	*trans-1,2*-DCE (µg/L)	1,1-DCE (µg/L)	1,2-DCB (µg/L)	Chloroform (µg/L)
WL018	Apr-99	2.4	<1	ND	ND	<1	ND
	Apr-97	1.3	<1	ND	ND	<1	ND
	Sep-93	24	ND	ND	ND	NA	ND
	Feb-91	3.2	ND	ND	ND	NA	ND
	Jul-89	11	ND	ND	ND	NA	ND
WL019	Apr-99	974	14.3	<1	<1	<1	1.3
	Apr-97	224	207	27.4	1.0	<1	ND
	Sep-93	930	ND	ND	ND	NA	ND
	Feb-91	15	ND	ND	ND	NA	ND
	Jul-89	430	ND	ND	ND	NA	ND
WL020	Apr-99	<1	ND	ND	ND	<1	ND
	Apr-97	<1	ND	ND	ND	ND	ND
	Feb-91	3.9	ND	ND	ND	NA	ND
	Jul-89	1.9	ND	ND	ND	NA	ND
WL021	Apr-99	831	76.7	4.9	<1	<1	ND
	Apr-97	41.8	15.7	3.4	<1	ND	ND
	Sep-93	14	ND	ND	ND	NA	ND
	Feb-91	1.5	ND	11	ND	NA	ND
	Jul-89	25	ND	5.8	ND	NA	ND
WL022	Apr-99	1.4	2.0	ND	ND	<1	ND
	Apr-97	36.2	31.7	4.3	<1	ND	ND
	Sep-93	42	ND	ND	ND	NA	ND
	Feb-91	4.9	ND	0.80	ND	NA	ND
	Jul-89	0.72	ND	ND	ND	NA	ND
WL060	Apr-97	ND	ND	ND	ND	ND	ND
WL061	Apr-99	ND	ND	ND	ND	<1	ND
	Apr-97	ND	ND	ND	ND	ND	ND
WL062	Apr-99	2.8	ND	ND	ND	<1	ND
	Apr-97	3.2	ND	ND	ND	ND	ND
	Nov-93	ND	ND	ND	ND	NA	ND
SB11WS	Apr-99	228	28.9	5.8	ND	<1	<1
SB11WD	Apr-99	197	146	263	1.1	<1	ND
	Apr-97	457	31.8	6.8	<1	1.1	<1
SB15WS	Apr-97	3,520	444	23.7	1.9	ND	<1
SB15WD	Apr-99	629	60.0	6.3	<1	ND	<1
SB16WD	Apr-99	107	51.5	103	<1	ND	ND

TABLE 5 (Concluded)
CHLORINATED ORGANIC COMPOUNDS DETECTED IN GROUNDWATER AND SURFACE WATER
OU1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Sample Location	Date	TCE (µg/L)[a]	*cis-1,2*-DCE (µg/L)	*trans-1,2*-DCE (µg/L)	1,1-DCE (µg/L)	1,2-DCB (µg/L)	Chloroform (µg/L)
RV001	Apr-99	ND	<1	ND	ND	<1	ND
	Apr-97	ND	<1	ND	ND	ND	ND
	Jul-89	ND	ND	ND	ND	NA	ND
RV002	Apr-99	<1	<1	ND	ND	<1	ND
	Apr-97	<1	<1	ND	ND	ND	ND
	Jul-89	ND	ND	ND	ND	NA	ND
RV003	Apr-97	1.4	<1	ND	ND	ND	ND
RV004	Apr-97	2.8	<1	ND	ND	ND	ND
RV005	Apr-97	1.6	<1	ND	ND	ND	ND

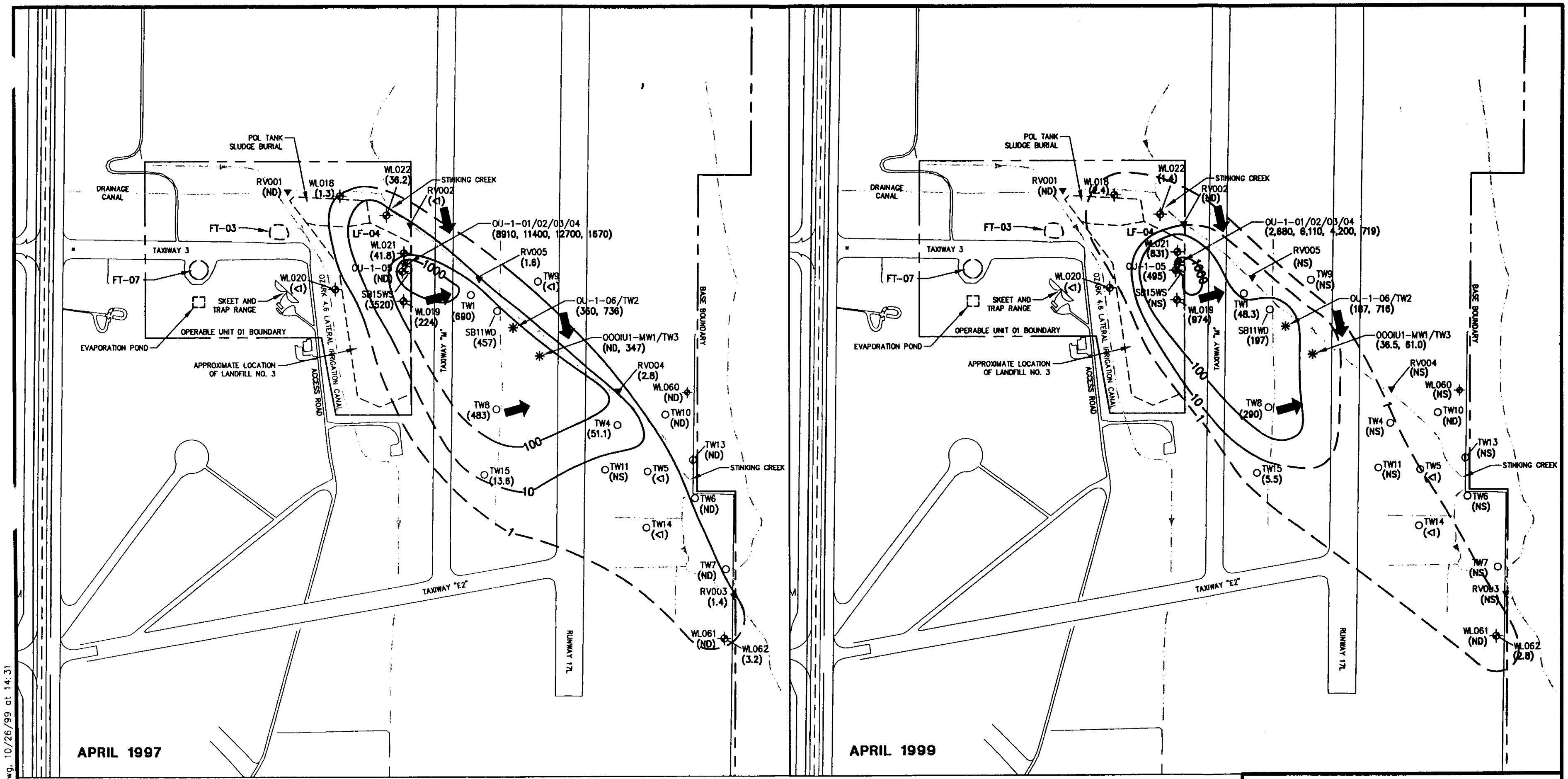
[a] µg/L = micrograms per liter.

[b] < 1 = Compound detected below limit of quantitation.

[c] ND = Compound not detected.

[d] NA = Compound not analyzed for.

Note: TCE = Trichloroethene; DCE = Dichloroethene; DCB = Dichlorobenzene.



LEGEND

▼	SURFACE WATER/SEDIMENT SAMPLING LOCATION	(13.6)	TCE CONCENTRATION (µg/L)
⌖	MONITORING WELL LOCATION	(NS)	NOT SAMPLED
○	MONITORING POINT LOCATION	(ND)	NOT DETECTED AT OR ABOVE LABORATORY DETECTION LIMITS
✳	WELL CLUSTER	➡	GROUNDWATER FLOW DIRECTION
- - -	SURFACE WATER		
—1—	LINE OF EQUAL TCE CONCENTRATION IN SHALLOW GROUNDWATER (µg/L) (DASHED WHERE INFERRED)		

N

0 400 800
FEET

FIGURE 3

DISTRIBUTION OF TCE IN SHALLOW GROUNDWATER AND SURFACE WATER

OU1
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Denver, Colorado

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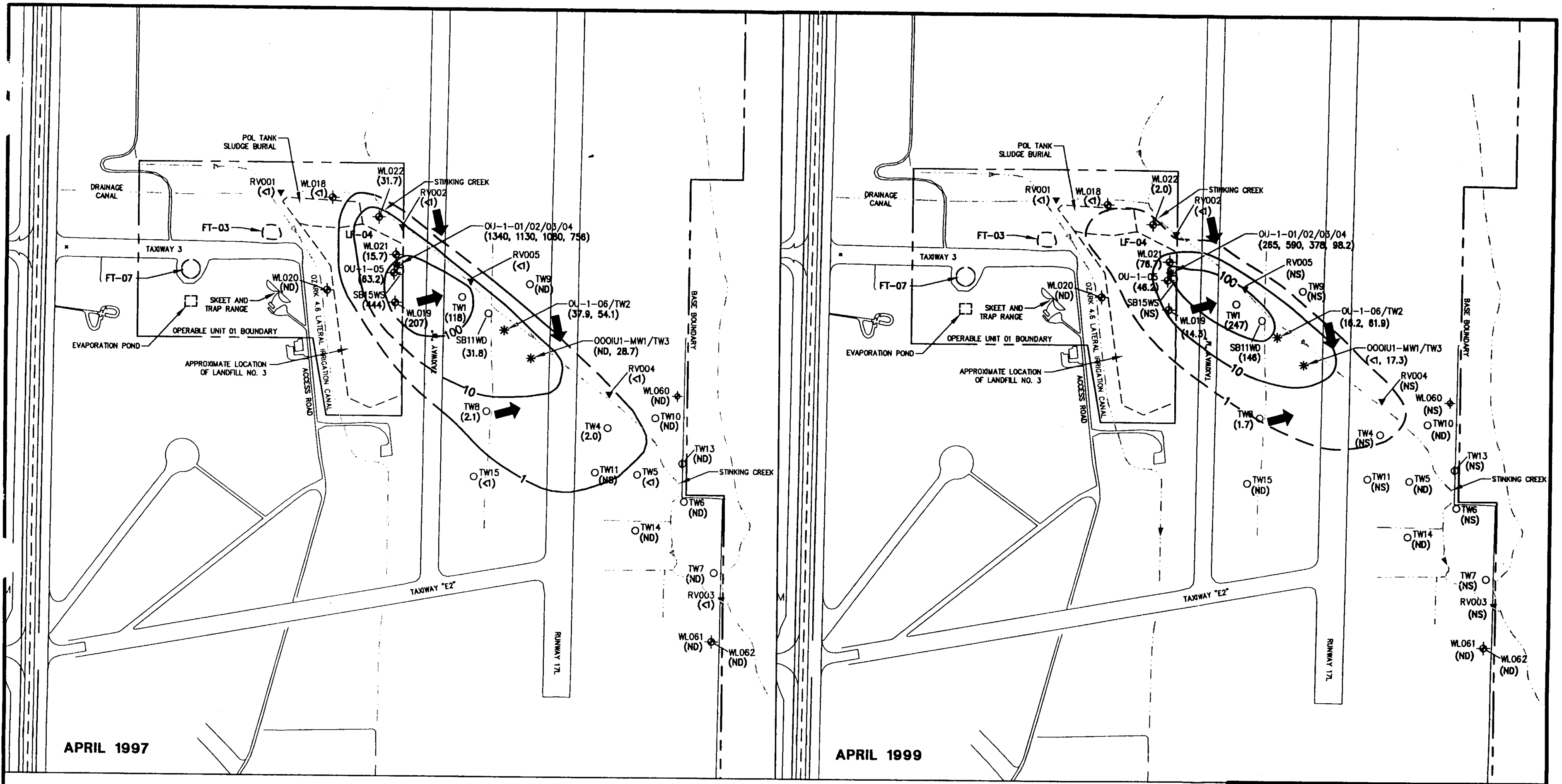


LEGEND

▼	SURFACE WATER/SEDIMENT SAMPLING LOCATION	(31.8)	CIS-1,2-DCE CONCENTRATION (µg/L)
⌖	MONITORING WELL LOCATION	(NS)	NOT SAMPLED
○	MONITORING POINT LOCATION	(ND)	NOT DETECTED AT OR ABOVE LABORATORY DETECTION LIMITS
✳	WELL CLUSTER	➡	GROUNDWATER FLOW DIRECTION
------	SURFACE WATER		
—1—	LINE OF EQUAL CIS-1,2-DCE CONCENTRATION IN SHALLOW GROUNDWATER (µg/L) (DASHED WHERE INFERRED)		

N

0 400 800
FEET

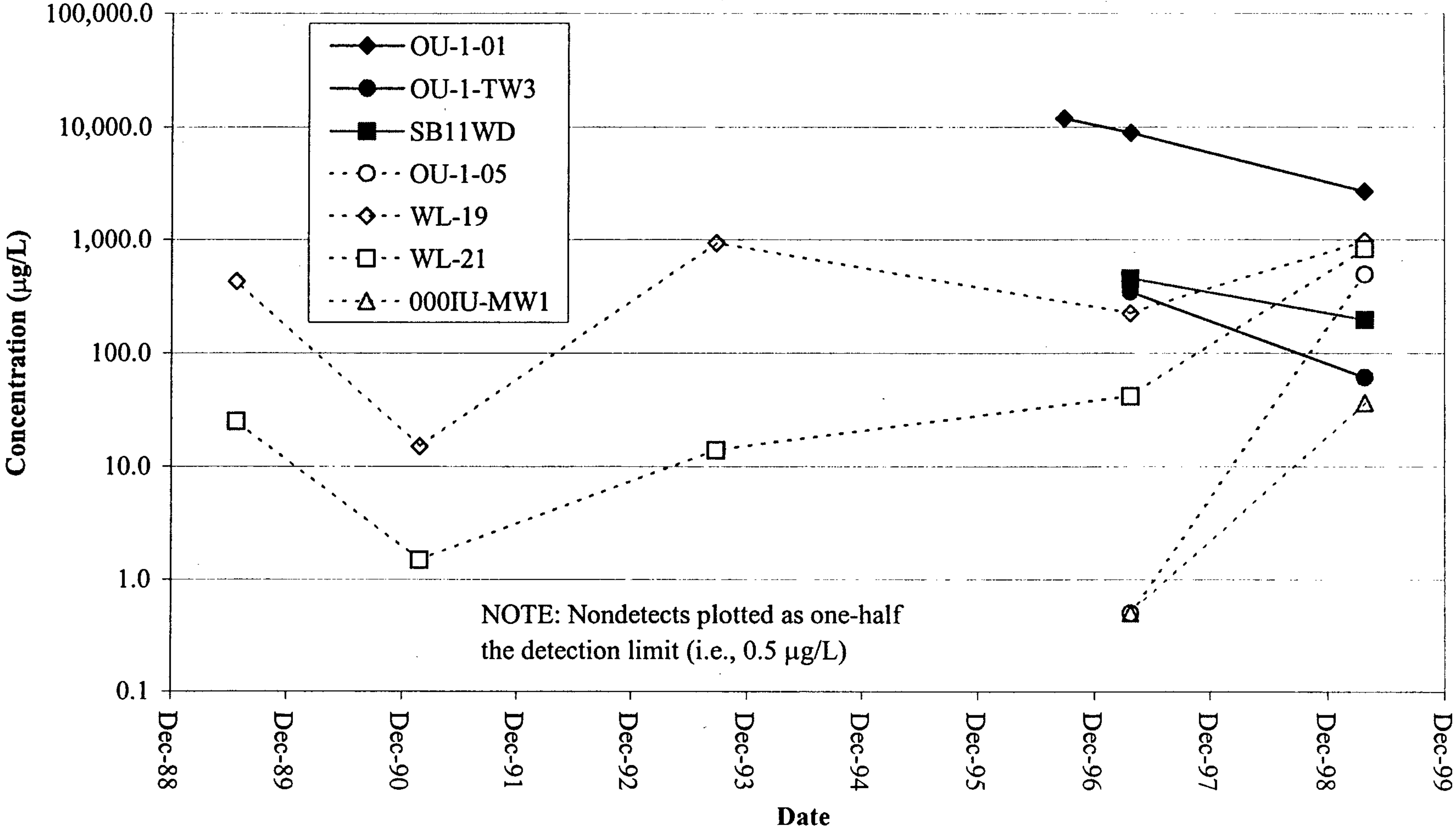
FIGURE 4

DISTRIBUTION OF CIS-1,2-DCE IN SHALLOW GROUNDWATER AND SURFACE WATER

OU1
RNA TS Addendum
Altus AFB, Oklahoma

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

FIGURE 5
CONCENTRATION VERSUS TIME FOR TCE
OU1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA



NOTE: Nondetects plotted as one-half the detection limit (i.e., 0.5 µg/L)

Concentrations of TCE in 13 of the 26 groundwater monitoring locations sampled in April 1999 have decreased since April 1997, while concentrations of TCE in 5 locations have increased. TCE remained below detection in another five locations, while three locations had not been sampled previously. TCE concentrations measured at surface water sampling locations RV001 and RV002 remained below laboratory detection limits in 1999.

Changes in TCE concentration over time for selected monitoring locations are shown on Figure 5. Monitoring locations that showed a significant increase in TCE concentrations from April 1997 to April 1999 include OU-1-05 (non-detect to 495 µg/L), WL019 (224 µg/L to 974 µg/L), WL021 (41.8 µg/L to 831 µg/L), and 000IU-MW1 (non-detect to 36.5 µg/L). Locations OU-1-05, WL-019, and WL021 are located in the general source area. Well OU1-05 is screened in a deeper groundwater interval indicating a downward vertical migration of the TCE plume at this location. Increases at shallow monitoring locations WL019 and WL021 is offset by significant decreases in TCE concentrations at adjacent shallow monitoring locations OU-1-01 (8,910 µg/L to 2,680 µg/L, Figure 6), OU-1-02 (11,400 µg/L to 6,110 µg/L), OU-1-03 (12,700 µg/L to 4,200 µg/L), and OU-1-04 (1,670 µg/L to 719 µg/L).

Downgradient from the source area, TCE concentrations decreased at all locations sampled in April 1997 and April 1999, with the exception of monitoring location 000IU-MW1. TCE increased from non-detect to 36.5 µg/L at 000IU-MW1, screened in a deeper groundwater interval. Conversely, TCE decreased (347 µg/L to 61.0 µg/L) in the shallow well (OU-1-TW3) paired with 000IU-MW1. This suggests a downward vertical migration of the TCE plume at this location. However, concentrations in other wells screened in deeper groundwater intervals in the downgradient portion of the TCE plume showed decreases in TCE concentrations (e.g., SB11WD, Figure 6), indicating vertical migration may be limited to localized areas within the downgradient TCE plume.

As shown on Figure 3, there is little change in the extent of the TCE plume from April 1997 to April 1999. The extent of the TCE plume appears to be stable and extends approximately the same length in 1999 as in 1997 (approximately 4,000 feet to WL062). However, some vertical expansion of the TCE plume has occurred in the source area (deep monitoring well OU-1-05), and at one downgradient location (deep well 000IU-MW1). Expansion of the TCE plume to the northeast may be limited by discharge to Stinking Creek because groundwater samples collected from monitoring locations northeast of Stinking Creek in April 1997 (WL060, TW10, and TW13) and April 1999 (TW10) did not contain detectable levels of TCE or other CAHs.

Isomers of DCE detected in April 1997 and 1999 groundwater samples include *cis*-1,2-DCE, *trans*-1,2-DCE, and 1,1-DCE. The DCE isomer detected most frequently and at the highest concentration was *cis*-1,2-DCE (1,340 µg/L at OU-1-01 in April 1997, and 590 µg/L at OU-1-02 in April 1999). The four locations with the highest concentrations of *cis*-1,2-DCE coincide with the highest TCE concentrations detected at well cluster OU-1-01, OU-1-02, OU-1-03, and OU-1-04. The size and shape of the April 1999 *cis*-1,2-DCE distribution is similar to the 1997 *cis*-1,2-DCE distribution indicating that the extent of this plume also is stable (Figure 4).

At all wells/points sampled in April 1999 and 1997, *trans*-1,2-DCE and 1,1-DCE were detected at concentrations significantly lower than *cis*-1,2-DCE (Table 5). This is expected if TCE is being degraded to DCE via reductive dechlorination, as *cis*-1,2-DCE is a more common daughter product of TCE biodegradation than the other DCE isomers (USEPA, 1998). Therefore, the presence of *cis*-1,2-DCE is a good indicator that degradation of TCE via reductive dechlorination is taking place in groundwater at LF-04.

2.4 Other Dissolved Chlorinated Hydrocarbon Contamination

Chloroform was the only other chlorinated organic compound detected in April 1999 at OU-1 (Table 5). Chloroform was detected in wells OU-1-02 and WL019 at low concentrations of 1.0 and 1.3 µg/L, respectively. 1,2-dichlorobenzene (1,2-DCB) was detected at low concentrations in 1997, but was not detected in 1999.

3.0 BIODEGRADATION OF CHLORINATED SOLVENTS

As discussed in the TS, 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 in OU-1 groundwater include anthropogenic carbon (i.e., fuel hydrocarbon compounds), and less chlorinated ethenes (i.e., DCE or vinyl chloride [VC]). Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states. Native electron acceptors include oxygen, nitrate, manganese, ferric iron, sulfate, and carbon dioxide. Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms typically use electron acceptors in the following order of preference: nitrate, manganese, ferric iron, sulfate, and finally carbon dioxide. Anaerobic destruction of the BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Bouwer, 1994; Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990). Under certain conditions, chlorinated ethenes also can be used as electron acceptors in microbially mediated redox reactions (reductive dechlorination).

As a part of the April 1999 sampling event, analyses were performed on groundwater samples to determine the concentrations of geochemical indicators of biodegradation. The results of these analyses are summarized in the following subsections.

3.1 Oxidation-Reduction Potential

Redox potential, a measure of the relative tendency of a solution to accept or transfer electrons, was measured for groundwater and surface water samples collected in 1997 and 1999 (Table 6). The dominant electron acceptor being reduced by microbes during BTEX oxidation is tied to the redox potential of the groundwater.

TABLE 6
GROUNDWATER GEOCHEMICAL DATA
OU-1
RNA TS ADDENDUM
ALTUS AFB, OKLAHOMA

Sample Location	Date	Temperature$^{a/}$ (°C)$^{d/}$	Dissolved Oxygen$^{a/}$ (mg/L)$^{e/}$	pH$^{a/}$	ORP$^{a/}$ (mV)$^{f/}$	Conductivity$^{b/}$ (µs/cm)$^{g/}$	Alkalinity$^{b/}$ (mg/L $CaCO_3$)$^{h/}$	Ferrous Iron$^{b/}$ (mg/L)	Chloride$^{c/}$ (mg/L)	Sulfate$^{c/}$ (mg/L)	Nitrate + Nitrite (mg/L)	Ammonia Nitrogen$^{c/}$ (mg/L)	Carbon Dioxide (mg/L)	TOC$^{c/}$ (mg/L)	Hydrogen Sulfide$^{b/}$ (mg/L)	Dissolved Hydrogen$^{b/}$ (nM/L)$^{j/}$	Ethene (mg/L)	Ethane (mg/L)	Methane$^{c/}$ (mg/L)
OU-1-01	Apr-99	15.6	0.9	6.9	236	4,730	360	0.1	310	1,890	1.01	<0.1	NA$^{k/}$	5.55	< 0.1	NA	ND$^{l/}$	ND	ND
	Apr-97	13.6	< 0.1	6.8	140	3,880	379	<0.05	330	1,780	<0.05	<0.05	210	4.19	NA	2.15	ND	ND	0.006
OU-1-02	Apr-99	14.9	0.9	6.8	276	4,160	360	< 0.1	288	1,750	0.28	<0.1	NA	2.62	< 0.1	NA	ND	ND	ND
	Apr-97	14.0	< 0.1	6.8	197	4,050	386	<0.05	341	1,690	<0.05	<0.05	420	3.10	NA	0.14	ND	ND	0.007
OU-1-03	Apr-99	15.2	0.4	6.9	273	4,440	300	< 0.1	337	2,010	1.60	<0.1	NA	1.96	< 0.1	NA	ND	ND	ND
	Apr-97	14.1	0.1	6.8	151	4,090	383	<0.05	384	1,780	<0.05	<0.05	262	45.8	NA	2.24	ND	ND	0.008
OU-1-04	Apr-99	15.8	0.9	6.8	260	4,760	380	< 0.1	340	2,110	0.50	<0.1	NA	2.28	< 0.1	NA	ND	ND	ND
	Apr-97	13.6	0.2	6.8	188	3,380	446	<0.05	207	1,440	0.17	<0.05	264	17.0	NA	1.12	ND	ND	0.002
OU-1-05	Apr-99	16.1	1.4	7.0	266	4,970	280	< 0.1	369	2,250	2.30	<0.1	NA	1.59	< 0.1	NA	ND	ND	ND
	Apr-97	16.6	0.3	8.1	201	4,620	220	<0.05	390	2,080	2.37	<0.05	100	1.44	NA	NA	ND	ND	0.001
OU-1-06	Apr-99	17.0	3.8	7.0	275	5,570	260	< 0.1	497	2,410	2.50	<0.1	NA	1.35	< 0.1	NA	ND	ND	ND
	Apr-97	17.5	1.3	NA	-25	7,060	NA	NA	657	3,050	1.00	<0.05	NA	2.53	NA	NA	ND	ND	0.005
OU-1-TW1(A	Apr-99	NA	NA	NA	NA	NA	NA	NA	381	2,200	0.73	<0.1	NA	4.20	<0.1	NA	NA	NA	NA
	Apr-97	18.5	4.1	6.9	165	4,610	320	<0.05	378	2,170	<0.05	<0.05	306	NA	NA	NA	ND	ND	0.058
OU-1-TW2	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Apr-97	18.3	3.3	NA	108	8,640	NA	NA	952	3,620	<0.05	<0.05	NA	NA	NA	NA	ND	ND	0.008
OU-1-TW3	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Apr-97	18.3	0.1	6.9	103	6,820	417	<0.05	699	2,880	<0.05	<0.05	320	2.48	NA	NA	ND	ND	0.021
OU-1-TW4	Apr-97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
OU1-TW5	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Apr-97	16.3	0.2	6.9	180	4,180	405	<0.05	579	1,460	0.37	<0.05	180	2.07	NA	NA	ND	ND	0.058
OU-1-TW6	Apr-97	15.3	0.9	7.2	131	3,400	325	<0.05	260	1,240	0.79	<0.05	264	29.8	NA	NA	ND	ND	<0.001
OU-1-TW7	Apr-97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
OU-1-TW8	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Apr-97	16.9	< 0.1	6.9	150	5,550	319	<0.05	724	1,920	0.99	<0.05	160	NA	NA	NA	ND	ND	0.011
OU-1-TW9	Apr-97	21.0	2.4	6.9	33	2,670	408	<0.05	230	680	7.80	<0.05	160	14.2	NA	NA	ND	ND	0.001
OU-1-TW10	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Apr-97	18.2	4.3	6.9	140	3,720	504	<0.05	417	1,150	2.29	<0.05	NA	1.06	NA	NA	ND	ND	ND
OU-1-TW13	Apr-97	15.0	0.1	7.1	63	4,300	320	<0.05	400	1,580	1.42	<0.05	128	1.55	NA	NA	ND	ND	ND
OU-1-TW14	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Apr-97	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
OU-1-TW15	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Apr-97	16.6	0.5	7.0	220	5,530	205	<0.05	687	2,160	2.23	<0.05	80	0.290	NA	NA	ND	ND	ND
000IU-MW1	Apr-99	18.2	0.9	7.0	249	4,920	200	< 0.1	541	1,880	3.01	<0.1	NA	1.42	< 0.1	NA	ND	ND	ND
	Apr-97	NA	NA	NA	NA	NA	210	NA	1500	5,300	19	NA	NA	52	NA	NA	NA	NA	NA

TABLE 6 (Concluded)
GROUNDWATER GEOCHEMICAL DATA
OU-1
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Sample Location	Date	Temperature[a] (°C) [d]	Dissolved Oxygen[a] (mg/L)[e]	pH[a]	ORP[a] (mV)[f]	Conductivity[b] (µs/cm)[g]	Alkalinity[b] (mg/L $CaCO_3$)[h]	Ferrous Iron[b] (mg/L)	Chloride[c] (mg/L)	Sulfate[c] (mg/L)	Nitrate + Nitrite (mg/L)	Ammonia Nitrogen[c] (mg/L)	Carbon Dioxide (mg/L)	TOC[c] (mg/L)	Hydrogen Sulfide[b] (mg/L)	Dissolved Hydrogen[b] (nM/L) [j]	Ethene (mg/L)	Ethane (mg/L)	Methane[c] (mg/L)
WL018	Apr-99	16.5	1.1	6.8	241	3,780	300	< 0.1	389	1,360	1.89	<0.1	NA	1.81	< 0.1	NA	ND	ND	ND
	Apr-97	14.6	0.4	7.0	165	3,800	283	<0.05	384	1,500	0.72	<0.05	184	16.1	NA	0.16	ND	ND	<0.001
WL019	Apr-99	16.8	0.8	6.9	232	4,770	300	0.1	342	2,120	1.24	<0.1	NA	2.09	< 0.1	NA	ND	ND	ND
	Apr-97	14.8	< 0.1	6.8	192	4,130	418	<0.05	320	1,900	<0.05	<0.05	212	3.56	NA	0.38	ND	ND	0.037
WL020	Apr-99	16.4	1.1	7.0	273	2,800	240	< 0.1	269	924	0.87	<0.1	NA	1.87	< 0.1	NA	ND	ND	ND
	Apr-97	16.3	3.6	7.0	158	3,000	250	<0.05	321	1,070	0.45	<0.05	114	15.7	NA	0.35	ND	ND	ND
WL021	Apr-99	14.8	0.7	6.7	264	4,170	440	0.1	298	1,600	0.17	<0.1	NA	3.28	< 0.1	NA	ND	ND	ND
	Apr-97	12.9	0.0	6.8	174	4,080	415	<0.05	341	2,010	<0.05	<0.05	402	3.67	NA	0.42	ND	ND	0.001
WL022	Apr-99	16.4	1.3	6.9	225	3,820	280	< 0.1	322	1,400	3.52	<0.1	NA	0.98	< 0.1	NA	ND	ND	ND
	Apr-97	13.3	< 0.1	7.0	-179	4,930	422	<0.05	398	2,180	0.37	<0.05	344	8.35	<0.1	0.66	ND	ND	0.078
WL060	Apr-97	14.4	0.3	7.1	136	4,800	311	<0.05	537	2,010	4.11	<0.05	120	1.18	NA	0.66	ND	ND	0.001
WL061	Apr-99	16.4	1.1	7.1	168	5,920	180	0.2	726	2,160	2.80	<0.1	NA	0.95	< 0.1	NA	ND	ND	ND
	Apr-97	16.4	1.2	7.1	151	5,700	157	<0.05	811	2,340	1.50	<0.05	82	0.33	NA	0.29	ND	ND	ND
WL062	Apr-99	14.9	0.3	7.0	242	6,370	260	< 0.1	730	2,450	3.53	<0.1	NA	1.33	< 0.1	NA	ND	ND	ND
	Apr-97	13.7	< 0.1	7.0	140	6,100	272	<0.05	830	2,480	1.41	<0.05	240	1.04	NA	0.19	ND	ND	ND
SB11WS	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SB11WD	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Apr-97	17.1	1.9	6.9	76	5,280	256	<0.05	517	2,230	1.41	<0.05	204	6.30	NA	NS	ND	ND	ND
SB15WS	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Apr-97	12.2	0.4	6.9	151	3,810	332	<0.05	406	1,820	<0.05	<0.05	256	3.90	NA	0.27	ND	ND	0.001
SB15WD	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
SB16WD	Apr-99	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RV-001	Apr-99	18.0	10.4	7.6	224	3530	260	0.1	270	1,400	< 0.1	<0.1	NA	2.91	< 0.1	NA	ND	ND	ND
RV-002	Apr-99	19.8	9.2	7.7	258	3,680	300	0.1	285	1,480	< 0.1	<0.1	NA	3.76	< 0.1	NA	ND	ND	ND

[a] Analysis performed at the well head by Parsons ES and USEPA personnel.
[b] Analysis performed in field laboratory by USEPA.
[c] Analysis performed at NRMRL.
[d] °C = degrees celsius.
[e] mg/L = milligrams per liter.
[f] mV = millivolts.
[g] µs/cm = microsiemens per centimeter.
[h] mg/L $CaCO^3$ = milligrams per liter calcium carbonate.
[i] ppm = parts per million.
[j] nM/L = nanomoles per liter
[k] NA = sample not analyzed for this parameter.
[l] ND = None detected.

Redox potentials measured in April 1997 at OU-1 range from –179 to 220 millivolts (mv), while redox potentials measured in April 1999 range from 168 mV to 276 mV. In every instance where redox potential was measured in both 1997 and 1999, the redox potential increased significantly. While 1999 redox potentials indicate a less reducing groundwater environment, the data are considered suspect.

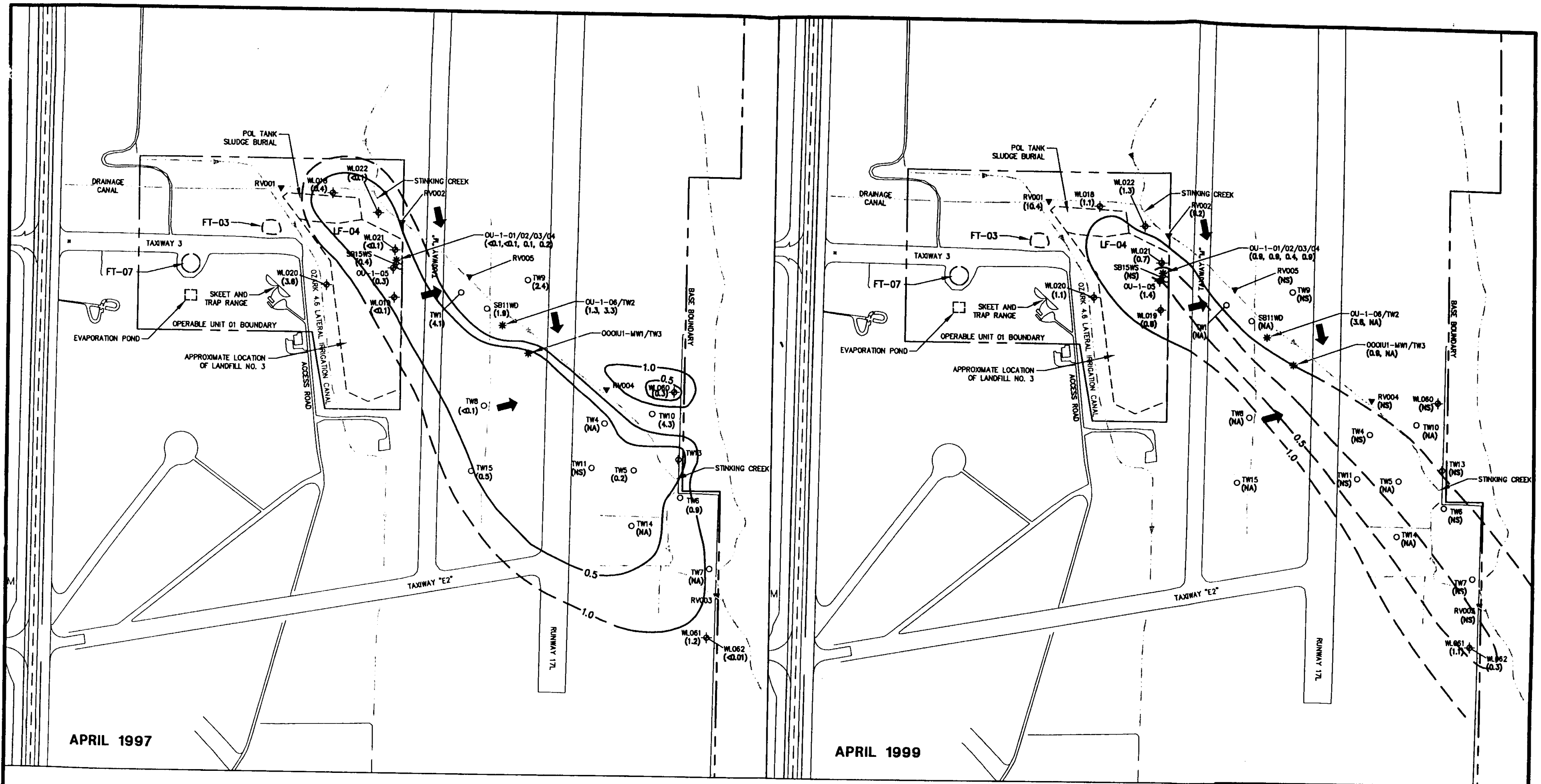
Measured site values are higher than the theoretical optimum level for sulfate reduction and methanogenesis (Norris *et al.*, 1994), this discrepancy is a common problem associated with measuring oxidizing potential using field instruments. It is likely that the platinum electrode probes are not sensitive to some of the redox couples (e.g., sulfate/sulfide). Many authors have noted that field redox potential data alone cannot be used to reliably predict the electron acceptors that may be operating at a site (Stumm and Morgan, 1981; Godsey, 1994; Lovley *et al.*, 1994). Groundwater data collected at OU-1 suggest that both sulfate reduction and methanogenesis are occurring in certain areas of the contaminant plume even though the measured redox potential range would exclude both processes.

Areas at the site with low redox potentials continue to coincide with areas characterized by elevated TCE concentrations; low DO, nitrate, and sulfate concentrations; and elevated ferrous iron and methane concentrations. This suggests that dissolved TCE at the site is undergoing a variety of biodegradation processes, including aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis. The same relationships between redox potential and electron acceptor/byproduct concentrations were noted during the April 1997 sampling event.

3.2 Dissolved Oxygen

DO concentrations in groundwater are used to evaluate whether aerobic respiration of organic carbon is occurring. Generally, DO concentrations above 1.0 milligrams per liter (mg/L) indicate sufficient DO to support aerobic respiration (AFCEE Technical Protocol, 1995 and USEPA, 1998). Table 6 summarizes DO concentrations measured at groundwater monitoring wells/points and surface water sampling locations. Groundwater DO concentrations ranged from less than 0.1 mg/L to 4.3 mg/L in April 1997, and ranged from 0.3 mg/L to 3.8 mg/L in April 1999. Figure 6 presents isopleth maps of groundwater DO at the site in April 1997 and April 1999. DO concentrations measured in April 1999 are similar to those measured in April 1997. However, the April 1999 DO distribution appears to be more elongated and narrower than in April 1997. Several downgradient and crossgradient wells were not sampled in April 1999 which may affect isopleth construction for the 1999 sampling event.

Comparison of Figures 2, 3 and 5 illustrates that the core areas of the BTEX and TCE plumes at OU-1 continue to be depleted of dissolved oxygen (i.e., anaerobic). The correlation between depleted DO and elevated BTEX is a strong indication that aerobic biodegradation of BTEX or other organic compounds has occurred, and continues to occur at the site. This is beneficial for the biodegradation of TCE and *cis*-1,2-DCE by producing a reducing groundwater environment that may be suitable for reductive dechlorination.



LEGEND

▼	SURFACE WATER SAMPLING LOCATION
⌖	MONITORING WELL LOCATION
○	MONITORING POINT LOCATION
✳	WELL CLUSTER
‐ · ‐ ·	SURFACE WATER
—1.0—	LINE OF EQUAL DISSOLVED OXYGEN CONCENTRATION (mg/L) (DASHED WHERE INFERRED)
(0.9)	DISSOLVED OXYGEN CONCENTRATION (mg/L)
(NA)	NOT AVAILABLE
(NS)	NOT SAMPLED
(ND)	NOT DETECTED AT OR ABOVE LABORATORY DETECTION LIMITS
➡	GROUNDWATER FLOW DIRECTION

FIGURE 6

DISSOLVED OXYGEN
IN GROUNDWATER

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3.3 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.

Concentrations of nitrate+nitrite (as N) were detected in all of the 15 monitoring wells/point groundwater samples analyzed for nitrate+nitrite in April 1999. Nitrate+nitrite results for groundwater samples collected in April 1997 and April 1999 and are presented in Table 6 and contoured on Figure 7. Nitrate+nitrite within the BTEX and TCE plumes was depleted (<1 mg/L) in April 1997. This suggests that denitrification was a significant process for the degradation of fuel hydrocarbons in 1997.

For April 1999 data, the average nitrate + nitrite concentration for well locations within the TCE plume (as defined by the 10 µg/L contour for TCE, Figure 3) was 1.2 µg/L, while the average nitrate + nitrite concentration outside the TCE plume was 2.6 µg/L. Therefore, while April 1999 data showed an increase in nitrate+nitrite concentrations within the TCE plume, the average nitrate + nitrite concentration within the TCE plume was still less than one-half of the average TCE concentration outside the plume. With the continued degradation and depletion of fuel hydrocarbons observed in 1999, denitrification may be limited by the availability of an organic substrate. Nitrate also may compete with TCE and *cis*-1,2-DCE as an electron acceptor under reducing conditions.

3.4 Ferrous Iron

Dissolved ferrous iron (Fe^{+2}) is the reduced form of iron and is a byproduct of ferric iron (Fe^{+3}) reduction. Increases in dissolved ferrous iron concentrations therefore indicate iron reduction is occurring as a result of biodegradation. Ferrous iron was detected in 6 of the 16 locations sampled and analyzed for ferrous iron during the April 1999 sampling event. Results are summarized in Table 6. Increases in ferrous iron concentrations were observed, ranging up to 0.2 mg/L. However, the limited occurrence and low concentrations of ferrous iron indicate that microbial biodegradation via iron reduction is not an important process at the site.

3.5 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 ORP reaction is commonly called sulfate reduction, which results in a decrease in groundwater sulfate concentrations.

Sulfate concentrations were detected in all of the groundwater and surface water samples collected in 1999 and are summarized in Table 6. Sulfate concentrations exceeding 20 mg/L were measured in April 1999 and April 1997 at all wells and surface water locations sampled. Groundwater samples collected in April 1999 from wells located within the CAH plume showed increases from April 1997 sulfate concentrations, while wells located

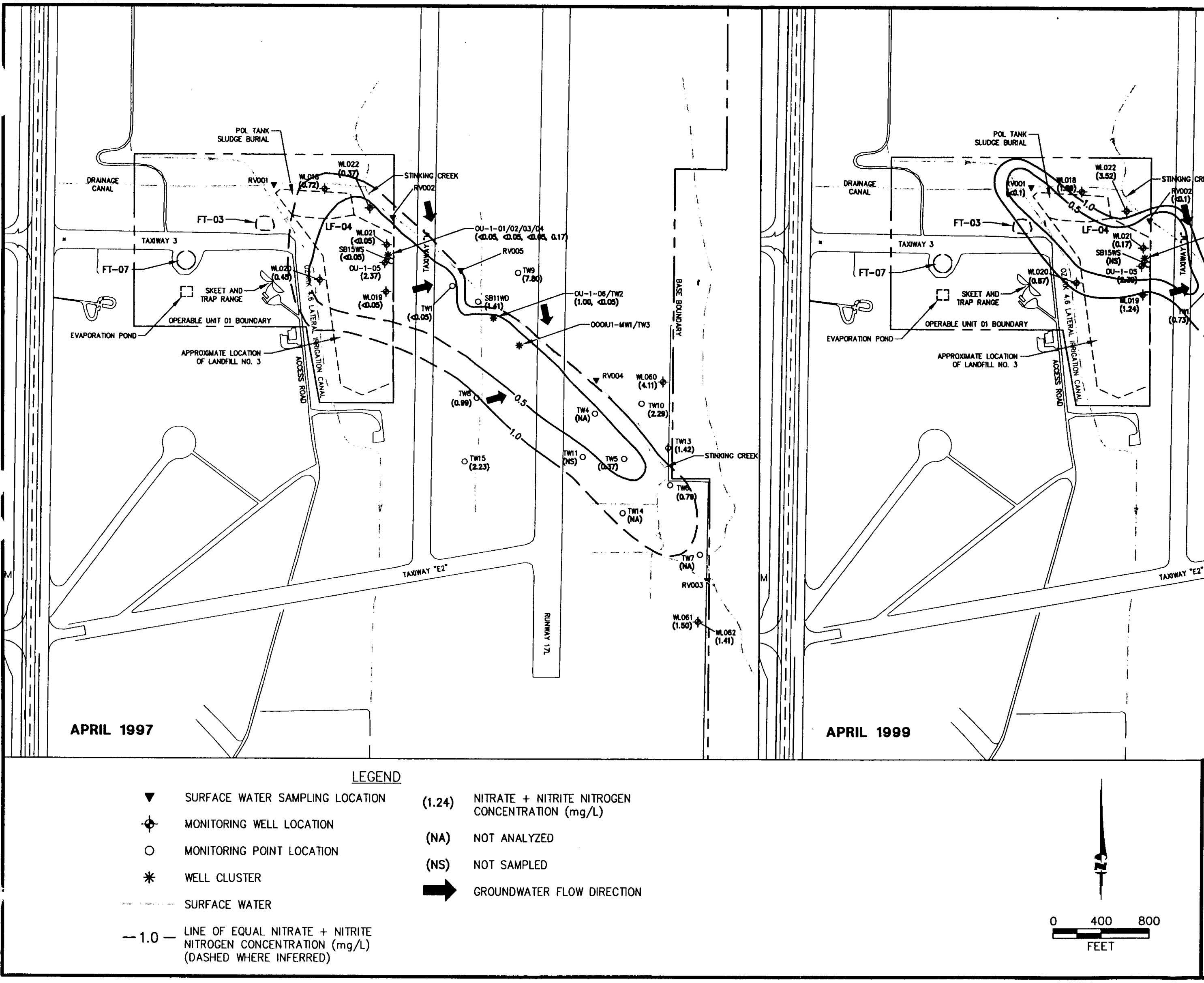

FIGURE 7

NITRATE + NITRITE AS NITROGEN IN GROUNDWATER

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downgradient showed decreases in sulfate concentrations. For April 1999 data, the average sulfate concentration within the CAH plume (as defined by the 10 µg/L TCE contour, Figure 3) was 1,660 µg/L, while outside of the plume the average sulfate concentration was 2,040 µg/L. Therefore, no correlation between elevated CAH concentrations and depleted sulfate exists. This likely is a result of a lack of anthropogenic carbon for use as an electron donor. This also indicates that the use of CAHs as electron acceptors under sulfate-reducing conditions may be inhibited due to the preferential use of sulfate.

3.6 Methanogenesis

Under highly reducing conditions, carbon dioxide is utilized as an electron acceptor, producing methane (methanogenesis). Methane, ethene and ethane concentrations were not detected in any of the groundwater or surface water samples collected in April 1999. Results are summarized in Table 6 and presented on Figure 8. Ethane and ethene also were not detected in April 1997.

Methane concentrations ranged from less than the detection limit of 0.001 mg/L to 0.078 mg/L in April 1997 (Table 6). The area of elevated methane concentrations in April 1997 coincides with the BTEX (Figure 2) and TCE (Figure 3) source area, indicating highly reducing conditions in response to degradation of petroleum hydrocarbons or native organic matter, as well as potential reductive dechlorination of TCE. However, this degree of reducing conditions are not reflected in the April 1999 methane data, indicating a change to less reducing conditions.

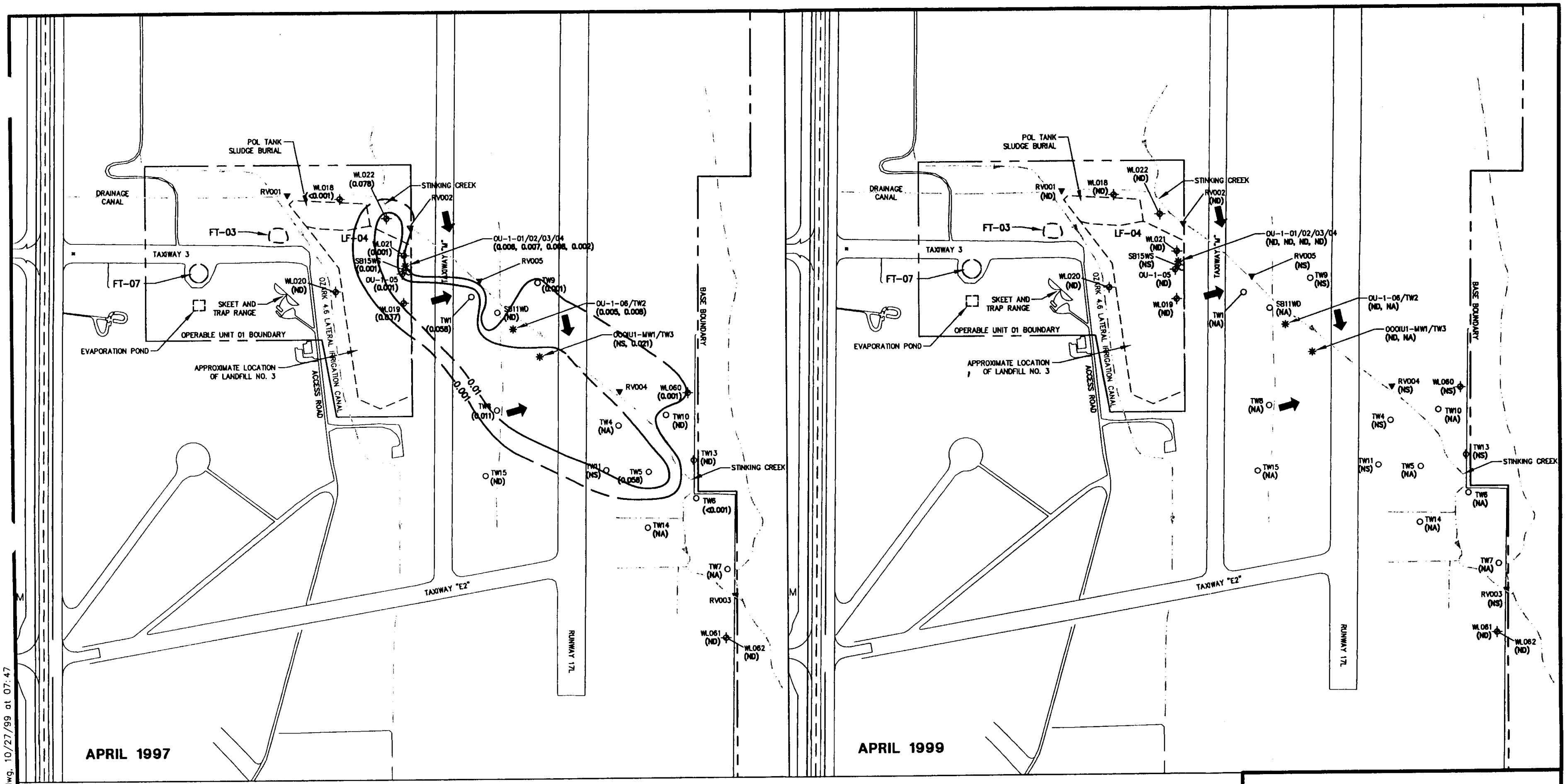
3.7 Ammonia/Ammonium

The presence of ammonia in groundwater can result from nitrate reduction (facilitated by microorganisms), fixing of atmospheric nitrogen (also a microbial process), or anthropogenic sources such as land application of fertilizer. Fixation of nitrogen normally occurs only under reducing conditions (ORP less than -500 mV [Stumm and Morgan, 1981]). Ammonia was not detected in any groundwater samples analyzed in April 1999 or April 1997 (Table 6).

3.8 Alkalinity

Total alkalinity (as calcium carbonate) is a measure of the ability of water to buffer changes in pH. Both aerobic and anaerobic biodegradation of BTEX produces carbon dioxide which, when mixed with water in the proper conditions, produces carbonic acid. In aquifers that have carbonate minerals as part of the matrix, carbonic acid dissolves these minerals, increasing the alkalinity of the groundwater. Therefore an increase in alkalinity can be observed in areas of active biodegradation of BTEX.

Alkalinity was measured in April 1999 at concentrations ranging from 180 mg/L to 440 mg/L. These results are summarized in Table 6. Alkalinity decreased in all of the groundwater samples between 1997 and 1999 (Table 6). In addition, the 1999 data indicate a significant reduction in BTEX concentrations and BTEX plume extent at OU-1, which suggests that alkalinity is sufficient to continue buffering the groundwater pH against future effects of biologically mediated oxidation reactions.



LEGEND

▼	SURFACE WATER SAMPLING LOCATION	(0.002)	METHANE CONCENTRATION (mg/L)
⌖	MONITORING WELL LOCATION	(ND)	NOT DETECTED AT OR ABOVE LABORATORY DETECTION LIMIT
○	MONITORING POINT LOCATION	(NA)	NOT ANALYZED
✳	WELL CLUSTER	(NS)	NOT SAMPLED
‐ · ‐	SURFACE WATER	➡	GROUNDWATER FLOW DIRECTION
—0.01—	LINE OF EQUAL METHANE CONCENTRATION (mg/L) (DASHED WHERE INFERRED)		

N

0 400 800
FEET

FIGURE 8

DISTRIBUTION OF METHANE IN GROUNDWATER

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3.9 Chloride

Chloride is removed from CAHs during reductive dechlorination and enters solution. Therefore, chloride concentrations in groundwater should increase above background levels within the plume, where degradation is occurring. Chloride concentrations are presented in Table 6 and shown on Figure 9. The highest chloride concentrations (>500 mg/L) were detected within the downgradient portion of the plume in April 1997 and April 1999 (Figure 9). Background chloride concentrations ranged from 321 mg/L (WL020) to 384 mg/L (WL018) in April 1997, and from 269 mg/L (WL020) to 389 mg/L (WL018) in April 1999. Analytical data therefore indicate that elevated chloride is present downgradient of the TCE source area. Elevated chloride concentrations may be a byproduct of reductive dechlorination where the chloride migrates ahead of the TCE plume due to its conservative nature (i.e., non-degraded and unretarded relative to TCE).

3.10 Summary of Biodegradation of Chlorinated Solvents

Several lines of chemical and geochemical evidence indicate that, although dissolved TCE at OU-1 is undergoing biologically facilitated reductive dechlorination and exhibits Type 1 behavior, the occurrence of this process is limited. The evidence supporting this is summarized below:

- The presence of TCE biodegradation metabolites that were not used in Base operations, particularly *cis*-1,2-DCE, is a direct indication that TCE is being reductively dechlorinated in the general source area.
- DO, ORP, and dissolved hydrogen data (Table 6 and Parsons ES, 1999) indicate that the groundwater environment is anaerobic, but not optimally reducing, in the source area and central portion of the TCE plume. This is conducive to only moderate rates of reductive dechlorination.
- The presence of elevated chloride concentrations in the southeastern (downgradient) portion of the TCE plume during both sampling events, indicates that biodegradation reactions are occurring in the source area and central portion of the TCE plume, and that chloride is migrating in the direction of groundwater flow.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The April 1999 TCE and *cis*-1,2-DCE plumes appear to be stable with little change in the extent of TCE and *cis*-1,2-DCE, although some vertical expansion was observed. The contaminant plume also shows indications of less reducing conditions in 1999 with an increase in nitrate concentrations, an increase in redox potential, and a decrease in methane concentrations. It is not clear whether any of these conditions are related to a 3 to 4 foot drop in groundwater levels from April 1997 to April 1999.

The chlorinated solvent plume at OU-1 exhibits conditions of anaerobic reductive dechlorination, where the primary source of biologically available organic carbon is anthropogenic fuel hydrocarbons (BTEX). Typical of these conditions is a decrease in

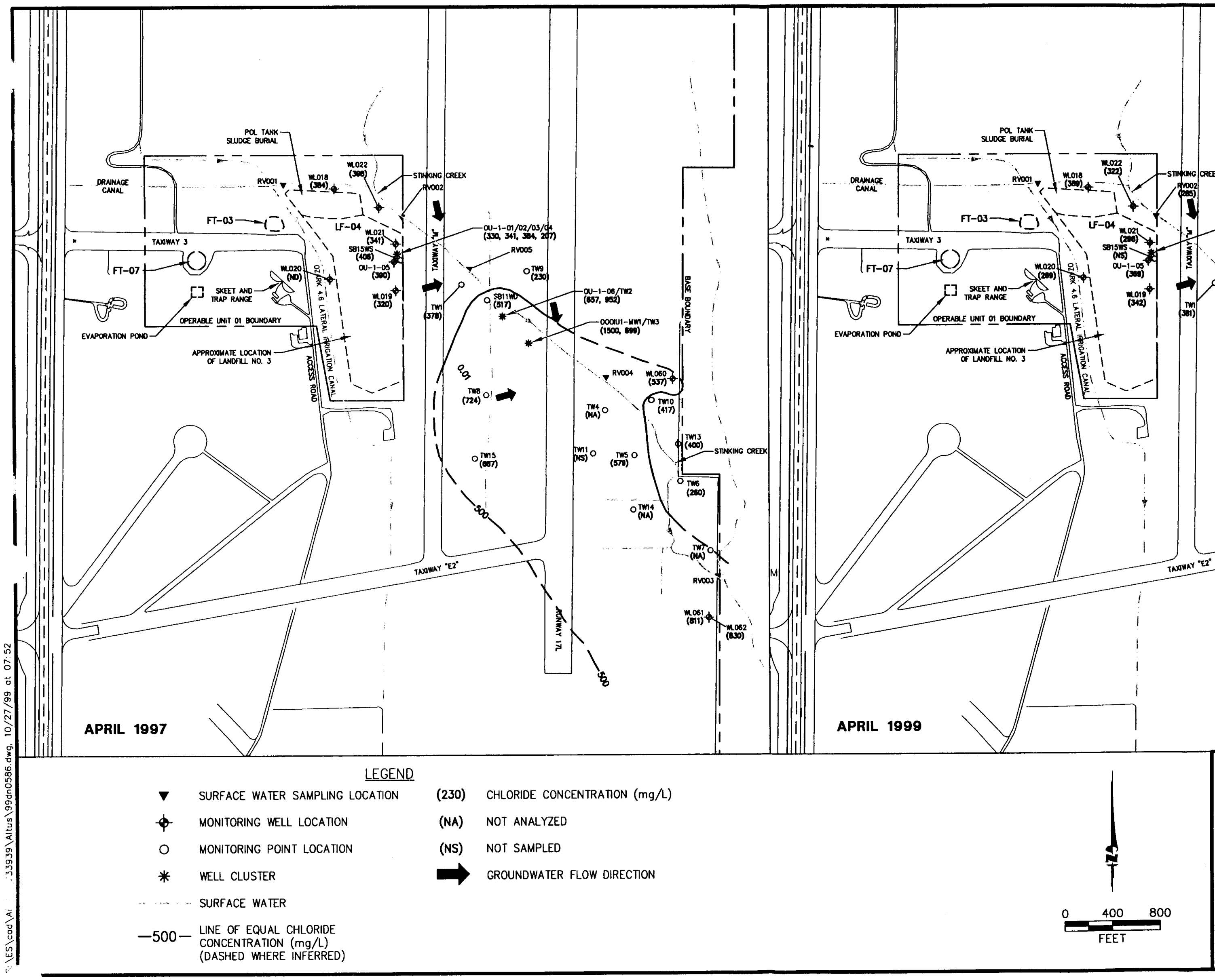

FIGURE 9

DISTRIBUTION OF CHLORIDE IN GROUNDWATER

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concentrations of TCE, an increase in *cis*-1,2-DCE, and eventually the accumulation of VC. Some of these characteristics are observed at the OU-1 site. Much of the TCE has been effectively degraded to *cis*-1,2-DCE by reductive dechlorination. The lack of VC in groundwater at OU-1 indicates that reductive dechlorination is not proceeding past the initial step that involves the transformation of TCE to DCE. Within the source area, VC would be expected to accumulate because the anaerobic degradation rate of VC is slow relative to TCE and *cis*-1,2-DCE. Because VC is not observed, further reductive dechlorination of DCE does not appear to occur at the site. The stability of the *cis*-1,2-DCE plume suggests that *cis*-1,2-DCE may degrade by aerobic oxidation or cometabolism (which do not produce VC) further downgradient under more aerobic conditions.

Observed BTEX and CAH plume behavior has not exceeded the conservative predictions made using the numerical and analytical models developed in the TS report (Parsons ES, 1997). BTEX was only detected at one well location in April 1999 (OU-1-01 at a concentration of 1 μg/L), indicating that BTEX has been effectively degraded. Model predictions suggested that without source reduction, significant migration of the CAH plume could occur with potential migration to Stinking Creek and the Base boundary. Given the observed rate of CAH plume migration, and considering that there are no impacted receptors at or downgradient from the site; natural attenuation, institutional controls, and continued LTM are recommended as the remedial option for CAH- impacted groundwater at the site. LTM should follow the suggested plan included in the TS (parsons ES, 1999). However, if significant migration of the CAH plume occurs, or reducing the remedial time-frame becomes desirable, engineered source reduction (dual-phase extraction) might be considered, as discussed in the TS.

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ATTACHMENT A

ANALYTICAL DATA

MEMORANDUM

MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP.
Environmental Science

In reply refer to: 99/JAD29
Contract # 68-c-98-138

To: Dr. Don Kampbell

Thru: Dr. Dennis Fine

From: John Daniel JAD

Subject: SF-0-70

Date: May 20, 1999

Copies: R.L Cosby
G.B. Smith
J. L. Seeley

As requested in Service Request # SF-0-70, headspace GC/MS analysis of 27 water samples from Altus AFB for chlorinated volatile organic compounds was completed. The samples were received April 19, 1999 and analyzed on May 13-14, 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 tables 1-2.

If you should have any questions, please feel free to contact me.

ManTech Environmental Research Services Corporation
R.S. Kerr Environmental Research Center, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 580-436-8660 FAX 580-436-8501

Table I. Quantitative Report for S.R. # SF-0-70 from Altus AFB.

Date received = 4/19/99

Originator = D.Kampbell
Concentration ppb

Date analyzed = 5/13-14/99

Compound Sample Name:	MW-1	TW-1A	RV-001	RV-002	RV-002 Field Dup	WL018	WL019	WL020	WL021	WL022
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	1.7	ND	ND	ND	ND	—	ND	—	ND
T-1,2-DICHLOROETHENE	ND	66.0	ND	ND	ND	ND	—	ND	4.9	ND
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	—	247	—	—	—	—	14.3	ND	76.7	ND
CHLOROFORM	ND	ND	ND	ND	ND	ND	1.3	ND	ND	2.0
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	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	36.5	48.3	ND	—	—	2.4	974	—	831	1.4
TETRACHLOROETHENE	ND	ND	ND	ND	ND	ND	—	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	—	—	—	—	ND	—	—	—	—	—
1,4-DICHLOROBENZENE	—	—	—	—	ND	—	—	—	—	—
1,2-DICHLOROBENZENE	—	—	—	—	ND	—	—	—	—	—

	WL061	WL061 Lab Dup	WL062	OU-1-01	OU-1-01 Field Dup	OU-1-02	OU-1-03	OU-1-04	OU-1-05	OU-1-06
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	ND	ND	ND	—	—	1.9	1.2	—	—	—
T-1,2-DICHLOROETHENE	ND	ND	ND	6.1	6.4	12.0	6.3	19.3	—	2.8
1,1-DICHLOROETHANE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
C-1,2-DICHLOROETHENE	ND	ND	ND	265	277	590	378	98.2	46.2	16.2
CHLOROFORM	ND	ND	ND	—	1.0	1.0	—	—	—	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	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	ND	ND	2.8	2680	2510	6110	4200	719	495	187
TETRACHLOROETHENE	ND	ND	ND	—	—	ND	—	—	—	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	—	—	—	ND	ND	—	ND	—	ND	ND
1,4-DICHLOROBENZENE	—	—	—	ND	ND	—	ND	ND	ND	ND
1,2-DICHLOROBENZENE	—	—	—	—	ND	—	—	—	ND	ND

	SB-11WD	SB-11WS	SB15D	SB15D Lab Dup	SB16D	TW-2	TW-3	TW-5	TW-8	TW-10
VINYL CHLORIDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,1-DICHLOROETHENE	1.1	ND	—	ND	—	1.1	—	ND	—	ND
T-1,2-DICHLOROETHENE	263	5.8	6.3	6.5	103	14.3	13.4	ND	—	ND
1,1-DICHLOROETHANE	—	ND	ND	ND	ND	—	ND	ND	—	ND
C-1,2-DICHLOROETHENE	146	28.9	60.0	56.6	51.5	61.9	17.3	ND	1.7	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	ND	ND	ND	ND	ND	ND	ND	ND
TRICHLOROETHENE	197	228	629	617	107	716	61.0	—	290	ND
TETRACHLOROETHENE	ND	ND	—	—	ND	ND	ND	ND	ND	ND
CHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,3-DICHLOROBENZENE	ND	—	ND	ND	ND	ND	—	ND	ND	ND
1,4-DICHLOROBENZENE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,2-DICHLOROBENZENE	—	ND	ND	ND	ND	ND	—	ND	—	ND

—* = Below Calibration limit(1.0 ppb) ND = None Detected Dup = Duplicate

Printer: 11 24 AM 5/20/1999

Table 2. Quantitative R[illegible] S.. 3F-0-70 from Altus AFB.

Date received = 4/19/99

Originator = D.Kampbell
Concentration ppb

Date analyzed = 5/13-14/99

	TW-14	TW-15	TW-15 Lab Dup	QC0513A 40 ppb	QC0513B 200 ppb	QC0513C 20 ppb	QC0513D 200 ppb	QC0513E 200 ppb	QC0514A 20 ppb	BL0513A
VINYL CHLORIDE	ND	ND	ND	31.2*	141*	14.7*	137*	149*	21.8	ND
1,1-DICHLOROETHENE	ND	ND	ND	42.5	211	24.0	220	228	22.8	ND
T-1,2-DICHLOROETHENE	ND	ND	ND	40.3	199	19.4	218	217	21.3	ND
1,1-DICHLOROETHANE	ND	ND	ND	36.9	208	19.5	215	214	NI	ND
C-1,2-DICHLOROETHENE	ND	ND	ND	41.3	199	22.3	226	220	21.5	ND
CHLOROFORM	ND	ND	ND	37.3	180	20.6	212	202	NI	ND
1,1,1-TRICHLOROETHANE	ND	ND	ND	37.7	189	21.9	204	213	NI	ND
CARBON TETRACHLORIDE	ND	ND	ND	38.6	214	21.1	199	212	NI	ND
1,2-DICHLOROETHANE	ND	ND	ND	40.9	182	22.0	207	205	NI	ND
TRICHLOROETHENE	—	5.5	5.4	39.7	197	19.9	195	193	19.6	ND
TETRACHLOROETHENE	ND	ND	ND	41.9	184	20.2	190	203	22.4	ND
CHLOROBENZENE	ND	ND	ND	41.8	208	22.2	225	228	NI	ND
1,3-DICHLOROBENZENE	ND	ND	ND	42.6	196	22.2	210	219	NI	ND
1,4-DICHLOROBENZENE	ND	ND	ND	42.2	198	21.9	211	216	NI	ND
1,2-DICHLOROBENZENE	ND	ND	ND	48.5	199	22.5	228	236	NI	ND

— = Below Calibration Limit(1.0 ppb ND = None Detected Dup = Duplicate QC = Quality Control Std BL = Blank NI = Not included in QC.
* = Vinyl Chloride is ~25 % low in QCs. A different standard was run at the end and Vinyl chloride was acceptable.

MANAGEMENT
TECHNOLOGY

MEMORANDUM
MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP.
Environmental Sciences

In reply refer to: 99-MB15

To: Dr. Don Kampbell

From: Mark Blankenship MB

THRU: Dr. Dennis Fine DFine

Date: April 21, 1999

Copies: R.L. Cosby
G.B. Smith
J.L. Seeley JS

Please find attached the analytical results for Service Request SF-0-70 requesting the analysis of Altus AFB, OK ground water samples to be analyzed for BTEXXX, TMB's and MTBE. The samples were collected April 14, 1999, April 15, 1999 and April 16, 1999. I received a total of 26 samples, in duplicate, in capped, 40 mL VOA vials on April 19, 1999. Samples were analyzed April 19 and April 20, 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.

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 4/21/99 SF-0-70 ALTUS AFB, OK

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
20 PPB QA\QC STD	18.9	18.1	18.9	19.1	19.5	19.5	19.2	20.5	20.2	18.5
10 PPB STD	9.3	9.5	9.5	10.3	9.7	9.8	9.5	10.2	9.8	9.6
GC LAB BLANK	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-1A	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-8	BLQ	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-14	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TW-15	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
MW-1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
RV001	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
RV001 LAB DUPLICATE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
10 PPB STD	9.2	8.9	8.8	9.7	9.1	9.1	9.0	9.8	9.5	9.2
RV002	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SB-11WD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SB-11WS	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SB-15D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
SB-16D	ND	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
WL-18	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-19	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-20	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1 PPB STD	0.9	0.9	0.9	1.0	0.9	0.9	1.0	1.0	0.9	1.0
WL-21	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-22	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-61	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
WL-62	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-01	ND	1.0	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-03	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
OU-1-06	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
20 PPB QA\QC STD	18.4	18.3	18.4	18.8	19.3	19.6	18.7	20.1	20.1	18.0

ND = [illegible] Detected; BLQ = Below Limit of Quantitation, 1ppb   Samples Collectec [illegible] '99, 4/15/99 and 4/16/99   Analyzed 4/19/ [illegible] D 4/20/99

MANAGEMENT
TECHNOLOGY

MEMORANDUM
MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP
Environmental Science

In reply refer to : 99-SH39
Contract #68-C-99-138

To: Dr. Don Kampbell   From: Sharon Hightower

Thru: Dennis Fine

Subject: SF-0-70   Date: April 20, 1999

Copies: R.L. Cosby
G.B. Smith
J.L. Seeley
L.K. Pennington LKP

Attached are TOC results for 17 Altus samples submitted April 19, 1999 under Service Request #SF-0-70. Sample analysis was begun April 20, 1999 and completed April 20, 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.

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Center, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 580-436-8660 FAX 580-436-8501

KAMPBELL ALTUS LIQUIDS SF-0-70
SAMPLES RECEIVED 4/19/99
SAMPLES ANALYZED 4/20/99 BY SHARON HIGHTOWER

SAMPLE	MG/L DOC
MW-1, 4/15	1.42
MW-1A, 4/15	4.20
RV001, 4/14	2.91
RV002, 4/14	3.76
WL-018, 4/14	1.81
WL-019, 4/15	2.09
WL-0-20, 4/15	1.87
WL-0-21, 4/14	3.28
WL-22, 4/14	.976
WL-0-61, 4/16	.945
DUP	.954
WP40	24.3
WL-062, 4/16	1.33
OU-1-01, 4/15	5.55
OU-1-2, 4/15	2.62
OU-1-3, 4/15	1.96
OU-1-04, 4/15	2.28
OU-1-05, 4/15	1.59
OU-1-06, 4/15	1.35
5 MG/L	4.95
WP40	24.2
BLANK	<.4

WP40 std. t.v.=24.0 +/- 2.40

MANAGEMENT
TECHNOLOGY

MEMORANDUM

MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP.
Environmental Science

In reply refer to: 99-31LP/lp
Contract # 68-C-98-138

To: Dr. Don Kampbell

Thru: D.D. Fine DFine

From: Lynda Pennington LKP

Subject: SR # SF-0-70

Ref:

Copies: R.L. Cosby
G.B. Smith
J.L. Seeley

Date: April 20, 1999

Attached are inorganic results for 17 Altus AFB samples submitted to MERSC under Service Request # SF-0-70. The samples were received April 19, and were analyzed April 19 and 20, 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.

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Center, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 580-436-8660 FAX 580-436-8501

Rec'd 4-19-99
Analyzed 4-19 and 4-20
by L. Pennington

S.R. # SF-0-70
Don Kampbell
Altus AFB, OKC

SAMPLE	NH_3 (N)	NO_2^-+NO_3^- (N)	Cl^-	SO_4^{-2}
	mg/L	mg/L	mg/L	mg/L
4/15 MW-1	<0.10	3.01	541	1,880
4/15 TW-1A	<0.10	0.73	381	2200.0
4/14 RV001	<0.10	<0.10	270	1,400
4/14 RV002	<0.10	<0.10	285	1,480
4/14 WL-018	<0.10	1.89	389	1,360
4/15 WL-019	<0.10	1.24	(342) (341)	(2,120) (2,100)
4/15 WL-020	<0.10	0.87	269	924
4/14 WL-021	(<0.10) (<0.10)	(0.16) (0.17)	298	1,600
4/14 WL-022	<0.10	3.52	322	1,400
4/16 WL-061	<0.10	2.80	726	2,160
4/16 WL-062	<0.10	3.53	730	2,450
4/15 OU-1-01	<0.10	1.01	310	1890.0
415 OU-1-2	<0.10	0.28	288	1,750
4/15 OU-1-3	<0.10	1.60	(332) (337)	(2,020) (2,010)
4/15 OU-1-04	<0.10	0.50	340	2,110
4/15 OU-1-05	<0.10	2.30	369	2,250
4/15 OU-1-06	(<0.10) (<0.10)	(2.50) (2.50)	497	2,410
Blank	<0.10	<0.10	<.50	<.50
AQC	4.99	11.4	10.4	57.7
AQC T.V.	4.80	12.0	10.8	58.0
Check Std.	1.03	1.04	4.94	4.84
Check Std. T.V.	1.00	1.00	5.00	5.00
Spike Recovery	101%	97%	100%	98%

MANAGEMENT
TECHNOLOGY

MEMORANDUM

MANTECH ENVIRONMENTAL RESEARCH SERVICES CORP.
Environmental Science

In reply refer to: 99-AZ23
68-C-98-138

To: Dr. Don Kampbell

Thru: Dennis Fine D. Fine

From: Amy Zhao & Lisa Hudson
A.Z. LH

Subject: SF-0-70

Date: April 26, 1999

Copies: R.L. Cosby
G.B. Smith
J.L. Seeley

As requested in Service Request #SF-0-70, gas analysis was performed for methane, ethylene and ethane from Altus AFB. The samples were received on April 19, 1999, and analyzed on April 20,1999. Calculations were done as per RSKSOP-175. Analyses were performed as per RSKSOP-194.

If you have any questions concerning this data, please feel free to contact me.

Printed 04/26/99 SF-0-70 Originator: D. Kampbell Site:Altus AFB

Sample Received 04/19/99 Sample Analyzed 04/20/99 Analyst: A. Zhao & L. Hudson

Sample	**Methane ppm (Gas)**	**Methane ppm mg/L(Water)**	**Ethylene ppm (Gas)**	**Ethylene ppm mg/L(Water)**	**Ethane ppm (Gas)**	**Ethane ppm (Water)**
100 ppm CH4	9.55E+01	~	**	~	**	~
100 ppm C2H4	**	~	9.08E+01	~	**	~
100 ppm C2H6	**	~	**	~	9.95E+01	~
HP. Helium Blank	~	**	~	**	~	**
Lab Blank	~	**	~	**	~	**
MW-1(4/15)	~	**	~	**	~	**
WL-0-18(4/14)	~	**	~	**	~	**
WL-0-19(4/15)	~	**	~	**	~	**
WL-0-20(4/15)	~	**	~	**	~	**
WL-0-21(4/14)	~	**	~	**	~	**
WL-0-21 Lab Dup(4/14)	~	**	~	**	~	**
WL-0-22(4/14)	~	**	~	**	~	**
WL-0-61(4/16)	~	**	~	**	~	**
WL-0-62(4/16)	~	**	~	**	~	**
OU-1-01(4/15)	~	**	~	**	~	**
OU-1-2(4/15)	~	**	~	**	~	**
OU-1-3(4/15)	~	**	~	**	~	**
OU-1-3 Field Dup	~	**	~	**	~	**
OU-1-4(4/15)	~	**	~	**	~	**
OU-1-05(4/15)	~	**	~	**	~	**
OU-1-06(4/15)	~	**	~	**	~	**
RV-001(4/14)	~	**	~	**	~	**
RV-002(4/14)	~	**	~	**	~	**
RV-002 Lab Dup	~	**	~	**	~	**
10ppmCH4	1.04E+01	~	~	**	~	**
10ppmC2H4	**	~	9.60E+00	~	**	~
10ppmC2H6	**	~	**	~	9.80E+00	~
Lower Limit of Quantitation	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.

AlTus AFB - April 1999
WaTer QualiTy - LF04 siTe

Sample	TOC ∇ fT.	Temp. °C	D.O. mg/L	pH su	Conductivy µS/cm	Redox mV	Ferrous mg/L	Alkalinity Total mg/L	Hydroge Sulfid- mg/L
WL-022	9.4	16.4	1.3	6.9	3820	+225	<.1	280	<.1
WL-018	10.8	16.5	1.1	6.8	3780	+241	<.1	300	<.1
i-RV 001	Creek	18.0	10.4	7.6	3530	+224	0.1	260	<.1
RV 002	Creek	19.8	9.2	7.7	3680	+258	0.1	300	<.1
WL-021	9.4	14.8	0.7	6.7	4170	+264	0.1	440	<.1
WL-020	16.4	16.4	1.1	7.0	2800	+273	<.1	240	<.1
WL-019	11.9	16.8	0.8	6.9	4770	+232	0.1	300	<.1
OW1-3	9.7	15.2	0.4	6.9	4445	+273	<.1	300	<.1
OW1-01	9.1	15.6	0.9	6.9	4730	+236	0.1	360	<.1
OW1-02	9.3	14.9	0.9	6.8	4160	+276	<.1	360	<.1
OW1-05	9.6	16.1	1.4	7.0	4970	+266	<.1	280	<.1
OW1-04	9.2	15.8	0.9	6.8	4760	+260	<.1	380	<.1
TW-1	12.3	VOA's only - Low yield							<.1
OW1-06	8.4	17.0	3.8	7.0	5570	+275	<.1	260	<.1
MW-1	10.1	18.2	0.9	7.0	4920	+249	<.1	200	<.1
WL0-62	7.6	14.9	0.3	7.0	6370	+242	<.1	260	<.1
WL0-61	7.3	16.4	1.1	7.1	5920	+168	0.2	180	<.1
TW-14	5.9	1 inch well - VOA's only - Low yield						-	
TW-2	5.8	" " "							
TW-10	4.0	1 inch well - VOA's only - Low yield							
TW-15	5.2	" " "							
TW-4	7.0	Dry well - Mud							
TW-5	5.2	"							
TW-8	5.9	1 inch well - VOA's only - Low yield							
SB16-D	11.5	" " "							
SB-11WD	6.8	VOA's only - Low yield							
SB16-S	11.2	No yield - Mud							
TW-3	11.6	1 inch well - VOA's only - Low yield							
SB-15D	6.8	" " "							
SB-11WS	6.9	No measurements - No yield							
TW-11	10.5	1 inch well - Mud only - No samples							

ATTACHMENT B

RESPONSES TO COMMENTS

PARSONS

Parsons Engineering Science, Inc. • A Unit of Parsons Infrastructure & Technology Group Inc.
1700 Broadway, Suite 900 • Denver, Colorado 80290 • (303) 831-8100 • Fax: (303) 831-8208 • www.parsons.com

14 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 Operable Unit 1, Altus AFB, OK

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 Operable Unit 1 (OU1), Altus Air Force Base (AFB), Oklahoma. The RNA TS Addendum was prepared by Parsons Engineering Science, Inc. (Parsons ES) for the Air Force Center for Environmental Excellence Technology Transfer Division (AFCEE/ERT) and Altus AFB. The intent of the RNA TS Addendum was to evaluate the role of natural attenuation in remediating chlorinated solvents in groundwater at OU1 over time. The Draft RNA TS Addendum was submitted to AFCEE in October 1999. Comments on the Draft RNA TS Addendum were received from AFCEE as reviewed by Jon Atkinson, dated 13 December 1999. Responses to these comments were prepared by Parsons ES and are presented herein.

Responses to AFCEE Comments: 13 December 1999

Comment 1) Pages 1 and 2, Sec 1.2: The time period for SAC control of the Base should be added to line 3 of page 2.

Parsons ES Response: *The text will be changed to indicate that the period for SAC control of the Base was from 1953 to 1961.*

Comment 2) Page 2, Sec 1.2, Para 2, Lines 5: Suggest writing out the "6" and "8" in "6 to 8 feet below" and other numbers less than 10 that occur throughout the report unless they describe units of analytical measurement (e.g., mg/L). This practice of writing numbers less than 10 as words is consistent with the Air Force *Tongue and Quill.*

Parsons ES Response: *It is Parsons ES practice to use numerals for any unit of specific measure (i.e., feet), not just analytical results. Therefore, request that the text not be changed.*

Comment 3) Page 7, Fig 1: In the title suggest changing "Map" to "Maps."

Parsons ES Response: *The title will be changed as suggested.*

Comment 4) Pages 21 and 22, Sec 2.3, Sent 2 and Sec 2.4, Line 3: The three typos in "ug/L" need to be corrected.

Parsons ES Response: *The typographic errors will be corrected.*

Comment 5) Pages 22 and 23, Sec 3.0, Sents 6 and 9. Recommend adding manganese to the lists of electron acceptors.

Parsons ES Response: *Manganese will be added to the list of electron acceptors as recommended.*

Comment 6) Page 28, Sec 3.3, Para 2: Suggest annotating the average background and in-plume concentrations of nitrate plus nitrite nitrogen and stating if any statistically significant differences occur between these two averages.

Parsons ES Response: *The average concentration of nitrate + nitrite (as nitrogen) both within and outside of the chlorinated aliphatic hydrocarbon (CAH) plume (as defined by the 10 ug/L contour for TCE) will be calculated and compared. A discussion of the average concentrations will be added to the text.*

Comment 7) Page 30, Sec 3.5, Para 2: Suggest annotating the average background and in-plume concentrations of sulfate and stating if any statistically significant differences occur between these two averages.

Parsons ES Response: *The average concentration of sulfate both within and outside of the CAH plume (as defined by the 10 ug/L contour for TCE) will be calculated and compared. A discussion of the average concentrations will be added to the text.*

Comment 8) Page 31, Sec 3.8:

a. Sent 2: Recommend adding that anaerobic biodegradation of CAHs also generates acids.

b. Last Sent: This statement appears to contradict the assertion in Wiedemeier et al., 1996, *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater*, p. 2-33 that: ". . . biodegradation of organic compounds rarely, if ever, generates enough acid to impact the alkalinity of groundwater." This apparent contradiction should be briefly addressed.

Parsons ES Response:

a. A statement will be added to the text indicating that both aerobic and anaerobic biodegradation of CAHs generate acids.

*b. The correct quotation from the AFCEE Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water (USEPA Publication EPA/600/R-98/128, September 1998) reads "...In the experience of the authors, biodegradation of organic compounds rarely, if ever, generates enough acid to impact the **pH** of the ground water."*

Alkalinity is important in the maintenance of groundwater pH because it buffers the groundwater system against acids, in particular carbonic acid produced from carbon dioxide generated during both aerobic and anaerobic biodegradation. While biodegradation may generate enough acids to increase alkalinity, the alkalinity is generally sufficient to buffer against significant changes in groundwater pH. Therefore, no change to the text is necessary.

Comment 9) Pages 33 and 35, Sec 3.10, Bullet 2: Although dissolved hydrogen is enumerated it does not appear in Table 1 or in any other text. This discrepancy should be resolved.

Parsons ES Response: *Dissolved hydrogen was analyzed for in April 1997, but not in April 1999. Dissolved hydrogen concentrations are summarized in Table 6, and a discussion of dissolved hydrogen is presented in the TS. A reference to Table 6 and the TS will be added to the second bullet in Section 3.10.*

Comment 10: Page 36, Sec 4.0:

a. Sent 1: To correct subject-verb agreement, recommend changing "have" to "has."

b. Sent 2: The typo in "ug/L" needs to be corrected.

c. Sent 4: Suggest expanding to recommend specific monitoring wells to be sampled, proposed analytes, and sampling frequency.

Parsons ES Response:

a. The text will be corrected as recommended.

b. The typographic error will be corrected.

c. The long-term monitoring (LTM) plan proposed in the TS details the recommended monitoring wells, proposed analytes, and sampling frequency. A reference to the LTM plan in the TS will be added to Section 4.0.

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 722450.36000